

**German Concrete, 1819 - 1877.
The Science of Cement from Trass to Portland.**

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Sinossi

Questa dissertazione è il risultato di una ricerca sullo sviluppo di moderne pratiche di costruzione in calcestruzzo che maturano in Germania nel corso dei primi tre quarti del XIX secolo, sullo sfondo di un più generale processo di modernizzazione del paese, e sulla base dell'osservazione di tecniche costruttive impiegate in Francia, Italia, Olanda e Regno Unito.

I primi moderni impieghi di calcestruzzo in Germania riguardano essenzialmente la costruzione di alcune fondazioni, in acqua, come in terreni umidi o palustri. Una testimonianza importante a questo proposito è ravvisabile nei riempimenti di sassi e malta che vengono utilizzati, tra la fine del XVIII, e gli inizi del XIX secolo, nelle cosiddette fondazioni a pozzo, e nelle fondazioni dei piloni e dei piedritti di alcuni ponti. Le prime sono costituite da muri circolari in muratura, e da riempimenti di sassi e malta, mentre le seconde sono delle palificate, con analoghi riempimenti di sassi e malta intorno alle teste dei pali. Dalla fine degli anni Venti, si osserva un uso più consapevole e strutturalmente autonomo del calcestruzzo in fondazioni subacquee, che si consolida, poi, dalla metà degli anni Trenta e durante gli anni Quaranta, quando il calcestruzzo viene riconosciuto come un materiale essenziale per questo genere di costruzioni.

L'abilità nel costruire fondazioni in calcestruzzo progredisce insieme con un crescente interesse verso la conoscenza della natura e delle proprietà dei leganti idraulici, che genera conseguenze sia sul piano scientifico, dando luogo a importanti studi di chimica sulla calce e sulla malta, sia sul piano della nascente produzione manifatturiera, con la fondazione e l'ampliamento di numerose fabbriche di calce idraulica e cemento.

Nella costruzione di edifici, l'uso del calcestruzzo si afferma più tardi che nel dominio della costruzione di fondazioni, ed è preceduto dallo sviluppo di un singolare materiale che va sotto il nome di *Kalksand*. Si tratta di un conglomerato molto magro, a base di calce aerea, il cui impiego si diffonde dalla metà degli anni Quaranta, e soprattutto nelle costruzioni rurali. Analogamente al calcestruzzo, il *Kalksand* viene principalmente gettato in casseforme per costruire muri, e, in alcuni casi, anche su centine per costruire volte, sebbene ciò accada più raramente. Tra la metà degli anni Cinquanta e la metà degli anni Sessanta, *Kalksand* e calcestruzzo vengono riconosciuti come materiali alquanto prossimi, e, l'uso del secondo finisce per prevalere.

Un ulteriore e non secondario aspetto della lavorazione del calcestruzzo, o di composti cementizi a esso prossimi, riguarda la produzione di pietre artificiali, tegole, decorazioni architettoniche, tubi e altri oggetti d'uso colati in stampi. Dopo diversi tentativi effettuati nel corso della prima metà del secolo, questo tipo di produzione dà luogo, nel corso degli anni Cinquanta e Sessanta, allo sviluppo di uno specifico settore della nuova produzione manifatturiera tedesca.

Dalla metà degli anni Sessanta, e per buona parte degli anni Settanta, diversi edifici sono interamente costruiti in calcestruzzo, dalle fondazioni alle coperture, seguendo principalmente esempi inglesi. Allo stesso tempo, le tecniche per costruire fondazioni in calcestruzzo divengono più raffinate e complesse, in particolare per quanto riguarda il tipo a pozzo, mentre lo studio del cemento è ulteriormente sviluppato attraverso nuove analisi chimiche, e attraverso l'esecuzione di prove di carico.

Parole chiave

Storia del calcestruzzo, storia del cemento, Germania, Roman cement, cemento Portland, Kalksand, pietra artificiale, fondazioni in calcestruzzo, edifici in calcestruzzo.

Abstract

This dissertation originates from an investigation about the arising of the modern, German building expertise involving the use of concrete, which develops during the first three quarter of the 19th century against the backdrop of a general modernisation process, and moving from the observation of more advanced building techniques in France, Italy, Holland and the United Kingdom.

Early uses of modern concrete in Germany essentially concern the construction of foundations underwater and in marshy soils. Between the end of the 18th and the begin of the 19th century, some traces are to be found in the mixtures of pebbles and mortar that are used as filling materials in the so-called well foundations, which consist of underground circular walls to be filled with rubble masonry work, and among the heads of the timber piles supporting the piers and the abutments of some bridges. From the end of the 1820s, we observe a more mature use of concrete to build underwater foundations, whose bearing capacity essentially depends on concrete itself. This trend further develops in the second half of the 1830s and during the 1840s, when concrete is recognized as an essential material to build underwater.

The expertise in building concrete foundations develops along with an increasing interest for the nature and properties of hydraulic binders. This produces consequences on the scientific plan, giving rise to the development of essential chemical studies about lime and mortar, and in the domain of manufacturing, involving the foundation and the enlargement of several hydraulic lime and cement plants.

The use of concrete to build above ground appears later than in the domain of the construction of foundations, and it is preceded by the development of a peculiar material, which is known as *Kalksand*. It is a very lean and lime-base conglomerate, the use of which spreads as of the mid-1840s, mainly in rural domains. Similar to concrete, it is poured in formworks to build walls and, in a few cases, onto centrings to build vaults. Between the mid-1850s and the mid-1860, *Kalksand* and concrete are recognized as similar materials, and the use of the second one gradually prevails.

An important aspect of the use of concrete, or of similar cement-based compounds, concerns the production of moulded artificial stones, tiles, architectural decorations, pipes and other kinds of objects. After several attempts dating back to the first half of the century, this kind of production improves during the 1850s and the 1860s, giving rise to an independent branch of the young German manufacturing.

From the second half of the 1860, a number of buildings are entirely built in plain concrete, from the foundations to the roofs, mainly following British examples. At the same time, techniques to build concrete foundations get more advanced and complex, especially for what concerns well foundations, while the study of cement is further developed through chemical analyses and strength tests.

Key words

History of concrete, history of cement, Germany, Roman cement, Portland cement, *Kalksand*, artificial stone, concrete foundations, concrete houses.

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Foreword

Most literature on German concrete focuses on the constructions that have been built since about the last fifteen years of the 19th century, as the use of reinforced concrete begins to spread. Instead, only a few studies have dealt with the early modern, German concrete, before the appearance of reinforcement. Most of these studies are articles, short essays and book chapters. They generally analyse facts that have occurred since about mid 19th century, and take into account limited geographic areas or specific aspects of the subject, like a building technique, an application, a company, a building typology, a group of buildings, or even a single building.¹

Unlike these previous studies, this dissertation searches for the origins of modern, German concrete, and reconstructs the way in which the ability to build with it gradually develops. It takes into account the territory that goes from the Kingdom of Hannover to northeast Prussia and from Baden to Bavaria, which approximately corresponds to the territory of the future German Empire. The relations between the German construction practices and the building culture of more developed neighbouring countries have been analysed as well, and besides concrete, different kinds of mortar-based conglomerate have been examined, along with the different materials, building techniques, applications and experiments that concern concrete or are related to it.

The investigation that has been carried out to develop this dissertation has principally focused on original sources. First 19th-century periodicals and books have been examined with the aim of developing a comprehensive vision of the facts, then in depth-analyses have been carried out in major German State archives, and in some local archives as well. Books, essays, articles and PhD thesis from the 20th century and from the 21st century have been taken into consideration as sources only after having developed a structural framework based on the more ancient sources, in order to avoid any uncritical assumption of concepts from recent studies.

This way of proceeding has made it possible to prove that the early modern, German expertise in building with concrete develops from the end of the 18th century to the third quarter of the 19th century, against the backdrop of the general modernisation process of Germany, and taking advantage from certain specific issues of that time, like the need for new, solid and affordable constructions, especially in the domain of the hydraulic engineering, the predominant scientific and analytical approach to the technological progress in opposition to the empirical way of proceeding that often prevails in other countries, and the effort to standardise the quality of manufacturing productions.

The first two issues originate from the rationalist culture of the German Enlightenment and favour studies about lime, cement and mortar. These studies make significant contributions to improving the knowledge of hydraulic binders for constructions and radically change the German construction culture from being essentially based on the use of aerial lime, to being the precursor of the

¹ See the bibliography at pp. 251–53.

standardisation of the quality of Portland cement. The need for new, solid and affordable constructions also urges to study lime and mortar, and furthermore requires German master builders to search abroad for new building materials and techniques, making it possible the observation of foreign concrete constructions in more developed neighbouring countries. At the same time, the scarcity of natural stones in several regions, along with the high transport costs due to the lack of developed waterways and railways, give rise to the interest for mortar-based compounds that can be moulded as stones or as different objects and decorations.

It is against the backdrop of such overwhelming changes that the modern, German ability in building with concrete develops, arising from an extraordinary combination of studies about lime, cements and mortar, attempts at producing mouldable mortar-based compounds, and surveys into foreign building materials and techniques, notably in the domain of hydraulic engineering. All these issues, which this dissertation analyses in parallel, are already to be observed at the turn of the 19th century, as the construction culture of the 18th-century is still prevalent and involves the use of aerial lime and pozzolanic cements to produce mixtures of pebbles and mortar that are used as filling materials in masonry and timber constructions. The improvements in the knowledge and in the production of modern hydraulic lime and cements that occur since the 1820s, along with the construction of several concrete foundations and the early production of cement-based artificial stones and moulded objects evidence that a new phase in the German history of cement and concrete has began and will lead to crucial evolution stages during the third quarter of the century, when concrete becomes an essential material to build foundations and vaults, the manufacturing of cement-based moulded objects gives rise to a specific manufacturing branch, and the quality of Portland cement is standardized through official norms.

The scientific approach that characterizes the study of hydraulic lime and cement during the first three quarter of the 19th century, and the search for standardizing the characteristics of Portland cement are essential issues to better understand the way in which reinforced concrete will later develop in Germany. It will in fact be bound to mathematical models, rules, standards and, later on, to the industrial production, as it is proved by the fact that the greatest German concrete building companies originate from Portland cement companies.

1 Lime, Trass, and early concrete traces

1.1 A favourable context to the rise of concrete construction

Emphasis on scientific and technical aspects of constructions, and an impelling need to improve the conditions of buildings, roads, and even entire villages, towns and landscape are crucial issues for the evolution of the German art of building at the turn of the 19th century. They are developed against the backdrop of a general effort to modernize Germany, which evolves, in little more than half a century, from being an aggregate of backward States and small political entities, still featuring existing medieval forms of administration and an agriculture-based economy, to be a united, modern and industrialised country.

In the wake of the arising national identity, a keen interest for technical matters of constructions is considered a German distinctiveness, in opposition to the otherwise dominant theoretical argumentations concerning ancient Italian architectural styles. It is no coincidence that the *Ober-Bau-Department* (Building Department) of Prussia, which is the State that leads the Germany unification process, strongly promotes a technical approach to the art of building.¹ This approach is clearly in evidence in the preface to the first issue of the *Sammlung nützlicher Aufsätze und Nachrichten, die Baukunst betreffend*, a periodical edited by the *Ober-Bau-Department* from 1797 to 1806. The prevailing artistic approach to building matters in Italian architecture is criticized, notably targeting those treatises that focus on architectural orders, “as if raising and decorating a column were of major importance, whereas all other features that the art of building provides to humans, in each of their undertakings, were irrelevant.”² Instead, the technical, and even scientific approach to architecture that several German theoreticians from the 17th and 18th century promote is thought to have triggered an evolution process, while the impressive buildings of the past in celebrated ancient lands remain in ruins.³ In line with such a belief, technical knowledge and building practice are considered as much respectable as art and theory. “We could be further developed,” it is stated in the mentioned preface “if art and knowledge had joined together in architecture sooner and deeper. They can achieve more only if they

¹ The Prussian *Ober-Bau-Department* is founded in 1770 and changed into *Ober-Bau-Deputation* in 1804 (about the *Ober-Bau-Department*, see Katja Laude, *Das Oberbaudepartement und die Untertanenbauten Möglichkeiten und Grenzen obrigkeitlicher Einflussnahme*, in *Brandenburgische Denkmalpflege*, 2009, vol. XVIII, pp. 61–75).

² “[...] als ob die Aufstellung und Verzierung einer Säule die Hauptsache, das Übrige aber was die Baukunst dem Menschen fast bey allen seinen Unternehmungen leistet, nur Nebensache wäre” (see *Vorrede*, in *Sammlung nützlicher Aufsätze und Nachrichten, die Baukunst betreffend*, I, 1797, (pp. III-IX), pp. III-IV).

³ See *ibid.*, p. IV. The mentioned theoreticians are: Nicolaus Goldmann (1611–1665); Friedrich August Wolf (1759–1824); Leonhard Christoph Sturm (1669–1719); Johann Friedrich Penther (1693– 1749); Lorenz Johann Daniel Suckow (1722–1801).

are combined, but not if each of them goes its own way. Artists risk weirdness without a scientific guide, whereas savants loose their capability to reflect, when they are robbed of artistic vision and feelings [...].”⁴

While such theoretical arguments are developed, the urge for modernisation calls for an improvement of construction standards. In this regard, a contribution is given by the policies that the *Ober-Bau-Department* enforces since the last decades of the 18th century in order to preserve forests, encouraging the use of masonry instead of timber.⁵ Studies about masonry techniques improve, namely focusing on stone bonds, and on walls made of earth, clay and straw, rammed in rudimentary provisional formworks.⁶ The master builder David Gilly (1748–1808), who is a main member of the *Ober-Bau-Department* and of the Berlin *Bauakademie*, is often engaged in such studies.⁷ In his *Handbuch der Landbaukunst*, published in several volumes and editions since 1797, he widely deals with the construction of walls, particularly stone-faced walls filled with “crushed bricks, fieldstones, slag, coarse

⁴“Weiter würden wir wahrscheinlich schon seyn, wenn Kunst und Gelehrsamkeit sich früher und inniger für die Architektin: vereiniget hätten. Gemeinschaftlich können beyde viel leisten, aber wenn jede ihren eigenen Gang gehet, so ist dieses nicht möglich. Ohne wissenschaftliche Leitung fällt der Künstler in das Gewagte und Abentheuerliche; ohne Künstlerauge und Kunstgefühl entgehet dem Gelehrten der Stoff zur Betrachtung [...]” (*ibid.*, pp. IV–V).

⁵ Reinhart Strecke gives an account about Prussian policies of wood saving in: Reinhart Strecke, *Anfänge und Innovation der preußischen Bauverwaltung. Von David Gilly zu Karl Friedrich Schinkel*, Köln, Weimar, Wien, Böhlau, 2000, pp. 89–90.

⁶ The building of walls made of earth rammed in provisional formworks principally spreads in France under the name of *pisé*, in this regard see François Cointeraux, *Ecole d'Architecture Rurale*, Paris, Chez l'Auteur, 1791 (Id., *Schule der Landbaukunst oder Unterricht durch welchen jeder die Kunst erlernen kann, Häuser von etlichen Geschossen aus blossem Erd- oder anderem sehr gemeinen und höchst wohlfeilen Baustoff selbst dauerhaft zu erbauen*, Hildburghausen, Johann Gottfried Hanisch, 1793). The master builder Johann Heinrich Hundt studies this construction technique, which becomes therefore known as Hundt'sche Baumethode; in this regard see the manuscripts: “Pisébau oder Aufführung der Wände mit gestampfter Erde”, 1797–1802 (Geheimes Staatsarchiv Preußischer Kulturbesitz in Berlin (GStA) PK, II.HA Generaldirektorium, Abt. 30.I, Oberbaudepartement, n° 149); “Einführung des sogenannten Pisé-Baues”, 1797–1802, (GStA PK, II.HA Generaldirektorium, Abt. 6.I, Preuß. Direktorialregistratur, n° 58; “Bauangelegenheiten, Gewährung von Zuschüssen, Genehmigung für Baumaßnahmen und Beschwerden gegen baupolizeiliche Anordnungen” 1809–1840, vol. I (GStA PK, I.HA Rep. 89 Geheimes Zivilkabinett, n° 28540). See also Alexander von Lengerke, *Darstellung der Landwirtschaft in den Großherzogthümern Mecklenburg*, vol. I, Königsberg, Gebrüder Bornträger, 1831, pp. 122–26.

⁷ See David Gilly, *Praktische Abhandlung aus der Landbaukunst, betreffend den Bau der sogenannten Lehm- oder Wellerwände wie man dieselben dauerhaft mit wenigen Kosten und einer wahren Holzersparung aufführen könnte*, Berlin, Friedrich Maurer, 1787; Id., *Beschreibung einer vortheilhaften Bauart mit getrockneten Lehmziegeln*, Berlin, [Lange], 1790. Several still existing documents about the search for affordable way of building massif walls made of clay and straw are at the GStA, see the manuscripts “Von den Einsassen des lithauischen Kammerdepartements nachgesuchte Prämien für vollführte massive Bauten”, 1800–1806 (GStA PK, II.HA Generaldirektorium, Abt. 7, Ostpreußen II n° 575); “Von den Einsassen des ostpreußischen Kammerdepartements nachgesuchte Prämien für vollführte massive Bauten”, 1800–1806 (GStA PK, II.HA Generaldirektorium, Abt. 7, Ostpreußen II n° 574); “Einführung und Erprobung des Baus von Untertanengebäuden aus getrockneten Lehmziegeln zur Einsparung von Holz”, 1797–1798, vol. I, Brandenburgische Landeshauptarchiv (BLHA), Potsdam, Rep. 2 KDK Kurmark D, n° 643. For a more extensive overview of the still existing documents about the search for affordable way of building massif walls at the turn of the century see Reinhart Strecke, *Inventar zur Geschichte der preußischen Bauverwaltung 1723–1848*, Berlin, Geheimes Staatsarchiv Preußischer Kulturbesitz, vol. I–II, 2005. In this regard see also Laude, *Das Oberbaudepartement...cit.*, p. 69.

gravel, sand and similar loose materials, which are embedded in a casting of lime that is intended to bind the whole into a mass".⁸

Such walls are similar to the ones that ancient Romans develop by simplifying the Greek work called *Emplecton*, depicted by Johann Joachim Winckelmann (1717–1768) in the *Anmerkungen über die Baukunst der Alten* of 1762.⁹ Gilly, however, relates this kind of masonry work to the medieval ruins of the Ritterschloß of Marienburg (Malbork Castle) in north-eastern Pomerania, and considers it a kind of typical medieval masonry bond, which, as he maintains, "is commonly known as Polish bond, but should be better named as gothic bond".¹⁰ (fig. 1.1.1–2) He does not consider the Polish bond appropriate to the German building needs of his time. "This kind of masonry," he warns, "needs to be built with such slowness and patience, that it ends up being inappropriate for the current state of our buildings, and for future expectations."¹¹ It is not a coincidence that, about forty years later, Karl Friedrich Schinkel (1781–1841), following in the footsteps of his mentor, describes stone-faced walls filled with rubble and mortar as Polish bond, and relates them to medieval building practices, which are no longer used at his time.¹² (fig. 1.1.3) "Most ancient walls," he writes, "specially gothic walls, are built this way, but this kind of constructions are less, or even not at all used nowadays, since they need to be built very slowly, due to the irregular setting; moreover there is a risk that, over time, the faces of the walls detach from the inside coarse masonry work."¹³

Prussian efforts to improve building conditions show positive consequences already at the end of the 18th century. An English traveller entering in Prussia via Hannover and Brunswick in 1799 notices the improvement of the landscape and notes: "Roads, plantations, net cottages, pleasant country estates, well built town and good inns take the place of the appearance of poverty and depopulation."¹⁴

⁸ See David Gilly, *Handbuch der Land-Bau-Kunst, vorzüglich in Rücksicht auf die Construction der Wohn- und Wirtschafts-Gebäude für angehende Cameral-Baumeister und Oeconomen*, vol. I, Berlin, Friedrich Vieweg der alter, 1797, pp. 238–39, and fig. 121.

⁹ See Johann Joachim Winckelmann, *Anmerkungen über die Baukunst der Alten*, Leipzig, Johann Gottfried Dyck, 1762, p. 14.

¹⁰ "[...] welche man den jetziger Zeit den polnischen Verband nennet, der aber eigentlich der gotische Verband genannt werden sollte" (Gilly, *Handbuch der Land-Bau-Kunst*...cit., p. 238).

¹¹ "Dergleichen Bauart kann aber nur mit einer Langsamkeit und Geduld ausgeführt werden, welche den jetzigen Verfassungen und Absichten unserer Bauten nicht angemessen seyn würde" (Gilly, *Handbuch der Land-Bau-Kunst*...cit., p. 239).

¹² See Karl Friedrich Schinkel, *Grundlage der praktischen Baukunst. Erster Theil. Mauerwerkkunst*, Berlin, Schenk & Gerstäcker, 1834, p. 2 and pl. IV, fig. 4.

¹³ "Die meisten alten, namentlich gothischen Gemäuer, sind auf diese Art verbunden; dagegen macht man heut zu Tage wenig oder gar keine Anwendung von dieser Construction, weil sie, des ungleichförmigen Setzens wegen, nur mit großer Langsamkeit ausgeführt werden kann, und dabei doch noch befürchten läßt, daß sich die gerade Steinverkleidung, mit der Zeit, von dem innern rauhen Mauerwerk ablöset" (Schinkel, *Grundlage der praktischen Baukunst*...cit.).

¹⁴ David Watkin, Tilmann Mellinghoff, *German Architecture and the Classical Ideal*, Boston, MIT Press, 1987, p. 2.

Since the 1790s, the publishing of several periodicals about architecture, building, gardens and even “taste” also shows the general wish to improve conditions of towns and landscape.¹⁵

In such a context, the search for solid and durable building materials is of primary importance, especially in hydraulic engineering, since the need for new and efficient roads, railways and waterways, intended to serve increasing manufacturing and trade, requires the construction of solid hydraulic works, such as locks, weirs, bridge piers and embankments. As a consequence, traditional materials like timber, straw, clay and ropes are considered less appropriate.¹⁶ (figg. 1.1.4-5) Faced with the lack of advanced inland expertise, German master builders improve their knowledge in hydraulic engineering by observing foreign and more advanced constructions, mainly in Italy, France and Holland, and by the reading of foreign technical literature, taking especially into account French construction treatises. It is through such surveys that some master builders also learn about concrete hydraulic foundations, as they have been used in France and Italy since mid-18th century. Acquired knowledge is then spread through the publication of some German literary work dealing with hydraulic engineering. The most representative is probably the *Allgemeine auf Geschichte und Erfahrung gegründete theoretisch-practische Wasserbaukunst* by the eminent hydraulic engineer Carl Friedrich Wiebeking (1762–1842).¹⁷

Urged by the need to build solid constructions, and based on foreign examples of hydraulic works, the use of bricks and stones gradually improves. (fig. 1.1.6) Evidence of this may be found in the replacement of several timber locks along the Bromberg channel in East Pomerania. Between 1792 and

¹⁵ The main periodical dealing with the abovementioned topics are: *Allgemeine Magazin für die Bürgerliche Baukunst* (1789–96), *Magazin für Freunde des guten Geschmacks* (1794–1799), *Ideen Magazin für Liebhaber von Gärten, englischen Anlagen und für Besitzer von Landgütern* (1796–1808), *Archiv für die Baukunst und ihre Hülfswissenschaften* (1818), *Monatsblatt für Bauwesen und Landesverschönerung* (1821–1830). For an overview of the German nineteenth-century architecture periodicals, see Rolf Fuhlrott, *Deutschsprachige Architektur-Zeitschriften. Entstehung und Entwicklung der Fachzeitschriften für Architektur in der Zeit 1789–1918*, München, Verlag Dokumentation, 1975.

¹⁶ Trade receives a significant impulse by the institution of the “Zollverein”, i.e. the customs union promoted by Prussia; it is founded in 1834 and expanded in the following years (see Hans-Werner Hahn, *Die industrielle Revolution in Deutschland*, München, Oldenbourg, 2005). The first German railway is opened on December 1835 in Bavaria, it connects the towns of Nurnberg and Fürth, (see Lothar Gall, Manfred Pohl, ed., *Die Eisenbahn in Deutschland. Von Anfängen bis zur Gegenwart*, München, C. H. Beck, 1999, p. 13).

¹⁷ Carl Friedrich Wiebeking, *Allgemeine auf Geschichte und Erfahrung gegründete theoretisch-practische Wasserbaukunst*, Darmstadt, Johann Franz Peter Stahl, vol. I, 1798, vol. II, 1799, vol. III, 1801, vol. IV, 1805, vol. V, 1807. It is furthermore to mention the publication of the *Beyträge zur hydraulischen Architektur* by Reinhard Woltmann (1757–1837), an hydraulic engineer and director of hydraulic works in northern towns, in Hamburg above all, who mainly learns from Dutch hydraulic engineering abilities (Reinhard Woltman, *Beyträge zur hydraulischen Architektur*, Göttingen, Johann Christian Dieterich, vol. I, 1791, vol. II, 1792, vol. III, 1794, vol. IV, 1799); and the publication of the *Praktische Anweisung zur Wasserbaukunst* by Gilly and Johann Albert Eytelwein (see David Gilly, Johann Albert Eytelwein, *Praktische Anweisung zur Wasserbaukunst, welche eine Anleitung zum Entwerfen, Veranschlagen und Ausführen der am gewöhnlichsten vorkommenden Wasserbaue enthält*, vol. I, Berlin, auf Kosten der Verfasser, 1802; Gilly, Eytelwein, *Praktische Anweisung zur Wasserbaukunst...cit.*, vol. II, Berlin, Realschulbuchhandlung, 1803; Johann Albert Eytelwein, *Praktische Anweisung zur Wasserbaukunst, welche eine Anleitung zum Entwerfen, Veranschlagen und Ausführen der am gewöhnlichsten vorkommenden Wasserbaue enthält*, Berlin, Realschulbuchhandlung, vol. III, 1805, vol. IV, 1808); Gilly and Eytelwein, anyway, essentially focus on Prussian hydraulic engineering works (“[...] werden wir uns vorzüglich auf die in dem Preußischen Staate vorkommende Wasserbauwerke”, Gilly, Eytelwein, *Praktische Anweisung zur Wasserbaukunst...cit.*, vol. I, p. 10).

1800, new ones that are built in brick masonry work bound with hydraulic mortar, using Dutch brick masonry constructions as models.¹⁸ (fig. 1.1.7)

Following the growing use of masonry in hydraulic works, increasingly more attention is paid to hydraulic mortar. In this regard, Johann Albert Eytelwein (1765–1849), who is also a main member of the *Ober-Bau-Department* and of the Berlin *Bauakademie*, asserts: “Taking the best care to choose good stones is not enough to build a good retaining wall; the same care should be taken in selecting materials to produce mortar.”¹⁹ The question of how hydraulic mortar could be appropriately produced and used becomes an essential issue, especially considering that early nineteenth-century German building culture is essentially based on the use of aerial mortar made of fat lime and sand. Valuable scientific research about the nature and properties of hydraulic lime and mortar is carried out in the early decades of the 19th century, giving an essential contribution to improve the general knowledge concerning these materials.

1.2 Theory and practices of lime and mortar, between alchemical heritage and scientific knowledge

Early nineteenth-century knowledge about lime and mortar partially derives from ancient knowledge and manufacturing practices, and from eighteenth-century chemical findings about the nature and properties of lime, which are, anyway, still influenced by alchemical beliefs. Lime is thought to be a substance produced from raw materials containing a combination of carbonic acid, crystallized water and lime earth, which is also called carbonated lime. Limestone is the most used raw material to produce lime for constructions. Fired in kilns, it is thought to lose water and carbonic acid, while lime earth combines with a supposed existing substance of heat, and forms quick lime.²⁰ This is thought to have a tendency to build its original state up again, combining with the same kinds of substances that have been lost during burning. For this reason, quick-lime is supposed to combine with water, release the substance of heat, and produce the so-called slaked lime, which is then thought to combine with carbonic acid from the air, and produce the phenomenon of hardening that changes it into a kind of reconstituted limestone.²¹

¹⁸ “[...] von Klinkern, nach der Art del holländischen Wasserbauten” (see [Johann Christian] Wutzke, *Bemerkungen über den Bromberger Kanal*, in *Preussische Provinzial-Blätter*, vol. VII, 1832, pp. 337–48).

¹⁹ “Bei aller Sorgfalt welche auf die gute Auswahl der Steine verwandt seyn kann wird man sich doch nicht schmeicheln können eine tüchtige Futtermauer zu erhalten, wenn nicht das Material zum Mörtel mit der größten Aufmerksamkeit ausgewählt und zubereitet wird” (Eytelwein, *Praktische Anweisung zur Wasserbaukunst...*cit., vol. III, p. 39).

²⁰ The conceptual origin of the substance of heat is to be searched in the concept of Plogistion that Johan Joachim Becher (1635–1682), and Georg Ernst Stahl (1659–1734) develop in the second half of the XVII century.

²¹ Concerning the concept of “chemical affinity”, see Ferdinando Abbri, *La chimica del Settecento*, Torino, Einaudi, 1978, chap. IV.

Most German master builders, architects, engineers and even chemists of early 19th century consider such chemical explications reliable. In an extended survey about limestone, lime and mortar, which is published in several issues in the *Sammlung nützlicher Aufsätze* between 1799 and 1800²², Paul Ludwig Simon (1771–1815), a notable master builder and teacher at the Berlin *Bauakademie*, maintains that “just the inclination [of lime] to combine with the water that has been lost during burning, and the capability to fix it as crystallized water, makes possible the use of lime to produce mortar.”²³ Gilly agrees with Simon, and, in 1805, he describes chemical combinations concerning lime as follows: “Through burning, lime earth undergoes an essential transformation. It is set free from carbonic acid and water, with which it was initially combined by nature, while the substance of heat pervades it. Later on, during the slaking process, the substance of heat parts with lime, which, instead, combines with water, due to great affinity between lime and water. Slaked lime has the property of absorbing carbonic acid from the air, adhering to surfaces of smooth bodies, and hardening until it becomes like a stone.”²⁴

Eytelwein essentially shares the same belief, although with a slight difference. He believes in the affinity between water contained in slaked lime and carbonic acid, rather than in the affinity between lime and carbonic acid. “Pure lime earth,” he writes in this regard, “strongly tends to combine with water, but it has a quite low tendency to combine with carbonic acid. Instead, water has a strong inclination to join with carbonic acid and, since atmosphere is full of it, water contained in slaked lime at first combines with carbonic acid in the air, and only after that it is entirely vaporized, carbonic acid and lime combine producing limestone.”²⁵

Eytelwein’s divergence is actually of minor importance, and has almost no implication in building practices. Instead, the belief that lime could be produced only from carbonated lime has two important implications. The first one is that lime is mainly considered an aerial binder that hardens only in the presence of air; the second concerns the fact that only limestones that contain much

²² Paul Ludwig Simon, *Ueber die Natur des Kalksteins*, in *Sammlung nützlicher Aufsätze und Nachrichten die Baukunst betreffend*, III, 1799, vol. I, pp. 96–112; Id., *Ueber die Natur des Kalksteins. Chemisches Verhalten des Kalkstein, Theorie des Kalks*, in *Sammlung nützlicher Aufsätze...cit.*, IV, 1800, vol. I, pp. 53–78; Id., *Ueber die Natur des Kalksteins. Analyse der Kalkstein-Arten, Verwendung des Kalks zum Mörtel*, in *Sammlung nützlicher Aufsätze...cit.*, IV, 1800, vol. II, pp. 84–119.

²³ “Eben diese Verwandtschaft sich mit dem beym Brennen verloren Antheil Wassers wieder zu vereinigen, diese Fähigkeit, das Wasser zum Chrystallisations - Wasser zu binden liegt vorzüglich bey der Verwendung des Kalks zum Mörtel zum Grunde” (Simon, *Ueber die Natur des Kalksteins. Analyse der Kalkstein...cit.*, p. 103).

²⁴ “Durch dieses Brennen erleidet die Kalkerde eine wesentliche Veränderung. Sie wird nämlich von der im rohen Zustande darin gebundenen Luftsäure und dem Wasser befreit, dagegen aber von der Wärmematerie durchdrungen. Letztere trennt sich wieder von dem gebrannten Kalke beim Löschen, vermöge der nähere Verwandtschaft des Wassers zur Kalkerde, und dieser gelöschte Kalk erhält sodann die Eigenschaft, sich aus der atmosphärischen Luft von neuen nach und nach mit Luftsäure zu sättigen, an der Oberfläche glatter Körper zu haften, und damit steinartig zu verhärten” (Gilly, *Handbuch der Land-Bau-Kunst...cit.*, pp. 109).

²⁵ “So groß auch das Bestreben der reinen Kalkerde ist, sich mit dem Wasser zu verbinden, so ist doch ihre Verwandtschaft zur Kohlensäure nur äußerst gering. Dagegen hat das Wasser eine große Verwandtschaft zur Kohlensäure, und weil sie sich überall in der Atmosphäre verbreitet findet, so vereinigt sie sich leicht mit dem Wasser des gelöschten Kalks und verbindet sich nach der Abdünstung des Wassers mit der Kalkerde zum Kalkstein” (Eytelwein, *Praktische Anweisung zur Wasserbaukunst...cit.*, vol. III, p. 40).

carbonated lime are considered appropriate raw materials to produce lime. They are defined “pure limestones” (reine Kalksteine), and are described as particularly white and hard. “Pure raw limestone [...] contains no other components than lime earth, carbonic acid and water,” Eytelwein asserts in this regard; and Gilly furthermore maintains that, “the more limestone is hard, the more it gives good lime [...]; therefore marble gives the best, hardest, and finest lime.”²⁶ There are almost pure limestones in quarries near the village of Rüdersdorf, in East Berlin. In his studies about lime, Simon analyses Rüdersdorf limestones and establishes that their content in carbonated lime can reach 97% of the entire composition.²⁷

Carbonated lime is also the main component of shells, which are therefore used to produce a kind of lime called *Muschelkalk*. The practice of producing lime from shells is very common in the Netherlands. In Germany, it is known through accounts that some technologists give in the second half of the 18th century, after having been on study journeys in Holland. Friedrich August Alexander Eversmann (1759–1837) is one of them. He describes the Dutch production of *Muschelkalk* in a book published in 1792.²⁸ Johann Beckmann (1739–1811), another German technologist, also writes about Dutch *Muschelkalk* in his work *Anleitung zur Technologie*, which is published in six editions between 1777 and 1809.²⁹ Following such observations, *Muschelkalk* is also produced in German Friesland, which is located near the Netherlands. It is documented that at least two limekilns produce lime from shells in the 1820s, the Roßmann und Kipp in the village of Stade, and the Brunkhorst und Westphalen in Buxtehude near Hamburg.³⁰

Despite all theoretical beliefs about lime transformation, practice shows that most kinds of limestone in nature also contain other substances besides carbonated lime; the most common ones are silica, clay and metal oxides. Since they are not supposed to have any chemical role in lime transformations, these substances are considered as impurities. Too much clay is even considered

²⁶ “Der rohe Kalkstein [...] enthält wenn er rein ist keine Bestandteile als Kalkerde, Kohlensäure und Wasser” (Eytelwein, *Praktische Anweisung zur Wasserbaukunst*...cit., vol. III, p. 39); “Je härter die Kalkstein sind, desto mehr und dest bessern Kalk geben sie [...]; daher giebt der Marmor den besten, härtesten und feinsten Kalk” (Gilly, *Handbuch der Land - Bau - Kunst*...cit., p. 107). In this regard, see also: Simon, *Ueber die Natur des Kalksteins. Chemisches Verhalten*...cit., pp. 76–78; Johann Beckmann, *Anleitung zur Technologie, oder zur Kenntniß der Handwerke, Fabriken und Manufakturen, vornehmlich derer, welche mit der Landwirtschaft, Polizei und Cameralwissenschaft in nächster Verbindung stehen*, Göttingen, Vandehoeck und Ruprecht, (1777), 1802⁵, pp. 309–11; Heinrich Gustav Flörcke, *Dr. Johann Georg Krünitz's Oekonomische Encyklopädie oder allgemeines System der Staats- Stadt- Haus- und Landwirthschaft*, vol. XCIV, Berlin, Joachim Pauli, 1804, p. 171; Eytelwein, *Praktische Anweisung zur Wasserbaukunst*...cit., vol. III, p. 39).

²⁷ Simon, *Ueber die Natur des Kalksteins. Analyse der Kalkstein*...cit., pp. 101–03.

²⁸ See Friedrich August Alexander Eversmann, *Technologische Bemerkungen auf einer Reise durch Holland*, Freyberg, Annaberg, Crazische Buchhandlung, 1792, pp. 173–79.

²⁹ Beckmann, *Anleitung zur Technologie*...cit., p. 311; Otto Christian Friedrich Reinhold, *Sammlung practischer Erfahrungen und Vorschriften, Cemente, Mörtel und Bétons betreffend*, in *Journal für die Baukunst*, vol. XV, 1841, (pp. 88–100, pp. 131–50), pp. 133–34.

³⁰ Friedrich Wilhelm Otto Ludwig Freiherr von Reden, *Bericht über die von dem Gewerbe-Vereine für das Königreich Hannover in den Monaten Mai und Juni 1835 veranstaltete erste Ausstellung inländischer gewerblicher Erzeugnisse*, in *Mittheilungen des Gewerbe-Vereins für das Königreich Hannover*, 1835, coll. 527–29.

harmful, since clay is thought to glaze around lime particles, hindering the combination of lime with water; in such cases lime is defined *todgebrannter Kalk* (dead-fired lime).³¹ Notwithstanding, some kinds of limestone that contain clay, *Märgel* (marls), are used to burn the so-called *Märgelkalk*, in regions where pure limestone is not available, as is the case in northern Brandenburg and Pomerania.³² It is worth mentioning that the chemist of the village of Bahrnberg in the principality of Branschweig-Lüneburg, a man named Jordan, finds a kind of marl suitable to produce hydraulic lime around 1778. Jordan announces his finding in the *Hannoversche Magazin* in 1782. "Four years ago," he writes, "I used lime-marl to produce a very solid putty or mortar, which hardens perfectly in water and binds all kinds of stones." Jordan even imagines several applications for this kind of hydraulic lime. "Prepared as mortar, without sand," he writes, "it can be used for hydraulic works, as well as for ordinary works in the place of common lime [...]. It adheres to clay-walls better than common lime [...]. It can be used to plaster floors, inside houses and in gardens, [...], and it can be used to produce bricks and tiles without fire."³³ Johann Georg Krünitz (1728–1796) mentions the possibility of producing hydraulic lime from marls in the thirty-second volume of the *Oekonomische Encyklopädie*, which is published in 1784, and Heinrich Gustav Flörcke (1764–1835), who edits the ninety-fourth volume of the same encyclopaedia in 1804, also mentions Jordan's hydraulic lime, when he writes the entry "Mörtel".³⁴ This however happens without considerable implications, as proved by the fact that Jordan's name appears in a 1796 book about manufacturing and trade in the principality of Branschweig-Lüneburg, as producer of several chemical products, but not of hydraulic lime.³⁵ If it had been implemented, Jordan's finding could have started the German manufacturing of hydraulic lime, artificial stones and tiles about half a century earlier.

Having travelled to France, Holland, Italy and throughout the Hapsburg Empire, Wiebeking knows several kinds of hydraulic lime and is also aware of their silica, clay and iron content. He considers hydraulic lime as an exception to Vitruvius' rule establishing that best lime is produced from pure limestone. "Vitruvius," he writes in 1805, "prefers lime burnt from hard limestone to build

³¹ See Eytelwein, *Praktische Anweisung zur Wasserbaukunst*...cit., vol. III, p. 39; Simon, *Ueber die Natur des Kalksteins - Chemisches Verhalten*...cit., pp. 77–78.

³² See Johann Georg Krünitz, *Oekonomische Encyklopädie oder allgemeines System der Staats- Stadt- Haus- und Landwirthschaft*, vol. XXXII, 1784, p. 658; Gilly, *Handbuch der Land - Bau - Kunst*...cit., p. 105. Krünitz marks the preference for pure limestone asserting that, if transport of stones from Rüdersdorf would be not expensive, it would be advisable to stop the production of lime from marls (*ibid.*, p. 658).

³³ "Seit vier Jahren habe ich gedachten Kalchmergel zu einem rechten festen Kitt oder Mörtel zuzubereiten heraus gebracht, der vorzüglich vom Wasser, [...], sich erhärtet, und mit allen Steinarten sich zu einem Körper verbindet"; "Er kann wohl zum Wasserbau, als in der Luft statt Kalch, aber ohne Zusatz vom Sande, als Mauerspeise, gebraucht werden, [...], Wenn Leimwände damit Überzogen werden, hängt er fest daran als der Kalch [...]. Man kann damit Fußböden, so wohl im Hause als auch in Gärtn überziehen, [...], ja man kan Mauer- und Dachziegeln davon ohne Feuer bereiten" (Jordan, *Nachricht*, in *Hannoversches Magazin*, XX, 1782, coll. 301–304).

³⁴ See Krünitz, *Oekonomische Encyklopädie*...cit., vol. XXXII, 1784, p. 730; Flörcke, *Dr. Johann Georg Krünitz's*...cit., p. 341.

³⁵ See Christian Ludwig Albrecht Patje, *Kurzer Abriß des Fabriken, Gewerbe-, und Handlungszustandes in den Chur Braunschweig-Lüneburgischen Landen*, Göttingen, Vandenhoeck und Ruprecht, 1796, p. 373.

masonries, and suggests using lime burnt from soft limestone for plastering. This statement is still true in most cases; however, there are some exceptions, as proved by Smeaton, whose experiments on mortar show the contrary. Some kinds of lime need to be used right away after slaking, like lime from Padua, which contains a large amount of silica, whereas others need to be slaked in pits and stay there for one year. Lime from Chorowitz in Moravia also needs to be used quickly, just like lime from Liège, which is well known in the Netherlands, and all other kinds of lime that contain a large amount of silica clay and iron, and are therefore suitable to compose hydraulic mortar.”³⁶ Wiebeking’s knowledge about hydraulic lime is almost pioneering in Germany, at a time when most master builders persist in praising the quality of aerial lime produced from pure limestone.

Coherently with such a conviction, master builders also believe that the best kind of mortar is only composed of aerial lime and sand. They even think that such kind of mortar is waterproof, once it has hardened. “Only through the combination with carbonic acid,” Simon writes, “slaked lime is anew transformed into raw limestone, and it can neither be dissolved in water, nor combine with other substances.”³⁷ In this same regard, Gilly furthermore asserts: “Lime mixed with sand gives the best mortar, which would even be suitable for hydraulic works, if such works could dry for at least one year long, before they come into contact with water.”³⁸ When it is not possible to let mortar harden before it comes into contact with water, lime is usually mixed with some “burnt clayish substances” that are supposed to accelerate the hardening process. “Since it is not always possible to let mortar set and harden [in a dry place] for one year,” Gilly recommends, “it is necessary to use, instead of sand, other materials, partly made of burnt clayish substances, which absorb water and cause a faster lime hardening.”³⁹ Mixtures of lime with such substances are called “cements”. “We use to call cement,” Gilly

³⁶ “Schon Vitruv Cap. V. Lib. II. giebt dem aus harten Kalksteinen gebrannten Kalk vor den aus weichen gebrannten zu den Mauern den Vorzug und will den letztern zur Bekleidung verwendet wissen. In der Regel ist diese Angabe auch noch jetzt richtig, aber es giebt Ausnahmen und Smeaton fand bey seinen über den Mörtel angestellten Versuchen das Gegentheil. Einige Kalkarten müssen gleich nach geschehener Löschung verarbeitet werden, wie z. B. der Paduanische Kalk, welcher viele Kieselerde enthält; andere müssen gelöscht in der Kalkgrube ein Jahr und länger bleiben. Der Mährische-Chorowitzer muß z. B. bald verbraucht werden; eben so wie der in Holland bekannte Lütticher Kalk und alle Kalkarten, die zu Wassermörtel gut sind, d. i. viel Kiesel-, Thon- und Eisenerde enthalte” (Wiebeking, *Allgemeine auf Geschichte...*cit., vol. IV, 1805, p. 307). Wiebeking’s reference about mortar experiments goes to John Smeaton (1724-1792) who plans and builds the Eddystone lighthouse in south England between 1756 and 1759, and carries out preliminaries experiments and test about the production of hydraulic lime and mortar (see Roberto Gargiani, *Concrete from archaeology to invention 1700-1769*, Lausanne, Presses polytechniques et universitaires romandes, 2013, pp. 309-16).

³⁷ “[...] nun durch den Beytritt der Kohlensäure, der gelöschte Kalk wieder zum rohen Kalk umgeändert wird, und in diesem Zustande weder Auflösbarkeit, noch Hang zur Verbindung mit andern Körper wahrnehmen lässt” (Simon, *Ueber die Natur des Kalksteins. Analyse der Kalkstein...*cit., p. 108).

³⁸ “Kalk mit Sand vermischt, giebt den besten Mörtel, der auch selbst zum Wasserbau brauchbar seyn Würde, wenn ein damit gemachter Bau nicht wenigstens ein ganzes Jahr Zeit haben müßte, um gehörig auszutrocknen, ehe man denselben dem Einwirken des Wassers bloßsetzt” (Gilly, *Handbuch der Land-Bau-Kunst...*cit., p. 118).

³⁹ “Da aber dieses nicht allemal möglich ist, dem Mörtel ein Jahr zum Trocknen und Binden zu lassen, so werden zu dessen Zubereitung anstatt des Sandes andere Materien gewählt, welche zum Theil aus thonartigen gebrannten Theilen bestehen, das Wasser sehr anziehen, und daher verursachen, daß der damit vermengte Kalk eher erhärtet” (Gilly, *Handbuch der Land-Bau-Kunst...*cit., p. 118). See also: Eytelwein, *Praktische Anweisung zur Wasserbaukunst...*cit., vol. III, pp.

further asserts, “mortar that is made of lime and other substances instead of sand, in order to make it suitable for hydraulic works.”⁴⁰ And, still in this regard, Wiebeking writes: “All masonry works, which either always stand in water, or often get wet, need to be built with cement-based mortar.”⁴¹

Several German master builders consider the Italian Pozzolana the best material to produce cement. Pozzolana is a kind of volcanic sand that is known since the time of Ancient Rome. Its modern use increases as of the 18th century and spreads in Mediterranean regions and along part of the Atlantic coast of Portugal and France, since pozzolana is mainly transported by ships.⁴² Instead, in Germany pozzolana is not really used, essentially for two reasons. First, it too expensive to be imported from Italy, as certain master builders asserts. “We may not make use of Pozzolana earth, which can only be found in Italy,” Gilly affirms, “since it is too expensive for us.”⁴³ In the same regard, Eytelwein states: “We do not prepare cement with pozzolana because it is too expensive.”⁴⁴ Wiebeking has the opportunity to observe the use of pozzolana in Venice, where he works as director of the department for waterways of the Austrian Hungarian Empire, from 1802 to 1805. “Pozzolana,” he writes in 1805, “is a kind of volcanic earth that can be found in the regions of Civitavecchia, Rome, Pozzuoli and Naples. From the first ones, we import a dark red sort to Venice, Trieste and Fiume, for our hydraulic engineering works.”⁴⁵ As a matter of fact, Wiebeking even suggests using pozzolana-based mortar to build a new masonry pier in the port of Trieste.⁴⁶ The second, and maybe even the most important reason of the non-use of pozzolana in Germany, is the availability of a similar kind of sand, which can be produced by grinding some volcanic tuff stones from the region of the Vulcan Eiffel in Rhineland. The ancient Romans probably discovered this kind of tuff when building a military road from Trier to Andernach. They used it between the years

^{48–50}; Simon, *Ueber die Natur des Kalksteins. Analyse der Kalkstein*...cit., p. 114; Friedrich Ludwig Aster, *Gesammelte Nachrichten von dem Cemente aus Trasse und wasserdichte Mauerwerke der Holländer*, Dresden, Leipzig, Samuel Gerlach, 1791³.

⁴⁰ “[Mörtell], welche aus Kalk, der nicht mit Sand, sondern mir andern Materien verfertigt worden, und zum Wasserbau gebraucht wird, und diesen nennt man gemeinlich Cement” (Gilly, *Handbuch der Land-Bau-Kunst*...cit., p. 119).

⁴¹ “Alles Mauerwerk, welches entweder stets im Wasser bleibt oder oftmals davon benetzt wird, muss mit Cement-Mörtel gemauert werden [...]” (Wiebeking, *Allgemeine auf Geschichte*...cit., vol. IV, 1805, p. 458).

⁴² See Gargiani, *Concrete from archaeology* to...cit., pp. 41–57.

⁴³ “Der Pozzolanerde, die nur in Italien gefunden wird, können wir uns, als einer zu kostbare Sache, nicht bedienen” (Gilly, *Handbuch der Land-Bau-Kunst*...cit., p. 126).

⁴⁴ “Die Bereitung eines Cements mit einem Zusatz von Puzzolane [...] ist bei uns ihrer Kostbarkeit wegen nicht im Gebrauch” (Eytelwein, *Praktische Anweisung zur Wasserbaukunst*...cit., vol. III, p. 50).

⁴⁵ “Puzzolana ist eine vulkanische Erde, die in den Gegenden von Civita Vecchia, Rom, Pozzuoli e Neapel gefunden wird. Von den ersten Gegenden beziehen wir sie nach Venedig, Trieste und Fiume, die braunrötlich ist, zu unsern Wasserbauten” (Wiebeking, *Allgemeine auf Geschichte*...cit., vol. IV, p. 309, n. 2).

⁴⁶ See Wiebeking, *Allgemeine auf Geschichte*...cit., vol. IV, (pp. 21–25), p. 24; Id., *Beyträge zur Hafen-, Seeufer- und Flussbaukunde, oder: Abhandlung über die Verbesserung der Häfen von Venedig, und über die Erhaltung der Inseln vor Venedig; über die Verbesserung des Laufs der Brenta, des Bacchiglione, und der Schiffahrts, so wie der Entwässerungs-Kanäle zwischen Venedig, Padua, Verona und der Etsch: nebst einem Vorschlage zur Anlage eines Seehafens vor Triest, auf genaue vom Verfasser angestellte Lokaluntersuchungen gegründet; und eine Beschreibung des Hafens Cronstadt*, München, auf Kosten des Verfassers, Gedruckt bey Franz Hübschmann, 1810, (pp. 37–42), p. 42.

50 and 100 AD to prepare hydraulic mortar and even concrete.⁴⁷ Following the decline of the Roman age, expertise in preparing hydraulic mortar and concrete using volcanic tuff from the Eifel tends to disappear over the centuries. During the Middle Ages, tuff stones from the Eifel are still used along the Rhine, but mainly to produce ashlar and grindstone, and much less milled powder to prepare mortar.⁴⁸ It is not before early 17th century that they regain a renewed importance for the production of hydraulic mortar, thanks to the increasing interest of Dutch builders.⁴⁹ From that time onwards, most tuff stones quarried in Rhineland are exported to Holland, where, by means of typical mills, they are ground into a kind of sand that takes the name of *Trass* or *Terras*. These terms probably derive from the Italian word *terrazzo*, meaning a typical flat roof from the region of Naples, which is usually built with pozzolana-based cement.⁵⁰ Exportation of volcanic tuff from Rhineland to Holland by ship along the Rhine is documented at least since the early 1600s, as well as rivalry over the control of tuff stone grinding, which arises between Holland and German States. During the 17th and 18th centuries, some German rulers try to encourage inland grinding, going to the extent of forbidding the exportation of raw stones to Holland.⁵¹ Early German *Trass* mills are set up since 1611, first in the village of Brohl, and, later on, in the village of Pleidt; they are called *Cement-Mühlen* (cement mills).⁵² Conflicts also arise between the German principalities of Cologne and Trier since the 17th century, for the predominance in tuff quarries exploitation, giving further evidence of the commercial importance that *Trass* is gaining. In the second half of the 18th century, *Trass* is considered the northern pozzolana. This is clearly noted by the master builder Christian Ludwig Ziegler (1748–1818), who, in 1773, writes: “In northern European regions, *Trass* has the same role that pozzolana has in southern regions.”⁵³ In the early 1800s, most tuff quarried in Rhineland is still ground in Holland and even resold to Germans, along the Rhine or, via Bremen,

⁴⁷ See Gustav Haegermann, *Vom Cäment zum Zement*, Wiesbaden, Berlin, Bauverlag GmbH, 1964, p. 31.

⁴⁸ See Haegermann, *Vom Cäment ...*, cit., pp. 31–32; Friedrich Quietmeyer, *Die Mörtelkunde von ihren ersten Anfängen bis zur zielbewußten Herstellung des Portlandzementes*, in Hans Riepert, ed., *Die deutsche Zementindustrie*, Zementverlag GmbH, Charlottenburg, 1927, (pp. 1–87), pp. 18–26.

⁴⁹ See Anton Hambloch, *Der Trass, seine Entstehung, Gewinnung und Bedeutung im Dienste der Technik*, Berlin, Julius Springer, 1909, p. 24.

⁵⁰ Hambloch, *Der Trass, seine Entstehung...cit.*, p. 12; Gargiani, *Concrete from archaeology to...cit.*, p. 68.

⁵¹ See Haegermann, *Vom Cäment...cit.*, p. 32.

⁵² *Ibid.*, p. 32. Some authors from the second half of the 19th century, and from the early 20th century, dealing with the topic of *Trass*, give as first German *Trass* mill the one that is set up in 1682 in Brohl by the Dutch man Bernhard von Santen (see Heinrich Wolffram, *Mittheilungen über Tuffstein, Trass und einige andere Baumaterialien der Vulkanische Eifel*, Diez an der Lahn, Franz Schickel, 1885, p. 6; Anton Hambloch, *Der rheinische Trass als hydraulischer Zuschlag in seiner Bedeutung für das Baugewerbe*, Andernach am Rhein, Selbstverlag des Verfassers, 1903, p. 8; Id., *Der Trass, seine Entstehung...cit.*, p. 24).

⁵³ “Überhaupt ist Tarras in den nördlichen Theilen Europas, was Puzzolane in den südlichen ist” (Christian Ludwig Ziegler, *Von dem Terras, der Puzzolana, und deren Substitutionsarten*, in *Hannoversches Magazin*, XI, 1773, (coll. 81–94), col. 85, cit. also in Flörcke, *Dr. Johann Georg Krünitz's...cit.*, p. 285).

along the river Weser.⁵⁴ Wiebeking condemns such practice, and, in 1805, he complains: “Tuff stones are transported to Holland where they are ground; then, strangely enough, they are sometimes sold in Germany along the Rhine, as if grinding tuff were a witchcraft!”⁵⁵

From Dutch ways of preparing *Trass*-based cement, German master builders draw instructions for the preparation of two kinds of different quality hydraulic mortar, *Trassmörtel* and *Bastard-Mörtel*. “The *Trassmörtel* that is used to build the foundations of most new locks in Holland,” Wiebeking explains, “is made of two parts of sieved lime from Liège and one part of *Trass*, [...]” while *Bastard-Mörtel*, which is used for walls that are not in water, “is made either of three parts lime, one part *Trass* and two parts sand, or of two parts lime and one part sand.”⁵⁶ A cheaper but less effective type of *Trass* is the so-called *wild Trass*, or *Tau*. This kind volcanic of ash can be found along the Rhine, especially near the town of Brohl, and it is locally used for affordable constructions.

The increasing reputation and demand of *Trass* leads to the search for similar and alternative materials. This mainly happens in regions that are far away from the Rhine, like Silesia, where, already in the 1780s, Adolph Traugott von Gersdorf tries to use some local basalt instead of *Trass*, to produce cement, after having translated into German the book by Barthélemy Faujas de Saint-Fond (1741–1819) *Mémoire sur la manière de reconnaître les différentes espèces de pouzzolane*. Some substitutes of Dutch *Trass* are also known in the early 1800s: the so-called *weiss Trass* produced near Braunschweig, a milled tuff produced in the village of Zabenstadt near Magdeburg, and the black volcanic sand from Weinfelder Kapelle, in the Eifel region.⁵⁷ Since it is easily available and affordable, the most common substitute for *Trass* is brick dust (*Ziegelmehl*), which is produced by grinding old bricks, tiles and every kind of terra cotta pieces, by means of hammers or similar hand tools. Cement and mortar are also prepared manually at that time, mixing the different components on wooden platforms, with shovels and rakes. To prove the efficacy of brick dust-based cement, Eytelwein, Gilly and Wiebeking note that Jean-Rodolphe Perronet (1708–1794) had used such a cement to build the Pont de Neuilly in Paris. They

⁵⁴ Zimmermann, *Einige Bemerkungen über die Festigkeit, Mischungsverhältnisse und Zubereitung des Bétons, oder des Mauerwerkes aus klein geschlagenen, mit Mörtel untermengten Steinen, dessen man sich zuweilen, um Fangdämme und Wasserschöpfen zu sparen, zur Fundamentierung von Bauwerken unter Wasser bedient*, in *Journal für die Baukunst*, vol. III, 1830, (pp. 1–31), p. 14.

⁵⁵ “So wird er in Steinen nach Holland verfahren und dort zu Pulver zerstossen und vermahlen; dann sonderbar genug, nicht selten wieder in Deutschland und am Rhein verkauft, als wenn eine solche Trassmühle eine Hexerey wäre!!” (Wiebeking, *Allgemeine auf Geschichte...*cit., vol. IV, cp. 309, n. 1).

⁵⁶ “Der *Trassmörtel* besteht bey dem Grundbau der neuesten Schleusen in Holland aus zwey Theilen gesiebten Lütticher Kalk und einem Theil *Trass*, [...]. Zu dem innern Gemäuer, welches nicht im Wasser steht, wird der sogenannte *Bastard-Mörtel* gebraucht. Erselbe besteht entweder aus drey Theil Kalk, ein Theil *Trass* und zwey Theile Sand, oder aus zwey Theil Kalk und ein Theil Sand” (Wiebeking, *Allgemeine auf Geschichte...*cit., vol. IV, p. 313, 314).

⁵⁷ See Gilly, *Handbuch der Land-Bau-Kunst...*cit., pp. 127–28; Harmen Jan Freiherr van der Wyck, *Uebersicht der Rheinischen Eifeler erloschenen Vulkane und der ErhebungGebilde, welche damit geognostischer Verbindung stehen, nebst Bemerkungen über den technischen Gebrauch ihrer Produkte*, Bonn, Eduard Weber, 1826, p. 95.

also recall the locks of the Bromberg Channel, whose lowest masonry joints are made of *Trass*-based mortar, whereas the rest of the masonry work is bound with a kind of mortar containing brick dust.⁵⁸

Besides *Trass* and brick dust, several other substances are considered suitable to prepare hydraulic mortar, although they are less used. The most known are iron powder, ash from peat burning, and the so-called ash from Tournai in the Flanders, known as Dornick ash, which is actually a residue from coal burning.⁵⁹ Most proficient master builders are also aware of a special mortar made by the French inventor Antoine-Joseph Loriot and, for this reason, commonly known as *Lorioticsche Mörtel*, (Loriot's mortar).⁶⁰ It is a cement-based mortar, which is prepared by using brick powder and some unslaked lime, to be added shortly before using mortar. Unslaked lime used in Loriot mortar is thought to absorb water and accelerate mortar hardening, like *Trass* and all other similar products. It is widely held that the only role of *Trass*, brick dust, and any other substance used to produce cements is that of absorbing water and accelerating the hardening process. This belief lasts until the end of the 1820s, when the chemical role of these substances in mortar is scientifically proved.

The use of cements out of water is not admitted, and it is even considered disadvantageous. According to Flörcke, for instance, "mortar prepared with *Trass* or pozzolana do not harden so well and completely as good ordinary mortar, if it is used out of water, just exposed to the air."⁶¹ The use of cements in building practice remains modest in early 19th century, and German master builders generally mistrust mixtures of different substances to improve the quality of mortar. In this regard, Simon writes: "Many people suggest using this or that substance to improve the quality of mortar, sometimes even with emphasis, but none of such substances really offers the promised advantages. The wish of unknown people to become famous, or at least to be praised for having contributed to fulfil this or that [building] need, lies behind these suggestions. Is the solidity of good mortar really scanty to the point of making necessary additives to improve it? Ancient expertise shows that mortar made of sand and lime lasts for a long time, exactly because of the simple composition [...]. Thus, why try to improve the solidity of mortar by adding further products, since its simplest kind is absolutely enough for us?"⁶²

⁵⁸ Gilly, *Handbuch der Land - Bau - Kunst*...cit., p. 129; Eytelwein, *Praktische Anweisung zur Wasserbaukunst*...cit., vol. III, p. 47; Wiebeking, *Allgemeine auf Geschichte*...cit., vol. IV, p. 317.

⁵⁹ See Gilly, *Handbuch der Land-Bau-Kunst*...cit., p. 225; Eytelwein, *Praktische Anweisung zur Wasserbaukunst*...cit., vol. III, p. 50. Dornick is an old German named for the town of Doornik, which is the Dutch name for Tournai.

⁶⁰ Simon, *Ueber die Natur des Kalksteins. Analyse der Kalkstein*...cit., p. 112; Gilly, *Handbuch der Land - Bau - Kunst*...cit., p. 121; Eytelwein, *Praktische Anweisung zur Wasserbaukunst*...cit., vol. III, p. 50; Wiebeking, *Allgemeine auf Geschichte*...cit., vol. IV, p. 319.

⁶¹ "Allein braucht man die Pozzolanerde oder Traß auch im Mörtel an Gemäuern, die außer dem Wasser der freyen Luft ausgesetzt sind, so ist die Erhärtung nie so groß und so vollkommen, als die von bloßem guten Mörtel" (Flörcke, Dr. Johann Georg Krünitz's *Oekonomische Encyklopädie*...cit., p. 198).

⁶² "[...] fehlt es nicht an Vorschlägen, die bald diesem, bald jenem Stoff als ein vorzügliches Mittel, die Bindbarkeit des Mörtels zu erhöhen, empfehlen, jedoch kann im Allgemeinen davon angeführt werden, dass keiner darunter den Vortheil leistet, den ihm der Erfinder öfters mit so vielem Nachdruck zuschrieb. Dergleichen Vorschläge entspringen mehrrenteils von dem Hang, den ihre Urheber haben, sich einen Namen zu machen, und wenigstens von unerfahrenen das Lob einzuernten, zur Verbesserung dieser oder anderer Bedürfnisse vieles beytragen zu haben. Allein ist denn die

1.3 Foreign models of concrete hydraulic foundations, the significance of Wiebeking's Wasserbaukunst

The widest survey of hydraulic works in the early 19th century is probably the one that Wiebeking carries out to write the mentioned treatise *Allgemeine auf Geschichte und Erfahrung gegründete theoretisch-practische Wasserbaukunst (Wasserbaukunst)*. Wiebeking already starts collecting materials about hydraulic works since 1794, during study journeys to Holland and France, and while he works for the Hapsburg Empire. Moreover he learns from technical literature, principally the ancient Vituvius' *De Architectura*, and the most recent eighteenth-century French construction books. It should be pointed out that concrete is never a focal interest for Wiebeking. The *Wasserbaukunst* is structured into ten thematic sections dealing with different specific hydraulic engineering domains (river engineering, construction of seawalls, harbours, etc.), but no section focuses on concrete constructions.⁶³ Wiebeking rather occasionally mentions the use of concrete in certain hydraulic foundations in Italy and France, and he mainly describes it as a mixture of pebbles and mortar. Furthermore, being essentially interested in completed work, Wiebeking sometimes overlooks essential studies about the way of preparing concrete, and incompletely projects based on concrete building techniques. In this way, he misses important occasions to introduce knowledge about these topics into German technical literature of his time.

Wiebeking's major literary reference is Bélidor's treatise *Architecture hydraulique*, which he declares to have used as a writing model. “[...] as I decided to write a book about hydraulic engineering,” Wiebeking relates, “it was especially useful to know that Belidor's work is based on descriptions and observations of hydraulic works, instead of obsolete theories; this is a feature that makes Bélidor's *Architecture Hydraulique* still up to date.”⁶⁴ Such an approach is coherent with the general inclination to give emphasis to building practices rather than to theories, and makes Wiebeking's *Wasserbaukunst* a precious tool to know how foreign hydraulic constructions act as source of knowledge for early German attempts at building with concrete.

Just from Bélidor's *Architecture hydraulique*, Wiebeking learns about the technique that the French military engineer François Milet de Monville adopts in 1748 to build the concrete foundations of a new dockside in the naval shipyard of Toulon. He describes the technique as follows: “Two rows of

Festigkeit, die ein gut behandelter Mörtel erlangt, so gering, dass es uns besonders um Zusätze zur Vermehrung desselben zu thun wäre? Die ältesten Erfahrungen belehren uns, dass der Mörtel aus blossem Kalk und Sand dem nagenden Zahn der Zeit trotzet, und der vorzügliche Grund dieser Unveränderlichkeit ist wohl in der Einfachheit seiner Bestandtheile zu suchen, [...]. Warum also zum Mörtel einen Zusatz zur Vermehrung der Festigkeit, wo uns das einfache vollkommen genüget?” (Simon, *Ueber die Natur des Kalksteins. Analyse der Kalkstein...*cit., pp. 116–17).

⁶³ This structure appears definitively clear from the third volume (1801).

⁶⁴ “Als ich [...] die erste Idee zu der Bearbeitung einer Wasserbaukunst fasste, da war mir der grosste Nutzen den die Belidorsche Wasserbaukunst (*Architecture Hydraulique*) gestiftet hat, gegenwärtig; wie derselbe lediglich aus denen darin enthaltenen Beschreibungen ausgeführter Wasserbauwerke und einiger Beobachtungen entstehe, und nicht aus ihren schon längst verdrängten Theorien” (Wiebeking, *Allgemeine auf Geschichte...*cit., vol. III, p. IX).

piles are rammed into the soil, close to each other in order to form two walls, and the space in-between is filled with pebbles and mortar, poured down by means of chests. A layer of mortar is laid on a first layer of pebbles, and this work is then repeated so many times until the height of 6 feet under the water level is reached. From this point onwards, the use of the chest is no longer necessary. The ensemble hardens and becomes as hard as a rock.”⁶⁵ Wiebeking compares this kind of foundations to ancient Roman constructions, and mentions that Vitruvius describes them in the *De Architectura*.⁶⁶

Approximately at the same time as the last volumes of Wiebeking *Wasserbaukunst* are published, even Alois Hirt (1759–1836), using Vitruvius as main reference, describes underwater foundations made of concrete poured inside enclosures of timber piles, in his *Baukunst nach den Grundsätzen der Alten*.⁶⁷ The significance of such descriptions should be assessed considering that the construction of such foundations will then considerably spread in the course of the century.

Wiebeking also takes Bélidor's description of a further kind of underwater foundation, which is adopted in the port Toulon around about mid-18th century. It involves the use of watertight and floating timber caissons, which are pulled on water to the foundation site, where they are gradually filled with concrete and sunk. This technique, however, will not really find application in Germany in the first three quarters of the 19th century.

Despite his careful description of the construction phases of the foundations that are carried out Toulon, Wiebeking neglects Milet de Monville's experiments about the composition and manufacture of pozzolana-based concrete. Furthermore, he does not explain that the “chest” used to pour it underwater is part of a more complex machine, specially conceived for the purpose and essentially made of a sawhorse holding a windlass, from which a chest full of concrete is lowered down into foundation pits and emptied by opening a hinged flap placed on the bottom.

⁶⁵ “Es werden nämlich zwey Reihen Pfähle (Pfahl an Pfahl) eingerammt. Zwischen diesen Wänden werden die Steine und der Mörtel durch Kästen auf den Grund gelassen. [...]. Ueber die erste Schicht Steine wird eine Schicht Mörtel geschüttet und so weiter bis 6 Schuh unter der Oberfläche des Wassers, wo man alsdann nicht mehr des Kastens oder der Maschine zum Ausschütten des Mörtels benötigt ist. Das Ganze erhärtet sich und wird wie ein Fels so hart” (Wiebeking, *Allgemeine auf Geschichte...cit.*, vol. III, 1801, p. 218).

⁶⁶ *Ibid.* It is probably worth to remember that the translation Vitruvius' *De Architectura* by August von Rode (1751–1837) had been just issued in 1796 (see Marcus Vitruvius Pollio, *Des Marcus Vitruvius Pollio Baukunst*, ed. August von Rode, Leipzig, Georg Joachim Göschen, voll. I, II, 1796).

⁶⁷ “When an harbour branch needs to be built in the sea, as long as pozzolana is available, Vitruvius teaches as follows: ‘Enclosures made of oak piles and transversal crosspieces are built underwater on a chosen place. The soil underwater, at the bottom of the enclosure, is then made regular by means of boards, and once this is achieved, a mixture of rubble and mortar (two measures of pozzolana and one measure of lime), which has been prepared in a trough, is poured until caissons are filled out.’ (“Ist beim Hafenbau ein Arm in dem Meere zu führen, so lehret Vitruv, mit der Voraussetzung, dass Puzzolana vorhanden sey, folgendes: (5,12.) ‘Man verfertige aus eichenen Pfählen und Querbändern wohlverbundene Kasten, welche an dem hiezu ausgewählten Orte ins Wasser gelassen, und festgestellt werden. Dann. werde der Grund unter dem Wasser innerhalb derselben vermittelst unterlegter Schwellen abgeglichen, und die Bruchsteine, welche in dem Troge mit dem angegebenen Mörtel (zwey Theile Puzzolana mit einein Theile Kalk) wohl gemischt worden sind, hineingegossen, bis der ganze zu bebauende Raum zwischen den Kasten ausgefüllt ist’” (Alois Hirt, *Die Baukunst nach den Grundsätzen der Alten*, Berlin, Realschulbuchhandlung, 1809. p. 121).

Wiebeking overlooks at least two further significant studies about concrete. They concern the building of seawalls in the port of Cherbourg and in the Venice lagoon. The construction of a new sea wall in the harbour of Cherbourg starts in 1783 following a project that engineer Louis-Alexandre De Cessart develops. It is essentially based on the construction of several huge timber cones, which are filled with loose stones and, in this way, sunk into the water to form a barrier in front of the Cherbourg shoreline.⁶⁸ Between 1784 and 1787, several counterproposals to De Cessart's project are developed; some of them are based on the use of pozzolana-based concrete, but Wiebeking only describes De Cessart's cones, overlooking all counterproposals.⁶⁹ Moreover, he even makes a mistake when, besides De Cessart's cones, he depicts seawall made of granite ashlar arranged in sunk caissons, which he mentions having been built since about the mid 1780s. To describe this seawall, Wiebeking translates a passage taken from Pierre Patte's *Mémoires sur les objets les plus importantes de l'architecture*, but Patte's *Mémoires* actually date back to 1769.⁷⁰ (fig. 1.3.1)

In Venice, Wiebeking is charged in 1803 with analysing the damages that a violent storm has caused to some typical Venetian stone masonry levees, the so-called *murazzi*. These essentially consist of Istria stone ashlar held together by means of pozzolana-based mortar, and they stand on foundations made of pebbles and pozzolana-based mortar.⁷¹ (fig. 1.3.2) The building of the *murazzi* starts in 1740, being preceded by several projects and trials involving the use of Istria stones laid on huge concrete basements, and by two attempts at building walls made of concrete poured into caissons.⁷² Although he develops a short historical excursus concerning the evolution of levees in Venice, Wiebeking neglects proposals and trials involving the use of concrete. He only describes ancient levees made of compressed earth, levees made of timber poles and loose stones, and a kind of *murazzi* made of Istria stones sealed up with pozzolana-based mortar, but standing on foundations made of pebbles and ordinary mortar. The non-use of pozzolana that Wiebeking observes in the foundations of the *murazzi* could be due to the high cost of this expensive material, which influences the construction of levees in Venice already during the XVIII century.⁷³

Following the damage that the storm has caused to the *murazzi*, Wiebeking develops harshly criticises this kind of constructions. "It is hard to hold back displeasure," he writes, "observing these

⁶⁸ See Roberto Gargiani, *Le cones de la rade de Cherbourg, ou du béton enseveli, 1781-1788*, in *Matières*, n° 10, 2012, pp. 81-99.

⁶⁹ The most innovative is described in a paper whose author remains anonymous; it consists in building two concentric cones, the internal of which should be less high than the external one, and the space between them should be filled with concrete. Moreover the central empty space delimited by the internal cone should be covered with a concrete vault poured on a centring built up on the little cone.

⁷⁰ See Wiebeking, *Allgemeine auf Geschichte...cit.*, vol. III, 1801, pp. 208; Pierre Patte, *Mémoires sur les Objets les plus importantes de l'Architecture*, Paris, Chez Rozet, 1769, p. 224.

⁷¹ See Wiebeking, *Allgemeine auf Geschichte und Erfahrung gegründete theoretisch-practische Wasserbaukunst*, vol. IV, cit., pp. 93-98; Id., *Beyträge zur Hafen-Seeufers- und Flussbaukunde...cit.*, 1810, pp. 14-20.

⁷² See Gargiani, *Concrete from archaeology to...cit.*, pp. 81-100, 186-99.

⁷³ See *ibid.*, pp. 205-13.

various Venetian buildings, which have cost the State millions, despite being only experiments.”⁷⁴ Quite to the contrary, when admiring the majesty of the palaces in Piazza San Marco, Wiebeking takes a close interest in knowing how the foundations of lagoon buildings are built. Venetian public engineers explain that the bearing walls of the buildings in Venice stand on timber piles rammed into the soil inside enclosures made of cofferdams, and that the spaces between the pile heads are filled with a casting of pebbles and mortar, which is then covered with a layer of mortar and timber boards, pressed into the mortar and nailed onto the pile heads, to be finally again covered with two further layers of timber boards.⁷⁵ (fig. 1.3.3) A similar technique is described in Belidor’s *Architecture hydraulique*; it consists in lying a timber frame on the bottom of a foundation pit surrounded by sheet piles, in ramming the timber piles inside the different framing fields, and in pouring Trass-based concrete among and over the pile heads.⁷⁶ We cannot rule out the idea that Wiebeking could have observed this kind of foundation technique during one of his study journeys to Holland, where it is often used to build the foundations of bridge piers.⁷⁷ Wiebeking considers this kind of foundation as the most advisable in case of marshy and unsteady soils, but he believes it more prudent to fill the framing compartments with brick masonry work instead of pouring pebbles and mortar.

Beyond Wiebeking’s studies, a further and important source of knowledge about the construction of concrete foundations is the project and the partial realisation of the locks of the so-called Grand Canal du Nord, between the towns of Venlo in the Netherlands, and Neuss in Rhineland. The channel is conceived by the French engineers of the Corp des Ponts et Chaussées attached to the Department de la Roer, between the end of the 18th and the beginning of the 19th century, when Prussia is under French control. Construction work starts in 1808, and stops in 1811, when the channel is no longer considered necessary.⁷⁸ Nevertheless, engineer Aimable Hageau (1756–1836), who has been involved in the planning and in the building of the channel, writes a book about it, which is published in 1819 and becomes known among German master builders.⁷⁹ According to Hageau’s, the foundations

⁷⁴ “Wenn man diese verschiedenen venetianischen Bauarten, welches lauter Versuche sind, die dem Staate Millionen gekostet haben, betrachtet: so kann man sich des Unwillen nicht erwehren” (Wiebeking, *Allgemeine auf Geschichte...cit.*, vol. IV, p. 98).

⁷⁵ See Wiebeking, *Allgemeine auf Geschichte...cit.*, vol. IV, pp. 381–82. The casting of pebbles and mortar used in Venetian timber piling foundations actually takes the place of clay, which is otherwise commonly poured over timber piles.

⁷⁶ See Bélidor, *Architecture hydraulique...cit.*, p. 184.

⁷⁷ See [Friedrich Wilhelm] Elsner, *Über die Anwendung des Béton-Mörtels zum Fundamentierung unter Wasser*, in *Journal für die Baukunst*, I, 1829, (pp. 236–45), pp. 241–42.

⁷⁸ The Gran Canal du Nord should create a direct waterway between France (Venlo is under French control from 1794) and Germany, avoiding the port of Rotterdam, which is not yet under the direct control of France at the time when the channel is conceived. The building of the channel is stopped in 1811, after the king of Holland, Louis Napoléon Bonaparte, has abdicated and Holland becomes part of the French Empire, making the achievement of the channel actually unnecessary (see Hans Scheller, *Der Nordkanal zwischen Neuss und Venlo*, Neuss, Stadtarchiv, 1980, pp. 4–7).

⁷⁹ Aimable Hageau, *Description du canal de jonction de la Meuse au Rhin*, Paris, Chez l’Auteur, 1819.

of the locks are conceived as 85 cm thick beds of concrete, poured into 1,5 meter deep pits. (fig. 1.3.4-5) Concrete is composed of lean lime from Namur, *Trass* from Brohl, sand, gravel and crushed bricks.⁸⁰

Beside the project and the partial completion of the Gran Canal du Nord, during the period of French control over Rhineland, some embankments along the Rhine are built on foundations consisting of *Trass*-based concrete, which is poured underwater into pits that are dug along the riversides, and are isolated from the stream by means of single rows of sheet piles. The embankments at the entrance of the Cologne port, for instance, are built in 1812 on 3 feet thick beds of concrete composed of two parts of lime, three parts of *Trass*, one part of sand, two parts of pebbles and two parts of sharp-cornered pebbles.⁸¹

1.4 Pebbles, rubble and mortar

A unique kind of foundation technique involving the use of pebbles, rubble and mortar is introduced in Berlin at the turn of the 19th century, on the initiative of a spirit maker and trader named Benjamin Georg (1739–1823). Georg is the owner of a wide estate situated between today's Friedrichstrasse, Georgenstrasse and Reichstagufner, which he intends to develop with new buildings.⁸² Because of the proximity to the river Spree, the soil of the area is quite marshy, and foundations for buildings need to rest at a depth of 22 feet in the ground.⁸³ After having used a traditional timber piling foundation to build a storehouse, in 1798 Georg starts building linear foundations composed by a number of underground masonry pillars, arranged in rows and connected at the top by means of arches, which are intended to support the bearing walls of the planned building. Pillars consist of circular walls

⁸⁰ "On well rammed soil, a first group of masons spread, ram and level a 35 centimetres thick layer of concrete. A second group of masons covers this layer with a second one of the same thickness, which need to be spread, rammed and levelled as well. Finally, a third group covers the second layer with a third one, which is 25 centimetres thick. Concrete is made using lime from Namur, the leanest available, or lime from Trier. It is composed of two parts of lime, one part and half of best quality *Trass* from Brohl, one part and half of sand taken from the river or from quarries, one part of gravel coming from the excavation of the foundation pit, two parts of rubble and two parts of egg-sized crushed bricks [...]." ("Sur ce sol bien battu, une première bande de maçons étendra, battra et arasera, dans la superficie des fondemens, une première couche de maçonnerie de béton de trente centimètres d'épaisseur. Une deuxième bande de maçons recouvrira cette couche de béton, d'une seconde couche de même épaisseur que la précédente, qu'on étendra, battra et arasera comme dessus. Enfin, une troisième bande de maçons recouvrira cette seconde couche de béton d'une troisième, à laquelle on donnera 25 centimètres d'épaisseur uniforme. Cette maçonnerie de béton sera faite avec de la chaux vive de Namur, la plus maigre qu'on pourra se procurer, ou de la chaux de Trèves. Elle sera composée de deux parties de cette chaux; d'une partie et demie de trass de Brohl de première qualité; d'une partie et demie de sable de rivière, ou de mine équivalent; d'une partie de gravier sorti de la fouille; de deux parties d'éclats de pierre, et de trois parties d'éclats de briques, réduits à la grosseur d'un œuf [...]" (*ibid.*, pp. 52–53).

⁸¹ See Elsner, *Über die Anwendung des Béton-Mörtels...cit.*, pp. 242–43; Julius von der Orbach, *Tufstein, Trass und hydraulischer Mörtel. Gesammelte Bemerkungen*, Coblenz, Karl Bädecker, 1849, pp. 27–28.

⁸² A portrait of Benjamin Georg, along with further information about the development of his estate in Berlin, are given in Berndt Weber, *Georgstrasse. Nach wem wurde die Georgstrasse in Berlin-Mitte benannt?*, in *Mitteilungen des Vereins für die Geschichte Berlins*, CI, 2005, n° 1, also published in www.diegeschichteberlins.de.

⁸³ See David Gilly, *Über die Gründung der Gebäude auf ausgemauerte Brunnen*, Berlin, Realschulbuchhandlung, 1804, p. 4.

made of bricks bound with brick dust-based hydraulic mortar, and of an inner filling made of rubble mixed with the same kind of hydraulic mortar that is used for the brick masonry work of the circular walls. The latter are built following the construction technique of the sinking wells, which is already known in several countries to build ordinary wells for water supply.⁸⁴ (fig. 1.4.1) First, a pit between 6 and 7 feet deep is dug into the soil, followed by wooden crown laid on the bottom of it, and a high portion of circular wall between 5 and 6 feet built on the wooden crown. Once this is completed, several vertical wooden bars are fixed by means of a rope all around the external surface of the wall portion, at a certain distance from one another, to form a sort of reinforcement chain. At this point, workers go inside the circular wall portion and dig some soil under the wooden crown, so that the wall sinks down, and a further similar portion is built on the top. The sequence is repeated until the circular wall has reached the necessary depth, that is to say, the bearing soil. The free interior space is then filled with rubble and mortar, and, once the filling has hardened, the ensemble becomes a solid underground pillar.

Following Georg's example, other Berlin landlords adopt this kind of foundation, which even attracts the attention of Gilly, who reports it in two articles published in 1798 and 1800 in the *Sammlung nützlicher Aufsätze*, and in a later pamphlet, which is published in 1804.⁸⁵ Beyond the mere description of the building technique, Gilly also searches for its origin. In French technical literature, he finds three quite different and unrelated references, dating from different ages. The first concerns a supposed use of masonry well foundations by ancient Egyptians during the 12th century; the second concerns the foundations of the Château de Saint Maur-des-Fossés near Paris, designed by Philibert De L'Orme (1510–1570) as cut stones pillars built deep into the ground and connected on the top through arches; and the third one concerns an ancient Indian building technique that appears very similar to the one adopted by Georg, since it also involves the building of circular walls that gradually sink into the ground, to be then filled with rubble, earth and sand.⁸⁶ British colonialists working on improving the fortifications of the city of Arcat are thought to have discovered this construction technique, as the French official Alexandre le Goux de Flaix reports in his memories, written after having served for a long time in India as an engineer. Le Goux de Flaix's memories are published in Paris in 1802, four

⁸⁴ According to Wiebeking, these places would be Italy, southern Germany and Rhineland (see Wiebeking, *Allgemeine auf Geschichte...cit.*, vol. IV, 1805, p. 358).

⁸⁵ David Gilly, *Über die Gründung der Gebäude auf ausgemauerte Brunnen*, in *Sammlung nützlicher Aufsätze und Nachrichten, die Baukunst betreffend*, 1797, vol. I, pp. 137–38, 1798, vol. II, pp. 124–24; Id., *Über die Gründung der Gebäude...cit.*, 1804. Gilly relates about wells foundations realized in the Unter den Linden alley and in the Jägerstrasse (*ibid.*, p. 2).

⁸⁶ The Château de Saint Maur-des-Fosses is built since 1541. “I let dig several holes,” De L'Orme writes, “as if I had planned to build four or five feet wide wells, [...] and I let fill the mentioned hole, or wells, with good masonry” (“...je feis faire plusieurs trous ou pertuis, come si l' eusse voulu faire des puis de quatre ou cinq pieds de large, [...] & faisois remplir lesdicts trous ou puis de bonne maçonnerie [...]” Philibert De L'Orme, *Le premier tome de l'architecture*, Paris, chez Federic Morel, 1567, pp. 45–47). See also Gilly, *Über die Gründung der Gebäude...cit.*, 1804, pp. 4–7 and pp. 23–26.

years after the first Berlin well foundation is completed. Solely on the basis of this observation, Gilly attributes a kind of German authorship of this building technique to Georg.⁸⁷

Wiebeking also depicts Georg's well foundations, and he agrees with Gilly concerning Georg's German authorship. "According to Mr. Gilly," Wiebeking writes, "Mr. Georg is the author of this invention in Germany, and I ought to mention him here, seeing that German writers only rarely write in favour of their compatriots."⁸⁸ Wiebeking is proud of writing about a supposed German invention, confirming the general engagement of the time in proving German technical proficiency. "Face to several useful inventions," Wiebeking complains, "we, the Germans, often tend to give the authorship to French or English people, irrespective of whether the invention occurred here, or in neighbouring lands."⁸⁹ It should nevertheless be noted that Wiebeking introduces Georg's well foundations as a corollary of foundations made of underground stone pillars, and, in this regard, he mentions eminent literary sources: Leon Battista Alberti's *De Re Aedificatoria*, Jacques-François Blondel's *Cours d'Architecture*, and Patte's *Mémoires sur les Objets les plus importantes de l'Architecture*.⁹⁰ It is probably by reading Blondel's *Cours d'Architecture* that Wiebeking also becomes aware of the cut stone pillar foundations adopted by Jacques-Germain Soufflot to build the church of Saint Geneviève in Paris, which he mentions as well.

Further evidence of the renown that Berlin well foundations gain at the beginning of the century is given by the fact that they are even described by Hirt in the already mentioned *Baukunst nach den Grundsätzen der Alten*, based on Gilly's writings as sources.⁹¹

⁸⁷ See Gilly, *Über die Gründung der Gebäude...cit.*, 1804, p. 7; and Alexander le Goux de Flaix, *Mémoires sur les travaux de constructions hydrauliques*, Paris, Chez Fauvre, 1802; Anon., *D'une nouvelle méthode de fonder, en substituant des puits de maçonnerie aux pilotis; extraite d'un mémoire de M. A. Le Goux de Flaix*, in *Mémorial de l'Officier di Génie*, 1803, pp. 231–36.

⁸⁸ "Nach Herrn Gilly kommt dem Herrn George in Deutschland diese Erfindung zu und es ist billig, dass davon auch hier Erwähnung geschieht, da die deutschen Schriftsteller nur selten ihren Landsleuten Gerechtigkeit widerfahren lassen" (Wiebeking, *Allgemeine auf Geschichte...cit.*, vol. IV, p. 360).

⁸⁹ "Es geht uns Deutschen mit mehreren nützlichen Erfindungen so. Wir sind stets geneigt dieselben den Franzosen oder Engländern zuzuschreiben. während wir sie entweder bey uns oder doch in benachbarten Ländern mit Nutzen angewendet finden" (Wiebeking, *Allgemeine auf Geschichte...cit.*, vol. IV, 1805, p. 360, n. 1). Georg is still remembered as "the inventor of building on wells" in 1823, the year of his death, in the eulogy published on the Berlin *Vossische Zeitung* (*Vossische Zeitung*, 1823, n° 7, p. 2, mentioned in Weber, *Georgstrasse...cit.*).

⁹⁰ See Wiebeking, *Allgemeine auf Geschichte und Erfahrung gegründete theoretisch-practische Wasserbaukunst*, vol. IV, cit., pp. 357–60 (see also Id., *Theoretisch-practische Wasserbaukunst*, München, Joseph Zängl auf Kosten des Verfasser, (vol. I, 1811; vol. II, 1812; vol. III, 1814, vol. IV, 1817), vol. II, 1812, pp. 565–66). Alberti considers appropriate to fortify the soil under columns of porticos with pillars, built deep into the ground and connected through inverted arches. Blondel, instead, proposes to build "arcades in foundations"; he makes reference, on the one hand, to Philibert Delorme, but he also mentions the method of the inverted arches described by Alberti; and Patte writes about the raising of "stone pillars from the good soil to be then connected with arches able to sustain the walls of the basement." See Leon Battista Alberti, *De Re Aedificatoria*, book III, chap. V; Jacques-François Blondel, *Cours d'Architecture ou Traité De la Décoration, Distribution & Construction des Bâtiments*, Paris, Chez la Veuve Desaint, 1777, vol. V, pp. 248–49; Pierre Patte, *Mémoires sur les Objets les plus importantes de l'Architecture*, Paris, Chez Rozet, 1769, p. 125.

⁹¹ "A kind of foundation based on pillars made of masonry wells, can be used in case solid soil lies deep in the ground, under several layers of unsteady earth soaked with groundwater. Being affordable, this technique is arising the interest of

The use of pebbles, rubble and mortar as filling materials in foundations is also an essential aspect of the construction of the bridges that Wiebeking carries out since 1806 in Bavaria, where he settles once Austria has been defeated by Napoleon in the battle of Ulm, and he is appointed *Geheimer Rat, and Chef des technischen Geheimen Zentralbüros im Straßen- und Wasserbauwesen* (Privy Councillor and Director of the technic central Office for Roads and Waterways).⁹² Perronet's stone arch bridges are Wiebeking's major reference although, for economical reasons, the use of stones in Bavaria needs to be reduced to a strict minimum. Wiebeking therefore conceives timber arch bridges, which are veritable carpentry machines. The original wish to build stone bridges however appears in the cladding works that Wiebeking builds on the faces of each bridge, assembling wood slats in a way that imitates stone works. (fig. 1.4.2) The arches rest on in-between timber piers and on masonry abutments, which stand on foundations made of timber piles and framings nailed to the pile heads. (fig. 1.4.3-6) In several cases, probably taking inspiration from the foundations of Venice buildings, Wiebeking pours mixtures of different kinds of aggregate and mortar between the pile heads and inside the compartments of the framings. Similar mixtures also fill the spaces between the pile heads of the in-between piers, the lowest parts of which are surrounded by several layers of fagots and stones, whereas the upper parts are surrounded by timber boards that are nailed to the piles, forming a sort of rudimentary formwork. (fig. 1.4.3) Wiebeking adjusts the composition of filling-mixtures on the basis of the local availability of materials, using different proportions of pebbles, rubble, crushed bricks, sand and either cement-based mortar or unslaked lime. He does not constantly use cements and, in several cases, he uses mixtures just made of pebbles, sand and unslaked lime, asserting that they become hard like stone once poured into water.⁹³ The use of unslaked lime is reminiscent of Loriot's mortar. However, it must be pointed out

precursors, but it was already used ages ago, and it is still in use in India. It was used in Egypt in the 12th century. Even Philibert de l'Orme describes a similar foundation technique that he used for one of the buildings he realized, and we observe that it has been recently and advantageously used in Berlin" ("Finden sich die festen Erdschichten sehr in der Tiefe, und hat man in den Fundaments graben viel mit unstätigen Erdlagen, und dem Grundwasser zu kämpfen, so giebt es eine Art des Grundlegens, wo die Pfeiler in der Form ausgemauerter Brunnen aufgeführt werden, und die in Rücksicht des geringem Kostenaufwandes die Aufmerksamkeit der Bauenden verdient., Diese Gründungsart ist schon vor Alters her, und jetzt noch in Indien üblich. In Aegypten bediente man sich derselben noch im raten Jahrhundert. Auch Philibert de l'Orme beschreibt eine ähnliche Gründungsmethode, von welcher er bey einem seiner Baue Gebrauch machte, und in der neuesten Zeit haben wir dieselbe bey einigen Bauen in Berlin mit Vortheil anwenden gesehen" (Hirt, *Die Baukunst...*cit., p. 121).

⁹² See Sergej Fedorov, *Carl Friedrich von Wiebeking und das Bauwesen in Russland. Zur Geschichte deutsch-russischer Architekturbeziehungen 1800-1840*, München, Berlin, Deutsche Kunstverlag, 2005, p. 27.

About Wiebeking's bridges, see Carl Friedrich Wiebeking, *Beyträge zur Brückenbaukunde, worin auch die neue Bauconstruction wohlfeiler und dauerhafter Bogenbrücken, nach welcher mehrere große Brücken vom Verfasser angegeben und ausgeführt sind, dargestellt ist; welche als eine Fortsetzung des Perronet'schen Werkes betrachtet werden kann*, München, auf Kosten des Verfassers, 1809; Id., *Theoretisch-practische Wasserbaukunst...*cit., vol. III, pp. 303-428.

⁹³ Wiebeking, *Beyträge zur Brückenbaukunde...*cit., p. 32. Just to give some examples: the timber piling foundation of the bridges near Neuötting (1807) are built using a filling of pebbles, sand and unslaked lime, whereas the compartments of the framework are filled with bricks and Trass-based mortar; spaces among the piles of the in-between piers are rather filled with bricks rubble, pebbles and cement; for the bridge of Augsburg (1807-08) Wiebeking uses mixtures of bricks rubble, pebbles and unslaked lime in timber piling foundations of the abutments and also for the in-between piers; the

that, unlike Wiebeking, Loriot used to add cement, namely brick dust, to his mortar. In order to make more savings, Wiebeking often builds the abutments in hollow masonry works and fills the empty spaces with pebbles, rubble and mortar (fig. 1.4.4)⁹⁴

In 1809, after about three years experience in building this kind of foundations, Wiebeking publishes the book *Beyträge zur Wasserbaukunst*, in which, after having depicted several bridges he has built until that date, he gives indications about how to build timber piling foundations. "Framings," he writes, "should be put on piles, and compartments should never be filled with clay or earth, as some people do, but with pebbles, little crushed stones, bricks rubble and cement or lime taken immediately after having been slaked, so that framings stand on a solid mass, which cannot be taken away by river stream or by groundwater."⁹⁵ Between 1810 and 1814, he applies this technique to build the foundations of the jetties heads at the entrance of the port of Lindau on the Lake Constance, those for the abutments and piers of the bridge of Rosenheim, and those for the piers with culverts of the weir of Landshut.⁹⁶ (fig. 1.4.7–10) The constructions in Rosenheim and Landshut are worth special attention, since the hollow brick masonry works of Wiebeking's early bridges are now transformed into walls that are built as the ancients used to do, namely by erecting exterior closed walls made of cut stones with unrefined internal faces, and by filling the in-between spaces with pebbles and mortar. It is just in the early 1810s that Wiebeking describes this kind of construction, in the second edition of the *Wasserbaukunst*, evoking the concept of *emplecton* described by Vitruvius.⁹⁷ An eminent literary reference

filling material for the foundation of the bridges upon the river Rott near the town Schärding (1808–09) is composed of coarse unrefined stones and mortar; the one for the bridge in Ettringen (1808–09) is made of pebbles and unslaked lime; the one for the bridge in Irsingen (1808–09) is made of pebbles, cement and unslaked lime; the one used for the bridge in Freysing (1808–09) is made of gravel and unslaked lime; in Altenmarkt gravel and cement-based mortar, i.e. composed by 2 parts of river sand, 1 part of brick dust and one part of unslaked lime.

⁹⁴ Hollow masonry filled with pebbles and mortar mixtures are to observe at abutments of the bridges near Augsburg, Ettringen, Bieseck (1808–09); Freysing; Mühldorf (1812–13).

⁹⁵ "Auf die Grundpfähle kommt der Schwellrost zu liegen, und dessen Felder sind niemals mit Thon oder Erde, wie einige thun, sondern mit Kiesel, kleinen Bruchsteinen, Ziegelschutt und Cement oder frisch gelöschenem Kalk auszufüllen, damit der Schwellrost auf eine solide Masse liege, die nicht vom Fluß oder von Quellen fortgeführt werden kann" (Wiebeking, *Beyträge zur Brückenbaukunde*...cit., p. 89).

⁹⁶ See Wiebeking, *Theoretisch-practische Wasserbaukunst*...cit., vol. II, pp. 104–08.

⁹⁷ "The back part of retaining walls made of large stones," Wiebeking explains, "as well as the inner part of freestanding walls, like the piers of bridges and weirs, can consist of unrefined stones, bricks, and even of a filling mixture made of gravel and mortar, which needs to be prepared with cement or freshly slaked lime if the wall is intended to come into contact with water. The filling mixture needs to be poured gradually, following the construction of the cut stone faces, so that it can harden and form a solid body. Vitruvius already complained (Lib. II. C. VIII.) about the fact that Romans used to pour rubble and mortar only after having built high cut stone faces. This kind of masonry work can be named filled-masonry (*Emplecton*), according to the Greek way [...]." ("Mauern aus grossen Werkstücken, mögen in ihrem hinteren Theil, wenn es Stützmauern sind, oder in ihrem Innern, wenn es freistehende Mauern sind, als a. B. die Brücken- und Wehrpfeiler, aus Bruchstein- oder Ziegelgemäuer, oder auch aus einer aus Kiesel und dünnen Mörtel bestehenden Füllmasse, die, so weit das gewöhnliche Wasser es bespüht, noch mit Cement oder frisch gelöschenen Kalch untermischt wird, bestehen. Diese Füllmasse muss nach und nach in dem hohlen Raum eingegossen werden, so wie die Umfassungsmauer empor steigt, weil sie auf diese weise trocknet, und einen festen Körper abgibt. Schon Vitruv klagt über das verfahren der Römer (Libr. II. C. VIII.) nach welchem die Futtermauern geflissentlich hoch aufgeführt wurden,

for this kind of construction is also Hirt's *Baukunst nach den Grundsätzen der Alten*. Using Vitruvius' *De Architectura* as an essential source, Hirt describes stone faced walls "filled with little stones and enough mortar", *opus reticulatum* faced walls filled with rubble and mortar filling, and the Greek *Emplecton*.⁹⁸ (fig. 1.4.12–13)

Since the turn of the 1810s, Wiebeking develops a better awareness of concrete, as it is used in France and, instead of writing about a mixture of rubble, pebbles and mortar, he introduces a pioneering use of the term *Beton*.⁹⁹ This probably comes from the studies about French hydraulic works that his son Carl Gustav (1792–1827) carries out. As chief engineer at the *Generaldirektion des Wasser-Brücken und Straßenbaues in München*, Carl Gustav visits the Canal du Midi in 1813, and relates it to his father, describing the use of hydraulic mortar to make watertight the *Rigole de la plaine*, a supply canal of the Canal du Midi, and the waterproofing work of the navigable bridge over the river Orviel, which the engineer Guillaume Catherine Laspinasse (1781–1818) restored using pozzolana-based concrete.¹⁰⁰ Laspinasse is also described to have used concrete to build the cills of locks that Carl Gustav does not precisely mention. Wiebeking repeatedly insists about the suitability of hydraulic lime and concrete to waterproof artificial channel and navigable bridges, and he moreover suggests replacing the gravel-filling over the arches of the medieval bridge over the Rhone, near the village of Pont-Saint-Esprit, with a mixture of mortar and crushed bricks.¹⁰¹ In October 1813, Wiebeking visits the lock of Beaucaire, which had been built five years before by the chief engineer Stanislas-Victor Grangent (1769–1843), at the connection between the Beaucaire channel and the river Rhône. He then gives an account of how concrete has been used, namely describing the two hundred meters long concrete cofferdam that had been built to isolate the building site of the lock from the river, and the foundation itself, which consists of a 1,22 meter thick bed of concrete.¹⁰²

1.5 The ambition at producing mortar artificial stones

Following the French tradition of the *pierres factices*, some researches and trials aiming at producing mortar mixtures suitable to be moulded as ashlar, architectural decorations and objects for different kinds of usage are developed since the 1810s. They are a far-from negligible corollary of the search for new building materials and techniques, and they represent opportunities to experiments in domains that are contiguous to the ones of concrete.

ehe das aus zerbrochenen Steinen und Mörtel bestandene Material eingefüllt wurde. Dieses Mauerwerk kann man mit den Griechen das Gefülltemauerwerk (Emplekton) nennen [...]” see *ibid.* p. 595).

⁹⁸ See Hirt, *Die Baukunst...*cit., pp. 151, 156–57.

⁹⁹ See Wiebeking, *Theoretisch-practische Wasserbaukunst...*cit., vol. II, p. 109.

¹⁰⁰ See Carl Friedrich Wiebeking, *Theoretisch-practische Wasserbaukunst...*cit., vol. III, pp. 81, 93, 502.

¹⁰¹ *Ibid.*, pp. 501–02. The use of hydraulic mortar to waterproof artificial channels will be then discussed in Bavaria toward the mid 1830s.

¹⁰² *Ibid.*, vol. III, pp. 119–20.

A first German attempt at manufacturing mortar artificial stones originates from a singular coincidence occurred during the period of the French occupation of Prussia. In May 1807, French soldiers take some personalities from the city of Halle hostage and deport them to the town of Pont-à-Mousson in France, where they stay for about two months. Among them, there are the land councillor Von Wedell, the police chief councillor Gabriel Wilhelm Gottlieb Keferstein (1755–1816) and the savant August Hermann Niemeyer (1754–1828), who later writes a book about the deportation, which is entitled *Beobachtungen auf einer Deportationsreise nach Frankreich im Jahr 1807*, and is published in two volumes in 1824 and 1826.¹⁰³ Considered state prisoners, they are put up in a local inn called Hôtel Imperial, whose host, a man named Mr. Montagne, has a “passion for building”, and has built a pavilion in his garden, “with several bells hanging from the roof” that recall “the bells of the Magic Flute to mind”, as Niemeyer remembers in his book.¹⁰⁴ A local mathematician named “Professor Fleuret” helped Montaigne build this pavilion. Fleuret is described in Niemeyer’s book as a former teacher of the military school who is living a quite sad existence in Pont-à-Mousson, after having passed through heavy difficulties during the period of the French Revolution, because of his fervent religiousness.¹⁰⁵ Still according to Niemeyer’s tale, he would have also planned a summer residence for the “emperor Paul”, but the project had faded into oblivion after that the emperor was murdered.¹⁰⁶ Apart from Niemeyer’s memories, Fleuret is actually almost known in the region of Pont-à-Mousson, and even in Paris, for the manufacturing of artificial stone pipes, made of a special kind of mortar poured into moulds. He produces such pipes, besides other objects, in an atelier where the three German deportees observe the manufacturing process and show interest for it. Von Wedell engages in learning Fleuret’s method, aiming at reproducing it once back in Germany, while Keferstein begins to translate into German a book about the manufacturing and use of artificial stones that Fleuret has just completed and published in 1807.¹⁰⁷

The mixture used by Fleuret to produce artificial stones is essentially made of lime, sand and rejects from iron manufacturing or crushed terracotta used as cements. Niemeyer carefully describes the manufacturing process that he observed in Pont-à-Mousson. “Once a certain amount of wet sand, mixed with crushed stones, flints and crushed terracotta had been prepared,” he writes, “an appropriate amount of burnt lime was put into a wicker and plunged into water, until lime produced bubbles. At this point, water flew away, and the resulting soaked lime was thrown into the previously prepared heap of sand and stone, and covered with part of them, taking care to close all holes in order to prevent any contact between lime and air. After 12–16 hours, decomposed lime, sand and stones were mixed by

¹⁰³ August Hermann Niemeyer, *Beobachtungen auf einer Deportationsreise nach Frankreich im Jahr 1807*, Buchhandlung des Waisenhauses, Halle, vol. I, 1824, vol. II, 1826; see in particular, vol. I, pp. 28–31.

¹⁰⁴ “So stand im Hofe ein kleines Lusthaus, an dessen Dach sich ringsum Glocken bewegten. [...] Ich dachte an die Glöckchen in der Zauberflöte” (Niemeyer, *Beobachtungen...cit.*, p. 196).

¹⁰⁵ *Ibid.*, pp. 196–97.

¹⁰⁶ Paul I, Tsar of Russia, was murdered in 1801.

¹⁰⁷ Niemeyer, *Beobachtungen...cit.*, p. 135, 198.

means of iron shovels, adding as much water as necessary, in order to get a kind of soft mortar, suitable to be poured in all kinds of moulds, as if it were clay.”¹⁰⁸

Toward the end of July 1807, following the peace treaties of Tilsit, the German deportees are released and, after a short stay in Paris, they come back to Germany. Keferstein publishes the translation of Fleuret’s book in 1808, Niemeyer writes his book of memories, and Von Wedell carries out some trials to produce artificial stone pipes, even using tools that he has brought from France.¹⁰⁹ Faced with the difficulty of exactly reproducing Fleuret’s method in Halle, and in the lack of all necessary raw materials, Von Wedell changes Fleuret’s receipt and produces a kind of quite lean aerial mortar made of 1/5 lime and 4/5 sand, instead of a mixture made of three equal parts of lime, sand and cement, as he learnt in Fleuret’s atelier.¹¹⁰ Despite that, Von Wedell’s trials give good results according to Niemeyer’s tell. Von Wedell’s receipt for lean mortar actually seems to forerun certain mixture of very lean mortar that will be used in several rural villages since the early 1840s to build walls and artificial stones.

Von Wedell probably sends a copy of Fleuret’s book to the *Ober-Bau-Deputation* in Berlin, and makes this office aware of his experiments. The idea of carrying out some trials even in Berlin emerges at this time, as proved in a passage of a report that the *Ober-Bau-Deputation* addresses to the king Friedrich Wilhelm III in December 1810. “Seeing the lack of sandstone in most part of the Kingdom, which compels us to spend money abroad,” the passage goes, “and considering the availability of limestone from the quarries of Rüdersdorf, near the capital, such kind of manufacturing could offer great advantages for all building activities, if the trials’ outcomes were good.”¹¹¹ By order of Friedrich Wilhelm

¹⁰⁸ “Wenn eine bestimmte Masse von Sand, gemischt mit zerschlagenen Feldsteinen, kleinen Kieseln und zerstoßenen Scherben zubereitet war, so ward eine verhältnismäßige Menge gebrannter Kalksteine in einen von Weiden geflochtenen Korb geschüttet, und dieser in einen mit Wasser gefülltes Gefäß gestellt, bis sich Blasen zeigten. Man ließ sodann das Wasser ablaufen, schüttete die getränkten Steine auf die angefeuchtete Sandmasse, und bedeckte sie damit einige Zoll hoch, so daß nicht die kleinste Öffnung blieb und jeder Zutritt der äußeren Luft abgeschnitten wurde. Nach 12–16 Stunden ward sodann mit eisernen Schaufeln der zerfallene kalk mit der Sandmasse durch einander gerührt, und so viel Wasser darauf gegossen, daß der nun gewonnene Mörtel, so lange er weich blieb, gleich dem Thon, in jede Form verarbeiter werden konnte” (Niemeyer, *Beobachtungen...*cit., p. 199).

¹⁰⁹ See Niemeyer, *Beobachtungen...*cit., p. 200; Georg Christoph Hamberger, Johann Georg Meusel, Joahnn Wilhelm Sigismund Lundner, *Das gelehrte Deutschland, oder Lexikon der jetzt lebenden deutschen Schriftsteller*, vol. XXIII, Lemgo, Meyetsche Hof-Buchhandlung, 1834, pp. 106–07.

¹¹⁰ In this regard, a statement in a letter by the *Ober-Bau-Deputation* is enlightening: “Since the quality of materials more or less changes from a country to another, it was not possible to fulfil all instruction and a different composition was unavoidable” (“Die Qualität des Materials welches in jedem Lande mehr oder weniger eine andere ist, ist Grund von Nothwendigen Abweichungen jener Vorschriften und machte andere Compositionen nothwendig”, see Königliche Ober-Bau-Deputation, letter to the Departement für die Gewerbe und den Handel im Ministerio des Innern, 25 December 1810, in GstA PK I.HA Rep. 93B, Ministerium für öffentliche Arbeiten, n° 1394, n. fol.); see also Niemeyer, *Beobachtungen...*cit., p. 200.

¹¹¹ “Jetzt da für den größten Theil der Monarchie der Sandstein fehlt, und das Geld dafür ins Ausland gehen müßte, und bey der Ergiebigkeit unserer wenigstens der Hauptstadt so nahe gelegenen Rüdersdorfer Kalksteinbrüche, möchte sich, wenn die Versuche genügende Resultate geben sollten, eine große und vortheilhafte Anwendung dieser Fabrikation für das ganze Bauwesen ergeben” (see Königliche Ober-Bau-Deputation, letter to the Departement für die Gewerbe und den Handel im Ministerio des Innern, 25 December 1810, cit.).

III, the *Ober-Bau-Deputation* contacts Von Wedell, who declares himself ready to participate to the trials, as long as they take place between March and May 1811, when he has planned a stay in Berlin. The *Ober-Bau-Deputation* charges the master builder Simon with the trials, probably because of his previous studies concerning lime and mortar. Simon carries trials in his own house between 1811 and 1812, producing artificial stone specimens and tiles in appropriate moulds. Von Wedel does not take direct part in the trials; he just maintains correspondence with the *Ober-Bau-Deputation*.¹¹² Simon uses mixtures made just of sand and lime, probably taking inspiration from Von Wedel's procedure rather than from Fleuret's instructions. Trials fail, and the *Ober-Bau-Deputation* writes to Fleuret in November 1812, asking his opinion on the matter. Fleuret answers one month later, asserting that he supposes the quality of the lime used in Germany to be the origin of the failure.¹¹³

Simon's death in 1815 gives further occasion to study some of the specimens that he had kept in his house. The master builder (*Bauconducteur*) Schwarz is charged with such studies that mark the conclusion of this early attempt at producing artificial stones in Prussia. (fig. 1.5.1 a, b) The following report, in fact, describes Fleuret's artificial stones as unsuitable for Prussian needs, and not comparable with the quality of local bricks. "We do not consider," the report goes, "this invention particularly advantageous for Prussian Lands, especially because it is not comparable with our burnt bricks, in what concerns durability and affordability."¹¹⁴

Two years later, on August 1817, when Friederich Wilhelm III visits the occupation-army in Paris, the French architect Antoine Raynal gives him a report about an Italian manufacturing process for artificial stones suitable for hydraulic works. Raynal has worked for fifteen years in Piedmont, a northwest Italian region, where he has learnt how to manufacture tetrahedral artificial stones called *Prismi*, which are suitable to build dams and embankments on foundations made of loose stones.¹¹⁵ (figg. 1.5.2 a, b) The mixture used to produce the *Prismi* consists of hydraulic lime, sand and small stones. It is poured in special moulds dug into the soil and divided into several compartments by means of timber boards.¹¹⁶ The king hands Raynal's report over to the interior Minister Friedrich Von Schuckmann, who then gives it to Heinrich von Bülow, a German diplomat in London, who will later take over the department for industry and trade of the Prussian foreign office, and, later on, is appointed foreign

¹¹² See *Bauconducteur Schwarz*, "Uebersicht von den im Monat Juni 1812 in dem Hause des verstorbenen Geheimen Ober-Bauraths Herrn Simonangefertigten Mörtelsteinen", 1815, (GstA PK I.HA Rep. 93B, n° 1394, n. fol.).

¹¹³ See Schwarz, "Uebersicht..." cit.

¹¹⁴ "Nach allem diesem scheint es uns nicht so sehr vortheilhaft diese Erfindung für die Preußische Länder insbesondere in Anwendung zu bringen, vorzüglich da sie in keinem Vergleich mit der Dauer und Wohlfeilheit unserer gebrannter Ziegel steht [...]" (Schwarz, "Uebersicht..." cit.).

¹¹⁵ See Antoine Raynal, "Mémoire sur la Fabrication des Pierres Artificielles Connues en Piémont sous le nom de Prismes. Pour servir à la Construction des Diges et autres ouvrages de maçonnerie exposés à la rapidité des Courantes" (ms., GstA PK I.HA Rep. 93B, n° 1394, 19 August 1817, n. fol.).

¹¹⁶ Prismi are actually a variation of another kind of artificial stone called "cantoni di smalto", whose use spreads in Tuscany since the 17th century. The early experiments for the production of cantoni di smalto are undertaken by Braccio Manetti, Famiano Michelini and Vincenzo Viviani. In this regard, see Gargiani, *Concrete from archaeology to...cit.*, pp. 34-39.

affairs minister. Nonetheless, Raynal's report falls into oblivion, probably because it is associated with the failed attempts at reproducing Fleuret's artificial stones. Evidence of this conceptual relation can be found in a short note on a cover letter accompanying a copy of Raynal's report, which is signed, inter alias, by Eytelwein. This note precisely recalls the failure in attempting to reproduce Fleuret's artificial stones in Berlin.¹¹⁷

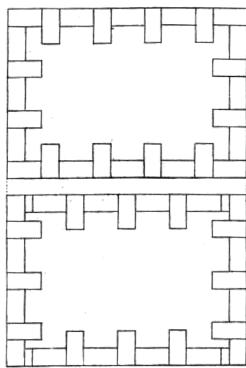
Despite Simon's failure, it is clear that some interest for mortar artificial stones is arising. Wiebeking introduces an interesting description of artificial stone in the second edition of his *Wasserbaukunst*. "Artificial stone" he writes, "can consist of a mass of lime and granite-sand or quartz-sand; crushed tuff stones, sandstones, pumice or volcanic ash and lime; marls, slaked lime and sand; melt iron slag poured into mould; clay and crushed pumice or volcanic ash; or, finally, clay and sand that actually produce bricks".¹¹⁸ Wiebeking also depicts the artificial sandstones that are produced in 1804 in Moravia, by mixing "two parts of quartz-sand, one part of slaked lime and one part of milled lime."¹¹⁹ This mass is described to having been poured and pressed into moulds, whose size could be adjusted through screws, in order to produce the ashlars used to build a wall in the park of the Castle of Felsberg. This kind of moulds is a pioneering example of the adjustable moulds for artificial stones that will be developed and even patented in the 1830s, in the United Kingdom.¹²⁰

¹¹⁷ Heinrich von Schuckmann, letter to Heinrich von Bülow, 16 January 1818, (GStA PK I.HA Rep. 93B, n° 1394, n. fol.).

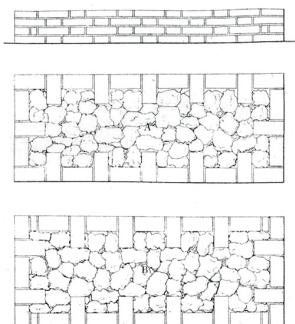
¹¹⁸ "Die Künstlichen steine bestehen entweder aus einer Masse von Granitsand oder Quarzsand und Kalk; aus gestossenen Tuffsteinen, Sandsteinen, Bimmstein oder vulkanische Asche und Kalk, oder aus Kalkmergel, frisch gelöschten Kalk und Bausand; aus geschmolzenen in Formen gegossenen Eisenschlacken; aus Thon und zerstossenen Bimmstein oder vulkanische Asche; oder endlich aus Lehm, Thon und Sand, welche letztere man Ziegel nennt" (Wiebeking, *Theoretisch-practische Wasserbaukunst*...cit., vol. II, p. 523); see also Wiebeking, *Allgemeine auf Geschichte*...cit., vol. III, pp. 322-23.

¹¹⁹ "Zur Verfertigung der künstlichen Sandsteine wird zum sichersten eine aus zwey Theil Quarzsand, ein Theil frisch gelöschten Kalk, und ein Theil zerriebenen Kalk genommen" (Wiebeking, *Theoretisch-practische Wasserbaukunst*...cit., vol. II, p. 524).

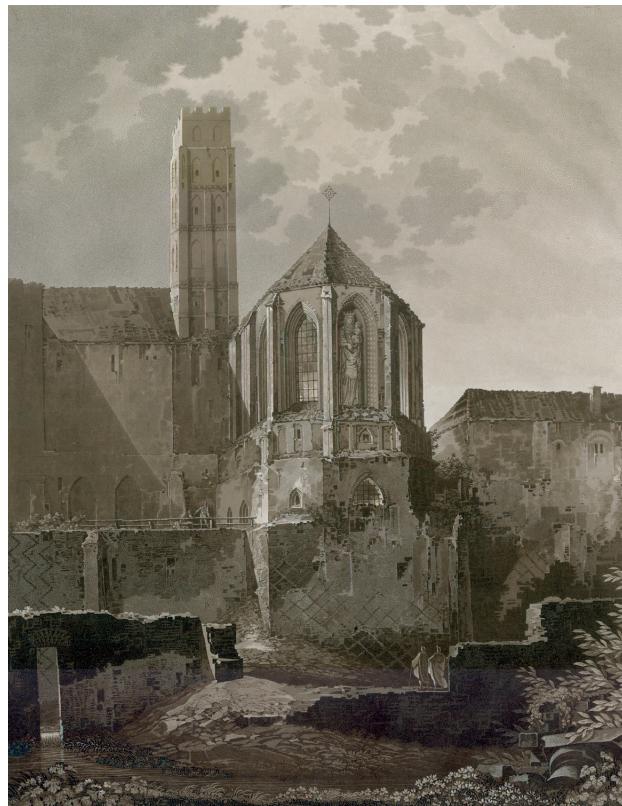
¹²⁰ The reference goes to the concrete artificial stones by William Ranger from Brighton.



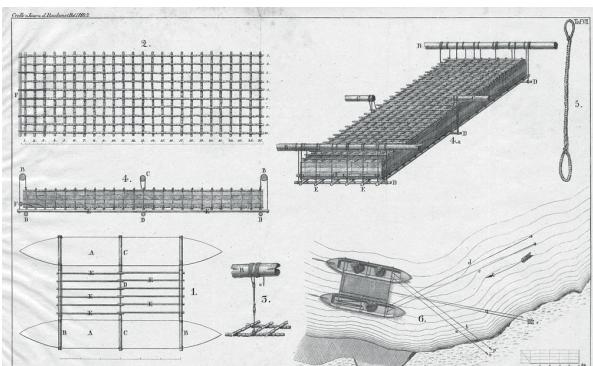
1.1.1



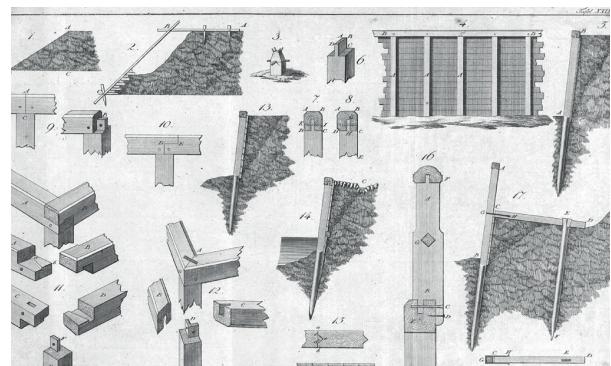
1.1.3



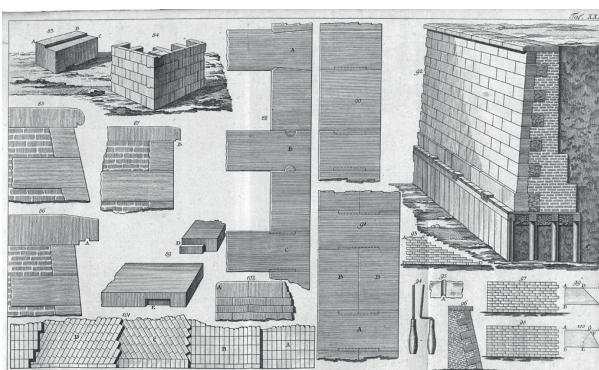
1.1.2



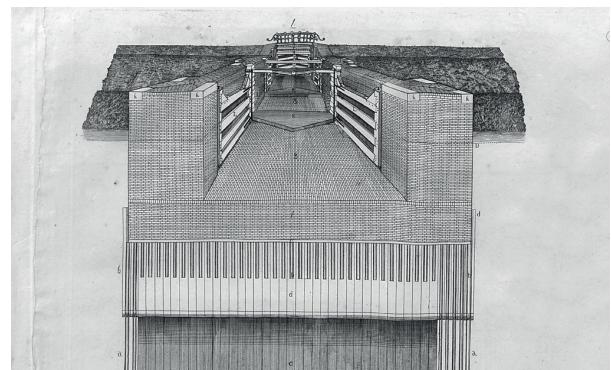
1.1.4



1.1.5

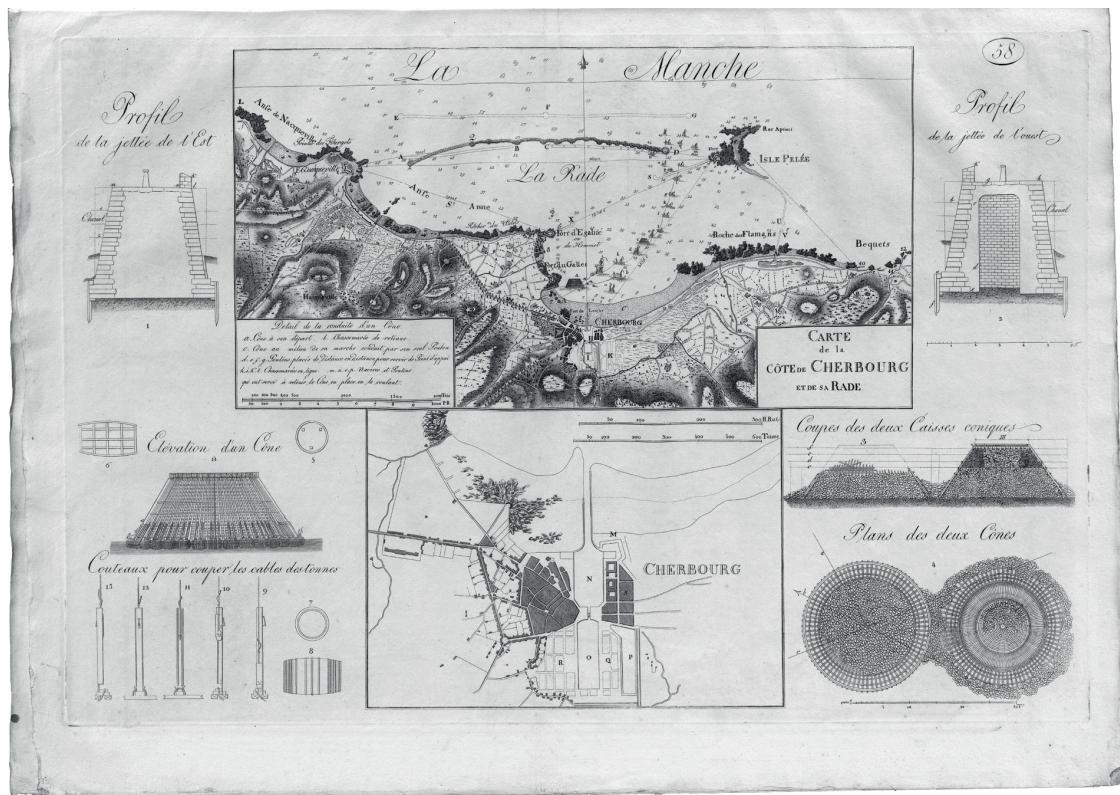


1.1.6

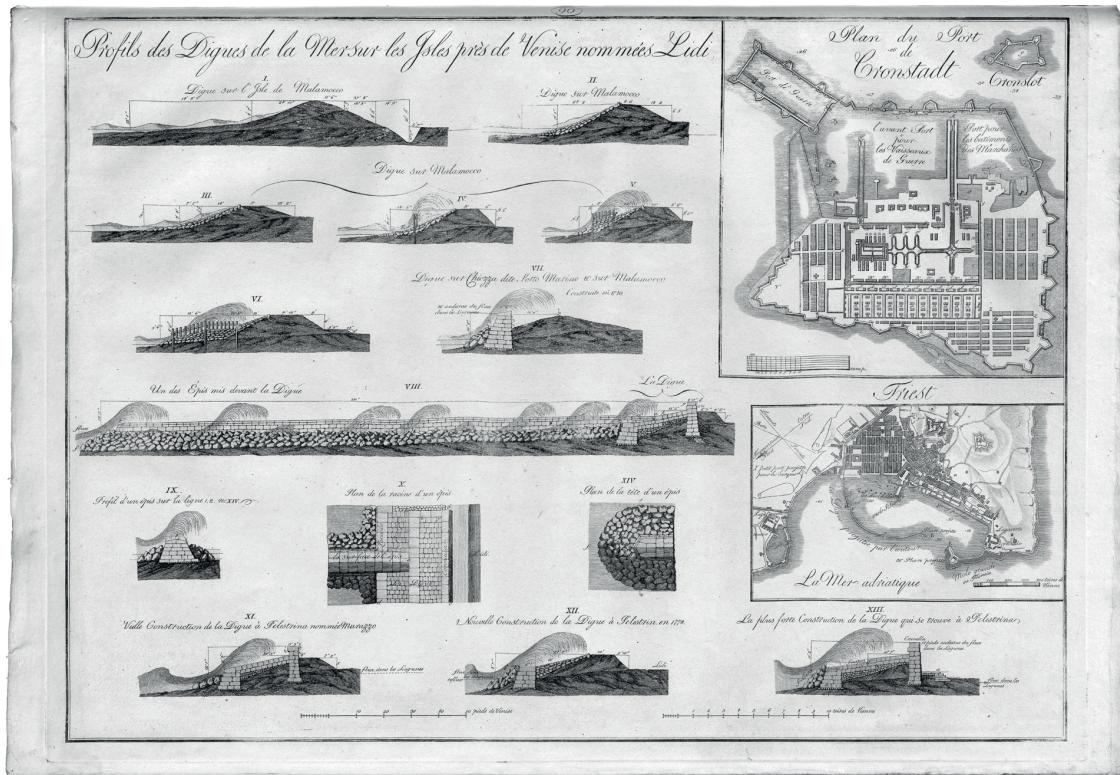


1.1.7

1.1.1. Representation of the Polish masonry bond (D. Gilly, 1797). 1.1.2. F. Gilly, view of the ruins of the Malbork Castle, 1799. 1.1.3. Representation of the Polish bond (K. F. Schinkel, 1834). 1.1.4. Sinking block for hydraulic works, made of bundle and ropes, draft (Spielhagen, 1829). 1.1.5. Timber hydraulic constructions, drawing (J. A. Eytelwein, 1805). 1.1.6. Brick and stone masonry hydraulic works, drawing (J. A. Eytelwein, 1805). 1.1.7. The Dutch lock called "Den Hoorn", made of brick masonry work on a timber piles foundation, drawing (C. F. Wiebeking, 1805).



1.3.1

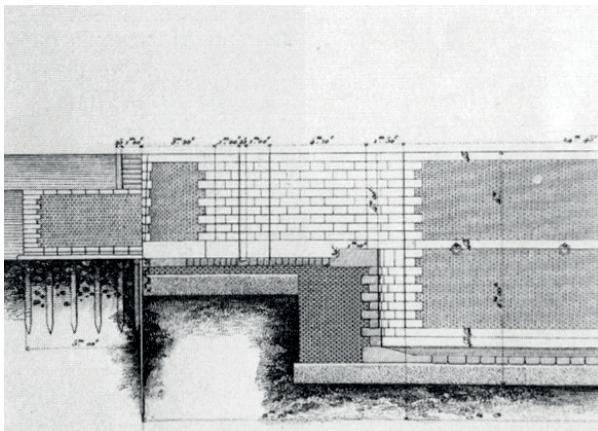


1.3.2

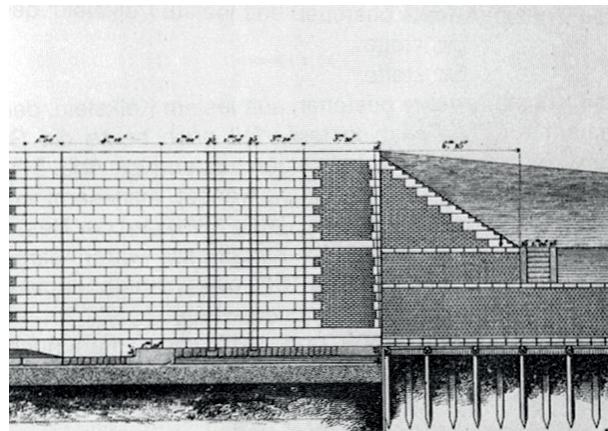
1.3.1. Seawalls in the port of Cherbourg, drawings (C. F. Wiebeking, 1801). 1.3.2. Levees and murazzi in Venice, drawings (C. F. Wiebeking, 1805).



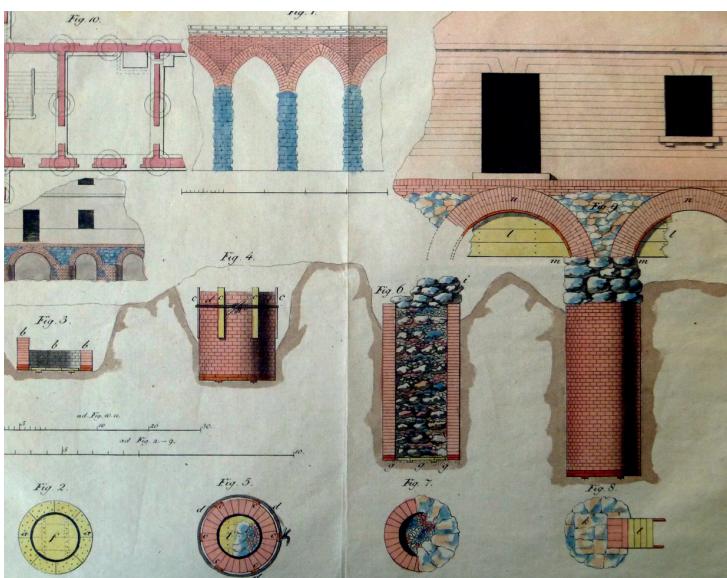
1.3.3



1.3.4

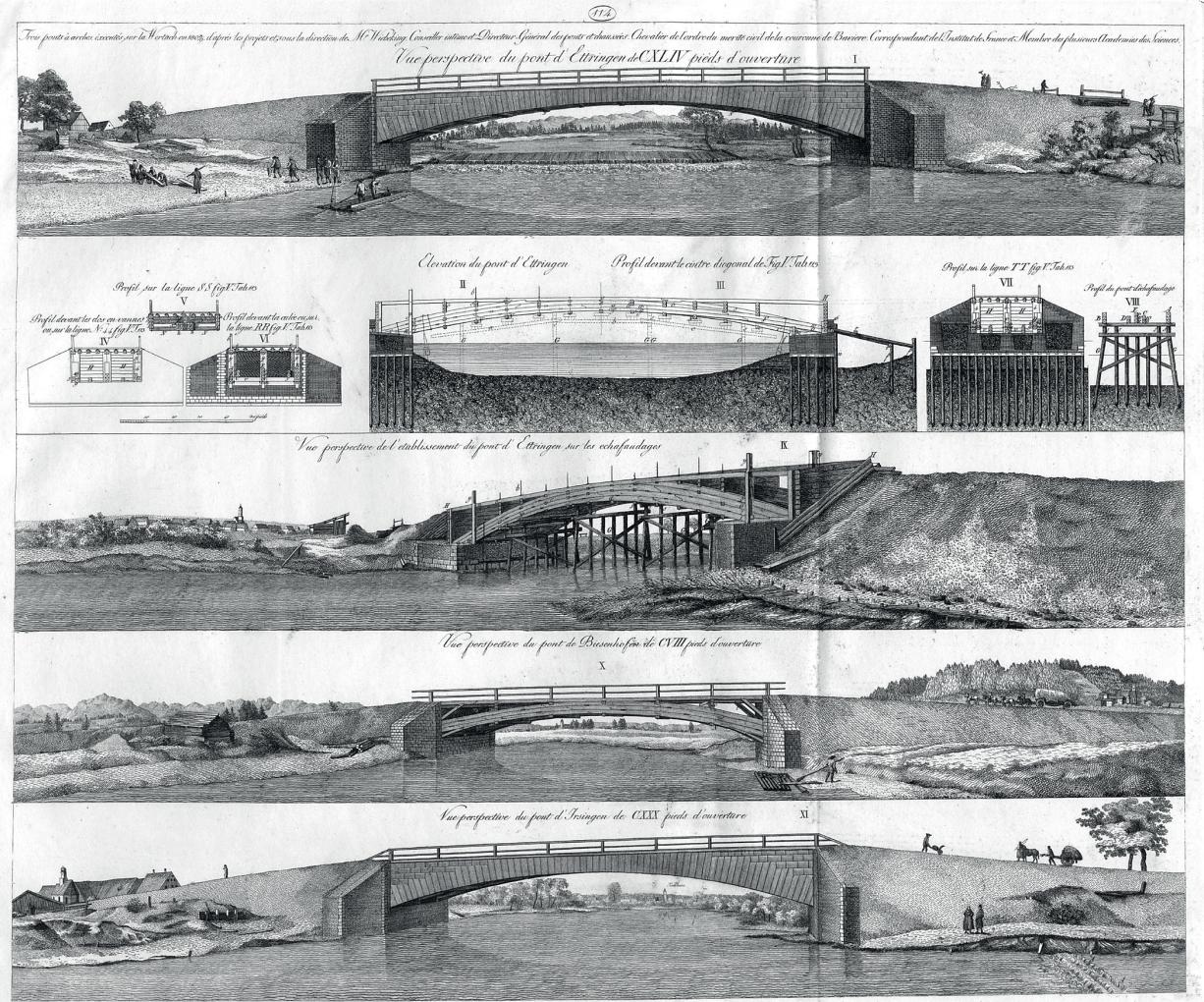


1.3.5

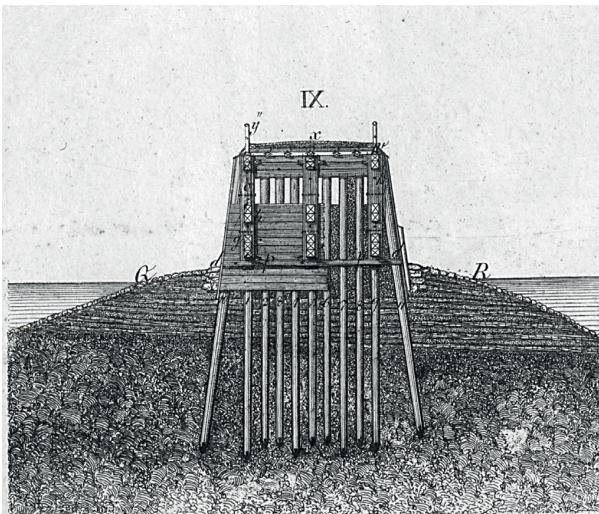


1.4.1

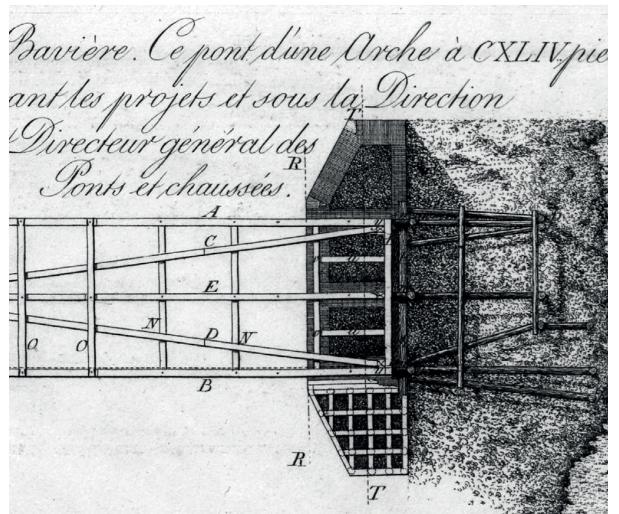
1.3.3. A timber piles foundation in Venice, n.d. 1.3.4. G. Grevembroch, piles drivers in Venice, watercolour, 18. century (repr., 1879). 1.3.5–6 A. Hageau, Grand Canal du Nord (1808–1811), sections of a lock (Hageau, 1819). 1.4.1 Masonry well foundations, draft; above on the right, a stretch of an underground pillar foundation taken from Philibert De l'Orme (D. Gilly, 1804).



1.4.2

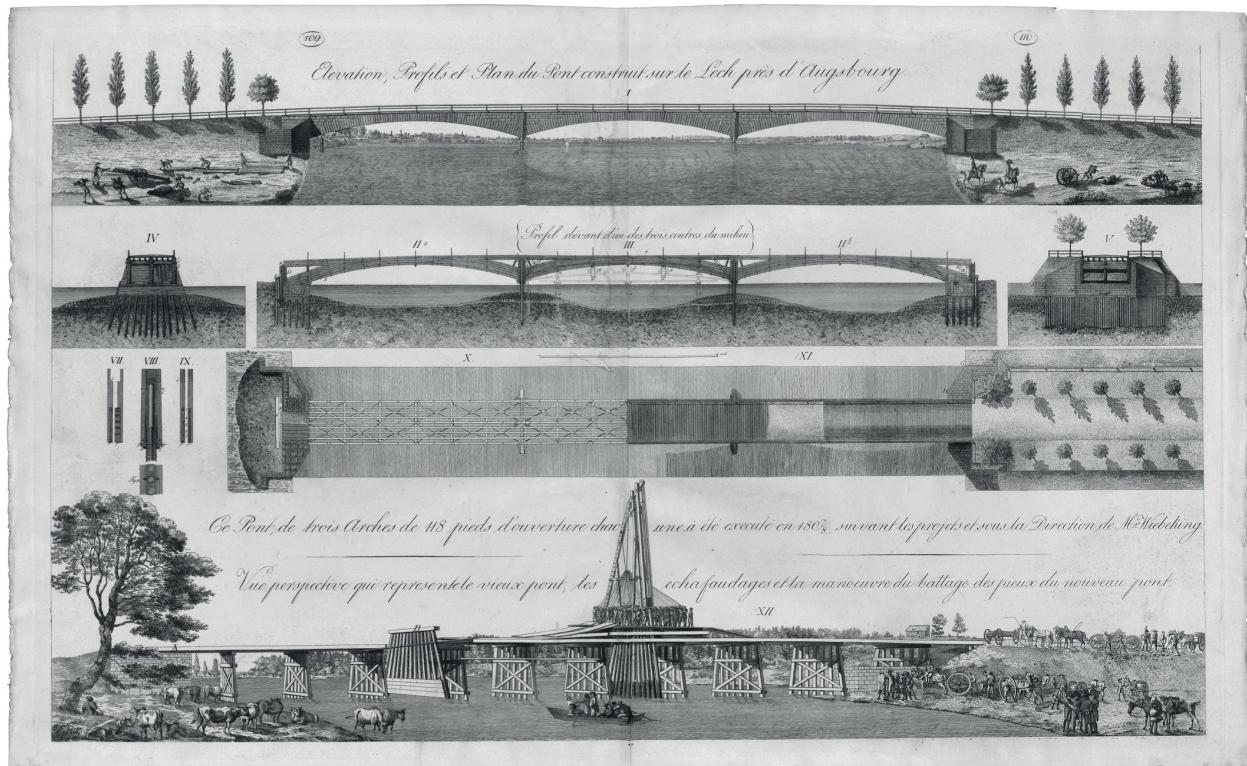


1.4.3

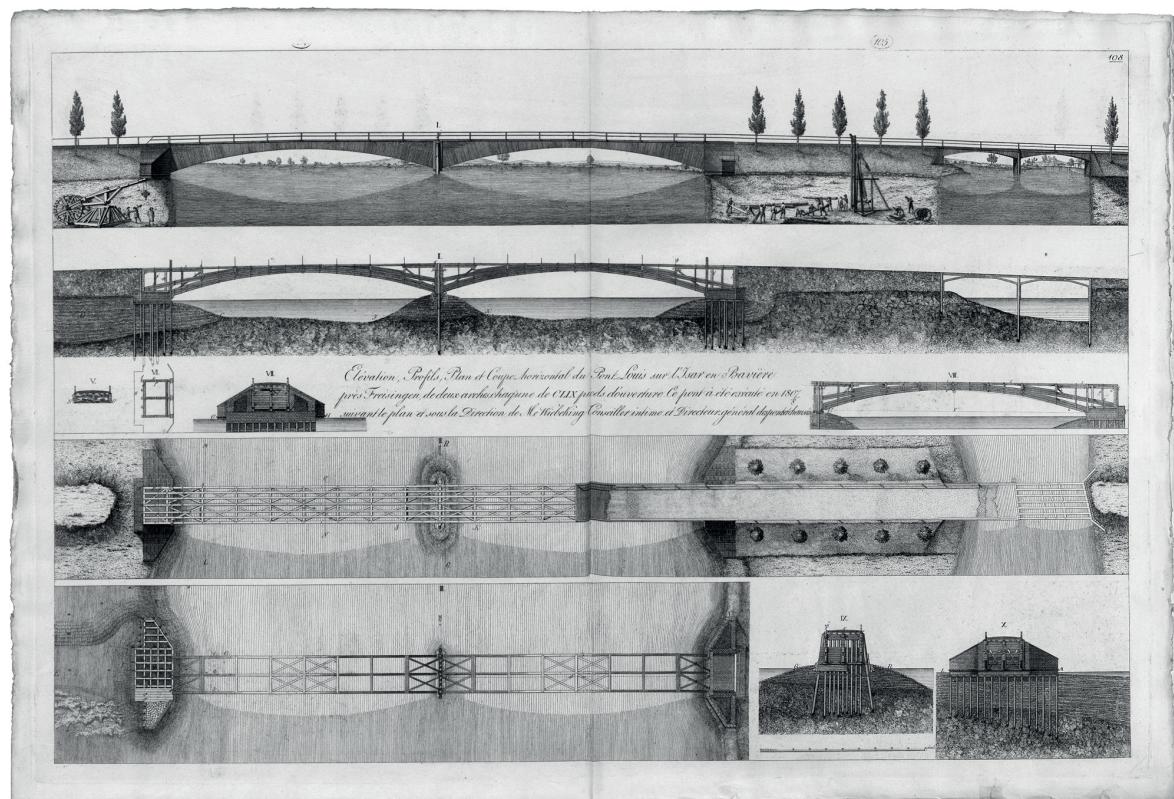


1.4.4

1.4.2. C. F. Wiebeking, bridge of Ettringen, drawings (Wiebeking, 1814). 1.4.3. C. F. Wiebeking, Bridge Louis over the Isar near Freysingen, drawing of an in-between timber pillar (Wiebeking, 1814). 1.4.4. C. F. Wiebeking, Bridge Louis over the Wertach near Etringen, drawing of a land pillar, detail (Wiebeking, 1814).

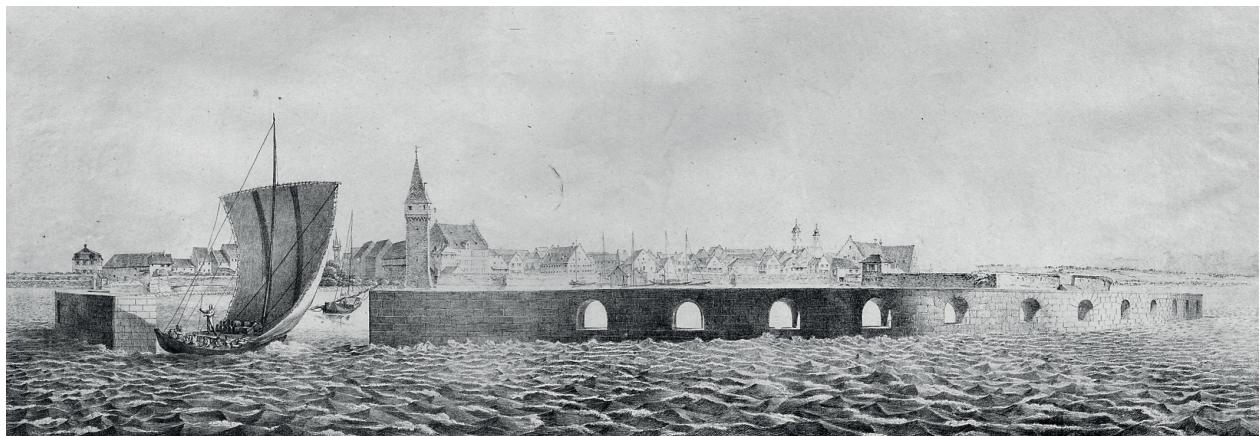


1.4.5



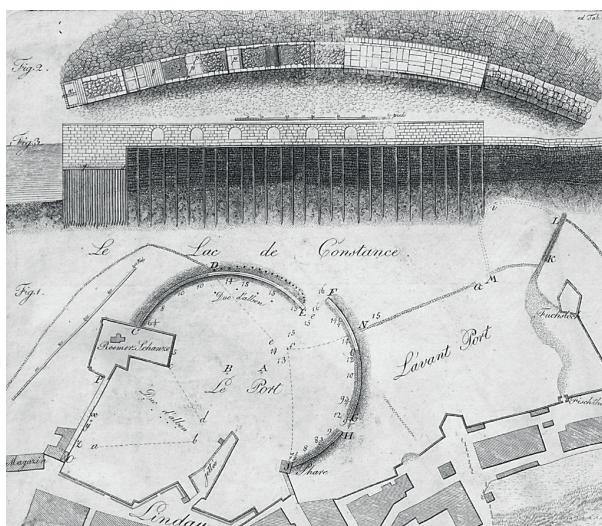
1.4.6

1.4.5. C. F. Wiebeking, Bridge over the Loch near Augsburg, drawings (C. F. Wiebeking, 1814). 1.4.6 C. F. Wiebeking, Bridge Louis over the Isar near Freisingen, drawings (C. F. Wiebeking, 1814).

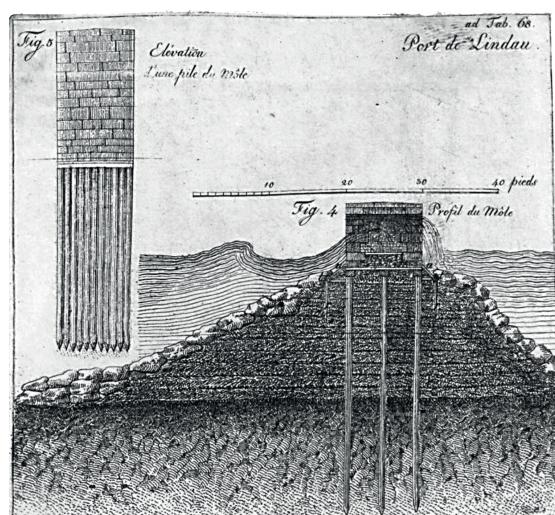


Vue perspective du port près de Lindau prise du côté du lac.

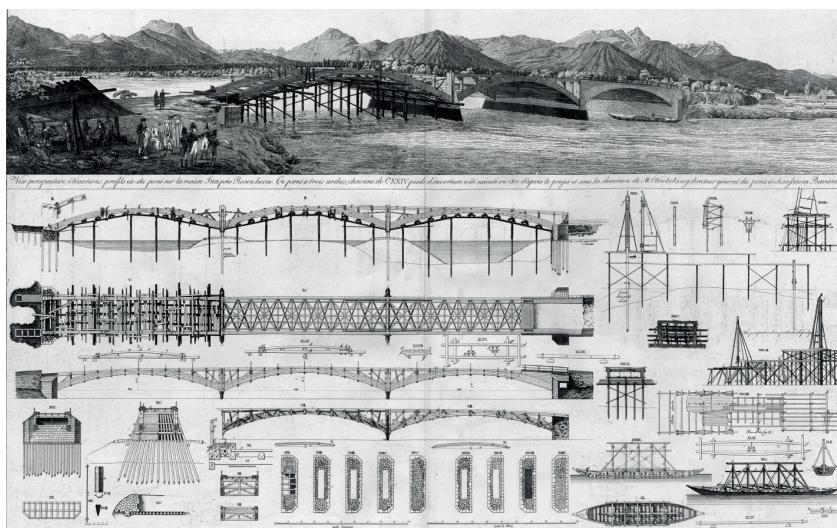
1.4.7



1.4.8

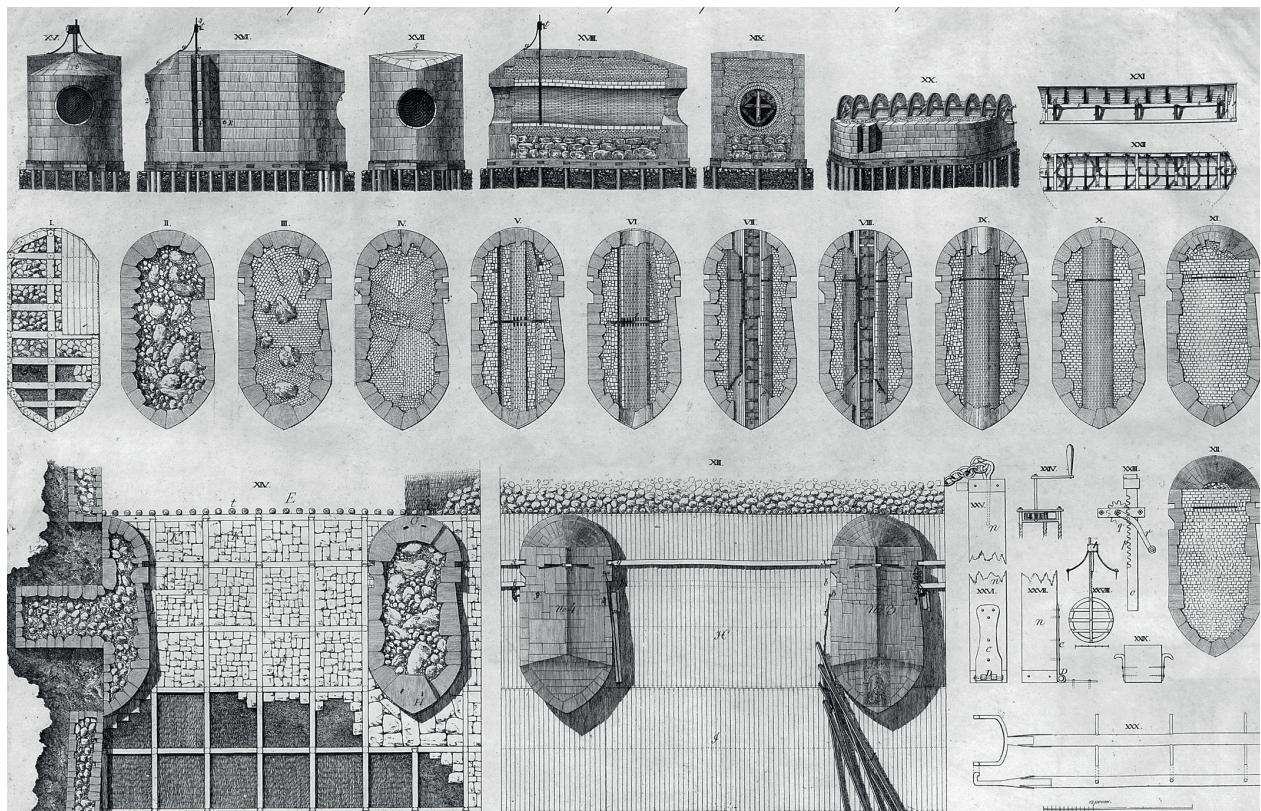


1.4.9

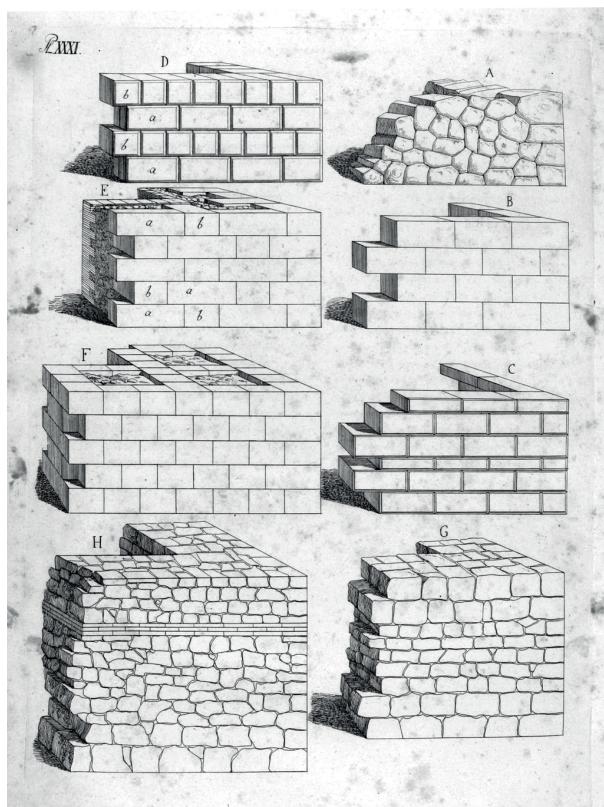


1.4.10

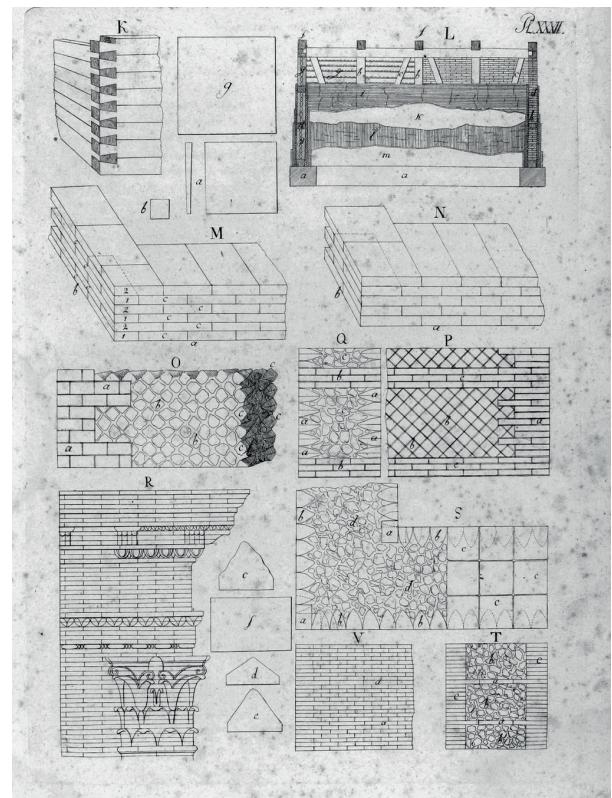
1.4.7. C. F. Wiebeking, the entrance at the port of Lindau on the Lake of Costance, draft (C. F. Wiebeking, 1812). 1.4.8. C. F. Wiebeking, the port of Lindau on the Lake of Costance, plan and section (C. F. Wiebeking, 1812); 1.4.9. C. F. Wiebeking, the entrance at the port of Lindau on the Lake of Costance, section, detail (C. F. Wiebeking, 1812). 1.4.10. C. F. Wiebeking, Bridge over the Inn near Rosenheim, drawings (C. F. Wiebeking, 1814).



1.4.11



1.4.12



1.4.13

1.4.11 C. F. Wiebeking, weir of Landshut, drawings, section of the pillars with culverts (C. F. Wiebeking, 1812); 1.4.12–13. Representation of ancient masonry bonds (A. Hirt, 1809).

Oberstift

Deutsch.

Von dem im Monat Juni 1812 in dem Gewässer des angeborenen
Gefässen Ober. Erzbischof gegen Simon vorgenommenen Versuch. Hanno

Zur	Pointe transversale	Sie sind		Bemerkungen.	
		die geöffnete geöffnete Seite der Seite unter Kugeln	die geschlossene geschlossene Seite der Seite über Kugeln		
1. Junij	5.	-	-	Der Ball ist gegen längere Zeit Rund = 8:2. ist sehr, die Wände zwischen nicht sehr großflächig.	
2. Junij	5.	länglich	-	Der Ball war auf einem 7:2 Stiel mit einer Kugel geschlossen. Der Stiel war nicht so groß wie der Ball zusammen.	
3. Junij	5.	abgeflacht	-	Der Ball war, wie ich zu verga- mmele, aus 9 Kugeln von den auf gleichem Rad 9 Junij, <td></td>	
4. Junij	5.	abgeflacht	-	die gewöhnlichen Maße von den aus länglichem Dachstein und ausgeflachten Ball 9 Junij zus- ammen.	
5. Junij	1.	länglich	-	mit Stielricht des 10 Junij.	
6.	1.	länglich	8:2.	Ein neuer Ball 10 Junij war auf einem 8:2. wurde geschlossen. Von 10 auf 11 umgedreht und die Kugeln waren geschlos- sen.	
7.	1.	länglich	8:2.	Der Ball war von zwei geschlossenen Kugeln, jenseit von eingestellten Prismen, die Schiefermauersteinen mit kleinen Kugeln und geringen glas- förmigen Plättchen gesetz- ten. Der zentralen geschlos- senen Kugel war ein kleiner Ball in der Mitte.	
8.	1.	länglich	8:2.	W. den Kugeln Ball = 8:2.	
9.	18.	-	-		

1.5.1 a, b

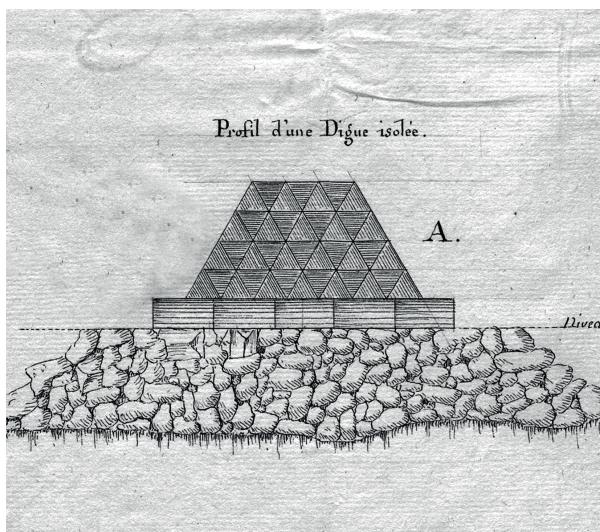
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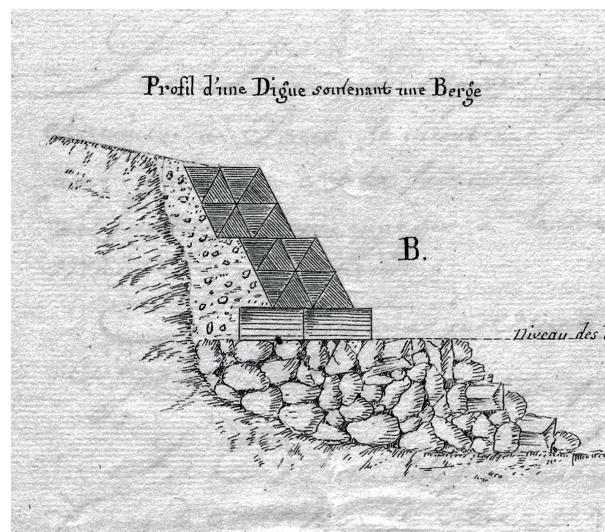
Wangenloß

an der und vor Weißburg ist angebrachtes Gefäß aus Ober. Erzbischof
hatten Simon, der Weißblicke Regierende eines Königlichen Gesellschaft
Ober. Erz. Siegelstein abgebrochenen Material. Stein und Kugeln, und
zu bei der Darstellung einzelnen gebrauchten Steinen.

Winkel	Zusammensetzung		Bemerkungen.
	Druckstein	Zugstein	
3. vertikaler rechteckiger 1g.	Flinsstein	I. 6:2 V. umgedreht	
An Kleinsten			
1. Stein	-	abgerundet mit abgerundeten winkigen Ecken.	
2. Langstein	-	abgerundet mit abgerundeten winkigen Ecken.	
1.	-	guter.	
2.	-	gut.	
3.	-	wurf.	
4.	-	gute.	
5.	-	blau.	
6.	-	mit schwärzlichem Fleisch und weißen Flecken.	◆
7.	-	und weißlichem Fleisch mit schwarzen Flecken.	◆
8.	-	und schwarzer Fleisch, weißem Knochen, blauen Flecken und Flecken.	✗
9.	-	mit schwarzer Fleisch und langer weißer Rinde.	✗
10.	-	mit schwarzer Einbettung und weißen Flecken Fleisch und weißem Fleisch.	◆



1.5.2 a,b

1.5.1 a, b. Bauconducteur Schwarz, tables reporting the results of studies about Simon's attempts at producing artificial stones (Schwarz, 1812).
1.5.2 a, b Artificial stones, draft of the so-called prismi, used in northern Italy to build levees (A. Raynal, 1817).

2 New knowledge about hydraulic lime, cements, and mortar

2.1 The “Theorie des besten Mörtels” by John

The belief that aerial lime is more effective than other binders begins to waver towards the end of the 1810s, following the results of the study about lime and mortar that the chemist Johann Friedrich John (1782–1847) carries out between 1810 and 1817, in the context of a competition promoted by the Koninklijke Hollandsche Maatschappij der Wetenschappen (Royal Holland Society of Sciences and Humanities), with the aim of discovering “the chemical reason that lime burnt from limestone makes masonry more solid and durable than masonry built using lime produced from shells, and how to improve this last one.”¹

At the time he engages in the Dutch competition, John has been studying the composition of several natural substances since about four years.² He has, inter alias, analysed a kind of limestone called *Lucullan* and some organic calcareous substances, such as eggshells and human bones.³ These studies surely help him investigating about lime. At first, John imagines that shells and limestone contain two different kinds of lime earth, and therefore give lime of different quality. Rather the opposite, chemical analyses show that shells and limestone contain the same kind of lime earth. “Marble and all kinds of limestone,” John writes about the matter, “react like shells; there is therefore no difference between the nature of organic and inorganic limes.”⁴ As second step, John moves to investigate the process of mortar hardening. Like most part of “the new chemists and architects”, he believes that “the phenomenon of

¹ “Quelle est la cause chimique, que la chaux de pierre fait sur le total une maçonnerie plus solide et plus durable, que la chaux de coquilles et quels sont les moyens de corriger à cet égard la chaux de coquilles”(see Johann Friedrich John, *Ueber Kalk und Mörtel im Allgemeinen und den Unterschied zwischen Muschelschalen- und Kalksteinmörtel insbesondere: nebst Theorie des Mörtel; eine von der Holländischen Gesellschaft der Wissenschaften gekrönte Preisschrift*, Berlin, Duncker und Humboldt, 1819, p. V).

² Coherently with the general cultural inclination that urges the reconciliation of theory and practice, John believes that theoretical chemistry has practical implications, and he therefore shows a major interest for useful substances; on this matter he affirms: “[...] the conviction of the importance of chemical analysis for medicine, mineralogy, applied chemistry, agronomy, technology, mining activities, botany, and for art and science urged me to undertake studies about these matters” (“[...] die Ueberzeugung von dem Einflusse chemischer Analysen auf Medicin, Mineralogie, Cammeralchemie, Agronomie, Technologie, Bergwerkskunde, Botanik u.s.w. überhaupt auf Künste und Wissenschaften, munterten mich auf, sie fortzusetzen”, Johann Friedrich John, *Chemische Untersuchungen mineralischer, vegetabilischer und animalischer Substanzen. Fortsetzung des chemischen Laboratoriums*, Berlin, Friedrich Mauerer, 1810, p. IX; see also Id., *Chemisches Laboratorium. Oder Anweisung zur chemischen Analysen der Naturalien. Nebst Darstellung der nötigsten Reagenzien*, Berlin, Friedrich Maurer, 1808, pp. IX-XII. John uses the expression Cammeralchemie [sic] for applied chemistry; a definition of Cammeralchemie is to find in Franz Karl Alexander Döbereiner, *Cameralchemie für Land- und Forstwirthe, Techniker, Sanitäts-, Cameral- und Justizbeamte, sowie überhaupt für alle Freunde der Naturwissenschaft*, vol. I, Dessau, Gebrüder Rats, 1855, p. 2.

³ John, *Chemische Untersuchungen...cit.*, 1810, pp. 219–51; Id., *Chemische Untersuchungen mineralischer, vegetabilischer und animalischer Substanzen. Fortsetzung des chemischen Laboratoriums*, Berlin, J. E. Hitzig, 1811, pp. 22–24, 88–93.

⁴ “[...] Marmorkalk und jeder Kalkstein verhält sich [...], wie Muschelschalenkalk, so dass darin kein Unterschied des Kalks der organischen und unorganischen Natur zu suchen ist” (John, *Ueber Kalk und Mörtel...cit.*, p. 23).

mortar hardening originates from the regeneration of limestone, namely that slaked lime loses water and absorbs carbonic acid from the air, forming a hardening mass that adheres to sand contained in mortar, and to the surface of bricks and stones.⁵ Nevertheless, the observations by the chemists Louis-Bernard Guyton de Morveau (1737–1816) and Johann Wolfgang Döbereiner (1780–1849) about supposed, natural affinities among earths, cast doubts on John's convictions about lime and mortar.⁶ De Morveau and Döbereiner believe that lime tends by nature to combine with silica and clay, and that, as observed by the French chemist Claude-Louis Berthollet (1748–1822), all these substances tend to combine in a kind of insoluble substance.⁷

Searching for possible earths' combinations in mortar, John first investigates whether a combination between lime and silica contained in sand were possible. He tries to dissolve a quartz crystal, which is a siliceous substance, in limewater, but a negative outcome pushes him to review the problem and search further. He thus examines several mortar samples from different ages, which he takes from notable German buildings: the Berlin Royal Palace, the Berlin Saint Peter Church, the Brandenburg Cathedral and the ruins of the Roman walls in Cologne. John attaches special importance to the study of Roman mortar, which he considers the "ideal" sample to analyse. Köln walls consist of rough masonry, with sizeable layers of coarse-grained mortar, and they therefore appear as giant conglomerate masses, similar to concrete. In this regard, the description given by John himself is enlightening: "These walls are built with bricks, clayish porphyry, several kinds of limestone, a kind of dark smoke grey sandstone, and so on. Mortar is produced with 3–4 inch-sized pebbles and sand with various grain sizes, from the finest to the coarsest ones. Since the quantity of lime is scarce in

⁵ "Die neueren Chemiker und Architekten sind der Meinung, Dass die Mörtelhärtung eine Regeneration des Kalksteins sey; dass das Kalkhydrat die Feuchtigkeit verliere und Kohlensäure aus der Luft anziehe, und dass die dadurch erhärtete Masse sich an den Sand des Mörtelgemenges und die Oberflächen der Mauersteine fest anlege" (John, *Ueber Kalk und Mörtel...*cit., p. 27).

⁶ Apart from water, substances composing mortar are considered different kinds of earth at that time.

⁷ In 1801, De Morveau had written: "when we had observed that two infusible earths, such as silica and lime, if fired in kilns, combine into an homogenized material, whose components cannot be disjoined except through chemical ways, we had to admit that at a certain temperature a mutual reaction occurs, due to a kind of real affinity" ("Mais lorsqu'on eut observé que deux terres infusible seules au feu de nos fourneaux, telles que la silice et la chaux, y couloient assez facilement en une matière homogène, dont les principes ne pouvoient plus être séparés que par des moyens chimiques, il fallut bien reconnoître une action réciproque qui devenoit efficace à une certaine température, c'est-à-dire, une véritable affinité" Guyton de Morveau, *Sur les affinités que les terres exercent les unes sur les autres, soit par la voie humide, soit par la voie sèche*, in *Annales de chimie ou Recueil de mémoires concernant la chimie et les arts qui en dépendent*, vol. XXXI, 1799, (pp. 246–68), pp. 246–47). With reference to De Morveau, in 1814, Döbereiner writes: "This eminent chemist found out that limewater [...] set silica earth and clay from soda apart – this is due, according to Berthollet, to the inclination of lime, silica and clay to combine forming an insoluble substance (artificial wollastonite etc.)" ("Dieser achtungswerte Chemiker fand nämlich, dass Kalkwasser [...] Kiesel- und Thonerde vom Kali trennt - ein Erfolg welcher nach Berthollet's Ansicht seinen Grund hat in der Tendenz des Kalks und Kiesel, oder Thonerde, sich mit einander zu einem unauflöslichen Körper (zu künstlichem Tafelspath u.s.w.) zu verbinden" (Johann Wolfgang Döbereiner, *Ueber das Verhalten des Kalks zu dem Kiesel- und Thonkali auf nassem Wege und über andere verwandte Gegenstände*, in *Journal für Chemie und Physik*, 1814, vol. X, p. 114). See also Claude Louis Berthollet, *Recherches sur les lois de l'affinité*, Paris, Baudouin imprimeur de l'Institut national des sciences & des arts, année IX, [1801].

comparison to that of sand and stones, [...] mortar is wastefully employed and sometimes forms $\frac{1}{4}$ feet thick layers [...]. Roman mortar in the city walls [of Cologne] looks like molasses and it is so hard that it can be sometimes compared to puddingstone, or to some special silica conglomerates.”⁸ John expects to find much carbonic acid in Roman mortar since, according to the current belief of that time, the more lime is pure the more carbonic acid it absorbs, and the more it hardens. Quite the contrary, chemical analyses show an extremely small amount of carbonic acid and an unexpected considerable amount of silica.⁹

Searching for the origin of silica discovered in Roman mortar, John analyses further limestone samples and finds out that, besides lime earth, they always contain a certain amount of silica clay and metal oxides. He therefore realizes that, during limestone burning, these three substances combine with part of lime earth, and that lime contained in mortar hardens partially through the combination with carbonic acid, and partially through the contribution of silica, clay and metal oxides, which are supposed to act as glue, making mortar extremely hard, and even water-resistant. John calls this explication *Theorie des besten Mörtels*, and defines silica, clay and metal oxides “the real cement in mortar”.¹⁰ As a consequence he realizes that “the larger the amount of cements is the harder and better mortar becomes, whereas the amount of carbonic acid is small.” At the same time, however, John warns against a too large amount of cement, which is thought to prevent lime slaking.¹¹

On the base of the principles of the *Theorie des besten Mörtels*, the lack of cement is thought to be the cause of the lower quality of lime produced from shells, in comparison with lime produced from stones. Coherently with this belief, limestone containing clay is considered a better raw material than pure limestone, suitable to produce a kind of lime which is appropriate to build underwater, and overground as well (hydraulic lime). John completely subverts the traditional convictions about lime and mortar, providing a chemical explanation of the role of silica and clay in hydraulic lime for building. The concept itself is not new. Smeaton had already proved that hydraulic lime contains clay, while Guyton de Morveau had formulated the early hypothesis about supposed chemical reactions involving

⁸ “Diese Gesteine sind theils mit gebrannten Ziegelsteinen, theils mit Ziegelsteinen, Thonporphyr, verschiedenen Arten Kalksteins, einem dunkel rauchgrauen Sandstein u. s. w. construirt. Der Mörtel selbst ist mit Geschieben von 3 bis 4 Zoll Durchmesser, dem feinsten Staube und Geschieben mit Sand von jeder zwischen beiden Extremen gelegenen Größe und Feinheit verfertigt. Ob nun gleich das Verhältniss des Kalkes zu dem Sande und den Geschieben, [...] gering ist, so ist der Mörtel doch sehr verschwenderig angewandt, denn er bildet oft $\frac{1}{4}$ Fuß dicke Lagen, [...]. Der Römische Mörtel in den Stadtmauern hat das Ansehen einiger Nagelfluhgebirge und ist von so einer ungemein großer Härte, daß das ganze Gemäuer oft mit dem Puddingstein, oder einigen besonderen Kieselconglomeren verglichen werden könnte” (John, *Ueber Kalk und Mörtel...*cit., pp. 34–35).

⁹ See also Friedrich Quietmeyer, *Zur Geschichte der Erfindung des Portlandzementes*, doctoral dissertation, Königliche Technische Hochschule zu Hannover, Tonindustriezeitung, Berlin, 1911, (pp. 73–78), p. 74.

¹⁰ John, *Ueber Kalk und Mörtel...*cit., p. 58.

¹¹ “Je größer daher die Menge jenes Cäments ist, desto härter, und vorzüglicher ist auch Mörtel und desto geringer der Gehalt an Kohlensäure Kalk. Es versteht sich jedoch, dass hier eine gewisse Grenze stattfindet, weil bei einer zu grossen Menge der dem Kalk beigemengten erdigen Theile ihm die Fähigkeit sich zu löschen, geraubt werden könnte [...]” (John, *Ueber Kalk und Mörtel...*cit., p. 58).

the different components of hydraulic lime. Moving from such premises, however, and being firmly convinced of the importance of applied chemistry, John develops a general theory of lime and mortar, in which he puts in relation the theoretical domain of chemistry with the practical domain of constructions, and he even develops a method to improve the quality of shells as raw material for lime by adding some silica, which is actually a method to produce a kind of artificial hydraulic lime. Once this is achieved, at the end of 1817, John gives the final report of his research up to the Royal Holland Society of Sciences and Humanities, and, in 1818, he is awarded the gold medal.

2.2 A new awareness about hydraulic lime and mortar, “die alte Theorie des Mörtels über den Haufen geworfen”

John's report is published as a book in 1819.¹² Shortly thereafter, Chrétien Constant Vauvilliers (1780–1848), a French engineer of the Corps des Ponts et Chaussées based in Strasburg, translates John's book into French and sends it to Louis-Joseph Vicat (1786–1861), an engineer of the same Corps who has published, in 1818, an essential book about the experimental researches on lime, mortar and concrete that he has carried out over about six years.¹³ Vicat writes a report about John's book, which is published in the *Annales de Chimie et de Physique* in 1821, and is followed by several other articles, reviews or simply mentions of John's work, which appear in French technical literature in the first half of the 1820s.¹⁴ While essential concepts of John's theory begin to circulate in France, in a specular way, the outcomes of Vicat's researches begin to be known in Germany through the translations of several French articles, which are mainly published in the *Polytechnisches Journal*.¹⁵

¹² *Ibid.*

¹³ Louis-Joseph Vicat, *Recherches expérimentales sur les chaux de construction, les bétons et les mortiers ordinaires*, Paris, Goujon, 1818.

¹⁴ Louis-Joseph Vicat, *Sur la Chaux et le Mortier en général et en particulier; sur la différence entre les mortiers de chaux de coquilles de moules et de pierres calcaires, avec théorie des mortiers*, in *Annales de Chimie et de Physique*, vol. XIX, 1821, pp. 15–25. Other writings or mentions about John's work are to find in: Johann Friedrich John, *Sur la chaux et le mortier en général, et en particulier sur la différence entre les mortiers de chaux de coquilles de moules et de pierres calcaires, avec la théorie des mortiers*, ed. Louis-Joseph Vicat, in *Annales des mines, ou Recueil de mémoires sur l'exploitation des mines, et sur les sciences qui s'y rapportent*, vol. VII, 1822, pp. 467–82; André Étienne Justin Pascal Joseph François d'Audebert de Féruccac, ed., *Bulletin des sciences technologiques*, vol. II, Paris, Au bureau du Bulletin (etc.), 1824, p. 106; Plusieurs Professeurs du Jardin du Roi, et des principales Écoles de Paris, ed., *Dictionnaire des Sciences Naturelles es d'après l'état actuel de nos connaissances, dans lequel on traite méthodiquement des différens êtres de la nature, considérés soit en eux-mêmes, soit relativement à l'utilité qu'en peuvent retirer la médecine, l'agriculture, le commerce et les arts*, vol. XXXIII, Strasbourg, Paris, F. G. Levraud, Paris, Le Normant, 1824, p. 32; Jean-Henry Hassenfratz, *Traité théorique et pratique de l'art de calciner la pierre calcaire et de fabriquer toutes sortes de mortiers, ciments, bétons, etc., soit à bras d'hommes, soit à l'aide de machines*, Paris, Carilian-Goeury, Mme Huzard, 1825, p. IX; Louis Jacques Thénard, *Traité de chimie élémentaire, théorique et pratique*, vol. I, Bruxelles, Canongeette et compagnie, 1829⁷, p. 347; Clement-Louis Treussart, *Mémoire sur les mortiers hydrauliques et sur les mortiers ordinaires*, Paris, Chez Carilian-Goeury, Anselin, Mahler et Compagnie, 1829, pp. 6–7, 49, 79–80, 142–48, 182, 214.

¹⁵ Louis-Joseph Vicat, *Ueber Kalk und Mörtel. Ein Auszug aus Hrn. Vicat's, Brücken- und Strassenbau-Inspektors, Recherches expérimentales sur les chaux de construction, les bétons et les mortiers ordinaires; et du Supplément inédit relatif à la fabrication des*

John and Vicat actually engage the study of lime and mortar from two different points of view. As a scientist, John largely explores the chemical combinations that he considers to be the origin of lime and mortar properties, whereas Vicat, being an engineer, gives more emphasis to practical experiments, and to a series of strength tests on mortar and concrete specimens, which he conceives in order to trace practical rules for the production of different kind of mortar and concrete. In spite of these two different approaches, both John and Vicat believe that hydraulic lime is more suitable than aerial lime both for hydraulic works and for buildings above ground, and Vicat develops a method to produce artificial hydraulic lime by firing mixtures of fat lime and clay, which is essentially similar to the one that John conceives to improve the quality of lime produced from shells.

Vicat's book impresses Moritz Karl Ernst von Prittwitz und Gaffron (1795–1885), a military engineer and captain of the Silesian Fortress-Engineer-Unit (Schlesische Festungspionier-Compagnie) who serves from 1815 to 1818 in France. Once back in Germany, Von Prittwitz is posted at the building of the Koblenz fortress until 1824.¹⁶ In this period, he engages in the translation of Vicat's book, and in the writing of an abstract of the *Traité sur l'art de faire de bons mortiers et notions pratiques pour en bien diriger l'emploi* by Antoine Raucourt de Charleville (1789–1841), an engineer of the Corps des Ponts et

pouzzolanes artificielles, in *Polytechnische Journal*, vol. IV, 1821, pp. 280–93 (Id., "Extrait de l'ouvrage intitulé: Recherches expérimentales sur les chaux de construction, les bétons et les mortiers ordinaires; et du Supplément inédit relatif à la fabrication des pouzzolanes artificielles", in *Annales de Chimie et Physique*, vol. XV, 1820, pp. 365–79); Id., *Bemerkung über einige Erscheinungen bei dem Brennen des gemeinen und künstlichen Kalkes*, in *Polytechnisches Journal*, vol. XII, 1823, pp. 429–33 (Id., Note sur quelques phénomènes que présente la caisson de la chaux ordinaire et de la chaux artificielle, in *Annales de Chimie et Physique*, vol. XXIII, 1823, pp. 424–29); Id., Untersuchungen über die Anwendung des hydraulischen Mörtels statt des Gipses zum Modelliren, in *Polytechnisches Journal*, vol. XV, 1824, pp. 186–207 (Id., Recherches sur la substitution du mortier hydraulique au plâtre, dans l'art du mouleur, in *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, XXIII, 1824, pp. 132–48); Id., Neuer hydraulischer Mörtel, in *Polytechnisches Journal*, vol. XVIII, 1825, p. 480 (Id., Théorie des ciments, in *Nouveau Bulletin des Sciences par la Société Philomathique de Paris*, 1825, pp. 184–85); Anon., Ueber Theorie der Mörtel von Hrn. Vicat, in *Polytechnisches Journal*, vol. XX, 1826, pp. 106–07 (Id., Théorie des ciments, in *Nouveau Bulletin des Sciences, par la Société Philomatique de Paris*, 1825, pp. 184–85); Louis-Joseph Vicat, Neue Thatachen zur Theorie der Kalkmörtel, in *Polytechnisches Journal*, vol. XXI, 1826, pp. 432–37 (Id., Nouveaux faits pour servir à la théorie des Cimens calcaires, in *Annales de Chimie et Physique*, XXXII, 1826, pp. 197–204); Id., Nachträgliche Bemerkung über die Mörtel, in *Polytechnisches Journal*, vol. XXII, 1826, pp. 166–67 (Id., Note de M. Vicat, Ingénieur en chef des Ponts et Chaussées, relativement à son dernier Mömoire sur les Mortiers, in *Annales de Chimie et Physique*, XXXII, 1826, p. 443). The Bavarian Kunst- und Gewerb-Blatt des polytechnischen Vereins für Bayern also publishes two articles about the different ways to adopt for obtaining a hydraulic mortar, including the use of natural and artificial hydraulic lime, see Anon., Ueber den Mörtel und dessen Verbesserung, in *Neues Kunst- und Gewerbblatt*, IX, 1823, pp. 109–14; Anon., Ueber Wasser-Mörtel, *ibid.*, pp. 285–87.

¹⁶ See Historische Commission der Königliche Akademie der Wissenschaften, ed., *Allgemeine Deutsche Biographie*, vol. XXVI, Duncker & Humboldt, 1888, entry "Prittwitz, Moritz Karl Ernst v. P. und Gaffron", pp. 609–11; see also Otmar Schäuffelen, *Die Bundesfestung Ulm und ihre Geschichte: Europas grösste Festungsanlage*, Ulm, Vaas, 1980, p. 25. Koblenz fortress was built between 1815 and 1834, using, inter alias, Trass-based mortar, see Petra Egloffstein, *Entwicklung von Kalk-Trass-Mörteln im preußischen Festungsbau am Beispiel der Festung Ehrenbreitstein, Koblenz*, in Institut für Steinkonservierung e. V., ed., *Hydraulische Bindmittel im 19. Jahrhundert auf dem Gebiet der heutigen Bundesländer Hessen, Rheinland-Pfalz, Saarland und Thüringen*, Mainz, Institut für Steinkonservierung e. V., 2012, pp. 15–20.

Chaussées.¹⁷ Moreover, between 1820 and 1822, taking Vicat's tests and John's theory as a reference, Von Prittitz carries out a series of strength tests on a number of mortar specimens, made of mortar mixtures containing different proportions of lean lime from Trier, fat lime from Mainz, Trass from Andernach, crushed bricks, and different kinds of sand.¹⁸ At first, he plans to test only tensile strength, which is called, at that time, *absolute Festigkeit*.¹⁹ For this purpose, he conceives a special contraption to pull two stones connected by means of mortar: one stone hanging from a metal bracket, the other holding a bucket, which is to be gradually filled with bricks.²⁰ (fig. 2.2.1) The real aim of this kind of test seems to be an investigation about the adhesion between mortar and stones, rather than about the tensile strength of mortar specimens. This is quite plausible for two kinds of reasons: the Koblenz fortress is mainly built in stone and brick masonry work, and Von Prittitz could have known of similar mortar adherence tests during his stay in France, since they are described in eminent French technical books of the early 19th century.²¹ Tests, however, do not work as hoped; they give incoherent outcomes, and Von Prittitz chooses to undertake compression and cantilever strength tests (*rückwirkende* and *relative Festigkeit*). He derives the procedure and the design of an appropriate machine to do cantilever tests from Vicat's book. This consists of a workbench where prismatic mortar specimens are fixed so that they partially stick out the bench in order to be charged with increasing suspended loads, until the specimens crack.²² (fig. 2.2.1) Von Prittitz's tests confirm the superiority of hydraulic lime over the

¹⁷ Antoine Raucourt de Charleville, *Traité sur l'art de faire de bons mortiers et notions pratiques pour en bien diriger l'emploi: précédé d'expériences récentes faites sur les Chaux de France et de Russie*, Saint-Pétersbourg, Voie de la Communication, 1822. A second edition of Raucourt's treatise is published in 1828 (Id., *Traité sur l'art de faire de bons mortiers et notions pratiques pour en bien diriger l'emploi ou méthode générale pratique pour fabriquer en tous pays la chaux, les cimens et les mortiers les meilleurs et les plus économiques*, Paris, De Mahler et Cie, 1828).

¹⁸ See Moritz Karl Ernst von Prittitz, *Versuche, angestellt in Coblenz, in den Jahren 1820 bis 1822*, in Id., ed., *Neue Versuche über den Kalk und Mörtel von L. J. Vicat und Andem*, Berlin und Posen, Ernst Sigfried Mittler, 1825, pp. 55–75.

¹⁹ For the 19th century nomenclature of different kind of strength, see Franz Joseph Ritter von Gerstner, *Handbuch der Mechanik*, vol. I, Prag, Johann Spurny, 1833², p. 241.

²⁰ A detailed description of the machinery is not to find, but an illustrations is published by Von Prittitz in 1825, see Von Prittitz, *Versuche...cit.*, p. 56, pl. III, fig. 4.

²¹ Louis-Charles Boistard (1763–1823), engineer of the Corps de Ponts et Chaussées, carries out mortar adherence tests in 1800. These tests are described by Boistard himself in a book dating from 1804, and later mentioned in the first volume of the *Traité de la Constructions des Ponts* by Émiland-Marie Gauthey (1732–1806), published posthumous in 1808 by his nephew Claude Louis Marie Henry Navier (1785–1836): see Louis-Charles Boistard, *Expériences sur la main d'œuvre de différens travaux dépendans du service des ingénieurs des ponts et chaussées, sur l'adhérence des mortiers de sable et de ciment employés à l'air et sous l'eau et sur l'usage des machines à épuiser*, J.-S. Merlin, 1804, p. 51, cit. in Émiland-Marie Gauthey, *Traité de la Constructions des Ponts*, ed. Claude Louis Marie Henry Navier, Paris, Chez Firmin Didot, 1809, p. 327; see also Louis-Charles Boistard, *Recueil d'expériences et d'observations faites Sur différens Travaux exécutés pour la construction du pont de Nemours, pour celle de l'arsenal et du port militaire d'Anvers, et pour la reconstruction du port de Flessingue; dans lequel on a traité la théorie de l'équilibre des voûtes*, Paris, J.-S. Merlin, 1822, p. 125).

²² Vicat, *Recherches expérimentales...cit.*, pl. I. Von Prittitz could have also read of cantilever beam tests in French technical literature of the early 19th century, which widely dealt with this topic as part of the widest theory of beam. The question is analysed in 1773 by Charles Augustin Coulomb, and Coulomb's solution spreads later, through Navier's teaching at the École des Ponts et Chaussées in the early 19th (see Jacques Heyman, *The strength of beams: Galilei to Navier*, in Roberto Gargiani, ed., *L'architrave, le plancher, la plateforme. Nouvelle histoire de la construction*, Lausanne, Presses

aerial one, as maintained by John and Vicat,²³ but they remain anyway unknown until 1825, when Johann Gustav Georg von Rauch (1774–1841), head of the Royal Corps of Prussian Engineers, promotes the publication of a collection of writings, including Von Prittwitz's translation of Vicat's book, the abstract from Raucourt de Charleville's treatise, and a detailed report about the tests of Koblenz.²⁴

This publication is announced in 1825 in the *Verhandlungen des Vereins zur Beförderung des Gewerbfleißes in Preußen* and, in 1827, in the *Allgemeine Literatur-Zeitung* with a short but positive and quite prophetical review about the scientific approach that is going to characterize to the study of lime and mortar in Germany in the following decades²⁵. “These writings,” the review goes, “shed new light on the preparation of different kinds of mortar, the ones that harden in the air, and the ones that harden underwater; furthermore they show how future studies should be developed, in order to come to precise and reliable results about this important subject.”²⁶

The contemporary spread of John's theory and Vicat's experimental researches breaks down the old belief in the superiority of aerial lime and mortar. And it is just Von Prittwitz who seizes that an essential change, in this regard, is happening, in the light of his own experience, and comparing John and Vicat's works. “It is extraordinary,” he writes, “that, almost at the same time when Mr. Vicat was carrying on his tests in France, professor John in Berlin was studying the same topic, and, although he adopted a radically different method, based just on chemical analysis, he came to almost similar results, through which the ancient theory of mortar has been thrown away, and knowledge has been considerably improved.”²⁷

polytechniques et universitaires romandes, 2012, (pp. 310–15), p. 312). Navier deals with this matter in a note to the 1813 edition of *La science des ingénieurs dans la conduite des travaux de fortification et d'architecture civile* by Bélidor, which is published just at the time as Vicat undertakes his experiments and tests (see Bernhard Forest de Bélidor, *La science des ingénieurs, dans la conduite des travaux de fortification et d'architecture civile. Par Bélidor*, ed. Claude Louis Marie Henry Navier, Paris, Chez Firmin Didot, 1813, (pp. 336–42), p. 337, n. 1, pl. XII).

²³ Von Prittwitz observes that lean lime from Trier is moderately hydraulic and could be improved through the addition of some Trass or bricks powder, that fat lime from Mainz has no hydraulic property but produces a good hydraulic mortar if mixed with Trass from Andernach.

²⁴ Von Prittwitz, *Neue Versuche*...cit.

²⁵ See *Auszug aus den Protokollen der monatlichen Versammlungen in den Monaten Juli und August des laufenden Jahres*, in, *Verhandlungen des Vereins zur Beförderung des Gewerbfleißes in Preußen*, IV, 1825, (pp. 129–33), p. 133; *Technologie*, in *Allgemeine Literatur-Zeitung*, vol. II, 1827, col. 480.

²⁶ “Durch diese Aufsätze wird ein ganz neues Licht, über die Bereitung der verschiedenen Arten von Mörtel, sowohl solcher, die in der Luft, als solcher, die auch unter dem Wasser erhärten, verbreitet, und der Weg gezeigt, welcher bey künftigen Forschungen, über diesen so wichtigen Gegenstand eingeschlagen werden muss, wenn man endlich zu bestimmten und sichern Ergebnissen gelangen will” (*Technologie*, in *Allgemeine Literatur-Zeitung*...cit.).

²⁷ “Es ist daher eine auffallende Erscheinung, daß ungefähr zu derselben Zeit, wo Herr Vicat diese Versuche in Frankreich anstellte, Herr Professor John in Berlin sich mit demselben Gegenstände beschäftigte, und auf einem dem vorigen entgegengesetzten Wege, nämlich durch bloße chemische Analyse, mit sehr geringen Abweichung ganz auf die nämlichen Resultate geführt wurde, als Vicat, wodurch die alte Theorie des Mörtels über den Haufen geworfen, und die Kenntniß desselben auf einen durchaus neuen Standpunkt gestellt worden ist” (Von Prittwitz, *Versuche, angestellt in Coblenz*...cit., pp. 63–64).

So soon a question seems to be ascertained, another one emerges about the eventual chemical role of clayish-siliceous substances, like pozzolana, *Trass* and brick dust in mortar. Having failed in trying to dissolve a quartz crystal in limewater, John maintains that siliceous substances must be burnt together with lime to act as a cement, and that therefore pozzolana, *Trass* and all similar substances have no other effect in mortar than absorbing water. Vicat, instead, basing on his wide practical experience, imagines that lime and pozzolana react together and produce good hydraulic mortar. A real controversy about John's point arises in the first half of the 1820s in France, between Vicat and Pierre Berthier (1782–1861), a mineralogist of the École des Mines. The two scholars write each other by means of articles published in the *Annales de Chimie et Physique*, which are then promptly translated into German and published in the *Polytechnische Journal*. The confrontation begins in 1823, when Berthier declares to agree with John for what concerns the inefficacy of siliceous substances in mortar.²⁸ "Mr. Vicat," he writes, "assumes that the chief cause of mortar solidity is the chemical action of lime on siliceous substances," while, "Mr. John believes that the substances that we mix together with slaked lime to produce mortar, which he names admixtures, are essentially inert."²⁹ Given this divergence, Berthier resolutely states: "Mr. Vicat's assertion about a chemical action of lime on siliceous substances has no factual base." And he furthermore adds "I agree with Mr. John about the fact that admixtures do not play any chemical role in mortar."³⁰ Vicat answers two times to Berthier listing a long series of facts taken from his own experience to corroborate his belief in the existence of chemical combinations between lime and siliceous materials.³¹ Far from being of secondary importance, the question raised by John, Vicat and Berthier is an aspect of some chemical questions about the nature and properties of siliceous substances, which will develop in the following years. In the context of the divergent opinions about the effectiveness or not of siliceous materials in mortar, it is still worth to mention that, in 1825, the eminent French engineer Clement-Louis Treussart (1779–1834) maintains that traditional hydraulic mortar composed of lime and pozzolana or *Trass* is more effective than mortar produced with Vicat's artificial hydraulic lime.³² Treussart's opinion will later be a reference for the Rhineland master builder

²⁸ Pierre Berthier, *Analyses de différentes Pierres à Chaux*, in *Annales de Chimie et Physique*, vol. XXII, 1823, pp. 62–91 (Id., *Analyse verschiedener Kalksteine in Bezug auf den besten Mörtel*, in *Polytechnisches Journal*, vol. XI, 1823, pp. 350–63).

²⁹ "M. Vicat admet, comme cause principale de la solidification des mortiers, l'action chimique que la chaux exerce sur les matières siliceuses [...]. M. John pense, au contraire, que les substances que l'on mêle avec la bouillie de chaux pour faire les mortiers, et qu'il nomme alliages, sont tout-à-fait passives" (Berthier, *Analyses...cit.*, p. 85, 86).

³⁰ "L'assertion de M. Vicat, que la chaux en général et la chaux hydraulique en particulier agissent chimiquement sur les matières siliceuses, n'est appuyée sur aucun fait [...]. Je pense avec M. John que les alliages ne jouent aucun rôle chimique dans les mortiers" (Berthier, *Analyses...cit.*, p. 88).

³¹ Louis-Joseph Vicat, *Notes en réponse à un Article de M. Bérthier, Ingénieur en chef des Mines, sur la théorie des mortiers*, in *Annales de Chimie et Physique*, vol. XXIII, 1823, pp. 69–80 (Id., *Bemerkungen, als Antwort auf den (vorstehenden) Aufsatz des Hrn. Berthier, Ingénieur en chef des Mines, über die Theorie des Mörtels*, in *Polytechnisches Journal*, vol. XI, 1823, pp. 363–73); Louis-Joseph Vicat, *Nouveaux faits pour éclairer la théorie des ciments calcaires*, in *Annales de Chimie et Physique*, vol. XXVIII, 1825, (pp. 142–147), p. 144 (Id., *Thatsachen zur Aufhellung der Theorie über Kalkmörtel*, in *Polytechnisches Journal*, vol. XVII, 1825, pp. 481–84).

³² Clement-Louis Treussart, *Extrait d'un Mémorial sur les Mortiers Hydrauliques*, in *Annales de Chimie et Physique*, vol. XXVI, 1824, pp. 324–29 (Id., *Ueber den hydraulischen Mörtel*, in *Polytechnisches Journal*, vol. XV, 1824, pp. 341–45).

Zimmermann, a German pioneer of the use of concrete to build hydraulic foundations, and a supporter of the use of *Trass* instead of artificial hydraulic lime.

2.3 Cement from England, and policies for the Gewerbeförderung

A further essential circumstance that supports the spread of hydraulic mortar use pertains the domains of manufacturing and trade, rather than the one of chemistry and engineering. It is produced by the early importation of the so-called Roman cement, which is a kind of efficient hydraulic lime that the English lime producer James Parker has developed in the early 1790s, burning marls from the Sheppey Island. Patented in 1796 by Parker himself, Roman cement becomes soon used in England to compose hydraulic mortar suitable to mould architectural decorations, and to build and plaster masonry walls, especially in case they are exposed to water or to the elements.³³ Unlike lime, Roman cement does not need to be slaked and can be packaged and transported far away from the production site, as any other manufacturing product. It therefore represents an efficient hydraulic binder and a manufacturing opportunity, which soon arises the interest of German master builders, as well as the interest of the civil servants and entrepreneurs who are involved in developing the German manufacturing.

Soon after the removal of the embargo known as Continental Blockade, which is in force from 1806 to 1814, in order to prevent trade and trips between the United Kingdom and European countries during the Napoleonic wars, early traces of Roman cement are to be found in Hamburg.³⁴ Since 1817, a Roman cement dealer named Benjamin Dodson works in neighbourhood of the Saint Michael Church, near the old port.³⁵ Dodson sells cement on behalf of a London manufacturer, along with “the tools that allow the use of cement” – probably moulds.³⁶

Besides trade, Roman cement becomes known in Germany through the so-called *technologische Reise*. This expression describes the study journeys that technicians, businessmen or civil servants undertake to investigate new industrial products and manufacturing processes abroad. England is the main goal of these journeys; most travellers are principally interested in mechanical things but some attention is also paid to new building techniques and materials, and it must be almost impossible for German travellers not to notice the Roman cement plasters and decorations that spread all over in

³³ See Arthur James Francis, *The Cement Industry 1796-1914: A History*, London, Newton Abbot, North Pomfret, Vancouver, David & Charles, 1977, pp. 26-42.

³⁴ Hamburg trades with England since the Middle Age, and a British community lives there permanently at least since 1611, when the Company of Merchant Adventurers had had the permission to set in the city, see Ortwin Pelc, *Hamburg und die Engländer im 19. Jahrhundert*, in Ortwin Pelc, Susanne Grötz, ed., *Konstrukteur der modernen Stadt. William Lindley in Hamburg und Europa 1808 – 1900*, München, Hamburg, Dölling und Galitz, 2008, (pp. 48-57), p. 49.

³⁵ See *Hamburgisches Address – Buch für das Jahr 1817*, Hamburg, Hermann am Fischmarkt, 1817, p. 70; *Hamburgisches Address – Buch für das Jahr 1818*, Hamburg, Hermann am Fischmarkt, 1818, p. 74; *Hamburgisches Address – Buch für das Jahr 1819*, Hamburg, Hermann am Fischmarkt, 1817, p. 76.

³⁶ See Christoph Arzberger, *Römisches Cement*, in *Kunst- und Gewerbe- Blatt des polytechnischen Vereins für das Königreich Bayern*, V, 1819, (coll. 598-600), col. 600).

London after the lapse of the Parker's patent in 1810. It is probably one of these travellers to provide the prince Leopold of Bavaria with a report about Roman cement, taken from the London department of buildings. The prince hands the report over to Christoph Arzberger (1772-1822), a mathematician and civil servant of high rank in Coburg. Arzberger analyses the report and writes a short article about it, which is published in the *Kunst- und Gewerbe-Blatt des polytechnischen Vereins für das Königreich Bayern* in 1819.³⁷ Arzberger describes Roman cement as a fine milled powder that is produced by firing and grinding clayish limestone, and he reports that this powder is appropriate to compose mortar suitable for hydraulic works, plaster works and mouldings. Arzberger also presumes that Roman cement could be reproducible in Germany by burning local marls. This idea will be then further developed in the following years, and several efforts will be undertaken to reproduce Roman cement in Germany.

Another significant investigation on Roman cement is the one by [Johann Heinrich] Krahmer, a master builder working for the Prussian *Ober-Bau-Deputation*, who goes on a study journey to England in 1821.³⁸ During a stay in London, Krahmer visits the house of Charles Francis, owner of the greatest Roman cement factories of that time, together with his associated John Bazley White. Upon his return to Berlin, Krahmer reports his observations to the *Ober-Bau-Deputation*. He synthetically describes the properties of Roman cement and lists all the applications he has observed in Francis's garden: several plaster works on walls, staircases, pavements, basins of fountains and many mouldings. Krahmer also reports to have seen some mouldings in gothic style, in the newly restored New College Chapel in Oxford. While, on one hand, Krahmer shows to be impressed by the quality of the Roman cement mortar and plaster he has observed, on the other hand, he complains about the impossibility to get detailed information about the raw materials and the manufacturing process of cement. As Arzberger before, he also believes that it could be possible to reproduce Roman cement in Germany after having investigated its composition through chemical analysis. Consequently, he brings from England to Berlin two casks of Roman cement and hands them over to Eytelwein, head of the *Ober-Bau-Deputation*, and to Peter Christian Wilhelm Beuth (1781-1853), head of the *Technische Deputation* (Technical Committee) and of the *Verein zur Beförderung des Gewerbefleißes in Preußen* (Society for supporting the development of manufacturing and trade in Prussia, or briefly *Gewerbverein*). (fig. 2.3.1.)

The two institutions led by Beuth are committed to supporting Prussia manufacturing and trade, the first is a public institution, the second a society of private entrepreneurs, which is inter alias

³⁷ Christoph Arzberger, *Römisches Cement...*cit.

³⁸ See [Johann Heinrich] Krahmer, letter from London to the Ministerium für den Handel das Gewerbe und das Bau-Wesen, 28 August 1821 (ms., GStA PK I.HA Rep.120 D XII 1, n° 3, vol. 1, n. fol.); Id., "Roman cement" (ms., GStA PK I.HA Rep.120 D XII 1 n° 3 vol. 1, 1r-9v, partly transcribed in Thomas Brunsch, *Die historische Verwendung zementgebundener Kunststeine im Außenraum im 19. und frühen 20. Jahrhundert unter besonderer Berücksichtigung Berlins und Brandenburgs*, doctoral dissertation, Technische Universität von Berlin, 2006, pp. 56-58). See also [Johann Heinrich] Krahmer, *Bemerkungen über die Dauer und Festigkeit des in England erfundenen Roman-Cement. Nebst Nachrichten von einigen andern Cementen*, in *Journal für die Baukunst*, III, 1830, pp. 476-83.

engaged in encouraging the arts and the art of building.³⁹ They promote policies aiming at encouraging the industrial development, which go under the name of *Gewerbeförderung*, and Roman cement soon becomes object of such kind of policies. In 1822, the *Gewerbverein* promotes a competition divided into several sections, including one that concerns the development of a mass for artificial stones, which should be produced from raw materials findable near Berlin, and should be suitable to mould solid and weatherproof objects and architectural decorations.⁴⁰ Krahmer's experience in London probably lies behind the idea of promoting this competition, but it is also worth to observe that a similar competition has been promoted in France one year earlier, by the *Société d'Encouragement pour l'Industrie nationale*, with the aim of encouraging the search for a new material that should be mouldable as gyps, and solid like limestone.⁴¹ The Prussian competition is moreover to be seen as an attempt at resuming the search for material suitable to produce mortar artificial stones, after the failure of Simon's trials. This is proven by the fact that applicants are invited to take into account Simon's experiments, besides a short list of books about hydraulic lime and pozzolana, including the one by John, the one by Vicat, and the “*Recueil des diverses Mémoires sur le Pouzzolanes naturelles et artificielles*” from 1805, written by Gratien Le Père (1769–1826).⁴²

The competition does not yield the expected results, at least in the short term.⁴³ Nevertheless, together with the text by Arzbeger, it probably contributes to raising the interest in Roman cement outside Prussia. In 1823, the king of Württemberg, Wilhelm I asks Friedrich Schmidt, a sort of industrial spy from Wurttemberg based in England, to search for information about Roman cement,

³⁹ See “Statut für den Verein zur Beförderung des Gewerbefleißes in Preußen” II Abtheilung, Bildung des Vereins, Art. 7, in Anon., *Ueber die Stiftung eines Vereines zur Beförderung des Gewerbefleißes in Preußen, nebst dessen Statut*, in *Polytechnisches Journal*, vol. IV, 1821, (pp. 486–94), p. 490.

⁴⁰ See *Preisaufgaben des Vereins. Vierte Preisaufgabe*, in *Verhandlungen des Vereins zur Beförderung des Gewerbefleißes in Preußen*, I, 1822, p. 22.

⁴¹ The competition promoted by the *Société d'Encouragement pour l'Industrie nationale* suggests trying either modifications of common gyps mortar composition, or inventing a new material similar to Roman cement or to the cement from Boulogne-sur-Mer. The activities undertaken by the *Société d'Encouragement pour l'Industrie nationale* must be well known in the circle of the *Gewerbverein*, since the French society is taken as a model for the foundation of the *Gewerbverein* itself (see Anon., *Ueber die Stiftung eines Vereines...*cit., p. 486). Moreover, the announcements of the competitions promoted by the *Société d'Encouragement pour l'Industrie nationale* are almost regularly translated and published in the *Polytechnisches Journal*, as it also happens for the competition in question (see Anon., X. *Preisaufgaben der Société d'Encouragement pour l'Industrie nationale aus der GeneralSitzung vom 3. Oktober 1821*, in *Polytechnisches Journal*, vol. VII, 1822, (pp. 89–127), pp. 125–26).

⁴² See *Preisaufgaben des Vereins. Vierte Preisaufgabe*, in *Verhandlungen des Vereins...*cit. The *Recueil des diverses Mémoires sur le Pouzzolanes naturelles et artificielles* is erroneously attributed also to Guyton de Morveau in the competition announcement; this is probably due to the fact that, just in 1805, Le Père et De Morveau publish together the *Recueil des rapport et observations sur les expériences faites à Cherbourg pour remplacer la pouzzolane dans les constructions hydrauliques*.

⁴³ Although proposals of methods to produce artificial mouldable masses come to the *Gewerbverein* (see *Auszug aus den Protokollen der monatlichen Versammlungen in den Jahren 1823*, in *Verhandlungen des Vereins zur Beförderung des Gewerbefleißes in Preußen*, III, 1824, (pp. 13–19), p. 16.

focusing on its quality, its price and its suitability to plaster buildings in Stuttgart.⁴⁴ In June 1823, Schmidt sends the king two reports, in which he asserts that Roman cement is an appropriate binder to plaster buildings. Just like Arzberger and Krahmer, even Schmidt believes that Roman cement could be reproduced in Germany, and considers this as an important occasion for the development of new manufacturing activities in Wurttemberg. He therefore suggests searching for clayish limestone along rivers, but the search, which actually takes place around 1823, does not give the expected results: the available amount of clayish limestone is judged too small and no cement manufacturing is actually yet undertaken in Wurttemberg.⁴⁵

While early awareness about Roman cement is spreading in Germany, English cement makers, such as James Frost, Edgar Dobbs, William Lockwood, James Pulham and Joseph Aspdin develop new kinds of cements by burning artificial mixtures of chalk and clay, in a way that is similar to John and Vicat's way to produce artificial hydraulic lime. Aspdin, in particular, patents a kind of cement in 1824, which he names Portland cement, since it is thought to give mortar the aspect of Portland stone.⁴⁶ An early short report about Aspdin's patent is taken from the *London Journal of Arts and Sciences*, translated into German and published on the *Polytechnisches Journal* in 1825, followed, in 1826, by a second short report giving an account of the controversy arisen in Britain about the real originality of Aspdin's patent, because of the closeness to Vicat's method for producing artificial hydraulic lime.⁴⁷ The announcement of this new finding does not seem, however, to produce any real consequence until the early 1840s, when a Hamburg dealer gets the licence to sell Portland cement on the continent.

2.4 The mortar artificial stones by Sachs, and the moulded statues by De la Rivallière-Preignac von Frauendorf

Two different kinds of mortar-based mouldable materials are developed in the first half of the 1820s in Prussia. The first one is developed by the Berlin master builder Salomo Sachs (1772–1855)

⁴⁴ See Helmut Albrecht, *Vom Caementum zu Zement*, in Id., ed., *Kalk und Zement in Württemberg: Industriegeschichte am Südrand der Schwäbischen Alb*, Ulstadt-Weiher, Landesmuseum für Technik und Arbeit in Mann, Verlag Regionalkultur, 1991, (pp. 117–30), pp. 125–29.

⁴⁵ Just as it happened at the beginning of the nineteenth Century in Boulogne-sur-Mer in France, see Charles-François Mallet, *Rapport fait par M. Mallet, au nom d'une Commission spéciale, sur le ciment découvert par M. Lacordaire, ingénieur des ponts et chaussées, à Pouilly, en Auxois, département de Saône-et-Loire*, in *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, XXVIII, 1829, (pp. 317–37), pp. 323–26; see also Liégard, Henry, Anselin, Blanchart, Lesage, *Rapport fait à la société d'Agriculture, de Commerce et des Arts, de Boulogne-sur-Mer, le premier floréal an 10; au nom d'une Commission chargée d'examiner les propriétés d'un plâtre-ciment*, in *Journal des Mines, ou Recueil de Mémoires sur l'exploitation des Mines, et sur les Sciences et les Arts qui s'y rapportent*, vol. XII, année X, [1802], pp. 459–89; Chaptal, *Note sur le plâtre-Ciment, découvert à Boulogne-sur-Mer*, in *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, année X, [1802], pp. 30–32.

⁴⁶ See Francis, *The Cement Industry*...cit., pp. 73–80.

⁴⁷ See Anon., *Neue Verbesserung in Verfertigung künstlicher Steine, worauf Joh. Aspdin, Maurermeister zu Leeds in Yorkshire, am 21. Oktober 1824. sich ein Patent geben ließ*, in *Polytechnisches Journal*, 1825, vol. XVI, pp. 304–05; Anon., *Hrn. Aspdin's künstliche Steine (Portland-Cement)*, in *Polytechnisches Journal*, 1826, vol. XIX, pp. 588–89.

with the aim of improving the quality of artificial stones made of rammed earth. Sachs conceives a mixture made of three measures of clay and one measure of mortar, this one being made of one measure of fat lime and two measures of sand.⁴⁸ He names the stones he produces with this kind of mixture *Mörtel-Steine* (mortar stones), and he has the occasion to test their solidity when, around about 1821–1823, he needs to replace a stretch of a 120 feet long enclosure wall of rammed earth, which a hurricane has partially destroyed.⁴⁹ Sachs also envisages the construction of walls consisting in two faces of mortar stones and rammed earth filling, which he describes in a book about the building techniques based of the use rammed earth, which is published in 1825.⁵⁰ Sachs attaches so much importance to this kind of walls that he takes care to describe and sketch an example in the letter that he addresses to the *Ober-Bau-Deputation* in 1825, to introduce a copy of his book.⁵¹ (fig. 2.4.1)

The second mortar-based mouldable material is developed in the wake of the French tradition of the *pierre factice*, by Charles de la Rivallière-Preignac, an ex-member of the Napoleonic army, who essentially aims at moulding statues. De la Rivallière-Preignac arrives in Prussia at the time of the French occupation and buys, in 1812, an estate called Frauendorf, situated between Berlin and Dresden, where he definitely sets up after the war.⁵² He has a sort of artistic ambition and desirers to realize an art gallery with paintings of battles and busts of generals. It is probably for this purpose that he develops a method “to produce hydraulic lime and artificial pozzolana, along with new hinges, a rolling mill, and other machines and tools to give form to the soft mass,” for which he obtains a patent in 1825.⁵³

Artificial pozzolana is actually burnt clay, and it is known in Germany through Dutch and French technical literature. An article about a kind of artificial pozzolana called “Amsterdam artificial cement” is taken from a Dutch report dating from 1809, and is published in 1812 in the *Allgemeine*

⁴⁸ Rammed earth artificial stones are developed in the context of the *pisé* building technique; in this regard, see Cointeraux, *Ecole d'Architecture*...cit.; Id., *Schule der Landbaukunst*...cit. About Sachs' artificial stones see Salomo Sachs, *Anleitung zur Erd-Bau-Kunst, (Pisé-Bau); mit Anwendung auf alle Arten von Stadt- und Land-Bauten, nebst einer vollständigen Lehre von der Konstruktion der Tonnen- Kappen- und Kreuzgewölbe in reinem Lehm und von der Anfertigung feuersicherer Dächer ohne alles Holzwerk, auch einer Anweisung, die Fundamente bis auf den Baugrund in bloßen Lehm anzufertigen*, Berlin, Carl Friedrich Amelang, 1825, pp. 39–51.

⁴⁹ See Johann Daniel Friedrich Engel, *Der Kalk-Sand-Pisébau und die Kalksand-Ziegelfabrikation*, Leipzig, C. H. Seemann, Leipzig, 1865, pp. 4–5.

⁵⁰ Sachs, *Anleitung zur Erd-Bau-Kunst*...cit., pp. 29–33.

⁵¹ See Salomo Sachs, letter to the Ober-Bau-Deputation, 17 October 1825 (ms. in “Verfertigung von künstlichen Bausteinen Patente” vol. 1, GstA PK I.HA Rep.120 D XII 1, n° 12, n. fol.).

⁵² For a biographical outline of Charles de la Rivallière-Preignac, see the autobiography of “Karl Franz Jakob Heinrich Schumann (1767–1827)”, in Reimar F. Lacher ed., *Kunstler(auto)biographien*, Berlin, Berlin-Brandenburgische Akademie der Wissenschaften, 2005, (pp. 65–72), pp. 71–72, n. 154 (www.berliner-klassik.de/publikationen/werkvertraege/lacher_autobiografien/autobiografien.html).

⁵³ “Auf eine neue Methode, hydraulischen Kalk und künstlichen Puzzolane zu verfertigen, ingleichen auf die für neu erkannten Charniere, an den zu dieser Fabrikation, außer andern Maschinen, bestimmten Walzwerk und auf das Instrument zum Formen der weichen Masse” (*Verzeichniß der im Königreiche Preußen im Jahre 1825 erhaltenen Patente, in Verhandlungen des Vereins zur Beförderung des Gewerbeleibes in Preußen*, V, 1826, p. 51; and *Verzeichniß der im Königreiche Preußen im Jahre 1825 erhaltenen Patente, in Polytechnisches Journal*, 1826, vol. XX, p. 193).

Literatur-Zeitung. “Amsterdam artificial cement” is produced firing clayish and rotten soil from the Amsterdam canals, and it has been patented in the 1780s by the Amsterdam cement handler Adrian de Booys.⁵⁴ Further explanations about artificial pozzolana are also to be found in a number of articles by Vicat, Berthier and Treussart, which appear in France in the early 1820s, and are then translated into German and published by the *Polytechnisches Journal*. “Since chemical analyses show that pozzolana is composed of silica, clay, iron oxide and a little lime,” Vicat writes in 1821, “it is easy to think that our clay, which consists of a similar composition, can be fired into artificial pozzolana.”⁵⁵ Raucourt de Charleville also deals with artificial pozzolana in his 1822 treatise about mortar, and Von Prittitz carefully relates information about it in his abstract published in 1825.⁵⁶ Vicat also deals with the question of moulding forms using hydraulic mortar instead of plaster in 1821 and 1823, sending two reports about the matter to the *Société d'Encouragement pour l'Industrie nationale*, for the second of which he even receives a gold medal on the proposal of Léonor Mérimée (1757–1836).⁵⁷

Towards mid 1820s, De La Rivallière-Preignac runs into financial trouble. He tries to sell the already achieved works for the art gallery to the University of Frankfurt, but vainly. In 1825, he goes bankrupt and the collection is auctioned off to pay creditors. Apart from a mention in the *Verhandlungen des Vereins zur Beförderung des Gewerbefleißes in Preußen*, his patent falls into oblivion. It is mentioned in some papers exchange between the city of Frankfurt an der Oder and the Home Office in Berlin dating from 1828, but without any practical implication.⁵⁸ The fact that the interest for developing mortar-based mouldable materials is anyway current is proved by a number of articles (mainly translations from foreign articles) that appear on the *Polytechnisches Journal* during the 1820s, and deal with English cements, cement-similar products and cement-based compounds, most of which are clearly described as

⁵⁴ Anon., *Veflag aan Zijne Excellentie den Minister van Eeredienst an Binnenlandsche Zaken, door de Eerste Klasse van het Koninklijk Instituut van Wetenschappen, Letterkunde en Schoone Kunsten, betrekkelijk den haar opgedragen last, nopens het fluk der buitenlandse, en de sedert 1789 uitgevondene binnenlandse Tras of Cement* (Bericht an Se. Excell. Den Minister der Gottesverehrung und der innern Angelegenheit, von der ersten Klasse des Königl. Instituts der Wissenschaften, Literatur und schönen Künste, betreffend den an sie gelangten Auftrag in Ansehung des ausländischen, und des seit 1789 erfundenen inländischen Trasses oder Cement), in *Allgemeine Literatur-Zeitung*, vol. III, n° 212, 1812, coll. 1-8.

⁵⁵ “Da ferner die chemische Analyse uns Kieselerde, Thonerde, Eisenoxyd und ein wenig Kalk als Bestandtheile der Puzzolana kennen lehrte, so war es sehr natürlich zu glauben, daß unsere Thonarten, die auf ähnliche Weise zusammengesetzt sind, durch Brennen sich in künstliche Puzzolanen verwandeln lassen könnten” (Vicat, *Ueber Kalk und Mörtel. Ein Auszug aus Hrn. Vicat's...cit.*, p. 288); original French text: “De même, puisque l'analyse chimique donne pour principes des pouzzolanes naturelles, la silice, l'alumine, le fer oxidé et un peu de chaux, il était tout simple de penser que nos argiles, dont la composition est toute semblable, pourraient se transformer, par la cuisson, en pouzzolanes artificielles” (Vicat, *Extrait de l'ouvrage intitulé...cit.*, p. 374).

⁵⁶ Raucourt de Charleville believes that air plays a crucial role for the production of pozzolana during clay burning (see Antoine Raucourt de Charleville, *Versuche mit verschiedenen Kalkarten in Rußland*, in von Prittitz, ed., *Neue Versuche über den Kalk und Mörtel...cit.*, p. 83).

⁵⁷ See Léonor Mérimée, *Rapport sur le prix pour la découverte d'une matière plastique se moulant comme le plâtre et pouvant résister à l'air autant que la pierre*, in *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, XXII, 1823, pp. 281–84. The *Polytechnische Journal* reports about that in 1824, see Vicat, *Untersuchungen über Anwendung des hydraulischen Mörtels statt des Gypses...cit.*

⁵⁸ See Brunsch, *Die historische Verwendung...cit.*, p. 61.

appropriate to produce artificial stone-made objects; and even the already mentioned announcement of the Portland cement patent can be seen under this light.⁵⁹

2.5 Roman cement applications and hydraulic lime manufacturing

Since at least the mid 1820s, some master builders begin to employ Roman cement imported from England to plaster walls, floors, and to seal masonry joints exposed to water or damp. Around 1826, Krahmer experiments with the use of Roman cement in a suburban villa nearby Berlin.⁶⁰ He plasters some exterior walls, staircases, and pavements, and he moreover seals the joints of a dock along the river Spree. In the same years, Roman cement is also used to seal the brick masonry joints of the locks along the Friedrich-Wilhelm Canal, and the joints of the new lighthouse in Kap Arkona on the island of Rügen. The definitive plans of the lighthouse are elaborated by August Adolph Gūnther (1779–1842), probably with the contribution of Schinkel, around 1825.⁶¹ The building is carried out between 1826 and 1827, under the supervision of the master builder Michaelis, who, in a later account, reports that the “3 floors of the lighthouse are built with fired bricks arranged in running bonds, the surface and the embossed joints being sailed with the so-called Roman cement, mixed with one part of sand and lime, as ordered from Newcastle.”⁶² The Roman cement for the construction of the lighthouse

⁵⁹ In this regard see: Anon., Universal- oder Parolik-Kitt (Parolic Cement). Von Th. Gill, in *Polytechnisches Journal*, III, vol. VIII, 1822, p. 19; Anon., Neuer Kitt oder künstlicher Stein, worauf Jak. Frost, Baumeister zu Finchley in Middlesex, dd. 11. Junius 1822 sich ein Patent geben ließ, in *Polytechnisches Journal*, IV, vol. XI, 1823, pp. 117–18; Anon., Ueber die Vortheile von Tickell's römischen Kitt (Roman Cement), in *Polytechnisches Journal*, IV, vol. XI, 1823, pp. 249–50; Samuel Bayshan, Methode, Vasen, Urnen, Beken und andere Zierrathe, die man bisher aus Stein und Marmor arbeitete, aus einer Verbindung von Artikeln zu verfertigen, die ehevor niemahls zu diesem Zweke gebraucht wurden, worauf Samuel Bayshan Gentleman zu New-castle-underline, in Staffordshire, am 26. Juli 1821. sich ein Patent geben ließ, in *Polytechnisches Journal*, VI, vol. XVI, 1825, pp. 305–08; John Phillips Beavan, Mörtel zum Bauen und zu anderen Zweken, worauf Joh. Phil. Beavan, Gentleman in Clifford Street, Middlesex, in Folge einer von einem im Auslande wohnenden Fremden ihm gemachten Mittheilung sich am 7. December 1825 ein Patent ertheilen ließ, in *Polytechnisches Journal*, VIII, vol. XXIII, pp. 558–59; Anon., Ueber Straßenbau, in *Polytechnisches Journal*, IX, vol. XXX, 1828, pp. 318–19; worth to mention are also two articles about two kinds of cement-based mortar developed in the United States and in Sweden, see J. J. Hawkins, Ueber römischen Mörtel (roman Cement); aus einem Schreiben des Hrn. J. J. Hawkins an die Pennsylvania Society for the promotion of the internal improvement, in *Polytechnisches Journal*, VIII, vol. XXIII, 1827, pp. 65–69; Anon., Ueber die Bereitung der hydraulischen Cemente, in *Polytechnisches Journal*, X, vol. XXXI, pp. 433–35.

⁶⁰ See Krahmer, *Bemerkungen...cit.*

⁶¹ See Reinhart Strecke, Schinkel und der Leuchtturm auf Kap Arkona, in *Jahrbuch Preußischer Kulturbesitz*, Berlin, Gebr. Mann Verlag, 1996, vol. XXXII, pp. 297–319.

⁶² “Diese vorgenannten 3 Etagen des Turms sind von guten gebrannten Ziegelsteinen im Kreuzverbande ausgemauert und auf die Außenfläche mit erhabenen Fugen mit sogenanntem römischen Zement, welcher aus Newcastle verschrieben wurde, unter Zusatz voneinem Teil Sand und Kalk abgefugt” (Landbaumeister Michaelis, “Erläuterung zu den Zeichnungen über den Bau des Leuchtturms zu Arkona, Bau- und Erläuterungsbericht des Landbaumeisters Michaelis vom 8. Januar 1830” (ms. GSTA I.HA Rep. 93D Lit Ok Tit. VIII n° 4, vol. 1, trans. in Strecke, *Schinkel und der Leuchtturm auf Kap Arkona...cit.*, p. 318). It is quite usual to seal external masonry joints with hydraulic mortar in the first half of the 19th century. For major buildings, entire external façades are sometime sealed daubing a thin layer of solid mortar and marking embossed joints. This happens because of the humble quality of bricks. Eminent examples of this

is in fact imported from Newcastle, despite the soil of Kap Arkona essentially consists of marls, clay and chalk, which are appropriate raw materials to produce hydraulic binders. The importation of Roman cement from England to Kap Arkona is a sign of the lack of knowledge and expertise in producing hydraulic binders at that time.

In 1826, Schinkel goes on a study journey to France, England and Scotland, together with his friend Beuth. In London, they both visit the building site of the Thames tunnel conceived by the engineer Marc Isambard Brunel, who personally led them around. In his travel diary, Schinkel drafts two sections of the tunnel structure and notices that the main building materials are bricks and Roman cement-based mortar.⁶³ (fig. 2.5.1) One year later, Beuth publishes an article about the construction of the Thames tunnel in the *Verhandlungen des Vereins zur Beförderung des Gewerbefleißes in Preußen*, highlighting the huge quantity of Roman cement that Brunel has been using since the beginning of the construction.⁶⁴ Traces of cement-based mortar are also to be found in the twenty-four turrets placed on the roof of Schinkel's Friedrichswerder Church in Berlin; the turrets are accomplished in 1828 and consist of a brick masonry work bond and plastered with cement-based mortar.⁶⁵

The spread of English Roman cement in the second half of the 1820s pushes the *Gewerbverein* to plan a new competition, which is at first intended to focus exactly on the reproduction of Roman cement. Aware of such intentions, the interior minister Friedrich von Schuckmann buys two casks of Roman cement from the factory of Francis and White in London, and gives them over to the *Gewerbverein* on April 1828, urging its technicians to investigate deeper about the properties of Roman cement.⁶⁶ Some tests take place between 1828 and 1829. They are conceived to verify if Roman cement-based mortar is suitable to produce artificial stones, sets under water, binds bricks, and, if it works efficiently as plaster under different conditions, notably in water containers.⁶⁷ (fig. 2.5.2) Despite the positive outcomes that most tests prove, in a report following the accomplishment of the tests, Roman cement is described as a material that is only partially useful in Prussia. It is considered too expensive for hydraulic engineering and not necessary to plaster ordinary building, since air in Germany is thought to be less humid than in England. It is, instead, considered valuable to seal founding walls against rising

façade treatment are the castle of Babelsberg in Potsdam, by Schinkel, Persius and Johann Heinrich Strack (1833–49); and the Heilandskirche in Sacrow, by Persius.

⁶³ See Karl Friedrich Schinkel, Tagebuchseite 29, published in Reinhard Wegner, Margarete Kühn, ed., *Karl Friedrich Schinkel. Die Reise nach Frankreich und England: Das Tagebuch*, München, Deutscher Kunstverlag, 1990, p. 46, p. 125.

⁶⁴ Peter Christian Wilhelm Beuth, *Der Tunnel unter der Themse*, in *Verhandlungen des Vereins zur Beförderung des Gewerbefleißes in Preußen*, VI, 1827, pp. 286–94.

⁶⁵ Only in 1843 the turrets were covered with zinc plates (see Stein, *Ueber den Bau eiserner Thurm spitzen*, in *Zeitschrift für Bauwesen*, X, 1860, (coll. 481–90), col. 484).

⁶⁶ Friedrich von Schuckmann, letter to the *Gewerbverein*, 6 April 1828, published in Anon., *Ueber die mit Roman Cement, aus der Fabrik von Francis, White und Francis, in London, angestellten Versuche*, in *Verhandlungen des Vereins zur Beförderung des Gewerbefleißes in Preußen*, VIII, 1829, (pp. 123–26), p. 123.

⁶⁷ Anon., *Ueber die mit Roman Cement...cit.*

damp, to bind the masonry works of vaults that are exposed to rain, and to plaster wet walls.⁶⁸ The competition is launched in 1829, but, rather than focusing on the reproduction of Roman cement, it demands to search for a kind of hydraulic mortar that is suitable to build underwater and over ground, and costs no more than six time the price of ordinary lime mortar.⁶⁹

Like the previous one, neither this competition has a winner. Nevertheless, exactly since the end of the 1820s, hydraulic lime and artificial pozzolana begin to be produced in the regions of the Joachimsthal and the Werbellinsee, northeast of Berlin, where considerable deposits of clay and lime are available, and even already exploited to produce lime and bricks.⁷⁰ Gottfried Menzel (1792–1870), an inspector of the Royal brickyard situated in the Joachimsthal, Johann Bernoulli and Theodor Buschius, two lime producers from the southwest area of the Werbellinsee (called Wildau), take the initiative since about 1827. Buschius produces artificial hydraulic lime and a kind of artificial pozzolana made of clay, silica and iron oxide, as described by Vicat.⁷¹ The Royal brickyard produces artificial hydraulic lime burning mixtures of 3 parts of marls, 2 parts of clay and a small amount of iron oxide. Marls are quarried open-air near the Werbellinsee during the fall, they are arranged in 2 feet high heaps, and remain exposed to the elements during the winter. They are then dissolved in water, mixed with clay and iron oxide in a clay mixer, to be then moulded in the form of bricks, dried in huts, and finally burnt in kilns. Like Roman cement, hydraulic lime from the Joachimsthal is not slaked. The fired blocks are crushed and ground into powder, first in a stamp mill, then in a grind mill, both powered by water. Lime powder is packaged in sacks and casks, and it is used in the region of Berlin. Several masonry works along the Finow canal are built using a kind of mortar made of one measure of Joachimsthal lime, and three measures of brick powder, which is also produced at the royal brickyard of the Joachimsthal, by grinding discarded bricks.⁷² The joints of the masonry works along the Finow canal are, instead, often sealed with pure hydraulic lime mortar.⁷³

⁶⁸ Ibid., p. 126.

⁶⁹ See *Preisaufgaben für die Jahre 1829 und 1830. Dritte Preisaufgabe*, in *Verhandlungen des Vereins zur Beförderung des Gewerbefleißes in Preußen*, VIII, 1829, p. 31.

⁷⁰ Gottfried Menzel, *Verfahren bei der Fabrication der Ziegel und des Mörtels auf der königl. preuß. Ziegelei bei Joachimsthal*, in *Verhandlungen des Vereins zur Beförderung des Gewerbefleißes in Preußen*, XXV, 1846, (pp. 52–73), pp. 72–73; and in *Polytechnisches Journal*, vol. CII, 1846, pp. 194–219.

⁷¹ See Zimmermann, *Einige Bemerkungen über die Festigkeit, Mischungsverhältnisse und Zubereitung des Bétons, oder des Mauerwerkes aus klein geschlagenen, mit Mörtel untermengten Steinen, dessen man sich zuweilen, um Fangdämme und Wasserschöpfen zu sparen, zur Fundamentierung von Bauwerken unter Wasser bedient*, in *Journal für die Baukunst*, vol. III, 1830, (pp. 1–31), pp. 13, 15. Buschius factory is also known, since 1846, as Wildauer brick and lime kiln, from the name of the small local area of Wildau (see Königl. Regierung. Abtheilung des Innern, *Vermischet Nachrichten*, in *Amtsblatt der Königlichen Regierung zu Potsdam und der Stadt Berlin*, 1846, p. 166).

⁷² Ibid., p. 73.

⁷³ Menzel, *Verfahren bei der Fabrication...*cit., p. 72.

2.6 Concrete hydraulic foundations, Trass versus hydraulic lime

Two different and reliable sources prove the use of *Trass*-based concrete for the building of the fountain on the Pfaueninsel in Potsdam, which is realized in 1825, following a design by Friedrich Martin Rabe (1765–1856). According to the Berlin master builder Braun, the fountain stands on a 2 feet higher bed of concrete, supporting a basin made of fired bricks, held together with *Trass*-based mortar.⁷⁴ A drawing by Albert Dietrich Schadow (1797–1869), dating back to January 1826, notably a cross section over the fountain, shows, instead, a different and much more complex design (fig. 2.6.1). The fountain appears as composed of two different and concentric basins, each one made of a horizontal layer of bricks laid edge on, and two circular walls made of bricks as well. The two horizontal layers of bricks appear spaced approximately 2 feet apart, whereas the two circular walls approximately 2/3 foot apart. In the cavity between the two concentric basins, two different kinds of filling materials are to be observed. A finer conglomerate forms a layer of about 2/3 foot on the bottom and fills the space between the two circular walls, whereas a coarse conglomerate fills the rest part of the space between the two horizontal layers of bricks. The finer filling material is probably *Trass*-based mortar, whereas the coarse one looks like a mix of rubbles and mortar. The central sculptural column stands on a layer of bricks laid edge on, over an entire block of rubble and mortar.

Knowledge and expertise developed in the previous years about concrete and hydraulic binders are essential prerequisites for the construction of the concrete foundation of the lock of Hamm, along the river Lippe, which the master builder Zimmermann carries out in 1828, after that the previous lock, standing on a timber foundation, has been dragged away by violent stream. Zimmermann has a quite wide knowledge about hydraulic lime, mortar and concrete, at the time he approaches the matter. He knows recent writings by John, Vicat, Raucourt de Charleville, Treussart, Hageau, Von Prittitz, together with some essential eighteenth-century technical literature.⁷⁵ He is moreover aware of the hydraulic mortar that the Swedish chemist Gustaf Erik Pasch (1788–1862) prepares using burnt and milled slate, instead of pozzolana, for the building of the Göta canal (1810–1832).

It is probably on the wake of the eighteenth-century building culture that Zimmermann considers foundations made of concrete poured inside enclosures as appropriate in case neither the use of caissons (very probably meaning the traditional ones filled with masonry work), nor cofferdams, and not even drainage are feasible.⁷⁶ “In case of difficult foundations,” he writes in 1829, “to build without resorting to caissons, cofferdams and drainage, concrete is appropriate and useful, as long as the

⁷⁴ See Braun, *Über Anwendung des Trass-Bétons zur Fundamentierung der Gebäude*, in *Journal für die Baukunst*, vol. III, 1830, (pp. 112–17), p. 113.

⁷⁵ He mentions Bélidor, Jean-Rudolph Perronet (1708–1794), Émiland-Marie Gauthey (1732–1806) and Reinhard Woltmann (1757–1837).

⁷⁶ Zimmermann anyway does not explain, which kind of filling he considers appropriate for caissons.

foundation site is sheltered from stream.”⁷⁷ Only in case of marshy soil, Zimmermann advises against the use of concrete poured straight onto the soil, and recommends using timber piling with framework or caissons. “I would not dare,” Zimmerman writes in this regard, “to build a concrete foundation on muddy and marshy soil, [...], I would choose piles or caissons.”⁷⁸

Zimmermann attaches great importance to the use of egg-sized crushed bricks in concrete mixtures. Only in the lack of bricks, he suggest using crushed stones, but he anyway recommends stones whose components have chemical affinity to cement. As examples, he lists tuff, clay stone and porphyry, whereas he advises against stones containing crystals, remembering of John’s failed attempt at dissolving a crystal in limewater. The surface roughness of crushed stones also plays a crucial role according to Zimmermann, since it is thought to improve the adherence to mortar. Zimmermann gives the adherence between mortar and crushed stones the same attention that is normally placed on adherence between mortar and stones, in case of traditional masonry works, since he considers concrete blocks as a kind of masonry work.⁷⁹

Cement is the further essential component of concrete, about which Zimmermann concisely states: “Excellent mortar containing strong cement is necessary to compose concrete for foundations, since these needs to harden in water or in wet soil.”⁸⁰ Facing the question already arisen by Treussart, whether artificial hydraulic lime or *Trass* is the most advisable material to produce a good kind of hydraulic mortar, Zimmermann takes the side of Treussart and arguments: “Vicat, the inventor of the so-called artificial hydraulic lime, thinks [...] that mortar composed of hydraulic lime and sand can replace cements,” whereas “Treussart thinks that hydraulic lime cannot make cements unnecessary, and that cement-based mortar is to prefer.”⁸¹ It comes as no surprise that Zimmermann agrees with Treussart, if we consider the easy availability and affordability of *Trass* in Rhineland. Zimmermann however bases his preference for *Trass* on the outcomes of strength tests that he himself carries out. He believes that mortar composed with artificial hydraulic lime reaches only humble strength eight weeks after having been produced, whereas *Trass*-based mortar gives much better results, under similar conditions. The limit of eight weeks to verify the hardening and strength of mortar is not accidental but intentional,

⁷⁷ “Die Nützlichkeit und Zweckmässigkeit des Bétons bei schwierigen Fundamentirungen, welche ohne Fangdämme und Ausschöpfung, oder nicht in Senkkästen ausgeführt werden sollen, ist mithin in die Augen fallend, unter der Voraussetzung, dass der Baugrund sicher und gegen Unterspülung geschützt sei” (Zimmermann, *Einige Bemerkungen über die Festigkeit...*cit., p. 6).

⁷⁸ “Auf schlammigem, morastigen Grunde würde ich doch nicht wagen, [...] einen Bau auf Béton zu gründe, sondern einen Pfahlrost oder senkkästen vorzuziehen” (Zimmermann, *Einige Bemerkungen über die Festigkeit...*cit., p. 8).

⁷⁹ *Ibid.*, p. 3.

⁸⁰ “Der Béton, der die Stelle des Fundament-Mauerwerk vertreten und entweder gänzlich unter Wasser, oder doch auf feuchtem Grunde erhärteten soll, erfordert daher einen ausgewählten vorzüglichen Mörtel und einen kräftigen Cement zu letzterem” (*Ibid.*, p. 12).

⁸¹ “Der französische Ingenieur Vicat, der verdienstliche Erfinder des künstlich bereiteten sogenannten hydraulischen Kalkes, ist [...] der Meinung, dass der Mörtel aus diesem Kalke und blossem Sandeemente ersetze, [...]. Dagegen ist der französische Ingenieur-General Treussart mit der Bahauptung aufgetreten, dass der hydraulische Kalk dieemente nicht entbehrlich mache, und dass der aus letzteren bereitete Mörtel vorzüglicher sei” (*Ibid.*, pp. 12–13).

since Zimmermann believes that “a masonry work is usually charged” eight weeks after having been built⁸². *Trass* that is milled near Koblenz and Andernach is the best one available, according to Zimmermann. It can be easily transported on boats along the rivers Rhine and Lippe, and is therefore more affordable than *Trass* coming from Holland upon Bremen via the river Weser. “According to my tests,” Zimmermann asserts, “no other cement can exceed the force of this kind of *Trass*”⁸³. Despite cheaper, *wild Trass* is “half so strong as ordinary *Trass*”, Zimmermann warns, and among the materials that could replace *Trass*, he mentions burnt and milled slate, brick powder and the artificial pozzolana produced by Buschius in Berlin.

Before starting to build the lock in Hamm, Zimmermann carries out a series of strength test on mortar specimens, made of different mixtures of aerial and hydraulic lime from limestones quarried along the river Lippe, artificial hydraulic lime and artificial pozzolana produced by Buschius in Berlin, *Trass* from Brohl, bricks powder, slate and sand. The different mortar mixtures are poured into parallelepiped-shaped moulds, composed by longitudinal wooden bars and divided in compartments by transversal partitions. Once filled with mortar, moulds remain underwater between seven and eleven weeks long, thereafter, Zimmermann recovers the specimens and tests their flexural and tensile strengths (*relative* and *absolute Festigkeit*). Among the mortar mixtures he tests, the one made of one measure of *Traß* from Brohl and 3/5 of hydraulic lime from Wallstädde, a village near Hamm, give the best outcomes, and Zimmermann therefore adopts it to build the lock of Hamm.

The building begins in the summer of 1828. Some already existing walls form the enclosure in which concrete can be soon poured. Mortar is prepared manually, using tools like “cudgels, masonry chisels, heavy shovels or the so-called clay-sabre, the same kind of tools that brick makers use.”⁸⁴ The mixing process is taken from the ancient way of preparing hydraulic mortar. “A certain quantity of *Trass* is laid to form a circle on a timber platform placed under a roof. An appropriate quantity of slaked lime is put in the middle of the circle, it is covered with *Trass* and pushed toward the centre to form a heap, which is then once again spread around by means of shovels. This work is repeated many times and, when it is up to the end, mortar is spread on the platform, workers hold close to each other, by hands or side-by-side, and tread on mortar pushing it in all direction, while someone else collects mortar that is squirted to far away and throws it to the centre. After having spread mortar so much and thin as possible, workers treat on mortar forming smaller and smaller circles, until they come so close each other that footprints overlap. This process is repeated many times, until mortar appears homogeneously mixed, smooth, and leaves nothing to be desired”⁸⁵.

⁸² *Ibid.*, p. 12.

⁸³ “Nach meinen Versuchen wird seine Wirksamkeit von keinem anderen cement übertrffen” (Zimmermann, *Einige Bemerkungen über die Festigkeit...*cit., p. 14).

⁸⁴ “Keule, Schlag-Eisen, schwere Schaufeln, oder so-genannte Thon-Säbel, wie sie die Ziegelei-Arbeiter haben” (Zimmermann, *Einige Bemerkungen über die Festigkeit...*cit., p. 27).

⁸⁵ “Auf einer festen, dichten und wagerecht abgeglichenen Unterlage von Bohlen oder Brettern, unter einem Dache, wird der zu einer gewissen Quantität Mörtel nöthige *Trass*, in Form eines Ringes oder Kranzes ausgebreitet. In den

Concrete is also prepared manually, by mixing six measures and half of mortar with three measures and half of crushed bricks. "We placed three 12 square feet sized typical containers for lime slaking next to each other," Zimmermann reports, "and we started to produce concrete by filling the containers one after another, in order to have three different work shifts, and, consequently, always some concrete ready to be poured. [...]. In each container, a layer of about 7 cubic feet mortar was spread on the bottom, then it was covered with a layer of about 12 cubic feet crushed bricks, and the two layers were trodden into mortar with wooden clogs. A second and, further on, a third layer of mortar and crushed bricks were laid the same way. Once this achieved, the raw concrete mass was stirred from one side to another, and vice versa, by means of shovels and hoes, then it was arranged in the middle in the form of a heap, as it happens for brickmaking. The heap of concrete was again spread and stirred so many times until all brick fragments were fully in mortar, the colour of bricks was no longer to be recognised, and no empty space at all was in concrete"⁸⁶.

To pour concrete Zimmermann builds a provisional carpentry over the foundation pit, from which workers can steer a pipe provided with a funnel at the top. Concrete is poured through this pipe, from the top of the foundation pit to the bottom, layer over layer. Zimmermann asserts that the use of pipes is advantageous in case the foundation pit is not deep, otherwise he recommends using machines with chests similar to the ones described by Bélidor and mentioned by Wiebeking. Apart from Zimmermann's case, machine with chests will be the most used tool to pour concrete underwater during the first three quarters of the 19th century in Germany.

inneren Raum dieses Ringes wird der zu dem Mörtel nötige Kalkbrei geschüttet, mit dem Trasse vom Rande überdeckt und, bald nach der Mitte zu in einen Haufen zusammen geschlagen, bald wieder mit Schaufeln ausgebreitet. Nachdem solches mehrere Male geschehen, und der rohe Mörtel von neuem auseinander gebreitet ist, fassen sich die Arbeiter zur gegenseitigen Unterstützung bei den Händen, oder stemmen sie auch wohl in die Seiten, und durchtreten so nach verschiedenen Richtungen diese Masse, während ein Arbeiter den am Rande zu weit verbreiteten Mörtel mit der Schaufel aufnimmt und wieder nach der Mitte zu wirft. Die Arbeit endigt damit, dass die Arbeiter den Mörtel, nachdem sie ihn kreisförmig so weit und so dünn als möglich auseinander gebreitet, dicht aneinander stehend, so dass der Fusstritt des einen fast in den des andern trifft, in engen und immer engern Kreisen, die Mitte aber einzeln, durchtreten. Ist solches wiederholt geschehen, so erhält man einen überaus gleichförmig-gemischten, geschmeidigen Mörtel, der in der Bereitung nichts zu wünschen übrig lässt" (Zimmermann, *Einige Bemerkungen über die Festigkeit...*cit., p. 27).

⁸⁶ "Man hatte drei Kalklösch-Kästen von 12 Fuss im Quadrat neben einander aufgestellt, worin die Bereitung des Betons successive angefangen und fortgesetzt wurde, so dass beständig Vorrath zum Versenken da war. [...] Auf den Boden des Kastens wurde zuerst eine Schicht von etwa 7 Cubik-Fuss Mörtel ausgebreitet. Dieser Mörtel wurde mit einer Schicht von etwa 12 Cubik-Fuss zerschlagener Ziegel bedeckt, und es wurden die Ziegel mit Holzschuhen in den Mörtel eingetreten. Hierauf folgte eine zweite Lage Mörtel und eine zweite von Ziegelstücken, ganz wie die vorigen, und eine dritte ganz eben so. Sodann wurde diese rohe Beton-Masse mittelst starker Schaufeln und Hakken, wie die der Ziegelei-Arbeiter, von der einen Seite des Kastens nach der entgegengesetzten übereinander gewickelt und zuletzt in einen Haufen nach der Mitte zusammen geschlagen. Dieser Haufen Wurde von neuem ausgebreitet und dasselbe Verfahren von einer anderen Seite des Kastens her und so lange wiederholt, bis man sahe, dass alle Ziegelstücke ganzlich vom Mörtel umhüllt waren, bis ihre Farbe nicht mehr zu erkennen und in der Masse nirgend mehr ein leerer Raum war" (Zimmermann, *Einige Bemerkungen über die Festigkeit...*cit., p. 29).

2.7 The completion of John's theory, Fuch's studies about lime and mortar

Which are the nature and properties of artificial pozzolana, whether or not pozzolana, *Trass* and brick powder have a chemical role in mortar, and why clay acts as cement only after having been burnt, are critical issues in French technical debate, during the second half of the 1820s. Several articles about these questions appear in the *Annales de Chimie et Physique*. They are by Vicat, Treussart and Pierre-Simon Girard (1765–1836), a French engineer of the Corps de Ponts, and they are soon translated into German and published by the *Polytechnisches Journal*.⁸⁷ Nevertheless, the questions remain open, and, in this regard, Girard, in 1827, states: “The several chemical researches carried out by eminent chemists with the aim of discovering the origin of the properties of volcanic and artificial pozzolana have not yet produced any acceptable theory of a phenomenon that has considerable importance for the arts.”⁸⁸

Johann Nepomuk von Fuchs (1774–1856), a Bavarian chemist, develops a theory about the matter in 1829, after having investigated about lime and mortar, on behalf of the director of the Bavarian *Ministerial-Bau-Section*, Von Purgel.⁸⁹ Before starting this research, Fuchs has already studied the chemical processes concerning the manufacturing of porcelain, and he has discovered much about the chemical structure and behaviour of silica.⁹⁰ He has understood that silica is, by nature, always combined with other substances, forming the so-called silicates, among which clay is the most common. Relying on this finding, as he investigates about lime and mortar, Fuchs understands that it is necessary to set silica free from the other substances forming the silicates in order to produce hydraulic lime. He believes that this is only feasible through a chemical reaction, which can be triggered by acids or by fire. In this way, Fuchs explains why clay needs to be burnt to act as cement, or, in other words, as artificial pozzolana.

⁸⁷ See Clement-Louis Treussart, *Notiz des General Treussart über die Bereitung der künstlichen Puzzolanen oder Trasse*, in *Polytechnische Journal*, 1826, vol. XXI, pp. 40–47 (Id., *Note du M. le général Treussart sur la Fabrication des Pouzzolanes ou trass factices*, in *Annales de Chimie et Physique*, 1826, vol. XXXI, pp. 243–53); Pierre-Simon Girard, *Ueber einige natürliche und künstliche Puzzolanen*, in *Polytechnische Journal*, 1827, vol. XXIII, pp. 60–65, 1827, vol. XXV, pp. 404–09 (Id., *Note sur les Pouzzolanes naturelles et artificielles*, in *Annales de Chimie et Physique*, 1826, vol. XXXIII, pp. 197–204); Louis-Joseph Vicat, *Bemerkung über künstliche Puzzolanen*, in *Polytechnische Journal*, 1827, vol. XXIV, pp. 175–77 (Id., *Note sur les Pouzzolanes artificielles*, in *Annales de Chimie et Physique*, 1827, vol. XXIV, pp. 102–05); Pierre-Simon Girard, *Notiz über die natürlichen und künstlichen Puzzolanen*, in *Polytechnische Journal*, 1827, vol. XXV, pp. 409–20 (Id., *Note sur les Pouzzolanes artificielles*, in *Annales de Chimie et Physique*, 1827, vol. XXXV, pp. 140–54).

⁸⁸ “Die chemischen Untersuchungen, welche viele ausgezeichnete Gelehrte anstellten, um die Ursache der Eigenschaften der vulkanischen und künstlichen Puzzolanen kennen zu lernen, haben bis auf diesen Tag noch auf keine annehmbare Theorie einer in den Künsten so häufigen Erscheinung geführt” (Girard, *Notizen über die natürlichen und künstlichen Puzzolane...cit.*, p. 409 (“Les recherches chimiques auxquelles beaucoup de savants distingués se sont livrés, pour connaître la cause des propriétés dont jouissent les pouzzolanes volcaniques et artificielles, n'ont pas abouti jusqu'aujourd'hui à donner une théorie passable d'un phénomène pourtant si commun dans les arts”, Girard, *Note sur les Pouzzolanes naturelle et artificielles...cit.*, p. 140). See also Treussart, *Ueber die Bereitung der künstlichen Puzzolanen...cit.*

⁸⁹ See Johann Nepomuk Fuchs, *Ueber Kalk und Mörtel*, in *Beilage zum Kunst- und Gewerbe-Blatt des polytechnischen Vereins für das Königreich Bayern*, XV, 1829, (coll. 1–56), col. 4.

⁹⁰ Johann Nepomuk Fuchs, *Ueber ein neues nutzbares Produkt aus Kieselerde und Kali*, in Karl Wilhelm Gottlob Kastner, ed., *Archiv für die gesammte Naturlehre*, vol. V, Nürnberg, 1825, pp. 385–412.

Coherently with this belief, Fuchs defines volcanic products like pozzolana and *Trass*, as clay that has been burnt by nature. “The volcanic products that are known under the names of *Trass* and pozzolana, and are considered good cements, are nothing else than burnt clay,” he states in this regard.⁹¹

This is the core and the most innovative point of Fuch’s theory about lime ad mortar, whose practical implications are no less important than the theoretical aspects. Just basing on this theory, Fuchs promotes the use of Bavarian marls as local raw materials for the production of hydraulic lime, and he even engages in mapping places around Munich, where it is possible to quarry them. He encourages Bavarian master builders to use hydraulic lime produced from local marls, both for hydraulic works, and for masonries above ground.

In 1829, Fuchs reads a dissertation about his research at a special sitting of the Bavarian *Polytechnischer Verein* (Polytechnic Society), where several participants come just on the purpose to hear about Fuch’s new achievements.⁹² The dissertation arises interest, but, at the same time, it also provokes the opposition of those who believe that the best hydraulic lime has already been discovered in France and England, and that Bavarians should acquire from those countries the principles of hydraulic lime manufacturing, rather than investing in researches. At that time, most people consider Roman cement from England as the best hydraulic lime available, and some of them even consider impossible to produce a similar material in Bavaria because of the lack of coke that is commonly used to burn Roman cement in England.⁹³ And it is probably just on the base of such convictions that August von Cetto (1794–1879), a Bavarian diplomat at the court of London, sends a request of information about Roman cement to the engineer Brunel, shortly after that the rebuilding of the fortress of Ingolstadt has begun in 1828.⁹⁴

In spite of opponents’ criticism, interest for Fuch’s theory soon increases, as it is proved by the fact that the dissertation is published in three different editions in the same 1829⁹⁵. The following year, Fuch’s takes part to a competition promoted by the Royal Holland Society of Sciences and Humanities with the aim of discovering “which are the characteristics that distinguish cements that harden in water,” and “which are the constituting principles and chemical combinations that act during their

⁹¹ “Als gute Cämente sind längst sehr berühmt die unter den Namen *Trass* und *Puzzolan*, bekannten vulkanische Produkte; unter welche man sich aber doch auch nichts anderes vorstellen darf, als gebrannte Thonsorten” (Johann Nepomuk Fuchs, *Ueber Kalk und Mörtel*...cit., col. 40).

⁹² See *Auszug aus den Protokollen der Sitzungen in den Monaten April, Mai und Juni 1829*, in *Kunst- und Gewerbe-Blatt des polytechnischen Vereins für das Königreich Bayern*, XV, 1829, n. 29, (coll. 389–92), col. 392.

⁹³ Anon., *Würdigung der Arbeit des Professors und Akademikers Fuchs über Kalk und Mörtel*, in *Kunst- und Gewerbe-Blatt des polytechnischen Vereins für das Königreich Bayern*, XVIII, 1832, (coll. 756–61), coll. 758–59.

⁹⁴ See Anon., *Hilfsmittel bei Bauführungen, Ueber den römischen Zement*, in *Allgemeine Bauzeitung*, II, 1837, pp. 390–92; also mentioned in Otto Christian Friedrich Reinhold, *Sammlung practischer Erfahrungen*...cit., pp. 154–55.

⁹⁵ Fuchs, *Ueber Kalk und Mörtel*...cit., in *Die neuesten Forschungen im gebiete der technischen und ökonomischen Chemie*, vol. III, 1829, pp. 1–26, 132–62; Id., *Ueber Kalk und Mörtel*, Leipzig, Barth, 1829.

solidification.”⁹⁶ Fuchs writes a report taken from the 1829 dissertation, and gives it up to the Holland Society in December 1830, moving the first step toward the international recognition of his theory.

2.8 Concrete foundations in technical literature

Since the very end of the 1820s, several essential articles dealing with the topic of concrete hydraulic foundations are published in the *Journal für die Baukunst*, and remain important references for over ten years. An early significant one is written by the hydraulic engineering inspector [Friedrich Wilhelm] Elsner, who describes the different types of concrete foundations that he has observed since about the beginning of the century along the Rhine, in northwest Germany, and in Holland as well. (fig. 2.8.1) One year later, the master builder Zimmermann writes an article about the concrete foundation that he has built for the lock of Hamm, and he furthermore explains all his convictions about hydraulic lime, *Trass* and concrete. Worth of mention is also an article by the master builder Braun from Berlin who, moving from the example of the concrete foundation of the fountain on the Pfaueninsel, suggests using concrete, not only in hydraulic engineering, but also to build the foundations of ordinary buildings on wet and unsteady soil.⁹⁷ “It is known,” Braun maintains, “that master builders of the past and nowadays have used concrete to build foundations underwater, but they have rarely used it to stabilize bad foundation soils for considerable buildings. And yet, under certain circumstances, poured concrete could be used with advantage to do without expensive timber pilings, especially if it is mixed with a cementitious material [...].”⁹⁸ “Instead of using natural stones,” Braun still goes on, “with affordable costs and even with less efforts, it is possible to build an artificial stone-mass that rapidly gains solidity, hardness, and becomes like a rocky base. Mixture of *Trass* from Brohl upon the Rhine, lime, sand and gravel, besides small pieces of granite, stones or bricks are appropriate for such a purpose [...].”⁹⁹ For an exhaustive overview of the publications about concrete foundations, a further article dating back to 1830 is still to be mentioned. It is written by an anonymous master builder from Colberg

⁹⁶ “Quels sont le caractere, auxquels on reconna’ira les Cements, qui s’endourcissent sous l’eau ? Quels en sont les principes constituants et quelle est la combinaison chimique, qui s’opere pendant leur solidification?” (Johann Nepomuck Fuchs, *Ueber die Eigenschaften, Bestandtheile und chemische Verbindung der hydraulischen Mörtel. Eine gekrönte Preisschrift vom Akademiker und Conservator Dr. J. N. Fuchs in München*, in *Polytechnisches Journal*, 1833, vol. XLIX, pp. 271–96).

⁹⁷ Braun, *Über Anwendung des Traß-Bétons...cit.*, pp. 112–17.

⁹⁸ “Es ist bekannt, dass ältere und neuere Baumeister sich häufig des Bétons zu den Fundamenten der Wasserbauten bedienten; seltener scheint derselbe zur Befestigung eines schlechten Baugrundes, worauf Land-Gebäude von Bedeutung aufgeführt werden sollen, benutzt worden zu sein, und doch dürfte der, besonders mit einem cementartigen Materiale gemischte und zubereitete Béton, in Masse gelegt, in manchen von dem Baumeister nach den Umständen zu erachtenden Fällen nicht ohne bedeutenden Vortheil zu benutzen und besonders der kostspieligen Pfahlrosten vorzuziehen sein” (Braun, *Über Anwendung des Traß-Bétons...cit.*, p. 112).

⁹⁹ “Statt der Fels-Platte ist es nun möglich, durch Kunst, und sogar mit leichter Mühe, und nach Verhältniss mit geringen Kosten, an Ort und Stelle eine Steinmasse zu erzeugen, die sehr bald eine solche Härte und Dichtigkeit erhält, dass sich darauf fast wie auf einem Fels bauen lässt. Es eignet sich dazu der aus Trass von Brohl am Rhein, aus Kalk, Sand, Kies, kleinen Granit- oder Bruch und Ziegel-Stücken verfertigte Béton ganz vorzüglich, [...]” (Braun, *Über Anwendung des Traß-Bétons...cit.*, pp. 112–13).

in Thüringen, and deals with foundations made of rubble and mortar, poured and rammed in pits, layer upon layer, straight on the foundation soil or even on timber piles, in case of extremely unsteady soil.¹⁰⁰ (fig. 2.8.2) This kind of conglomerate, which is introduced as “gerammter Béton” (rammed concrete), is actually similar to Wiebeking’s “pebbles and mortar”, and it probably even derives from Bélidor’s description of Milet de Monville’s concrete. The use of the French term *demoiselle*, to better describe the pile driver used to ram rubble in mortar, and the French expression *en quinconce*, to explain the appropriate arrangement of timber piles in the soil, support the hypothesis of a French origin, even more if we consider that Bélidor uses the term *demoiselle* and the expression *en quinconce* in the *Architecture hydraulique*. It should be anyway pointed out that, unlike Milet de Monville, who uses pozzolana-based concrete, the German author gives up the use of *Trass*, which is considered too expensive and not necessary for foundations out of water. Common slaked lime, or mixtures made of one measure of slaked lime and three measures of sand are considered appropriate to the purpose.¹⁰¹ The unavailability of hydraulic binders in several German regions, together with the general adverse economic conditions, often urges master builders to do without cements, adapting foreign building techniques to local constraints.

Just taking the cue from the case of the rammed concrete, it is worth to observe that examples of French hydraulic works still have a role in German technical literature from the 1830s. The hydraulic engineer Otto Christian Friedrich Reinhold, for instance, mentions the 0,65 meters thick concrete bed foundation of the bridge over the Loire in Roanne, in an article about the building of stone bridges, dating back to 1831.¹⁰² And it is very probably with reference to French examples that the building counsellor from Hesse-Kassel Friedrich Fyck mentions about the possibility of building foundation by means of sunken caissons that are filled with concrete, in his book about the construction of roads and bridges that is published in 1831.¹⁰³ Much more critical is, however, Vicat’s memory about the concrete foundations of the bridge over the Dordogne, which Johann Friedrich Wilhelm Dietlein (1787–1837), who teaches *Straßen-, Brücken-, Schleusen- und Kanalbau* at the Berlin Bauakademie since 1824, translates into German and publishes in *Journal für die Baukunst* in 1832.¹⁰⁴ (figg. 2.8.3a,b,c,) The building of concrete foundations is also part of Dietlein’s lectures at the *Bauakademie*, which are published between

¹⁰⁰ See Anon., *Die Schwung-Ramme, ein Beitrag zum Grundbau*, in *Journal für die Baukunst*, vol. II, 1830, pp. 341–50.

¹⁰¹ *Ibid.*, p. 344.

¹⁰² The building of the bridge in Roanne dates back to 1789, see Otto Christian Friedrich Reinhold, *Beiträge zur Bestimmung der Höhe der Gewölbsteine und Stärke der Widerlager und Mittelpfeiler grosser massiver Brücken; durch viele Beispiele erläutert und insbesondere für Practiker gesammelt und zusammengestellt*, in *Journal für die Baukunst*, 1831, (pp. 363–407), p. 399.

¹⁰³ See Friedrich Fyck, *Die Verwaltung des Straße- und Brückenbaues mit Rücksicht auf möglichste Kosten-Ersparniß, Wohlthätigkeit für die ärmeren Volksklassen, uns Aufhebung der Frohdienste*, Cassel, Johann Christian Krieger, 1831, (pp. 57–67), p. 65.

¹⁰⁴ Louis-Joseph Vicat, *Bemerkungen beim Bau der Brücke über die Dordogne bei Souillac*, ed. Friedrich Wilhelm Dietlein, in *Journal für die Baukunst*, 1832, vol. V, pp. 73–86.

1830 and 1832, in different issues of the *Journal für die Baukunst*.¹⁰⁵ Dietlein describes concrete as “a mass made of stone-pieces and hydraulic mortar,” and he then explains that hydraulic mortar “has been composed over centuries mixing either lime and sand, or lime, sand and cement (pulverized volcanic products like pozzolana, brick powder, iron oxide, iron filings), or even just lime and cement, in quite various ratios.”¹⁰⁶ Dietlein knows John and Vicat’s books, but he seems not to be aware of Fuchs’ research about lime and mortar. This is probably the reason why he does not seize the origin of the hydraulic property as proved by the assertion: “substances that give mortar the property of hardening underwater have not yet been discovered.”¹⁰⁷ Instead, Dietlein shows having much more clear ideas about the uses of concrete. As usual at that time, he asserts that concrete is to be poured underwater inside enclosures made of piles or sheet piles, straight on foundation soils or on timber pilings. This last case is thought to be particularly appropriate for the building of locks. (fig. 2.8.4) To pour concrete underwater, Dietlein lists three kinds of tools: simple shovels, which should be used only when foundation pits are less deep than 4 or 5 feet; pipes, to use in case pits are between 5 and 10 feet deep; and suspended buckets with trap door for deeper pits. Dietlein also suggests using concrete to fill the spaces between sunken caissons in row, and he even draws the sketch of a cut-stone faced wall filled with a kind of rubble masonry filling. (fig. 2.8.5)

In the same year as Dietlein’s lectures are published, the German translation of the huge French collection of lectures given by Joseph-Mathieu Sganzin (1750–1837) at the Ecole Polytechnique in Paris is published, providing a further essential reference from the French building culture about the production of concrete and about the use of it to build foundation underwater, especially if we consider that the construction of the concrete foundation of the lock of Huningue by the French engineer Louis Alexis Beaudemoulin (1790–1875), which will play an important role for the construction of some locks in Bavaria in the second half of the 1830s, is described in a note added to the text, along with a mention of the concrete foundation that Zimmermann carries out in Hamm.¹⁰⁸ The construction of stone-faced

¹⁰⁵ Johann Friedrich Wilhelm Dietlein, *Grundzüge der Vorlesungen in der Königl. Bau-Akademie zu Berlin über Strassen-Brücken- Schleusen- Canal- Strom- Deich und Hafen-Bau*, in *Journal für die Baukunst*, 1830, vol. III, pp. 33–87, 327–58, 420–64, 1831, vol. IV, pp. 90–120, 302–41, 1832, vol. V, pp. 36–72, 155–203, 245–79, 315–85; for what concerns concrete see especially vol. III, pp. 330, 341, 344–46, vol. IV, pp. 303, 311.

¹⁰⁶ “Béton ist eine aus Steinstücken und hydraulischem oder Wassermörtel (Mörtel, der unter Wasser erhärtet) zusammengesetzte Masse. Den hydraulischen Mörtel hat man schon seit sehr langer Zeit dadurch erhalten, dass man Kalk, entweder mit Sand allein, oder mit Sand und Cement (pulverisierten vulkanischen Produkten, wie Puzzolane, oder Ziegelmehl, Hammerschlag, Esienfeilspähne), oder auch mit Cement allein vermischt, unter ziemlich verschiedenen Verhältnissen der Menge des Kalkes, Sandes und Cements” (Dietlein, *Grundzüge der Vorlesungen...cit.*, 1830, vol. III, p. 344).

¹⁰⁷ “Welche Bestandtheile eigentlich einem Wassermörtel die Eigenschaft geben, unter Wasser zu erhärten, ist noch genau ausgemittelt” (Dietlein, *Grundzüge der Vorlesungen...cit.*, 1830, vol. III, pp. 344–45).

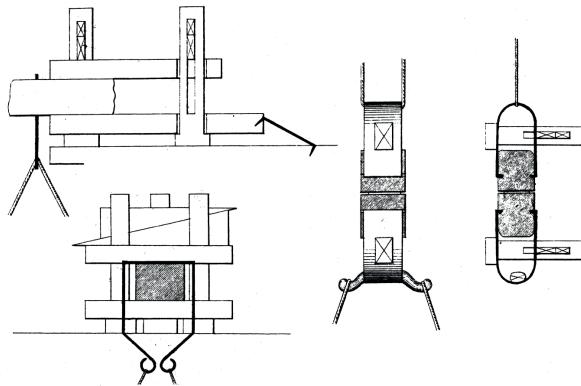
¹⁰⁸ Joseph-Mathieu Sganzin, *Lehrbuch des Straßen-, Brücken-, Kanal- und Hafen-Baukunde*, ed. [Hermann] F. Lehritter, G. H. Strauß, Regensburg, Friedrich Pustet, 1832, vol. I, (pp. 116–51), pp. 144–51, vol. II, pp. 52–56, 206–07, n. 22.

walls filled with concrete is also described with reference to the ancient Greek *emplecton* and to the Roman *opus incertum*.¹⁰⁹

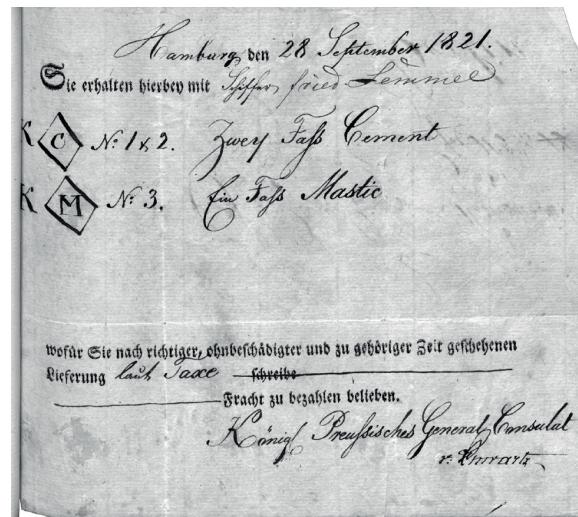
Accounts about how to produce concrete, are also given in a number of other books pertaining different domains, like the treatise *Elemente der technischen Chemie*, written by the chemist and physician Ernst Ludwig Schubarth (1797–1868) and published in 1831, the book by Moritz Ferdinand Gaetzschmann (1806–1895) about the construction of walls for underground mines, which is also published in 1831, and the treatise about artificial stones and binders by Ludwig Friedrich Wolfram, which dates back to 1833.¹¹⁰

¹⁰⁹ *Ibid.*, vol. I, pp. 160–62. About the possible use of this kind of stone-faced walls filled with concrete see also vol. II, pp. 225–227.

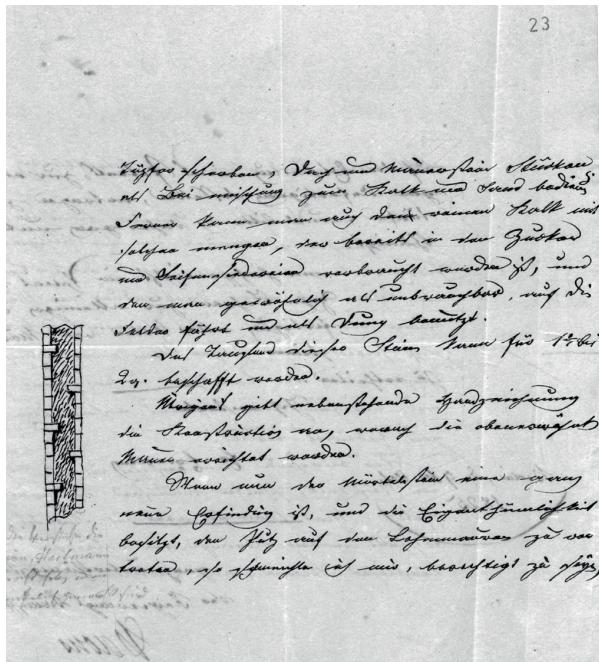
¹¹⁰ See Ernst Ludwig Schubarth, *Elemente der technische Chemie, zum Gebrauch beim Unterricht königl. Gewerbinstitut und den Provinzial-Gewerbeschulen*, vol. I, Berlin, August Rücker, 1831, pp. 402–16 (1833², pp. 392–402); Moritz Ferdinand Gaetzschmann, *Anleitung zur Grubenmauerung*, Schneeberg, Carl Schumann, 1831, pp. 20–4; Ludwig Friedrich Wolfram, *Lehre von den künstlichen Bausteinen und Verbindungsstoffen, oder Lehre von getrockneten Lehmsteinen, von der Zubereitung, vom Brennen und von der Anwendung aller Ziegeleierzeugnisse vom Brennen des Kalkes und Gipses, vom Baue der Ziegel, Kalk- und Gipsöfen, von den Mörteln aller Art, von den Kitten u. s. w., mit Rücksicht auf bedeutende Bau- und Kunstwerke der Alten und Neuern*, Stuttgart, Carl Hoffmann, Wien, Carl Gerold, 1833, pp. 53–56, 78–116.



2.2.1



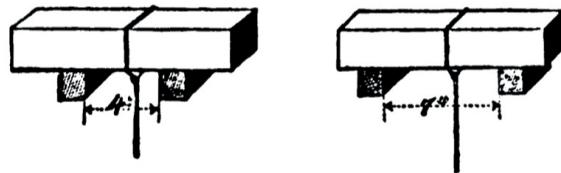
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2.4.1

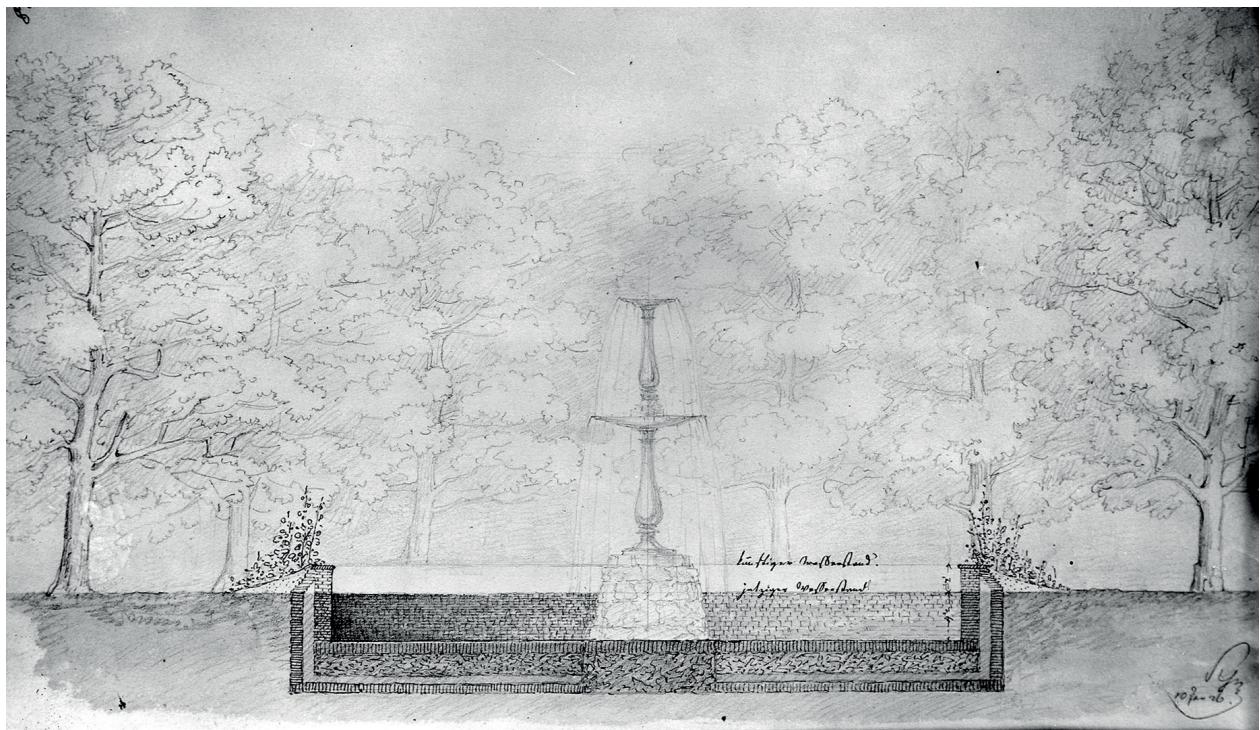
Im Anfang Kunst wurde häufig hier eingetragen und gesucht, um die Römer-Gebinde zu erkennen und später ringsum unter den Baustoffen die aufzufinden; die Stadt ist 13 Jahrhundert auf die Höhe von Ringen und von Kreisen
aufgebaut und zwischen diesen sind zahlreiche Gräber und Friedhöfe mit starken Feldmauern
gelegen. Wird alle Zugänge auf 10 Fuß erhöht, so werden die
Felder davon nicht mehr überdeckt und werden
nicht mehr gebraucht. Ein Dorf soll nicht
mit 10 Fuß einer Mauer verbunden sein, und
ein klein. Wohnung oder Wohnturm
in einem von solchen und - wird die
Kirche unter den Säulen unter dem Altar. Viele
der alten sind zerstört. Auf dem unter Teufelsberg
in Chatham ein Museum der archäologischen
Arbeiten in allen Zweigen in der Nähe. Oftmals werden
die Tiere aufgezogen, welche gegen die Feinde gekämpft
haben gegen East India und, wie einige sagen
und ringsum große Felsgänge, alle auf, alle versteckt.
Viele Höfe und den Turm ist eine Burg = heißt es
Captain Brown's Castle: gebaut. Versteckt
sind in derselben 8000 Männer und
8000 Kanonen mit 15 Mann an jedem Ende.

2.5.1

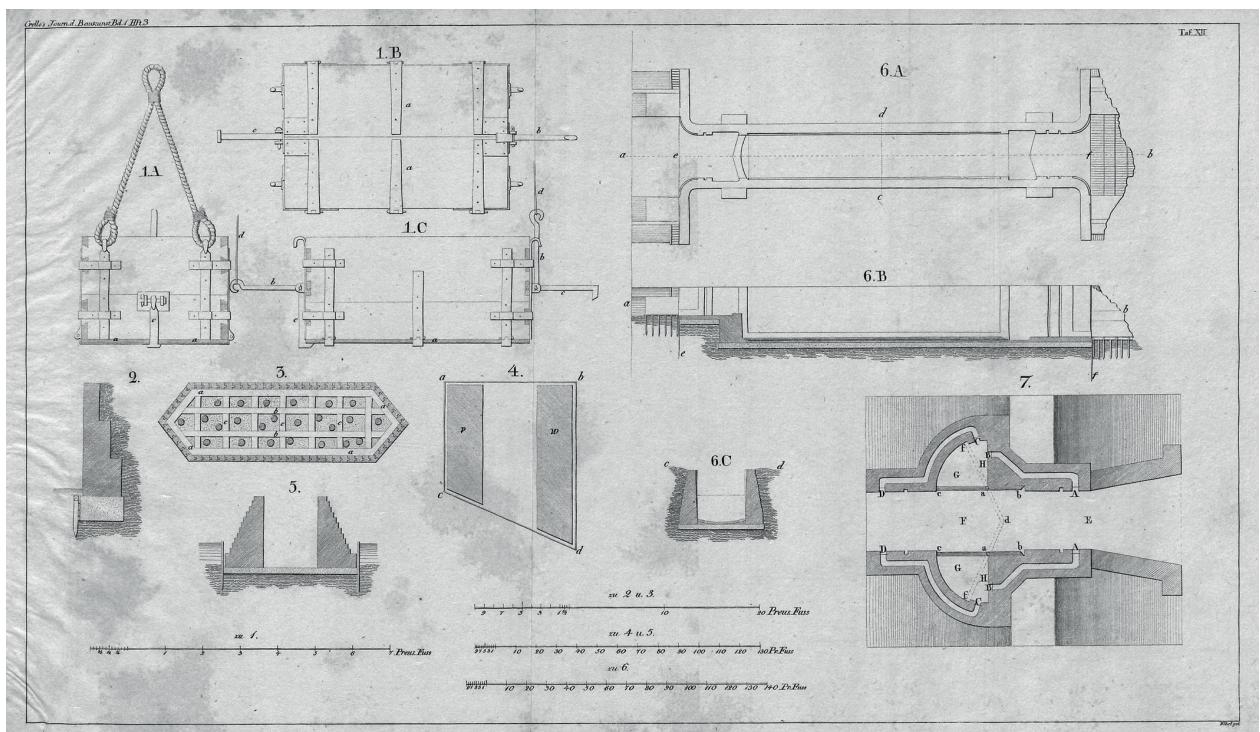


2.5.2

2.1.1. M. K. E. von Prittwitz, installations for strength tests, 1820-1822, on the left, longitudinal section and front elevation of the contraption to test the "relative strength"; on the right side elevation and cross section of the contraption to test the "absolute strength" (M. K. E. von Prittwitz, 1825). 2.3.1. Receipt for the import of two casks of Roman cement and one cask of Hamelin mastic at the port of Hamburg, 1821. 2.4.1. S. Sachs, letter to the Prussian building committee, 17 October 1825, detail, draft of an artificial stones-faced wall filled with rammed earth. 2.5.1. K. F. Schinkel, journal of the journey to France and England, sketch of the transversal section of the Thames tunnel in London, 1826. 2.5.2 Strength test of cement-based artificial stones (Anon., 1829).

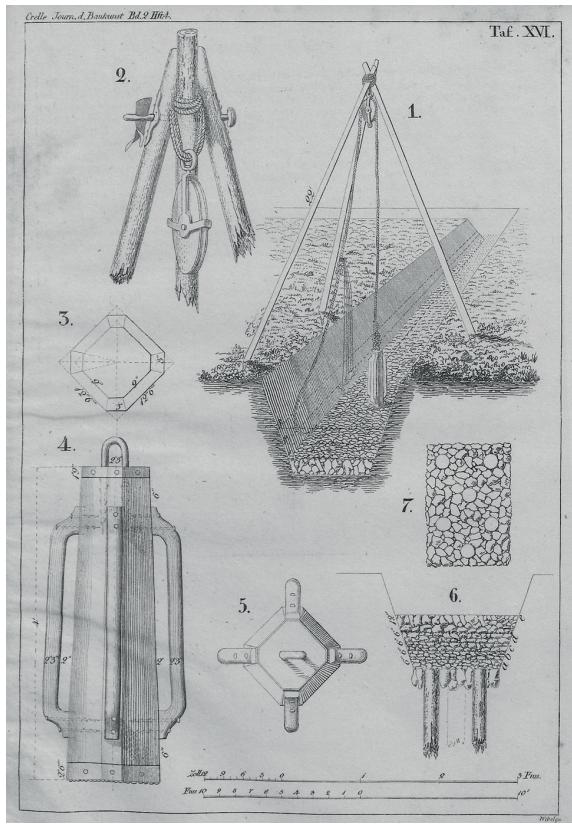


2.6.1

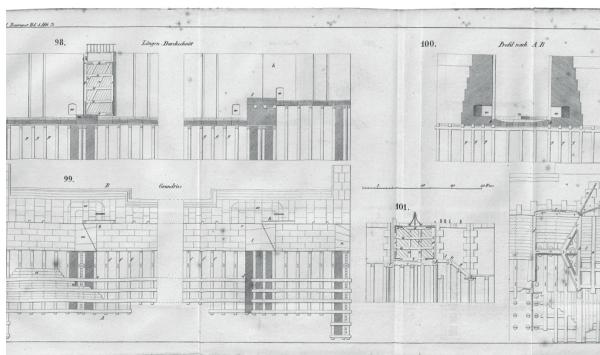
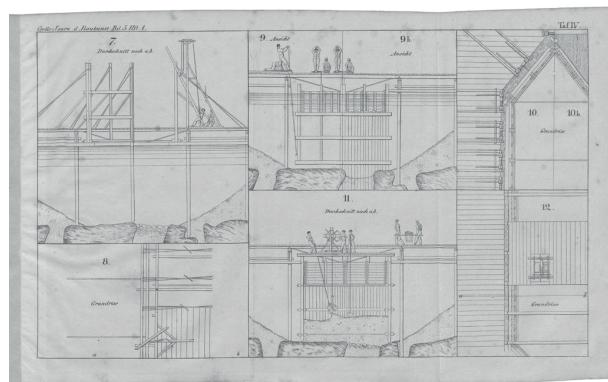
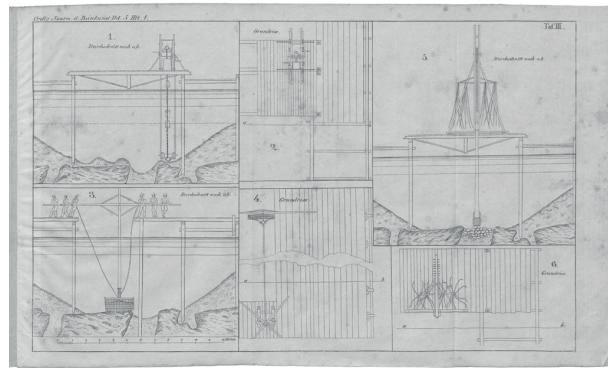


2.8.1

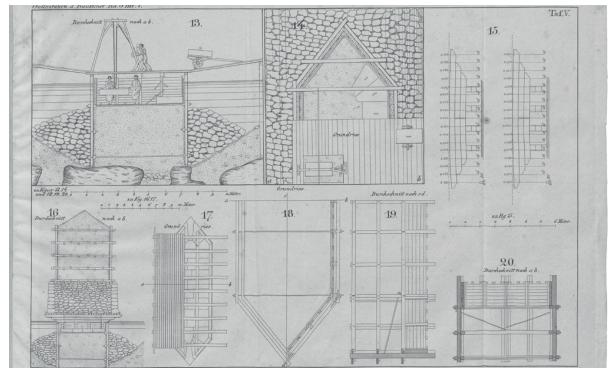
2.6.1. Fountain on the Pfaueninsel, section (A. D. Schadow, 1826). 2.8.1. Drafts of concrete foundations and relative tools, figg. 1 A-C box to pour concrete; fig. 2 embankment along the Rhine; fig. 3 bridge pillar foundation: timber framework, timber piles and concrete filling; figg. 4-6 embankments at the entrance of the port of Cologne along the Rhine; figg. 6A-C Aimable Hageau, a lock of the Grand Canal du Nord (Elsner, 1829).



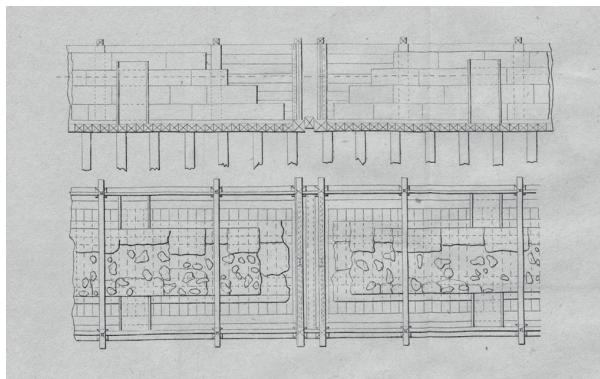
2.8.2



2.8.4



2.8.3 a,c



2.8.5

2.8.2. Foundation made of "rammed concrete", draft (Anon., 1830). 2.8.3. a-c. L.-J. Vicat, foundation of a pillar of the bridge de Souillac, 1812-1824 (ed. F. W. Dietlein, 1832). 2.8.4. Draft of timber piling foundation for a lock (F. W. Dietlein, 1831). 2.8.5. Masonry work in sinking caisson for foundations underwater (F. W. Dietlein, 1830).

3 Hydraulic lime and cement manufacturing

3.1 The Bavarian hydraulic lime, a *mineralischer Schatz*

The manufacturing of hydraulic binders flourishes in several German regions during the 1830s, following the theoretical and practical achievements occurred during the previous decade. From Friesland to Silesia, and southwards to Bavaria, it initially develops far away from the Rhine, where *Trass* is not easily available. In northeast and central regions, from the Frisian coast to Kassel, hydraulic binders are mainly produced on the initiative of private entrepreneurs imitating the manufacturing process of English Roman cement – in some cases, even using marls imported from England – and they are defined cements. In southern regions, instead, early hydraulic binders are produced as implementation of the German scientific studies about lime and mortar, and they are usually called hydraulic lime. In Bavaria, furthermore, state institutions support the development of hydraulic lime manufacturing, with the aim of making available better-quality and more affordable mortars and plasters by exploiting local marls. The research about lime and mortar that Fuchs carries out on behalf of Von Purgel is also to be seen under this light. Indeed, a clear technical difference between natural hydraulic lime and cements burnt from marls has not yet been formulated at that time. Cement is considered a very effective hydraulic lime, and English Roman cement is thought to be the best hydraulic lime available on the market of building materials. In this regard, it is worth to read the enlightening words by Carl Wilhelm Dempp, a teacher at the *Königliche Baugewerbeschule* of Munich, who, in 1838, states: “The theory of binders distinguishes common or aerial lime from the hydraulic one, which is also called cement.”¹

In the early 1830s, the main promoter of hydraulic lime production and use in Bavaria is the state civil engineer Friedrich Panzer (1794–1854), who, moving from Fuchs’ theory, engages in experimenting and promoting the production and use of hydraulic lime burnt from local marls. Based in Wurzburg since 1826, Panzer is appointed responsible for the building of a city barn in 1830. He plans to build an underground masonry silo, which is a kind of construction that needs to be realized with high-quality hydraulic mortar, in order to preserve cereals from soil moisture. In a preliminary survey of different kinds of barns and silos realized across the centuries, Panzer takes into account the studies that the French agronomist Charles Philibert de Lasteyrie (1759–1849) has carried out at the turn of the 1820s, proving the importance of using hydraulic mortar to build the masonry work of silos for cereals.² De Lasteyrie even envisages the possibility to build silos made of concrete by pouring

¹ “Die Baukunst unterscheidet in der Lehre von den Bindestoffen Beim Kalke - gewöhnlichen oder gemeinen, auch Luftkalk, und hydraulischen oder Wasserkalk, auch Zement genannt” (Carl Wilhelm Dempp, *Ueber die Benutzung des Mergelkalkes zu hydraulischem Kalk im Allgemeinen, und dessen Anwendung in Bayern insbesondere*, in *Allgemeine Bauzeitung*, III, 1838, (n° 49, pp. 442–43, n° 50, pp. 447–50, n° 51, pp. 454–57), n° 49, p. 442).

² See Charles Philibert de Lasteyrie, *Des fosses propres à la conservation des Grains, et da la manière de les construire, avec différents moyens qui peuvent être employés pour le même objet*, Paris, Imprimerie Royle, 1819; Id., *Rapport fait par M. de*

mixtures of pebbles and hydraulic mortar into pits shaped as formworks for circular walls and vaults. Some German articles about techniques for storing cereals, which are published between 1821 and 1824 in the *Polytechnisches Journal* and in the *Monatsblatt für Bauwesen und Landesverschönerung*, report about De Lasteyrie's building principles for silos.³ (fig. 3.1.1,2) The importance of using hydraulic lime is clearly highlighted, but none of these articles deals with concrete silos, and Peter Ludwig Maréchaux (1764–1832), a naturalist based in Munich, who writes a long dissertation about the topic of cereals storing, runs into a mistake asserting that De Lasteyrie proposes to pour concrete just as filling material of a stone-faced masonry works.⁴

Panzer seizes the importance of using hydraulic lime-based mortar to build a moisture proof masonry silo, and, following Fuch's example, he engages in a survey of marl deposits in the valley of the river Main, approximately between "Bamberg and Aschaffenburg", before he starts building the silo.⁵ For each kind of marl he finds, he verifies the clay content and burns two samples, one in red burning coal one hour and a quarter long, the other in strong fire four hours long.⁶ Burnt samples are ground into powder and mixed with rainwater to form two different doughs, which are then put into two glasses and covered with some other water, waiting for their hardening after 24 hours, and after 14 days. In this way, Panzer establishes that lime produced from marls quarried close to the village of Randersacker south of Wurzburg are the best ones he has found, and he consequently uses them to burn the hydraulic lime he needs to build the silo. Burnt marls are ground in a local chalk mill, since limekilns of that time are not yet equipped with mills. Mortar is prepared mixing one measure of lime, 2/3 of sand and a little amount of fat lime, and it is used to bind the bricks and to plaster the surfaces of the masonry work.

During the construction of the silo, Panzer gathers the knowledge he is developing in a short pamphlet, giving special emphasis to the usefulness of the hydraulic lime produced from Bavarian marls.

Lasteyrie, au nom du Comité d'agriculture, sur le silo ou fosses à conserver les grains, de M. de Lacroix, établi à Ivry, près Paris, in *Bulletin de la Société d'encouragement pour l'industrie nationale*, XXI, 1822, pp. 286–88; Id., Rapport fait par M. de Lasteyrie, au nom d'une Commission spéciale, sur les fosses à grains, in *Bulletin de la Société d'encouragement pour l'industrie nationale*, XXII, 1823, pp. 241–49.

³ Peter Ludwig Maréchaux, *Würdigung sämmtlicher bis jetzt bekannt gewordener Methoden, das Getreide, mehrere Jahre hindurch, ohne Nachtheil für dasselbe, aufzubewahren*, in *Polytechnisches Journal*, vol. V, 1821, (pp. 334–76), pp. 347–50; Anon., *Ueber die Silos oder Erdgruben zur Aufbewahrung des Getreides*, in *Polytechnisches Journal*, vol. IX, 1822, pp. 329–31; Anon., *Zweckmäßige Getreide-Magazine*, in *Monatsblatt für Verbesserung des Landbauwesens du für zweckmäßige Verschönerung des Bayerischen Landes*, II, 1822, pp. 9–13; Miszellen, *Ueber die Silos oder Erdgruben zur Aufbewahrung des Getreides*, in *Polytechnisches Journal*, vol. X, 1823, p. 123; Anon., *Ueber die Korngruben oder sogenannten Silos*, in *Polytechnisches Journal*, vol. XIII, 1824, pp. 255–59.

⁴ See Maréchaux, *Würdigung*...cit., p. 349.

⁵ "The building of an airtight and moisture proof masonry silos," Panzer writes in 1830, "needs the use of hydraulic lime to bind stones, fill all gaps, and plaster interior and exterior surfaces of walls" ("Ein gemauertes Silo, welches aller Feuchtigkeit und der atmosphärischen Luft unzugänglich seyn soll, erfordert die Anwendung des hydraulischen Kalkes, sowohl als Bindingmittel der Steine und zur Ausfüllung aller Zwischenräume, als auch als Ueberzug von innen und von außen," Friedrich Panzer, *Abhandlung über die Aufbewahrung des Getreides in Silo's*, Würzburg, Carl Strecker, 1830, p. 18).

⁶ At that time, the colour of flames is the clue for lime makers to understand the degree of burning (see Valentin Biston, *Manuel théorique et pratique du chaufournier*, Paris, Roret, 1828, p. 55).

The pamphlet is published in 1830 and becomes a reference text about the way to produce and use natural hydraulic lime, together with the 1829 dissertation by Fuchs.⁷ (fig. 3.1.3)

Further crucial events for the development of Bavarian hydraulic lime happen during 1831. The *Polytechnischer Verein für das Königreich Bayern* (Bavarian Polytechnic Society) promotes a competition aiming at awarding “the engineer or builder who, following Fuchs’ theory and practical instructions about marls, discovers a kind of local hydraulic lime that is suitable to prepare good-quality mortar, suitable to protect façades exposed to the elements, to make wet walls and moist houses dry, to build water containers, cereals silos and hydraulic works like sewer, basements etc.”⁸ It is worth to point out that, in a note to the announcement, “applicants are invited to take into account the interesting essay by the engineer Friedr. Panzer in Wurzburg,” proving the importance of the 1830 pamphlet by Panzer as source of knowledge about hydraulic lime.⁹ Only two competitors apply, the first one is Panzer, and the second one is Andreas Zenner, the owner of a limekiln in Munich. Nevertheless, the initiative should not be underestimated, since it is a clear sign of an arising confidence in the possibility of developing the Bavarian manufacturing of good-quality hydraulic binders, while the opposition to Fuch’s theory is decreasing. On the wake of such events, Panzer publishes a pioneering manual expressly focused on the production and use of Bavarian hydraulic lime in 1831.¹⁰ “This essay,” he writes in the preface, “aims at explaining how useful is hydraulic lime produced from marls, making people [...] more familiar with this mineral treasure that mountains shelter on both sides of the river Main, between Bamberg and the Spessart mountain range.” “Words from this book,” he still goes on, “should come to private people who build new houses or ameliorate existing ones, and to artisans who more or less work with mortar, such as masons, stonemasons, painters, roofers, plasterers, fountain builders, lime makers, etc. [...].”¹¹

⁷ Panzer, *Abhandlung über die Aufbewahrung...*cit.

⁸ “Demjenigen Ingenieur, Bau- oder Maurermeister, welcher nach Anleitung der von Hrn. Hofrath und Akademiker Dr. Fuchs in München herausgegebenen Abhandlung über den Mörtel inländischen hydraulischen Kalk aufsucht, daraus hydraulischen Mörtel bereitet und anwendet, um feuchte Wände und Wohnungen trocken, die Wetterseiten der Gebäude schützend und dauerhaft zu machen, dann Wasserbehälter, Wasserbauten überhaupt, Kloaken, Keller etc. herzustellen und trockene Silo's zur Aufbewahrung des Getreides zu erbauen: die dreifache goldene Medaille” (*Preisaufgaben des polytech. Vereins in Bayern*, in *Polytechnisches Journal*, vol. XL, 1831, (pp. 387-89), p. 388).

⁹ “Man macht di Theilnehmer auch zugleich auf die interessante Abhandlung des k. b. Ingenieurs Hrn. Friedr. Panzer in Würzburg [...] aufmerksam” (*Preisaufgaben des polytech. Vereins in Bayern...*cit., p. 388).

¹⁰ Friedrich Panzer, *Anleitung über die Bereitung des Mörtels aus hydraulischem Kalke in Beziehung auf die Auffindung des vorzüglich hierzu sich eignenden Mergels, so wie über das Verfahren, welches bei der Anwendung des hydraulischen Mörtels, sowohl bei Landgebäuden, als auch bei Bauten im Wasser zu beobachten ist*, Würzburg, (Würzburg, Becker, 1831), München, Lindauer'sche Buchhandlung, 1832.

¹¹ “Der Zweck des gegenwärtige Aufsatzes besteht darin, den Nutzen des hydraulischen Kalkes zu zeigen und das Verfahren zu erläutern, wie man sich bei der Bereitung des Mörtels mit hydraulischen Kalke mit Benutzung des Mergels zu verhalten hat; ferner das Publikum, [...], näher mit diesem mineralischer Schatz, welche die Gebirge zu beyden Seiten des Mainflusses zwischen Bamberg und dem Spessart in unerschöpflicher Masse in ihren Schoos einschließen, vertraut zu machen. Daher sollen diese Worte zunächst an Private, welche neue Gebäude aufführen, oder an den bestehenden Verbesserung vornehmen lassen, so wie an alle Handwerksleute, die mit der Anwendung des Mörtels in näherer, oder entfernterer Beziehung stehen, als Mauerer, Steinhauer, Tüncher, Dachdecker, Gypser, Brunnenmacher, Kalkbrenner u.s.w. gerichtet seyn [...]” (Panzer, *Anleitung über die Bereitung des Mörtels...*cit., p. 4).

Beyond mere technical instructions, two concepts expressed in Panzer's book are particularly relevant in view of the future manufacturing and use of hydraulic binders. The first concerns the necessity of theoretical and scientific knowledge, while the second is about the suitability of hydraulic lime both for hydraulic works, and for ordinary masonry exposed to moisture and to the elements.¹² "Hydraulic lime," Panzer asserts, "was already known in Italy, Holland, England and France; but the lack of scientific knowledge has prevented a wider and general use of it. In recent times, the development of a theory, notably in chemistry and mineralogy, has shed a light on the deficient knowledge, which was based only on practical experiences, and we should be thankful to the eminent scholars who have discovered the chemical combination that allows mortar to harden underwater. Those who want to know more about this revolutionary discovery should read the dissertation by Dr. Fuchs [...], which I used as guide."¹³ Germans scholars and building masters should actually be aware of the suitability of hydraulic lime for hydraulic and ordinary works, since John, Von Prittitz and Fuchs have already proved it. Nevertheless, in the early 1830s, the ancient belief in the superiority of aerial lime still seems to be deep-rooted, and it influences most master builders. "The expression hydraulic lime," Panzer warns, "should not mislead to think that this kind of lime is only in water effective," and, in order to support this statement, he moreover remembers that some kinds of hydraulic mortar composed with Trass or brick powder, like the Loriot mortar, have already been successfully used out of water.¹⁴

Again in 1831, besides the writing of the manual about hydraulic lime, Panzer builds a stone masonry arch bridge in the village of Schönungen, using hydraulic lime-based mortar for the masonry work, underwater and above ground. "The external parts of the masonry," he relates in this regard, "are made of sandstone ashlar, whereas the internal parts are made of unrefined stones. The foundations of the abutments supporting the vault, as well as the foundations of the abutments wings, stand entirely underwater, whereas the abutments, the vault and the wings only occasionally come into contact with water. The use of hydraulic lime has made this building particularly solid."¹⁵ Even to prepare the so-

¹² See Panzer, *Anleitung über die Bereitung des Mörtels...*cit., pp. 4–5, 23–29.

¹³ "Der hydraulische Kalk war in Italien und in Holland, später in England und in Frankreich schon längst bekannt; es stand jedoch der weiteren Verbreitung und allgemeinen Anwendung desselben der Mangel an wissenschaftlicher Begründung entgegen. In neuester Zeit mußte die Unvollkommenheit bloßer Erfahrungen dem Lichte der Theorie, nämlich der Chemie und Mineralogie weichen. Großen Gelehrten, die deßhalb unsern innigsten Dank verdienen, gebührt das Verdienst, das chemische Verhalten der Substanzen des Mörtels ermitteln zu haben, wobei die Erhartung im Wasser vor sich geht. Wer sich näher mit dieser nützlichen, im Bauwesen Epoche machenden Erfindung, bekannt machen will muß die von Herrn Dr. Fuchs [...] verfaßte Schrift lesen, welche ich als leitende Norm benutzt habe" (Panzer, *Anleitung über die Bereitung des Mörtels...*cit., pp. 3–4).

¹⁴ "Der Name des hydraulischen Kalkes darf nicht verführen, als leiste er seine Dienste los im Wasser" (Panzer, *Anleitung über die Bereitung des Mörtels...*cit., p. 5).

¹⁵ "Die äußere Bekleidung besteht aus gehauenen, großen Quadern von Sandsteinen, das Innere des Gemäuses aus unzugerichteten Bruchsteinen. Die Fundamente der Widerlager des Gewölbes, so wie der Flügel liegen ganz unter Wasser; die Widerlager und das Gewölbe selbst, die Flügel und dergl. sind dem Wasser abwechselnd ausgesetzt. Die Anwendung des hydraulischen Kalkes hat diesem Bauwerke eine große Festigkeit verschafft" (Friedrich Panzer, *An die Redaktion des Kunst- und Gewerbe-Blattes, in Kunst- und Gewerbe-Blatt des polytechnischen Vereins für das Königreich Bayern*, vol. X, 1832, (coll. 111–44), col. 111, n. 1).

called *Reissboden* (drawing floor) – a flat and open-air place where all bridge stones are designed at real scale –, Panzer builds a 30 square feet floor made of bricks bond with hydraulic-based mortar, and covered with a 2 inches thick layer of the same kind of mortar. He probably conceives this kind of construction on the base of an ancient Italian building technique, which he has learnt from the architect Johann Gottfried Gutensohn (1792–1851), and he has described in the 1831 book about hydraulic.¹⁶ Six month after that the bridge has been accomplished and the drawing floor has been abandoned, Panzer is pleased to verify that the hydraulic mortar layer is still in good conditions.

Encouraged by Panzer, several builders and masons experiment with hydraulic lime-based mortar between the summer of 1831 and the winter of 1832, to build or restore masonry works of different sizes. Panzer collects reports about these experimental works, and publishes them in the *Kunst- und Gewerbe-Blatt des polytechnischen Vereins für das Königreich Bayern* in 1832.¹⁷

About two years after the publication of Fuchs' theory, the reputation of the Bavarian hydraulic lime has so much increased that it is even compared with English Roman cement. “Until now,” it is stated in an article published on the *Polytechnisches Journal* in 1831, “people have considered hydraulic lime a rare natural product, and they have even believed that a good-quality lime was only in England available. Instead, plenty of good hydraulic lime is also to be found in Bavaria, but we could not recognize it due to the lack of scientific knowledge, and we have used expensive pozzolana from Rome, bitumen from Lobsan and Trass from Andernach or from other places, leaving hydraulic lime unexploited.”¹⁸ It comes therefore as no surprise that, in 1832, it is considered scandalous that, shortly after the publication of Fuch's dissertation, a civil servant was sent “to learn the art of producing hydraulic lime in England, where there was not a grain of theory, hydraulic lime was produced only from one kind of raw material, following a quite empirical method, and nobody was therefore able to provide any explanation based on general principles, making impossible the production of hydraulic

¹⁶ See Panzer, *Anleitung über die Bereitung des Mörtels...*cit., p. 27. Panzer himself mentions Gutensohn as source (see *ibid.*, p. 24). Between 1819 and 1823, Gutensohn spends a long stay in Rom, where he uses to draw the monuments he observes (see Johann Gottfried Gutensohn, *Denkmale der christlichen Religion oder Sammlung der ältesten christlichen Kirchen Roms vom 4ten bis zum 13ten Jahrhundert*, Roma, Johann Michael Knapp, vol. I, 1821, voll. II-III, 1824; Id. *Sammlung von Denkmalen und Verzierungen der Baukunst in Rom vom 16ten Jahrhundert*, Roma, Romanis, voll. I-III, 1826). An increasing use of hydraulic lime to build floors, in some case even imitating natural stones, develops in the following decades.

¹⁷ A bridge is built in Veithhöchheim and a lock is built in Dühlstadt, while restoration works are carried out at an existing lock in Schweinfurt and at a channel near the Julius hospital in Wurzburg. Besides these major works, several masons tests hydraulic lime to plaster walls in private houses. See Panzer, *An die Redaktion des Kunst- und Gewerbe-Blattes...*cit.

¹⁸ “Der hydraulische Kalk, den man sich bis jetzt nur als ein seltnes Naturproduct dachte, der z. B. nur in England von der erforderlichen Güte gefunden würde, der aber nun in ganz Bayern, von jeder Qualität und im Ueberflusse vorhanden ist, den wir aber bisher, aus Mangel einer gründlichen Theorie, nicht kannten und unberührt ließen, während man Puzzolane von Rom, Traß von Andernach und anderen Orten, Lobsaner Erdpeckitt u. mit großen Kosten statt des einfachen hydraulischen Mörtels verwendete” (Anon., *Ueber Aufbewahrung des Getreides in Silo's und die Benutzung des hydraulischen Mörtels zur Erbauung derselben*, in *Polytechnisches Journal*, vol. XXXIX, 1831, (pp. 427-33), p. 428).

lime under different conditions.”¹⁹ The man who is told having been sent to England is probably Christoph Maria Joseph Schmitz (1796–1866), inspector at the porcelain factory of Nymphenburg, and member of several technical committees in Bavaria.²⁰ According to Dempp, Schmitz goes on a study journey to England at the turn of 1831, exactly on the purpose to learn about cement. Back to Munich, he is told having undertaken successful experiments, which later act as references for the foundation of several cement kilns around Munich.²¹ Nevertheless, Fuchs and Panzer’s contribution to the development of Bavarian hydraulic lime remain undeniably prevalent, and even officially recognized in 1832, as the Bavarian *Polytechnischer Verein* awards Panzer for the competition launched in 1831, and the Dutch Society of Science awards Fuchs for the competition dating back to 1830. On the wake of this acknowledgement, the Bavarian *Polytechnischer Verein* also awards Fuchs a special double gold medal, for having contributed to the scientific development of the country.²²

In April 1832, Panzer is moved from Würzburg to Bamberg, where he has the occasion to study the so-called *schwarzer Kalk* (black lime), a local lean lime, which is burnt from marls quarried in villages close to Bamberg, and is known since centuries for being particular solid and durable.²³ Panzer observes mortar joints containing black lime in several important buildings in Bamberg, like the cathedral, the gate of the Carmelite monastery, and the city walls, and he realizes that mortar joints are sometimes better preserved than sandstone. Still according to Panzer, black lime-based mortar has been used to plaster the façades of the town hall building, which Johann Anwander (1715–1770) paints with frescos in 1755, and to bind the bricks and the tiles of several humble buildings in Bamberg and in the surroundings. (fig. 3.1.4) Panzer himself verifies how solid are brick-masonry walls assembled with black lime-based mortar when he has to demolish the ones of an old stable; walls prove to be so solid that

¹⁹ “[...] Jemand auf Kosten des Staats nach England geschickt wurde, um dort die Kenntniß, hydraulischen Kalk zu breiten, sich zu erwerben – dort, wo man damals hierüber noch kaum den Schatten von einer Theorie hatte, und nur mit einem gewissen Materiale auf ganz empirischem Wege hydraulischen Kalk darzustellen mußte, und daher gar nicht im Stande war, eine, auf allgemeine Grundzüge sich stützende Anleitung zu geben, ihn unter verschiedenen Umständen zu bereiten, wie sie hier schon hatten” (Anon., *Würdigung der Arbeit des Professors und Akademikers Fuchs...*cit., col. 759).

²⁰ About Christoph Maria Joseph Schmidt, see Anon., *Nekrolog. Christoph Schmitz*, in *Kunst- und Gewerbe-Blatt des polytechnischen Vereins für das Königreich Bayern*, vol. XLIV, 1866, coll. 442–48, esp. coll. 445–46 for what concerns Schmitz’s contribution to the industrial development of Bavaria between 1829 and 1836, when he is inspector at the Nymphenburg porcelain factory.

²¹ See Carl Wilhelm Dempp, *Ueber die Benutzung des Mergelkalkes...*cit., p. 443. Dempp mentions the cement kilns belonging to the following cement producer: Gasteiger, Rechel, Schmidt and Höß, Stießberger und Zenner, this last one probably being the same Zenner who applies for the competition promoted in 1831 by the Bavarian *Polytechnischer Verein*.

²² *Preisvertheilung des polytechnischen Vereins*, in *Kunst- und Gewerbe-Blatt des polytechnischen Vereins für das Königreich Bayern*, XVIII, 1832, (coll. 643–49), col. 649.

²³ The villages mentioned by Panzer are Tütschengereuth, Triesenbach, Oberhaid, Burgebrach, see Friedrich Panzer, *Ueber das Vorkommen des hydraulischen Kalkes in der Keuperformation, über die Dauerhaftigkeit absolute und rückwirkende Festigkeit desselben und der Steine, als Beitrag zu dem Bau des Kanals zur Verbindung der Donau mit dem Main*, München, Lindauer’sche Buchhandlung, 1836, p. 3.

Panzer let them break into big blocks, which he then uses as artificial stones to build the walls of a new stable.²⁴

Panzer analyses the chemical composition of the Bamberg black lime and discovers that it contains clay, which he considers the origin of solidity, according to Fuchs' theory. "The solidity of this lean lime," he asserts, "is due to chemical features, it namely contains between 5 and 14 pour cent clay."²⁵ With the aim of developing a local manufacturing of hydraulic lime, Panzer asks the royal home office for the construction of a mill, which he himself then designs. It is a typical animal-powered machine, with an inclined wheel that horses or oxen move, putting in motion the millstones through a machine made of shafts and cogwheels (fig. 3.1.5). The mill is built up in the workshop of the *Königliche Bauinspektion* (public office for building), and it is furthermore provided with a stamp mill to crush burnt marls before they come into the grind mill. According to Panzer's initial plan, burnt marls should have been crushed by hands, as it often happens for the production of brick powder, but this operation is later considered less advantageous that the building of a mechanical stamp mill connected to the grind mill, in a way that both machines are powered by the same animals. On a request from Panzer, the mill is entrusted to Karl Zelger, probably an independent architect from Bamberg, with the aim of involving private people into the business, and better spreading the awareness of the advantages that the hydraulic lime provides.²⁶ This seems to be quite unusual at that time. "Being a civil servant," Panzer observes in this regard, "I was not allowed neither to sell hydraulic lime to private citizens, nor to distribute it to communities, but this was necessary in order to let know about this material".²⁷ The mill is at first only occasionally used, and it is powered by daily workers instead of animals, since wages of occasional workers are considered more affordable than the regular feeding of animals.²⁸ (fig. 3.1.6) Once ground, lime is packaged in barrels for salt previously washed, in the lack of containers expressly conceived for lime, and it is delivered together with instructions for use.²⁹

In 1833, hydraulic lime from Zelger's mill is used for the restoration works of the Bamberg cathedral, in which Panzer is personally involved. Together with the architect Carl Alexander von Heideloff (1789–1865), who has been appointed responsible of the restoration in 1831, he develops a plan to recover the exterior parts of the cathedral, with special regard for the western towers, which are

²⁴ See Panzer, *Ueber das Vorkommen...cit.*, pp. 3–5.

²⁵ "Die Festigkeit diese mageren Kalkes ist lediglich seinen chemischen Eigenschaften zuzuschreiben; es befindet sich nämlich in demselben eine Quantität Thon, welche zwischen 5 und 14 Prozent variiert [...]" (Panzer, *Ueber das Vorkommen...cit.*, p. 5).

²⁶ A civil architect from Bamberg named Zelger is listed among the participants at the Second Meeting of German Architect and Engineers, which takes place in Bamberg from 8th to 10th September 1843 (see *Zeitschrift für praktische Baukunst*, III, 1843, pp. 228–29).

²⁷ "Meine Stellung als Königlicher Baubeamter ließ nicht zu den Absatz des hydraulischen Kalkes an Private, oder Gemeinden zu besorgen, und doch war dieses nothwendig, um dieses nützliche Material mehr bekannt zu machen" (Panzer, *Ueber das Vorkommen...cit.*, p. 7).

²⁸ *Ibid.*, p. 23.

²⁹ See Karl Zelger, *Hydraulischer Kalk*, in *Korrespondenten von und für Deutschland*, 1834, n° 52; in *Königlich Bayerisches Intelligenzblatt für den Ober-Main-Kreis*, 1834, n° 27, p. 257; and in *Tagblatt der Stadt Bamberg*, 1835, n° 117, p. 468.

seriously damaged.³⁰ The plan is achieved in April 1833 and works start in the summer of the same year. Panzer is the only supervisor from August to December, while Von Heideloff is engaged in some other restoration works in Nuremberg. He uses hydraulic lime-based mortar to repair and, in some cases, even to rebuild several architectural elements of the towers façades, notably bases and capitals of columns, and cornices of windows. “The cathedral western towers,” he later relates, “which are about 700 years old, are built with a kind of keuper sandstones that is little cohesive; columns were so weathered that they were on the point of collapse; the bases, the capitals, and all other ledges were ruined to the point of being unrecognisable, as if they were eroded stones. All damaged ornaments, ledges etc. were remade at affordable cost, and this western part of the cathedral is now put on safety for centuries.”³¹

Between February 1834 and April 1835, a short advertisement written by Zelger to promote hydraulic lime from the Bamberg mill is published at least in three different local newspapers. Zelger lists several kinds of works for which hydraulic lime is considered appropriate. “One can build,” he writes, “dry houses, watertight basins, imperishable canal systems made of clay pipes laid in mortar, durable exhaust channels, watertight and dry basements, watertight and snow-resistant roofs made of tiles and hydraulic lime-based mortar, durable plaster on façades exposed to the elements, dry floor in breweries, distilleries and son on”.³² Furthermore, he also asserts that hydraulic lime is appropriate “to produce relief decorations in plaster and ornaments that, as proved by solid experience, perfectly withstand the elements.”³³ These words are probably related to the restoration works carried out at the Bamberg cathedral in 1833, and prove that a certain interest in the production of architectural elements and decorations made of mortar-based artificial stone is growing in Bavaria.

As a matter of fact, some objects made of hydraulic mortar, along with some others made of brick bond and plastered with hydraulic mortar, are exhibited at the *Industrieausstellung* (industrial exhibition) that is held in Munich in 1834. “It is with intense joy that we observe,” it is stated in an official exhibition report, “several products made of hydraulic lime. They arise great expectations and deserve encouragement by the State and by public. The iron trader J. G. Schmidt from Munich exhibits

³⁰ See Achim Hubel, *Die beiden Restaurierungen des Bamberger Domes. Zur Geschichte der Denkmalpflege im frühen 19. Jahrhundert*, in *Berichte des Historischen Vereins Bamberg*, vol. CXXI, 1985, (pp. 45–90), pp. 78–81.

³¹ “Die westlichen Thürme des Domes, welche nahe an 700 Jahren alt seyn mögen, sind aus Keupersandsteine von geringer Kohärenz erbaut; die Säulen waren so sehr verwittert, daß sie den Einsturz drohten, und ihre Basen und Kapitale, so wie die übrigen Gesimse bis zur Unkenntlichkeit vom Steinfraße zerstört. Mit verhältnismäßig wenig Kosten wurden alle beschädigten Ornamenten, Gesimsglieder, u. s. w. wieder hergestellt, so, daß dieser gegen Westen gekehrte Theil des Domes auf Jahrhunderte hinaus gesichert ist” (Panzer, *Ueber das Vorkommen...*cit., p. 6).

³² “Man baut hiermit trockene Häuser, wasserdichte Bassins, unvergängliche Wasserleitungen, wobei thönerne Röhren in hydraulischen Mörtel gelegt werden, dauerhafte Abzugskanäle, trockne, wasserdichte Keller, haltbare, von Regen und Schnee undurchdringliche Dächer, wenn nur die Ziegel gehörig damit eingespeißt werden fertig dauerhaften Bewurf an den Wetterseiten, trockne Böden in Brühäusern, Brantweinbrennereien, Färbereien u.s.w.” (Zelger, *Hydraulischer Kalk...*cit.).

³³ “Selbst plastische Verzierungen lassen sich in dem Bewurfe der Gebäude mit hydraulischem Kalke herstellen und eine feststehende Erfahrung hat bewiesen, daß solche Ornamente dem Einflusse der Witterung vollkommen widerstehen” (Zelger, *Hydraulischer Kalk...*cit.).

cement powder and several object made of cement, among which a water container is especially interesting. G. Reihl from Munich has produced four grindstones made of hydraulic lime and quartz-sand, which probably still permits improvements. Finally, Mr. J. Karlinger from Miesbach has sent several busts made of hydraulic lime.”³⁴ Even on this occasion, Fuchs is praised for the scientific contribution that has made possible a proper exploitation of hydraulic lime and mortar. “We should one more time thank the eminent court counsellor and academic Dr. Fuchs,” it is still asserted in the same report, “for the scientific basis of knowledge about hydraulic lime, and, even more, for the development of it in our homeland”.³⁵ The artificial stone objects exhibited in Munich in 1834 seem an anticipation of the huge variety of objects of the same kind that will be exhibited at several industrial expositions in the second half of the 19th century.

While the described events develop, between 1832 and 1834, Panzer collects different kinds of marls around Bamberg, which he first analyses and then burns into lime to produce hydraulic mortar specimens, in view of compression and tensile strength tests he intends to undertake. He prepares different cylindrical specimens that he lets harden underwater until January 1835, when the tests take place. An original contraption is set up to conduct the tensile strength tests (fig. 3.1.7). It consists of two symmetric parts, each one made of two curved stirrups joined through two metallic plates with a half-circular cut on one side. The whole is done so that, when the two symmetric parts are brought near to each other, the metallic plates form an empty circle, in which it is possible to fix a cylindrical specimen provided with a groove in the middle of the curved surface. A couple of stirrups hang from a hook, while the other holds an increasing suspended load, until the specimen cracks. The installation for the compression strength test recalls the one conceived by Gauthey to test the stones that Soufflot intended to use for the pillars of dome of the church of Saint-Geneviève in Paris.³⁶ It consists of a lever inserted into a wall, which holds a hanging weight, and compresses a specimen put on a pole, which stands close

³⁴ “Mit inniger Freude erblikten wir bei der Ausstellung von 4 Ausstellern mehrere Fabrikate aus hydraulischem Kalke, die noch zu großen Erwartungen berechtigen, und jede mögliche Aufmunterung vom Staat und Publicum verdienen. Eisenhändler J. G. Schmidt von München stellte nicht bloß Cementpulver aus, sondern auch mehrere Fabrikate aus solchem, worunter sich namentlich ein Wasserbehälter sehr vorteilhaft auszeichnete. G. Reihl in München hatte 4 Schleifsteine aus hydraulischem Kalke und Quarzsand verfertigt, die vielleicht noch einstige Vervollkommenung zulassen. Hr. J. Karlinger in Miesbach endlich sandte mehrere Büsten aus hydraulischem Kalke verfertigt” (Anon., *Die im November 1834 zu München gehaltene Industrieausstellung*, in *Polytechnisches Journal*, LIV, 1834 (pp. 393–427) p. 410). Joseph Karlinger has a several kilns in Miesbach and burns hydraulic lime using coal that he quarries in a site close to his plants; he will later develop and patent a method to produce pipes made of poured hydraulic lime-based mortar (see Anon., *Beyträge zur Geschichte des Bergbaues auf Braunkohle im Königreich Bayern*, in *Kunst- und Gewerbeblatt des Polytechnischen Vereins für das Königreich Bayern*, vol. XXVI, 1840, (coll. 236–68), coll. 263–64; Anon., *Vaterländische Notizen und Briefe*, in *Bayerische National-Zeitung*, 1838, n° 192, p. 780).

³⁵ “Dank sey hier herzlich wiederholt unserem hochverdienten Hofrathe und Akademiker Dr. Fuchs, dem wir die wissenschaftliche Begründung der Lehre vom hydraulischen Kalke verdanken, und der sich auch um die immer weiter greifende Anwendung desselben in unserem Vaterlande so hochverdient gemacht” (Anon., *Die im November 1834 zu München gehaltene Industrieausstellung*, in *Polytechnisches Journal*, LIV, 1834, (pp. 393–427), pp. 410–11).

³⁶ See Émiland-Marie Gauthey, *Traité de la Constructions des Ponts*, ed. Louis Marie Henry Navier, vol. I, Paris, Firmin Didot Frères, 1832, p. 199, pl. XIII.

to the wall. (fig. 3.1.7) To evaluate the real compression strength of the specimens, Panzer develops a calculation that takes into account the weight of the lever and a sort of multiplier effect due to the distance between the specimens and the hanging weight.³⁷ Using the two described installations, Panzer also tests some local natural stones, bricks, and between 800 and 350 years old mortar samples taken from the Bamberg cathedral, from the Carmelite Church and from the Church of Saint Elizabeth. Once the tests are achieved, Panzer concludes that burnt bricks and hydraulic lime-based mortar form the best combination of building materials to realize solid masonries, which are even better resistant than some kinds of natural stones commonly used in Bamberg.

Around about 1835, Bavarian hydraulic lime appears among the teaching topics at the *Landwirtschaft- und GewerbeSchule* in Aschaffenburg. The dean of the school, the naturalist Martin Balduin Kittel (1798–1885), writes and publishes in 1836 a pamphlet in which, with reference to Fuchs and Panzer, he traces all essential knowledge of that time about hydraulic lime, and, furthermore he describes Panzer as “the first one in Bavaria who really seizes and develops this discovery in the domain of his activity,” and whose “commitment made possible it to establish natural cement plants in Würzburg, Schweinfurt and Bamberg.”³⁸

3.2 Cement manufacturing in Northwest and central Germany, from Hamburg to Kassel

Around about 1829, two Hamburg entrepreneurs, Shipmann and Hester, start on cement manufacturing in a plant situated near the port. They import marls from England, which are burnt in a common limekiln and ground in a mill.³⁹ The hydraulic engineer Reinhard Woltmann (1757–1837), who is at that time responsible for the hydraulic engineering works in Hamburg, writes a very positive report about Shipmann and Hester’s cement in 1831. “In hydraulic engineering,” Woltmann asserts, “Hamburg cement has the same good properties as the best English Roman cement, and both cements are better than *Trass* or *Tarras*, since mortar prepared using these cements and as little water as possible remains cohesive underwater, gains hardness over days and weeks, and becomes solid like a stone, making it almost impossible to scrape it with a knife. This kind of mortar hardens in few hours and can be used inside and outside buildings, in moist and in dry places. Instead, *Trass*-based mortar falls apart if it is poured into water immediately after having been prepared, and it is not effective if it is used in

³⁷ See Panzer *Ueber das Vorkommen...*cit., pp. 24–38.

³⁸ “Er war der Erste in Bayern, welcher die Entdeckung richtig aufgriff und im Bereiche seines Wirkungskreises mit Erfolg in das Leben führte. Auf seine Bemühung entstanden in Würzburg, Schweinfurt und Bamberg Niederlagen von hergerichtetem natürlichem Cämente, welcher nichts zu wünschen übrig lässt” (Martin Balduin Kittel, *Der hydraulische oder Cäment-Kalk aus der Umgegend Aschaffenburgs und dessen Benutzung*, Aschaffenburg, M. I Wailandt's Wittib und Sohn, 1836, p. 3).

³⁹ See Reinhold, *Sammlung practischer Erfahrungen...*cit., pp. 94–96; J. Cohn, *Ueber die Wichtigkeit der Cemente: in Beziehung auf gesunde Wohnungen, dauerhafte Wasser- und Prachtbauten, Kunststein, Anlegung von Silo's, so wie auf Fabrik-Industrie; nebst Vorschlägen zur Gründung fester Steinufer als Bedämmung gegen Stromgefahr, so wie zur Nachforschung auf inländische Puzzolane oder Trass*, Breslau, Druck der Stadt- und Universitäts-Buchdruckerei von Grass, Barth & Comp., 1855, p. 10.

dry places; it hardens like a stone only in moist places, in foundations, in basements, and in retaining walls.”⁴⁰ Woltmann also suggests using cement-based mortar to build “concrete walls, made of every kind of rubbles.” This is a quite pioneering idea at that time, as concrete is only little used in foundations, and it is essentially prepared with *Trafß*.⁴¹

In the early 1830s, further cement kilns are founded in the Frisian villages of Carolinensiel and Emden, in Hamelin south of Hannover, in Barbis near the Harz Mountains, in Lerbeck near Minden, and in Kassel.⁴² Owner of the cement kiln in Emden is [Burchard Wilhelm] Rodewyk, who defines the cement he produces as “Römischer Cement”, since, he explains, “it is in every respect similar to the product that is fabricated in England.”⁴³ Rodewyk also highlights the relation between hydraulic lime and cement. “Cement has the same properties,” he writes, “as an excellent-quality hydraulic lime, that is to say a kind of lime that becomes like a mush once mixed with water and, in some cases, even with some sand, hardens underwater and above ground, becomes like a good sandstone, and gains hardness over time [...].”⁴⁴ Rodewyk, as usual, suggests using cement to compose hydraulic mortar for masonry works exposed to water or moisture, and to produce mortar-based artificial stones. “Cement mixed with sand and water,” he explains, “can be used to fabricate objects of whatever form, instead of using cut stones.”⁴⁵

The cement manufacturing in Kassel starts on the initiative of Ernst Friedrich Martin Koch (1786–1860), a gunpowder producer, who undertakes the production of building materials after the end

⁴⁰ “Dieser Hamburgische Cement hat zum Wasserbau gleich gute Qualität mit dem besten Englischen Patent-Cement, und beide übertreffen den Trass oder Tarras darin, dass sie, zum Mörtel mit so wenig Wasser als möglich zubereitet und unverzüglich ins Wasser geworfen, ihre Cohärenz behalten, selbige schnell zunehmend vermehren und in einigen Tagen und Wochen dergestalt versteinern, dass man mit dem Messer kaum noch etwas davon abschaben kann ; auch ist dieser Mörtel überall, an feuchten und trocknen Orten, unter und über der Erde, im Innern wie im Aeußern der Gebäude, vortrefflich, und erhärtet in einigen Stunden; der Trass-Mörtel hingegen, frisch ins Wasser geworfen, fällt auseinander, ist auch in freier Luft nicht dauerhaft; nur an feuchten Orten, in Fundamenten und Kellern, Futter- und Vorsetzmauern u .s. w. erhärtet er allmälig zu Stein” (Reinhard Woltmann, *Nachricht über den Cement aus der Fabrik der hiesigen Bürger Schipmann et Hester*, in Reinhold, *Sammlung practischer Erfahrungen*...cit., p. 94).

⁴¹ “Béton-Gemäuer von allerlei Steinbrocken” (Woltmann, *Nachricht über den Cement*...cit., p. 94).

⁴² See Reinhold, *Sammlung practischer Erfahrungen*...cit., p. 89. Owner of the factory in Barbis is a certain Mr. Wode, while the factory in Carolinensyhl belongs to a certain Mr. Timmen (see Fr. von Reden, *Bericht über die von dem Gewerbe-Vereine für das Königreich Hannover in den Monaten Mai und Juni 1835 veranstaltete erste Ausstellung*...cit., col. 529; Karin Kraus, *Hydraulische Bindemittel im 19. Jahrhundert auf dem Gebiet der heutigen Bundesländer Hessen, Rheinland-Pfalz, Saarland und Thüringen*, in IFS-Berichte, *Institut für Steinkonservierung e. V.*, 2012 n° 43).

⁴³ “Derselbe wird deshalb Römischer Cement genannt, weil er in jeder Beziehung demjenigen Fabricate gleich kommt, welches in England bereitet und in den Handel gebraucht wird” ([Burchard Wilhelm] Rodewyk, *Ueber die Anwendbarkeit und die Art des Gebrauches des sogenannten Römischen Cementes*, in Reinhold, *Sammlung practischer Erfahrungen*...cit., (pp. 90-93), p. 90).

⁴⁴ “Die Eigenschaften des Cements sind die eines hydraulischen Kalks der trefflichsten Art, das heisst, eines Kalks, welcher, mit Wasser zu einem dicken Brei angerührt, sowohl ohne als auch mit Sandzusatz unter Wasser nicht weniger schnell wie an der Luft, zu einer steinartigen Masse erstarrt, sehr bald die Härte eines guten Sandsteins gewinnt, älter werdend fortwährend an Härte zunimmt [...]” (Rodewyk, *Ueber die Anwendbarkeit*...cit., p. 90).

⁴⁵ “Endlich kann man aus dem Cements, mit Sand und Wasser gemengt, steinartige Körper von jeder beliebigen Form bilden, welche die Stelle von behauenen Steinen vertreten” (Rodewyk, *Ueber die Anwendbarkeit*...cit., p. 91).

of the Napoleonic wars, in view of increasing post war building activities.⁴⁶ Around 1817, Koch builds up a stamp mill to crush and grind chalk, which he hopes to sell for the restoration works of the Kassel city castle, the so-called Kattenburg, which a fire had damaged during the period of the French occupation. Nevertheless, the restoration works of the Kattenburg are stopped in 1821, following the death of the prince Wilhelm I who had promoted them, and Koch undertakes other manufacturing activities. In 1823, he rents a mill for fertilizers and, shortly after, he joins the *Ziegel- und Braunkohlwerk Mönchenberg*, a company that exploits local coalmines and, at the same time, burns bricks from local lime deposits. Owner of the company are the brothers Johann Werner (1782–1850) and Carl Anton Henschel (1780–1861), who, together with their own father Georg Christian Carl (1759–1835), also own the local foundry, and Carl Anton, in particular, will later play an important role for the spread of cement use in Kassel.⁴⁷ Around 1825, the mining counsellor Adolph Schwarzenberg (1799–1864) discovers deposits of marls in Mönchenberg, close to the clay deposits that are exploited for the brickyard. He announces this discovery in *Landwirtschaftliche Zeitung für Kurhessen* in 1825, but Mönchenberg marls remain unexploited until the fall of 1832, when Koch decides to move from chalk to cement production, after having received a positive assessment by Carl Anton Henschel and by Johan Conrad Bromheis (1788–1855), who is the head of the “*kurhessische Bauverwaltung*” (Hessian Building Office).⁴⁸ In 1833, Koch writes an explanatory leaflet about cement, and sends a copy of it to all Hessian Building Offices.

Almost contemporary with the beginning of Koch's cement production is the foundation of the cement plant in Hamelin, on the initiative of the engineer Georg Dietrich Wendelstadt (1790–1860) and the banker Adolph Meyer (1807–1866). The plant is built on the western side of the river Weser, and it initially consists of a single burning chamber kiln, and a steam-powered mill.⁴⁹ The production starts in 1833, following the release of a ten years exclusive license on the part of the king Wilhelm IV.⁵⁰

⁴⁶ Albrecht Hoffmann, *Ernst Koch (1786–1860). Ein Pionier der hessischen Zementindustrie*, in *Jahrbuch 2010 Landkreis Kassel*, Kassel, 2010, pp. 69–74. About Ernst Koch see also Harm-Hinrich Brandt, *Die Industrie- und Handelskammer Kassel und ihre Vorläufer, 1763–1963*, Kassel, Industrie- und Handelskammer Kassel, 1963, pp. 78–79.

⁴⁷ Johann Werner Henschel (1782–1850) founds the *Ziegel- und Braunkohlwerk Mönchenberg* around 1820, and his brother Carl Anton joins the company in 1827 (see Sigfried Lotze, *Beiträge zu einer Geschichte hessischer Unternehmer im frühen 19. Jahrhundert. Die Familienbeziehungen niederhessischer Textil- und Farbenfabrikanten*, in *Zeitschrift des Vereins für hessische Geschichte und Landkunde*, vol. XCVI, 1991, (pp. 233–54), p. 235 and p. 249, n. 12). About Carl Anton Henschel see also Conrad Matschoß, *Grosse Ingenieure. Lebensbeschreibungen aus der Geschichte der Technik*, München, J. F. Lehmanns, 1954, pp. 161–73; Brandt, *Die Industrie- und Handelskammer Kassel*...cit., pp. 75–77; Kurt Ewald, *Henschel, Carl Anton*, in *Neue Deutsche Biographie*, vol. VIII, Berlin, Hartmann Heske, 1969, pp. 553–54.

⁴⁸ See Hoffmann, *Ernst Koch*...cit., p. 70.

⁴⁹ See Silke Schulte, *Geschichte der Stadt Hameln*, in Niedersächsisches Ministerium für Inneres, ed., *Niedersachsenbuch 2009. Rattenfängerstadt Hameln*, Hameln, C. W. Niemeyer, 2009, (pp. 24–32), p. 29; Friedrich Wilhelm Otto Ludwig Freiherr von Reden, *Amtlicher Bericht über die siebzehnte Versammlung der deutschen Naturforscher und Aerzte zu Pyrmont im September 1839*, in Lorenz Okenfuß, ed., *Isis oder Encyclopädische Zeitung von Oken*, 1840, (coll. 928–30), col. 929.

⁵⁰ See Königliges Privilegium zu Cementbereitung (ms., Niedersächsisches Landesarchiv Hannover (NLH), Hann. 80, n° 15903). See also Von Reden, *Bericht über die von dem Gewerbe-Vereine für das Königreich Hannover in den Monaten Mai und Juni 1835 veranstaltete erste Ausstellung*...cit., col. 528; Id. *Das Königreich Hannover statistisch beschrieben, zunächst in*

(fig. 3.2.1) On June 1833, Meyer writes a letter to the local land magistrate, asking for the ban on the exportation of raw stones suitable to produce cement, in order to leave them available for the cement plant. This proves that the production of cement is running full-bore at that time, using local raw materials.⁵¹ In 1835, Wendelstadt und Meyer take part to the first *Ausstellung inländischer gewerblicher Erzeugnisse* (Exhibition of inland manufacturing products) organized by the *Gewerbe-Vereine für das Königreich Hannover* (Society for Manufacturing and Trade in the Kingdom Hannover), where they are awarded a gold medal for the quality of the cement they produce, and for having contributed to the development of a promising manufacturing branch. “Cement (N°1644) by Wendelstadt und Meyer,” it is stated in an exhibition official report, “has generally proved to be particularly good; it is equal to the English cement but more affordable. For this reason, and for having opened the way to a new manufacturing branch, Wendelstadt and Meyer are awarded a silver medal.”⁵² The factory grows during the 1830s and it is provided with a second and more modern kiln, with separate combustion chamber.⁵³

In 1834, the already mentioned limekiln Brunkhorst und Westphalen in Buxtehude begins to burn cement using marls imported from England, besides grinding Trass from stones imported from Holland, and fat lime from shells and from Rüdersdorf limestones.⁵⁴ The production grows in the following years and the plant is provided with a second mill at the turn of the 1840s. In 1842, the year

Beziehung auf Landwirtschaft, Gewerbe und Handel, vol. I, Hannover, 1839, p. 464; Id., *Amtlicher Bericht über die siebzehnte Versammlung der deutschen Naturforscher und Aerzte zu Pyrmont...cit.* Ernst Meyer Hermann, “Leicht wie ein Gedanke”. *Erste Große deutsche Kettenbrücke: 1836/39 bei Hameln erbaut*, in *Die Weser*, XLIV, 1970, n. 1, (pp. 48–49), p. 48; Hort Knobe, *Hamelner Wasserbauwerke an der Weser. Die Geschichte der Schleusen und Wehre, der Münsterbrücke und des Hafens*, Bielefeld, Verlag für Regionalgeschichte, 2003, p. 119.

⁵¹ See Adolph Meyer, letter to the Königlicher Großbritannischer Hannoverscher Landdrost zu Hannover (ms., NLH, Hann. 74 Hannover, Hameln n° 3102).

⁵² “Der von HH. Wendelstadt und Meyer auf die Ausstellung gebracht Cement (N° 1644) hat sich, nach ziemlich allgemeinen Urtheile, als besonders gut bewährt; er ist dem Englischen vollkommen gleich zu stellen, und sein Preis sehr mäßig. Deshalb, so wie in Betracht, daß jene Herren dem Königreiche einen neuen nicht unwichtigen Industrie-Zweig zugewandt haben, ist denselben die silberne Medaille zuerkannt” (Von Reden, *Bericht über die von dem Gewerbe-Vereine für das Königreich Hannover in den Monaten Mai und Juni 1835...cit.*, col. 529). The Gewerbe-Verein für das Königreich Hannover is founded in May 1834, see *Mittheilungen des Gewerbe-Vereins Hannover*, 1834.

⁵³ A description following a visit of the Wendelstadt und Meyer cement factory, made by the members of Gesellschaft deutscher Naturforscher und Aerzte zu Pyrmont in 1839, proves that this kiln is operating at that time, see Von Reden, *Amtlicher Bericht über die siebzehnte Versammlung der deutschen Naturforscher und Aerzte zu Pyrmont...cit.*

⁵⁴ See “Fragen, welche von Seiten der auswärtigen Mitglieder des Gewerbe-Vereins den einzelnen Besitzern der Fabriken und von Gewerbe-Anstalten zur Beantwortung vorgelegen sind”, 1834 (ms., Stadtarchiv Buxtehude, Rep. HG 28,28, n. fol.); “Königliches Ministerium des Innern. Resolution”, 9 August 1835 (ms., Stadtarchiv Buxtehude, Rep. HG. 29,18, n. fol.); Anon., *Zusammenstellung der Nachrichten über die seit 1838 im Königreiche Hannover neu entstanden oder wesentlich vergrößerten und verbesserten Fabriken*, in *Mittheilungen des Gewerbevereins für das Königreich Hannover*, in *Mittheilungen des Gewerbe-Vereins für das Königreich Hannover*, 1842-1843, 1843, (coll. 325-408), coll. 399-400; Reinhold, *Sammlung praktischer Erfahrungen...cit.*, p. 89; Heike Linderkamp, “Die Industrialisierung in Buxtehude. Anfänge und Entwicklung bis zum Beginn des 20. Jahrhunderts”, Buxtehude, Buxtehude Stadtarchiv, 1992. Trass is commonly exported from Rhineland to Holland via the Rhine and then imported via the river Weser or via Hamburg to Niedersachsen; this trade is due to the lack of railways and proper waterways between Rhineland and Niedersachsen.

of the great fire of Hamburg, after which huge quantities of building materials are necessary to rebuild a great part of the city, the plant comes to produce 60 barrels cement a day.⁵⁵

3.3 Further production of hydraulic lime and the persisting fascination of English Roman cement in Prussia

At the turn of the 1830s, Prussia seems to be torn between the persisting ambition to reproduce English Roman cement, and the actual development of hydraulic lime manufacturing. In the early 1830s, after the pioneering experiences that have arisen around the Werbellinsee, hydraulic lime begins to be produced in the town of Oppeln, Silesia, exploiting marls discovered in a place called Moritzberg.⁵⁶ Lime from Oppeln is moderately hydraulic and is slaked by pouring water on burnt stones laid on sieves, so that slaked lime falls through nets as a powder, which is then usually mixed with *Trass* or brick powder. During the 1830s, lime from Oppeln is used to build the masonries of several hydraulic works in Oblau, Breslau and Brieg, and it is known even in Berlin.⁵⁷

While the development of local hydraulic lime manufacturing is in progress, the Prussian *Gewerbverein* promotes a new competition in 1833, in order to urge, once more, the development of inland hydraulic cement with properties similar to the ones of the English Roman cement."⁵⁸ This competition shows more or less similitudes with the competitions promoted in 1822 and 1829, apart from the fact that now the reference to Roman cement is openly declared. Shortly thereafter, the Prussian *Ober-Bau-Deputation* organizes a series of tests that take place in Berlin between 1834 and 1835, aiming at shedding lights on the effectiveness of the principal materials available in Prussia to produce hydraulic mortar, namely *Trass* from Cologne, hydraulic lime from Joachimsthal, hydraulic lime from Oppeln and Roman cement from England.⁵⁹ Four different kinds of hydraulic mortar are prepared using the just mentioned materials as essential components. *Trass* is mixed with lime from Rüdersdorf in equal measures; lime from Oppeln is mixed with 1 and $\frac{1}{4}$ quartz-sand and $\frac{1}{4}$ brick powder; Roman cement is mixed with quartz-sand in equal measures. Each kind of mortar is used to bind samples of

⁵⁵ Anon., *Zusammenstellung der Nachrichten über die seit 1838 im Königreiche Hannover neu entstanden oder wesentlich vergrößerten und verbesserten Fabriken...*cit., col. 400.

⁵⁶ Today Opole in Poland

⁵⁷ See Ober-Bau-Inspector Feller, *Bekanntmachungen vermischten Inhalts. Baumaterialien-Lieferung*, in *Oeffentlicher Anzeiger als Beilage des Amtsblatts der königlichen Regierung zu Oppeln*, 1834, (pp. 618–19), p. 619; C. Hoffmann, *Notizen über den Kalk vom Moritzberge bei Oppeln, und dessen Verwendung zum Mörtel bei Wasserwerken zu Breslau*, in *Notiz-Blatt des Architekten-Vereins zu Berlin*, 1839, pp. 18–19.

⁵⁸ See *Preisaufgaben für die Jahren 1833–34. Erste Preisaufgabe betreffend die Anfertigung eines hydraulischen Cements aus inländischen Materialien von gleicher Güte als der Englische Roman Cement*, in *Verhandlungen des Vereins zur Beförderung des Gewerbfleißes in Preußen*, XII, 1833, pp. 30–31.

⁵⁹ See *Auszug aus den Protokollen der Versammlung des Vereins in den Monaten November und Dezember d. I. J.*, in *Verhandlungen des Vereins zur Beförderung des Gewerbfleißes in Preußen*, XIV, 1835, (pp. 277–80), pp. 279–80; Brunsch, *Die historische Verwendung...*cit., pp. 61–66.

yellow bricks from the village of Glindow and red bricks from Rathenow, which are then put into wooden boxes so that, between the brick samples, two different free compartments remain and are filled with mortar and crushed stones (sandstone, granite and limestone), forming a sort of coarse concrete. Once filled, the four boxes are put underwater in the Spree, where they remain for one year and half. In addition, samples of the four different kinds of mortar are laid on a wall exposed to moisture, where they remain as much time as the boxes stay underwater. On September 1835, the samples are checked and the four different kinds of mortar are assessed in relation to their use underwater and as plaster.⁶⁰

The constant search for raw materials suitable to produce hydraulic lime and cement in Prussia produces further positive consequences in the second half of the 1830s, and brings to the foundation of some new lime and cement kilns. One is founded in 1836 in Tarnowitz, north of Oppeln, while a further kind of limestone to produce hydraulic lime is discovered in Schimntiz, south of Oppeln.⁶¹ In 1837, a kind of lime that slakes very slowly is produced with limestones findable on a small hill near Rüdersdorf, called Krienberg.⁶² Chemical analyses prove that these limestones contain appropriate substances to produce cement, but a real manufacturing does not start due to the lack of proper installations. After having arisen some interest on the part of the *Stadtbaurath* Langerhans in 1839, limestones from Krienberg are once again taken into consideration in 1841, as the entrepreneurs Haslinger and Schondorff, who have built in Moabit a kiln based on English models, undertake new tests and compare the features of Krienberg cement with the ones of Roman cement imported from England. The two products appear similar; Krienberg cement hardens a little slower than Roman cement, but it is considered good enough to be mixed with twice so much sand than Roman cement, making significant savings possible. Haslinger and Schondorf start manufacturing cement in Moabit and succeed in selling it for the construction of important new buildings in Berlin and in the vicinity, such as the Berlin cathedral, the *Neues Museum* by Friedrich August Stühler (1800–1865), and the *Schloß Babelsberg* in Potsdam.⁶³

⁶⁰ Mortar made of *Trass* and lime from Rüdersdorf appears as the best binder underwater, followed by mortars composed with Joachimsthal lime, Roman cement and Oppeln lime; this last one seems, instead, to be the best binder to plaster wet walls, followed by Roman cement and Joachimsthal lime (see Brunsch, *Die historische Verwendung...*cit., pp. 61–66).

⁶¹ See Cohn, *Ueber die Wichtigkeit...*cit., p. 10, n. 1; Hoffmann, *Notizen über den Kalk vom Moritzberge...*cit., p. 19. Tarnowitz cement is used for the building of the fortresses of Neisse and Posen.

⁶² See Anon., *Notiz über den in Moabit angefertigten Cement: nach einer Mittheilung der Herren Haslinger und Schondorff*, in *Notiz-Blatt des Architekten-Vereins zu Berlin*, I, 1847, pp. 12–13.

⁶³ “Der Krienberg-Cement ist übrigens in Berlin schon angewendet worden: Beim neuen Dom, dem neuen Museum, beim Normalkrankenhaus, der neuen Ulanen-Kaserne, dem Zellen-Gefängniss, dem Artillerie-Laboratorium, dem Königl. Stadtgericht, dem Friedrich-Wilhelms-Hospital, bei der Städtischen Gasanstalt; ferner beim Schlossbau zu Babelsberg, zu verschiedenen Bauten der Berlin-Hamburger Eisenbahn, und noch mehreren grossen Privathäusern” (Anon., *Notiz über den in Moabit angefertigten Cement...*cit., pp. 12–13).

3.4 Mortar, plaster and concrete, experimental uses of Kassel and Hamelin cement, and the attempts at building continuous masonry elements

The very early applications of Koch's cement in Kassel are disappointing. They are actually quite simple, and mainly concern restorations of roofs and walls, but the lack of expertise causes several failures. The Kassel architect Johann Daniel Wilhelm Eduard Engelhard (1788–1856) later reports about this false start, which also involves some constructions of his own. "People who had trusted cement," he relates, "were so disappointed that a general discontent about it arose. Many failed reparations of walls, roofs, etc., were to be seen in Kassel. I myself used cement to whitewash the wet façade of a building, but, less than two years later, cement fell down. I cladded a Corinthian pediment with stone plates fixed and plastered by means of cement, but, during the same summer I did it, parts of the cladding-work cracked, causing danger to pedestrians. And this happened despite I had chosen workers with care, I had instructed them and looked after their work. As a consequence, nobody wanted to hear any longer about cement, and some people even complained having vainly spent considerable amounts of money."⁶⁴

It is probably in response to early failures that Koch manages to get a positive assessment in an article dealing with hydraulic lime, which is published in 1833 in the *Annalen der Pharmacie*, a periodical edited by the chemist Justus von Liebig (1803–1873). "Mr. Koch's cement," the text goes, "has all the properties that a binder should have. It forms real artificial clinking stones, a sort of regenerated limestone, and it has the same quality as the celebrated Roman cement [...]. Besides the huge masonry works underwater for which Koch's cement has already been successfully employed, we have observed big water containers made of bricks put edge on and bond with this cement, which are since long time full of water and have proved to be watertight as if they were carved in single stone pieces. As we tried to break such a masonry work assembled with this cement, cracks arose in stones earlier than in cement joints; the cement mass had formed a sort of continuum with stones."⁶⁵ Such enthusiastic words are

⁶⁴ "Das Publicum fasste nun schon einiges Zutrauen zu dem Gegenstande, fand sich aber doch vielfältig in seinen Erwartungen getäuscht, so dass die Cementconstructionen fast zum öffentlichen Ärgerniss wurden. Man sah an vielen Gebäuden in Cassel misslungene Ausbesserungen an Mauern, Wänden, Dächern u. s. w. Auch ich hatte an einem Gebäude, mit einer Plateform, die feuchte Frontmauer mit Cement tünchen lassen, musste aber sehen, dass die Tünche im zweiten Jahre wieder abfiel. Die Steinplattenbedeckung eines Ziemlich grossen Frontons corinthischer Ordnung hatte ich mit Cement überziehn und dichten lassen, und in demselben Sommer löseten sich ganze Stücke derselben ab und droheten auf die Vorübergehenden zu fallen; gleichwohl hatte ich die Werkleute zu diesen beiden Arbeiten sorgfältig gewählt und sie mit ängstlicher Genauigkeit dazu angewiesen und überwacht. So kam es denn, das hier Niemand mehr etwas von dem Cement wissen wollte und Mancher eine beträchtliche vergebliche Ausgabe zu beklagen hatte" (Johann Daniel Wilhelm Eduard Engelhard, *Über den Casseler Cement*, in *Journal für die Baukunst*, vol. XX, 1844, (pp. 165–88, 189–98), pp. 166–67).

⁶⁵ "In der That leistet das Cement des Herrn Koch Alles, was man nur von einem Kitt verlangen kann. Es bildet einen wahren künstlichen klingenden Stein, einen regenerirten Kalkstein, und kommt in seinen Eigenschaften vollkommen mit dem berühmten romischen Cement überein, [...]. Aufser den gröfseren Mauerungen unter Wasser, bei denen das Koch'sche Cement angewendet war und sich vollkommen bewährt erwiesen bat, haben wir z. B. grofse Wasserbehälter gesehen, welche aus auf die schmale Kante gestellten und mit diesem Cement verbundenen Ziegeln (Backsteinen)

probably not completely reliable. They are, in any case, in evident contradiction with Engelhard's memories, and Engelhard is far from being a detractor of Koch's cement. Quite to the contrary, he has high expectations with regard to it. Having observed applications in pozzolana-base mortar during a study journey to Italy in 1809, Engelhard hopes that modern cement could replace all traditional cementitious mixtures.⁶⁶ "If this material proves to be good," he reasons, "a gap in our current way of building could be filled, since mixtures of lime and brick powder are very defective, and *Trass* and pozzolana are little, or even not at all, available in Germany"⁶⁷. Engelhard is notably fascinated by the Roman way of building aqueducts made of bricks, tuff and a mixture of gravel and mortar, and by the rest of plaster and cement coverings that he admires on the side columns of the Temple of Fortuna Virilis in Rome, where he furthermore observes the use of pozzolana-base mortar for the rebuilding of the pavement of Ponte Sisto. "First an about one foot high basement of tuff stone was laid in pozzolana and lime," he relates, "then, this basement was covered with 8 inches wide and long cobbles, placed very close to each other in a second bed of lime and pozzolana, to form the real pavement."⁶⁸

With the aim of improving the reputation of the cement he produces, Koch writes a pamphlet of instructions to apply cement in 1835. Three years later, the pamphlet will be published as a book, being one of the earliest examples of German manuals about cement. In 1836, Koch asks the *Hessian Handel- und Gewerbeverein* (Hessian Society for Manufacturing and Trade) for an official inspection of the cement-based whitewashing, plaster and mortar that have been applied during the construction of Schwarzenberg's private house between 1834 and 1835. A committee is set up for the purpose, gathering the major local experts about technical matters, namely Engelhardt, Arzenberg, the Henschel brothers and Heinrich Bluff (1805–1878), who is the editor of the *Gewerbeblätter für Kurhessen*, a periodical edited by the *Hessian Handel- und Gewerbeverein*. The inspection gives satisfactory outcomes, and it has been assessed that Koch's cement is suitable not only for hydraulic works, "but also for works to realize in

zusammengesetzt waren, die, schon seit langer Zeit mit Wasser angefüllt, so wenig die geringste Menge Wassers durchliefsen, wie ein aus einem ganzen Stein gehauener Trog. Als wir versuchten, ein, mit diesem Cement verbundenes Mauerwerk zu zerschlagen, so entstanden die Brüche eher in den Steinen selbst, als in den Cementfugen; die Masse des Cementes hatte mit den Steinen gleichsam ein Continuum gebildet" (Anon., *Ueber den hydraulischen Kalk*, in *Annalen der Pharmacie*, vol. V, 1833, (pp. 241–46), pp. 244–45).

⁶⁶ See Johann Daniel Wilhelm Eduard Engelhard, *Instruction für junge Architekten zu Reisen in Italien*, in *Journal für die Baukunst*, vol. XI, 1837, pp. 1–24, 155–74, 203–38, 303–33, esp. pp. 308–09, 312.

⁶⁷ "Bewährt sich dieses Material wirklich, so wurde eine bedeutende Lücke in unserem hiesigen Constructionssystem ausgefüllt sein. Die Mischung von Kalk und Ziegelmehl ist sehr unvollkommen, und *Trass* und Puzzolane haben wir in Deutschland wenig oder gar nicht" (Engelhard, *Über den Casseler Cement*...cit., p. 167).

⁶⁸ "Zuerst wurde über dem dazu erbauten Planum ein durchlaufendes Strafsenfundament von Tufsteinen in Puzzolana und Kalk gemauert; es mochten diese Lagen zusammen einen Fufs hoch sein; über diesem wurde sodann das eigentliche Steinpflaster, bestehend aus regulär-quadratischen, übereck stehenden, etwa 8 Zoll breiten und langen Steinen gesetzt, ebenfalls in Kalk und Puzzolana, aber sehr dicht aneinander gefügt" (Engelhard, *Instruction*...cit., p. 308).

places that are dry or alternatively dry and moist, as long as cement is carefully handled and mixed with an appropriate amount of sand, according to the kind of work to realize.”⁶⁹

As Engelhard builds his own villa between 1837 and 1839, he makes wide use of cement. He builds usual masonry works in moist places, but he also carries out interesting construction experiments.⁷⁰ Firmly convinced of the perfect cohesion between stones and cement mortar, he builds bond-beams made of stone plates and cement mortar inside the bearing walls, at the base of each floor. He describes such constructions as “a sort of cohesive stone-chains through the walls.”⁷¹ To improve the cohesion between bricks and cement mortar, he even conceives special porous bricks made of clay and coal slivers, which he orders at the Mönchenberg brickyard and then uses to build the window corners.⁷²

But the most interesting experiments that Engelhard carries out during the construction of his house probably concern two roof gardens. Engelhard has admired flat roofs during his journey to Italy, and therefore desires to build similar ones in his own house, trying, however, to improve their waterproofness. (fig. 3.4.1) “Such constructions are realized in southern lands more frequently than in our country,” he writes in this regard, “but this does not necessary mean that they are always well built. Quite the contrary, disadvantages of flat roofs are the same in northern and in southern lands, where moisture is even more unfavourable for health than in North, but people do not care about it”. “I have seen many such roofs,” Engelhard still relates, “several of which could be preserved years long if they were carefully built and maintained; thus, I could not resist to build something similar, trying to overcome imperfections I had observed [...].”⁷³ Engelhard builds a first flat roof by pouring a 1/3 inch

⁶⁹ “[...] selbst bei Bauten an solchen Stellen mit größtem Vortheil verwendet werden kann, wo es entweder ganz im Trocken steht, oder abwechselnd den Einflüssen feuchter und trockner Witterung ausgesetzt ist” (Adolph Schwarzenberg, Carl Anton Henschel, Johann Werner Henschel, Johann Heinrich Buff, *Gutachten die Brauchbarkeit des Koch'schen Cements betreffend. Protokoll 18ten Juni 1836*, in *Gewerbeblätter für Kurhessen*, I, 1836, (pp. 137–39), p. 139).

⁷⁰ Engelhard’s villa is a very well known building in Kassel at that time, and it is named Engelsburg because of its impressive size, in this regard see Ruth Stummann-Bowert, *Philippine Engelhard, geborene Gatter. Ein Bürgerliches Frauenleben zwischen Aufklärung und Empfindsamkeit*, in Trauden Weber-Reich, ed., “Des Kennenlernens werth”. *Bedeutende Frauen Göttingens, Göttingen, Wallstein*, 2002, (pp. 27–52), p. 49. Engelhard also reports having successfully built a container for effluent made of bricks and cement mortar in a public cowshed, at the insistence of a local mason, and despite previous failures (Engelhard, *Über den Casseler Cement...cit.*, p. 167).

⁷¹ “[...] zusammenhängenden Steingurt durch jedes Stockwerk” (Engelhard, *Über den Casseler Cement...cit.*, p. 175)

⁷² It is also worth of mention that, basing on such strong confidence in the perfect cohesion n between bricks and cement mortar, in 1837, a bearing wall at the ground floor of a house in Kassel was cut over a length of 13 feet, and replaced with an arch made of bricks and cement mortar; see Ernst Friedrich Martin Koch, *Gesammelte Erfahrungen über die Verarbeitung u. die verschiedenen Anwendungen des Cemente aus den Cementfabriken von Ernst Koch in Hessen-Kassel und Hanau*, Kassel, Leipzig, Theodor Fischer, 1838, pp. 17–18.

⁷³ “[...] so Etwas freilich in südlichen Ländern öfter vorkommt, als hier; aber man muss nicht glauben, dass die Terrassen dort immer vollkommen gelungen wären; eher das Gegentheil. Man beachtet nur die Nachtheile davon dort nicht so sehr; wiewohl man im Grunde ebensowohl Ursach dazu hätte, als im Norden; denn Feuchtigkeit ist im Süden der Gesundheit noch nachtheiliger, als bei uns. Ich hatte viele dergleichen Terrassen gesehen, und mehrere derselben in Bau und Besserung Jahre lang erhalten; so dass ich dem Wunsche nicht widerstehen konnte, Etwas der Art hier machen zu lassen, und zu versuchen, die Nachtheile und Unvollkommenheit derer, die ich gesehen hatte, dabei zu vermeiden; [...]” (Engelhard, *Über den Casseler Cement...cit.*, p. 182).

thick layer of mortar composed of cement and sand, on a floor bearing structure made of wedge-shaped stone plates, which form flat vaults between timber beams. The whole is then covered with clay and vegetable soil to arrange a garden. Apart from the garden arrangement, this kind of construction is similar to certain British floors of the end of the 18th century, which are made of flat brick vaults spanning between timber beams, the whole being covered with sand and brick tiles.⁷⁴ The second flat roof that Engelhard builds consists of grooved timber beams, transversal iron-sticks, and crushed bricks embedded between the sticks. Once this is achieved, cement mortar is poured all over the entire construction. Together with the crushed bricks, it forms a sort of coarse concrete between the beams, while, in the upper part, a homogeneous and watertight base of cement mortar supports the garden. This complex floor structure seems to merge the building technique of floors made of timber beams and clay rolls (*Lehmplatzen*), with the building technique of the Italian flat roofs, which shows a concrete casting on boards fixed on beams. Furthermore, it also seems an ancestor of the floors made of iron beams and concrete filling, whose construction develops in Germany not before the 1870s. (fig. 3.4.2) In spite of the efforts to improve the waterproofness, Engelhard's floors are permeable because of cracks arisen in cement mortar. One year after they have been achieved, the suspended gardens must be dismantled, and the floor structures are covered with tiles and limestone plates laid in cement mortar.

Besides Engelhard's constructions, the dome of the new Henschel foundry in Kassel, which is conceived by Carl Anton Henschel and realized between 1837 and 1839, after a fire had destroyed the previous building on September 1836, deserves a special attention for being a masterly example of construction exploiting the rapid and strong cohesion between cement mortar and bricks. Henschel imagines a circular building made of brick masonry work, covered with a dome and provided with two side wings on the back part of it.⁷⁵ (fig. 3.4.3) For the construction of the dome, he envisages to use hollow clay pots and cement-based mortar, without resorting to any centring, just relying on the rapid setting of cement, and on its strong cohesion with bricks. Describing Henschel's plans for the dome, Koch maintains that such kind of vaults "become like single masses and therefore demand less care about the abutment."⁷⁶ Henschel's idea of building a masonry vault without any centring recalls the construction of the Thames tunnel, even more if we consider that Henschel meets Brunel during a journey to England between 1833 and 1834, just as Brunel is testing the cohesion of bricks and cement mortar through the experimental construction of two impressive half arches.⁷⁷ A reference for the use of hollow clay pots could be found, instead, in the Schinkel's *Vorläge-blätter für Maurer* of 1834, in which

⁷⁴ See Bill Addis, *Iron in floor structures: the development of fireproof floors*, in Gargiani, ed., *L'architrave...cit.*, (pp. 492–98), p. 495, fig. 2.

⁷⁵ See Jos Tomlow, *Die Kuppel des Gießhauses der Firma Henschel in Kassel. Eine frühe Anwendung des Entwurfsverfahrens mit Hängemodellen*, in *Architectura*, vol. XXIII, 1993, pp. 151–71.

⁷⁶ "Da sich das Gewölbe fast zu einer einzigen Masse vereingt, so braucht man weniger auf die Stärke der Widerlagen zu sehen" (Koch, *Gesammelte Erfahrungen...cit.*, p. 20).

⁷⁷ It is a construction consisting of a pier supporting an half arch on a side, and a quarter of arch on the other sides, both made of bricks, cement mortar and some iron bars in mortar, and built without centring (see Francis, *The Cement Industry...cit.*, p. 48).

fireproof ancient vaults made of hollow clay pots bond with pozzolana based-mortar, besides more recent ones made of pots and gypsum-based mortar, as they are usually built in Paris, are illustrated and described.⁷⁸ (fig. 3.4.4) Henschel conceives special hollow clay-pots provided with grooves on the external circular surface in order to improve adhesion between bricks and cement mortar, and he orders such clay-pots in different diameter sizes, since the section of the dome masonry work is intended to decrease as the building goes ahead. Pots are laid tangentially to the curve, and special double curved hooks provided with a load on the lower side keep pots together during the mortar setting, while special stirrups hold the mortar applied on the intrados until it sets (fig. 3.4.5). In the lack of centring, the layout of the curve is shown by different length cables hanging from a metallic bar, which is fixed on the top of high pole placed in the centre of the building.⁷⁹

Despite all expectations, the dome collapses as it is still under construction.⁸⁰ Henschel therefore plans a new construction, which is now made of six alternate rings of bricks and hollow clay pots bond with cement mortar. Unlike the previous ones, hollow pots now have smooth surfaces and are laid perpendicularly to the tangents. The lowest ring is made of ordinary bricks and forms a sort of solid base for the further rings, which are made of hollow pots (fig. 3.4.6–7). The third ring is made of pots filled with cement mortar, probably to form a sort of solid belt approximately in the middle of the dome, and the fifth one is made of pots whose diameter is just half the size than the diameter of other pots. The last ring forms a crowning of two concentric circular rows of ordinary size hollow pots, which support a lantern acting as a chimney.⁸¹ (fig. 3.4.8–9)

On the wake of the restored reputation, Koch's cement begins to be even used outside Kassel, and Koch founds a second cement kiln in the early 1836, in Hanau, southern Hessen, together with the entrepreneur Friedrich Deines (1802–1876).⁸² In 1837, the Thuringian *Baukondukteur* Lünzner, reports having experimented with Koch's cement on a request from the Erfurt *Gewerbverein*, as he has built four bridges over the river Lache, along the road from Weißensee to Kindelbrück. Lünzner explains having used pure cement mortar for the underwater masonry work, and mortar containing $\frac{1}{2}$ measure of sand each measure of cement for the overground masonry work. Workers are told having used winnowing fans to throw water against the overground masonry work and improve the mortar hardening, a practice that will later become usual. Lünzner declares to be satisfied of Koch's cement and he even suggests using it to compose concrete for hydraulic foundations.

While Koch's cement is variously experimented in Hessen and Thüringen, Wendelstadt and Meyer's cement is used for some small and large-scale applications in northwest Germany. In 1837, Carl

⁷⁸ See Schinkel, *Grundlage der praktischen Baukunst. Erster Theil...*cit., p. 13, pl. XVIII.

⁷⁹ See Koch, *Gesammelte Erfahrungen...*cit., pp. 19–20.

⁸⁰ The collapse of the dome is mentioned by Koch (Koch, *Gesammelte Erfahrungen...*cit., p. 20), and by Gotthilf Heinrich Ludwig Hagen (Gotthilf Heinrich Ludwig Hagen, *Ueber Form und Stärke gewölbter Bogen*, Berlin, Ernst und Korn, 1862, p. 25).

⁸¹ Following this project, the construction of the dome is successfully achieved in 1839.

⁸² See Hoffmann, *Ernst Koch...*cit., p. 70.

Johann Elbers (1768–1845), the owner of a dye-works situated near Hagen in Rhineland⁸³, needs to repair a wooden container for bleaching powder, and asks the director of the *Gewerbeschule* in Hagen, Mr. Goerthe, for technical information about the matter.⁸⁴ Goerthe suggests him using Wendelstadt and Meyer's cement to plaster the internal surface of the container after having driven iron nails with large heads in order to better fix the plaster work to the wood. Instead of following Goerthe's advice, Elbers builds a completely new container made of bricks assembled and plastered with cement-based mortar. Elbers uses mortar made of two equal measures of cement and sand to bind bricks, and pure cement-based mortar to plaster the internal surface of the container. The pure cement mortar shrinks too much, cracks and Elbers needs to plaster the container twice, taking care of repairing each crack that arises while mortar hardens. Once this is achieved, Elbers builds a container for oil using the same building technique and both constructions gain a certain importance as Goerthe reports about them at the seventeenth assembly of the *Deutsche Naturforscher und Aertzte zu Pyrmont* (German Naturalists and Physicians in Pyrmont), which takes places in 1839. “The suitability of hydraulic lime to build water containers is well known, and attempts at using hydraulic lime-based masses to manufacture water pipes have been already carried out in France,” Goerthe asserts, “but hydraulic lime has not yet been used neither for barrels, notably for those intended to contain bleaching liquids, nor for oil containers.” “Cement from the Weser,” he then goes on, “as well as *Trass* from Andernach, Roman-Cement, and other similar materials should be recommended exactly for this kind of uses, seeing that such tools are more affordable when they are built using hydraulic lime than sandstone [...].”⁸⁵ The already mentioned Kassel mine counsellor Schwarzenberg takes part in the same assembly and relates about “lime, *Trass* and other kinds of cement”, mentioning successful cases of natural cement uses to build “containers for brine, alum lye, salt, sodium chlorate and potassium chlorate.”⁸⁶

⁸³ Carl Johann Elbers founds his dye-works near Hagen in 1822. It is a so-called Türkischrotfärberei (from Türkischrot, which means dark red). This kind of plant produces red wool clothes with yellow and withe patterns, which are called Bandanos (see Anon., *Amtlicher Bericht über die siebzehnte Versammlung...*cit., col. 938). English clothes long time prevail on German market, but, since the 1840s, German concurrence becomes significant (see August Zoller, *Stuttgart und seine Umgebungen*, Stuttgart, Köhler, 1841, p. 258).

⁸⁴ Beuth founded the *Gewerbeschule* in Hagen in 1824.

⁸⁵ “Die Benutzung des hydraulischen Kalks zu Wasserbehältern ist allgemein bekannt, selbst die Anfertigung von Wasserleitungsröhren aus dieser Masse ist in Frankreich versucht worden; aber Küpen, besonders zur Anfertigung von Bleichflüssigkeiten, und Oelbehälter möchten wohl früher nicht daraus dargestellt worden seyn, doch dürfte sich hierzu und zu ähnlichen Zwecken der Wesercement, eben so aber auch der Andernacher Traß, der Roman-Cement und andere diesen sich gleich verhaltende Stoffe sehr empfehlen, um so mehr, da die aus dem hydraulischen Kalk gefertigten Geräthe billiger zu stehen kommen, als solche aus Sandstein [...]” (Anon., *Amtlicher Bericht über die siebzehnte Versammlung...*cit., coll. 939–40).

⁸⁶ “Bergrath Schwarzenberg fügt Bemerkungen über verschiedene Kalk-, Traß-, und Cementarten hinzu und führte Beispiele an, wo der natürliche Cement mit Glück zu Gefäßen verwendet worden ist, in denen Salzlaugen, Alaunlaugen, Chlornatrium, behandelt werden sollten” (Anon., *Amtlicher Bericht über die siebzehnte Versammlung...*cit., coll. 940). The list of participants at the assembly proves that he is exactly Bergrath Adolph Schwarzenberg from Kassel (*ibid.*, coll. 813–17).

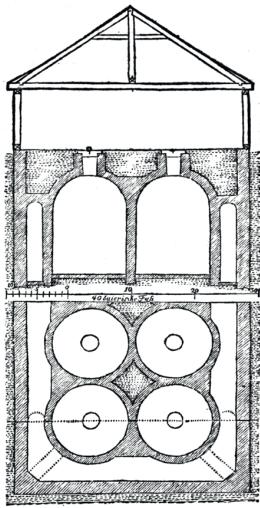
A more impressive use of Wendelstadt and Meyer's cement concerns the building of the bridge over the river Weser in Hamelin. Already the foundation of Wendelstadt and Meyer's cement plant along the river Weser in Hamelin is probably connected to the construction of this bridge, seeing that Wendelstadt is charged with the design of it in 1831. He conceives a suspension bridge made of two stone masonry abutments and a central pier supporting two chain-suspended road decks. (fig. 3.4.10–13) During the planning phase, Wendelstadt studies similar previous works and has personal contacts with specialists who know about cement. An important reference is the Menai Suspension Bridge (1819–1826) by Thomas Telford (1757–1834), the abutments of which are made of stone-faced walls filled with rubble masonry work; mortar is partly composed with hydraulic lime and the exterior joints are sealed with Roman cement mortar.⁸⁷ Furthermore, around 1833, Wendelstadt orders to test metal chains in the Henschel foundry in Kassel, at the presence of Carl Anton, who is just back from England where he has met Brunel, as previously mentioned.

The project for the bridge is accomplished in 1833 but works begin not before 1836, after the plans have been approved. The foundations stand straight on the soil and consist of stone masonry work bond with pure cement mortar.⁸⁸ The free spaces between ashlar and sheet piles around the foundation pits are filled with crushed stone and cement mortar, which can be seen as a sort of rudimentary coarse concrete. The masonry work of the abutments and of the pier consists of stone-faced walls bond with pure cement mortar and a filling made of unrefined stones and mortar of inferior quality named *Cementstein-Asche*. This is made of slags from the cement production, namely bad burnt cement stones and ash ground into powder, and it also used to build a 57 feet long retaining wall close to the central pier.

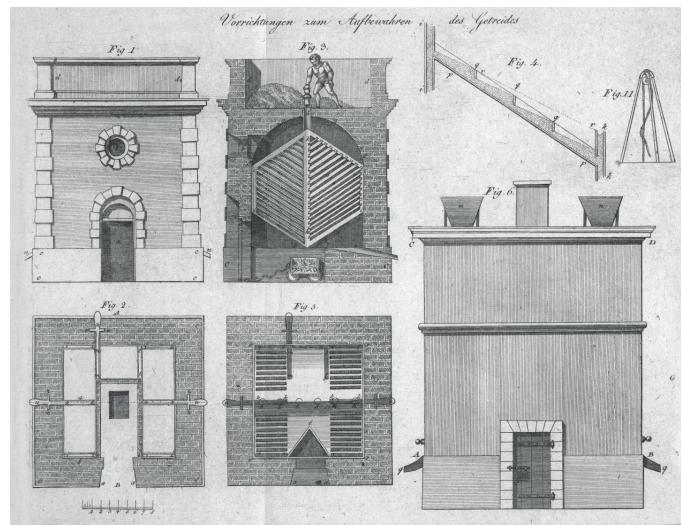
The foundations of the abutments for the chain anchorages on both sides of the bridge deserve a special attention, since they consist of 4 beds of concrete poured on a kind of clayish and almost unsteady soil. Concrete is made of crushed stones, slaked lime and *Cementstein-Asche*. Besides the construction of the major bearing parts of the bridge, cement-based mortar is also used to build the drawing floor, similarly to what Panzer had done to build the little bridge in Schönungen.

⁸⁷ See Thomas Telford, *An historical and descriptive account of the suspension bridge constructed over the Menai Strait in North Wales: with a brief notice of the Conway bridge*, London, Ibotson and Palmer, 1828, p. 24.

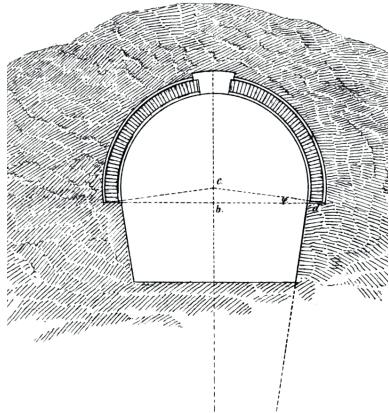
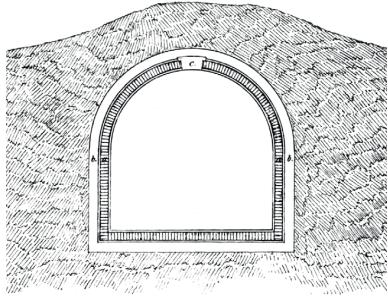
⁸⁸ For an exhaustive account about the construction of the Hamelin Bridge, see Anon., "Zusammenstellung wichtiger Erscheinungen und Ergebnisse in Beziehung auf die bei der Hamelner Kettenbrückenbau gemachten Erfahrungen", [n.d.], (ms., NLH, Hann. 109, n° 1069); see also Michael Mende, "Not only a Matter of Taste but ... of the Laws of Mechanics": *The Adoption of British Models in Nineteenth-Century Continental Suspension Bridge Design*, in *Journal of Design History*, vol. VI, 1993, (pp. 77–95), pp. 84–93.



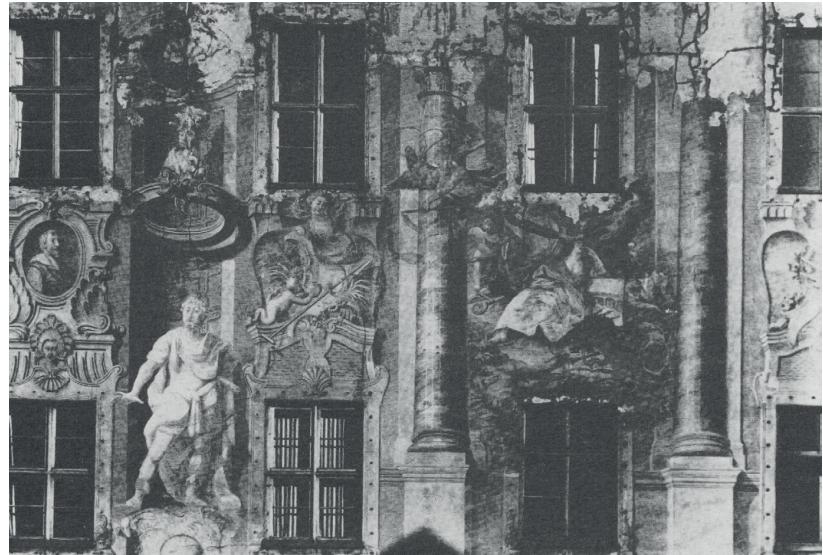
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3.1.2

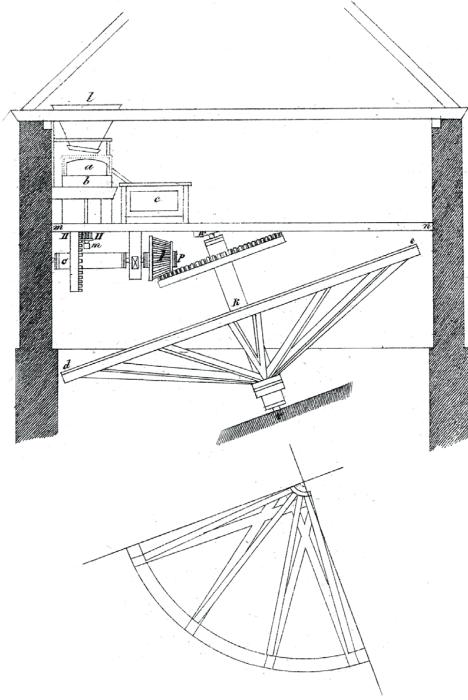


3.1.3. a, b

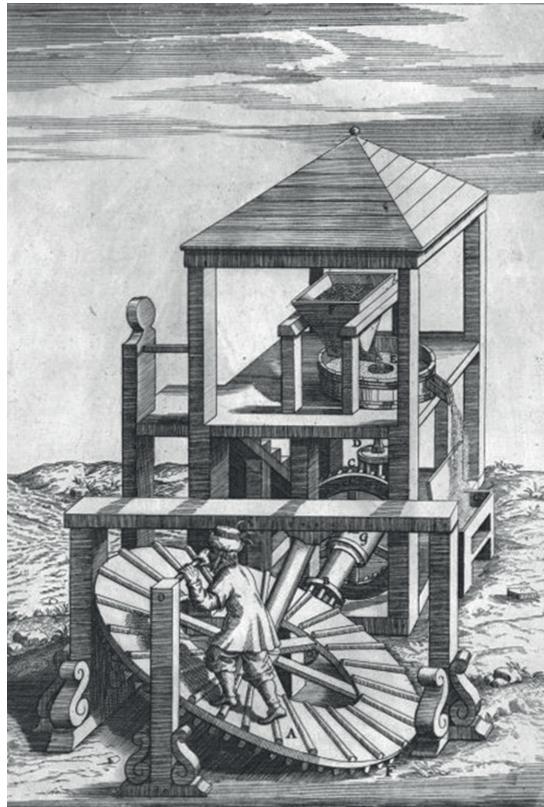


3.1.4

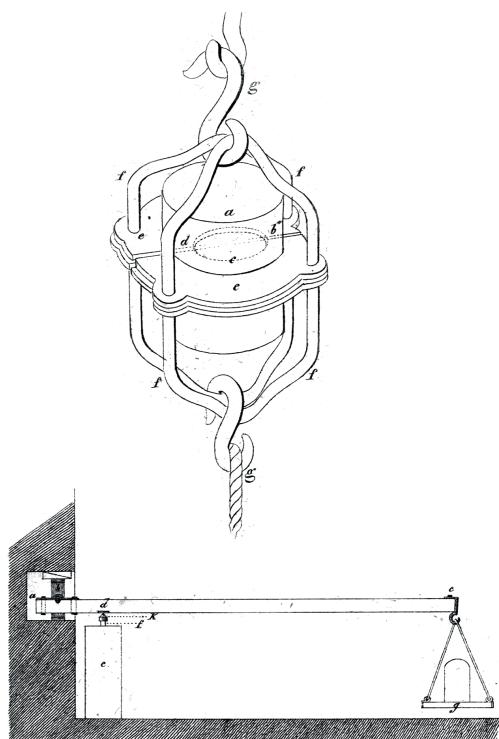
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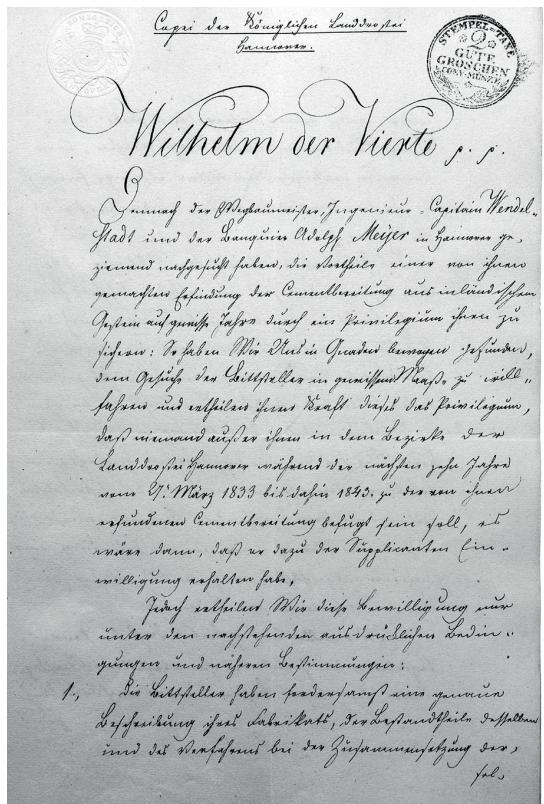
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3.1.6



3.1.7



3.2.1

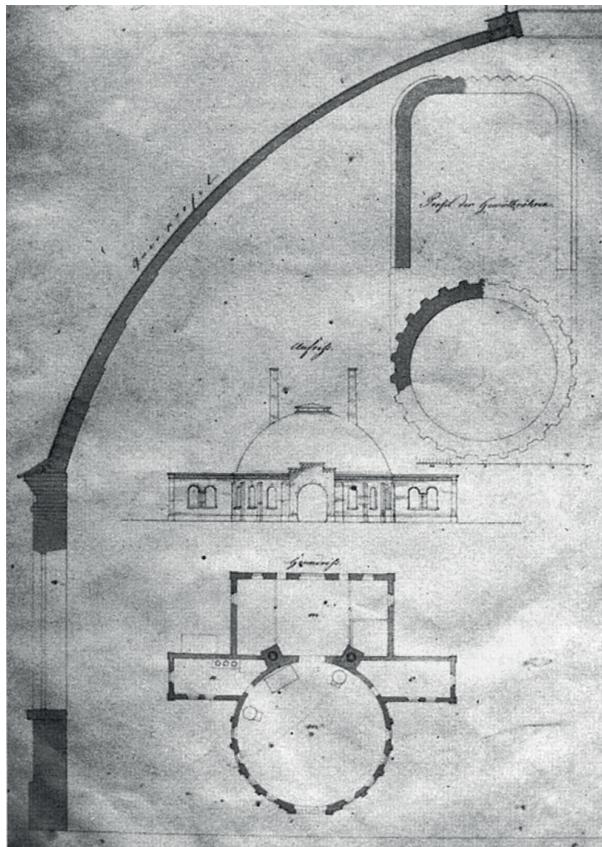
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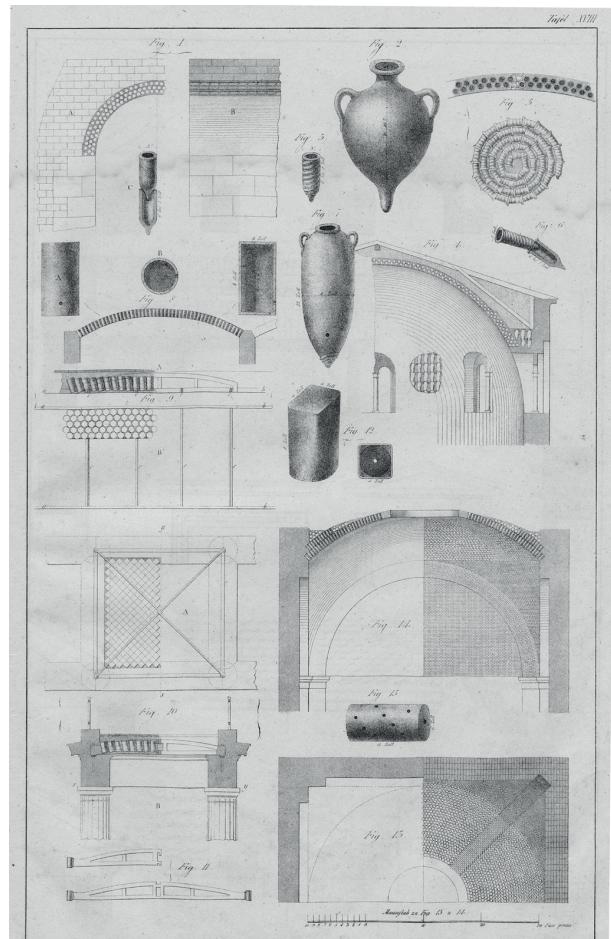
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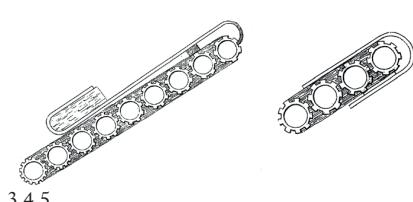
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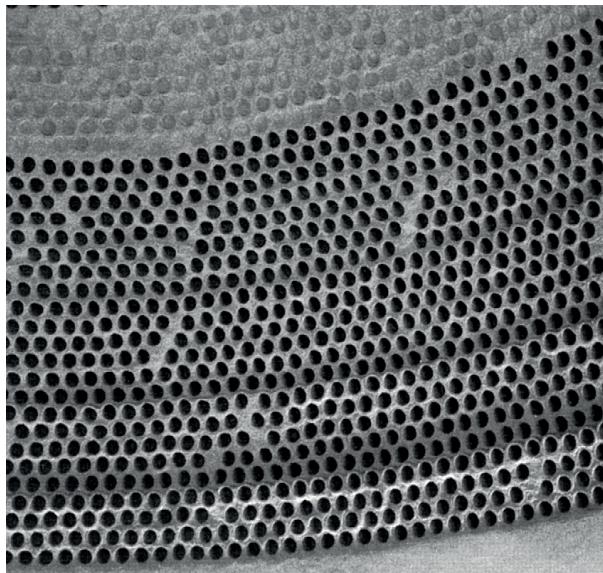


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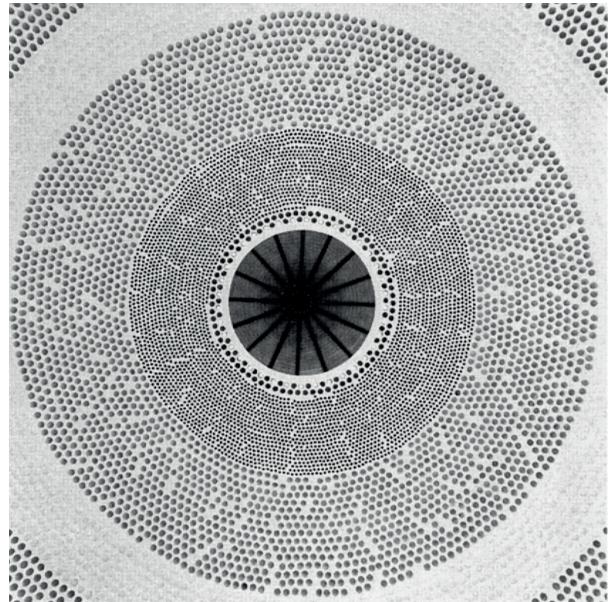


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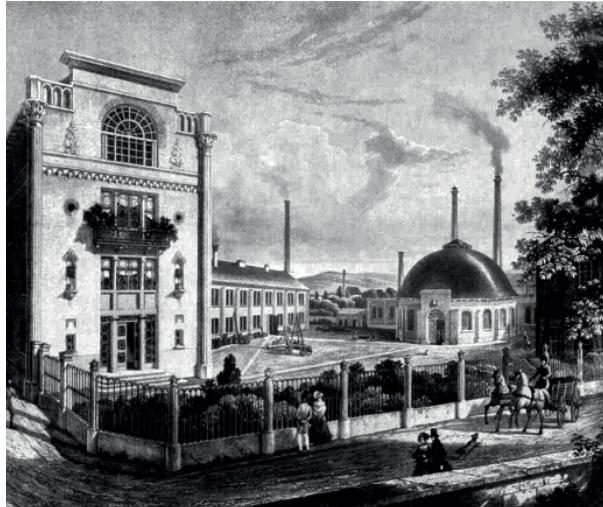
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3.4.6



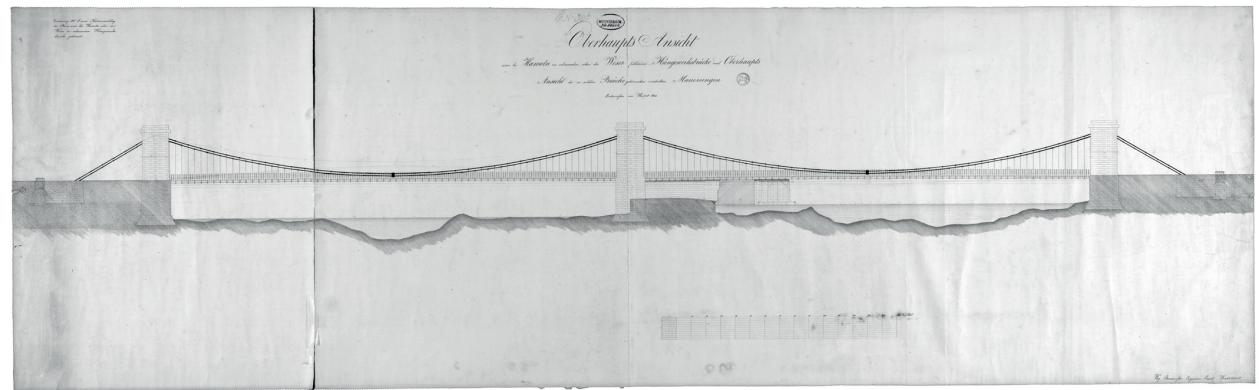
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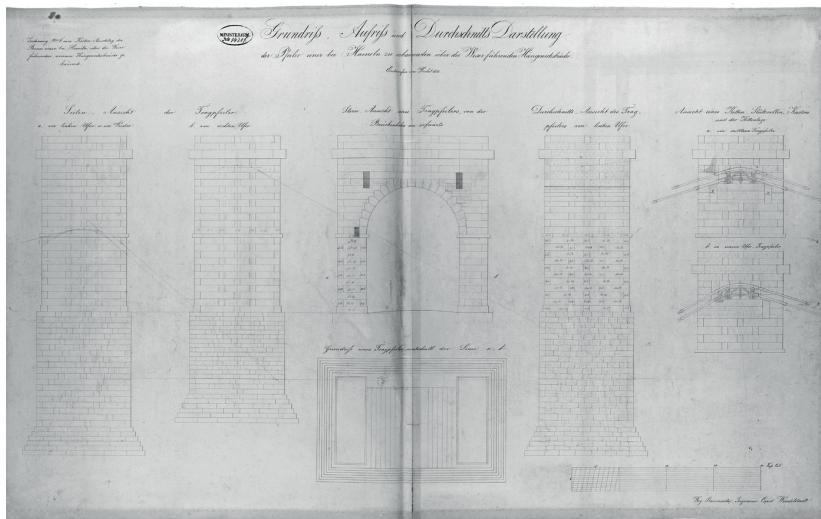


3.4.9



3.4.10

3.4.6-7. C. A. Henschel, the dome of the foundry in Kassel from inside. 3.4.8. C. A. Henschel, the dome of the foundry in Kassel, aquatint, (J. H. Martens). 3.4.9. C. A. Henschel, the dome of the foundry in Kassel before 1977. 3.4.10. G. Wendelstadt, design for the suspension bridge of Hamelin, elevation 1833.



3.4.11



3.4.12



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4 Concrete foundations, walls, artificial stones

4.1 Concrete foundations in regions along the Rhine, the persisting use of *Trass*

On the wake of the theoretical and practical advancements that have occurred approximately during the first third of the century, the use of concrete to build hydraulic foundations gradually spreads since about the mid 1830s, against the backdrop of a very favourable scenario. Manufacturing, mining activities and trade enhance, boosted, inter alias, by the construction of the early railways and by the institution of the Zollverein (Customs Union). As a consequence, several new hydraulic works need to be built, namely foundations for docks, bridges and locks, in order to realize or ameliorate roads, waterways, and the just mentioned railways. Such works need to be built with greater solidity than previous similar ones, sometimes despite difficult orographic features, and, as long as possible, rapidly and without resorting to arduous and expensive provisional works like cofferdams. Considering these constraints, the use of concrete appears in several cases as an appropriate solution, since, as Zimmermann has already highlighted, concrete can be poured straight underwater, in enclosures just delimited only by sheet piles, or by poles rammed close to each other. Furthermore, the use of concrete is now supported by the improved knowledge and expertise about hydraulic binders, and about pebbles and mortar, which, in some case, have been already acknowledged as concrete.

As long as the manufacturing of artificial hydraulic binders does not spread all over Germany, the use of concrete will develop mainly in regions where natural hydraulic binders are available at an affordable cost. Different compositions of concrete are therefore to be observed from region to region, according to the local availability of binders. *Trass*-based concrete is mainly used in regions along the Rhine, where a number of locks, bridges and river docks need to be built as of about the mid 1830s, following the development of local mining activities. In 1834, the old and so-called *Papiermühlleschleuse* (lock at the paper mill) in Werden upon the river Ruhr, which is a right tributary of the Rhine, is replaced with a new construction standing on a *Trass*-based concrete foundation. This construction acts as a model for the building of further locks along the Ruhr, approximately between the second half of the 1830s and the end of the 1840s.¹ The foundations of these locks consist essentially of 88 feet long, 18 feet large and 3½ feet thick beds of concrete (fig. 4.1.1). Slaked lime, *Trass* and different kinds of crushed stones, namely quartz gravel, sandstones and bricks, are mixed together to produce concrete. Lime is taken from different limekilns along the Rhine, and from the nearby towns of Velbert and

¹ See Carl Hoffmann, *Beton-Fundirungen bei den Wasserbauten an der Ruhr*, in *Notiz-Blatt des Architekten-Vereins zu Berlin*, I, 1847, pp. 5–8; Gotthilf Heinrich Ludwig Hagen, *Handbuch der Wasserbaukunst. Erster Theil: Die Quellen*, Königsberg, Gebrüder Bornträger, 1841, p. 769; Id., *Handbuch der Wasserbaukunst. Zweiter Theil: Die Ströme und Kanäle*, Königsberg, Gebrüder Bornträger, 1852, p. 20; Id., *Brunnen, Wasserleitung und Fundirungen*, Berlin, Ernst & Korn, 1870, p. 311. Further locks along the Ruhr are built in Ruhrtort (achieved in 1841), Duisburg (the lock on the Ruhr channel and the lock of the harbour, achieved in 1844), Dahlhausen (achieved in 1844) and Mühlheim (achieved in 1845) (see Hoffmann, *Beton-Fundirungen...cit.*, p. 5).

Ratingen, whereas *Trass* is taken from Brohl and Andernach, and is transported first along the Rhine, then along the Ruhr up to the building sites. Each measure of *Trass* is mixed with about $\frac{1}{2}$ measure of slaked lime to prepare mortar, which is then mixed with twice as much aggregate. The foundation site is first dug up and shored with sheet piles along the minor sides, whereas poles are rammed 4 feet apart from each other along the major sides, and the spaces between the poles are filled with boards and strips. (fig. 4.1.2 [fig. 1, 2]) Once this is achieved, mud is swept away from the bottom of the pit using a special shovel provided with a long handle and a rope (fig. 4.1.3), and concrete is poured down using boxes similar to those that Bélidor describes (fig. 4.1.2 [fig. 1–5]). Three layers of concrete are poured upon each other and tamped with a tool made of a flat stone fixed at a long pole (fig. 4.1.4). About eight days later, when concrete has set and hardened a little, three further provisional timber shores are built on the concrete bed, two along the major sides and one along the short side upstream, at a certain distance from the previous shores, so that they form three formworks to be filled with concrete, in order to realize three 10 feet high permanent walls, which are intended to act as retaining walls along the most stressed sides of the lock chamber. (fig. 4.1.5 [fig. 6]; 4.1.1 [figg. 261 a,c,d,l]) This last one is then built out of ordinary stone and brick masonry work, standing partially on the concrete bed, and partially on the just-mentioned concrete walls.

The building of the locks along the Ruhr also deserves a special attention for the use mortar and concrete mixers powered by steam engines. Concrete mixers consist of eight-sided wooden drums hinged on standing structures, and are provided with built-in rotating iron shafts, so that drums rotate and mix mortar and aggregate together.² Mortar mixers, instead, are similar to pug mills; a typical one essentially consists of an immobile horizontal drum containing a central rotating shaft provided with several knives and connected to the steam engine (fig. 4.1.2 [fig., 7–9]). The drum can either be made of wood or sheet iron; it is fixed on two poles and has got a longitudinal opening on the upper part of it to charge lime and *Trass*. When the steam engine works, the shaft rotates and the several knives mix lime and *Trass*, which come out as mortar through a trap door placed on the bottom of the drum.³ The fact that the drum lies horizontally is worth of attention, seeing that pug mills of that time generally stand, and consequently have a vertical rotating shaft. Writing just about the building of the Ruhr locks, the hydraulic engineer Gotthilf Heinrich Ludwig Hagen (1797–1884) puts into evidence this feature, and refers to mortar pug mills used in France, namely the ones employed to build the Pont de Neuilly, the Canal de Saint Martin, and the harbours of Lorient and Toulon.⁴ Apart from the vertical position, one of the pug mills used to build the Canal de Saint-Martin shows important similitude with the pug mills used along the Ruhr. A carefully description of it is given by the engineer of the “Corp des Ponts” Édouard de Villiers du Terrage (1780–1855) in 1826. The machine “consists of an iron framed barrel,” De Villiers relates, “which is larger at the top and tighter at the bottom, and of a vertical iron shaft

² Hagen, *Handbuch der Wasserbaukunst. Erster Theil...*cit., p. 777; Id., *Brunnen, Wasserleitung...*cit., p. 323.

³ Hagen, *Handbuch der Wasserbaukunst. Erster Theil...*cit., pp. 768–69; Id., *Brunnen, Wasserleitung...*cit., p. 311.

⁴ Hagen, *Handbuch der Wasserbaukunst. Erster Theil...*cit., pp. 769–70.

provided with knives and rakes that turn horizontally inside the barrel at different levels.”⁵ De Villiers defines this pug mill “*machine à mortier anglaise*” hinting at an English origin, which is actually to be found in the so-called “clay cutting tool” used in British porcelain factories.⁶ (fig. 4.1.5) Mortar mixers used in France are human or animal-powered machines, unlike the German ones used on the building sites of the Ruhr locks, and this is probably the reason that the first stand vertically and the second lie horizontally. A horse moves on a horizontal plan and can easily push a beam fixed on a vertical shaft, whereas steam engine flywheels normally stand vertically and can rotate a horizontal shaft by means of a simple chain, easier than a vertical shaft. The pug mills used along the Ruhr could therefore be seen as machines adjusted to the new steam technology, whose adoption is favoured by the local availability of coal.

At the same time as the river Ruhr begins to be improved as waterway, a railway line is planned to link the towns of Düsseldorf and Elberfeld, through a mining region stretching along the river Wupper, a further tributary of the Rhine. The railway is built between 1838 and 1841, entailing the construction of a huge bridge across the Wupper, close to the village of Sonnborn.⁷ (fig. 4.1.6–7) The engineer Friedrich Eduard Salomon Wiebe (1804–1892), who is already entrusted with the building of the entire railway, designs the bridge. Wiebe has studied at the Berlin Bauakademie at the time as Dietlein teaches *Straßen-, Brücken-, Schleusen- und Kanalbau*, and, once promoted master builder in 1836, he travels through Belgium, France and England.⁸ It is probably through these experiences that he learns about concrete and, when he comes to design the bridge of Sonnborn, he chooses to build three of the five freestanding piers on concrete foundations. (fig. 4.1.8) The foundation of the central pier is provided with timber piles, whereas the two lateral ones stand straight on the soil, which is made of gravel and clay. Concrete is produced using local *Trass* and it is poured into the foundation pits only after that these ones have been dried out; this shows evidence of the lack of expertise about concrete building at that time.⁹

⁵ “[...] se compose d’un tonneau cerclé en fer, et un peu plus étroit en haut qu’en bas, [...] et d’un arbre vertical en fer, armé de couteaux et de rateaux [sic]; tournant horizontalement à différentes hauteurs dans ce tonneau” (Édouard de Villiers du Terrage, *Description du Kanal de Saint-Denis et du Canal Saint-Martin*, Paris, Carilian-Goeury, 1826, p. 37).

⁶ See J. Bastenaire-Daudenart, *Die Kunst weisses Steingut anzufertigen mit durchsichtiger Glasur nach Art der Franzosen und Engländer anzufertigen: nebst einer Abhandlung über die im Musselfeure eingeschmolzenen Steingutfarben*, ed. Georg Frick, Ilmenau, Bernhard Friedrich Voigt, 1832, pp. 54–55 (Id., *L’Art de fabriquer la Faience blanche, recouverte d’un émail transparent à l’instar français & anglais suivi d’un traité de la peinture à revêbère*, Paris, Anselin, 1830). A further description and an illustration of the “clay cutting tool” is also to find in Johann Wilhelm David Korth, Johann Georg Krünitz’s *Oekonomische Encyklopädie oder allgemeines System der Staats-Stadt-Haus- und Landwirthschaft*, vol. CLXXII, Berlin, Pauli, 1839, entry “Steingut”, pp. 342–90, esp. pp. 361–62 and pl. I, fig. 8974.

⁷ See [Eduard] Römer, *Die Düsseldorfer-Elberfelder Eisenbahn*, in *Allgemeine Bauzeitung*, VIII, 1843, (pp. 60–77), pp. 62–64.

⁸ See Hermann Julius Meyer, ed., *Meyers Konversations-Lexikon: eine Eycyklopädie des allgemeinen Wissens*, Leipzig, Wien, Bibliographisches Institut, vol. XVI, 1890, p. 592, entry “Wiebe”.

⁹ “In order to pour the concrete layer as much carefully as possible, water was pumped out during this work” (“Um die Betonschicht möglichst sorgfältig schütten zu können, wurde das Wasser während dieser Arbeit ausgepumpt” Römer, *Die Düsseldorfer-Elberfelder Eisenbahn...cit.*, p. 63).

Further examples of concrete foundations are to be observed in the town of Mannheim, which is situated at the confluence of the rivers Rhine and Neckar, and where a new port is built between 1835 and 1840, along the artificial canal that connects the two rivers bypassing the natural mouth, which is considered unfit for navigation. The quays of the port are built on foundations made of timber piles, frameworks, and *Trass*-based concrete poured into the free fields of the frameworks, among the piles heads, similar to certain foundations by Wiebeking. As already observed for the building of the bridge in Sonnborn, water is drained out from the foundation pits before concrete is poured, and an impressive Archimedes screw powered by about twenty men, pulling and pushing beams connected to the screw shaft, is set up for this purpose.¹⁰ (fig. 4.1.9)

During the building of this port, the city council of Mannheim takes the decision to build a suspension bridge over the Neckar, and entrusts the engineer Wendelstadt with planning of it in 1839, shortly after the opening of the Hamelin Bridge. (fig. 4.1.10) Wendelstadt submits the plans in 1840 and the bridge is built between 1842 and 1845, with the collaboration of Adolph Funk (1819–1889), an architect from Hannover, and Georg Lüttich, an engineer who has already taken part to the construction of the Hamelin Bridge. The piers of the bridge in Mannheim stand on 7 feet high beds of concrete, which is poured straight onto the soil inside enclosures made of sheet piles, which are dried out by means of lift pumps. (fig. 4.1.11–13) A closed cofferdam is built all around the top of each concrete bed, in order to form a further watertight enclosure in which workers build the early masonry layers of the piers. The lowest parts of these cofferdams (about 7 feet high) are made of concrete, whereas the upper parts (about 5 feet high) are made of clay. Concrete is produced in a provisional cabin on the riverside, by mixing slaked lime, *Trass* and aggregate. Once prepared, it is charged into wagons on rails and transported from the riverside to the pouring places, via a provisional bridge. It is then poured into the foundation pits by means of boxes, each one hanging from a crane by eight ropes, and being provided with two trap doors that workers can open by releasing two chains and four ropes. Each crane is provided with two rollers and a gearshift; it can be moved on rails, which in turn lie on a movable bridge, so that concrete can be easily and uniformly poured all over the bottom of the pit. (fig. 4.1.12) The use of local *Trass* to build the foundation of the Mannheim Bridge, despite the fact that Wendelstadt is a cement maker, is evidence of how important the local availability of *Trass* is to determine the composition of concrete. And this is also further stressed by the building of the *Trass*-based concrete foundations for the piers of the suspension bridge of Mühlheim am Rhein, which is built between 1842 and 1844 and becomes known as the *Schloßbrücke*; and by the *Trass*-based concrete foundation of the lock along the Ruhr, which is also built in Mühlheim am Rhein between 1843 and 1844, following the model of the lock at the paper mill in Werden.¹¹

¹⁰ See Anon., *Technische Notizen auf einer Reise nach dem Unter-Rhein, im Herbst 1835*, in *Zeitschrift über das gesammte Bauwesen*, I, 1836, (pp. 101–07), p. 101.

¹¹ See Hoffmann, *Beton-Fundirungen...cit.*, p. 6;

4.2 Concrete foundations in Bavaria and Pomerania, the exploitation of local hydraulic lime

The building of the canal to connect the rivers Danube and Main, commonly known as Ludwig-Kanal, becomes a significant occasion for using Bavarian hydraulic lime to produce mortar and concrete, on the wake of Fuchs and Panzer's advices. The engineer Heinrich Joseph Alois Freiherr von Pechmann (1774-1861) designs the canal between 1828 and 1832.¹² It stretches from Kelheim to Bamberg, partially exploiting the rivers Altmühl and Regnitz, and involving the building of ninety-eight masonry locks, several bridges, culverts and embankments.¹³ (fig. 4.2.1-2)

In 1836, shortly before works start, some arguments arise about how to ensure the waterproofing the bed of the canal.¹⁴ Von Pechmann's intention is to exploit the principle of filtering cloudy water through sand. He plans to fill up the canal, stretch after stretch, with water containing clay, which is supposed to filter through the natural sandy bed of the canal, until this is completely clay-logged and, therefore, watertight. "Cloudy water," Von Pechmann reasons, "becomes clear after flowing through sand, which keeps back all particles that make water cloudy; in this way, sand becomes waterproof."¹⁵ To prove his assertion, Von Pechmann mentions the water purification plant in Paris, which consists of sand filters being replaced periodically because they get saturated. In addition, he also

¹² About the conception and the building of the Ludwig-Kanal see Heinrich Joseph Alois von Pechmann, *Entwurf für den Kanal zur Verbindung der Donau mit dem Main*, München, 1832; Carl Theodor von Kleinschrod, *Die Kanal-Verbindung des Rheins mit der Donau: unter Benutzung amtlicher Quellen beleuchtet*, München, G. Frank'sche Buchhandlung, 1834; *Auszüge aus den Protokollen der zweiten Generalversammlung der Aektiengesellschaft für den Ludwig-Donau-Main-Kanal*, voll. I-XII, 1836-1848, esp. vol. II, 1837, pp. 31-49, vol. III, 1838, p. 20, vol. IV, 1839, pp. 47-49, vol. V, 1840, p. 24; Heinrich Joseph Alois von Pechmann, *Der Ludwig-Kanal. Eine kurze Beschreibung dieses Kanals und die Ausführung desselben*, München, Joseph Lindauer'sche Buchhandlung, 1846; Friedrich Schultheis, *Der Ludwig-Kanal. Seine Entstehung und Bedeutung als Handelsstrasse*, Nürnberg, Hofmann, 1847; Heinrich Joseph Alois Freiherr von Pechmann, *Der Ludwigskanal. Kurze Geschichte seines Baues und seiner noch bestehenden Mängel, sowie die Mittel, sie zu entfernen und zu verbessern und den Kanal zu seiner Vollkommenheit zu erheben*, Nürnberg, Friedrich Korn'schen Buchhandlung, 1854; G. Dulk, *Notizen über den Ludwigs-(Main-Donau)-Kanal*, in *Zeitschrift Für Bauwesen*, XII, 1862, coll. 227-38. Building materials are quarried along the course of the waterway, including limestone to produce hydraulic lime, see Schultheis, *Der Ludwig-Kanal. Seine Entstehung und Bedeutung...*cit., pp. 42, 53.

¹³ The course of the river Altmühl is exploited between Kelheim and Dietfurt, whereas the course of the river Regnitz is exploited between Bamberg to the confluence with the Main. Von Pechmann initially plans to build ninety-four locks but, during the building, the number of locks needs to be upgraded to ninety-eight.

¹⁴ The bill for the building of the Ludwig-Kanal is released in 1834, one year later the Aektiengesellschaft für den Ludwig-Donau-Main-Kanal is founded, and early excavation works begins in 1836, near Nurnberg and Bamberg.

¹⁵ "Die Natur hat dem Sande die Eigenschaft gegeben, trübes Wasser rein durch sich hindurch laufen zu lassen, und die Körper, die es trübes machen. in seinen Zwischenräumen zurück zu halten. Dadurch allein macht die Natur den Sand wasserdicht" (Heinrich Joseph Alois von Pechmann, *Über die Mittel, welche angewendet werden, um die in Sandboden gegraben Theile des Ludwigs-Kanals wasserdicht zu machen*, in *Journal für die Baukunst*, (XV, 1841, pp. 160-79; XXII, 1845, pp. 1-14), XV, 1841, p. 162). About the waterproofing of the Ludwing-Kanal see also: Heinrich Joseph Alois von Pechmann, *Ueber die angewendeten Mittel, um die in Sand gegrabenen Theile des Ludwigskanales wasserdicht zu machen*, in *Allgemeine Bauzeitung*, V, 1840, pp. 375-82, (this articles is translated into French, see Id., *Moyens employés pour rendre étanche le Canal Louis au droit des biefs creusés dans le sable*, in *Annales des Ponts et Chausses*, 1841, pp. 18-34); Von Pechmann, *Der Ludwig-Kanal. Eine kurze Beschreibung...*cit., pp.38-42; Von Pechmann, *Der Ludwigskanal. Kurze Geschichte seines Baues...*cit., 1854, pp. 53-67.

mentions the canals and basins in the park of Nymphenburg near Munich, which are built in sandy soil without resorting to any special waterproofing system.¹⁶ In order to verify what he maintains, in March 1836, Von Pechmann digs a 4 feet deep and 6 square feet wide pit in the sandy soil of a garden in Nurnberg, and fills it up with running water coming through an appropriate pipe from a near basin. Eight days later, he verifies that the sandy soil has become watertight, but such evidence is not enough convincing for the *Kanalbaudirektion*, the body that manages the building of the canal, and, on the wake of arisen perplexities, Panzer, who has been meanwhile appointed responsible for the building of the canal stretch between Forcheim and Bamberg, comes into play and proposes to pour a kind of mortar made of hydraulic lime and water onto the canal bed to make it waterproof. Other engineers propose, instead, either to tamp clay on the canal bed, or to cover it with stone plates joined by means of hydraulic mortar or moss. Von Pechmann agrees to test these different techniques, including the one proposed by Panzer, on a canal stretch near Nurnberg. Panzer's mortar proves to harden quite rapidly, but several splits arise and make it ineffective. In spite of that, Panzer does not give up the idea of exploiting hydraulic lime to waterproof the canal and undertakes a second attempt using a mixture made of slaked lean lime, hydraulic lime, sand and gravel, which can be considered a sort of concrete. This attempt also fails, and Von Pechmann complains that the mixture used by Panzer "could be scraped off with the soil of a boot."¹⁷

Panzer's proposals are set aside, but further occasions to use Bavarian hydraulic lime-based concrete arise when the construction of the locks begins. Von Pechmann originally plans to build locks on masonry foundations, resorting to timber pilings only in case of very unsteady soil. He even asserts having illustrated a lock standing on a timber piling foundation in the atlas containing the initial plans for the building of the canal.¹⁸ A still existing atlas, whose dating remains controversial but should be antecedent to 1835, shows, however, a stone and brick masonry lock standing on a 2 feet high layer of not better-explained material, which is represented using a pattern that hints at a sort of conglomerate.¹⁹

¹⁶ Von Pechmann, *Über die Mittel, welche angewendet werden, um die in Sandboden gegraben Theile des Ludwig-Kanals wasserdicht zu machen...* cit., XV, 1841, p. 163; Id., *Über die angewendeten Mittel, um die in Sand gegrabenen Theile des LudwigsKanales wasserdicht...* cit., p. 375.

¹⁷ "[...] von Froste ausgelöset, daß ich, so wie jeder, der es versuchte, sie mit der Sohle des Stiefels abschaben konnte" (Von Pechmann, *Der Ludwigskanal. Kurze Geschichte seines Baues...* cit., p. 58). In spite of the essential failures, Panzer attaches great importance to the use of hydraulic lime for the building of the Ludwig-Kanal, he describes the attempts he has carried out in a specific chapter joined to his 1836 book about hydraulic lime (see Friedrich Panzer, *Mittel gegen das Versickern des Wassers in Sandboden*, in *Ueber das Vorkommen...* cit., pp. 38–40, also published in *Allgemeine Bauzeitung*, III, 1838, p. 402). Seeing the disappointing results of the test, Von Pechmann finally waterproofs the canal bed filtering water mixed with clay, and, over some stretches, with mud (see Von Pechmann, *Der Ludwigskanal. Kurze Geschichte seines Baues...* cit., pp.58–59).

¹⁸ See Von Pechmann, *Der Ludwigskanal. Kurze Geschichte seines Baues...* cit., 1854, p. 68.

¹⁹ See Heinrich Joseph Alois von Pechmann, *Atlas zu dem Entwurfe für den Kanal von Donau an den Main*. Most libraries dates this atlas back to 1832, as it should have been joined to the book *Entwurf für den Kanal zur Verbindung der Donau mit dem Main* published in 1832 (see n. 16). As a matter of fact, the *Description des principales collections que renferme l'établissement géographique de Bruxelles, fondé par Ph. Vandermaele*, contained in *Dictionnaire des hommes de lettres, des savans, et des artistes de la Belgique* also lists an *Atlas zu dem Entwurfe für den Kanal von Donau an den Main* dating it back to 1832

(fig. 4.2.3) The same pattern is used to draw the covering of artificial canal beds on navigable bridges.²⁰ (fig. 4.2.4a,b) Despite plans, and despite the fact that the ninety-eight locks of the canal are “to be built on very different kinds of soil, from the most solid made of rocks to some kinds of marshy peat soil,” timber piles are not used and most locks are “built on a between 3 and 4 feet tick beds of masonry work laid all over the foundation sites, and bound with hydraulic mortar.”²¹ Difficulties arise however in the building of four locks situated close to the rivers Danube, Altmühl and Regnitz, which provoke strong flooding and make drainage systems ineffective.²² (fig. 4.2.5–9) The building of cofferdams is therefore considered necessary and, to realize them, Von Pechmann takes inspiration from the lock of Huningue, which the already mentioned French engineer Beaudemoulin has built in 1825 to connect the “Rhone-Rhine Canal” to the Rhine.²³ Beaudemoulin had originally planned to build a masonry lock standing on a concrete bed foundation, inside a pit surrounded by ordinary cofferdams made of clay rammed between timber walls. An unexpected landslide, however, occurred along one of the major sides of the pit during the excavation works, and reduced the available space. This drove Beaudemoulin to conceive an innovative construction consisting of a watertight encasement composed of a concrete bed as base, two rows of sheet piles along the minor sides, and two trapezoidal concrete cofferdams along the major sides, with sloping faces towards the interior of the encasement. (fig. 4.2.10) Once the water has been drained, the walls of the lock chamber are partially built on the sloping sides of the concrete cofferdams, which become an essential part of the entire construction, instead of just being provisional works. Beaudemoulin himself writes of “a concrete encasement, which becomes part of the lock walls, after having acted as cofferdams.”²⁴ Moving from this example, Von Pechmann develops the idea of building similar watertight encasements, each one being made of a 3½ feet thick bearing bed of concrete and four concrete cofferdams, two trapezoidal ones along the major sides, similar to those that

(see *Dictionnaire des hommes de lettres, des savans, et des artistes de la Belgique: présentant l'énumération de leurs principaux ouvrages; suivi de la description des principales collections que renferme l'Établissement géographique de Bruxelles*, Bruxelles, Etablissement géographique fondé par Ph. Vandermaelen, 1837, p. 245). However, the Landesarchiv Baden-Würtemberg only provides for Von Pechmann's Atlas the general indication of “antecedent 1835”, see *Atlas zu dem Entwurfe für den Kanal von Donau an den Main* back, Landesarchiv Baden-Würtemberg, GA 105 Nr. 842 1-10.

²⁰ Initially 13 navigable bridges are planned, but only 10 are actually built (see Rotraut Trapp, *Die Brücke des Ludwig-Donau-Main-Kanals*, in *Frankenland. Zeitschrift für fränkische Landeskunde und Kulturpflege*, 2003, (pp. 287–306), p. 289).

²¹ “Die 98 Schleusen des Ludwigs-Kanals müssten, wie bei der Länge desselben von 23 deutschen Meilen zu erwarten war, auf sehr verschiedenartigen Boden gegründet werden. Er wechselt von festem Felsengrund bis zu beinahe sumpfartigem Torfboden. Dennoch wurde bei keiner einzigen Schleuse ein Rost angewendet. Sie sind alle auf eine 3 bis 4' hohe, über die ganze Grundfläche der Schleuse sich ausdehnende Schicht von Mauerwerk gegründet, das mit guten, hydraulischen Mörtel ausgeführt ist” (Von Pechmann, *Der Ludwig-Kanal. Eine kurze Beschreibung*...cit., p. 43).

²² “As we began to dig the pits for these locks, floods from the nearby Regnitz and Danube were so strong that it was impossible to drain out water” (“Bei 4 dieser Schleusen war, als man die Baugrube auszugraben anfing, der Zudrang des Wassers in dieselbe aus der nahen Regnitz und Donau so groß, daß man es unmöglich fand, die Baugrube durch Schopfwerkzeuge leer zu halte” Von Pechmann, *Der Ludwig-Kanal. Eine kurze Beschreibung*...cit., p. 44).

²³ See Louis Alexis Beaudemoulin, *Recherches théoriques et pratiques sur la fondation par immersion des ouvrages hydrauliques et particulièrement des écluses*, Paris, Carilian-Goeury, 1829, esp. pp. 6–32.

²⁴ “[...] un encaissement de béton qui, après avoir fait fonction de batardeaux, entrerait ensuite dans le massif de la maçonnerie des bajoyers” (Beaudemoulin, *Recherches théoriques et pratiques*...cit., p. 12).

Beaudemoulin had built, and two minor ones with rectangular transversal sections along the short sides, which are intended to be later demolished in order to build up the lock gates. (fig. 4.2.11) Concrete is mixed in horizontal drums, which are powered manually, and it is poured into the foundation pits by means of boxes hanging from movable manual bridge cranes. (fig. 4.2.12) The concrete caissons remain full of water over a winter, and, once the concrete has hardened and the water has been drained out, masons build the walls of the lock chamber, partially on the trapezoidal cofferdams. Besides the reference to Beaudemoulin's lock, it is anyway to point out that the practice of building the walls of the lock chamber partially on the underground retaining concrete walls is already to be observed, although just *in nuce*, in the already mentioned locks along the Ruhr. (fig. 4.1.1)

The four locks on concrete foundations are built between 1836 and 1841. Two are situated in Bamberg (one at the so-called Bughof, south of the town, and one at the Nonnengraben, in very centre of the town), one in Kelheim, and the forth one is probably the Windmühlenschleuse in Erlangen, because of its proximity to the river Regnitz, although Von Pechman does not explain this in detail. (fig. 4.2.5-9) The building of the lock at Bughof starts first, and it therefore acts as a sort of trial construction, also being the occasion to experiment with three different concrete mixtures. The first is made of fine milled hydraulic lime and coarse-grained brick powder, the second is made of hydraulic lime and sand, and the third is a mixture of black lime from Bamberg, sand and brick powder.²⁵ This last mixture is the most affordable one, and also proves to be as good as the first two ones. Von Pechmann gives a mention of the hardness of concrete. "The two longitudinal cofferdams," he writes in this regard, "were so strong that they could be partially used as sidewalls of the chamber, whereas the short cofferdams upstream and downstream were demolished and the debris was used to build the wing-walls."²⁶

It is still worth mentioning that a further, but minor occasion to use concrete along the Ludwig canal is given by the building of several road-bridges. They are timber framework bridges resting on masonry abutments, which are made of unrefined cut stones and are provided with a 40 cm high concrete platforms at the top, which act as bearing decks for the timber beams.²⁷ (fig. 4.2.14)

While the building of the Ludwig canal in Bavaria is coming to the end, the engineer Friedrich Neuhaus (1797–1876) and the master builder Schwan construct an impressive concrete foundation, partially on timber piles, for a 1.309 feet long quay, which is built between 1842 and 1844, along the

²⁵ See W. Winckelmann, *Ueber die Fundirung der Schleuse Nr. 93 des Ludwigs-Kanals, an der Ausmündung desselben in die Regnitz bei Bamberg*, in *Zeitschrift für praktische Baukunst*, 1843, (pp. 231–35), p. 231.

²⁶ "Die beiden Seitenwände dieser Kästen konnten auf Grund ihrer erreichten Festigkeit für die Seitenmauern der Schleusenkammer mit verwendet werden. Die an den beiden Schmalseiten von Ober- und Unterhaupt befindlichen Wände dieser Kästen wurden ausgebrochen und diese Bruchstücke zum Bau der Flügelmauern verwendet" (Von Pechmann, *Der Ludwigskanal. Kurze Geschichte seines Baues...*cit., p. 69).

²⁷ Trapp, *Die Brücken des LudwigDonau-Main-Kanals...*cit., p. 298.

river Oder in Stettin.²⁸ The quay is part of the general construction plan of the Stettin railway station, and it is intended to be the juncture between land and water transports, serving as a mooring for ships and as platform for rails (fig. 4.2.14 [fig. 1]).

A number of difficulties characterize this building task. Due to the tightness of the land lot, the quay needs to be built in water, rather than on the riverside, in order to create later some land-surface by burying a strip of river. Moreover, the consistency of the soil changes along the riverbank, from sandy and unsteady to rocky, and the depth of the foundation consequently changes as well. The building site is divided into six sections; a kind of foundation consisting of a 10 feet high concrete basement standing straight on rocks is planned for the first two sections upstream, whereas the foundations along all other sections are provided with timber piles and concrete is poured among the upper parts of the piles forming a between 13 and 40 feet high basement, which is finally covered with timber beams and boards. (fig. 4.2.15 [fig. 3-5])

Since *Trass* is too costly in Stettin because of transport, the use of hydraulic lime produced by burning marls from the nearby island of Wollin is taken into consideration.²⁹ The chemical composition of Wollin marls is investigated, proving that it mainly consist of lime (about 80%) and silica (about 10%), besides minor quantities of clay and iron oxides. The underwater hardening of mortar made with Wollin hydraulic lime is furthermore verified, checking the consistence of samples kept covered with water in glasses, eight days, and four weeks long. The concrete strength is also tested charging, with rails, a 3 square feet wide and 1 feet high specimen that has hardened four weeks long underwater in the Oder.³⁰

The production of mortar and concrete is fully mechanized. Necessary installations are placed close to the riverside and consist of a mortar mixer, eight drums to mix concrete, and a steam engine to power all machineries. (fig. 4.2.16) The mortar mixer is essentially composed of a circular pit provided with five fixed toothed spokes on the bottom, and a turning wheel provided with six toothed spokes at the top. (fig. 4.2.17) When the wheel turns, teeth mix together sand and lime, and mortar flows through a side opening into a lower pit, pushed by the centrifugal force that the turning speed produces. Since it is a mortar mixer with a vertical rotating shaft, the connection with the flywheel is ensured by a chain and a pulley, unlike the case of the mortar mixers observed for the building of the Ruhr locks. It is probably worth noting that, approximately at the same time as the Stettin quay is under construction, the engineer Carl Wilhelm Hoffmann uses a similar mortar mixer on the building site of the Berlin

²⁸ See L. Schwan, *Beschreibung des Baues einer Kaimauer zu Stettin an der Oder vorlängs des dortigen Eisenbahnhofes, insbesondere des dabei in Anwendung gebrachten Gründungsverfahrens mittelst Beton aus Wolliner Mergelkalk*, in *Zeitschrift für Praktische Baukunst*, VIII, 1848, coll. 145–62. About Fridrich Neuhaus, see Anon., *Friedrich Neuhaus - Ein vergessener Eisenbahnpionier*, in *Mitteilungen des Vereins für die Geschichte Berlins*, LXXVIX, 1983, pp. 109–13.

²⁹ See Schwan, *Beschreibung des Baues einer Kaimauer zu Stettin...cit.*, coll. 160–61.

³⁰ The Prussian Centner is about 50 kg.

Neues Museum by Friedrich August Stüler (1800–1865).³¹ The origin of such machines is actually to be found in France, in the mortar mixer invented by German Boffrand toward the middle of the 18th century, and made particularly famous by Perronet, who used it on the building site of the Pont de Neuilly.³²

Once the mortar is ready, it is mixed in the concrete drums with crushed stones, bricks, and rubbles taken from the demolition of nearby fortification walls. Concrete then falls from the drums straight into wagons on rails, to be transported to the riverside and put into barges that supply it all along the building site. Schwan asserts having later improved the kind of concrete mixer used to build the foundation of the quay along the Oder, by installing the drum on a sloping structure, so that concrete components can be charged from the upper extremity, and got out from the lower extremity, once mixed.³³ (fig. 4.2.18) This kind of sloping concrete drums, which Schwan pretends having invented, is actually reminiscent of the frustum-shaped concrete drums that are used in France for the building of the Paris fortification as of 1840, and that the *Allgemeine Bauzeitung* publishes in 1843.³⁴ (fig. 4.2.19)

The first construction phases of each stretch of the Stettin quay consist in ramming two rows of sheet piles into the riverbed; the one towards the river stream is stronger and slopes towards the landside, whereas the opposite one is lighter and stands vertically. Once this is achieved, concrete is poured by means of boxes into the foundation pits along the stretches where no timber piling is planned; otherwise, first piles are rammed, and then concrete is poured down. Piles also slope according to the angle of the sheet piles, and a special kind of box is conceived to pour concrete among them. It is narrow and it is connected to a long handle by means of a hinge, so that worker can push the box slantwise between the sloping poles. (fig. 4.2.15)

The increasing need for underwater concrete foundations between the second half the 1830s and the first half of the 1840s urges the awareness of how crucial the availability of effective and affordable hydraulic binders is, especially in places where neither *Trass*, nor natural hydraulic lime are available, and gradually opens the way to the manufacturing of artificial cements. An evidence of such awareness is given by the words that the Bavarian engineer Carl Maximilian von Bauernfeind (1818–1894) writes, in this regard, in 1843. Charged by the Nurnberg Railway-Committee with trials aiming at producing artificial hydraulic lime from materials findable near the towns of Hof and Münchberg, Von Bauernfeind states: “the need for hydraulic lime becomes particularly crucial [...], when the conditions of the soil on which bridges, culverts, locks and other masonry works need to be built, impose the use of

³¹ The building site for the Neues Museum is considered one of the most advanced of that time, in this regard see Werner Lorenz, *Classicism and high technology - the Berlin Neues Museum*, in *Construction History*, vol. XV, 1999, (pp. 39–55), pp. 45–48.

³² See Gargiani, *Concrete from archeology*...cit., pp. 150–51.

³³ Schwan, *Beschreibung des Baues einer Kaimauer*...cit., col. 155.

³⁴ See Alfred Lecointe, *Bemerkungen über einige mechanische Verfahrungsarten zur Bereitung des Mörtels und Betons*, in *Allgemeine Bauzeitung*, VIII, 1843, pp. 399–400.

concrete foundations. [...] even in case no natural hydraulic lime is available, there are materials to produce it artificially, reaching the same quality at lower costs.”³⁵ A few years later, the master builder Schwan reports about the construction of the Stettin quay and complains that, although “concrete is recognized as one of the most valuable materials to build underwater, a general use of it is limited by the fundamental need of costly Trass, in places where natural hydraulic lime is not available.”³⁶

4.3 Lean conglomerate for rural buildings, the development of *Kalksand*

While the use of concrete is entering the domain of underwater constructions, some publications in technical literature report about above ground concrete constructions that have been realized abroad. From 1832 onward, the *Polytechnisches Journal* reports about the buildings entirely made of concrete that the architect François-Martin Lebrun has been constructing in southern France as of 1828.³⁷ The book about concrete constructions that Lebrun publishes in 1835 in Paris is soon translated into German and published in 1837 in Ulm (Wurttemberg).³⁸ Although Lebrun describes concrete as appropriate to all kinds of construction, the German editor takes care to stress a sort of prevalent suitability of concrete for hydraulic works and for building vaults, and he furthermore highlights how crucial the availability of local hydraulic lime is to produce affordable concrete. These are essential aspects of the spread of concrete building in Germany. We have already stressed the importance given to

³⁵ “Der Mangel an hydraulischem Kalk wird bei Wasserbauten um so mehr fühlbarer, [...], wenn der Baugrund für Brücke, Dürchlässe, Schleusen und anderes Mauerwerk, Betonfundationen bedingt.” “[...] wenn wir auch kein natürlichen hydraulischen Kalk besitzen, so fehlt es uns doch nicht an Materialien, künstlichen zu bereiten, der, bei gleicher Qualität, viel billiger ist als jener” (Carl Maximilian von Bauernfeind, *Ueber hydraulischen Kalk und Mörtel aus Natur- und Kunstprodukten des Fichtelgebirgs*, in *Kunst- und Gewerbe-Blatt des polytechnischen Vereins für das Königreich Bayern*, XXVIII, 1843, (coll. 624–47), coll. 624–25).

³⁶ “Eines der schätzenswerthesten Materialien zum Wasserbau ist anerkannt der Beton, dessen allgemeiner Anwendbarkeit nur der Umstand entgegen steht, daß die Herstellung der Masse in größeren Quantitäten für alle diejenigen Gegenden zu theuer wird, wo sich ein natürlichen hydraulischer Kalk nicht vorfindet und zur Bildung des Mörtels die sehr kostspieligen Zuschläge von Trass angewendet werden müssen” (Schwan, *Beschreibung des Baues einer Kaimauer zu Stettin an der Oder...cit.*, coll. 160–61).

³⁷ See Charles-Pierre Gourlier, *Bericht des Hrn. Gourlier über eine Abhandlung des Hrn. Lebrun d. jüng., Maumeister zu Alby, Dept. du Tarn, die Anwendung des Grund oder Steinmörtel (béton) zum Baue ganzer Wohnhäuser betreffend*, in *Polytechnisches Journal*, XIII, vol. XLIV, 1832, pp. 114–19 (Id., *Rapport fait par M. Gourlier, au nom du Comité des arts économiques, sur un mémoire de M. Lebrun jeune, architect à Alby, département du Tarn, relatif à l'emploi du béton pour la construction entière d'une maison d'habitation*, in *Bulletin de la société d'Encouragement pour l'Industrie Nationale*, XXXI, 1832, pp. 99–103); Anon., *Ueber die Benutzung des Steinmörtels zu verschiedenen Bauten*, in *Polytechnisches Journal*, XVI, vol. LXII, 1836, p. 155; Charles-Pierre Gourlier, *Ueber das Verfahren des Hrn. Lebrun, Bauten aus Wassermörtel; ein der Société d'Encouragement von Hrn. Gourlier erstatteter Bericht*, in *Polytechnisches Journal*, XXII, vol. LXXXV, 1842, pp. 431–33 (Id., *Rapport fait par M. Gourlier, au nom du Comité des arts économiques, sur les constructions en béton de M. Lebrun, architecte à Montauban (Tarn-et-Garonne)*, in *Bulletin de la société d'Encouragement pour l'Industrie Nationale*, XLI, 1842, pp. 283–286).

³⁸ François-Martin Lebrun, *Méthode pratique pour l'emploi du béton en remplacement de toute autre espèce de maçonnerie dans le construction en général*, Paris, Chez Carilian Goeury, 1835; Id., *Der Steinmörtel oder praktische Anweisung den Steinmörtel bei Gebäuden im Allgemeinen, besonders aber bei Bauten an und unter dem Wasser, bei Gewölben etc. statt jeder andern Art von Mauerarbeit Vortheil zu benutzen*, Ulm, Nübling, 1837.

the exploitation of local raw materials to produce hydraulic binders, and the rising awareness about the importance of concrete to build underwater, while, the ambition of building conglomerate vaults gradually develops as of about the second half of the 1840s as an essential aspect of the German building culture, even with some references to conglomerate vaults of the Roman antiquity. In order to better seize the German approach to Lebrun's way of building in concrete, it is worth quoting a passage taken from the preface to the just mentioned translation. "The concrete buildings by Mr Lebrun," the text goes on, "are durable, as it has been certified by Committees, and affordable, in comparison to all other kinds of masonries; they might therefore produce an essential change in the current way of building, especially underwater, and for the construction of vaults. Wurttemberg and other German States have even an edge on France, since they have plenty of natural hydraulic lime, which is an essential material to produce concrete, and they do not need to produce it artificially."³⁹ It is still worth noting that the term *Béton* is translated with the old German compound word *Steinmörtel*, which was already to be found in some dictionaries from the 18th century.⁴⁰ As already observed dealing with Wiebeking's *Wasserbaukunst*, the term *Béton* gradually enters the German language under the influence of French building culture, firstly in the specific lexicon of hydraulic engineering, and later in the general lexicon of constructions. As a matter of fact, just a few years later, the second edition of Lebrun's book about concrete, which dates back to 1843, is translated into German using the term *Béton*.⁴¹

Again in 1837, Heinrich Friedrich Franz Körte (1782–1845), who teaches natural science at the *Landwirtschaftliche Akademie* of Möglin in Pomerania, translates and publishes in the periodical *Möglin'sche Jahrbücher der Landwirtschaft* a short Swedish book about a construction technique based on the use of rough-cut stones, timber and a sort of raw conglomerate, which the entrepreneur Carl August Rydin (1798–1877) has conceived to build affordable and fireproof houses in short time, after that a fire

³⁹ "Die Bauten, welche Herr Lebrün aus Steinmörtel aufführte, die Dauerhaftigkeit derselben, welche durch Commissionen beurkundet wurde, die entschiedene Wohlfeilheit derselben im Vergleich mit den andern Maurerarbeiten, dürften, besonders beim Wasser- und Gewölbebau, eine gänzliche Reform in der bisherigen Art zu bauen herbeiführen. Würtemberg und andere deutsche Staaten haben über dieß noch einen bedeutenden Vorzug vor Frankreich, indem sie den hydraulischen Kalk, ein Hauptmaterial bei Verfertigung des Steinmörtels, von Natur aus in großer Menge besitzen, und nicht zu Verfertigung des künstlichen hydraulischen Kalkes ihre Zuflucht nehmen dürfen" (Lebrun, *Der Steinmörtel oder praktische Anweisung*...cit., n.p.)

⁴⁰ About the definition of *Steinmörtel* in 18th century, see Lukas Voch, *Baulexikon, oder Erklärung der teutschen und französischen Kunstuörter in der bürgerlichen Kriegs- und Schiffbaukunst, wie auch der Hydrotechnik und Hydraulik*, Augsburg, Leipzig, Matthäus Riegers sel. Söhnen, 1781, p. 285; Johann Karl Gottfried Jacobsson, Otto Ludwig Hartwig, Gottfried Erich Rosenthal, Johann Karl Gottfried, *Jacobssons technologisches Wörterbuch oder alphabetische Erklärung aller nützlichen mechanischen Künste, Manufakturen, Fabriken und Handwerker, wie auch aller dabey vorkommenden Arbeiten, Instrumente, Werkzeuge und Kunstuörter, nach ihrer Beschaffenheit und wahrem Gebrauche*, Berlin, Stettin, Friedrich Nicolai, vol. IV, 1784, p. 279. Both dictionaries define *Steinmörtel* as a lime-based concrete, but Voch also introduces the entry "*Betonmörtel*", which is described as a sort of *Steinmörtel* containing pozzolana, *Trass* or Dornick ash (see Voch, *Baulexikon*...cit., pp. 40-41).

⁴¹ See François-Martin Lebrun, *Traité pratique de l'art de bâtir en béton*, Paris, Carilian et Goeury et Victor Dalmont, 1843, Id., *Practische Abhandlung über die Kunst mit Béton zu bauen*, in *Journal für die Baukunst*, vol. XIX, 1843, pp. 135-86, 195-253, 287-346.

had destroyed his town Borås, in 1827.⁴² Rydin suggest using rough-cut stones to build foundations, timber to build a framework structure which goes from the foundation to the roof, and conglomerate to build walls by filling the framework fields and, at the same time, covering the timber elements in order to protect them in case of fire. (fig. 4.3.1) Conglomerate is made of stones, pebbles and a kind of quite lean mortar made of four parts of sand and one part of lime. Rydin first pours mortar in layers between provisional timber boars that have been fixed at the framework poles, and then he arranges stones in the mortar, with the aim of saving mortar.

Johann Gottlieb Prochnow, a farmer from the village of Bahn in Pomerania, is aware of the previously mentioned publications, besides the *Traité sur l'art de faire des bons mortiers* by Antoine Raucourt de Charleville and the *Cahiers de l'Ecole d'Architecture Rurale* by François Cointereaux, which deal with the building technique of *pisé* or rammed earth.⁴³ Searching for an affordable technique to build fire and weather proof walls, Prochnow adjusts the techniques he has read about to the local availability of building materials, and conceives walls entirely made of a very lean conglomerate produced with sand and ordinary lime. He applies this technique to build a stable and a shed at his estate around about 1840. Shortly thereafter, the ruler of the Gryfino department, Carl Freiherr von Steinaecker, asks Prochnow to write some instructions about the technique he has conceived. The instructions are published in 1842 and represent the main source of knowledge about Prochnow's buildings.⁴⁴ These ones have foundations made of rough-cut stones, timber roofs, and walls made just of lean conglomerate poured and tamped in quite rudimentary timber formworks, which Prochnow actually takes from Cointereaux's illustrations of rammed earth constructions. (fig. 4.3.2 [fig. 1–9]) They consist of two longitudinal faces made of boards kept at an appropriate distance by means of three crosspieces at the bottom, and six stakes, which are engaged into the crosspieces and bound two by two at the top by means of ropes. Conglomerate is made of ten measures of gravel, two measures and half of sand, and one measure of lime. Unlike Lebrun, Prochnow gives up the use of hydraulic lime, since it is not easily available in his region.⁴⁵ Nevertheless, in case rough-cut stones for foundations were unavailable, Prochnow suggests using a kind of lean conglomerate containing some pebbles and brick rubble, which are supposed to give the "mortar the property of rapidly hardening in presence of

⁴² Carl Gustaf Rydin, *Gjutna kalkbrukshus. Ett nytt byggnadssätt*, Stockholm, Georg Scheutz, 1834; Id., *Das gegossene Kalkmörtelhaus. Eine neue Bauart von C. H. Rydin [sic!]*, ed. Heinrich Friedrich Franz Körte, in *Möglinsche Jahrbücher der Landwirtschaft*, vol. II, 1837, pp. 151–81. See also Carl Gustaf Rydin, *Gegossenes Kalkmörtel-Haus. Eine neue Bauart von Rüdin [sic]*, ed. Ström, in *Kunst- und Gewerbeblatt des Polytechnischen Vereins für das Königreich Bayern*, XXVIII, 1842, coll. 502–13, in *Polytechnisches Journal*, 1842, vol. LXXXV, pp. 423–31.

⁴³ Antoine Raucourt de Charleville, *Traité sur l'art de faire de bons mortiers et notions pratiques pour bien en diriger l'emploi: précédé d'expériences récentes faites sur les chaux de France et de Russie*, St. Pétersbourg, Voies de communication, 1822, Id. *Traité sur l'art de faire de bons mortiers et d'en diriger bien l'emploi, ou Méthode générale pratique pour fabriquer en tous pays la chaux, les ciments et les mortiers les meilleurs et les plus économiques*, Paris Malher et Cie, 1828². François Cointeraux, *Ecole d'Architecture Rurale*, Paris, Chez l'Auteur, 1791.

⁴⁴ Johann Gottlieb Prochnow, *Anleitung zur Kunst, Wohnungen und Wirthschafts - Gebäude in sehr kurzer Zeit wohlfeil, Feuer- und Wetterfest zu erbauen aus reinem Sande und sehr wenigem Kalk*, Schwedt, J. C. W. Jantzen, 1842.

⁴⁵ Ibid., p. 7.

humidity.”⁴⁶ Prochnow’s conglomerate can be considered a sort of non-hydraulic fine-grained concrete, which, in case of foundations, becomes a kind of real hydraulic concrete. In spite of that, Prochnow uses neither the term “Beton”, nor “Steinmörtel”, and resorts to the compound word “Formmasse”, which essentially means moulding compound. Prochnow also envisages pouring lean conglomerate in appropriate moulds to produce artificial stones. (fig. 4.3.2, [fig. 11]) This idea very probably derives from Coitereaux’s book, but it is also to be seen in the wake of the German ambition of producing mortar-based artificial stones, and we cannot rule out the idea of a possible influence of Sach’s artificial stones. Even if it seems not to have considerable consequences in the short term, the idea of producing artificial stones made of lean conglomerate will be implemented about fifteen years later, opening the way to the manufacturing of sand-lime bricks.⁴⁷

Since about the mid 1840s, the use of lean conglomerate spreads from Bahn to some other villages of Pomerania, Brandenburg, Silesia and even in Bavaria, producing a number of occasions to experiment with variations and even, in some cases, to improve the mixture and the formworks. Around about 1845, the entrepreneur Emil Berndt builds two factories and fourteen houses in poured lean conglomerate in “Deuben near Dresden”.⁴⁸ Berndt uses a kind of conglomerate made of lime, coal slags and mud. Coal slags are reminiscent of the Dornick ash, and, at the same time, seem to anticipate the production of slag-based concretes and cements that develops about twenty-five years later. The master builder Johann Daniel Friedrich Engel (1821–1890), who is a major promoter of lean conglomerate, realizes two rural buildings in 1847 in Brandenburg, and Albrecht Daniel Thaer (1752–1828), who is the agronomist who has founded the already mentioned *Landwirtschaftliche Akademie* of Möglitz, builds two rural buildings in Möglitz.⁴⁹ (fig. 4.3–5) In some cases, however, the main role of supporting the roof and stabilizing the whole building is entrusted to traditional timber frameworks. (fig. 4.3.3 [fig. 40], 4.3.4 [fig. 38–39], 4.3.5 [fig. 44–45]) Between 1845 and 1847, the entrepreneur Johann Carls Leuchs realizes several buildings in lean conglomerate in “weißen Au, près de Nuremberg”.⁵⁰ The main one is an imposing building that covers a surface of about 350 feet by 36 feet, and houses a factory and residences, instead of the much more common rural activities. (fig. 4.3.6) Foundations are made of hydraulic lean conglomerate, which is produced using black lime from the nearby town of Bamberg, whereas walls are built using a mixture of fat lime, sand and pebbles. The use of lancet windows appears quite original for

⁴⁶ Ibid., p. 16.

⁴⁷ Ibid., pp. 28–30. In 1854, the physician Anton Bernhardi conceives a press for the mass production of lean conglomerate bricks that he considers suitable to build affordable and salubrious houses for workers; see Johann Daniel Friedrich Engel, *Ueber Kalkziegelfabrikation und Kalkziegelbau*, in *Polytechnisches Journal*, vol. CLIII, 1859, pp. 100–09; Id., *Der Kalk-Sand-Pisébau und die Kalksand-Ziegelfabrikation...cit.*, pp. 99–118; Bernhard Liebold, *Zement*, Halle, Hendel, 1874, p. 53.

⁴⁸ See C. Gebhardt, *Der Aschenstampfbau*, in *Zeitschrift für Bauhandwerker*, XVII, 1873, pp. 159–60, 174–75.

⁴⁹ Engel, *Der Kalk-Sand-Pisébau und die Kalksand-Ziegelfabrikation...cit.*, pp. 94–95.

⁵⁰ Johann Carl Leuchs, *Verbesserte Darstellung der Kitte, Mörtel, künstliche Steine, künstliche Massen, des Siegellaks, der Oblaten, der Löthe, und Anwendung der ersteren zum wohlfeilsten Bau von Häusern, Mauern, Kellern, Fußböden, Dächern, Rauchfängen, Wasserbecken, Wasserröhren, Brücken und Strassen*, Nürnberg, C. Leuchs & Co., 1848, pp. 114–29. See also Anon., *Ueber Häuserbau mit Mörtel*, in *Kunst- und Gewerbeblatt des Polytechnischen Vereins für das Königreich Bayern*, XLII, 1856, p. 576.

lean conglomerate buildings, and allows the removing of bearing wooden frames once the conglomerate has hardened, whereas ordinary windows in lean conglomerate buildings are generally provided with permanent bearing frames, similar to what happens for buildings in rammed earth. (fig. 4.3.3 [fig. 30], 4.3.7) The way of building windows that a certain Mr Badeke from the village of Fiddikow develops is also original. Badeke first builds full walls, and then cuts the openings of doors and windows once the conglomerate has hardened.⁵¹

According to Engel, the early attempts at building lean conglomerate vaults date back approximately to the mid 1840s. Badeke is said to have built 11-feet-span and 15-inches-thick vaults of lean conglomerate between brick masonry arches, which are similar to certain ancient Roman barrel vaults; whereas a certain Mr Blut from Cöslitz in Pomerania is said to have tried the contrary, that is, masonry vaults between lean conglomerate arches.⁵²

Similarly to concrete, lean conglomerate is also produced mechanically in some cases. Prochnow suggests using a singular mixer that he takes from Rydin, in a text that he publishes in 1845 as an update of the 1842 instructions. It essentially consists of a box provided with some internal crosspieces and an opening to charge loose materials and take out the conglomerate, which is fixed on two wheels of a horse-cart, so that, when the cart is drawn, the wheels turn and the conglomerate components mix together. (fig. 4.3.9 [fig. 3-4]) In the village of Cöslitz in Silesia, lean conglomerate is prepared in turning drums, which are similar to the ones used for concrete, whereas a singular kind of mixer is to be observed in the village of Fiddichow in Pomerania. It is a sort of Archimedes screw placed in a horizontal long box, which is provided with an upper opening at an extremity, to charge lime and aggregates, and a bottom opening at the opposite extremity, to collect the conglomerate that the turning screw has mixed. (fig. 4.3.1 [fig. 5-8]; fig. 4.3.9 [fig. 7-10]) Leuchs uses a kind of mixer that is similar to the ones that are used on the building sites of the Pomeranian fortresses.⁵³ It is an animal-powered machine consisting of a circular basin, a central pole and a beam, which is hinged on the central pole and holds poles and brushes to mix lime and aggregates in the basin. (fig. 4.3.7-8)

Improvements of formworks mainly aim at reinforcing the side faces, which otherwise easily bend. For this purpose, Prochnow imagines to fix the vertical poles to the horizontal boards, and connecting the two sides of the formwork by means of crosspieces at the bottom and at the top, instead of using ropes. Further improvements concern the replacement of timber crosspieces with metal

⁵¹ See Johann Daniel Friedrich Engel, *Der Bau in Kalk-Sand-Pisée*, in *Zeitschrift für praktische Baukunst*, VII, 1847, (coll. 9-14), col. 12.

⁵² See Engel, *Der Bau in Kalk-Sand-Pisée*...cit., col. 14.

⁵³ See Moritz Karl Ernst von Prittwitz, *Beschreibung einer mechanische Vorrichtung zur Bereitung des Mörtels*, in *Verhandlungen des Vereins zur Beförderung des Gewerbeleisses in Preußen*, XI, 1832, pp. 283-84. A similar kind of mortar mixer will be also used during the 1850s, on the building site for the building of the lock and the fortifications of Spandau near Berlin (see Cremer, *Mörtelmachine, welche bei dem Bau des Schifffahrtsschleuse des Berlin-Spandauer Kanals bei Plötzensee in Anwendung gekommen ist*, in *Zeitschrift für Bauwesen*, VI, 1856, coll. 192-94).

adjustable screws, and the design of different formworks pieces expressly conceived to build wall corners. (fig. 4.3.9 [fig. 13]; fig. 4.3.10–11)

Thanks to the previously described developments, interest for lean conglomerate constructions increases during the second half of the 1840s, and, between about 1847 and the very early 1850s, a number of publications, among which even monographic books, describe the practical rules to apply this way of building.⁵⁴ In some of these publications lean conglomerate is named *gestampfter Mörtel* (rammed mortar), in some others *Kalksand*, and the building technique is defined as *Kalksandbau*, *Kalksandpisé*, or *Kalksandpisébau*. *Kalksand* is the main name under which lean conglomerate acquires its own place in the panorama of the building techniques used in Germany and, simultaneously, certain awareness about the similarity between *Kalksand* and concrete begins to develop, opening the way the spread of concrete use in constructions above ground during the following two decades.

4.4 Concrete and cements in Hamburg, between Dutch, French and English influences

Significant events concerning cements, hydraulic mortar and concrete develop in Hamburg between 1843 and 1846, against the backdrop of the reconstruction and modernization of the town, after the great fire of 1842. Around about 1843, the merchant Emil Müller is licensed to sell Portland cement from the factory J. M. Maude, Son, & Co in London.⁵⁵ In 1846, Müller himself writes about Portland cement and its properties in a report that he sends to the *Journal für die Baukunst*, mentioning, inter alias, about the flexural strength tests on beams and cantilevers that the engineer Eduard J'Anson junior has carried out in 1845 in Maude's factory.⁵⁶ According to Müller, Portland cement has been used in Hamburg to plaster parts of the façades of some important buildings like the Alster-Arkaden (1843), the Börsen-Arkaden (1845) and the Wachtgebäude (guard-building) at the St. Paul harbour (1845). (fig. 4.4.1–2)

A crucial point in the context of the reconstruction of Hamburg concerns the improvement of the connection between the rivers Alster and Elbe, involving the building of a lock in the *kleiner Alster*, which is known under the name of Rathausschluse, from 1843 to 1846, under the directorship of the

⁵⁴ Engel, *Der Bau in Kalk-Sand-Pisé...*cit.; Leuchs, *Verbesserte Darstellung...*cit.; Johann Christian Wedeke, *Der Bau mit gestampftem Mörtel*, Quedlinburg und Leipzig, Gottfried Basse, 1850; Johann Daniel Friedrich Engel, *Der Kalk-Sand-Pisébau*, Wriezen, Roeder, 1851; [Friedrich Conrad Theodor] Krause, *Anleitung zur Kalk-Sand-Bau-Kunst*, Glogau, Flemming, 1851.

⁵⁵ In an early book about Portland cement, dating back to 1853, the Berlin master builder [Wilhelm Andreas] Becker asserts that Portland cement appears in Germany not before 1843 (see [Wilhelm Andreas] Becker, *Erfahrungen über den Portland-Cement*, Berlin, Gebauersche Buchhandlung (I. Petsch), 1853, esp. pp. 3–4, 46). About the factory J. M. Maude, Son, & Co see Francis, *The cement industry...*cit., pp. 110–13.

⁵⁶ See Emil Müller, *Vom Portland-Zement*, in *Journal für die Baukunst*, vol. XXIII, 1846, pp. 368–72; the same article is also published in the Austrian *Allgemeine Bauzeitung* (see Anon., *Portland-Zement*, in *Allgemeine Bauzeitung*, XI, 1846, pp. 111–13).

Bauinspector Johann Hermann Maack (1809–1868).⁵⁷ Mack has travelled between 1835 and 1838 to Holland, northern France, England and Scotland to study the most advanced hydraulic works of that time, and it is probably in the wake of what he has learnt during these study journeys that he plans to build the lock in the *kleiner Alster* on a concrete foundation.⁵⁸ (fig. 4.4.4–5) He therefore undertakes trials to test the effectiveness of concrete underwater, and experiments with specimens prepared according to what he considers to be the typical English way to produce concrete, namely by mixing the different components kept dry, and adding water just at the final step. The mixture is composed of hydraulic lime burnt from Blue Lias stones from the south of England, which have a particularly good reputation, together with egg-sized pebbles, sand and iron powder, this last one also being taken from England.⁵⁹ After having been kept several months underwater, the specimens do not give encouraging outcomes. Maack therefore gives up the English way of producing concrete and resorts to *Trass*-based concrete, which he has studied from Rondelet and observed in Holland.⁶⁰ To prepare it, he uses five measures of slaked lime from Prussia, six of *Trass*, eight of sand and an appropriate amount of water to get a kind of hydraulic mortar that he then mixes with twice the amount of rubble.

In 1844, while the lock in the *kleiner Alster* is still under construction, the *Gesellschaft zur Beförderung der Künste und Nützlichen Gewerbe* (Society for the encouragement of arts and useful crafts), better known as *Patriotische Gesellschaft*, promotes a competition for the design of the new seat of the Society, which becomes known as the *Haus der Patriotische Gesellschaft*. The new building is intended on being built on the site of the old town hall, which has been destroyed by the fire of 1842. (fig. 4.4.6–7) Maack and the architect Heinrich Wilhelm Burmster (1802–1849), who have been charged with the examination of the soil of the plot, suggest pouring a concrete bed foundation all over the site, exploiting the timber piles of the old town hall, which are still in the foundation's soil.⁶¹ (fig. 4.4.8) Since

⁵⁷ It is the Rathausschleuse of today; in this regard see Jörn Gutbrod, *Wiederherstellung der biologischen Durchgängigkeit der Alster an der Rathausschleuse in Hamburg*, master degree dissertation, Hamburg, Technische Universität Hamburg-Harburg, 2003, esp. pp. 14–16. About Johann Hermann Maack and his hydraulic works in Hamburg see Stephan Rolph, *Johann Hermann Maack: 1809 bis 1868: Bauinspektor der Brücken und Schleusen in Hamburg von 1841 bis 1868: sein Lebensweg und seine Bauwerke*, Hamburg, C. W. Dingwort, 1987.

⁵⁸ About Maack's education as hydraulic engineer, see Stephan, *Brücken für Hamburg*...cit., pp. 13–16.

⁵⁹ See Johann Hermann Maack, *Einiges über die Bereitung und Anwendung des Concrets oder Betons, mit besonderes Rücksicht auf die Fundirung des Gebäudes der Patriotischen Gesellschaft*, in *Verhandlungen und Schriften der Hamburgischen Gesellschaft zur Beförderung der Künste und Nützlichen Gewerbe. Verhandlungen vom Jahre 1845*, vol. I, 1846, (pp. 263–270), pp. 264–266. About the reputation of hydraulic lime from Blue Lias, and the state of art of knowledge and practice concerning cement and concrete in England, see Charles William Pasley's *Observations on limes, calcareous cements, mortars, stuccos and concrete, and on puzzolanas, natural and artificial*, London, John Weale, 1838.

⁶⁰ For Maack's opinion about hydraulic lime, *Trass*-based mortar and its use in Holland, as well as for the reference to Rondelet, see Franz Gustav Joachim Forsmann, Johann Hermann Maack, "Bericht den Vorschlag des Ingenieurs Giles über die Anwendung des hydraulischen Kalkes beim Bau der Hammerbrook-Schleuse u. s. w. betreffend," 14 April 1845 (ms., Staatsarchiv Hamburg (SAH), 321-2 Baudeputation, B451, n. fol.).

⁶¹ See Johann Friedrich Voigt, *Bericht der am 2. Mai 1844 niedergesetzten Commission, zur Beratung über den Bauplan für das Gebäude der Patriotischen Gesellschaft*, in *Verhandlungen und Schriften der Hamburgischen Gesellschaft zur Beförderung der Künste*

the design of the building, which has been entrusted to the architect Theodor Bülau (1800–1861), is expected to still be in progress at the beginning of the works, the concrete bed laid all over the site is intended to be a sort of raft slab that enables a free placement of the walls and columns of the basement.⁶²

Two streets, the canal named Nikolaifleet, and a secondary smaller canal surround the site. The side along the Nikolaifleet is the most exposed to tide and it is therefore provided with a provisional cofferdam in the spring of 1844. It is a kind of cofferdam covered with boards that act as a gangplank during periods of low tide, and is to be removed once the walls of the basement are completed.⁶³ (fig. 4.4.8–9) Excavation works take place during the summer of 1844; sheet piles reinforced by slanting poles are rammed along the two watersides, whereas the two street-sides are shored. (fig. 4.4.8, 10–11) Due to the lack of free space around the foundation pit, the small canal is covered with boards and provided with sheds to store materials, and to prepare mortar and concrete. Seven measures of slaked lime, five of *Trass* and thirteen of sand compose the mortar. Concrete is initially produced adding pebbles to mortar based on a 2:1 ratio; but, due to the lack of pebbles at an affordable price, these are later replaced with gravel and brick rubble.⁶⁴ Maack asserts having used a lower amount of *Trass* in comparison to the foundation of the lock in the *kleiner Alster* because he believes that the foundations of buildings are less demanding than those of locks, whereas he considers it advantageous to use a larger amount of lime in the presence of brick rubble, seeing that lime and bricks bind well together.⁶⁵ Concrete is transported by means of wheelbarrow from the sheds over the small canal onto a scaffolding-bridge placed over the foundation pit, and poured down by means of shovels from a height of about 20 feet, in parallel strips, each one measuring 4 feet in height. The scaffolding-bridge consists of two 8 feet large gangplanks fixed on a framework of bars and crossbars, which can be shifted each time a strip is completed. Part of the concrete foundation is finished within December 1844, when works must be stopped because of the onset of frost. Concrete is kept underwater until April 1845, when works resume, and the foundation is completed within the summer of the same year.⁶⁶

While the building of the *Haus der Patriotische Gesellschaft* goes ahead, in April 1845, Maack begins to plan the lock at Hammerbrook, east of Hamburg. On this occasion, supported by the master

und Nützlichen Gewerbe. *Verhandlungen vom Jahre 1844*, vol. I, 1845, (pp. 120–37), p. 136; Theodor Bülau, *Das Haus der patriotischen Gesellschaft in Hamburg oder: Einiges über einen Neubau*, Hamburg, I. I. Nobiling, 1849, p. 1.

⁶² *Ibid.*

⁶³ *Ibid.*, p. 2.

⁶⁴ See Bülau, *Das Haus der patriotischen Gesellschaft...cit.*, p. 3.

⁶⁵ See Maack, *Einiges über die Bereitung und Anwendung des Concrets oder...cit.*, p. 266.

⁶⁶ About the development of the works for the building f the concrete foundation see Bülau, *Das Haus der patriotischen Gesellschaft...cit.*, pp. 2–4; Voigt, *Bericht der am 2. Mai 1844...cit.*, p. 136; W. A. Kramer, *Berich über die Deliberation-Versammlung vom 31 October 1844*, in *Verhandlungen und Schriften der Hamburgischen Gesellschaft zur Beförderung der Künste und Nützlichen Gewerbe. Verhandlungen vom Jahre 1844*, vol. I, 1845, (pp. 167–71), p. 169; Heinrich Hübbe, *Bericht über die 362^{te} Deliberations-Versammlung vom 3. April 1845*, in *Verhandlungen und Schriften der Hamburgischen Gesellschaft zur Beförderung der Künste und Nützlichen Gewerbe. Verhandlungen vom Jahre 1845*, vol. I, 1846, (pp. 358–62), p. 360.

builder Franz Gustav Joachim Forsmann (1795–1878), Maack engages in a short controversy with the British engineer Francis John William Thomas Giles (1787–1847) about whether hydraulic lime or cement made of fat lime and *Trass* is the most appropriate binder to produce hydraulic mortar. This is somewhat similar to Zimmermann's argument about the same matter, which dates back to the end of the 1820s and has Treussart and Vicat as main references, even more if we consider that the reference to Vicat is still current in the controversy between Maack and Giles. In a report to the Hamburg *Baudeputation*, Giles asserts that both hydraulic lime and cement made of fat lime and pozzolana or *Trass* are suitable for constructions underwater, whereas only hydraulic lime is appropriate in case of constructions exposed to the air; thus, to build the lock at Hammerbrook, he suggests using hydraulic lime burnt from Blue Lias, which he considers to be suitable for the foundation and for the masonry of the lock chamber.⁶⁷ Maack and Frosmann, instead, consider that the belief in the unsuitability of *Trass*-based mortar for masonry works exposed to air is wrong, and mention, as supportive examples, the Dutch houses, which they claim to usually being built with *Trass*-based mortar, and the Italian pozzolana-based mortar, which is thought to work underwater and above ground.⁶⁸ Giles diplomatically answers that, although he is not aware of Dutch buildings, and although he does not consider the taking of Italian buildings as examples appropriate because of the difference of weather and temperature between Italy and Germany, he considers both *Trass*-based and hydraulic lime-based mortar as generally appropriate to humid places, and consequently to the lock at Hammerbrook.⁶⁹

Meanwhile, the construction of the walls and columns in the basement of *Haus der Patriotische Gesellschaft* goes ahead, but, during the summer of 1845, a crack appears in the concrete foundation, causing water to seep into the basement, and the appearance of further visible cracks in the masonry works under construction. The leak in concrete is covered with some layers of bricks laid in cement-based mortar, and the water seeping stops. The accident is considered overcome, but it is further discussed at the assembly of the as *Patriotische Gesellschaft* that takes place in December, following a request of information from a participant.⁷⁰ Three eminent members of the *Patriotische Gesellschaft* answer and comment about the matter, Bülau, the jurist Johann Friedrich Voigt (1806–1886), and the hydraulic engineer Heinrich Hübbe (1803–1871). Bülau and Hübbe reassure the public of the fact that the accident has caused no further consequences, and that the construction is solid.⁷¹ According to the first, different hardening between the mass of concrete that has been poured in 1844, and the one that

⁶⁷ See John William Thomas Giles, "Bericht an eine hochlöbliche Bau-Deputation" 8 April 1845 (ms., SAH, 321–2 Baudeputation, B451, n. fol.).

⁶⁸ See Forsmann, Maack, "Bericht den Vorschlag des Ingenieurs Giles..." cit.

⁶⁹ See John William Thomas Giles, "Sr. Wohlweisheit Herrn Senator Ienisch Präfes hochlöblicher Bau-Deputation," 22 April 1845 (ms., SAH, 321–2 Baudeputation, B 451, n. fol.).

⁷⁰ See Heinrich Hübbe, *Bericht über die 368^{te} Deliberations-Versammlung vom 18. Dezember 1845*, in *Verhandlungen und Schriften der Hamburgischen Gesellschaft zur Beförderung der Künste und Nützlichen Gewerbe. Verhandlungen vom Jahre 1845*, vol. I, 1846, (pp. 593–600), pp. 595–600.

⁷¹ Nevertheless, Bülau express hard criticism against the effectiveness of concrete foundation four years later, see Bülau, *Das Haus der patriotischen Gesellschaft...cit.*, pp. 1–2.

has been poured in 1845, has caused the crack, whereas Hübbe believes that the difference of load between the perimeter walls and the columns supporting the central hall is at the origin of the crack. (fig. 4.4.12) Voigt, instead, declares to worry about the solidity of concrete foundations, even more considering the fact that a further huge building in Hamburg is going to be built on a concrete foundation, namely the new Nikolaikirche (Church of Saint Nicholas), which is intended to take the place of the previous church destroyed during the fire of 1842.⁷² (fig. 4.4.15)

A discussion about the reconstruction of the Church of Saint Nicholas begins just a few days after the fire, and a technical committee gathering eminent Hamburg engineers, architects and master builders is soon set up to study the matter.⁷³ After studies about the urban planning, which take about two years, an architectural competition is launched in Mai 1844. Forty-four projects are submitted within the established time limit of six-months, and a public exhibition is opened on the 19th of December. A few days after the exhibition opening, a further project arrives from London on a ship that ice has held up several days long in Cuxhaven. It is by the English architect George Gilbert Scott (1811-1878), and Müller introduces and supports it in Hamburg. The project is admitted, and, on Mai 1845, Scott is officially appointed architect for the building of the new church of Saint Nicholas, while discussions about some changes and improvements of the plans are still on going.⁷⁴ (fig. 4.4.16) Scott appoints Henry Green Mortimer as clerk of works in Hamburg and develops further plans in London.⁷⁵ From this time onward, the Saint Nicholas Church becomes a sort of melting pot of influences coming British, Dutch and France building culture, with significant consequences for the construction of the concrete foundation.

Excavation works start on October 1845 from the front side of the church, where the building of a high tower is planned.⁷⁶ Scott plans a square bed of concrete with each side measuring 30 meters

⁷² See Hübbe, *Bericht über die 368^{ste} Deliberations-Versammlung...*cit., p. 597. About the concrete foundation of the Church of Saint Nicholas see also: Joseph Egle, *Notizen über die Kunkurrenz zur Lieferung eines Bauplanes für die St. Nikolai-Kirche in Hamburg*, in *Allgemeine Bauzeitung*, XIII, 1848, (pp. 123-27), p. 127; Ferdinand Stöter, *Geschichte und Beschreibung des St. Nikolai Kirchenbaues in Hamburg*, Hamburg, Boysen, 1883, pp. 37-38; Julius Faulwasser, *Die St. Nikolai-Kirche in Hamburg*, Hamburg, Boysen & Maasch, 1926, pp. 82-83; Stefan M. Holzer, *Statische Beurteilung historischer Tragwerke*, Berlin, Ernst & Sohn, 2013, p. 267-68.

⁷³ The committee was composed by the “Oberingenieur Heinrich, Baudirektor Wimmel, Wasserbaudirektor Hübbe, Ingenieur Lindley und den Architekten de Chateauneuf, Ludolph und Klees-Wülbern” (Faulwasser, *Die St. Nikolai-Kirche...*cit., p. 48).

⁷⁴ Before designing the plans for the competition Scott visits the building site of the Cologne Cathedral, having direct contact with the building master responsible for the completion of the Cologne Cathedral Ernst Friedrich Zwirner (1802-1861); Zwirner is later appointed consultant of the committee that judges the projects of the competition (Faulwasser, *Die St. Nikolai-Kirche...*cit., pp. 60, 71).

⁷⁵ Mortimer is killed in a fall on the building site of the church in 1849; Scott erects a memorial window to him in 1850 in the church of Saint Nicholas in Witham (see “Monumental inscriptions at St. Nicolas, Witham”, Essex Record Office, T/Z 151/29). Beside Mortimer, Scott’s representative in Hamburg is William Burlison, and the building contractors are Johann Philipp Friedrich Heydtmann e Heinrich Wilhelm Müller (Faulwasser, *Die St. Nikolai-Kirche...*cit., p. 82).

⁷⁶ Excavation works involve the removing of “more than one million and half of cubic feet of earth” and give the occasion to discover, on the one hand, details about the history of the area, which seems having first been the landfill of an

under the tower; whereas, for all the other walls and pillars of the church, he plans to build concrete footings, which are two and a half times wider than the thickness of the walls and pillars standing above.⁷⁷ (fig. 4.4.17–19) A complex design of earth shoring and timber carpentry is expressly conceived to build up the formworks to pour concrete, especially for the footings, whose transversal sections taper from the bottom to the top. (fig. 4.4.18–23) According to the Hamburg historian Ferdinand Stöter (1811–?), Scott travels to Holland to visit some hydraulic works under construction and to learn about how to produce concrete, before he undertakes some trials and develops a concrete mixture made of lime, *Trass*, sand, gravel and crushed bricks.⁷⁸ Carl Julius Faulwasser (1855–1944), a later Hamburg historian and architect, confirms what Stöter tells and, in this regard, writes: “The concrete mixture is based on Dutch examples, being made of crushed bricks, gravel, slaked lime powder and *Traß*.⁷⁹ In a short note on a plan illustrating the formwork of the external side of the tower foundation, *Trass*-based concrete is instead related to French models and is described as a kind of “French Beton” made of “12 measures of pozzolana or Dutch Trass, 6 of good sand, 9 of unslaked lime, 13 of stone scrape [...] not exceeding the size of an egg, 3 of iron scales from the forge.”⁸⁰ (fig. 4.4.24) Concrete is poured down and tamped in layers from scaffolding, while iron bars with bent extremities are laid between the concrete layers, forming a kind of rudimentary reinforced concrete. The use of iron bars is reminiscent of the experiments that Brunel and Francis have carried out in London, but we cannot rule out the idea that the accident that occurred during the building of the foundation of *Haus der Patriotische Gesellschaft* has also played a role. Once the concrete bed and footings are achieved, the foundation is completed with a basement made of bricks and a kind of mortar that, according to what Müller in a later commercial leaflet maintains, is Portland cement-based.⁸¹ In the same leaflet, Müller also maintains that some Portland cement is used to produce the concrete for the foundation of the tower, but this assertion does not find any further confirmation in the previously mentioned historical sources by Stöter and Faulwasser. The foundation is finally achieved in summer 1846, and on 24th of September, the first stone ceremony takes place on the site of the chancel. (fig. 4.4.25–27)

abattoir, and, on the other hand, even to make a scientific discovery namely the one of a rare mineral named Struvite, from the name of the diplomat Heinrich Christian Gottfried von Struve (1772–1851) (see Stöter, *Geschichte und Beschreibung des St. Nikolai Kirchenbaues...cit.*, p. 37).

⁷⁷ See Faulwasser, *Die St. Nikolai-Kirche...cit.*, p. 82.

⁷⁸ See Stöter, *Geschichte und Beschreibung des St. Nikolai Kirchenbaues...cit.*

⁷⁹ “Für die Betonmischung wurden nach holländischem Vorbild geschlagene Ziegel und Kies mit zerstäubtem Kalk und *Traß* verwandt” (Faulwasser, *Die St. Nikolai-Kirche...cit.*, p. 82).

⁸⁰ SAH, pl. 720-1, 361-2, XII 36b, s.d.

⁸¹ See Emil Müller, commercial leaflet about Portland cement, in “Angebote von Zement durch in- und ausländische Firmen, 1834–1869”, SAH, 326-2 I Strohm- und Hafenbau - Geräte und Baumaterialein 160.

4.5 Moulded cement-based artificial stones and mortar tiles

The forefront of research for the development of mortar-based moulded artificial stones goes through a crucial period during the 1840s, driven by the availability of more efficient hydraulic lime and cement, and by the examples of artificial stones developed abroad, like the ones patented by William Range from Brighton in England and the ones developed by Victor Poirel for the harbour of Algiers.⁸² Considering that the availability of hydraulic lime or cement is an essential condition to produce this kind of artificial stone, it is no surprise that important contributions come from some cement makers, among which Gustav Ernst Leube (1808–1881) from Ulm in Württemberg is a major representative. Leube is actually a chemist who has special interest in mineralogy and geology.

Being aware of the works by John, Vicat and Fuchs, Leube discovers a kind of limestone that is suitable to produce hydraulic lime as he investigates stones from the Blautal, west of Ulm. Around about 1838, together with his brother Julius, Leube sets up a kiln, which he later gradually develops into a real cement and artificial stone factory, and experiments with the use of hydraulic lime to build a pavement floor outside his apothecary shop, made of a kind of concrete.⁸³ “I let a pavement be built in front of my apothecary shop,” Leube writes in his personal journal, “under the guidance of the city Bauinspektor Frühwirt. A one and half inch thick coat of mortar made of 1 Simri (20 litres) of hydraulic lime and 2 Simri of gravel was laid on a good base, and it hardened in a short time. I have no doubts that this type of pavements is going to become usual in this town.”⁸⁴ As a matter of fact, Leube is entrusted with the

⁸² A short notice about William Ranger's artificial stones appears on the *Polytechnisches Journal* already in 1832, and the same periodical also informs about Ranger's patent for the production of cement artificial stones (see Anon., *Ein neues Baumaterial, in Polytechnisches Journal*, XLVII, 1832, pp. 73–74; Anon., *Verzeichniß der vom 24. Nov. 1832 bis 22. Jan. 1833 in England ertheilten Patente*, in *Polytechnisches Journal*, XLVII, 1832, (pp. 308–10), p. 308. Information about the artificial stones produced by Poirel for the harbour of Algiers are given in the translation of Lebrun's second book about concrete constructions (see Lebrun, *Practische Abhandlung über die Kunst mit Béton zu bauen...*cit. p. 173), and in a book by the General Major Carl von Decker about warfare in Algeria (see Carl von Decker, *Algerien und die dortige Kriegsführung*, Berlin, Friedrich August Herbig, 1844, pp. 384–89).

⁸³ About Leube's life see Edgar Breuss, Wilhelm Günther, Kurt Kaindl, Rudolf Zrost, *175 Jahre Leube. Chronik eines Familienunternehmens 1838 bis 2013*, Leube, St. Leonhard, 2013, especially pp. 8–16 and 106–22; and see also Robert Oedl, Werner Leube, Gustav Schefold, *125 Jahre Gebrüder Leube in Ulm und 100 Jahre Gartenau*, Gartenau, Zementwerk Gebrüder Leube, 1964. The history the development of hydraulic lime manufacturing in Ulm on the part of Leube meets the one the foreman Johann Daniel Weil (1791–1862) from the village of Blaubeuren, who carries out empirical experiments with lime and *Trass*, in the same years as Leube studies stones from the Blautal. Since 1838, Weil has his own quarry for marls and produces hydraulic lime in a kiln. At the presence of the *Kreisbaurat* Bühler, Leube and Weil test some marls shortly before each of them start his own hydraulic lime manufacturing; however, it is not clear whether Weil asks Leube to analyse scientifically the efficacy of his marls, or Leube asks Weil for a burn test in the kiln, before he builds up his own in Ehrenstein. Weil's business grows after 1838, and in 1845 Weil's son-in-law, who is a builder, joins the kiln, which is transformed into the company Weil & Sigloch. In this regard see Albrecht, *Vom Caementum zu Zement...*cit., p. 129; and Oedl, Leube, Schefold, *125 Jahre Gebrüder Leube...*cit., pp. 9–14.

⁸⁴ “Vor meiner Apotheke wurde unter Leitung von städt. Bauinspektor Frühwirt ein Trottoir gemacht. Nachdem ein guter Grund gemacht war, wurde eine 1 ½ Zoll dicke Schicht von 1 Simri (= 20 Liter) hydraulischem Kalk und 2 Simri Kies eingebaut, die nach kurzer Zeit erhärtete. Ohne Zweifel wird die Anwendung zu Trottoirs allgemein in der Stadt werden”

building of a concrete floor in the cathedral of Ulm in 1840, and with further ones in Stuttgart and Munich in the following years. The use of such floors gradually increases on the wake of the development of public spaces in nineteenth-century towns, being the prelude to the development of concrete floors for roads, and to the production of ready-made concrete floor-tiles. In some cases, a deliberate intention to imitate natural stone for decorative purposes is observed. The architect Johann Heinrich Friedrich Adler (1827–1908) reports that the floor in the octagonal northwest hall of the *Neues Museum* by Stüler is made of “marble and Portland-cement”. This consists of a base of Portland cement-based mortar finished with marble cement, which is a finer mortar made of double burnt gypsum treated with alum.⁸⁵ (fig. 4.5.1)

Beyond floors made of mortar coats or concrete, in 1840 Leube also produces the artificial ashlar that are used to restore a bridge along the road between Ulm and Gögglingen, and the ones that are used to build a bridge along the road between Ulm and Wieblingen. Such stones consist of a mixture made of one measure of hydraulic lime and three measures of sand.⁸⁶ Around about the mid 1840s, Leube delivers hydraulic lime and natural stones for the restorations works at the Ulm cathedral that the master mason Ferdinand Trän (1811–1870) is carrying out, and for some other works at the churches in the villages of Pfuhl and Blaubeuren.⁸⁷ On these occasions, besides natural stones, Leube also offers samples of artificial stone columns and capitals, which are first moulded and then chiselled finer. Some of these elements are even said to have been installed in the cathedral of Ulm.⁸⁸ During the building of the railway between Ulm and Friedrichshafen, Leube, who has been entrusted to provide cement for the ordinary masonry works and for the very demanding construction of the Rosenstein-

(Ernst Gustav Leube's journal, 8 Novemebr 1839, published in Oedl, Leube, Schefold, *125 Jahre Gebrüder Leube...*cit., p. 38). One year before the *Polytechnisches Journal* publishes an article about the construction of road floors made of asphalt on concrete bases in France (see Anon., *Ueber die Verwendung des natürlichen und nachgeahmten Erdharzes zu Fußpfaden, Fahrbahnen und architektonischen Zwecken in Frankreich*, in *Polytechnisches Journal*, XIX, vol. LXIX, 1838, (pp. 426–32), p. 427), and another article about the use of concrete to build street-paving in the United Kingdom (Anon., *Ueber die Anwendung von Steinmörtel zum Straßenbau*, in *Polytechnisches Journal*, XIX, vol. LXX, 1838, pp. 459–60).

⁸⁵ See Friedrich Adler, *Das Neues Museum in Berlin*, in *Zeitschrift für Bauwesen*, III, 1853, (coll. 23–34, 571–86), col. 576. In the *Neues Museum*, Stüler also makes wide use of terrazzo floors taking inspiration from the technique of the Venetian terrazzo (see Gargiani, *Concrete from archeology...*cit., p. 31). However, as proved by analyses that have been carried out at the occasion of recent restoration works, terrazzo floors in *Neues Museum* are made using gyps-based mortar instead of cement-based mortar, as it was usually done in Italy (see Staatliche Museen zu Berlin - Stiftung Preußischer Kulturbesitz, ed., *The Neues Museum Berlin*, Leipzig, Seemann, 2009, p. 124, pp. 176–82). Stühle also makes wide use of marble cement, even on columns; according to Adler the ones in the treble hall next to the Ägyptische Hof are built in masonry of bricks bound with Portland cement-based mortar (see Adler, *Das Neues Museum in Berlin...*cit., col. 29).

⁸⁶ See Breuss, Günther, Kaindl, Zrost, *175 Jahre Leube...*cit., p. 112.

⁸⁷ See Oedl, Leube, Schefold, *125 Jahre Gebrüder Leube...*cit., p. 38.

⁸⁸ See Breuss, Günther, Kaindl, Zrost, *175 Jahre Leube...*cit., p. 114. Leube also delivers hydraulic lime to build part of the brick masonry work of the fortress of Ulm (see Otmar Schäuffelen, *Die Bundesfestung Ulm und ihre Geschichte*, Ulm, Vaas, 1980, p. 43).

tunnel, proposes to replace wooden railway sleepers with concrete artificial stones, and he even manages to install a number of these artificial stone sleepers in the station of Einsingen, south-west of Ulm.⁸⁹

What also dates back to the early 1840s an eminent but not successful attempt at producing artificial rocks to build two waterfalls imitating Alpine scenery in the park of Glienicke in Potsdam, according to the Romantic taste of the time. Friedrich Carl Alexander von Preußen (1801–1883), the third born son of the king Friedrich Wilhelm III, plans these waterfalls together with the landscape painter August Wilhelm Ferdinand Schirmer (1802–1866). In this regard, the poet and landscape painter August Kopisch (1799–1853) reports: “They tried to reproduce alpine nature by building artificial rocks of every kind of material, but they had finally to give up this attempt and build a base made of stones from Rüdersdorf and bricks in Roman-Cement, over which they stacked so many small and large erratic stones, until the envisaged effect was achieved.”⁹⁰ (fig. 4.5.2)

In such a context, and on the wake of the trials from the mid 1830s, almost pioneering serial productions of ready-made small construction elements and decorations made of moulded cement-based mortar develop during the 1840s. They especially concern roofing tiles. At least since 1841, Heinrich Engelhardt, a builder from Nordhausen in Thüringen, produces his own cement and declares to be able to also produce “beaver tail tiles in different shapes, colours and sizes, even polished ones, to hang houses,” besides, “arabesques, rosettes, and all kinds of decorations made of cement, for inside and outside, according to any sketch, rapidly and at affordable costs.”⁹¹ In 1842, Engelhardt submits a

⁸⁹ See Oedl, Leube, Schefold, *125 Jahre Gebrüder Leube...cit.*, pp. 38–39. Some years before the *Polytechnisches Journal* had already reported about the use of concrete for the construction of bases for rails, in combination with other materials like timber and slates, and about a proposition for the construction of concrete-ways instead of railways (see Anon., *Ueber die Anwendung von Schieferplatten als Unterlagen für Eisenbahnen*, in *Polytechnisches Journal*, XV, vol. LIII, 1834, p. 457; Joseph Jopling, *Ueber Plattformen für Eisenbahnen*, in *Polytechnisches Journal*, XVII, LX, 1836, pp. 2–5 (Id., *Jopling's improved railway platforms*, in *Mechanics' Magazine*, vol. XXIV, 1836, pp. 97–99); Charles Blacker Vignoles, *Ueber ein Eisenbahnsystem mit hölzernen Längebalken als Unterlage*, in *Polytechnisches Journal*, XVIII, vol. LXIV, 1837, (pp. 2–12), p. 9 (Id., Mr. Vignoles' system of longitudinal timbers for the upper works of railways, in *Mechanics' Magazine*, vol. XXVI, 1837, pp. 257–61); Anon., *Ueber eine neue Art von hohlen Schienen für Eisen oder Schienenbahnen*, in *Polytechnisches Journal*, XVIII, vol. LXV, 1837, pp. 9–11 (J. R., *Hollow cylindrical rail for railways*, in *Mechanics' Magazine*, vol. XXVII, 1837, pp. 49–50); Charles-Chrétien-Constant Vauvilliers, *Bericht des Hrn. Vauvilliers über eine Abhandlung des Hrn. Thomassin, in welcher mit Steinmortel gebaute Bahnen als vorzüglicher als die Eisenbahnen gepriesen werden*, in *Polytechnisches Journal*, XVI, vol. LXI, 1835, pp. 225–28 (Id., *Rapport fait par M. Vauvilliers, au nom du Comité des arts mécaniques, sur un ouvrage de M: Thomassin, ayant pour titre: De la supériorité des chemins de béton sur les chemins de fer*, in *Bulletin de la Société d'Encouragement pour l'Industrie National*, XXXIV, 1835, pp. 227–30).

⁹⁰ “Man versuchte die Alpenatur hervorzubringen, künstliche Steine von allerlei Stoffen zu bilden, kam indessen zuletzt davon zurück und zog ein Unterbauen mit Ziegeln und Rüdersdorfer Steinen und Roman-Zement vor, worauf man größere und kleinere erratische Blöcke türmte und schichtete, bis der gewünschte Effekt wirklich bewunderungswürdig erreicht wurde” (August Kopisch, *Die Königlichen Schlösser und Gärten zu Potsdam. Von der Zeit ihrer Gründung bis zum Jahre MDCCCLII*, Berlin, Ernst & Korn, 1854, p. 217); in this regard see also Johann Georg Ludwig Sievers, *Bauten für den Prinzen Karl von Preussen*, Berlin, Deutscher Kunstverlag, 1842, p. 72.

⁹¹ “Biberschwanz-Ziegeln, zum behängen der Häuser, von verschiedener Form, Farbe und Größe, selbst poliert; [...] Arabesken, Rosetten und alle Arten Verzierungen, in und an die Wohnhäuser aus erwähnter Zementmasse nach jeder beliebigen Zeichnung schnell und sehr billig gefertigt” (Heinrich Engelhardt, announcement in *Nordhäuser*

sample of his cement to the Prussian *Gewerbverein*, in order to take part to the competition promoted in 1833 concerning the reproduction of Roman cement with inland raw materials; the *Gewerbverein* considers the quantity of cement that Engelhardt has sent too small to undertake trials, and the submission has no other consequence than a mention in the magazine of the *Gewerbverein*.⁹² Approximately in the same years as Engelhardt promotes his cement and moulded objects, Adolph Kroher (1825–1892), a paper trader from Augsburg in Bavaria, undertakes the production of hydraulic lime in Staudach, after having heard of local limestone and marl deposits from two local plaster makers. The business starts around 1844 and largely improves in the following years. Beyond cement, Kroher also produces two types of moulded tiles, rhombic ones, and a kind of double-hollow roofing tile, which is called an S-shaped tile. (fig. 4.5.3–7) Kroher uses a mixture made of two equal measures of hydraulic lime and sand, which is poured, spread and pressed in moulds. For rhombic-shaped tiles, he conceives a special open mould, which is hinged on an appropriate desk called *Handschlagtisch*.⁹³ (fig. 4.5.8)

Besides tiles, it is to mention that, in 1848, the already mentioned Karlinger from Miesbach, who had already exhibited moulded figures at the Munich industrial exhibition in 1834, patents a system to produce pipes made of hydraulic lime-based mortar, very probably moving from Fleuret's concept of pipes made of *pierre factice*. The method is based on the use of a quite complex contraption made of two concentric cylinders, a pole, and two spacers, which are assembled together so that they form a round mould for pipes. A first cylinder made of brass or copper sheet is wrapped in clothes, laid into the longitudinal half of a solider counter cylinder and covered with the other half of the same counter cylinder. The two halves are fixed together by means of ropes or clasps, and a pole is introduced into the metallic cylinder, being kept exactly in the middle of it by means of wooden steering spacers placed at the two extremities. The whole contraption is now raised and set vertically before cement-based mortar is poured into the space between the pole and the metallic cylinder. Once the mortar has set a little, the contraption is laid down, the metallic cylinder is extracted first, then the pole, and finally the counter cylinder is opened.⁹⁴ (fig. 4.5.9) This method will be criticized for its complexity toward the mid 1850s, when further productions of cement mortar pipes develop and give rise to an important branch of the production of moulded objects made of cement-based mortar.

Nachrichtenblatt, 4. March 1841, in GStA PK I.HA Rep.120 XXII Nr. 3, cit. in Brunsch, *Die historische Verwendung...cit.*, p. 66.

⁹² See *Auszug aus den Protokollen der Versammlungen des Vereins in den Monaten September und Oktober d. l. J.*, in *Verhandlungen des Vereins zur Beförderung des Gewerbfleisses in Preussen*, XXI, 1842, p. 139; *Auszug aus den Protokollen der Versammlungen des Vereins in den Monaten Januar und Februar d. l. J.*, in *Verhandlungen des Vereins zur Beförderung des Gewerbfleisses in Preussen*, XXIII, 1844, p. 29.

⁹³ See Adolph Kroher, *Cement und Cementwaaren-Fabrik in Staudach*, Augsburg, Rackl & Lochner, 1878; Kroher, *Staudacher Zementdachsteine. Ein Jubiläum*, in *Tonindustrie Zeitung*, XLIII, 1919, pp. 443–44; Charles George Dobson, *The history of the concrete roofing tile. Its origin and development in Germany*, London, Batsford, 1959, Id., *Geschichte des Betondachsteins - Seine Herkunft und Entwicklung in Deutschland*, Hildesheim, Hagemann, 1959.

⁹⁴ See J. Karlinger, *Verfahren zur Verfertigung von Wasserleitungsröhren aus hydraulischem Kalk*, in *Kunst- und Gewerbe-Blatt des polytechnischen Vereins für das Königreich Bayern*, XL, 1854, coll. 99–102, and in *Polytechnisches Journal*, XXXV, vol. CXXXII, 1854, pp. 202–04.

4.6 Concrete fillings for bridge decks, and to restore masonry cracks

Besides underwater foundations, concrete is also used in the second half of the 1840s as filling material to build the deck of some stone masonry viaducts, as Wiebeking had suggested doing for the Pont over the Rhone in Pont Saint-Esprit in France. An example is to be seen in the railway viaduct that is built between 1844 and 1847 near Görlitz in Silesia.⁹⁵ It is 1.494 feet long and crosses the valley of the river Neisse, being partially built on the riverbed. (fig. 4.6.1) Concrete is made of cement, sand and sandstone rubble. It is first poured among the pile heads of the timber piling foundations of the three piers standing in the riverbed, and then as filling material for the bridge deck. (fig. 4.6.2) This is composed of groups of three lengthwise and frustum-shaped vaults that stand on the half of each 30 feet wide bridge-vault and are covered first with concrete, then with sandstones forming the road floor. (fig. 4.6.3) Being frustum-shaped, vaults slope from the axe of the piers toward the key of the vaults in order to allow rainwater drainage from the surface of the deck through a system of internal drains. A similar structure is adopted for the deck of the bridge that is built between 1844 and 1848 in Frankfurt, along the Main-Neckar railway. That deck is composed of groups of five lengthwise vaults covered with a kind of concrete that is made of local hydraulic lime taken from nearby village of Somborn, Trass and crushed bricks.⁹⁶

Hydraulic mortar and concrete fillings are also used during the restoration works of the bridge over the valley of the river Diemel (1847–1851), close to the town of Warburg in Rhineland, which are undertaken around about 1849, as the dismantling of the vault centring produces serious damage to the piers. Cement-based mortar is used to set in replacing ashlar and to fill cracks in order to restore the structural continuity of the work. All piers stand on stone masonry foundations, except the one on the left riverside, which stands on a stone-faced wall filled with concrete. The fact that this pier still stands despite several ashlar of the wall faces are fallen apart is considered evidence of the solidity of concrete.⁹⁷ (fig. 4.6.4–5)

4.7 The concrete foundations of the piers for the railway bridges in Dirschau and Marienburg, the development of local artificial cement by Lentze

The engineer Johann Carl Wilhelm Lentze⁹⁸ (1801–1883) gives an essential contribution to develop the manufacturing of artificial hydraulic binders around about the mid 1840s, as the construction of two railway bridges along the so-called Ostbahn (the Eastern Railway connecting Berlin

⁹⁵ About the building of the Görlitz viaduct see Ludwig Benjamin Henz, *Der Bau des Neisse-Viaducts bei Görlitz in der Niederschlesisch-Märkischen Eisenbahn*, in *Zeitschrift für den Bauwesen*, V, 1855, coll. 281–344.

⁹⁶ See Ad. Braubach, *Main-Brücke bei Frankfurt in der Main-Neckar-Eisenbahn*, in *Zeitschrift für den Bauwesen*, VI, 1856, coll. 479–88.

⁹⁷ See Ludwig Benjamin Henz, *Die Restauration des Diemel-Viadukt*, in *Zeitschrift für den Bauwesen*, II, 1852, coll. 15–34.

⁹⁸ See A. W., *Geheimer Oberbaurath a. D. Karl Lentze †*, in *Centralblatt der Bauverwaltung*, III, 1883, n° 26, pp. 233–34.

and Königsberg) is planned to cross the river Vistula near the town of Dirschau, and the river Nogat near to the town of Marienburg.⁹⁹ Lentze, who has already worked as hydraulic engineering director in Münster and Düsseldorf, and Wiebe, who has just completed the building of the already mentioned bridge in Sonnborn, take part in a committee that is entrusted with preliminary studies in 1844.¹⁰⁰ The committee drafts a first plan of the bridges and calculates that the one in Dirschau should be divided into 10 spans, whereas the bridge in Marienburg should be divided in 5 spans.¹⁰¹ Once preliminary studies are accomplished, Lentze is tasked with the further design of the bridges, and he is asked by the finance minister Eduard Heinrich von Flottwell to go on a journey to France and to the United Kingdom, to study recent “iron bridges”. Lentze spends the winter abroad between 1844 and 1845, and, beyond iron bridges, he also studies how to produce hydraulic mortar and concrete, especially in the United Kingdom, as proved by some still existing documents. From the “Papers of the corps of royal engineers”, Lentze takes some notes about a kind of concrete conceived by George Godwin (1789–1863) as a mixture of sand, ballast, and lime taken from the villages of Dorking and Halling.¹⁰² (fig. 4.7.1) Visiting the building site of the Albert Docks in Liverpool, Lentze also takes note of two different hydraulic mortar compositions, a stronger one made of three measures of lime, one of sand, half of pozzolana and half of slags, and a weaker one made of one and three quarters measures of lime, three of sand, and one quarter of pozzolana.¹⁰³ On the same building site, Lentze observes a kind of mortar mixer, which is composed by a circular container and two millstones turning in the container around a vertical shaft.¹⁰⁴ (fig. 4.7.2) Such machines are similar to the so-called “Machine française de M. Saint-Léger”, which is used on the building site of the canal of Saint Martin in Paris after the “machine à mortier anglaise” is set aside, and a still existing sketch proves that Lentze studies the canal of Saint Martin.¹⁰⁵ (fig. 4.7.3) It comes therefore as no surprise that Lentze will later use similar mixers in Dirschau and in Marienburg

⁹⁹ Today Tczew and Malbork in Poland.

¹⁰⁰ See Friedrich Wilhelm Freiherr von Reden, Die Eisenbahnen Deutschlands, *Statistisch-geschichtliche Darstellung ihrer Entstehung, ihres Verhältnisses zu der Staatsgewalt, so wie ihrer Verwaltungs- und Betriebs-Einrichtungen*, Berlin, Posen, Bromberg, Ernst Siegfried Mittler, 1846, pp. 315–21; *Stenographische Berichte über die Verhandlungen der durch die Allerhöchste Verordnung vom 4. November 1851 einberufenen Kammern*, Zweite Kammer, 30 March – 19 May 1852, vol. III, Berlin, Deckersche Geheime Ober-Hofbuchdruckerei, 1852, n° 162, pp. 1195–97; Georg Christoph Mehrtens, *Zur Baugeschichte der alten Eisenbahnbrücken bei Dirschau und Marienburg*, in *Zeitschrift für Bauwesen*, XLIII, 1893, (coll. 97–122), coll. 99–100.

¹⁰¹ See Mehrtens, *Zur Baugeschichte der alten Eisenbahnbrücken*...cit., col. 100.

¹⁰² See [ascribed to] Johann Carl Wilhelm Lentze, notebook (ms., Stadt Archiv Soest, P.1.436, fol. 25).

¹⁰³ See Johann Carl Wilhelm Lentze, *Bemerkungen über die grösseren Brücken – Bauwerke in Frankreich, England und Irland, aus einer Reise im Winter 1844/45 gesammelt*, Berlin, I. Petsch, 1846 (in Stadt Archiv Soest, P. 1. 813), p. 26.

¹⁰⁴ *Ibid.*, pl. XVI.

¹⁰⁵ See the sketch in Stadt Archiv Soest, P. 1.590, n. fol.; De Villiers du Terrage, *Description du Canal de Saint-Denis*...cit., pp. 38–41. It is moreover intriguing to observe that according to Rondelet the Machine française de M. Saint-Léger derives from the Trybomilus (see Jean-Baptiste Rondelet, *Traité théorique et pratique de l'art de bâtir*, vol. I, Paris, Firmin Didot Frères, 1834, p. 349), a grind mill illustrated in the treatise *Theatrum Machinarum* by Georg Andreas Böckler, known as Bocklerius, “architect and engineer in Nurnberg”, as he defines himself on the cover of treatise (see Georg Andreas Böckler, *Theatrum machinarum novum*, Nürnberg, Christoff Gerhard, 1661, pl. 52).

Once back in Prussia, Lentze, together with the building counsellor Spittel from Danzig, designs the plans of the two bridges.¹⁰⁶ The one in Dirschau is now conceived as a 5 spans suspension bridge, whereas the bridge in Marienburg is designed as an iron framework bridge.¹⁰⁷ The piers of both bridges are conceived as masonry constructions standing on concrete foundations. The lowest parts of them, from the foundations to the bridge decks, are designed as ashlar-faced walls filled with brick masonry work, whereas the upper parts, over the bridge decks, are of full brick masonry work and form two towers, “according to the style of the aristocratic houses of the Prussian province”.¹⁰⁸

Fat lime taken at the port of Danzig and *Trass* imported from Rhineland could be used to produce hydraulic mortar, but Lentze prefers to search for local raw materials suitable to produce hydraulic cement.¹⁰⁹ Knowledge of English building culture probably plays a crucial role for this choice, and we cannot rule out the idea that Lentze also takes inspiration from Charles William Pasley's experiments about artificial cement. Lentze finds deposits of calcareous and siliceous marls about three miles away from the building site in Dirschau, and performs some experiments with burning different mixtures of both kinds of marls, until he comes to develop a kind of cement that, mixed with sand, hardens underwater and proves to have satisfactory compression strength.¹¹⁰ Lentze moreover verifies that the kind of mortar he intends to use does not set too rapidly, so that mortar and concrete can be produced in appropriate plants, and can be transported to the building sites of the different piers before the mortar setting begins. The construction of the plants to produce cement, mortar and concrete begins in 1846, shortly after the excavation works have been started.

Due to financial difficulties, however, works are stopped on October 1847, at the time as Lentze goes on a second study journey to England. Once back to Prussia, he modifies the plans of both bridges, which are now finally both designed as framework beam-bridges: the one in Dirschau stretching over six spans, and the one in Marienburg over two spans.¹¹¹ (fig. 4.7.4–9) Nothing changes, however, for the already planned production of artificial cement and concrete, which remains as it has been conceived in 1845.

¹⁰⁶ Danzig is today Gdańsk.

¹⁰⁷ The number of spans for the bridge in Dirschau is drastically reduced in comparison with the estimation by the Committee, in order to let ice blocks better flow during spring; see Mehrtens, *Zur Baugeschichte der alten Eisenbahnbrücken...cit.*, col. 101.

¹⁰⁸ See Anon., *Die Eisenbahn zwischen Berlin und Königsberg*, in *Illustrierte Zeitung*, vol. VI, 1846, p. 218.

¹⁰⁹ See Johann Carl Wilhelm Lentze, *Beschreibung einiger Hülfsseinrichtungen von dem Bau der Weichsel- und Nogat-Brücken. II. Die Cementhütte und die Mörtelmühle für den Bau der Weichselbrücke*, in *Zeitschrift für Bauwesen*, XII, 1861, (coll. 375–80), coll. 375–77.

¹¹⁰ Lentze's cement contains 64% of calcium carbonate, 30% silica and 4% clay besides small quantities of iron oxide; and mortar is made of one part of cement and one part and 1/7 of sand; Lentze also carries out strength tests consisting in regularly charging sample of mortar applied on stone, over one year, and ascertains that mortar withstand 1800 Pfund (about 900 Kg) of pressure (see Lentze, *Beschreibung einiger Hülfsseinrichtungen...cit.*, col. 380).

¹¹¹ See Albert Julius Licht, *Der Portland-Cement und der hydraulischer Kalk der Cement-Fabrik zu Dirschau*, Danzig, Schroth, 1867, p. 1; Königlich Preuzischen Ministerium der Oeffentlichen Arbeiten, ed., *Archiv für Eisenbahnwesen*, Berlin, Julius Springer, 1911, p. 911.

Works resume in April 1850, and the cement and concrete plants are rapidly accomplished. The one in Dirschau starts producing in 1850.¹¹² It is situated between the right riverside of the Vistula and the area where the railway station is going to be built. (fig. 4.7.10) A shed where calcareous and siliceous marls are mixed together (*Steinwäsche*), three further sheds where calcareous-siliceous mixtures dry, four continuous fire kilns and a steam-powered mill to grind cement and produce mortar and concrete compose the entire plant. (fig. 4.7.11-12) Calcareous and siliceous marls are first plunged into water, transformed into mashes and mixed together in a horse-powered clay-cutting tool. Mixtures coming from the clay-cutting tool are moulded as little cubic blocks with each side measuring 2,5 inch; these are first dried in the appropriate sheds, and then brought to kilns to be fired. Each kiln is provided with six gates at the base – three to charge fuel and three to take out burnt cement.¹¹³ (fig. 4.7.13) They are set in a square and two roofs shelter their lowest parts from the rain, whereas two bridges and a lift made of ropes and pulleys are placed at the top making it possible to charge calcareous-siliceous blocs. The kilns are charged every six hours and each one produces thirty barrels (120 Sheffels) cement everyday, by burning a barrel (1 and 1/5 cubic foot) of coal from Newcastle.

Burnt cement blocs are checked after having cooled, and only the ones that are perfectly burnt are brought to the mill. This is installed in a three-floored building. Eight grind mills, similar to the ones that Lentze has observed in Liverpool, are placed in line at the highest floor, over a longitudinal camshaft that is connected to the flywheel of a steam engine (fig. 4.7.14). Being used as mill and as mortar mixers, they are first charged with burnt cement blocks, and, once these are ground into powder, workers add sand and water to produce mortar. This is then transported by means of wheelbarrows to a trap door placed in the floor, and thrown into wagons on rails to be transported to the building site. To produce concrete, mortar is thrown together with some gravel, through a second trap door, into a sloping and steam-powered concrete drum placed at the second floor of the building, where the two different materials are mixed together and fall into the wagons on the ground floor.

The cement plant in Marienburg starts producing in 1851.¹¹⁴ It is similar to the one in Dirschau but smaller, being equipped with a clay-cutting tool, a shed to dry marls mixtures, one kiln, six grind mills and a concrete drum. No wagons on rails are available in the Marienburg plant; mortar and concrete are transported in wheelbarrows or even in containers on shoulders, which are called *Vögel*.

¹¹² Königlich Preuzischen Ministerium der Oeffentlichen Arbeiten, ed., *Archiv für Eisenbahnwesen...*cit., p. 105; *Auszug aus der Mittheilung des Herrn Ministers für Handel etc. an die Kamern über den Stand des Baues der Ostbahn, der Westphälischen und Saarbrücker Eisenbahn in November des Jahres 1851*, in *Zeitschrift für Bauwesen*, II, 1852, p. 126. About the development of works see also Anon., *Deutschland. Berlin*, in *Frankfurter Volkszeitung*, 29 December 1852, n° 311, n. p.

¹¹³ Continuos kiln is called Rumford kiln, from the name of the inventor Sir Benjamin Thompson, Count Rumford, (1753–1814), an American-born British physicist who graduates in München and spends the most important part of his carrier in Germany. The early Rumford kilns are used in Rüdersdorf. Lentze himself defines the kiln he lets build in Dirschau and Marienburg as Rumford kiln (see Lentze, *Beschreibung einiger Hülfsseinrichtungen...*cit., col. 378).

¹¹⁴ *Auszug aus der Mittheilung des Herrn Ministers für Handel etc. an die Kamern über den Stand des Baues der Ostbahn, der Westphälischen und Saarbrücker Eisenbahn in November des Jahres 1851...*cit., p. 124.

Lentze later reports that these containers weight about 110 Pfund (55 kg) once filled, and that workers therefore used to put a sort of straw pillow on their shoulders.

The bridge in Dirschau is built since 1850, starting from the foundation of the left abutment, the closest to the cement plant.¹¹⁵ The foundations of all piers are achieved in 1852, the masonry work up to the level of the deck in 1853, and the towers in 1855. The construction of the bridge in Marienburg starts in 1851 from the right abutment. The foundations are completed in 1854, the lower masonry works in 1855, and the towers in 1856. All freestanding piers are built the same way. (fig. 4.7.15–16, 18) A larger area than the foundation site is surrounded with sheet piles; the soil is dug up to a depth of about 10 feet under the natural riverbed, and a smaller enclosure of sheet piles is rammed. Inside this second enclosure, timber piles are rammed at a depth of about 20–22 feet and their heads are cut one foot over the ground. Concrete is poured over the timber piles forming a 10 feet high base. It is composed by combining one measure of mortar (made of one measure of cement and one measure and 1/7 of sand), and two parts of gravel made of stones whose diameter measures approximately between ¼ and ½ inch. Similar to what already observed in other cases, 3 feet high concrete walls are built all around the upper surface of the concrete bases and form a closed and watertight space where masons build the lowest masonry layers of the piers, after that the water has been drained.

Concrete foundations for the abutments of the bridge in Dirschau are built straight on sand, without any timber pilings. (fig. 4.7.17) They support structures made of about 30 feet high tapering brick pillars linked by reversed arches at the bottom, and by ordinary arches at the top, which in turn support the slip road between the bridge deck and the land road. An about 3 feet high bed of lean concrete made of one measure of mortar and six of sand is poured over these arches to build the base for the pavements. The same kind of lean concrete is also used to partially fill the spaces between the brick pillars. The abutments of the bridge in Marienburg are, instead, built in a similar way to all other freestanding piers.

Besides their importance as being two pioneering examples of imposing iron constructions in Germany, the bridges in Dirschau and Marienburg are also recognized as two cases of successful use of hydraulic mortar and concrete produced with local raw materials. In this regard, it is worth reading the words that the Prussian minister of industry, trades and public works, August von der Heydt expresses in 1857. “The discovery and the exploitation of good materials to produce mortar and cement has already proved in France how profitable the exploration of the soil is;” he writes, “the same has been also proved by the brilliant success of the search for appropriate building materials that has been carried out for the construction of the bridge over the Vistula near Dirschau.”¹¹⁶ The renown of the cement plants

¹¹⁵ See Johann Carl Wilhelm Lentze, *Die im Bau begriffenen Brücken über die Weichsel bei Dirschau und über die Nogat bei Marienburg*, in *Zeitschrift für Bauwesen*, V, 1855, coll. 445–58.

¹¹⁶ “Wie lohnend die Erforschung des Bodenreichstum werden kann, haben die seit längere Zeit in Frankreich der Auffindung und Nutzbarmachung guter Materialien zur Mörtel- und Cementbereitung zugewendeten Bestrebungen dargethan; nicht minder die glänzenden Erfolge, welche die dem Bau der Weichselbrücke bei Dirschau vorangegangen Untersuchungen und die darauf gegründeten Fabricationen geeigneter Baumaterialien geliefert haben” (August von der

in Dirschau und Marienburg is probably also due to the fact that they sell cement for other public and private works. Moreover, after the completion of the bridges, the plant in Dirschau carries on the production of cement, which becomes known as “Dirschauer Cement”.¹¹⁷

4.8 Further studies about materials to produce hydraulic mortar and concrete

The increasing need for effective and affordable hydraulic mortar and concrete pushes to take all the materials that are appropriate for producing hydraulic binders into account. Thus, in the second half of the 1840s, new chemical investigations take place. Some concern the so-called Santorin earth, a kind of volcanic sand from the Greek island of Santorin, which shows properties similar to those of pozzolana and *Trass*. The Santorin earth becomes known in Germany through accounts given by Bavarian engineers that work at the court of Otto Friedrich Ludwig von Wittelbach (1815–1867), who is king of Greece since 1832. The engineer Wilhelm von Weiler uses Santorin earth-based concrete to build, at the turn of the 1840s, the foundations of the quays of the new port of Syros, the vaults of the military hospital on the same island, and some flat terraces.¹¹⁸ (fig. 4.8.1–2) The Austrian engineer Karl von Körber reports about Von Weiler’s concrete in an article that is published in the *Allgemeine Bauzeitung* in 1841.¹¹⁹ Von Körber also reports about successfully experiments with the use of Santorin earth that have been carried out in the harbour of Trieste, giving rise to further and wider uses of this material along the northeast Italian coast.

Following the Athens insurgency of 1843 against king Otto, several German scholars and technicians are obliged to leave Greece. Franz Stauffert, who has worked as state architect in Athens since 1835, is among them. He probably settles in Wien after having left Greece, and becomes an editor of the *Allgemeine Bauzeitung*.¹²⁰ Stauffert is principally known for a long report about the state of the

Heydt, *Circular-Verfügung vom 19. April 1858, die Aufstellung von Baumaterialien-Verzeichnissen in den einzelnen Baukreisen betreffend*, in *Zeitschrift für Bauwesen*, VIII, 1858, (coll. 369–71), col. 369.

¹¹⁷ See Lentze, *Beschreibung einiger Hilfseinrichtungen...*cit., col. 377; Licht, *Der Portland-Cement und...*cit.

¹¹⁸ Von Weiler develops a plan for the town of Ermoúpoli on the island of Syros, since 1835; in this regard, see Anna Frangoudaki, Caglar Keyder, *Ways to Modernity in Greece and Turkey: Encounters with Europe, 1850-1950*, London, New York, Tauris, 2007, pp. 240–41.

¹¹⁹ Karl von Körber, *Ueber den Gebrauch der Santorinerde*, in *Allgemeine Bauzeitung*, VI, 1841, pp. 266–68; see also Johann Christian Wedeke, *Handbuch der Landbaukunst und der Landwirthschaftlicher Gewerbe für Baumeister, Landwirthe und Cameralisten*, vol. I, Leipzig, Romberg, 1851, coll. 331–35.

¹²⁰ In this regard see Christian Ludwig Friedrich von Förster, *Schlussbemerkung zu diesem Jahrgange der Allgemeine Bauzeitung*, in *Allgemeine Bauzeitung*, XI, 1846, (pp. 397–98), p. 398. According to Christiana Fountoulakis and Alexander Papageorgiou-Venetas Stauffert’s name would be Friedrich (see Christiana Fountoulakis, *Foreign architects in Greece during the period 1750-1850*, in Evangelos Konstantinou, ed., *Das Bild Griechenlands Im Spiegel Der Voelker (17. Bis 18. Jahrhundert) the Image of Greece in the Mirror of Nations (17th-18th Centuries)*, Frankfurt am Main, Peter Lang, 2008, pp. 89–102; Alexander Papageorgiou-Venetas, *Städte und Landschaften in Griechenland zur Zeit König Ottos (1833-1862): eine Periegesis*, Mainz und Ruhpolding, Franz Philipp Rutzen, 2009), whereas Von Förster calls him Franz. Papageorgiou-Venetas also asserts that the editor of the *Allgemeine Bauzeitung* would be Richard Förster (see Papageorgiou-Venetas,

Greek art of building, which is published in 1844; but he should be also remembered as the author of a report focusing on the building materials used in Greece, including the Santorin earth, which is published in 1846 in the *Journal für die Baukunst*.¹²¹ “The volcanic ash from Santorin, called ασπρόχωμα,” Stauffert writes, “has such a binding force that even big buildings on the island are made of mortar prepared with this ash mixed with different sized stones, very little, hand and egg sized ones.”¹²² In the same year, Franz Ludwig von Welden (1782–1853), a Lieutenant of the Austrian army, reports in the *Kunst- und Gewerbe-Blatt des polytechnischen Vereins für das Königreich Bayern* about the quay foundations made of alternating layers of pebbles and Santorin earth based-mortar poured into sunken caissons that he observes in Trieste.¹²³ On the wake of such an interest, the chemist Franz Carl Leonhard Elsner (1802–1874) promotes the analysis of some Santorin earth samples in the laboratory of the *Gewerbe-Institut* in Berlin.¹²⁴ According to him, the master builder Salzenberg has brought these samples to Berlin, and he has even written a report about the Santorin earth. It is very probable that Elsner means the Berlin architect and Schinkel’s scholar Wilhelm Salzenberg (1803–1887), who travels to Constantinople in 1847 on behalf of Friedrich Wilhelm IV, and makes some stops in northern Italy along the way back to Germany, as proved by the fact that he publishes a report about the Italian stucco he has observed in Parma, in the *Notiz-blatt des Architekten-Vereins zu Berlin* in 1847.¹²⁵ In the same issue, a report about the Santorin earth immediately follows the one about the stucco, and one cannot rule out the idea that this is exactly the report by Salzenberg that Elsner mentions, although regrettably no author is given for it.¹²⁶ The report shows and compares the chemical contents of Santorin earth, pozzolana and *Trass*, and furthermore informs about the fact that the Santorin earth “has been recently and successfully used to produce concrete for hydraulic works at the sea in Syros, Trieste and Venice,

Städte und Landschaften in Griechenland...cit., pp. 15–16), whereas Christian Friedrich Ludwig Förster (1797–1863) actually founds the periodical in 1836 and remains the editor of it until 1862.

¹²¹ See Franz Stauffert, *Der jetzige Zustande der Baukunst in Griechenland*, in *Beilage zur Allgemeinen Bauzeitung. Ephemeriden*, 1844, n° 1, pp. 1–8, n° 2, pp. 17–25, n° 3, pp. 33–38, n° 4, pp. 41–58, n° 5, pp. 69–95; Id., *Über die Baumaterialien des alten und des neuen Griechenlands, und über die geognostischen Verhältnisse dieses Landes*, in *Journal für die Baukunst*, vol. XXIII, 1846, (pp. 101–30, 268–319), pp. 278–79.

¹²² “Die vulcanische Asche von Santorin, ασπρόχωμα genannt, hat eine so bindende Kraft, dass auf der Insel grosse Gebäude aufgeführt werden, die nur aus ganz kleinen, hand- und eigrossen Steinen, in den mit der Asche angemachten Mörtel gelegt, bestehen” (Stauffert, *Über die Baumaterialien*...cit., p. 279).

¹²³ Franz Ludwig von Welden, *Ueber die Eigenschaften des Santorin-Mörtels und seiner Anwendung bei Bauten in und außer Wasser*, in *Kunst- und Gewerbeblatt des polytechnischen Vereins für das Königreich Bayern*, XXXII, 1846, coll. 683–93.

¹²⁴ See Franz Carl Leohard Elsner, *Ueber die Zusammensetzung des Santorins und dessen technische Verwendung*, in *Verhandlungen des Vereins zur Beförderung des Gewerbefleißes in Preußen*, XXVIII, 1849, pp. 86–87, and in *Polytechnisches Journal*, vol. CXIII, 1849, pp. 157–58.

¹²⁵ See Ottobrina Voccoli, *La rinascita dell’arte musiva in epoca moderna in Europa. La tradizione del mosaico in Italia, in Spagna e in Inghilterra*, doctoral dissertation, Universitat de Barcelona, 2009, pp. 306–07; Wilhelm Salzenberg, *Stucco a Lucido*, in *Notiz-Blatt des Architekten-Vereins zu Berlin*, I, 1847 pp. 15–16.

¹²⁶ [Wilhelm Salzenberg], *Santorin-Erde*, in *Notiz-Blatt des Architekten-Vereins zu Berlin*, I, 1847, p. 16.

where people highly recommend it.”¹²⁷ Again in 1847, a certain P. Schulze visits the building site of new quays in the harbour of Trieste, where he examines the same kind of concrete foundations that Von Welden had already observed, and writes about them in a report published by the *Notizblatt des Architekten-Vereins zu Berlin* in 1848.¹²⁸ Between November 1848 and Mai 1849, the Prussian *Kriegs- und Handels-Ministerium* promotes some tests to compare the hardening of concrete produced with *Trass* and with Santorin earth.¹²⁹ The tests take place on the building site of the Berlin cathedral. A certain quantity of Santorin earth is transported to Berlin by land, and the *Ingenieur-Major* Block gives necessary information about how to use it, on the basis of the already published reports, and of the personal experience he has acquired during some journeys to Venice, Trieste and to Greece. Once a supervising technical committee including the engineer Lentze has been set up, the tests start. Three wooden 2,5 square feet wide boxes are assembled: the first is filled with alternating layers of *Trass*-based mortar and pebbles, the second with layers of pure Santorin earth-based mortar and pebbles, and the third with pebbles and mortar made of Santorin earth and sand. The hardness is tested after 7, 11 and 42 days, hence realizing that the quality of the Santorin earth does not match that of *Trass*. Moreover, it is also established that concrete made of alternate layers of mortar and pebbles is less appropriate than mixtures of mortar and stones. This dispels the myth of Milet de Monville’s way of producing concrete, which had actually been more of a theoretical reference, than a practical rule to follow, seeing that, in Germany, concrete is usually mixed before being poured. In the context of the interest for the Santorin earth, it still deserves some attention a report dating back to 1851, and written by Xaver Johannes Landerer, a chemist at the Bavarian court, who relates having successfully filled dental cavities with mixtures of lime, Santorin earth and water.¹³⁰ This peculiar use of Santorin earth-based mortar seems a late legacy of the closeness between the domain of building and the one of medicine that characterizes the eighteenth-century studies about lime, before medicine and chemistry develop as two different disciplines.¹³¹

Approximately in the same years as the studies about the Santorin earth develop, a certain scientific interest for iron slags arises, probably being urged by the increasing available amounts of such materials, as consequence of the iron industry development. Von Bauernfeind analyses iron slags in the context of the already mentioned trials ordered by the Nurnberg Railway-Committee, and, few years

¹²⁷ “Diese Erde ist nun bei den Meeresbauten zu Syra, Venedig und Triest mit sehr günstigem Erfolge zur Betonbereitung angewendet worden und wird von dort aus lebhaft empfohlen” (see Anon. *Santorin-Erde...cit.*)

¹²⁸ See P. Schulze, *Anwendung von Santorin-Erde und Puzzolane*, in *Notiz-Blatt des Architekten-Vereins zu Berlin*, vol. II, 1848, pp. 25–26.

¹²⁹ See Anon., *Ueber die Anwendung von Santorin-Erde in Preussen gemachten Versuche*, in *Zeitschrift für die Bauwesen*, I, 1851, coll. 293–302, 347–56.

¹³⁰ See Xaver Johannes Landerer, *Ueber die Santorinerde und deren Gebrauch als Zahnkitt*, in *Polytechnisches Journal*, vol. CXXII, 1851, p. 468.

¹³¹ The reference is principally to the crucial studies by Joseph Black (1728–1799), see Joseph Black, *Experiments upon Magnesia alba, Quicklime and some other Alcaline Substances*, in *Essays and observations, physical and literary*, vol. II, Edinburgh, 1756, (pp. 157–225), pp. 184–225.

later, Elsner promotes some further chemical investigations in the laboratory of the *Gewerbe-Institut* in Berlin. “It is well known,” he then asserts in 1847, “that iron slags milled into fine powder and added to lime produce a good kind of hydraulic mortar. Since the origin of this property must be due only to their chemical composition, I found important, from a technical-chemical point of view, [...], to undertake some analyses [...]”¹³²

Interest for the Santorin earth and iron slags does not anyway seem to produce the same important consequences that the emergence of Portland cement from England is going to produce. In 1847, the Bavarian chemist Max Joseph von Pettenkofer (1818–1901) runs investigations about the chemical features of Portland cement, and compares them to the ones of Bavarian hydraulic lime. The architect Leo von Klenze (1784–1864) asks him to engage in this kind of research, after having verified that Portland cement is more effective than Bavarian hydraulic lime in producing mortar and plaster, and he even provides Von Pettenkofer with samples of Portland cement and Bavarian hydraulic lime, taken from different producers.¹³³ Von Pettenkofer’s scholar Anton Hopfgartner undertakes early analyses, while his mentor brings works ahead to conclusion. Both then relate about their works in 1849.¹³⁴ Von Pettenkofer realizes that the better quality of English Portland cement is essentially due to the use of more appropriate raw materials, and to a stronger firing. He verifies that English cement contains some alkali that he considers as substances facilitating the melting of clay, a process through which silica are freed from silicates (as previously argued by Fuchs), while clay covers lime particles and prevents slaking reaction. Von Pettenkofer reports having received from Fuchs a sample of marl coming from the Sheppey Island and having verified that this kind of stone produces cement that hardens very fast underwater if it is burnt at a moderate fire, whereas it produces cement that harden slowly but strongly, if it is burnt at a strong fire. He furthermore verifies at the microscope that, whereas Bavarian hydraulic lime particles take the shape of spheres, the ones of Portland cement are scale-shaped and therefore facilitate the cohesion. It is interesting to mention the example that Von Pettenkofer gives to explain such a phenomenon, since it just pertains the domain of building. “To compare the two kinds

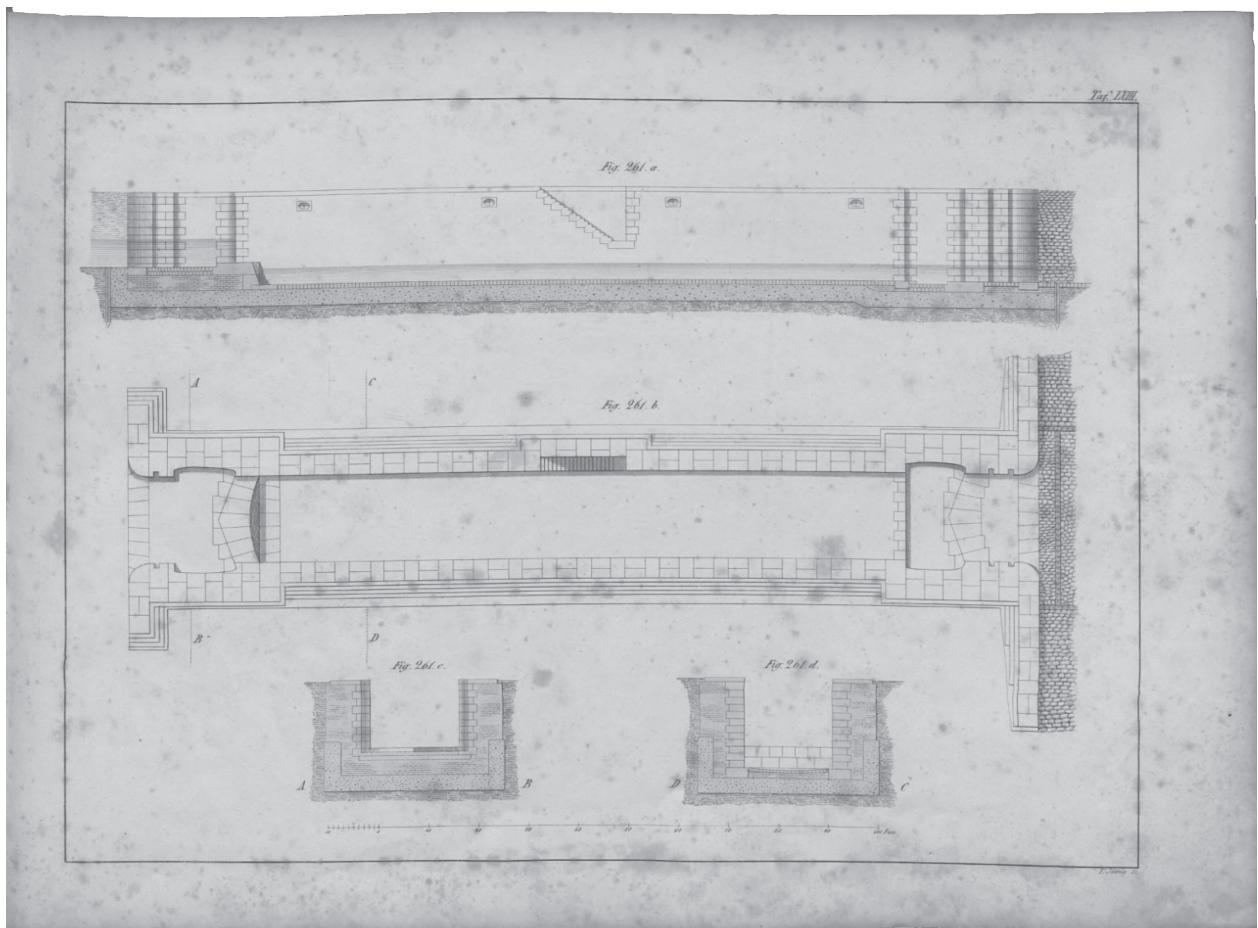
¹³² “Es ist bekannt, daß Hohofenschlaken [sic!], im fein gepülverten Zustande, als Kieselcemente dem gebrannten Kalk hinzugesetzt, einen sehr guten hydraulischen Mörtel liefern. Da diese Eigenschaft der Hohofenschlacken einzig und allein nur in deren bestimmter chemischen Zusammensetzung ihren Grund haben kann, so schien es mir in technisch-chemischer Beziehung von Wichtigkeit, [...], einer chemischen Analyse zu unterwerfen [...]” (Franz Carl Leohard Elsner, *Ueber Hohofenschlacken [sic!] als hydraulische Cämente*, in *Verhandlungen des Vereins zur Beförderung des Gewerbefleißes in Preußen*, XXVI, 1847, (pp. 89–90), p. 89; the same in *Polytechnisches Journal*, vol. CVI, 1847, pp. 312–22, and in *Kunst- und Gewerbe-Blatt des polytechnischen Vereins für das Königreich Bayern*, XXXIII, 1847, coll. 686–88).

¹³³ See Carl von Voit, *Max von Pettenkofer zum Gedächtniss*, München, Verlag der k. b. Akademie in Commission des G. Franz'schen Verlags, 1902, pp. 26–27; Otto Neustätter, *Max Pettenkofer*, Wien, Julius Springer, 1925, p. 23; Harold Breyer, *Max von Pettenkofer Arzt im Vorfeld der Krankheit*, Leipzig, Hirzel, Teubner, 1980, pp. 44–45; Karl Wieninger, *Max von Pettenkofer. Das Leben eines Wohltäters*, München, Hugendubel, 1987, pp. 117–21.

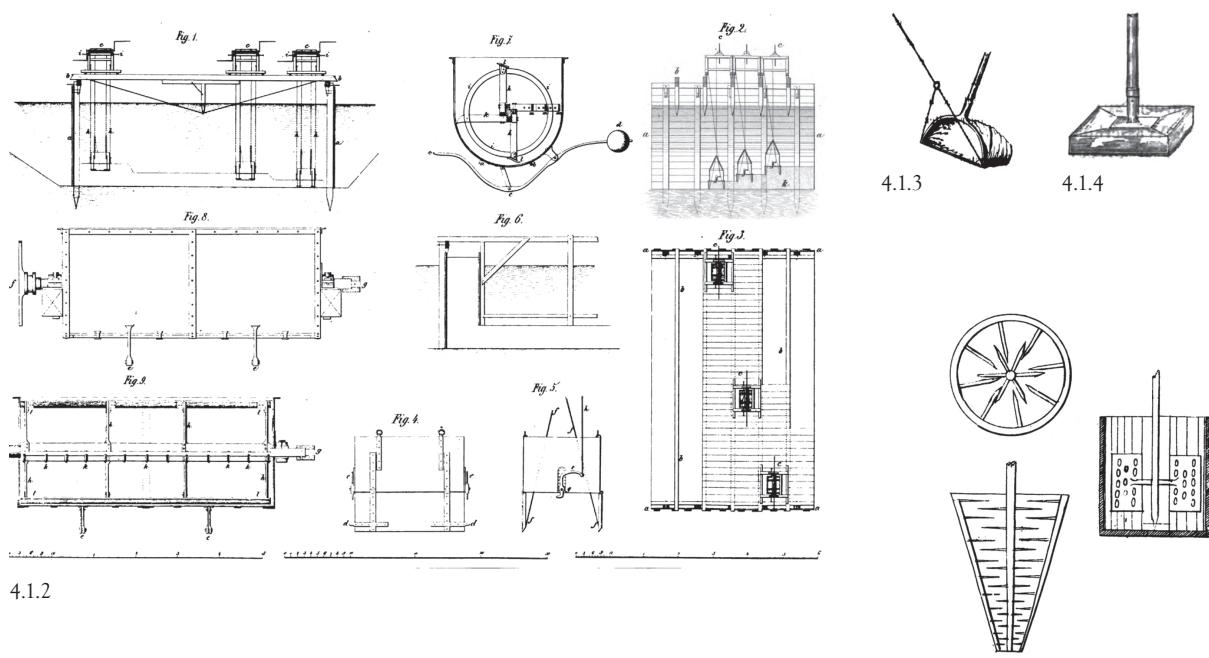
¹³⁴ See Max Joseph von Pettenkofer, *Bemerkungen zu Hopfgartner's Analyse eines englischen und eines deutschen hydraulischen Kalkes*, in *Polytechnisches Journal*, vol. CXIII, 1849, pp. 357–71; see also Anton Hopfgartner, *Analyse zweier hydraulischen Kalkes, eines englischen (Portland-Cement) und eines deutschen hydraulischen Kalkes*, in *Polytechnisches Journal*, vol. CXIII, 1849, pp. 351–57.

of masses, one should imagine a first wall made of ashlar, and a second one made of layer of boulders; in the first case surfaces come in touch, whereas in the second case just points touch each other, leaving much more in-between empty spaces than in the first case.”¹³⁵

¹³⁵ “Denkt man sich beide in auseinanderliegenden Massen, so lässt sich das eine einer Mauer von Quadern, das andere einer Schichte von Rollsteinen vergleichen; beim ersten berühren sich Flächen, beim letzteren Punkte, daher so viele Zwischenräume mehr, als beim ersten” (see Von Pettenkofer, *Bemerkungen zu Hopfgartner's...cit.*, p. 368).



4.1.1



4.1.2

4.1.5

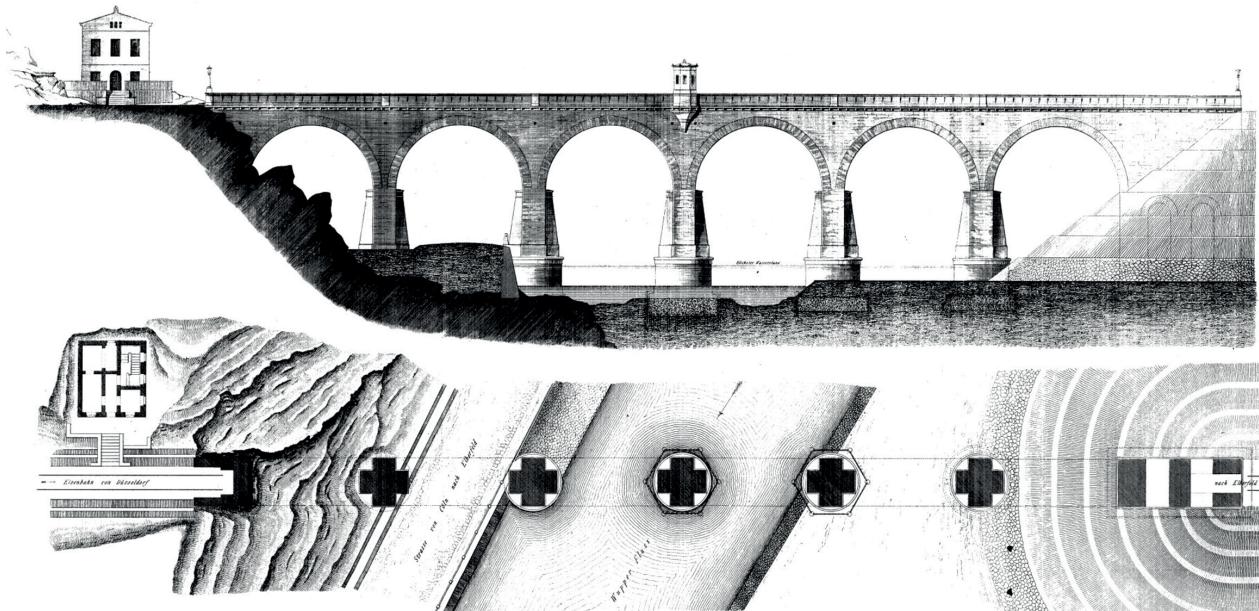
4.1.1. Drawing of a typical lock along the river Ruhr, plan and sections, since 1834 (G. H. L. Hagen, 1852). 4.1.2. Drawings about the building of a typical Ruhr lock; figg. 1-2 longitudinal and transversal sections over the foundation pit during concrete pouring; fig. 3 the foundation pit, view from above, the cranes to pour concrete in the foreground; fig. 6 section over the concrete foundation, detail; figg. 4-5 box to pour concrete; figg. 7-9 mortar mixer (C. Hoffmann, 1847). 4.1.3. A typical shovel to dredge up the soil of a foundation pit (C. Hoffmann, 1847). 4.1.4. A typical tool to tamp concrete (C. Hoffmann, 1847). 4.1.5. Clay cutting tool (G. Frick, 1832).



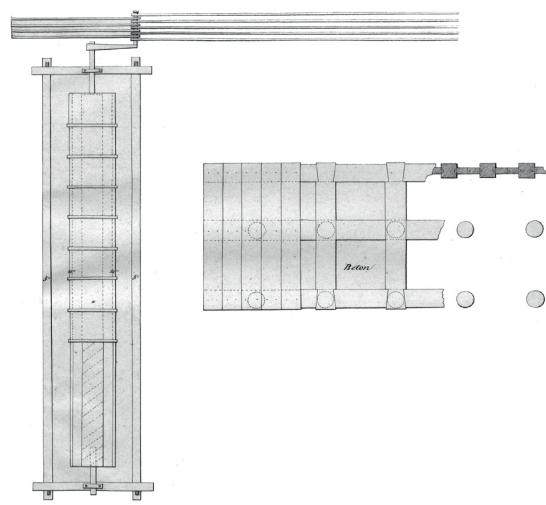
4.1.6



4.1.7



4.1.8

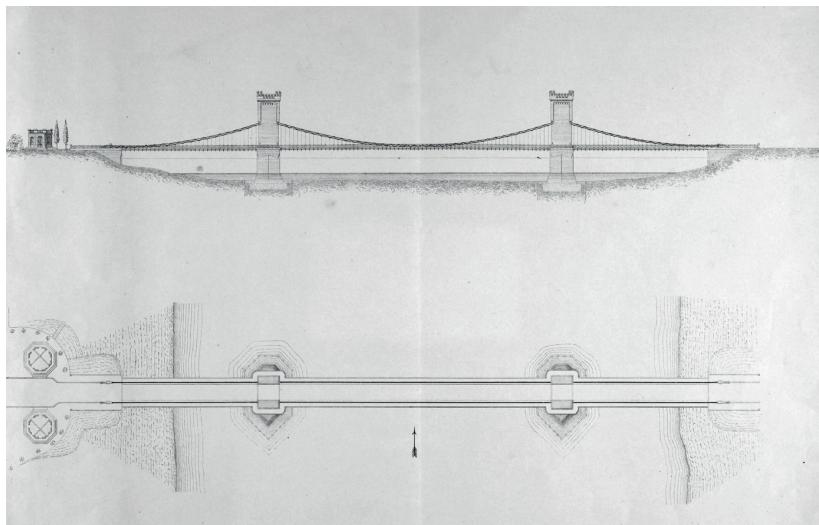


4.1.9

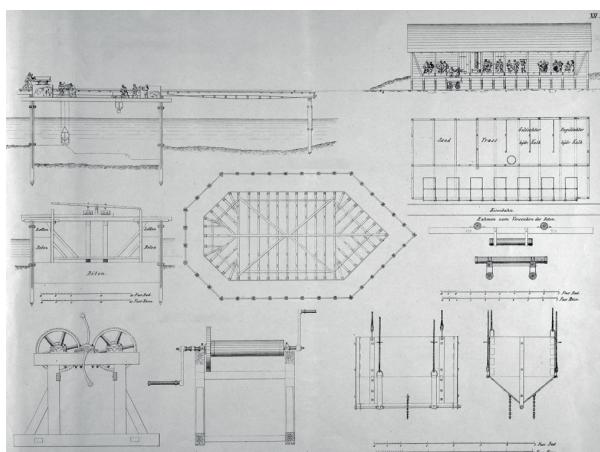
4.1.6. The bridge of Sonnborn in a post card from 1899. 4.1.7 View of the bridge of Sonnborn, (Anon., 1860). 4.1.8. F. E. S. Wiebe, the bridge of Sonnborn, plan and view showing the concrete foundations ([E.] Römer, 1843). 4.1.9. Port of Mannheim (1835–1840), plan of a stretch of the foundation of a quay, and section of the Archimed screw used to dry out the foundation pits (Anon, 1836).



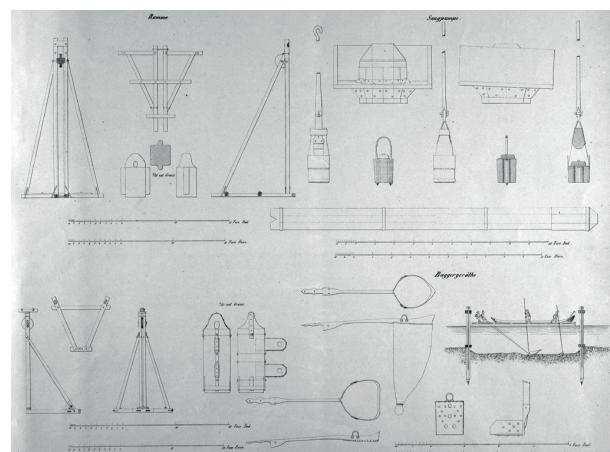
4.1.10



4.1.11

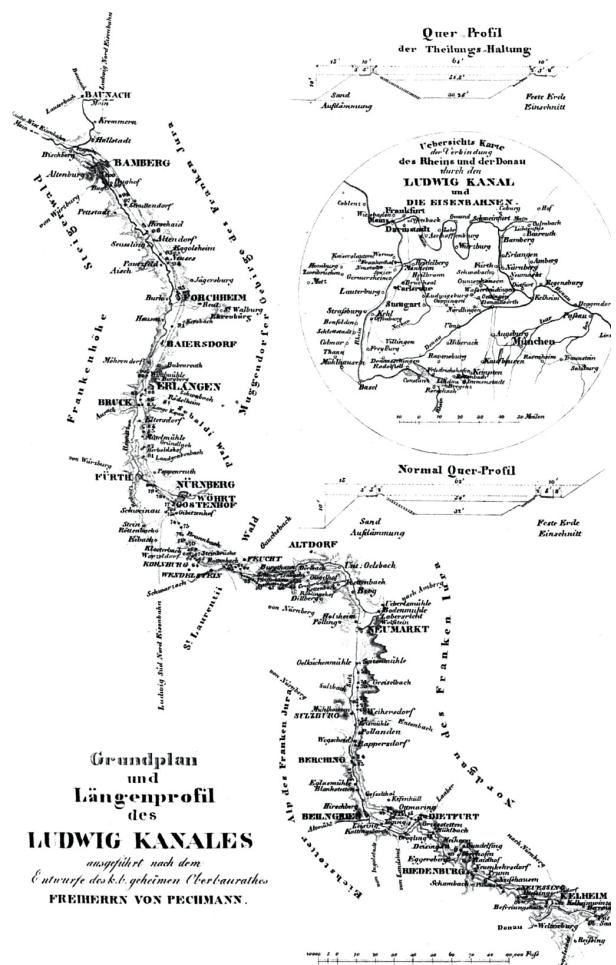


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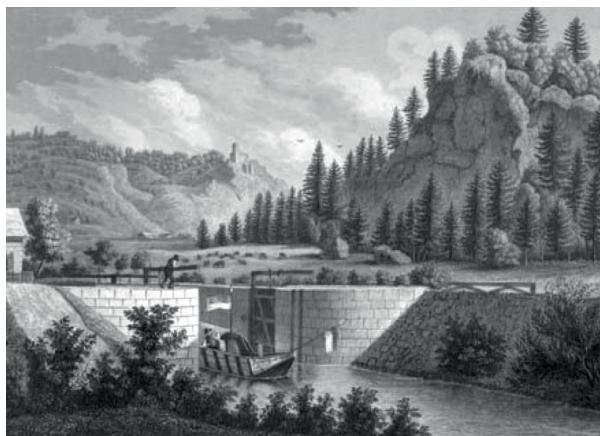


4.1.13

4.1.10. G. Wendelstadt, sunspension bridge in Mannheim (1842–1845), engraving (W. Hablitscheck, appr. 1850). 4.1.11. G. Wendelstadt, sunspension bridge in Mannheim, longitudinal section and plan, repr. (Anon., n.d.). 4.1.12. G. Wendelstadt, sunspension bridge in Mannheim, the construction of a concrete foundation, sections and plan; the crane and the bok to pour concrete; the shed to store materials and produce mortar and concrete; repr. (Anon., n.d.). 4.1.13. Sunspension bridge in Mannheim, construction tools, repr. (Anon., n.d.).



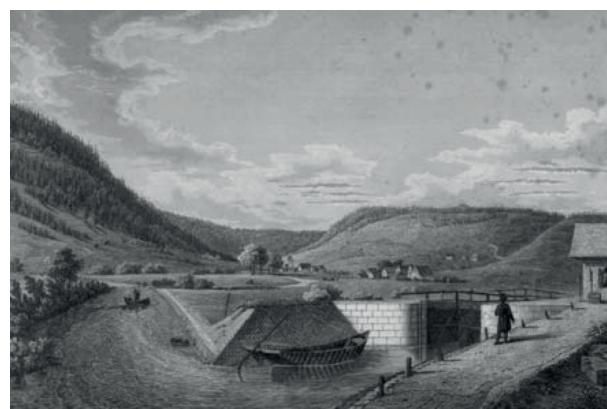
4.2.1



4.2.2a



4.2.2b

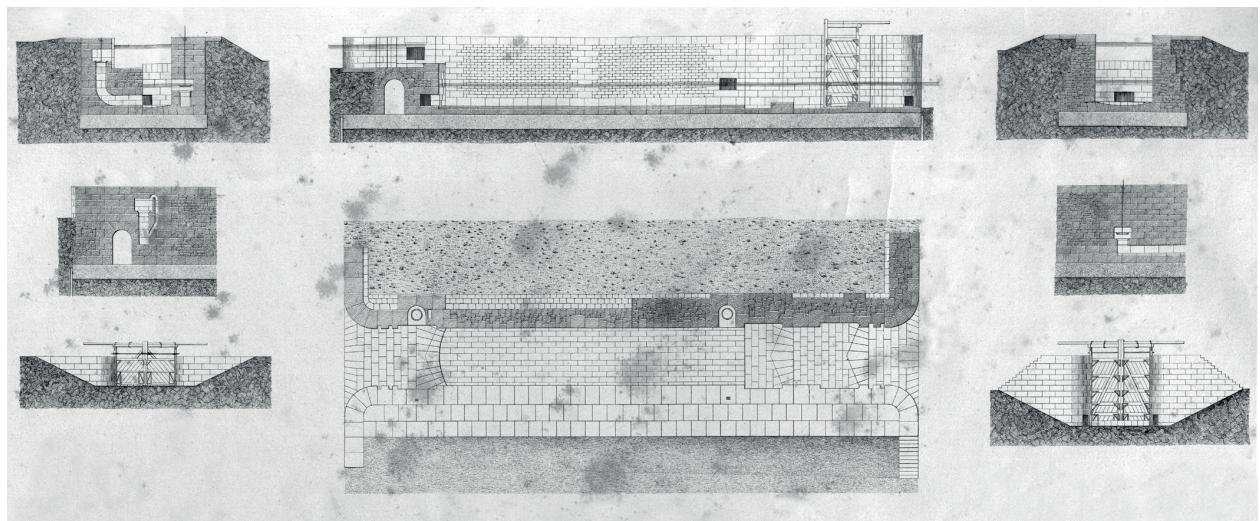


4.2.2c

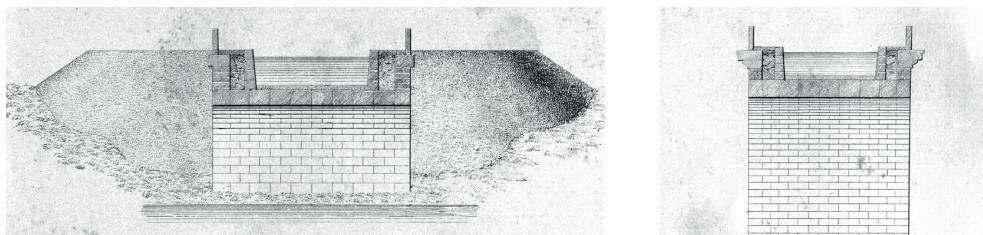


4.2.2d

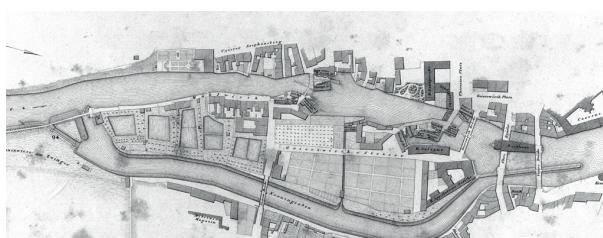
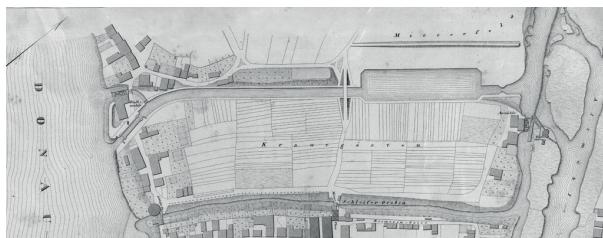
4.2.1. H. J. A. von Pechmann, Ludwig-Kanal (1836–1846), plan, engraving (A. Marx, 1847). 4.2.2. H. J. A. von Pechmann, Ludwig-Kanal, view of some locks, from a to d, locks near Randek, Froscheim, Dietfurt, Berching, engraving (A. Marx, 1847),



4.2.3



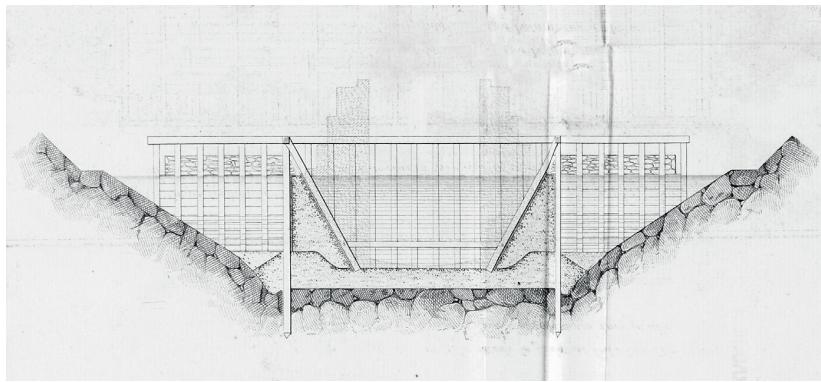
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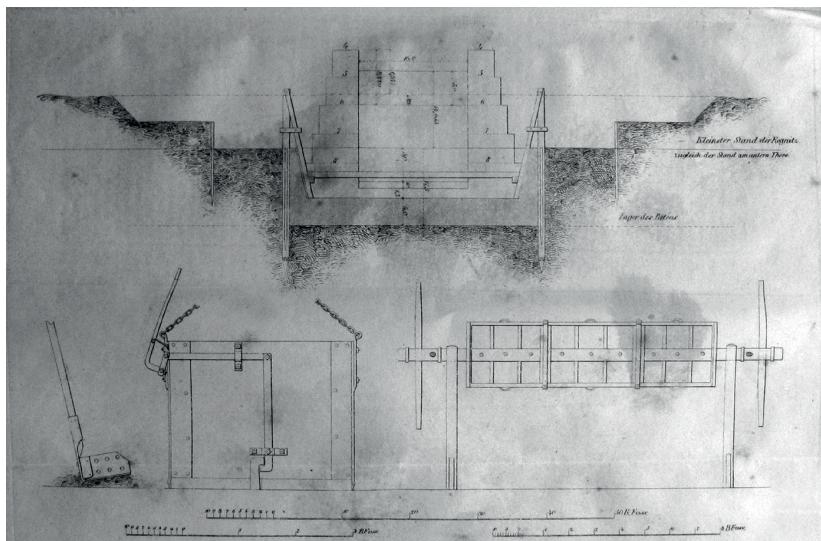
4.2.5-7

4.2.8-9

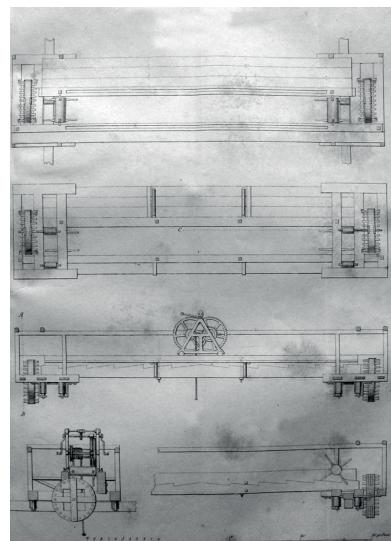
4.2.3. H. J. A. von Pechmann, Ludwig-Kanal, design of a lock, plan and sections (Von Pechmann, 1832). 4.2.4. H. J. A. von Pechmann, Ludwig-Kanal, design of navigable bridge, sections, details, (Von Pechmann, 1832). 4.2.5-7. H. J. A. von Pechmann, Ludwig-Kanal, plan of the locks in Kehlheim, Bamberg (Nonnegraben), Erlangen (Windmühle), (Von Pechmann, 1832). 4.2.8-9. H. J. A. von Pechmann, Ludwig-Kanal, view of the locks in Kehlheim and in Bamberg-Nonnegraben, engraving (A. Marx, 1847).



4.2.10



4.2.11

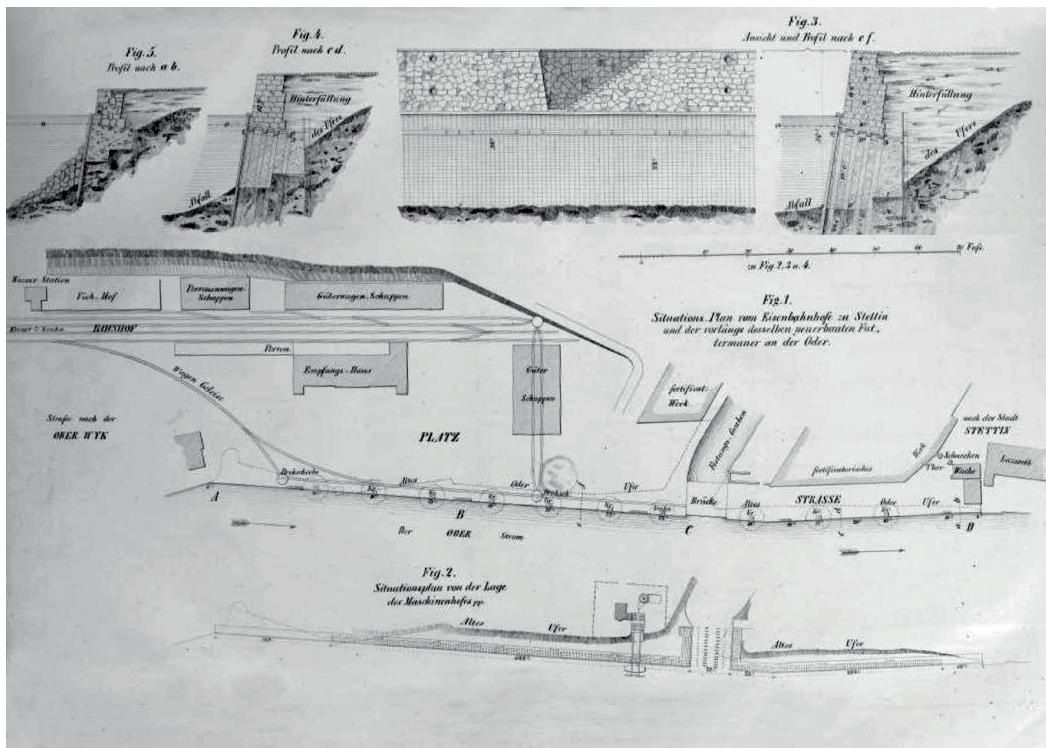


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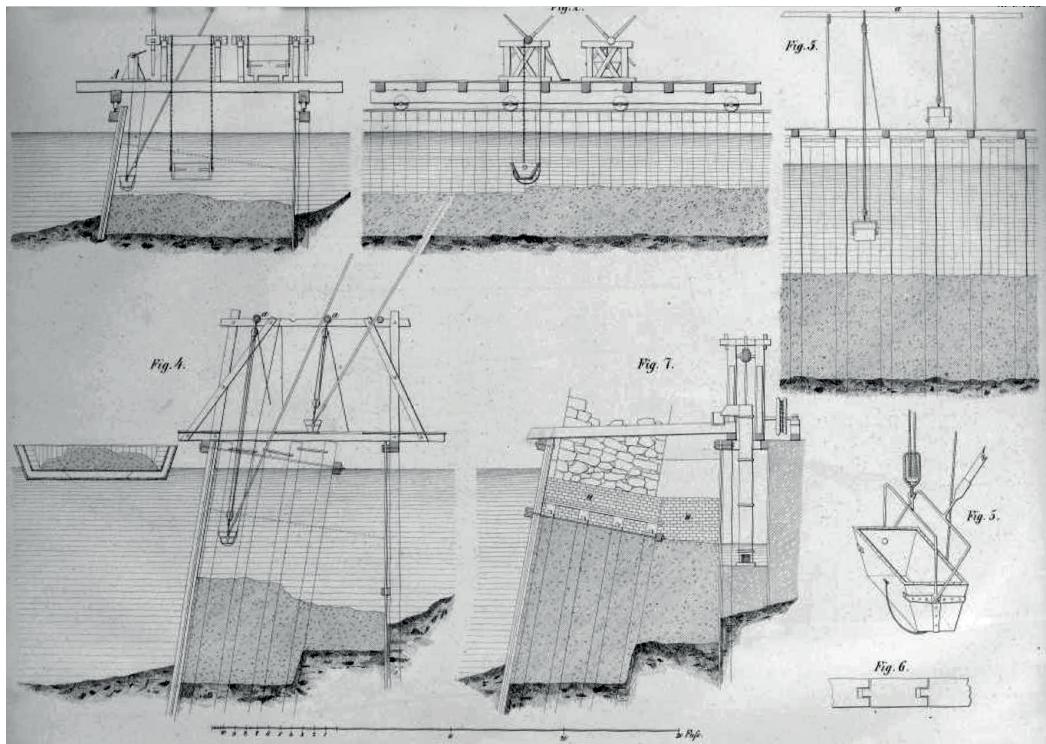


4.2.13

4.2.10. L.-A. BeauDEMoulin, lock at Huningue, transversal section, 1825 (BeauDEMoulin, 1829). 4.2.11. H. J. A. von Pechmann, Ludwig-Kanal, lock at the Bughof in Bamberg, transversal section, and tools to build the foundation: a shovel to dredge the pit, a box to pour concrete, section of a concrete drum (Winkelmann, 1843). 4.2.12. H. J. A. von Pechmann, Ludwig-Kanal, sections and view from above of a bridge crane to pour concrete (Winkelmann, 1843). 4.2.12. H. J. A. von Pechmann, Ludwig-Kanal, a road bridge crossing the channel, Berg bei Neumarkt (Trapp, 2003).

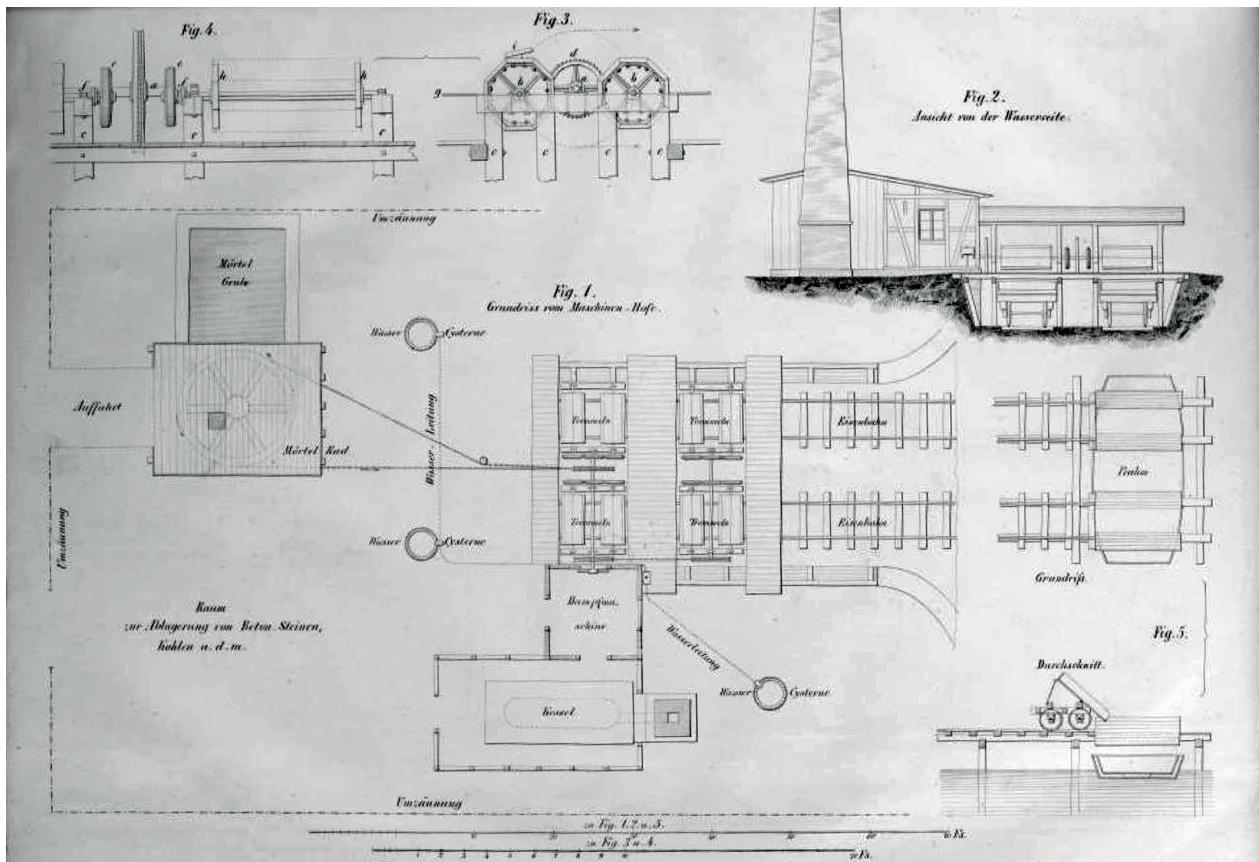


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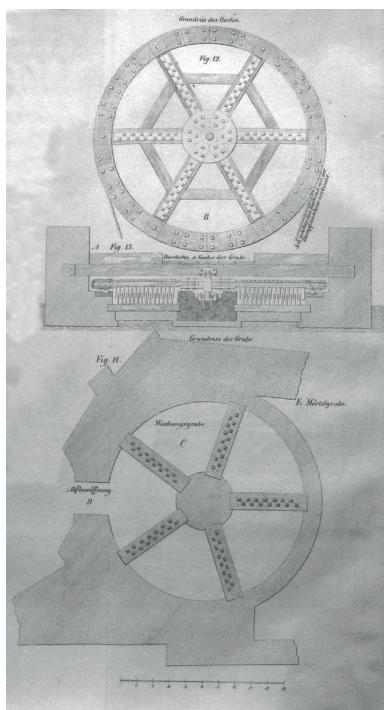


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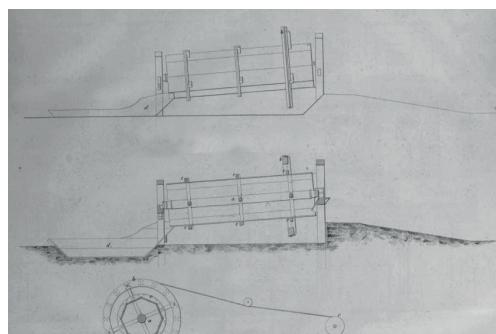
4.2.14. Neuhaus, Schwan, dock along the river Oder in Stettin (1842–1844) design, sections, frontal view, planimetry (Schwan, 1848). 4.2.15. Neuhaus, Schwan, dock along the river Oder in Stettin, drawings of the concrete foundation during concrete pouring, sections (Schwan, 1848).



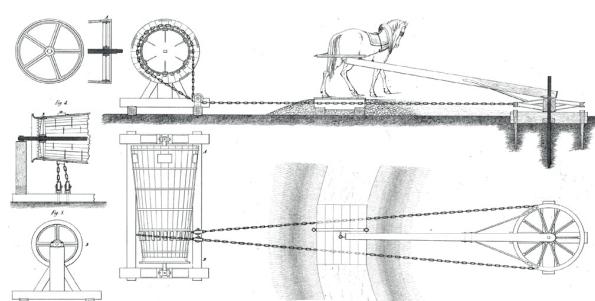
4.2.16



4.2.17

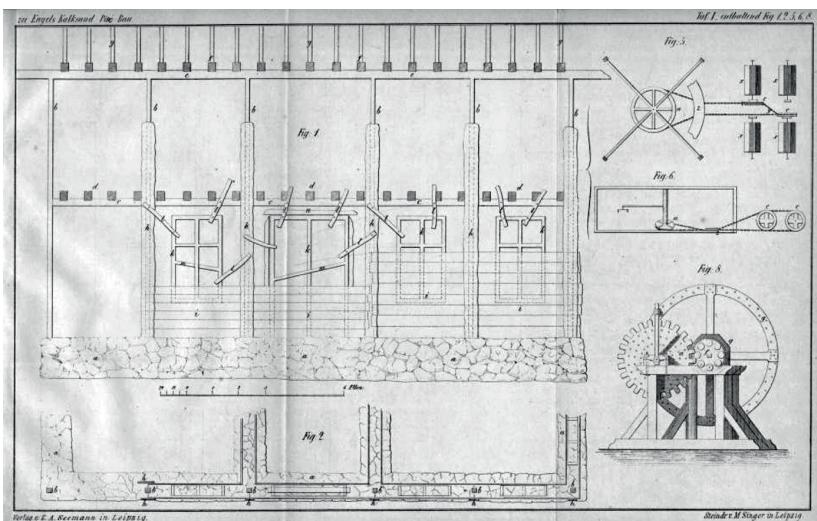


4.2.18

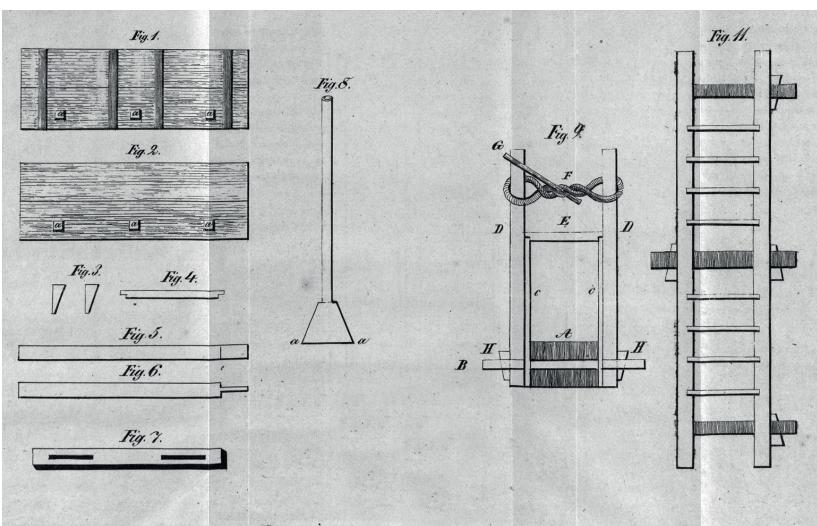


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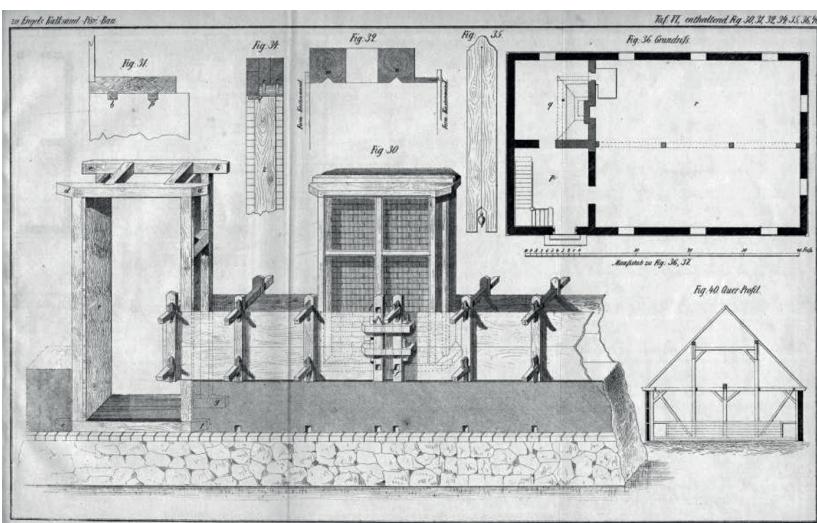
4.2.16. Neuhaus, Schwan, dock along the river Oder in Stettin, installations for the manufacturing of mortar and concrete (Schwan, 1848). 4.2.17. C. W. Hoffmann, mortar mixer used on the building site of the Neues Museum in Berlin (Anon., 1842). 4.2.18. Schwan, design for a sloping concrete drum (Schwan, 1848). 4.2.19. Frustum-shaped concrete drum used to build the fortification of Paris (Lecointre, 1843).



4.3.1

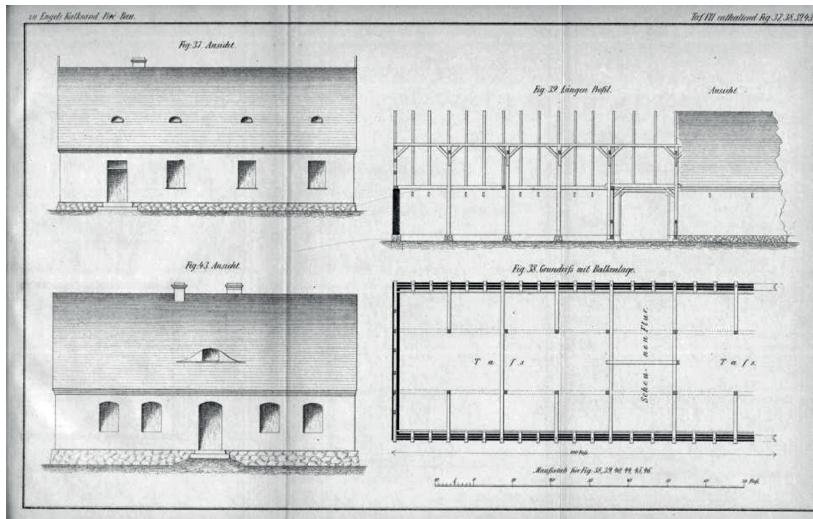


4.3.2

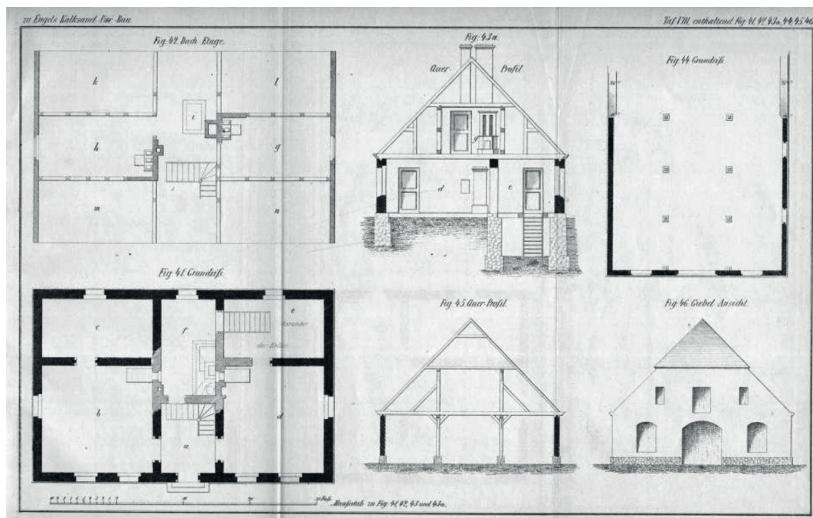


4.3.3

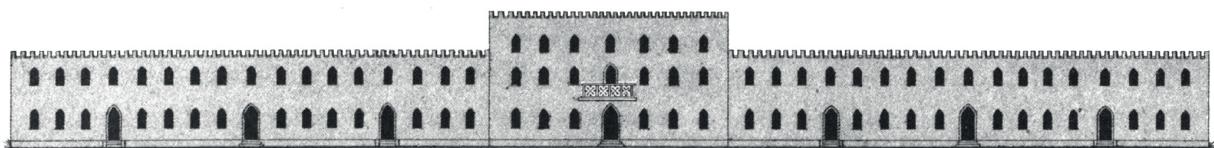
4.3.1. Representation of Rydin's method of building, and mortar mixer for lean conglomerate used in Cöslitz (J. D. F. Engel, 1865). 4.3.2. J. G. Prochnow, tools to build with lean conglomerate, formwork for walls, pestle, mould for lean conglomerate artificial stones (J. G. Prochnow, 1842). 4.3.3. Draft of the building of a lean conglomerate wall and design for a rural house (plan) and a shed (section) (J. D. F. Engel, 1865).



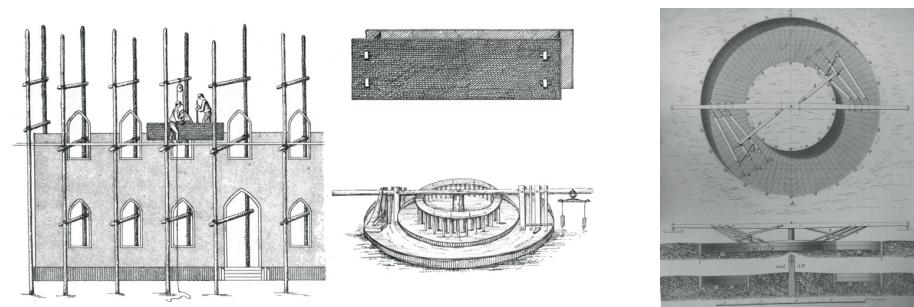
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4.3.5



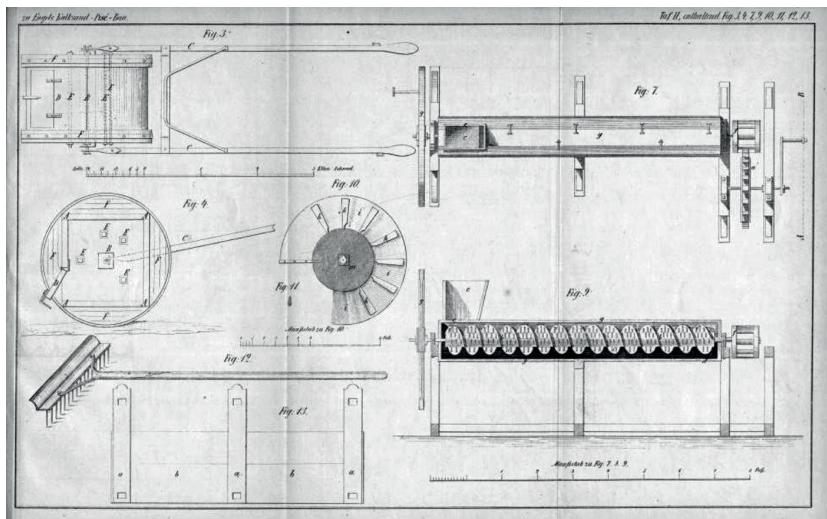
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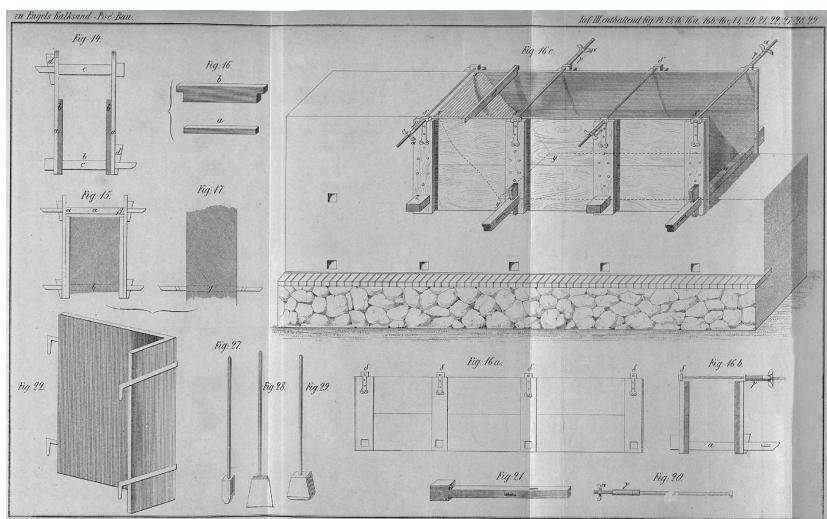
4.3.7

4.3.8

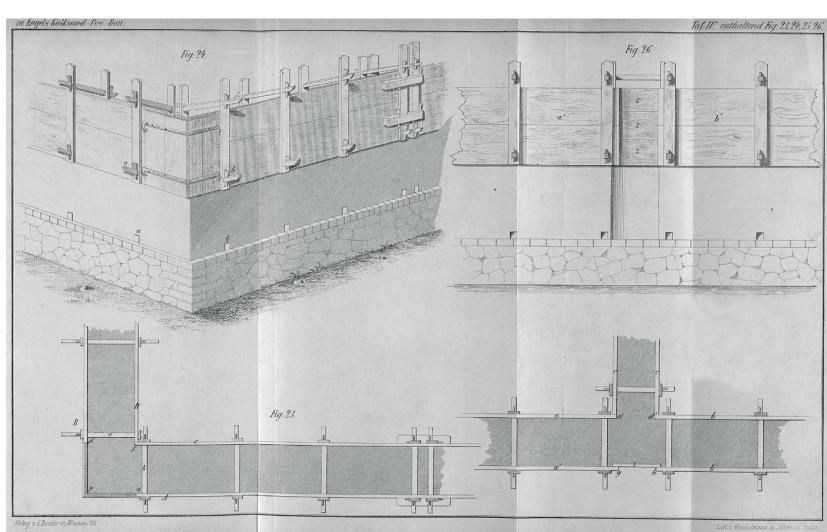
4.3.4. Drawings of rural houses (front views) and a shed (plan and section) (J. D. F. Engel, 1865). 4.3.5. Drawings of a rural house (plans and section) and a shed (plan and sections) (J. D. F. Engel, 1865). 4.3.6-7. J. C. Leuches, manufacturing building in lean conglomerate in "Weissen Au", front view, draft of the construction of a wall, formwork and mortar mixer (J. C. Leuches 1848). 4.3.8. Von Prittitz, typical mortar mixe used to build fortresses in Silesia (M. K. E. von Prittitz, 1832).



4.3.9



Jörgen E. Rooder



4.3.11

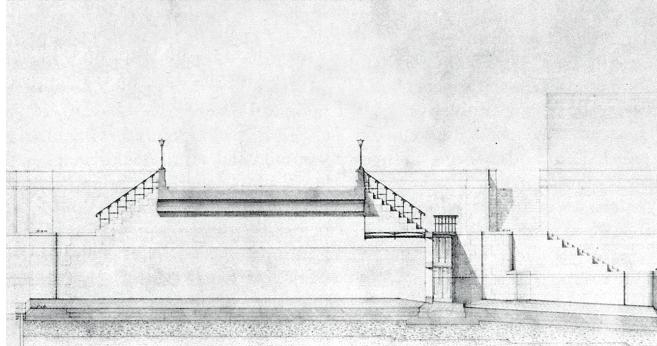
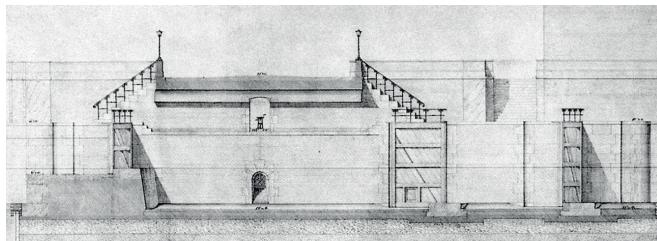
4.3.4. Rydin's mortar mixer, and mortar mixer used in Fiddichow in Pomerania (J. D. F. Engel, 1865). 4.3.10-11. Improvements to the formwork systems for lean conglomerate (J. D. F. Engel, 1865).



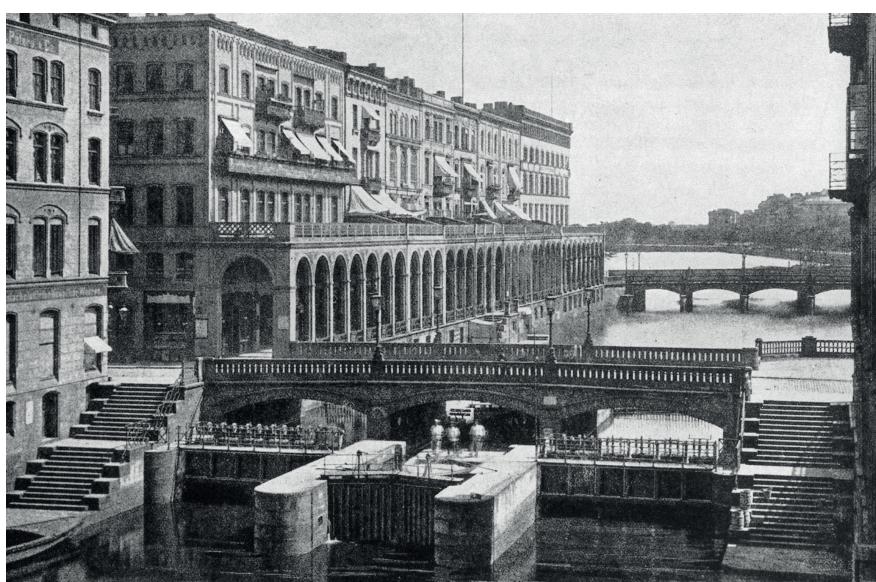
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4.4.2

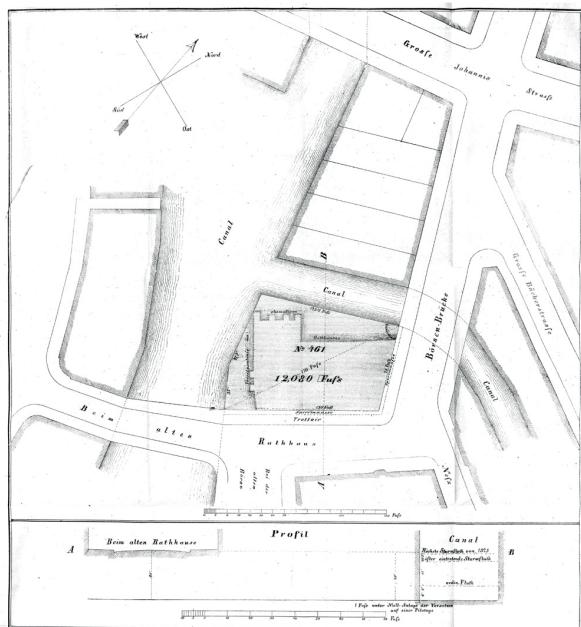


4.4.4

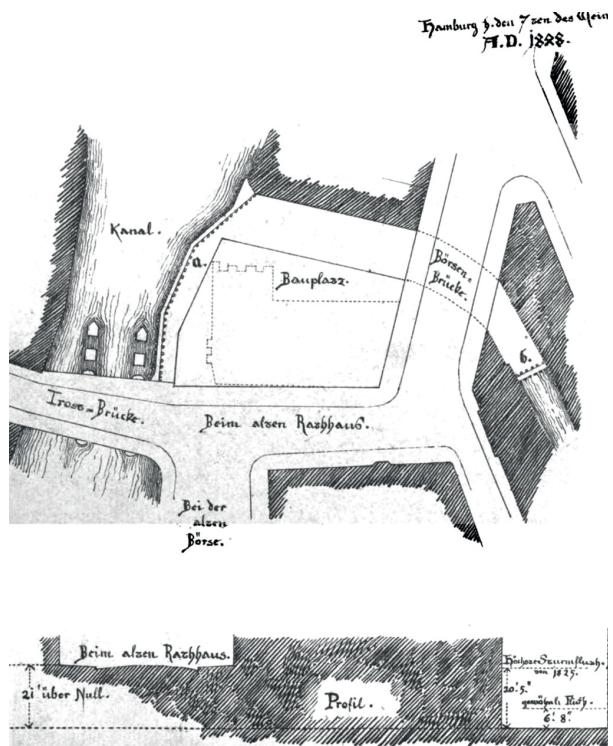


4.4.5

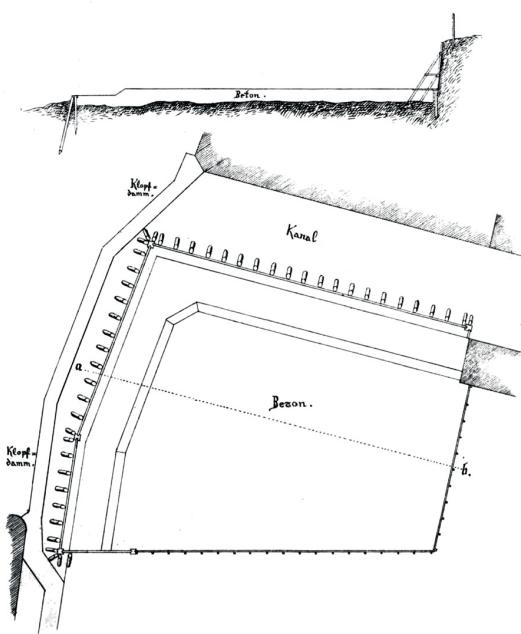
4.4.1-3. Hamburg, view of the façades of the Alsterarkaden, the Exchange building and the arcades, engraving (J. Gray, 1860). 4.4.5. J. H. Maack, design of the Alsterschleuse (1843–1846). 4.4.4 J. H. Maack, Alsterschluse, photography, (Koppmann, 1880).



Grundriss des der Gesellschaft zur Verteidigung der Hanse u. nördlichen Gewerbe gehörigen Hauses sel. 1846 u. dagegen Umgelung
Hamburg, den 26. Januar 1846.
S. A. Nagel gezeichnet

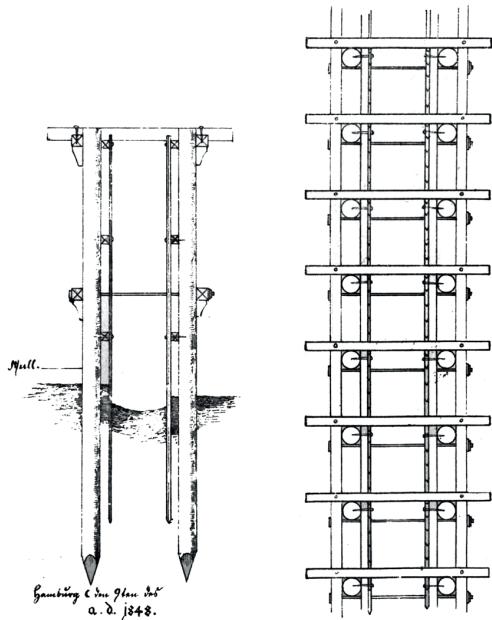


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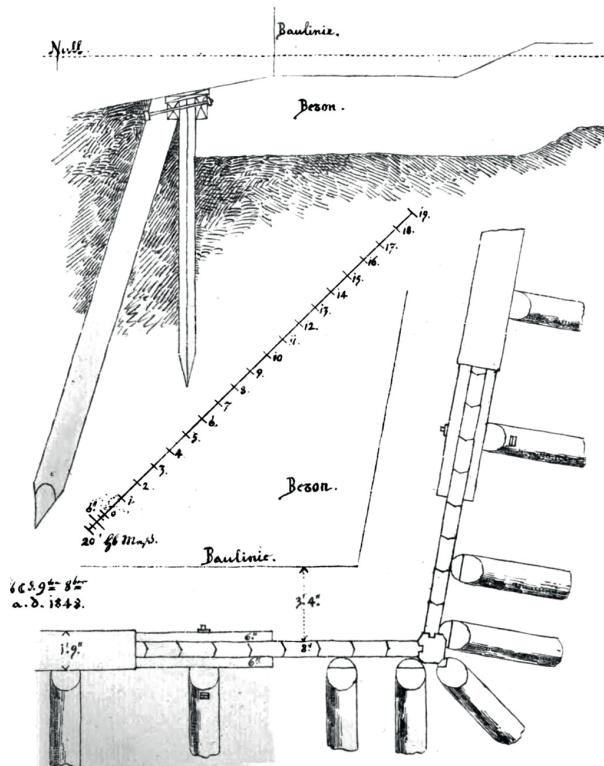
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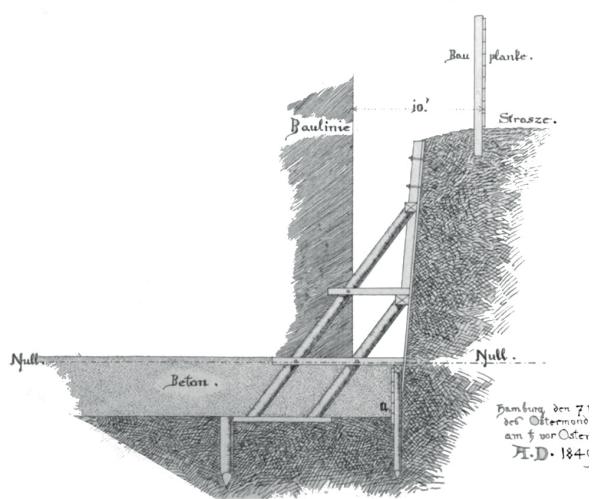


4.4.9

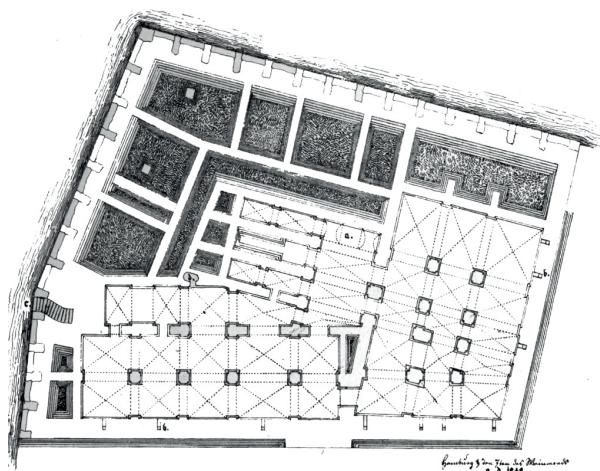
4.4.6. T. Bülow, Haus der Patriotische Gesellschaft (1844–1847), Hamburg, planimetries. 4.4.8. T. Bülow, Haus der Patriotische Gesellschaft, desing of the concrete foundations, plan and section. 4.4.9 T. Bülow, Haus der Patriotische Gesellschaft, design of the provisional cofferdam, section and view from above.



4.4.10



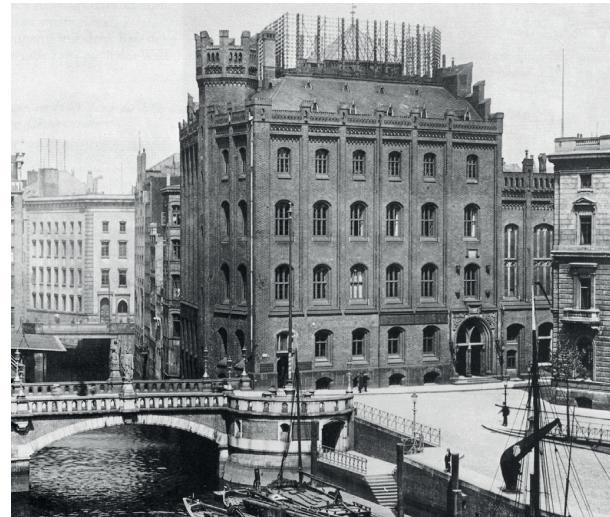
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4.4.12



4.4.13

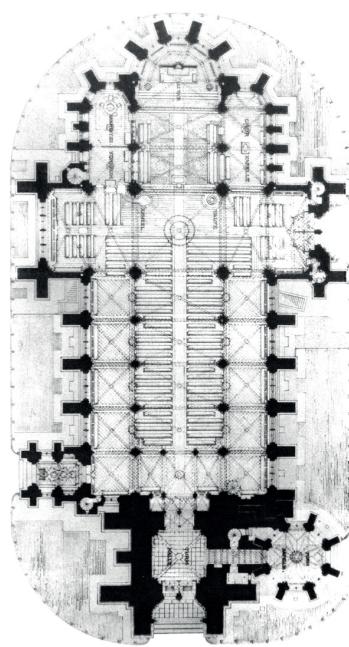


4.4.14

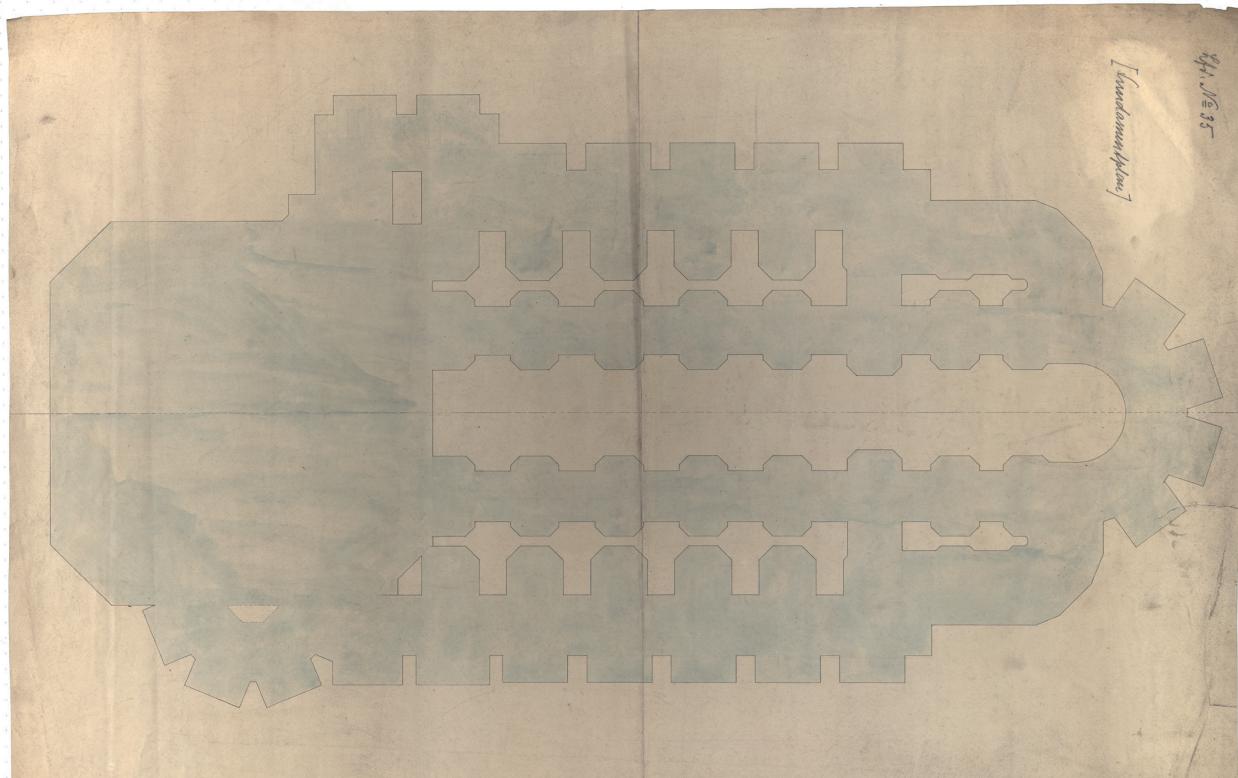
4.4.10. T. Bülau, Haus der Patriotische Gesellschaft, drafts of the sheet piling work. 4.4.11. T. Bülau, Haus der Patriotische Gesellschaft, draft of the shoring works. 4.4.12 T. Bülau, Haus der Patriotische Gesellschaft, plan of the basement level. 4.4.13. T. Bülau, Haus der Patriotische Gesellschaft, painting (K. Kaufmann). 4.4.14. T. Bülau, Haus der Patriotische Gesellschaft, photography (unknown author and date).



4.4.15

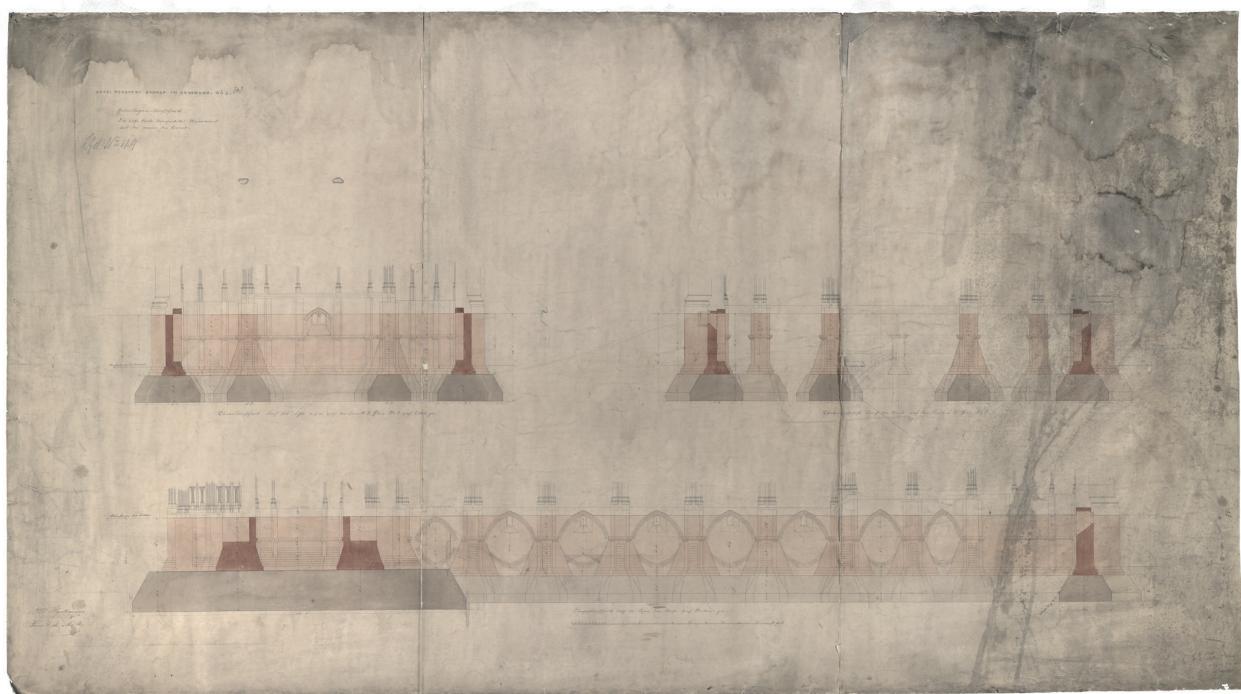


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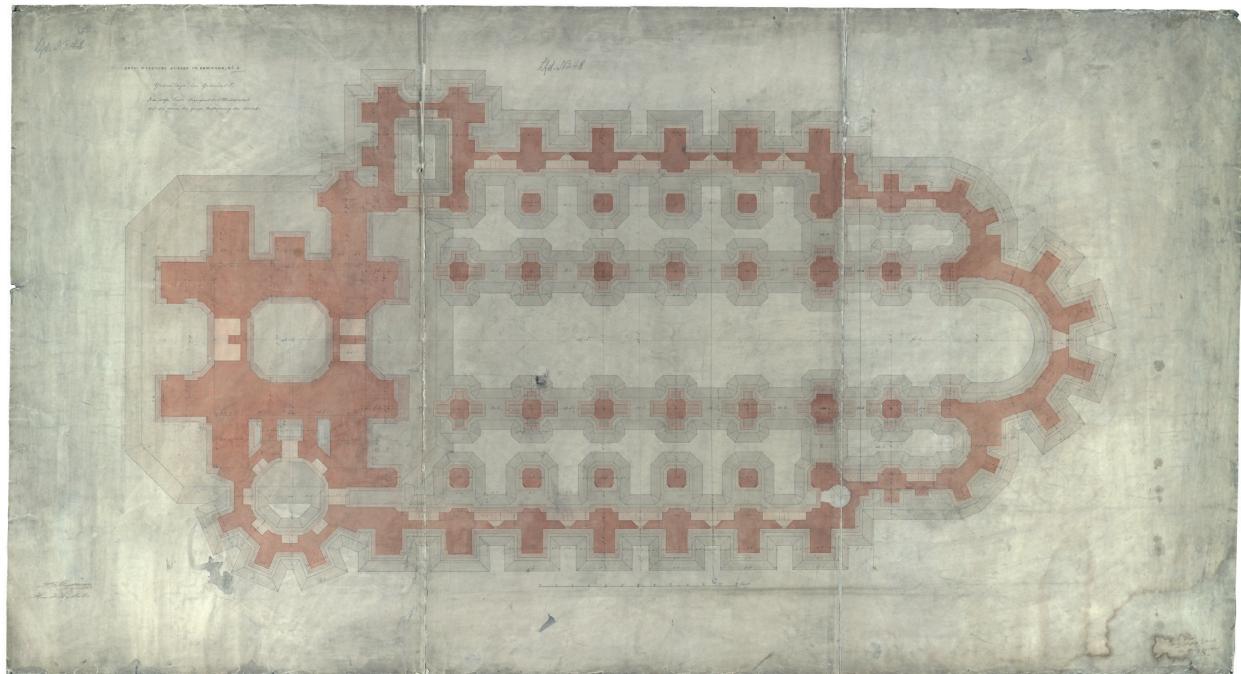


4.4.17

4.4.6. J. Suckert, The Hamburg fire of 1842, the Hopfenmarkt and the church of St. Nicholas, coloured lithography, 1845. 4.4.16. G. G. Scott, new church of St. Nicholas, plan, 1845. 4.4.17. G. G. Scott, new church of St. Nicholas, plan of the concrete foundations 1845.

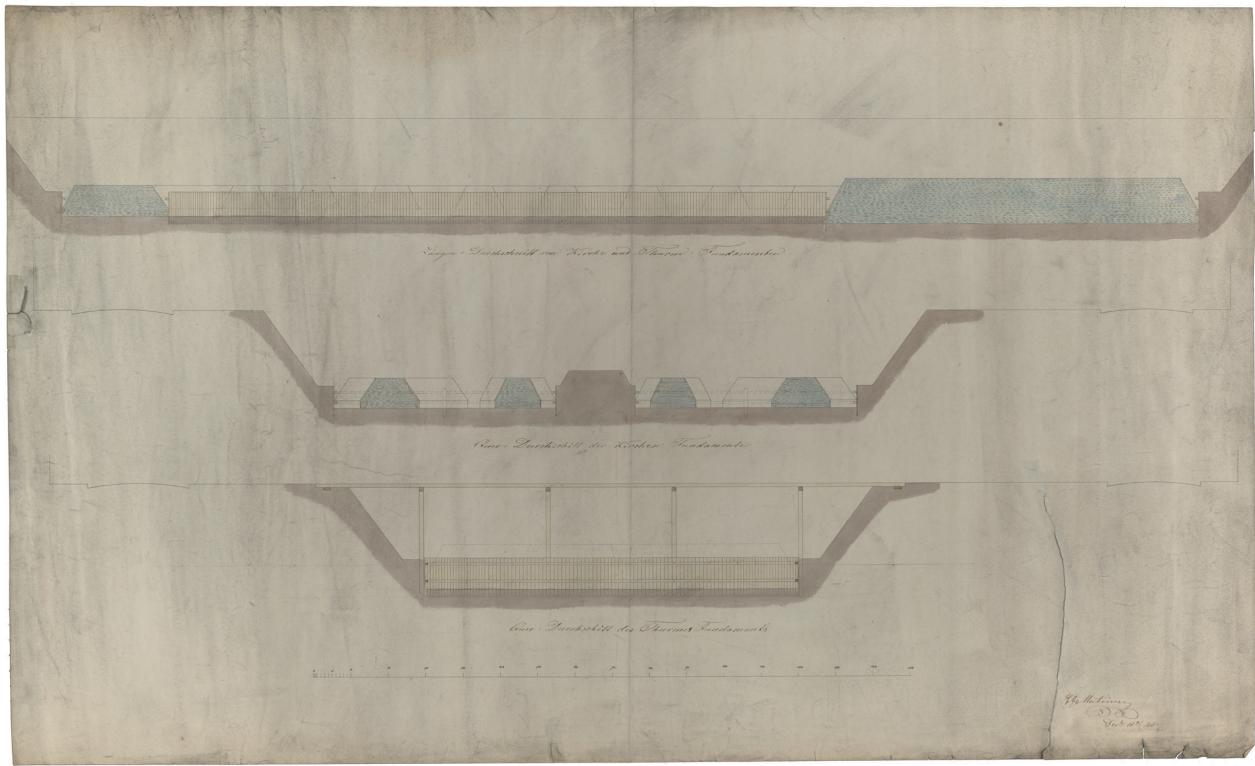


4.4.18

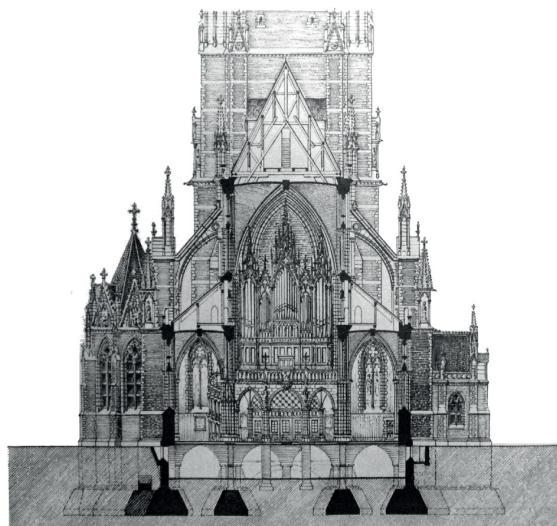


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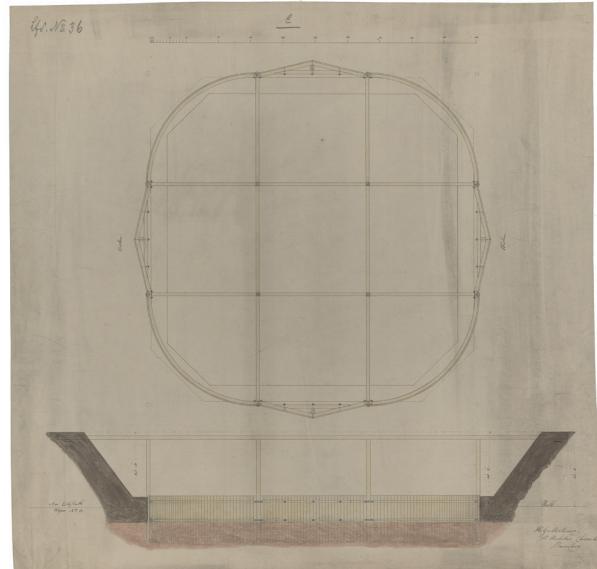
4.4.18. G. G. Scott, new church of St. Nicholas, concrete foundations, sections, 1845. 4.4.19. G. G. Scott, new church of St. Nicholas, concrete foundations, plan, 1845.



4.4.20

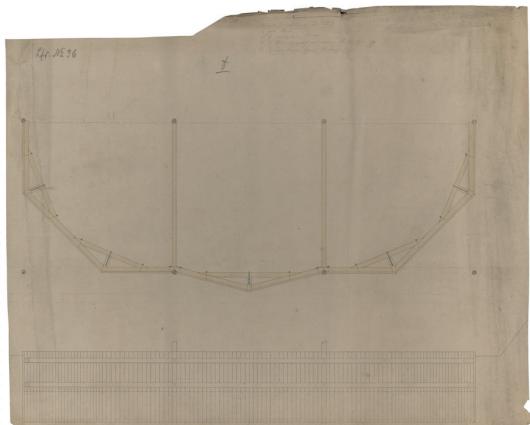


4.4.21



4.4.22

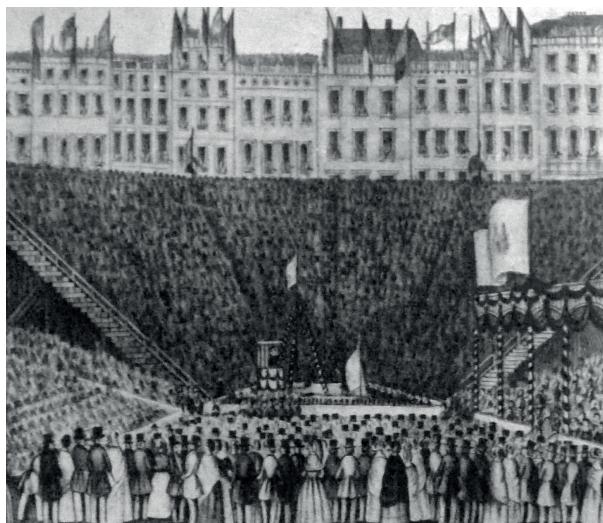
4.4.20. G. G. Scott, new church of St. Nicholas, the foundation pit with the shoring works, longitudinal and transversal sections, 1845. 4.4.21. G. G. Scott, new church of St. Nicholas, trasversal section (J. Faulwasser, 1926). 4.4.22. G. G. Scott, new church of St. Nicholas, shoring works for the foundation of the tower, plan and transversal section, 1845.



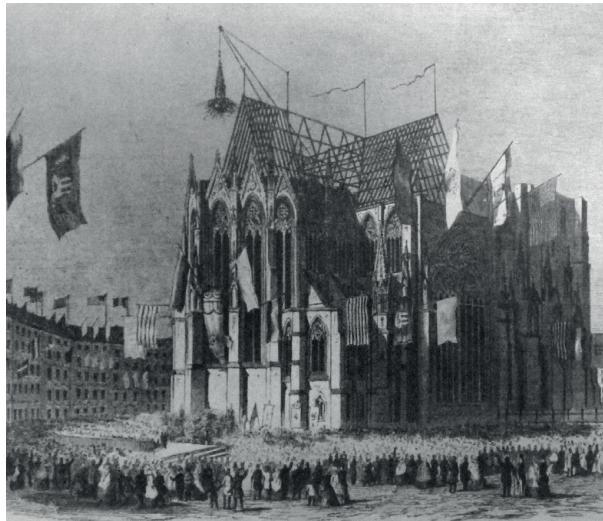
4.4.23

13 parts of Zinc wire or Lat. Strip
6 good Lime
9 of unslakker Lime
13 of Stone Aggregate not exceeding 30 mm
3 of Iron Scales from the Lodge

4.4.24



4.4.25

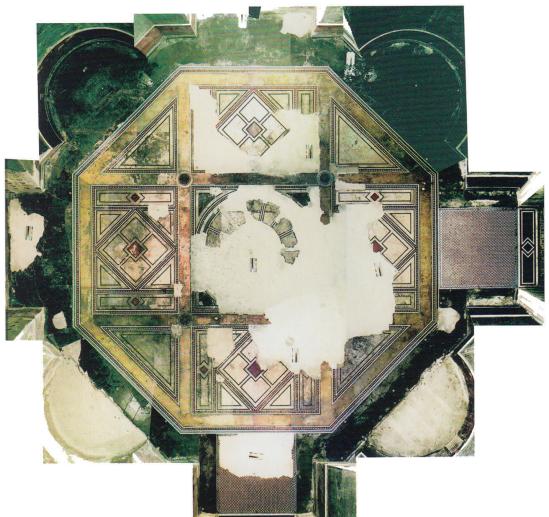


4.4.26

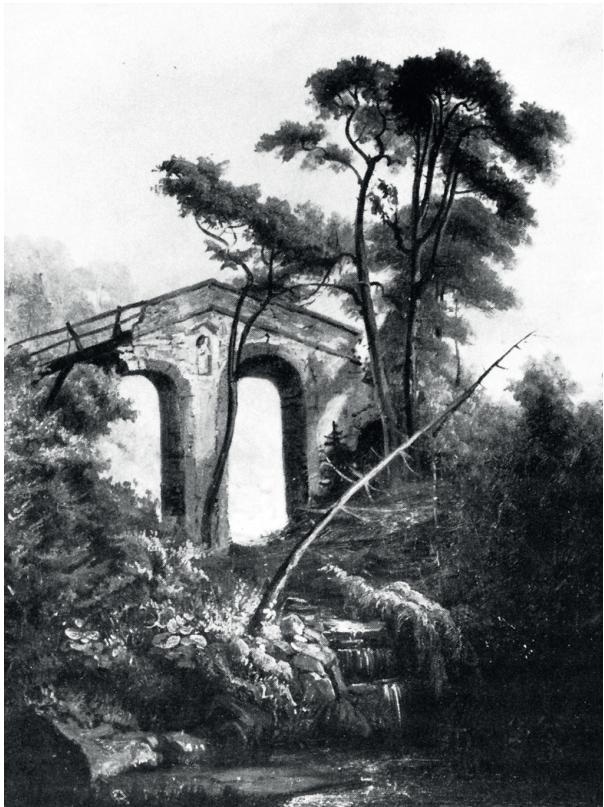


4.4.27

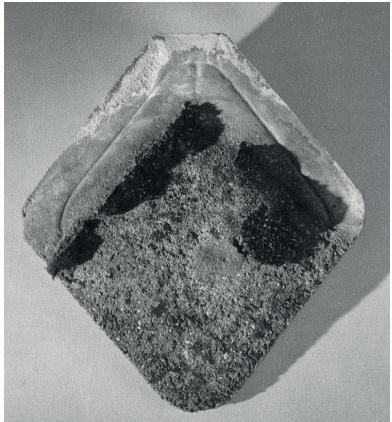
4.4.23. G. G. Scott, new church of St. Nicholas, shoring works for the foundation of the tower, plan, 1845. 4.4.24. G. G. Scott, new church of St. Nicholas, the composition of concrete, detail from the plate in fig. 4.4.23. 1845. 4.4.25. G. G. Scott, new church of St. Nicholas, the first stone ceremony on 24 September 1846 (Faulwasser, 1926). 4.4.26. G. G. Scott, new church of St. Nicholas, workers ceremony for the achievement of the bearing structures on 18 October 1859 (Faulwasser, 1926). 4.4.27. G. G. Scott, new church of St. Nicholas, photography (author unknown, approx. 1868).



4.5.1



4.5.2



4.5.3

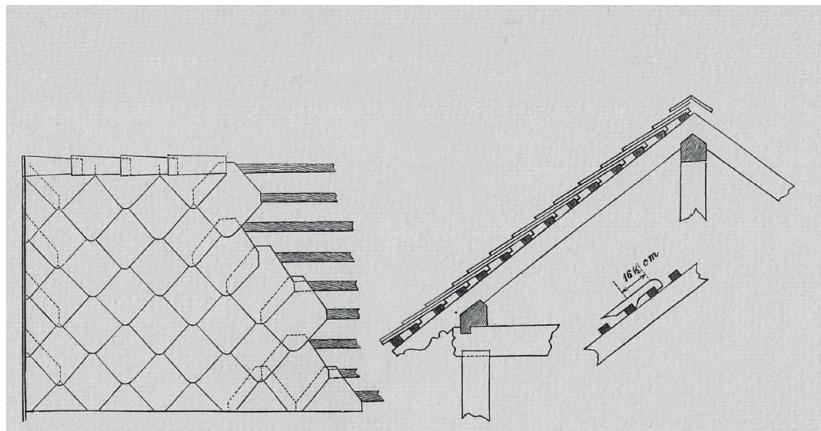


4.5.4



4.5.5

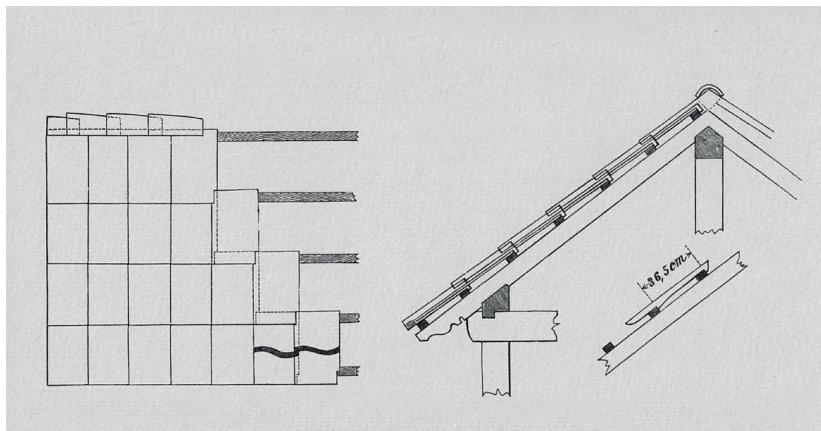
4.5.1. F. A. Stüler, Neues Museum Berlin, artificial marble floor. 4.5.2. A. Lompeck, The Teufelsbrücke in Klein-Gliencke park, painting, approx. 1850. 4.5.3. A. Kroher, rhombic concrete roofing tile, approx. 1848. 4.5.4. A. Kroher, mould for S-shaped roofing tiles, (unknown date). 4.4.5. A. Kroher, Roof of Kroher's farmhouse, covered with S-shaped concrete tiles, Staudach, approx. 1870.



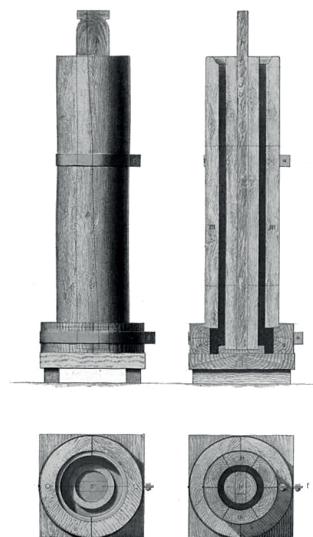
4.5.6



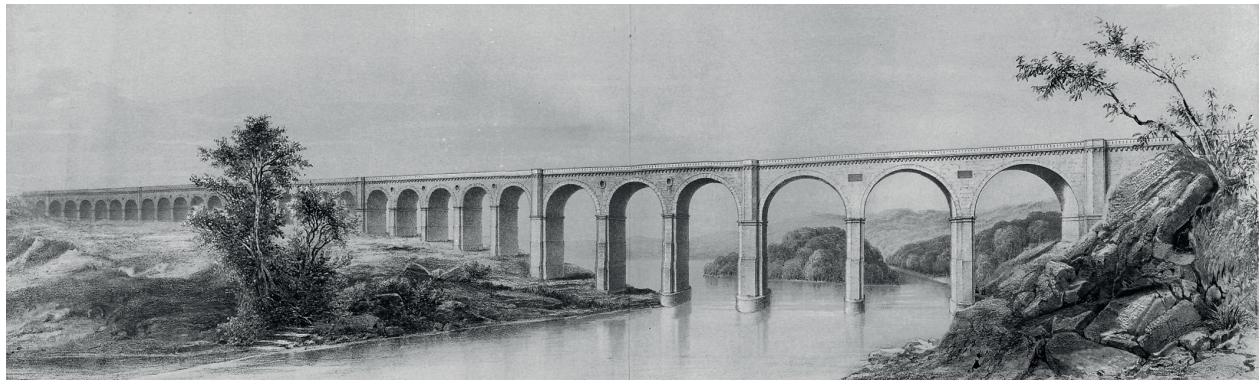
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4.5.7

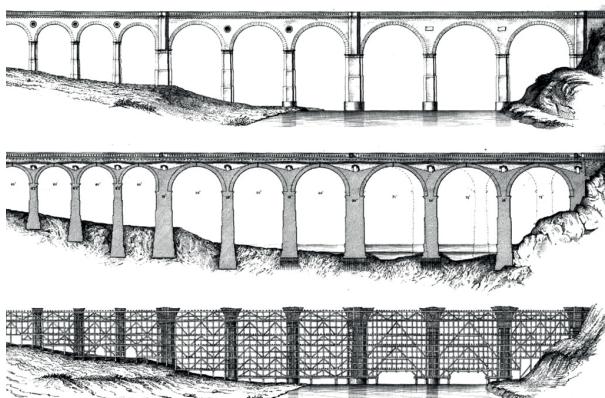


4.5.9

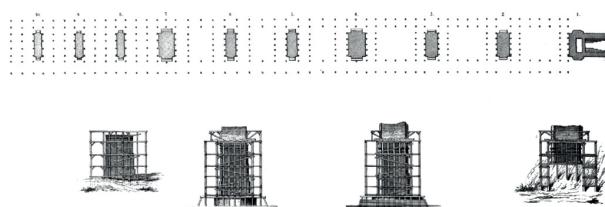
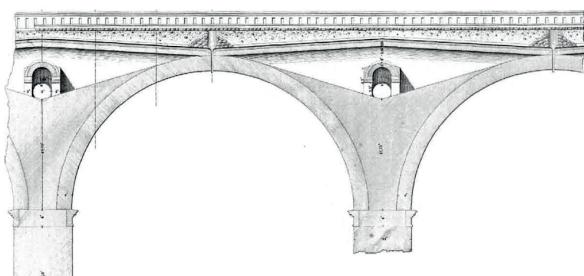


4.6.1

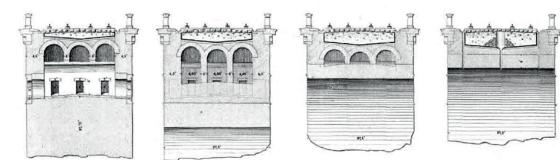
4.5.6-7. A. Kroher, instructions to install rhombic and S-shaped tiles (Kroher, 1878). 4.5.8. A. Kroher, the special mould to produce the rhombic tiles (Handschlagtisch), photography (unknown date). 4.5.9. Representation of a mould for circular pipes, made of two concentric cylinders, similar to the one that Karlinger from Miesbach patents in 1848 (Becker, 1860). 4.6.1. Viaduct of Görlitz, Silesia, (1844–1847), view (L. B. Henz, 1855).



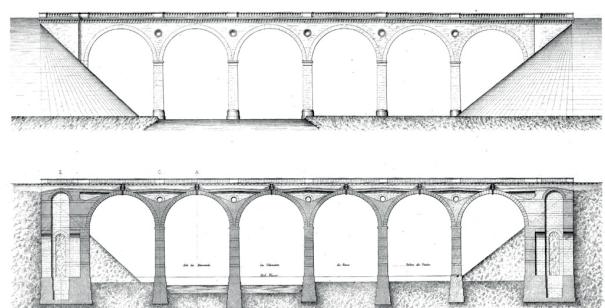
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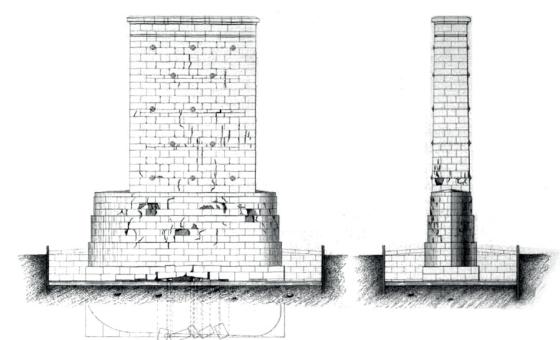
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4.6.4



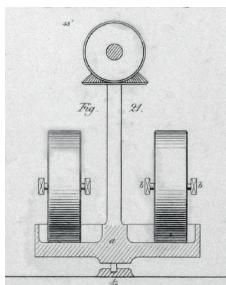
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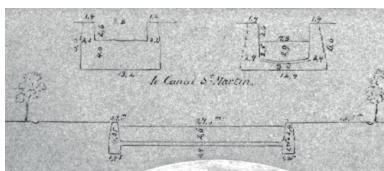
4.7.1

Papers of the corps of royal engineers
Notes by Connelly
See animals supposed with many in view London 1770 Salts
of Urine Salting. The Posthorn happens to be 2 lbs. Brin
water. has fine copper salts with low Salts
is known from Gippsland you may mention, show for
woodpecker. Mopan jagoroff. Show the molts when
Mopan is avenged with all its might & will
via St. Peters siegypelt wonder in the great sea
forest woods. fine cab. Hand Salts etc go
fine copper salts in Mopan which shows 15 months
Cavalcade. Show 1 cab. Hand Copper & unpolished
the 8 and fine Salts with salts, wings were 30
cab. of Salts 3 1/2 lb. of salt with fine copper Mopan
anywhere. has salts in the London earthworks
it must justify me Dorking. it is darker in
Dorking and Hatting fine copper salts.
the 8th Salting marsh in the Cavalcade suppose
has Salts but which was fit yapp batavia's about
3 1/2" or new cab. of.

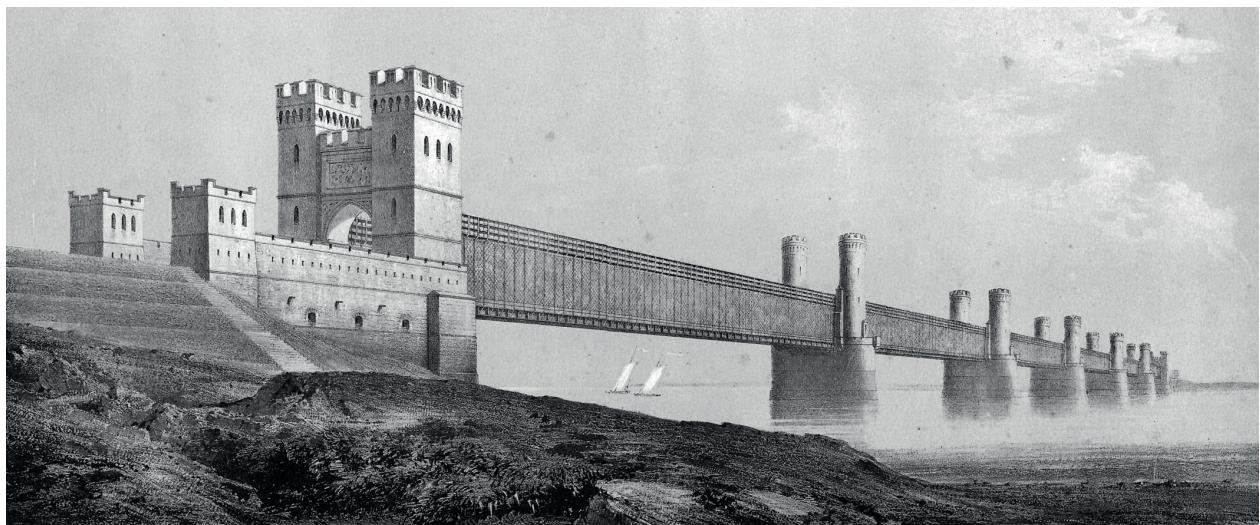
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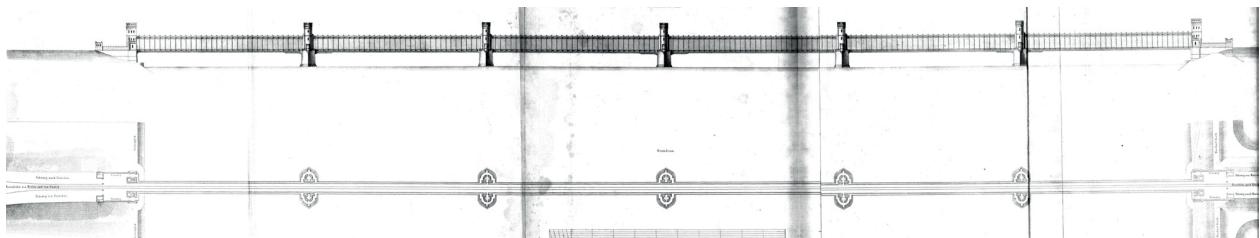
4.7.2



4.6.2. Viaduct of Görlitz, Silesia, view, section and plan of the central part (L. B. Henz, 1855). 4.6.3. Viaduct of Görlitz, Silesia, the bridge deck, longitudinal and transversal sections, showing the concrete filling and the drainage system (L. B. Henz, 1855). 4.6.4. Bridge over the river Diemel close to Warburg, Rhineland, (1847–1851), Front view and longitudinal section (L. B. Henz, 1852). 4.6.5. Bridge over the river Diemel, pier n. IV, longitudinal and frontal view of the pier showing and sections over the foundation pit (L. B. Henz, 1852). 4.7.1. J. C. W. Lentze, notes about the production of concrete in England taken from the Papers of the Royal Corp of Engineers, apprx. 1846–1847. 4.7.2. J. C. W. Lentze, the mortar mixer used on the building site of the Liverpool docks, 1846. 4.7.3. J. C. W. Lentze, sketch of the Canal de St. Martin in Paris (unknown date).



4.7.4



4.7.5

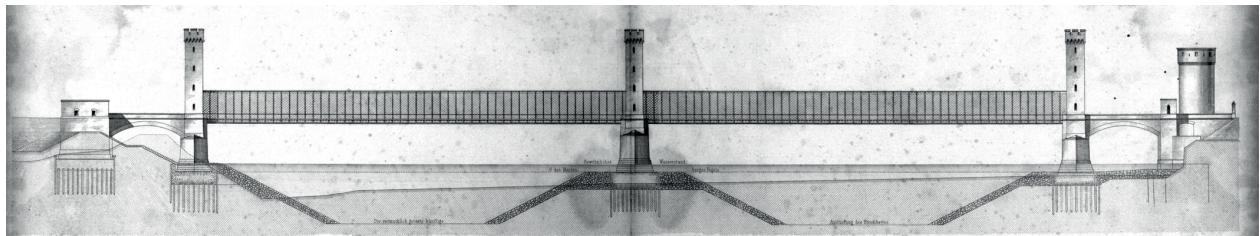


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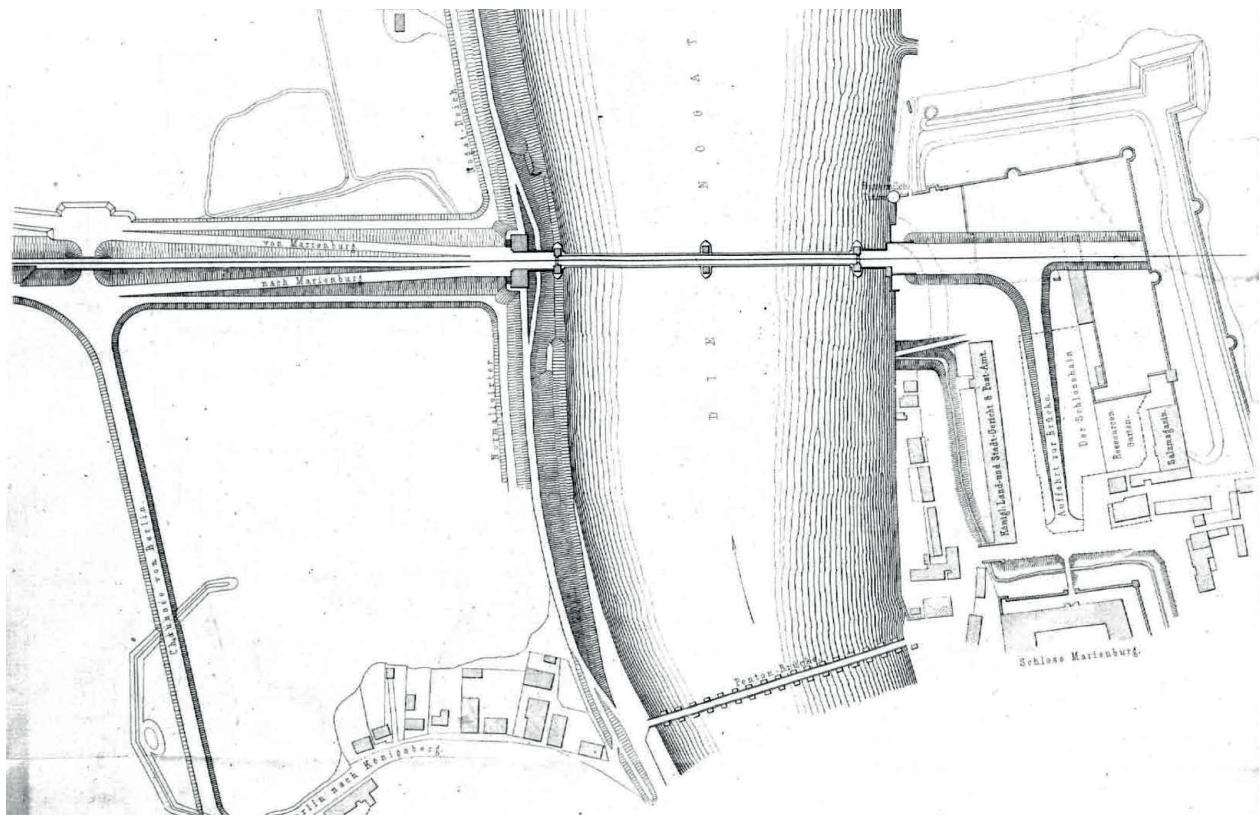
4.7.4–6. J. C. W. Lentze, the bridge over the Vistula in Dirschau (1846–1855), prospektic view, plan, planimetry (Lentze, 1855).



4.7.7

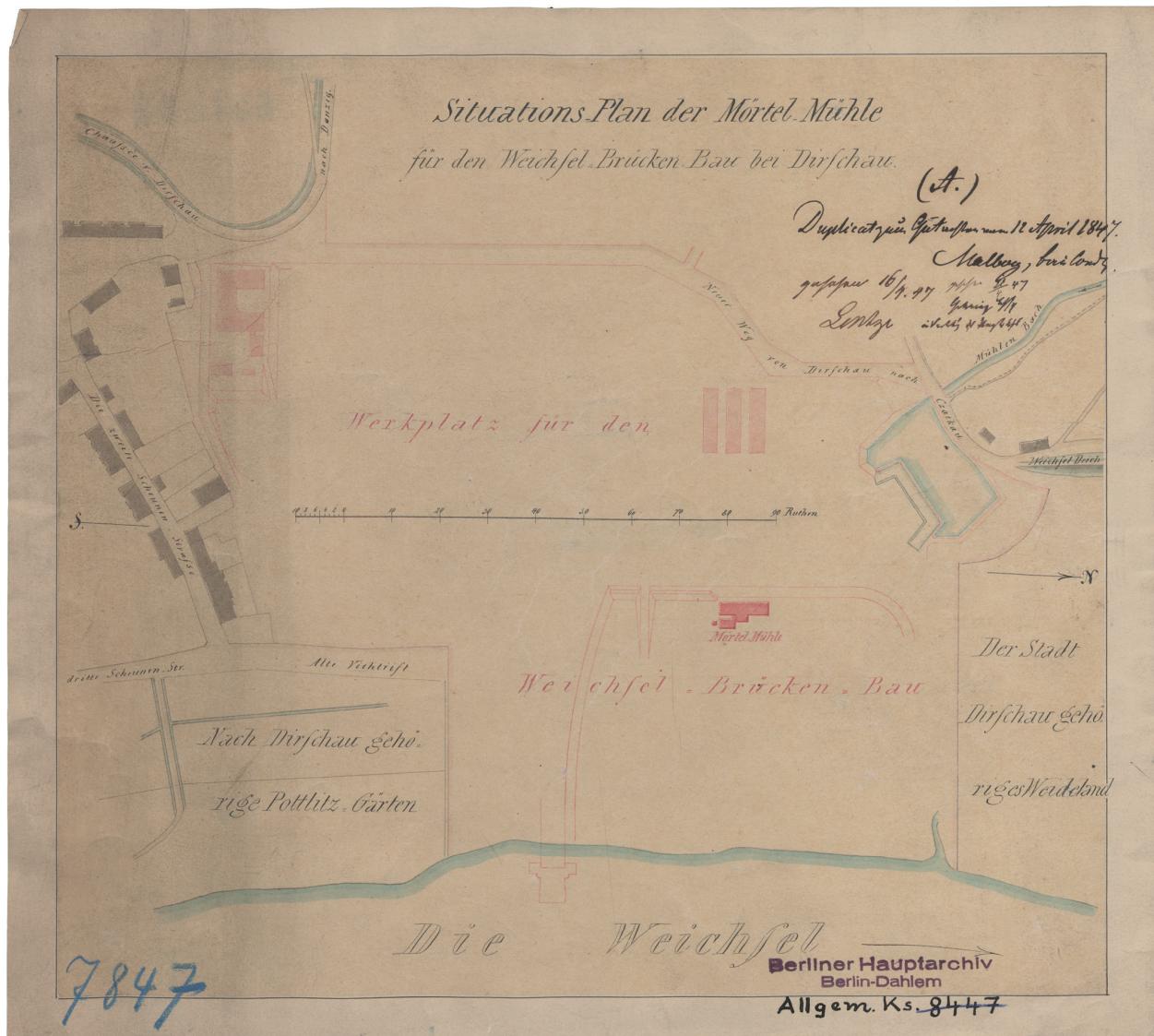


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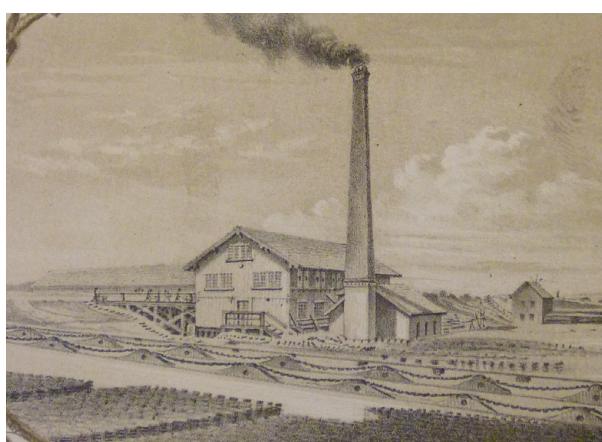


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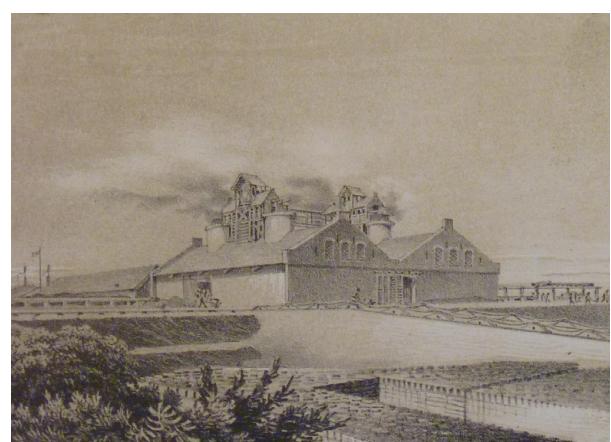
4.7.7-9. J. C. W. Lentze, the bridge over the Nogat in Marienburg (1846–1856), prospektic view, plan, planimetry (Lentze, 1855).



4.7.10

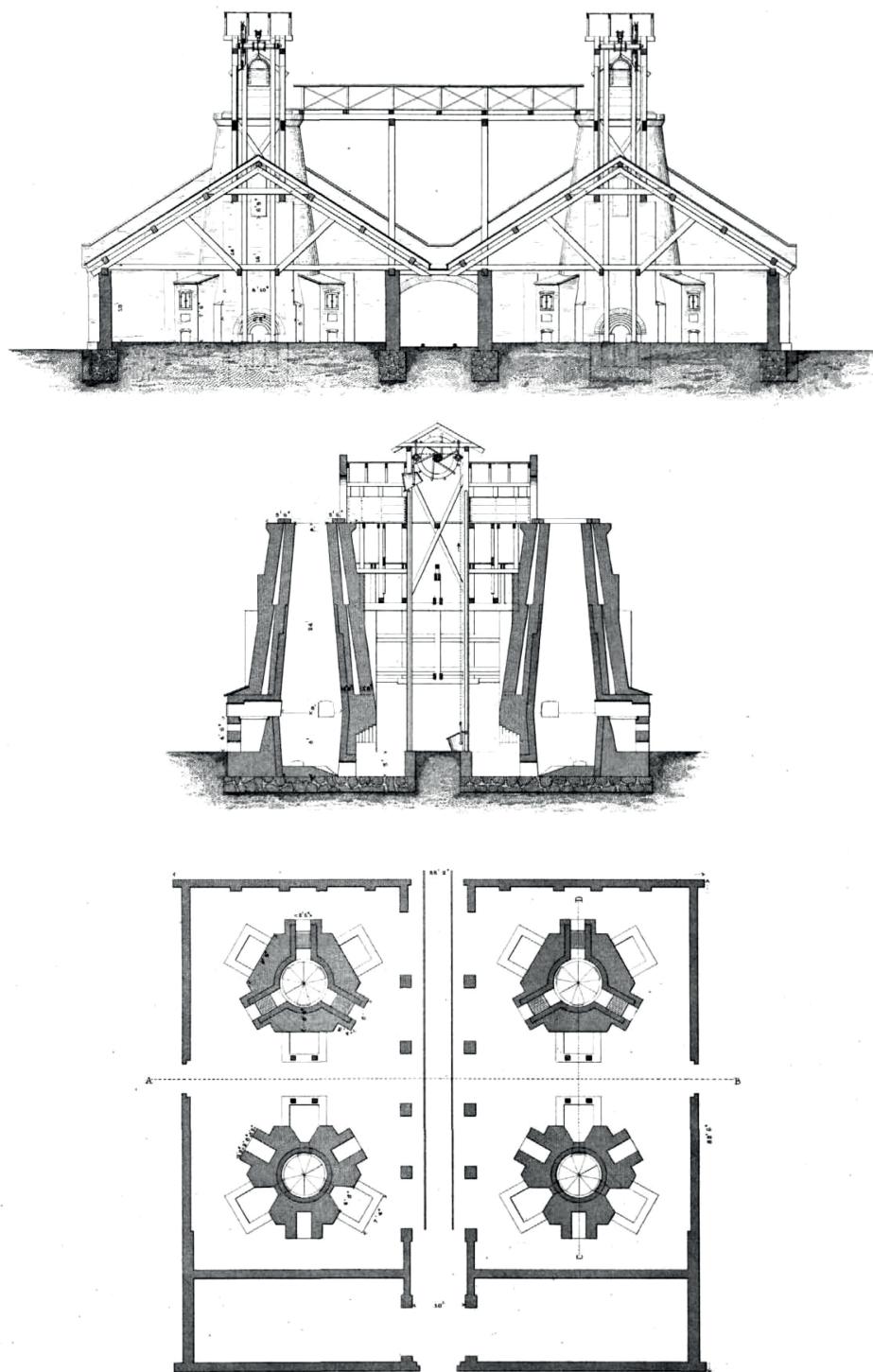


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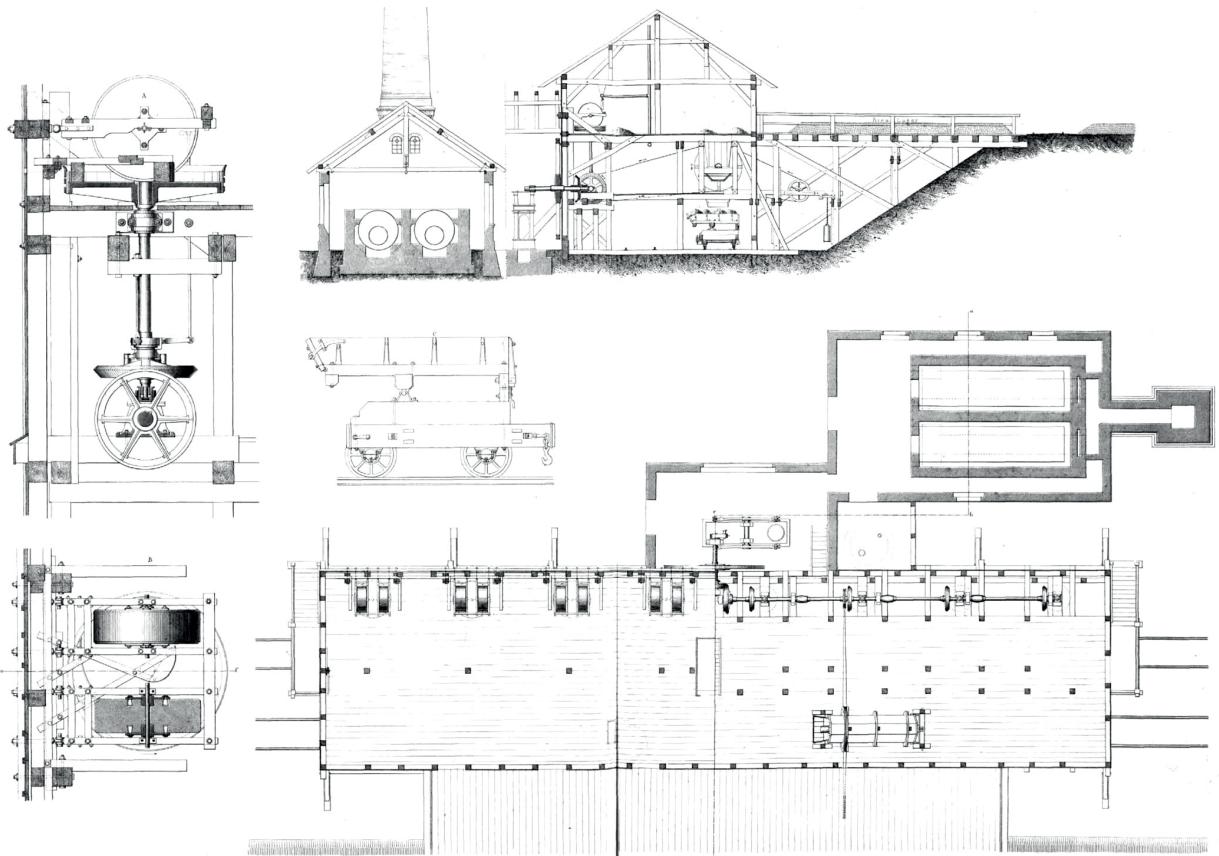
4.7.12

4.7.10. J. C. W. Lentze, planimetry for the building site installations with indication of the mortar mill plant, 1847. 4.7.11–12. J. C. W. Lentze, view of the mortar mill and of the cement plant in Dirschau (unknown date).

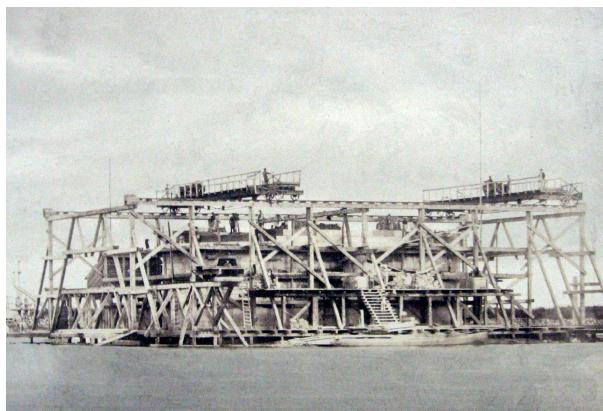


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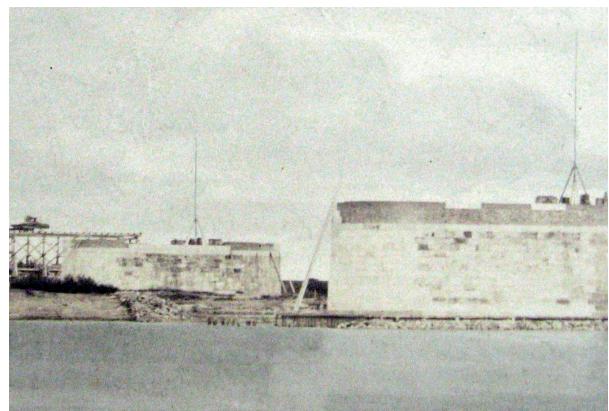
4.7.13. J. C. W. Lentze, sections and planimetry of the cement plant in Durschau, (Lentze, 1861).



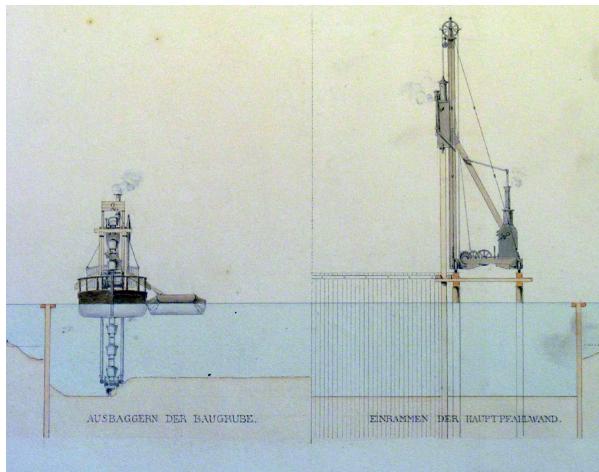
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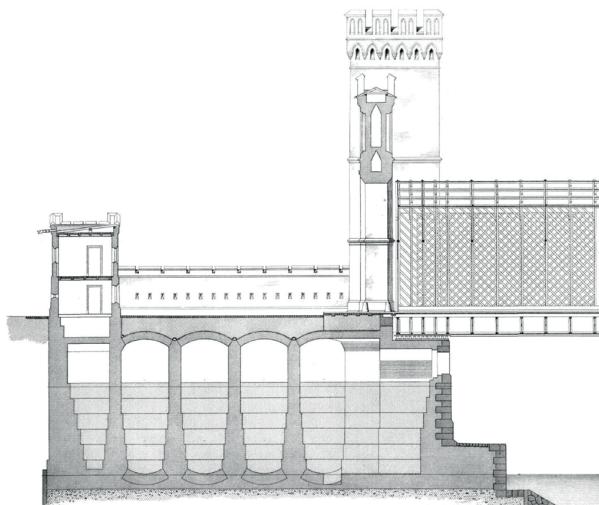
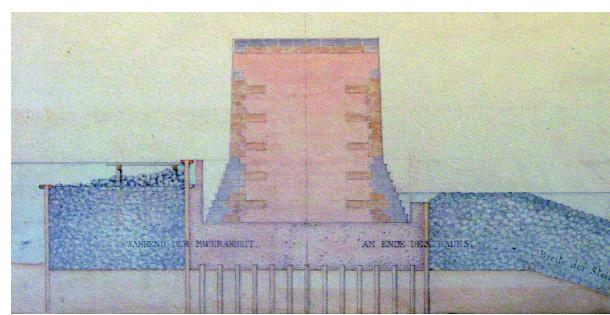
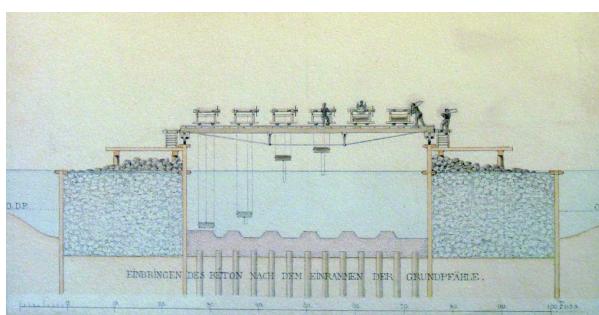
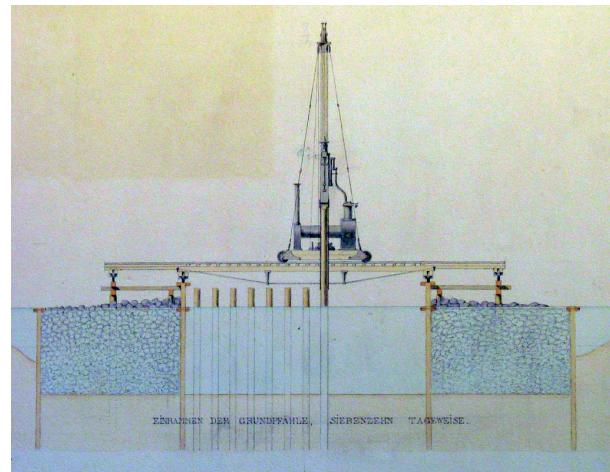
4.7.15 a,b



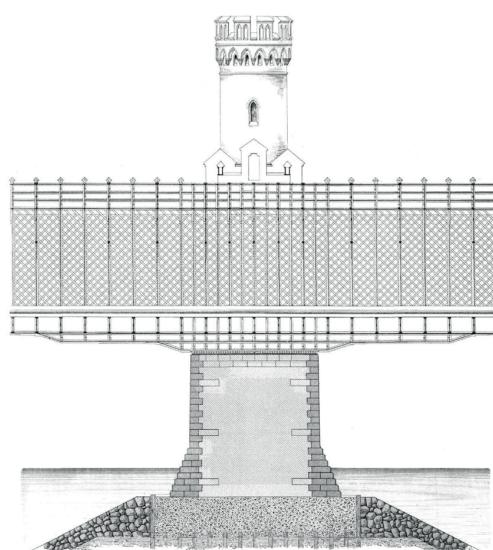
4.7.14. J. C. W. Lentze, section and plan of the mortar mill plant in Dirschau, with section and view from above of a mortar mill, (Lentze, 1861).
4.7.15. a, b. The construction of the piers of the bridge in Dirschau, photographies by W. Schiestl (Ramm, 2004).



4.7.16 a-d

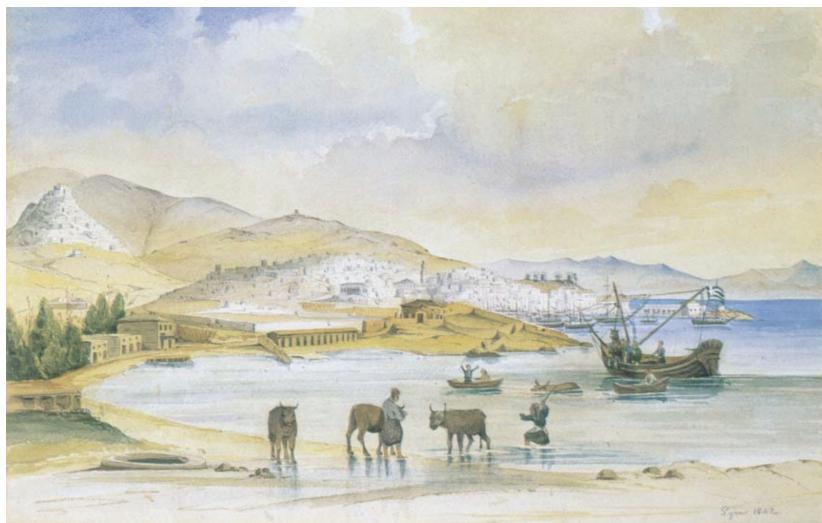


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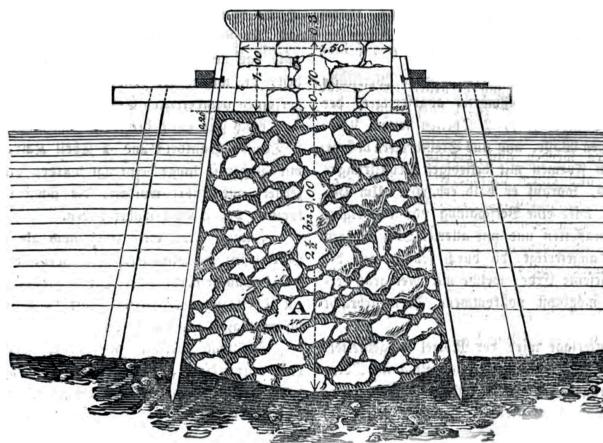


4.7.18

4.7.16. J. C. W. Lentze, bridges of the Vistule in Dirschau and bridge over the Nogat in Marienburg, representation of the construction of a freestanding pier (unknown date). 4.7.18-18. J. C. W. Lentze, bridges of the Vistule in Dirschau, landpier and freestanding pier, sections (Lentze, 1855).



4.8.1



4.8.2

4.8.1. W. v. Weiler, view of the town of Hermoupolis on the island of Syros, watercolor, 1842. 4.8.2. K. v. Körber, representation of a seawall built on a concrete foundation in Syros (Körber, 1841).

5 Portland cement and concrete constructions, from foundations to roofs

5.1 Portland cement and the prevalent use of it to bind brick masonry works

At the turn of the 1850s, Portland cement gains increasing attention, the use of it gradually increases and Prussia plays a leading role in this regard. Between 1849 and 1850, the Berlin master builder [Wilhelm Andreas] Becker experiments with this binder during the construction of a manufacturing plant powered by a water mill in Spandau; he notably applies a kind of pure Portland cement-based mortar to fill the empty spaces that has mistakenly arisen as sheet piles are rammed into the soil.¹ (5.1.1) This is anyway a minor example, compared to the foundations made of Portland cement-based concrete that are realized in 1851 in Berlin to build the bridge over the Luisenstadt canal, close to the Wassertorplatz, along the so-called Berlin *Verbindungsbaahn*.² This railway is built between December 1850 and October 1851, following the plans drawn by the already mentioned engineer Neuhaus, and the use of Portland cement-based concrete can probably be attributed to Neuhaus' previous experience with concrete building in northern Prussia, for the construction of the Eastern Railway branch, between Berlin and Stettin.³ A further pioneering use of Portland cement in concrete foundations is to be observed in Königsberg, where a retaining wall along the river Pregel, close to the end station of the Eastern Railway, which is realized between 1851 and 1853, is built on a foundation made of timber piles and Portland cement-based concrete, poured among the pile heads.⁴

Apart from the just mentioned examples of concrete foundations, the use of Portland cement mainly concerns the production of mortar to bind and plaster brick masonry works, in the very early 1850s, and it may be viewed as a sort of experimentation field to learn about how to manage with this almost new building material. In 1851, the master mason [Carl Ludwig] Schüttler builds a balcony on the main façade of his own house in the Berlin neighbourhood of Moabit, using bricks bound with Portland cement-based mortar.⁵ (fig. 5.1.2) Eight pillars and six beams, two longitudinal and four transversal ones, support the balcony. Each beam consists of a shallow-arched row of bricks arranged

¹ See [Wilhelm Andreas] Becker, *Erfahrungen über den Portland-Cement...*cit., p. 1; Id., *Praktische Anleitung zur Anwendung deremente zu baulichen, gewerblichen, landwirtschaftlichen und Kunst-Gegenständen*, Berlin, Nicolaische Verlagsbuchhandlung, 1860, pp. 25–26; the second edition of this book is published in 1869. About the hypothesis of Becker's first name, see *Verzeichniss derjenigen Baumeister des Preussischen Staats, welche nicht im Staatsdienste als Baubeamte angestellt sind*, in *Beilage zur Zeitschrift für Bauwesen*, III, 1853, n.p.

² See [Wilhelm Andreas] Becker, *Der feuerfeste Treppenbau von natürlichen und künstlichen Steinen. Nach den neuesten Erfundenen und Ausführungen mit besonderer Berücksichtigung der Constructionen zum praktischen Gebrauche bearbeitet*, Berlin, Ernst & Korn, 1857, p. 56, n. 3; the foundations are 4 ½ feet high, and concrete is composed of one measure of Portland cement, two measures of sand and two measures of equal amounts of limestone and brick rubble. It is mixed in wooden drums, poured by means of buckets into pits surrounded by sheet piles, and it hardens in eight days.

³ See Königlich Preussischen Ministers der Öffentlichen Arbeiten, ed., *Berlin und seine Eisenbahnen 1846–1896*, Berlin, Julius Springer, 1896, vol. I, pp. 236–57; Anon., *Friedrich Neuhaus - Ein vergessener Eisenbahnspionier...*cit., p. 110.

⁴ See Becker, *Der feuerfeste Treppenbau...*cit., p. 56, n. 3.

⁵ See Becker, *Praktische Anleitung...*cit., p. 33.

edge on, and of three further rows of flat bricks on each side of the just mentioned arched one, arranged edge on and perpendicular to the ground. The floor lying over the beams consists of two layers of bricks bound with Portland cement-based mortar; the ones of the lowest layer are arranged diagonally, whereas those that form the upper layer are arranged perpendicularly to the façade. The whole construction is finally plastered with Portland cement-based mortar. This kind of construction can be considered as the paroxysm of the belief in the feasibility of monolithic building elements made of bricks and cement-based mortar, which is also echoed in the words that the master builder Paul Emanuel Spieker (1826–1896) expresses a few years later, as he describes the compression strength test that he carries out on a pillar-specimen made of bricks and Portland cement-based mortar, in the context of the construction of the evangelic church of Wiesbaden (1852–1862). “One can be sure of building an artificial monolith,” Spieker asserts, “if Portland cement, which rapidly binds and gets the hardness of a stone, is used instead of ordinary mortar”⁶

A number of publications from the early 1850s, dealing with English cements, are signs of the increasing general interest for Portland cement. The savant Karl Emil Franz von Schafhäutl (1803–1890) publishes a survey about the history of Roman and Portland cements in 1851, in the *Polytechnisches Journal*.⁷ He traces a path that goes from Smeaton’s studies about hydraulic lime to Von Pettenkofer’s analyses of Portland cement, mentioning, inter alias, Pasley’s trials for the production of artificial cement and the compressive strength tests on specimens of cement-based concrete that the English cement company White & Sons carries out in 1847.⁸ The master builders Johann Christian Wedeke and Johann Andreas Romberg (1806–1868) give a comparative account of Roman and Portland cements in the first volume of the *Handbuch der Landbaukunst*, which they write together and publish in 1851, asserting that the use of Roman cement is decreasing as consequence of the spread of Portland cement.⁹ They also mention the strength tests that another important English cement company, the Robins, Aspdin and Comp., carries out in 1848, taking into account beams made of bricks bound with cement-based mortar (for flexural strength tests) and artificial stones of cement-based mortar (for compressive strength tests). It is then probably thinking just of Roman cement that Wedeke and Romberg define modern cements as unsuitable to produce concrete. Roman cement is in fact thought

⁶ “[...] verwendet man namentlich, statt gewöhnlichen Mörtel, einen raschen bindenden, etwa den in Kurzem zu Steinhärte gedeihenden Portland-Cement, so kann man gewiss sein, einen künstlichen Monolith hergestellt zu haben [...]” (Paul Emanuel Spieker, *Bericht über eine Probe auf Tragvermögen von Backsteinen aus geschlemmter Erde*, in *Zeitschrift für Bauwesen*, V, 1855, (coll. 474–79), col. 478).

⁷ Karl Emil Franz Schafhäutl, *Das Portland- und Roman-Cement. Ein Beitrag zur Geschichte der Cemente oder hydraulischen Mörtel in England, nebst einem Anhange über die Theorie der Erstarrung der Mörtel und über den glänzenden Stucco der Alten*, in *Polytechnisches Journal*, vol. CXXII, 1851, pp. 186–208, 267–93.

⁸ *Ibid.*, pp. 202–08, 267–79.

⁹ See Johann Christian Wedeke, Johann Andreas Romberg, *Handbuch der Landbaukunst und der landwirtschaftlichen Gewerbe...cit.*, vol. I, coll. 328–29. The dates of birth and death of Wedeke remain unknown, whereas the ascertained period of activity is to be placed between 1835 and 1858 (see Katalog der Deutschen Nationalbibliothek).

to set too rapidly, preventing workers from levelling and tamping the mass appropriately.¹⁰ As a matter of fact, the property of setting rapidly, which had allowed the building of extremely demanding masonry works like the vaults of the Thames tunnel in London, is considered disadvantageous as the use of concrete spreads. Concrete for important hydraulic works needs to be produced in huge amounts, in appropriate plants, to then be transported to the places where it will be poured and tamped. This working sequence requires time and urges to develop artificial cements with a slower setting time, as Lentze has already realized at the time as he has developed the cement for the construction of the bridges in Dirschau and Marienburg. A detailed account about the 1847–48 tests by the White & Sons and the Robins, Aspdin and Comp. is then given in a report by the naturalist Johann Caspar Garthe (1796–1876), which is published in 1852.¹¹

Some simple rudimentary experiments to test the quality of Portland cement also take place in Berlin between 1851 and 1852, on the initiative of the master builder August Ferdinand von Fleischinger (1804–1885), who works as building counsellor for the ministry of the war and has planned the new barrack near Hallesches Tor in Berlin together with Karl Wilhelm Drewitz (1806–1888).¹² At the end of the summer of 1851, Von Fleischinger orders Becker, who has been appointed clerk of works for the building of the barrack, to carry out experiments with Portland cement. At that time, two limekilns produce Portland cement in Germany, according to Becker; they are the already mentioned kiln of Brunkhorst and Westphalen in Buxtehude, and the kiln of Adolph Jencquel in Moorrege near Uetersen.¹³ They are both situated at the mouth of the river Elbe, where they can take advantage from English trade, and, as a matter of fact, Jencquel imports chalk and coal from England, whereas clay is widely available in Uetersen; a chalk mill is moreover available along the river Pinna, a right tributary of the Elbe.¹⁴ Portland cement from England is obtainable in Berlin from four dealers, among which there is the already mentioned hydraulic lime maker Hasler from Moabit.¹⁵ Becker chooses to test Portland cement taken from the kiln of Brunkhorst and Westphalen, which he considers as the best one produced in Germany, and Portland cement taken from the English factories of Francis and White, and

¹⁰ *Ibid.*, coll. 329–30.

¹¹ Johann Caspar Garthe, *Die neuesten englischen Versuch über Vergleichung des Portland- und Roman-Cements*, in *Polytechnisches Journal*, vol. CXXIV, 1852, pp. 25–48.

¹² See Karl Wilhelm Drewitz, *Casernement für das Königliche Garde-Dragoner-Regiment auf dem sogenannten Upstall vor dem Halleschen Tor bei Berlin*, in *Zeitschrift für Bauwesen*, V, 1855, coll. 521–42.

¹³ See Becker, *Erfahrungen über den Portland-Cement...cit.*, pp. 14–15. Becker also mentions a third kiln, the Zürhelle & Elster in Hamburg, which begins to produce Portland cement in the late 1840s, but stops the manufacturing shortly after (*ibid.*, p. 15); in this regard see also Friedrich Quietmeyer, *Zur Geschichte der Erfindung des Portlandzementes*, doctoral dissertation, Königliche Technische Hochschule zu Hannover, 1911, p. 148; it is anyway very probably that exactly Becker is Quietmeyer's source.

¹⁴ See Michael Plata, *Die Zementfabrik in Moorrege*, in *Demokratische Geschichte*, vol. XXII, 2011, (pp. 125–42), pp. 125–31.

¹⁵ The other dealer are Schüttler & Comp., which Becker introduces as the exclusive reseller of Portland cement from the factory of Robins, Aspdin & Comp.; Woderb and Goslich (who moreover mill Trass and produce hydraulic-lime and Roman cement); and Albert Reinicke, who is the reseller of Portland cement from the factory of White and Sons (see Becker, *Erfahrungen über den Portland-Cement...cit.*, pp. 51–52).

Robins, Aspdin and Comp. Since he believes that enough tests have been carried out focusing on the behaviour of cement-based mortar placed underwater and exposed to the air, Becker decides to investigate about how Portland cement-based mortar withstands fire and frost.¹⁶ This choice is to be seen against the backdrop of the current industrial and urban development, which requires the availability of mortar to build heat-resistant masonry works for chimneys and structures supporting boilers for steam engines, as well as frost-resistant masonry works to build water supply, sewer networks, and even public urinals, in order to improve the sanitary conditions of towns. At first, Becker burns several samples of cement-based mortar mixtures in a fireplace of the new barrack, as it is still under construction; then, he verifies the effects of frost on some mortar specimens, by soaking them in a kind of salt solution, whose particles gain volume by crystallising, and reproduce the effect of water expansion upon freezing.¹⁷ Becker learns this technique from the French naturalist Cyprien Prosper Brard (1786–1838), who had developed it to test the behaviour of natural stones in case of frost.¹⁸

While Becker's experiments go on, Portland cement is used to plaster the façades of the barrack, which look like they were made of cut stones, and to build the four staircases of the same building.¹⁹ Three of these are entirely built on site in brick masonry work bound with Portland cement-based mortar, whereas the fourth one is assembled using prefabricated steps. The master mason Fehse produces these steps arranging flat bricks and layers of Portland cement-based mortar in provisional wooden formworks, which are then removed once the mortar has set. Steps are furthermore finely plastered with the same kind of cement-based mortar that has been used to bind the bricks, and they are finally put into place as if they were steps made of cut stones. Fehse, Czarnikow and Schuttler are the main producers of prefabricated steps in Berlin; they actually begin to experiment with this kind of manufacturing as early as the second half of the 1840s, but it is only due to the introduction of Portland cement that they come to produce reliable steps.²⁰ (fig. 5.1.3) The barrack is completed in 1854 with annexed stalls, the brick masonry vaults of which are bound with Portland cement-based mortar, after

¹⁶ *Ibid.*, p. 20, n. 1.

¹⁷ *Ibid.*, pp. 21–43.

¹⁸ As Becker relates the method is described in Anon., *Ueber das von Brard in Vorschlag gebrachte Verfahren, um zu ermitteln, ob Steine den Wirkungen des Frostes widerstehen können, oder nicht*, in *Verhandlungen des Vereins zur Beförderung des Gewerbeleßes in Preußen*, VIII, 1829, pp. 178–80; this article is an extract from Anon., *Sur le Procédé proposé par M. Brard pour reconnaître, immédiatement, les pierres qui ne peuvent pas résister à la gelée et que l'on désigne ordinairement par les noms de pierres gélives ou pierres gelées*, in *Annales de chimie et de physique*, vol. XXXVIII, 1828, pp. 160–70. Further sources, which Becker mentions, are Jean-Baptiste Rondelet, *Theoretisch-praktische Anleitung zur Kunst zu bauen*, ed. Carl Heinrich Distelbarth, vol. I, Leipzig und Darmstadt, Karl Wilhelm Leske, 1833, pp. 475–78; Friedrich Christian Accum, *Physische und chemische Beschaffenheit der Baumaterialien deren Wahl, Verhalten und zweckmässige Anwendung*, vol. I, Berlin, Reimer, pp. 255–60. It is furthermore worth to mention that the master builder Johann Christian Wedeke describes Brard's technique in 1842, although Becker does not mention him (see Johann Christian Wedeke, *Handbuch der bürgerliche Baukunst: Allgemein fasslich für Maurer- und Zimmermeister und die es werden wollen*, Quedlinburg, Gottfried Basse, vol. I, 1842, pp. 145–47).

¹⁹ See Becker, *Erfahrungen über den Portland-Cement...* cit., p. 20; Drewitz, *Casernement für das Königliche Garde-Dragoner-Regiment...* cit., coll. 538–41.

²⁰ See Becker, *Der feuerfeste Treppenbau...* cit., pp. 59–60; Id., *Praktische Anleitung...* cit., p. 34.

having verified that the hydraulic lime taken from the factory of Haslinger in Moabit has not enough binding force for such purpose.²¹ Besides these examples, it is also worth mentioning that Portland cement is used in 1852 to plaster the interior walls of the bathrooms in the Sommer-Lazareth of the Charité hospital in Berlin, which are exposed to warm and damp air, and to bind the bricks of a masonry structure supporting a boiler in the basement of the same hospital.²² A singular experiment takes place in the same period at the Berlin Garnison-Lazareth, where a container made of bricks bound and plastered with Portland cement-based mortar is filled with urine and excrements, and kept outside over a winter, in order to verify how Portland cement resists acids and frost.²³

Outside Berlin, Portland cement mortar is used in a number of Prussian villages and towns for quite various purposes. In Königsberg, it is used together with lime and sand to produce the mortar that binds the masonry work of the foundations of the local railway station.²⁴ The cornices on the façade of the Gymnasium school building of Anklam in Mecklenburg, which is built between 1850 and 1852, are plastered with Portland cement-based mortar, as well as the basin of the fountain that is built to decorate the space housing the industrial exhibition of Breslau in 1852. For the construction of the church of the village of Brodwin northeast of Berlin, between 1852 and 1853, Portland cement-based mortar is even used as a sort of glue to fix the finials (*Kreuzblumen*) on the roof.²⁵

A considerable boost to use cement-based mortar comes indirectly from the 1853 Berlin building regulation, which imposes limitations on the use of wood in order to reduce the danger of fires.²⁶ It establishes that jutting out balconies are to be built in masonry or metal, and, following this prescription, some balconies and loggias are realized on the model of Schüttler's balcony, using, however, iron bars as reinforcement. The constructions completed by the master builder Hahnemann in 1854, by the master mason Lüdke in 1858, and by the master mason Riehmer in 1858 are pertinent examples in this regard.²⁷ (fig. 5.1.4-5) The same regulation from 1853 also orders that "the staircases of each building must be fireproof," and, consequently, pushes the construction of staircases made of brick

²¹ See Drewitz, *Casernement für das Königliche Garde-Dragoner-Regiment*...cit., coll. 533–34.

²² See Becker, *Erfahrungen über den Portland-Cement*...cit., pp. 19–20; Hesse, *Das neue erbaute Sommer-Lazareth bei der Charité-Kranken-Heil-Anstalt in Berlin*, in *Zeitschrift für Bauwesen*, III, 1853, (coll. 343–50), col. 346.

²³ See Becker, *Erfahrungen über den Portland-Cement*...cit., p. 44.

²⁴ See Becker, *Der feuerfeste Treppenbau*...cit., p. 56, n. 2, 3; the exact mixture is composed of three measures of sand, three quarters of lime, one quarter of Portland cement. It is probably still worth to notice that the frameworks of doors and windows of the stations along the Ostbahn are plastered with Krienberg cement-based mortar, whereas the rest of the buildings consist of exposed brick masonry work; see Winterstein, *Bericht über die Reise des Architekten-Vereins und des Vereins für Eisenbahnkunde nach Königsberg*, in *Zeitschrift für Bauwesen*, IV, 1854, (coll. 543–71), col. 552.

²⁵ See M. Gottgetreu, *Das Gymnasium zu Anklam*, in *Zeitschrift für Bauwesen*, II, 1852, coll. 455–58; P. R. Brecht, *Kirche zu Brodwin*, in *Zeitschrift für Bauwesen*, IV, 1854, coll. 209–12; C. Studt, *Ueber die auf die Exercier-Platz zu Breslau erbaute Halle für die Schlesische Industrie-Ausstellung im Jahre 1852*, in *Zeitschrift für Bauwesen*, II, 1852, (coll. 533–38), col. 536.

²⁶ See Königliches Polizei Präsidium, Karl Ludwig Friedrich von Hinckeldey, *Neue Bau-Ordnung für Berlin*, in *Zeitschrift für praktische Baukunst*, XIII, 1853, coll. 133–52.

²⁷ See Königliches Polizei Präsidium - Karl Ludwig Friedrich von Hinckeldey, *Neue Bau-Ordnung für Berlin*...cit., col. 143; Becker, *Praktische Anleitung*...cit., pp. 32–34.

masonry works bound with Portland cement-based mortar, as well as the manufacturing of prefabricated steps.²⁸ Drewitz builds a fireproof staircase made of bricks and Portland cement mortar in the guard building that he constructs in 1853 in the west end of Berlin.²⁹

The technique used to produce prefabricated steps is also applied to manufacture a wide range of objects and decorations, such as containers, vases, and even artificial rocks to decorate gardens, in the wake of the attempt that had taken place at Glienicke in the early 1840s. Around 1849, Fehse produces such kinds of artificial rocks for the garden that Peter Josephh Lenné (1789–1866) designs for the villa of Johann Friedrich August Borsig (1804–1854), which is built in the neighbourhood of Moabit according to the plans of the architect Johann Heinrich Strack (1805–1880).³⁰ (fig. 5.1.6) The technique of producing ready-made decorations and objects made of bricks and cement-based mortar spreads so much in Berlin that it becomes known in the early 20th-century historiography as the “Berlin System”.³¹

5.2 The manufacturing of Portland cement by Bleibtreu

Although, as previously observed, some lime kilns at the mouth of the Elbe already produce Portland cement since the late 1840s, the actual German manufacturing of Portland cement is thought to date back to the mid 1850s, when to the entrepreneur and savant Hermann Bleibtreu (1821–1881) undertakes the manufacturing of cement from inland raw materials in a plant that he founds in Stettin, after having carried out studies and trials based on his knowledge and skills in chemistry. Using the expression “authentic Portland cement from inland raw materials” in 1860, Becker soon recognizes Bleibtreu as the initiator of the German manufacturing of Portland cement, in accordance with the general belief in the importance of scientific knowledge in developing manufacturing practices, and with the general effort to exploit inland raw materials.³²

Bleibtreu is born in an entrepreneurial family based near Bonn. At a young age, he begins to study natural sciences and geology, but he is forced to stop due to the death of his father in 1839, when he needs to take over the ownership of the family mine of alum, together with his brother.³³ As of 1842,

²⁸ See Königliches Polizei Präsidium - Karl Ludwig Friedrich von Hinckeldey, *Neue Bau-Ordnung für Berlin*...cit., col. 140; Becker, *Der feuerfeste Treppenbau*...cit., p. 2.

²⁹ See Karl Wilhelm Drewitz, *Das neue Wachtgebäude am Unterbaum zu Berlin*, in *Zeitschrift für Bauwesen*, V, 1855, (coll. 467–72), col. 470.

³⁰ See Becker, *Praktische Anleitung*...cit., pp. 27–29.

³¹ See Knut Stegmann, *Das Bauunternehmen Dyckerhoff Et Widmann. Zu den Anfängen des Betonbaus in Deutschland 1865–1918*, Tübingen, Berlin, Ernst Wasmuth, 2014, p. 39; see also Wilhelm Petry, *Betonwerkstein*, München, Deutscher Beton-Verein, 1913; Adolph Leonhardt, *Von der Cementware zum Konstruktiven Stahlbetonfertigteil*, Wiesbaden, Berlin, Bauverlag, 1964, pp. 1–10.

³² See Becker, *Praktische Anleitung*...cit., p. 66.

³³ See Wilhelm Petry, *Zum 50 jährigen Bestehen des Vereins Deutscher Portlandzement-Fabrikanten. 75 Jahre deutscher Portlandzement. – Ein Rückblick auf die Anfänge der deutschen Portlandzementindustrie und auf das Schaffen von Hermann*

he can once again pursue his passion for chemistry attending the lectures that Von Liebig and Hermann Franz Moritz Kopp (1817–1892) give at the university of Gießen. In 1845 he becomes Liebig's assistant and moves to the London Royal College, where von Liebig's previous assistant August Wilhelm von Hoffmann (1818–1892) has been charged to set up a chemical laboratory. According to Karl Goslich, who has been the technical director of the Stettin cement plant for several years, Bleibtreu tries to get information about Portland cement during his stay in London, at the suggestion of Ernst Friedrich Zwirner (1802–1861), the master builder of the Cologne cathedral. He is then thought to come back to Bonn in 1852, taking the text of Aspdin's patent from England, and a little information about the raw materials necessary to produce Portland cement, whereas the manufacturing process of it is kept as a secret by the British cement makers.³⁴ Based on an informal family writing that Bleibtreu's son Leopold has made available, the engineer Wilhelm Petry (1883–1936) maintains, instead, that Bleibtreu comes back to Bonn in 1846, without having studied cement during his stay in London, and that, not before the beginning of 1852, a certain architect Becker pushes him to study Portland cement. The architect that Petry mentions is probably Becker from Berlin, considering moreover that Bleibtreu would later send a sample of the very early Portland cement he burns to him specifically.³⁵

Apart from such biographical speculations, it is a matter of fact that Bleibtreu studies about cement during 1852, and, making reference to Von Pettenkofer's explanations, he experiments with different mixtures of lime, clay and alkaline substances. He develops a procedure to burn a kind of artificial cement, and applies for a patent on October 1852.³⁶ During the winter between 1852 and 1853, while the release of the patent is pending, Bleibtreu takes into account the use of chalk from Wollin and from Rügen in Pomerania to produce cement.³⁷ He therefore moves to Züllchow near Stettin, where the relatives of his wife Dorothea Rosalie Sadée (1823–1899) live, and undertakes a series of trials burning mixtures of chalk from Rügen, trachyte (which contains silica) and phonolite (which contains alkaline feldspar).³⁸ Petry guesses that Bleibtreu actually moves to Pomerania because he fears the competition of Trass in Bonn, once again confirming how deep-rooted the use of this material is in

Bleibtreu, in *Der Bauingenieur*, VIII, 1927, (pp. 643–45), p. 643. The mine was approximately in "Hardt near Pützchen", which is today a neighbourhood of Bonn.

³⁴ See Karl Goslich, *Stettiner Portland-Cement-Fabrick 1855–1905*, Stettin, H. Susenbeth, 1905, esp. p. 1; see also Id., *Einhundert Jahre Portlandzement*, in *Zeitschrift für angewandte Chemie*, XXXVII, 1924, (pp. 265–67, 297–98, 504–05), p. 265.

³⁵ See Petry, *Zum 50 jährigen Bestehen...cit.*, p. 643; Hermann Bleibtreu, *Der erste Zementbrand der Stettiner Portland-Cementfabrik im Dezember 1853*, in *Zement*, XIV, 1925, n° 10, (pp. 212–13), p. 213.

³⁶ See Hermann Bleibtreu, "Beschreibung eines neuen Verfahrens zur Darstellung hydraulischer Cement", 1852 (ms., GStA, I HA Rep. 120 TD.D n. 206, foll. 1–4 r/v).

³⁷ The patent is released on March 1853.

³⁸ See Goslich, *Stettiner Portland-Cement-Fabrick...cit.*, pp. 1–2; see also Historische Kommission bei der Bayerischen Akademie der Wissenschaften, ed., Otto Stollberg-Wernigerode, *Neue Deutsche Biographie*, vol. II, Berlin, Dunker & Humblot, 1955, entry "Bleibtreu, Hermann", pp. 297–98.

Rhineland.³⁹ In Züllchow, Bleibtreu meets the entrepreneur Paul Gutike, who agrees to invest money to install a cement plant on the site of an old brickyard that he expressly buys on December 1852. Early trials, however, do not give encouraging results, and, on February 1853, Bleibtreu goes back to Bonn, where, via reading some books, he learns about deposits of septarian clayish stones in Pomerania, which he supposes to be similar to the ones that English cement makers use. He returns to Züllchow, and after having successfully verified what he has learnt from the books in Bonn, he goes on a journey to England, with the aim of learning how to build an appropriate cement kiln. On September 1853, he sets up in Züllchow with his family, and begins to build the first nucleus of the future cement plant. The first burning test in a proper kiln is successfully carried out on December 1853.⁴⁰ Raw materials are chalk from Wollin and septarian clay from Züllchow; they are soaked in a container full of water, mixed together according to a ratio of 4,5:1, and shaped in moulds as little bricks called *Koksen*, which are first dried, and then fired. Well-burnt *Koksen* are ground into first quality cement powder, a barrel of which is sent as a sample to the Stettin artificial stones maker Philipp Loewer, who is based in the village of Grabow, whereas the remaining part is mixed with a quarter of powder obtained by grinding the partially burnt *Koksen*; samples of this lower quality cement are sent to Becker in Berlin, as previously mentioned, and to Loewer as well. The remaining cement-powder obtained from the partially burnt *Koksen* is finally packaged in nine casks, of which we know from Bleibtreu that two casks are sent to the near village of Anklam, two others to Berlin, and one is kept on the site of the plant to be then used, on February 1854, to plaster some provisional buildings, and to test the construction of beams made of bricks and cement-based mortar.⁴¹ In 1854, Bleibtreu's cement plant is transformed into a public limited company named Stettiner Portland Cement Fabrik. The British prohibition to export Portland cement and Blue Lias limestones, from December 1854 until the end of the Crimean War in 1856, probably supports the early development of this pioneering German cement company.⁴² In 1855, the Stettiner Portland Cement Fabrik is awarded a gold medal at the Paris industrial exhibition, while the plant in Züllchow is enlarged.⁴³ Bleibtreu leads the company until April 1856, when he goes back to Bonn and undertakes the foundation of a second cement factory, the Bonner Portland Cement Fabrik, which starts producing in 1858.

On the wake of Bleibtreu's examples, in 1855, the Stettin entrepreneur Johannes Heinrich Quistorp (1822–1899) buys a limekiln in the village of Lebbin, on the Wollin Island, and transforms it into a Portland cement factory, for which he first exploits local raw materials, and later stones taken

³⁹ English Portland cement produced by the factory Robins Aspdin & Goodwin is moreover available in Köln, since 1848, from the dealer J. Simonis (see Haegermann, *Vom cæmentum...*cit., p. 49, image caption 111).

⁴⁰ See Petry, *Zum 50 jährigen Bestehen...*cit., p. 644; Bleibtreu, *Der erste Zementbrand...*cit.

⁴¹ Bleibtreu, *Der erste Zementbrand...*cit., p. 213.

⁴² See Becker, *Praktische Anleitung...*cit., p. 3.

⁴³ See Julius Manger, *Der Stettiner Portland-Cement in Versuche und Erfahrungen dargestellt und beleuchtet*, Stettin, F. Heffenland, 1860, p. 3.

from Rügen.⁴⁴ Still existing documents provide evidence that, between 1856 and 1858, Quistorp sends samples of the cement he produces, to several master builders based in the towns of Swinemünde, Naugard, Stettin, Magdeburg and Halle, and that, as of 1858, he has a dealer in Berlin.⁴⁵

5.3 The acknowledgment of the monolithic behaviour of concrete, and the further spread of concrete foundations

The acknowledgement of the critical role that concrete plays as an appropriate material to build foundations, underwater and in wet soil, further develops as of the beginning of the 1850s, and, at the same time, the awareness that the construction of monolithic building elements is possible by using concrete, instead of ordinary masonry works bound with cement-based mortar, gradually rises. William Löbe (1805–1891), a writer specialized in agricultural topics, expresses such a conviction in 1850. “Concrete forms dense uniform masses,” he writes, “which in a short time become as solid and resisting as medium-hard rocks, so that a layer of concrete can be considered as a single piece of stone. This is the principal property of concrete,” he still goes on, “the one that makes it appropriate to build foundations, since no other kind of masonry work is more reliable against uneven pressure on the soil. This happens exactly because concrete lies homogeneously on large soil surfaces, as a uniform and stiff mass, and cannot settle partially, as it happens with ordinary stone masonry works.”⁴⁶ The master builders Wedeke and Romberg express the same conviction in 1851, in the first volume of the *Handbuch der Landbaukunst*, using almost the same words that Löbe has used one year before.⁴⁷

⁴⁴ It is the village Lubin Insel Wollin of today. About Quistorp see Rudolf Vierhaus, ed., *Deutsche Biographische Enzyklopädie*, vol. VIII, München, K. G. Sauer, 2007, entry “Quistorp, Johannes (Heinrich)”, p. 130; see also Anon., “Beiträge zur Genealogie und Geschichte der Familie Quistorp. Der Stettiner Zweig”, 2008, in www.quistorp.de, pp. 111–12.

⁴⁵ See Carl Görcke, model of commercial letter with attachments, 1. April 1858 (ms., Brandenburgisches Landeshauptarchiv Berlin (BLAB), A Rep. 010-01-01, Nr. 321, foll. 1,2 r/v).

⁴⁶ “Die vorzüglichste Eigenschaft des Gußmauerwerks besteht darin, dichte und gleichförmige Massen zu bilden, welche in kurzer Zeit die Festigkeit und die Widerstandsfähigkeit von Steinen mittlerer Härte annehmen, so daß eine Schicht Gußmauerwerk wie ein Stein aus einem einzigen Stück angesehen werden kann. Dieser Eigenschaft wegen eignet sich das Gußmauerwerk vorzugsweise zu Grundmauern, da kein anderes Mauerwerk größere Sicherheit gegen die ungleiche Zusammenpressung des Bodens darbietet; die Ursache davon ist, daß das Gußmauerwerk, welches eine gleichförmige starre Masse bildet, und mit einer breiten Fläche auf dem Boden aufliegt, sich nicht theilweise setzen kann, wie dies bei den Steinen des gewöhnlichen Mauerwerks möglich ist” (William Löbe, *Encyclopädie der gesammten Landwirthschaft, der Staats-, Haus- und Forthwirthschaft und der in die Landwirthschaft einschlagenden technischen Gewerbe und Hülfsissenschaften*, vol. I, Leipzig, Otto Wigand, 1850, pp. 204–05).

⁴⁷ “Die vorzüglichste Eigenschaft des Betons besteht darin, dichte und gleichförmige Massen zu bilden, welche in kurzer Zeit die Festigkeit und den Widerstand von Steinen mittlerer Härte annehmen, so daß eine Schichte Beton wie ein Stein aus einem einzigen Stücke betrachtet werden kann. Hieraus ergeben sich die wichtigen Dienste, die der Beton beim Bauen leistet. Besonders anwendbar ist er zu den Grundmauern aller Arten von Gebäuden, weil kein anderes Mauerwerk als der Béton größere Sicherheit gegen ungleiche Zusammenpressungen des Baugrundes darbieten, die so verderblich auf alle Arten von Bauwerken wirken. Der Beton nämlich, der eine gleichförmige und starre Masse bildet und mit einer breiten Fläche auf dem Boden aufliegt, kann sich nicht theilweise setzen, wie es bei den Steinen des

How to prepare hydraulic mortar and concrete, and how to build concrete foundations are moreover described in a number of construction manuals published as of the turn of the 1850s. Wedeke describes how to build foundations made of sunken wells filled with concrete, and foundations made of concrete poured underwater in enclosure of sheet piles, straight on the soil or on timber piles, in the second volume of the *Handbuch der bürgerlichen Baukunst*, mentioning two German hydraulic works from the 1840s as pertinent and exemplar references: the lock at Bughof in Bamberg, and the dock along the river Oder in Stettin.⁴⁸ (fig. 5.3.1) Accounts about how to build foundations for bridge piers by pouring concrete in enclosures of sheet piles can also be found in the huge manual about the art of building bridges that the Bremen building superintendent Heinrich Müller (1819–1890) publishes in four volumes between 1850 and 1854.⁴⁹ Max Becker (1817–1884), who is the responsible master builder for hydraulic engineering in the Grand Duchy of Baden and professor at the School of engineers in Karlsruhe, deals with the way of building concrete foundations for bridge piers and for locks in the *Baukunde des Ingenieurs*, while, further indications about concrete as an appropriate material to build foundations underwater, as well as in wet and unsteady soils, are also provided in the building lexicon by the master builder Leo Bergmann.⁵⁰

Beyond such literary sources, we also observe that the adoption of concrete foundations in building practice gradually increases as of the early 1850s, driven by the development of the railways, which gives rise to the need for different buildings and constructions. The previously described concrete foundations of the bridges in Dirschau and Marienburg, which are completed in the early 1850s although they are conceived in the second half of the 1840s, as well as the foundations of the railway bridge near the Wasserthorplatz in Berlin, and the ones of the retaining wall along the river Pregel near the Königsberg railway station, are also to be observed in this light, beside being pioneering cases of artificial and Portland cement use.

gewöhnlichen Mauerwerkes zu geschehen pflegt” (Wedeke, Romberg, *Handbuch der Landbaukunst und der landwirtschaftlichen Gewerbe...*cit., vol. I, col. 330).

⁴⁸ See Johann Christian Wedeke, *Handbuch der bürgerlichen Baukunst: Allgemein fasslich für Maurer- und Zimmermeister und die es werden wollen*, Quedlinburg ind Leipzid, Gottfried Basse, vol. II, 1849, pp. 60–62.

⁴⁹ See Heinrich Müller, *Die Brückenbaukunde in ihrem ganzen Umfange. Ein Handbuch für Ingenieure und Baumeister*, Leipzig, Romberg, voll. I-II, 1850, vol. III, 1852, vol. IV, 1853, esp. vol. I, pp. 33–43 (about mortar and concrete), pp. 84–87 (about the mortar tests published by the master builder Zimmermann in 1829), pp. 225–38 (about concrete poured underwater in enclosure of sheet piles), and vol. III, pp. 66–84 (about foundations of bridge piers).

⁵⁰ Max Becker, *Der Brückenbau in seinem ganzen Umfange, und mit besonderer Rücksicht auf die neusten Constructionen*, Stuttgart, Carl Macken, 1854, esp. p. 87 about the use of layers of hydraulic mortar and concrete as waterproof filling over vaults, p. 97 and p. 100 about the concrete foundations and the use of concrete on the deck of the Nydeckbrücke in Bern, p. 131 about the concrete foundations of the Pont du Carroussel in Paris, and p. 221 about the concrete foundations of the freestanding piers of the suspension bridge in Budapest; Id., *Der Wasserbau in seinem ganzen Umfange*, Stuttgart, Carl Macken, 1856, esp. p. 15 about sunken wells filled with concrete, p. 136 about the concrete foundation of the connection lock between the river Elz and Elz-Dreisam Kanal, p. 191 again about concrete foundations for locks, p. 267 about the waterproofing of canal bridges by means of hydraulic mortar or concrete, p. 280 about concrete foundations of river embankments and locks at the mouths into the sea. See Leo Bergman, *Baulexicon oder Realencyclopädie des gesammten Bauwesens*, vol. I, Leipzig, Ernst Schäfer, 1855, pp. 224–25.

The now well-known technique of pouring and tamping concrete in simple enclosures of sheet piles remains predominant for little over a decade.⁵¹ A pertinent example is to be observed in the foundation of the warehouses that the architect Christian August Eduard Pötzsch (1803–1889) conceives as an ensemble of different contiguous buildings to construct in different phases, on a large site situated in Leipzig, close to the railway stations of the lines to Magdeburg and to Dresden. The construction begins in 1850, and it is the presence of ground water close to the surface (between 7 ½ and 11 feet underground), due the proximity of the river Parthe, that leads to the adoption of a concrete foundation.⁵² (fig. 5.3.2–3) Concrete is composed of slaked lime, *Trass* from Brohl, sand, bricks and stone rubble. It is poured and tamped in five layers all over the building site, up to reach the thickness of 6 feet, while the pit is kept dry by means of pumps. The basement, which is built straight on the concrete foundation, consist of brick masonry walls and vaults that are bound with Roman cement-based mortar, while *Trass*-based mortar is used to build a 2 ½ high plinth of unrefined stones supporting the outer walls.

More demanding concrete foundations are constructed to build, between 1854 and 1855, two towers housing mechanical elevators for freight wagons in Ruhrort and Homberg near Duisburg, on the two opposite sides of the Rhine. The elevators are intended to move the wagons from the ordinary level of the embankments, onto an appropriate steamboat that crosses the river (fig. 5.3.4–5) They are to replace a previous and inefficient system of ramps that had been put into service in 1852, whereas the construction of a bridge is not taken into account for military reasons. The master builder Emil Hermann Hartwich (1802–1879) proposes the construction of the elevator towers system to the Cöln-Mindener and to the Ruhrort-Crefeld-Kreis Gladbach railway companies, having British models as reference.⁵³ The foundations must be particularly solid, considering that they need to support the weight of the towers, which are about 100 feet high, and the stress produced by the machineries. (fig. 5.3.6) Each foundation consists of an 8 feet high concrete base, which is surrounded by three concrete retaining walls on the landside, whereas the waterside remains open to allow the connection between the steamboat and the platform of the elevator, after having been delimited by means of a provisional cofferdam during the construction. (fig. 5.3.7–10) Concrete is composed of hydraulic lime from the not faraway town of Ennigerloh, *Trass* from Brohl and sandstone rubble. The use of *Trass* is considered unavoidable after a preliminary hardening test of hydraulic lime-based mortar has failed. The masonry work of the towers partially consists of ashlar and partially of bricks; the outer joints are made of Portland cement-based mortar, whereas the inner ones consist of *Trass*-based mortar.

⁵¹ The increasing need to build even in place where orographic conditions are very unfavourable pushes the adoption of more complex techniques to dig and shore foundations pits since the end of the 1850s.

⁵² See Anon., *Die neuen Lagerhäuser in Leipzig*, in *Zeitschrift für praktischen Baukunst*, XIII, 1853, coll. 97–100.

⁵³ The hydraulic mechanisms powered by a steam engine are in fact delivered by British engineer industrialist William Georg Armstrong (1810–1900), who is also the owner of a patent for such elevator system. About the conception and building of the elevator towers in Ruhrort and Homberg, see Theodor Weishaupt, *Die Homberg-Ruhrorter Rheintraject-Anstalt*, in *Zeitschrift für Bauwesen*, VII, 1857, coll. 347–90.

The old way of pouring and tamping concrete in superimposed layers of rubble and mortar is applied in Leipzig in the context of the complex foundations that are constructed to build, between 1855 and 1856, on extremely marshy soil, the ensemble of buildings that compose the Thüringer Bahnhof, namely a locomotive shed, a gasworks, a shed for coal, a building for workers, and the passenger hall.⁵⁴ Concrete does not actually play a main role in this case, but the foundation technique is anyway worth mentioning. As the construction of each building begins, the marshy soil is removed over a depth of about 4 or 5 feet, and replaced with rammed sand, while different pumps keep the pits dry. Despite being a better kind of bearing soil, such a basement of rammed sand is not yet solid and compact enough to support the footings made of cut stones that have been planned as the foundations of the above-standing walls. Therefore, about one feet-thick bases of concrete, made of layers of rubble and mortar, are poured and tamped onto the sand soil, in order to better distribute the weight of the masonry footings over the sand, and prevent that stones detaching from each other. For the main role that rammed sand plays, this kind of foundation is called *Sandfundirung*. (fig. 5.3.12)

Concrete, instead, plays the main role in the foundations that support the three piers and two abutments of the bridge over the Rhine in Cologne, which is built between 1855 and 1859, and is known as *Dombrücke* (Cathedral Bridge).⁵⁵ (fig. 5.3.13) The foundations of the piers are built straight on a kind of gravelly soil that proves to be solid enough to make timber piles avoidable. (fig. 5.3.14) Concrete is made of *Trass*-based mortar mixed with pieces of basalt-lava stones, and melted rests of bricks production.⁵⁶ It is mixed in a concrete-mill, powered by a steam engine, and it is then transported on the river by means of an appropriate steamboat, to finally be poured underwater, inside enclosures of sheet piles, by means of boxes.⁵⁷ The masonry work of the piers consists of basalt-lava stone faced walls, and brick masonry filling. Pure *Trass*-based mortar is used to bind the masonry work underwater, whereas for the rest of it, some sand is added to the mortar.⁵⁸ The foundation of the left abutment partially consists of a 10 feet high concrete base standing on gravel, and partially of a 14 feet high masonry footing made of bricks bound in pure *Trass*-based mortar. A similar kind of construction is

⁵⁴ About the foundations of the buildings of the Thüringen railway station, see, Witzeck, *Die Gründung der Gebäude des Thüringischen Bahnhofes bei Leipzig*, in *Zeitschrift für Bauwesen*, X, 1860, coll. 213–22. The replacement of marshy soil with sand had been already tried in Berlin, for the building of the Hamburger Bahnhof, but the attempt failed and the foundation was partially realized adopting the method of sunk wells, and partially of a timber framework (see Friedrich Hoffmann, *Der Bahnhof der Berlin-Hamburger Eisenbahn in Berlin*, in *Zeitschrift für Bauwesen*, VI, 1856, (coll. 487–96), coll. 494–96).

⁵⁵ About the conception and the building of the Dombrücke in Cologne, see Hermann Lohse, *Die Rheinbrücke bei Cöln*, in *Zeitschrift für Bauwesen*, VII, 1857, coll. 307–14; Id., *Die Rhein-Brücke bei Cöln*, XIII, 1863, (coll. 175–96, 335–70), coll. 178–92, 189–96. The hydraulic master builder Friedrich Wilhelm Wallbaum draws the initial plans, which are approved in 1854; the works for the foundations of the piers start in the spring of 1855 under the supervision of the master builder Hermann Wilhelm Lohse (1815–1893), who at the same time modifies the plans according to new request from the railway company, until 1856; the architect Johann Heinrich Strack (1805–1880) develops the architectural plans, and the building of the bridge is achieved in 1859.

⁵⁶ Lohse, *Die Rheinbrücke bei Cöln*, cit., 1863, col. 190.

⁵⁷ Lohse, *Die Rheinbrücke bei Cöln*, cit., 1857, col. 312.

⁵⁸ Lohse, *Die Rheinbrücke bei Cöln*, cit., 1863, coll. 189–91.

adopted for the foundation of the right abutment, the concrete base being 7 ½ feet high, and the masonry footing 26 ¾ feet high.⁵⁹ (fig. 5.3.15–16)

Besides the previously described major cases, we also observe the construction of concrete foundations for the piers of several other railway bridges, like the five ones near Küstrin, along the railway line connecting Küstrin to Frankfurt (Oder), which is built between 1856 and 1857; the bridge over the Ruhr in Alstaden, which is built in 1862, along the railway line connecting Mühlheim and Duisburg; and the bridge over the river Elbe and over the adjacent tidal land, which is built between 1857 and 1859, near the town of Wittenberg south-east of Berlin, along the railway line connecting this same town to Halle.⁶⁰ The concrete used in Wittenberg is produced with sand, stone rubble and Portland cement. It is mixed in drums powered by a steam engine, and it is transported first in wagons on rails, and then on barges, close to the foundation pits, where it is poured down by means of boxes. For the construction of the bridge in Wittenberg, concrete is also used to build 3 feet-thick cofferdams enclosing the foundation pits of the piers standing in the riverbed. Similar 5 feet thick concrete cofferdams are also adopted to build, between 1856 and 1857, the piers of the bridge over the Mosel near Konz, along the Saarbrücken-Trier-Luxemburger railway, whereas the foundations themselves are made, in this case, of unrefined sandstones bound with pure *Trass*-based mortar.⁶¹ Ordinary cofferdams filled with rammed earth are instead built to surround the pits for the concrete foundations of the piers supporting the railway bridge over the river Neckar near Jartfeld, which is built between 1867 and 1869, using Portland cement-based concrete.⁶²

It is probably in the wake of such examples that even some other kinds of buildings are built on concrete foundations. This is the case of the church of Saint Barbara in Gleiwitz in Silesia, which is realized between 1855 and 1859 according to the plans conceived by Stüler.⁶³ Again because of the

⁵⁹ *Ibid.*, coll. 191–94.

⁶⁰ The bridges near Küstrin are the Warthe-Brücke (bridge over the river Warthe), the Fluth-Brücke der Warthe (bridge over the tidal land next to the river Warthe), the Festungsgraben-Bridge (the bridge over the moat of the Küstrin fortress), the Oder-Brücke (the bridge over the river Oder), and the Vorfluth-Brücke der Oder (bridge over the tidal land next to the river Oder); about these bridges, see Stein, *Die Bauanlagen der Kreuz-Cüstrin-Frankfurter Eisenbahn*, in *Zeitschrift für Bauwesen*, VIII, 1858, coll. 459–86. About the bridge in Alstaden see *Mittheilungen aus Vereinen. Architekten-Verein zu Berlin. Versammlung am 31. Mai 1862*, in *Zeitschrift für Bauwesen*, XII, 1862, col. 563; to have exhaustive information about the construction of this bridge, taking also into account the bridge deck, see also Baeusch, *Der eiserne Ueberbau der Eisenbahnbrücke über die Ruhr bei Alstaden auf der Strecke Mülheim - Duisburg*, in *Zeitschrift für Bauwesen*, XXIII, 1873, coll. 341–44. About the bridges along the railway from Wittenberg to Halle see the *Protokoll des Vereins für Eisenbahnkunde zu Berlin*, 9 October 1860, in *Zeitschrift für Bauwesen*, XI, 1861, coll. 334–48.

⁶¹ See Anon., *Die Bauanlagen der Saarbrücken-Trier-Luxemburger Eisenbahn*, in *Zeitschrift für Bauwesen*, XIII, 1863, (coll. 43–58), coll. 49–50.

⁶² See Max Becker, *Handbuch der Ingenieur-Wissenschaft*, vol. V, *Ausgeföhrte Constructionen des Ingenieurs*, n° 6, *Die Kabelschiffahrt und die Eisenbahnbrücke über den Neckar bei Jartfeld*, Stuttgart, Carl Mäcklen, 1870, pp. 36–38.

⁶³ Gleiwitz is the Polish town of Gliwice nowadays. About the church of Saint Barbara see Anon., *Eine frühere Gleiwitzer St. Barbara. Nach 400 Jahren durch den Neubau der evangelischen Kirche ersetzt*, in *Oberschlesien in Bildern*, 1934, n.p.; Jolanta Rusinowska-Trojca, *Städtebau und Wohnarchitektur des 19. Jahrhunderts in Gleiwitz (Gliwice)*, doctoral dissertation, Rheinische Friedrich-Wilhelms-Universität, Bonn, 2005, p. 55.

presence of groundwater close to the surface, due to the proximity of the river Klodnitz, the walls of the church are built on about 4 ½ feet high concrete footings, and the tower, on an about 7 feet-high concrete base.⁶⁴ (fig. 5.3.19) An unexpected and irregular subsidence of the soil produces a worrisome inclination of the tower, as it is still under construction and has reached the height of 60 feet. Despite the accident, the concrete foundation does not suffer any damage, the tower is charged with a counterweight of 5000 Centner, and it is then finally straightened up between 1860 and 1861, by digging some earth and stabilizing the soil with sheet piles.⁶⁵

The Hamburg Kunsthalle, which is built between 1864 and 1869 according to the plans by the architects Georg Theodor Schirrmacher (1833–1864) and Hermann von der Hude (1830–1908), also stands on an about 3 feet and 6 inches high concrete foundation, which stretches all over the building site. (fig. 5.3.20–21) According to a report by Von der Hude, the foundation soil proves to be almost solid, but a certain irregularity in the composition of it pushes to build a concrete foundation.⁶⁶ Concrete is produced manually, by mixing slaked lime with Portland cement, sand and crushed bricks; and the building of the entire foundation takes about eight weeks.

5.4 Lean conglomerate as a German kind of concrete for constructions above ground

Even once concrete has been definitively recognized as an appropriate material for foundations, there is no agreement about the suitability of it to build above ground, despite the several examples of houses entirely constructed in poured concrete in France and in England. The architect Gustav Adolph Breymann (1807–1859), who is a professor of architecture at the *Polytechnische Schule* in Stuttgart, distrusts the solidity of concrete constructions like walls and vaults, and claims the better suitability of traditional masonry. He even advises against the construction of walls made of cut stone-faces and concrete filling, since he believes that “the solidity of a wall chiefly depends on the quality of the masonry bound, and not only on the width of the wall itself.”⁶⁷ In accordance with this belief, he also suggests limiting the construction of freestanding concrete walls to fences, which do not need to bear any other load than their own. Furthermore, he warns about a supposedly lesser reliability of concrete vaults in comparison to masonry ones, although he shows to be aware of the solidity of the ancient vaults that Romans used to build with pozzolana-based concrete.⁶⁸

⁶⁴ About the concrete foundation of the tower, see Assmann, *Verfahren bei Geraderichtung des Thurmes an der evangelischen Kirche in Gleiwitz*, in *Zeitschrift für Bauwesen*, XIII, 1863, coll. 67–70.

⁶⁵ 1 Centner = 100 Pfund = 50 kg.

⁶⁶ See Hermann von der Hude, *Die Kunsthalle in Hamburg*, in *Zeitschrift für Bauwesen*, XVIII, 1868, coll. 3–8.

⁶⁷ “[...] die Stärke einer Mauer nicht nur von ihrer Dicke, sondern besonders auch von einem guten Verbande abhängig ist [...]” (Gustav Adolph Breymann, *Allgemeine Bau-Constructions-Lehre, mit besonderer Beziehung auf Hochbauwesen*, Stuttgart, Hoffmann, 1849, (pp. 25–26), p. 26).

⁶⁸ Breymann, *Allgemeine Bau-Constructions-Lehre*...cit., pp. 82–83.

Unlike Breymann, Löbe makes a brief mention of the suitability of concrete to build above ground, having Lebrun as main reference.⁶⁹ However, he gives more emphasis to the use of lean conglomerate rather than to concrete, and stresses that the two materials can be applied using the same technique, namely by pouring and tamping the conglomerate masses into formworks. In this way, Löbe hints at certain closeness between lean conglomerate and concrete.⁷⁰ Such closeness becomes acknowledged equivalence in Wedeke's description of basements made of hydraulic lean conglomerate (which he calls "rammed mortar"). "It is recommended," he writes in 1850, "not to build the walls of basements in rammed mortar, because it does not harden in places where the air is wet, and it neither becomes solid enough to support the weight of the above standing walls. If someone wants to build basements in rammed mortar," Wedeke goes on, "he has to use fast hardening hydraulic lime mixed with much stone rubble [...]."⁷¹ He then explains that such a kind of mortar is called concrete, and invites readers to refer to the *Bürglerliche Baukunst*, which he has written together with Romberg, to know about how to produce and apply concrete. In a similar way to Wedeke, [Friedrich Conrad Theodor] Krause lists concrete among the materials that can be used to build the foundation of walls in lean conglomerate.⁷²

The recognition of the closeness between concrete and lean conglomerate further develops during the first half of the 1850s, and it is even widespread belief that lean conglomerate has prevented the spread of concrete use for constructions above ground. In this regard, Wedeke asserts that "rumours coming from France seven or eight years ago, about the replacement of bricks and stones with concrete to build walls, seem to have passed unheeded," whereas "the attempts at building freestanding walls, and even entire buildings made of rammed mortar, are giving, satisfactory results."⁷³ In 1851, Engel shows

⁶⁹ "But concrete is also very suitable to build above ground" ("Aber auch zur Ausführung von Hochbauten eignet sich das Gußmauerwerk ganz vorzüglich" Löbe, *Encyclopädie der gesammten Landwirthschaft*...cit., p. 205).

⁷⁰ *Ibid.*, pp. 202–04.

⁷¹ "Kellerwände aber mit diesem Mörtel aufzustampfen, kann nicht angerathen werden, weil der Mörtel in der feuchten Luft nie erhärten, also auch niemals die genügende Festigkeit erlangen würde, die Wände der Etagen mit vollkommener Sicherheit zu tragen. Will man aber auch das Souterrain in dieser Art aufführen, so muß hierzu schnellbindender hydraulischer Kalk verwendet werden [...]. Was die Zubereitung eines solchen Mörtels betrifft, der auch Beton genannt wird, so verweisen wir dieserhalb den sehr geehrten Leser auf § 25 in der zweiten Abtheilung des zweiten Theils unserer *Landbaukunst*" (Wedeke, *Der Bau mit gestampftem Mörtel*...cit., p. 11). It is however almost contradictory on the part of Wedeke to advice against the use of formworks, which are considered provoking a waste of wood, in third volume of the *Landbaukunst* dating from 1858, which he again writes together with Romberg (see Johann Christian Wedeke, Johann Andreas Romberg, *Handbuch der Landbaukunst und der Landwirthschaftlichen Gewebe für Baumeister, Landwirte und Cameralisten*, vol. III, Leipzig, Romberg, 1858, col. 148).

⁷² Krause, *Anleitung zur KalkSand-Bau-Kunst*...cit., pp. 64–65.

⁷³ "Es sind etwa sieben oder acht Jahre her, seit aus dem südlichen Frankreich sich eine Stimme vernehmen ließ, die das dahin übliche Material zur Aufführung von Wänden, nähmlich künstlich und natürliche Steine, durch Beton ersetzt wissen wollte; ihr Ruf scheint in Deutschland verhallt zu sein [...]. Versuche, um freistehende Mauern und ganze Gebäude von reinem Mörtel zu erbauen, die nach mehrjährigen Bemühungen her genügende Erfolge lieferten" (Wedeke, *Der Bau mit gestampftem Mörtel*...cit., p. 3).

himself to agree with Wedeke, asserting: “The technique of building with rammed lime and sand [...] has almost suppressed the use of concrete.”⁷⁴

In the wake of such opinions, lean conglomerate comes to be considered a sort of more affordable German version of concrete to build above ground. Leuchs gives evidence of this approach reacting to early news about François Coignet’s buildings made of “mortar pressed into moulds”, which appear in German periodicals around about 1855.⁷⁵ Leuchs claims the German primacy over the building technique that Coignet promotes. “For a long time,” he writes, “we construct buildings of artificial stone in Germany using a more simple mixture, which consists of twelve parts of sand and one part of lime.”⁷⁶ Engel also maintains a sort of actual analogy between Coignet’s concrete and the German lean conglomerate. Dealing with the possibility of adding ash to the composition of lean conglomerate, in a short report that he writes in 1856 as a supplement to the book about *Kalksand* from 1851, Engel asserts that “the company Coignet Père & Fils & Comp. in Paris produces a kind of compressed lean conglomerate (compressed concrete) made of 1 measure of lime, 1 measure of coal ash and between 6 and 8 measures of coarse sand, which provides very good results.”⁷⁷ Engel even suggests adding some Portland cement to lean conglomerate mixtures, to build foundations, or just to improve the quality of the conglomerate.⁷⁸

In such a scenario, further buildings are constructed with walls in lean conglomerate. Engel considers it particularly worth mentioning the one that is built in 1853 in the Brandenburg village of Stechow, to house a barn and a stall, because of its impressive dimensions. It measures 250 feet by 60 feet, and walls are 20 feet high. All outer ones, and even a few inside, are made of lean conglomerate. A timber framework structure, however, still plays a fundamental static role, as well as the four brick masonry buttresses at the four corners of the building.⁷⁹ (fig. 5.4.1-2) For an administration building of a quarry in Rüdersdorf, lean conglomerate is used to fill the free field of the exposed timber framing structure.⁸⁰ (fig. 5.4.3) Further examples of lean conglomerate use are also to be observed near Hamburg, where, as of 1856, the engineer Scheer undertakes experiments to find out an appropriate mixture to

⁷⁴ “Die Methode, Gebäude aus Kalk und Sand auszustampfen [...] hat die Verwendung des Betons fast ganz verdrängt” (Johann Daniel Friedrich Engel, *Der Kalk-Sand-Pisébau. Nachtrag*, Charlottenburg, Huber, 1856, p. 2).

⁷⁵ See François Coignet, *Benutzung des geformten und zusammengepressten Mörtels*, in *Polytechnisches Journal*, XXXVII, CXL, pp. 101–04, and in *Kunst- und Gewerbe-Blatt des polytechnischen Vereins für das Königreich Bayern*, XLII, 1856, coll. 404–08 (Id., *Emploi des bétons moulés et comprimés*, in *Le Génie industriel*, vol. X, 1855, pp. 218–20).

⁷⁶ “[...] in Deutschland schon längst Gebäude aus künstlichen Steinen von einer viel einfacheren Zusammensetzung, nämlich aus 12 Sand und 1 Kalk hergestellt werden” (Anon., *Ueber Häuserbau mit Mörtel...cit.*).

⁷⁷ “[...] so fertigt gegenwärtig das Haus Coignet Père & Fils & Comp. in Paris einen Kalksandpisé (béton comprimé) aus 1 Theil Kalk, 1 Theil Steinkohlenasche und 6 bis 8 Theilen grobem Sand an, welcher sehr gute Resultate liefern soll” (Engel, *Der Kalk-Sand-Pisébau. Nachtrag...cit.*, p. 6).

⁷⁸ *Ibid.*, pp. 5–6.

⁷⁹ Johann Daniel Friedrich Engel, *Sammlung landwirthschaftlicher und ländlicher Bauausführungen*, Berlin, Ernst & Korn, 1864, foll. XXII–XXIII.

⁸⁰ See Engel, *Der Kalk-Sand-Pisébau. Nachtrag...cit.*, p. 15; Id., *Sammlung landwirthschaftlicher und ländlicher...cit.*, foll. XXIV.

build the outer walls of the houses for inspectors of the railway between Altona and Kiel.⁸¹ He finally develops a mixture consisting of one measure of slaked lime and eight measures of gravel containing walnut-sized stones. About ten years later, the walls of the inspectors' houses along the Ostholsteinische railway are also built using a similar kind of lean conglomerate.⁸² (fig. 5.4.4)

During the second half of the 1850s, the technique of building in lean conglomerate goes through some further experiments that concern the construction of vaults. The master builder E. H. Hoffmann (1822–1896) experiments with the construction of sixteen small vaults in lean conglomerate, even using small amounts of Portland cement in four cases, as he builds his own house in 1856.⁸³ Most of these vaults are a failure and need to be demolished and rebuilt, but, according to Hoffmann, the reason for the failure is to be found in geometrical mistakes, rather than in the unsuitability of lean conglomerate. In the same year, the already mentioned master builder Salzenberg writes a report about the ancient Roman art of building conglomerate vaults; he mentions the ones of the Baths of Diocletian and those of the Basilica of Constantine in Rome as eminent examples, and provides the description with drafts.⁸⁴ (fig. 5.4.5) He ascribes the solidity of ancient Roman vaults to the use of pozzolana-based mortar, which he believes to harden well, rapidly and, above all, without shrinking. At the same time, he advises against the construction of new conglomerate vaults, since he believes that the kind of mortar that is usually employed at his time shrinks too much and causes the collapse of the vaults. "The ordinary mortar used in our brick masonry buildings [...]," Salzenberg writes, "hardens slowly, shrinks, and it should therefore be used in as little amount as possible; while the use of conglomerate to build vaults should be absolutely ruled out".⁸⁵ In 1858, reporting about the construction of the lean conglomerate vaults he has carried out in his own house, Hoffmann replies to Salzenberg's observations about the problem of mortar shrinking, and maintains that the small amount of lime that is used in lean conglomerate produce modest shrinking effects, therefore making lean conglomerate suitable to the construction of vaults. "We have a material that is similar to that poured mortar," Hoffmann states with reference to the kind of mortar that Romans used, "it is the rammed lean conglomerate, which does not

⁸¹ H. Tellkampf, *Ueber den Bau von Wärterhäusern mit Umfassungsmauern von Kalkpise*, in *Zeitschrift für praktische Baukunst*, XXVI, 1865, coll. 113–22.

⁸² *Ibid.*

⁸³ See E. H. Hoffmann, *Mittheilungen über Gewölbe aus Stampfmörtel*, in *Zeitschrift für Bauwesen*, VIII, 1858, coll. 453–56. Hoffmann has already published a book about vaults in 1853 (E. H. Hoffmann, *Über Form und Stärke gewölbter Bögen*, Berlin, Nauck, 1853).

⁸⁴ Wilhelm Salzenberg, *Einige Bemerkungen über die Gewölbeconstruction des antiken Rom*, in *Zeitschrift für Bauwesen*, VII, 1857, coll. 424–29. In this report, Salzenberg improperly use the expression *muro in sacco* to indicate the conglomerate of the vaults (*ibid.*, col. 424).

⁸⁵ "Dem gewöhnlichen Mörtel unserer neueren Backsteinbauten mangeln diese Eigenschaften, er erhärtet langsam, schwindet beim Erhärten und darf daher nur in geringer Quantität angewendet werden; Gusswerk in Gewölben muss bei diesem Mörtel ganz ausgeschlossen bleiben" (Salzenberg, *Einige Bemerkungen über die Gewölbeconstruction...cit.*, col. 425).

have the blameworthy property of shrinking because it has no large amounts of lime".⁸⁶ In the same report from 1858, Hoffmann also describes a barn he has conceived for a private builder in western Prussia as a construction with walls in lean conglomerate, which, in order to make savings, are composed of pillars, discharging arches and thin filling-panels. (fig. 5.4.6) According to Hoffman's report, Stüler visits this building and hardly criticizes it.

In 1857 Hoffmann builds a thin (7 inches thick at the key, and 8 inches at the imposts) 5 feet span vault in lean conglomerate for a small road bridge, whereas, in 1858, to build three further bridges, he resorts to a kind of raw stone masonry work with quite wide tamped mortar joints.⁸⁷ He first pours and tamps a roughly 3 inches thick layer of mortar on the centrings, then he places voussoirs at 2 inches distance from each other, and finally covers and tamps the whole construction with mortar. The mortar mixtures he adopts to build the joints of these bridges are almost similar to the ones that are commonly used for masonry works, being composed of one part of cement and five parts of sand, in one case, and one measure of hydraulic lime and six measures of sand, in the two other cases.

A corollary of the evolution of lean conglomerate applications during the second half of the 1850s concerns the beginning of the serial manufacturing of the so-called *Kalksandziegeln* (sand-lime bricks), based on the use of a cast iron press, which Friedrich August Anton Bernhardi (1813–1889), a physician based in Eilenburg in Saxony, develops from 1850 to 1854, and patents in 1856.⁸⁸ (fig. 5.4.7) The essential principle of the manufacturing of lean conglomerate artificial stones goes back to Prochnow and to Sachs, whereas the ameliorated production technique takes advantage of the improved expertise in producing mechanical cast iron machines.⁸⁹ The pressure produced with the long levers of the press makes bricks more compact and resistant, than the ones that are produced by just tamping mortar into moulds with a pestle.⁹⁰ Bernhardi himself starts a manufacturing of presses in Eilenburg around about 1854, and, in the following years, other entrepreneurs move from his idea to develop similar machines, as proved by the fact that the Ekart Maschinenbau-Anstalt in Berlin produces a kind of press for sand-lime bricks since at least the late 1850s. It is documented that an Ekart press is used on

⁸⁶ "[...] so ist doch zu erwähnen, dass wir ein jenem Mörtelguss ganz ähnliches Material besitzen, nämlich das Stampfmörtelwerk. Bei diesem fällt die getadelte und tadelnswerthe Eigenschaft unseres gewöhnlichen Mörtels, „das Schwinden“, fort, indem dieses, wie es scheint, in dem zu grossen Kalk-Gehalt des gewöhnlichen Mörtels begründet ist, welchen der Stampfmörtel nicht besitzt“ (Hoffmann, *Mittheilungen über Gewölbe...*cit., col. 453).

⁸⁷ See E. H. Hoffmann, *Ueber Anwendung von Stampfmörtel bei kleinen Brückengewölben*, in *Zeitschrift für Bauwesen*, X, 1860, coll. 263–66; see also Engel, *Der Kalk-Sand-Pisébau und die Kalksand-Ziegelfabrikation...*cit., pp. 85–86.

⁸⁸ Bernhardi is politically engaged and fights to ameliorate the conditions of the new arising working class. It is probably on the backdrop of this engagement that he develops the idea of producing affordable quality bricks, in order to allow the building of hygienic but affordable flats for workers. It is interesting to notice how Bernhardi studies the social disadvantages of mechanical manufacturing (he publishes in 1848 a study entitled *Ueber die sozialen Nachtheile des gewerblichen Maschinenuwesens*), but, at the same time, exploits just the principle of mechanical manufacturing to improve the an aspect of workers life. Bernhardi himself starts the production of this press in 1854. In this regard see Anon., *Kalksand-Mauerstein - vom Arzt entwickelt*, in *Die Baustelle*, 2014, n° 2, pp. 26–27.

⁸⁹ See Engel, *Der Kalk-Sand-Pisébau und die Kalksand-Ziegelfabrikation...*cit., p. 4.

⁹⁰ Bernhardi maintains having also invented a mechanical mixer to prepare the mortar necessary to produce the bricks; according to Engel, this mixer is similar to the lean conglomerate mixer already developed in Fiddikow.

the manor of Lietzow near Nauen north-west Berlin to construct, probably after the fire of 1859, a number of buildings, which are partially made of ordinary bricks, partially of poured lean conglomerate, and partially of sand-lime bricks.⁹¹

The development of sand-lime bricks manufacturing is also to be seen in relation to the production of artificial concrete ashlar that is spreading in France, in the United Kingdom, and in Germany as well. As Engel observes, the use of artificial concrete stones, like the ones that the factory Czarnikow produces in Berlin, develops in Germany slower than in other countries, since bricks remain more affordable. Sand-lime bricks could therefore be seen as a further adjustment of a technique that is spreading abroad, to local and limited economic conditions, as if sand-lime bricks were a sort of more affordable version of artificial concrete stones, just like poured lean conglomerate is considered a more affordable version of concrete. Documented examples of the use of sand-lime bricks in the years immediately after the invention of the Bernhardi's press are to be observed in Eilenburg, in the nearby village of Jeseswitz [sic.], and in Lübchow near Cöslin in Pomerania. (fig. 5.4.8–10) Among them, the building realized in Jeseswitz is particularly worth mentioning, since it is a sort of experiment, being partially built in ordinary brick masonry work, and partially with sand-lime bricks; according to Engel, this experiment proves that sand-lime bricks dry sooner than the ordinary ones.⁹²

5.5 The manufacturing of *Cementwaaren*

As of roughly the turn of the 1850s, on the basis of better availability of good-quality cements, and of the increased skills in producing mortar and concrete, the old ambition of producing artificial stones, architectural decorations, and various other objects by moulding cement-based compounds gives rise to a real manufacturing branch, which becomes known as the one of the *Cementwaaren*. The already mentioned factory Czarnikow develops a mixture composed of Portland cement, gravel and natron, by which it produces moulded decorations for important buildings constructed during the 1850s and the 1860s, in Germany and abroad. All cement-based moulded decorations of the Gildengebäude of Riga, which is built between 1853 and 1860, and the ones of the Stadttheater of the same town, which is built between 1861 and 1863 according to the plans of the architect Ludwig Bohnstedt (1822–1885), come from the Czarnikow.⁹³ (fig. 5.5.1–2) They are moulded in Berlin, in wooden and plaster moulds; they are then transported by barges along the river Oder to Stettin, and, after, by ships on the Baltic sea further

⁹¹ See Anon., *Steinpresse zur Fabrikation von Ziegel und Pisé-steinen*, in *Zeitschrift für Praktischen Baukunst*, XXI, 1861, coll. 127–28; Engel, *Der Kalk-Sand-Pisébau und die Kalksand-Ziegelfabrikation...cit.*, pp. 104–05; Anon., *Ueber Kalkpisébau*, in *Zeitschrift für praktische Baukunst*, XXVII, 1867, coll. 162–63.

⁹² See Engel, *Der Kalk-Sand-Pisébau und die Kalksand-Ziegelfabrikation...cit.*, pp. 115–18.

⁹³ See Anon., *Die Kunststeingießerei im Dienste der modernen Baukunst*, in *Zeitschrift für praktische Baukunst*, XXVI, 1866, coll. 23–28; Anon., *Der Werth des künstlichen Baumaterials*, in *Zeitschrift für praktische Baukunst*, XXVI, 1866, (coll. 117–22), col. 120; Leonhardt, *Von der Cementware zum Konstruktiven Stahlbetonfertigteil...cit.*, p. 3; about the new Gildengebäude in Riga, see Arnold von Tideböhl, *Fürst Alexander Suworow, General-Gouverneur von Liv-, Esth- und Kurland, 1848–1861*, Riga, W. F. Häcker, 1862, pp. 45–47; about the Stadttheater, see *ibid.*, pp. 96–98.

to Riga.⁹⁴ Among them, the bas-relief of the pediment realized by the sculptor Friedrich August Wittig (1823 or 1826–1893)⁹⁵ according to the plans elaborated by Bohnstedt, which shows “The Poetry and her influence on life”, becomes particularly known.⁹⁶ (fig. 5.5.2) Czarnikow also produces all the window cornices of the psychiatric hospital in Eberswalde northeast Berlin, which is designed by the architect Martin Carl Philipp Gropius (1824–1880) and built between 1862 and 1865.⁹⁷ (fig. 5.5.4–5) Gropius praises the durability of Czarnikow moulded cornices, along with the aesthetic effect that the grey colour of cement produces in combination with the colour of bricks. “The intention to produce a slightly more agreeable effect of colours on the façades pushed to provide windows with moulded, cement-based cornices. [...] The manufacturer Czarnikow in Berlin assumed a ten-years long durability guarantee against weather effects. Until now, such cement-based moulded works, which are produced on the building site, have proved to be durable, and their colour suits to the one of bricks.”⁹⁸ The arch-shaped lintels consist of single pieces, whereas the windowsills and the jambs consist each of two joined pieces. Some difficulties arise just while finishing the joints, since the hue of poured cement mortar is slightly different from the one of the precast elements. Moreover, several sills show to be not perfectly sealed up and cause water seeping. Such complications do not in any way affect Gropius’ confidence in the opportunity of decorating façades with cement-based moulded elements. “Such minor complications,” Gropius writes in this regard, “may not induce to desist from such experiments, since the development of imperishable artificial stones would be a great advantage for architecture. Nothing else could be more appropriate to monumental buildings. It would be possible to reproduce ancient architectural elements like plates, pillars, abacus, plinths, cornices, etc., in desired sizes and without joints, which affect the ideal forms of such elements.”⁹⁹ As a matter of fact, an increasing demand for such decorating elements, especially on the part of the arising middle-class, supports the production of cement-based mouldings.¹⁰⁰

⁹⁴ Anon., *Der Werth des künstlichen Baumaterials...*cit.

⁹⁵ See Hermann Alexander Müller, *Biographisches Künstler-Lexikon der Gegenwart*, Leipzig, Bibliographische Institut, 1882, p. 563; and Daelen, Eduard, “Wittig, August” in *Allgemeine Deutsche Biographie*, vol. XLIII, Leipzig, Duncker & Humblot, 1898, pp. 638–39.

⁹⁶ “Die Poesie in ihrer Einwirkung auf das Leben” (Anon., *Die Kunststeingießerei im Dienste der moderne Baukunst...*cit., col. 27).

⁹⁷ See *ibid.*, coll. 27–28; Martin Carl Philipp Gropius, *Die Provinzial-Irren-Anstalt zu Neustadt-Eberswalde*, in *Zeitschrift für Bauwesen*, XIX, 1869, (coll. 147–94), coll. 182–83.

⁹⁸ “Der Wunsch, den Fassaden eine etwas freundlichere farbige Wirkung zu verleihen, führte auf die Anwendung der in Cementguss ausgeführten Fenstereinfassungen für die Außenfronten. [...] Der Fabrikant, Herr Czarnikow in Berlin, hat eine zehnjährige Garantie für die Wetterbeständigkeit übernommen. Es haben sich bis jetzt diese Steingussarbeiten, die auf der Baustelle selbst angefertigt werden, in Bezug auf ihre Dauer wohl bewährt. Die Farbe steht sehr gut zu der Farbe der Ziegel [...]” (Gropius, *Die Provinzial-Irren-Anstalt...*cit., col. 182).

⁹⁹ “Diese kleinen Nachtheile können indess nicht Veranlassung sein, derartige Versuche aufzugeben. – Es würde ein grosser Gewinn für die Architektur sein, wenn es gelingen sollte, einen schönfarbigen und unverwüstlich dauerhaften künstlichen Stein herzustellen. Nichts würde geeigneter für monumentale Bauwerke sein. Man würde dann die durch die antike Kunst erfundenen architektonischen Elemente: Wand, Stütze, Abakus, Plinthe, Gesims etc., nach beliebigen Verhältnissen und Dimensionen herstellen können, ohne ihre ideale Form durch die Roheit der Ziegelfuge zu beeinträchtigen” (Gropius, *Die Provinzial-Irren-Anstalt...*cit., col. 183).

¹⁰⁰ See Mohamed Scharabi, *Architekturgeschichte des 19. Jahrhunderts*, Tübingen, Wasmuth, 1993, p. 161.

The apostles' figures, as well as the pinnacles and the stone fretworks of the altar that the already mentioned Loewer from Grabow constructs in 1858 for the Stephanskirche in Gartz south of Stettin are made of moulded, Portland cement-based mortar, whereas the load-bearing parts are made of bricks, bound and plastered with the same kind of Portland cement-based mortar.¹⁰¹ The altar of the St. Marien church in Strasbourg in the Uckermark is produced in a similar way by Czarnikow around about 1865.¹⁰² (fig. 5.5.6–7) Czarnikow also moulds the high reliefs and the bas-reliefs, inside the pediments and over the central windows of the façade of the Stadttheater in Leipzig, which is built between 1864 and 1868 according to the plans by the architect Carl Ferdinand Langhans (1781–1869).¹⁰³ (fig. 5.5.8–9)

Along with architectural decorations, the manufacturing of moulded cement-based pipes for water supply and drainage systems significantly develops. The brothers Born from Erfurt in Thüringen criticize the method patented by Karlinger in 1848 to produce circular pipes, which they consider too complex. Instead, they believe in the greater effectiveness of a manufacturing process that is similar to the one that Fleuret had developed at the turn of the century, and which consists in pouring and tamping concrete between timber boards, all around a pole, the surface of which has been previously treated with some fat materials, so that it can be extracted once the concrete has set.¹⁰⁴ (fig. 5.5.10) The brothers Born report having successfully built a 700 feet-long water pipe in 1852 for the town of Kölleda northeast of Erfurt, and a 200 feet-long water pipe in 1854 in the town of Erfurt.

Some lavatories in the already mentioned Garnison-Lazareth in Berlin are equipped with a drainage system based on the use of pipes made of Portland cement-based mortar. Each main drain is assembled with several hollow and frustum-shaped elements, which are produced applying mortar around a wooden open mould. (fig. 5.5.11) Some of such elements are provided with side holes to allow connections with sanitary installations at each level. They are fabricated by a master mason named Eyffert, together with the already mentioned artificial stones maker Fehse.¹⁰⁵ Similar drains are also built by the master mason Lehmann in 1853 for the lavatories of the Lazareth in Spandau, and, in 1854, for the Lazareth in Prenzlau.¹⁰⁶ Concerning sanitary installations, it must be also mentioned that Fehse moulds toilets and other sanitary basins in cement-based mortar.¹⁰⁷

¹⁰¹ See Herrmann, *Hochaltar in der Stephanskirche zu Gartz, aus Portland-Cement erbaut*, in *Zeitschrift für Bauwesen*, X, 1860, coll. 311–16.

¹⁰² See Anon., *Die Kunststeingießerei im Dienste der moderne Baukunst...*cit., coll. 27–28.

¹⁰³ The reliefs in the main pediment are moulded on models by the sculptor Hugo Hagen (1818–1871), the one in the two minor pediments on models by the sculptor August Wittig (1823–1893) (Anon., *Die Künstlerischen Verzierungen des neuen Stadttheaters zu Leipzig*, in *Zeitschrift für praktische Baukunst*, XXVIII, 1868, (coll. 309–14), col. 309); see also Brückwald, *Das Stadt-Theater in Leipzig von Langhans*, in *Zeitschrift für Bauwesen*, XX, 1870, coll. 291–98.

¹⁰⁴ See Gebrüder Born, *Ueber Verfertigung von Wasserleitung-Röhren aus Cement*, in *Polytechnisches Journal*, vol. CXXXIV, 1854, pp. 136–40. See also Fleuret, *L'art de composer...*cit., esp. pl. 18–21.

¹⁰⁵ See Becker, *Praktische Anleitung...*cit., p. 42.

¹⁰⁶ *Ibid.*

¹⁰⁷ See C. Hennicke, *Ueber die Anlage von Abtritten in Wohngebäude und öffentlichen Anstalten*, in *Zeitschrift für Bauwesen*, VII, 1857, (coll. 123–44), col. 139.

Small concrete open-channels are built along a number of streets in Berlin at least since 1853. They are made of concrete composed with Portland cement, sand and different kind of stone and brick rubble. Some of them are poured on site, using a wooden profile to give the channel the desired concave shape, whereas, some others, consist of precast elements produced in appropriate workshops.¹⁰⁸ (fig. 5.5.12) Underground drainage pipes are built assembling elements that are similar to the ones for open-channels. They are, however, appropriately joint-shaped along the linear edges and at the curved extremities.¹⁰⁹ (fig. 5.5.13, above) The bottom of such pipes is flat so that they may be easily placed on the ground, and the different bottom and upper elements are assembled staggered like in an ordinary masonry bound. (fig. 5.5.13, below) Pipes of such a kind are used to build a number of drainage installations in Berlin around about the mid 1850s, and to build road culverts in the region of Sławno in eastern Pomerania, probably using cement from the Stettiner Portland-Cement Fabrik.¹¹⁰ In the early 1860s, they are also produced by the factory Krüger in Gdansk, in order to build the culvers along the railway connecting Bromberg and Torun in Pomerania.¹¹¹ Moreover, the sewerage of the town of Witten along the river Ruhr is realized, since 1867, with cement-pipes that are produced using cement from the Bonner Portland-cement Fabrik.¹¹²

The cement producers Wilhelm Gustav Dyckerhoff (1805–1894) and Carl Brentano (1833–1898), who found the company Dyckerhoff & Brentano in 1861, in Eltville am Rhein near Wiesbaden, also engages in producing cement-based moulded objects as of about 1862, principally floor slates, which earn the company a contract for paving some stations along the Baden railways.¹¹³ In 1864, Brentano leaves the cement company, and Dyckerhoff carries on the business with his two first sons; the company henceforth takes the name of Dyckerhoff & Sohns. In 1865, Dyckerhoff, together with the merchant Heinrich Lang (1818–1887), and probably also in collaboration with the master builder Franz Erwin Serger (1817–1879), found the company Lang & Cie in Karlsruhe, which is registered at the local

¹⁰⁸ See Becker, *Praktische Anleitung...*cit., pp. 35–37, esp. p. 37.

¹⁰⁹ *Ibid.*, pp. 51–53.

¹¹⁰ Becker mentions a 168 feet long channel realized in 1855 by the master mason Eyfferth between the Potsdamerstraße to the Leipzigerstraße (the round shaped part of it are, however made of masonry work), a 1300 feet long channel realized in 1856 between the Matthäusstraße and the Bellevuestraße, a 200 feet long channel realized Kopernicher-Tor, and a channel realized by the master mason Lehmann in 1857 at the Humboldt-Hafen (see Becker, *Praktische Anleitung...*cit., pp. 51–52); for the culvert in the region of Sławno, see Sanftleben, *Anfertigung und Verwendung von Portland-Cement-Röhren zu Chaussee-Durchlässen*, in *Zeitschrift für Bauwesen*, IX, 1859, coll. 417–20, and in *Polytechnisches Journal*, XL, vol. CLIV, pp. 421–23; Becker, *Praktische Anleitung...*cit., p. 51. Krüger in Gdansk also produces poured cement-mortar pipes.

¹¹¹ P. Ernst, *Ueber Cementröhren und deren Anfertigung*, in *Zeitschrift für Praktische Baukunst*, XXXI, 1871, (coll. 235–42), col. 235.

¹¹² See Freudenberg, *Die Canalisierung der Stadt Witten*, in *Zeitschrift für Bauwesen*, XXIII, 1873, (coll. 135–52), coll. 138, 146.

¹¹³ In 1863, Dyckerhoff and Brentano builds a large factory in the nearby Amöneburg am Rhein, which historically remains the main seat of the company, and the headquarters is still nowadays located in Amöneburg (*ibid.*, p. 27). About the history of the Dyckerhoff & Sohns, see Curt Piorkowski, *Dyckerhoff Portland-Zementwerke A.G.: Mainz-Amöneburg*, Leipzig, Arndt, 1937, pp. 5–13.

Chamber of Commerce as a *Cementwaaren* company, focusing the production of “pipes, floor slabs, farming tools, and architectural decorations”.¹¹⁴ The Dyckerhoffs devote much part of their initial professional activity to the search for appropriate techniques to produce cement-based moulded objects, and take the Berlin factories like the Czarnikow as main models. In this way, they learn how to produce objects made of brick cores surrounded by cement-based mortar. The relation between the companies Dyckerhoff & Sons and Lang & Cie is close, especially with the entry of Eugen Julius Richard Dyckerhoff (1844–1924), the third son of Wilhelm, into the Lang & Cie in 1866. Eugen Dyckerhoff has already experimented with the manufacturing of concrete floor slabs in the family cement factory, around about 1864, before leaving for a toughly one-yearlong stay in Marseille, and, even once in the Lang & Cie, he carries on studies and experiments in the laboratory of the Dyckerhoff & Sohns, focusing in particular on the composition of concrete. He soon replaces the Berlin way of building objects containing a brick masonry core, with a moulding technique consisting of pouring and tamping in moulds almost mushy cement-based concrete, containing as little water as possible. The technique is considered to be in relation with Coignet’s *béton aggloméré*, especially on the base of Eugen’s stay in France. It should nevertheless not be ignored that the concept of manufacturing artificial stones and other objects by pouring and tamping conglomerate masses in formworks or moulds, is part of the German practices of building and manufacturing for at least about a couple of decades. From about 1867, the Lang & Cie delivers early moulded concrete pipes, to the town of Karlsruhe and to a number of other towns in Baden.¹¹⁵ The technique that is adopted to produce such concrete pipes is essentially similar to the ones that Karlinger had patented in 1848. Besides the search for improving concrete mixtures, the Lang & Cie also engages in producing a collection of moulds for architectural decorations, working with several artists of the time, among which is the sculptor Karl Friedrich Moest (1838–1923), who will later produce statues that remain representative symbols of the company, and, at the same time, evidences the ability in moulding concrete.

In 1869, following the entry of Gottlieb Widmann (1817–1894) into business, the company Lang & Cie is transformed into Dyckerhoff & Widmann. The new company exhibits a range of cement-based moulded products at the *Landesgewerbeausstellung* (regional industrial exhibition) that takes place in Offenbach in 1869, taking advantage of the pavilion of the Dyckerhoff & Sons. Shortly after, Dyckerhoff & Widmann entrusts Moest with the realizations of a cement-based moulded statue, which should represent the expertise that the company has achieved, at the *Allgemeine Industrieausstellung* (General industrial exhibition) of Kassel in 1870. The statue is the celebrated *Triumph der Galathea*, which is also known as *Galatheabrunnen* since the figures stand in a fountain. The *Galatheabrunnen* is

¹¹⁴ About the history of Lang & Cie, see Stegmann, *Das Bauunternehmen Dyckerhoff Et Widmann...cit.*, pp. 21–53, esp. p. 33 for what concerns the foundations and the registration at the Chamber of Commerce in Karlsruhe; Gert v. Klass, *Weit spannt sich der Bogen: 1865–1965: die Geschichte der Bauunternehmung Dyckerhoff & Widmann*, Wiesbaden, Bartels, 1965, pp. 7–53.

¹¹⁵ Stegmann, *Das Bauunternehmen Dyckerhoff Et Widmann...cit.* p. 46. The famous expression *Stampfbeton* appears not before the end of the 1880s (*ibid.*, p. 44, n 218).

ultimately not exhibited in Kassel, but sold to the town of Karlsruhe, to be placed in the park called Sallenwäldchen. Seeing the presence of a wire netting inside the cement-based mortar, the statue is also to be related to the early inventions of objects made of metallic nets and cement-based mortar, which are mainly developing in France, and will have important consequences in Germany around the mid 1880s.¹¹⁶ A second Galatheabrunnen is produced to be exhibited at the International Exhibition that takes place in Wien in 1873, whereas, for the *Kunst- und Gewerbeausstellung* (Exhibition of art and industry) that takes place in Munich in 1876, Moest erects two further statues, namely two virile figures representing the construction and the functioning of railways (*Eisenbahnbau und Eisenbahnbetrieb*). (fig. 5.5.14-17)

5.6 Improvements to scaffoldings and sheet pilings for foundations underwater, the building of the bridge over the Rhine in Koblenz

The possibility of pouring concrete underwater, in enclosures surrounded by sheet piles, instead of building cofferdams, has long been considered a major advantage of concrete foundations, seeing that sheet pilings are more affordable and easier to build than cofferdams. Nevertheless, due to particular orographic conditions, even the construction of sheet pilings sometimes demands complex solutions that are worth attention. This is what happens with the construction of the freestanding piers of the bridge over the Rhine in Koblenz, which is constructed between 1862 and 1864 under the supervision of the already mentioned master builder Hartwich.¹¹⁷ (fig. 5.6.1-3) The bearing soil lies under deposits of gravel, the thickness of which is irregular. At the place where the left freestanding pier is to be built, the stratum of gravel is about 16–17 feet-deep; this is considered enough to build an enclosure of sheet piles fixed on scaffoldings made of poles rammed into the gravelly soil, cross beams, and metal wind bracings, which are tied up at the poles by means of metallic ring instead of screws and bolts, in order to prevent a supposed weakening of the poles. (fig. 5.6.4) Once the construction of the scaffoldings is achieved, the sheet piles are driven into the gravel, making them slip between two longitudinal beams, which are tied up at the poles of the scaffoldings by means of double ferrules. (fig. 5.6.4 [fig. 4]). The necessity of securing the sheet piles to the poles of the scaffoldings in a very solid manner is due the fact that all gravel must be removed from inside the enclosure, to reach the bearing soil, and the pressure of the exterior gravels, along with the one produced by the stream, are considered a danger for the stability of the piles.

¹¹⁶ The reference goes to the patents by Joseph Monier (1823–1906). It is just between 1881 and 1886 that the German engineers Gustav Adolph Wayss (1851–1917) and Matthias Koenen (1849–1924) move from the patent registered in Germany by the French inventor Joseph Monier (1823–1906) to develop an early mathematical model to calculate a reinforced concrete slab.

¹¹⁷ See Emil Hermann Hartwich, *Rheinbrücke bei Coblenz*, in *Zeitschrift für Bauwesen*, XIV, 1864, (coll. 385–416, 529–79), coll. 404–09.

Even more complex is the assembly of the provisional works to build the foundation of the right freestanding pier. The depth of the gravel stratum amounts to 2 or 3 feet, which is considered too small to drive the poles of the scaffoldings, and the sheet piles as well. Scaffoldings are therefore pre-assembled on dry land and transported on the river by means of barges and rafts, to be then sunk into the water at the desired places using stones as ballast. (fig. 5.6.5) The longitudinal scaffoldings are built and put into place as first. They are transported by means of two parallel barges, which are kept at a fixed distance by means of a timber floor. This floor is provided with a central hole, which is as large as the scaffolding, and supports a framework timber structure provided with pulleys and ropes to hold the scaffolding and to sink it into the water as the barges are over the right place. (fig. 5.6.6 above) Due to lack of space, each transversal scaffolding is instead put on a raft, which can partially enter into the free space between the longitudinal scaffoldings; it is fixed at these scaffoldings and kept hanging over the water by means of chains, so that the raft can be taken away, before the scaffolding is sunk into the water. (fig. 5.6.6 below) Once all scaffoldings are in place, the sheet piles are installed, fixing the ones upstream with a double system of beams and ferrules, for precaution against the force of the stream.

Concrete is poured down using a pipe anchored at a bridge crane, and forms an about a 10 feet-high base of concrete. Following a procedure that is now common, concrete cofferdams are erected on the concrete bases, in order to form watertight caissons where workers build the lowest masonry layers of the piers, once water has been drained out. (fig. 5.6.7–8) Trass-based concrete is used for the foundations of the left freestanding pier, whereas, for the right one, some Portland cement is added to the concrete mixture. It is partially taken from the plant of Bleibtreu in Bonn, and partially from England. The foundations of the two abutments of the bridge are, instead, built in enclosures made of ordinary sheet piles, using Trass-based concrete. (fig. 5.6.9)

5.7 Sinking wells, sinking caissons, and pneumatic caissons

Since about the mid 1860s, German master builders' ability in building foundations made of sunken wells is confronted by further evolutions, due to the increasing need to build foundations in marshy soil and underwater, sometimes at considerable depth. This is the case of the Oder valley south of Stettin, which is marshy land, crossed by two main arms of the river Oder and by several other smaller watercourses, where, as of 1864, new bridges and docks need to be built, in order to improve the already mentioned Eastern Railway, which reaches Stettin from Berlin on the west side of the Oder, and then crosses the Oder valley to go further to Stargard.¹¹⁸ (fig. 5.7.1) The so-called Fluthbrücke (bridge

¹¹⁸ See Architekten Verein zu Berlin, *Mittheilungen aus Vereinen, Versammlung am 18. November 1865*, in *Zeitschrift für Bauwesen*, XVI, 1866, col. 320; Verein für Eisenbahnkunde zu Berlin, *Protokoll vom 14. November 1865*, in *Zeitschrift für Bauwesen*, XVI, 1866, col. 330; Hagen, *Brunnen, Wasserleitung und Fundirungen...cit.*, p. 365; Theodor Stein, *Erweiterungsbauten der Berlin-Stettiner Eisenbahn ausgeführt 1864–1869*, Berlin, Ernst & Korn, 1870; Wilhelm von Haselberg, *Die Brücken der Berlin-Stettiner Eisenbahn im Oderthal bei Stettin*, in *Zeitschrift für Bauwesen*, XXIV, 1879, (coll. 359–78), coll. 362–64; Teichgräber, *Die Brücken im Oderthale bei Stettin*, in Vv. Aa., ed., *Bericht über eine*

over the tideland), which is built between 1864 and 1865, stand on thirteen piers and two abutments, the foundations of which consist of masonry sunken wells, partially filled with concrete. (fig. 5.7.2) Each well is made a 1½ feet thick circular wall standing on a timber crown. It encloses a 12 feet-wide circular space, which is gradually dug out, while water is drained out by means of a pump. The tool used to dig the soil inside the well is the so-called Indian spade; it actually consists of a shovel hinged at a long pole, and moved by means of a chain, so that workers can stand on scaffoldings placed over the well, and do not need to work inside of it, while it is sinking. A 4-feet-thick bed of concrete is poured onto the bottom of each well, with the main aim of stopping water-raising from the soil, whereas the rest of it is then filled with brick masonry work.¹¹⁹ (fig. 5.7.3) The two abutments are each built each on three sunken wells, whereas all piers each stand each on two wells.

The viaduct over the Silberwiese, which is built between 1867 and 1868 in the context of the same improvement project for the Stettin-Stargard railway line, is also initially conceived as a bridge standing on sunken well foundations. Nevertheless, after having successfully verified the bearing capacity of the soil by means of a test-pier standing on an ordinary masonry foundation, the plan for the construction of the sunken wells is abandoned, and the piers are actually built on ordinary masonry foundations.¹²⁰ The main pier of the swing bridge over the watercourse called Kahnfahrt (east of the Fluthbrücke) is, instead, built on a sunken well foundation. It consists of a cylindrical wall standing on a crown made of stone plates, which are kept together by means of curved iron bars. (fig. 5.7.4) As already observed in the case of the Fluthbrücke, concrete is poured only at the base of the well, whereas the remaining part of the pillar is filled with brick masonry work. The right abutment of the same bridge over the Kahnfahrt stands, instead, on a roughly 7 meters deep foundation made of concrete poured inside an enclosure of sheet piles, and the piers of the nearby bridge over the watercourse called Zeglin stand on an ordinary timber piling foundation with, concrete poured among the pile heads.¹²¹ (fig. 5.7.5)

The building of a new central freight depot also belongs to the improvement project for the Berlin-Stettin-Stargard railway. It is carried out between 1864 and 1869 and involves the construction of a dock along the river Parnitz, in order to allow the connection between water and rail transports. This dock is built on foundations consisting of square-shaped sunken wells, with each sidewall measuring 16 feet in length and 21 inches in thickness, which stand 8 feet from each other.¹²² They are filled with concrete and masonry work, and are moreover anchored each other by means of rails. Two-stones-thick arches cover the space between the wells, and the remaining part of the dock is built in ordinary masonry work. (fig. 5.7.6-7)

Bauwissenschaftliche Studienreise nach der Pommerschen Künste, Julius Springer, Berlin, 1887, pp. 7-13. About the composition of the soil in the Oder valley, see W. v. Haselberg, *Die Brücken der Berlin-Stettiner...*cit. col. 362.

¹¹⁹ See Stein, *Erweiterungsbauten der Berlin-Stettiner Eisenbahn...*cit., pp. 2-3.

¹²⁰ *Ibid.*, pp. 15-16. This change to the original project misleads Hagen to assert that the Viaduct of the Silberwiese is built on sunken well foundations (see Hagen, *Brunnen, Wasserleitung und Fundirungen...*cit., p. 365).

¹²¹ Haselberg, *Die Brücken der Berlin-Stettiner Eisenbahn...*cit., coll. 362-63.

¹²² See Stein, *Erweiterungsbauten der Berlin-Stettiner Eisenbahn...*cit., p. 53.

Hagen defines square-shaped sunken wells as *Senkkasten*, sinking caissons, which should not be confused with the caissons for foundations underwater that Bélidor describes in his *Architecture hydraulique*.¹²³ The term *Senkkasten* is also used, during the 1860s, to mean a kind of light version of the masonry square-shaped sunken wells, which actually concerns preassembled closed timber walls that are sunk into the soil as the excavation of the soil goes on. They are used to build the foundations of ordinary buildings, in case the bearing soil lies not very deep in the ground, as it happens for the locomotive shed of the Berlin-Potsdam-Magdeburg railway station, which is built between 1863 and 1864.¹²⁴ The entire building consists of a main semicircular shed, which stands along the rails of the station and houses a turntable with thirteen places for locomotives, an octagonal tower housing facilities for workers, and a smaller staircase tower. (fig. 5.7.8) The vertical bearing structures consist of masonry pillars standing on masonry footings, which, in turn, stand on concrete bases. (fig. 5.7.9–10) For precautionary reasons, the foundation pits along the rails are shored up with 16 feet-high sloping sheet piles along the rails' side, while the other sides are provided with ordinary timber shoring works. All other foundation pits are instead built adopting the method of the sinking caissons. (fig. 5.7.11) At first, a kind of caisson made of poles, wind bracing and horizontal boards, is used. This proves to be weak, and it is replaced with a stronger one, which is less high and is made of 1 and ½ inches thick vertical boards, kept together by means of horizontal boards forming two bands all around the inner surface of the caisson. (fig. 5.7.12) The largest caisson is the octagonal-shaped one, which is assembled for the foundation of the staircase tower. Concrete is poured at the bases of the caissons, and it consists of Portland cement, sand and crushed stones.

Quite large sinking caissons, entirely filled with concrete, are also used to build the foundations of the Nationalgalerie in Berlin, which is designed by Stüler from 1862 to 1865 (the year Stüler dies), and constructed between 1866 and 1876.¹²⁵ The Austro-Prussian war of 1866 stops the preliminary works for a short period, during which some tests are carried out to verify the hardening of different kinds of cement underwater, and the compression strength of several specimens, some made of concrete, and some others made of bricks and cement mortar.¹²⁶ Works resume at the end of the war, caissons are driven into the soil, which is dug out and replaced with concrete. On the basis of the outcomes of the strength tests from 1866, concrete is produced using Portland cement from the Stettiner Portland-Cement Fabrik, sand and stone rubble. It is mixed in drums powered by hands, and it is lowered down into the caissons by means of usual boxes. The whole foundation is achieved in the summer of 1867.

¹²³ See Hagen, *Brunnen, Wasserleitung und Fundirungen...*cit., p. 364.

¹²⁴ See H. Weise, *Locomotiv-Haus der Berlin-Potsdam-Magdeburg Eisenbahn in Berlin*, in *Zeitschrift für Bauwesen*, XV, 1865, coll. 435–58.

¹²⁵ See Georg Gustav Erbkam, *Die Königliche National-Galerie*, in *Zeitschrift für Bauwesen*, XIX, 1869, coll. 265–82; Hermann Zwick, ed., *Jahrbuch über die Leistungen und Fortschritte auf dem Gebiet der praktischen Baugewerbe*, vol. I, Leipzig, Carl Scholtze, pp. 253–54. The gallery is built under the supervision of the master builders Carl Ferdinand Busse (1802–1868), Rienicke, and Johann Heinrich Strack (1805–1880).

¹²⁶ See Erbkam, *Die Königliche National-Galerie...*cit., coll. 270–76.

Huge masonry sinking caissons to be entirely filled with concrete are instead conceived by the Hamburg engineer Johannes Christian Wilhelm Dalman (1823–1875), in order to build the masonry dock on the northern side of the Sandthor harbour, between 1866 and 1872, after having observed a similar kind of foundation visiting the port of St. Nazaire in France in 1854.¹²⁷ Although they are square-shaped, Dalmann uses the expression *Senkbrunnen*, sunken wells, to indicate such constructions, and, for this reason, the same expression is used in this text. The building of a masonry dock in the port of Hamburg is not usual at that time, as most constructions are made of timber. Dolphins, which consist of a number of piles, driven into the riverbed and connected above the water level, are the most typical structure to provide a fixing point for ships, while barges transport goods from and to the riversides. (fig. 5.7.13–14) Dalmann himself has built the southern quay of the Sandthor harbour, which is opened in 1866, as a traditional timber structure on piles. Small concrete bases are built under the footing of the masonry walls that stand inside and on the back of the sheds, whereas the front walls, along the waterside, are made of timber, and stand on foundations made of masonry footings and timber piles.¹²⁸ (fig. 5.7.15–17) The southern quay, which is 1870 meters long and supports ten sheds, several rails, and thirty-seven cranes powered by steam engines, is entirely made of brick masonry work and stands on the already mentioned sunken well-foundations. The walls of the wells are made of bricks bound in hydraulic mortar, and are connected at the top by brick masonry vaults. (fig. 5.7.18) According to Hagen, the building of the wells for the Sandthor quay involves several difficulties, since several wells often slope on one side while sinking into the ground, and demand considerable efforts to be straightened out; in spite of that none of them is told having been damaged.¹²⁹

An important secondary corollary of the techniques to build deep underwater foundations concerns the use of different kinds of pressurized chambers that sink into the soil to build wells of considerable depth, which are then filled with concrete and with brick masonry work. The use of this building technique actually spreads in Germany as of about the mid 1860s, mainly to build the foundations of bridge piers, but the original concept of it essentially derives from the idea of the hollow pressurized iron pile that the British surgeon Laurence Holker Potts (1789–1850) patents in 1843, and that the engineers William Cubitt (1805–1861) and John Wright modify in 1851 to build the foundations of the piers for the Rochester bridge.¹³⁰ Pott's hollow iron pile is opened at the lower end, and closed at the top by a cap. It is connected to a pump that sucks the air and provokes a depressurization inside the pile, which descends into the soil by gravity, assisted by the atmospheric pressure, while the loosened soil that is collected at the same time inside the pile is pumped out. Once this is achieved, the cap is removed, a new pile is set at the top and the procedure is repeated. Cubit and

¹²⁷ See Johannes Christian Wilhelm Dalmann, *Hafen-Anlagen in Frankreich und Holland*, in *Zeitschrift für Bauwesen*, (VI, 1856, coll. 361–92, VII, 1857, coll. 313–48), VII, 1857, coll. 329–39.

¹²⁸ See Johannes Christian Wilhelm Dalmann, *Der Hafen von Hamburg-Altona, insbesondere die Anlage des Sandthor-Quais in Hamburg*, Berlin, Ernst & Korn, 1868, p. 6

¹²⁹ See Hagen, *Brunnen, Wasserleitung und Fundirungen...cit.*, p. 367.

¹³⁰ *Ibid.*, pp. 374–413.

Wright invert the operating principle of Pott's pile by inflating air, instead of extracting it. The pressure inside the pile prevents groundwater from rising, while workers dig the soil from inside, and bring the debris out in buckets, passing through a decompression chamber. The French engineers of the *Compagnie des chemins de fer de l'Est* (East Railway Company), lead by Émile Vuigner (1798–1865), develop a further variation of the pressurized pile when they build the foundations of the bridge over the Rhine in the town of Kehl, at the boundary between France and the Grand Duchy of Baden, between 1858 and 1861. (fig. 5.7.20–22) The bridge is intended to connect the French eastern railways with the Baden ones, and the construction of it is therefore based on an international agreement, establishing that the French railway company takes charge of building the piers with the relative foundations, whereas the Baden railway company should construct the bridge deck.¹³¹ Following this accord, the building site for the piers of the bridge in Kehl becomes a privileged observatory for German master builders to learn how to build foundations by means of pressurized chambers. The French engineers combine together the concept of the pneumatic pile with the one of the diving bell, and develop the so-called *Luftkasten* (pressurized caissons).¹³² These are rectangular-shaped cast iron caissons, which are open at the bottom, like large-sized diving bells. They are provided with three different pipes on the top, two for the inflation of air and for workers access through decompression chambers, whereas the third pipe is filled with water to regulate pressure, and it is provided with a rotating digging machine to regularly extract the soil the that workers dig. (fig. 5.7.24) Four contiguous caissons, each one measuring 7 m. in length, 5.8 m. in width and 3.6 m. in height, are built up and placed in a square to build the foundations of the abutments, whereas the caissons for the freestanding piers measure 5.5 by 5.5 m. at the base, and are 3.6 m. high. Three caissons are placed in line two build the foundation of each central pier, whereas four caissons in line are necessary to build the foundations of the two other piers, close to the abutments. (fig. 5.7.23) The building site of each pier is surrounded with scaffoldings covered with a roof; they house all the necessary installations, namely the steam-engine, the pumps, a bridge crane and the system made of jacks, screw and metal bars to suspend the caissons and let them sink gradually and regularly. (fig. 5.7.24) Workers in each caisson dig the soil and push the debris toward the central pipe, into a dip filled with water, where the digging machine collects them in buckets that go up to the surface. Contiguous caissons sink simultaneously, while closed shoring walls, made of timber, and enveloped in thin metal sheets to reduce the friction with earth, are regularly built up on the caissons as they sink, forming enclosures that are then filled with concrete. This is made of artificial cement from Colmar, sand and pebbles from the Rhine. It is produced on the scaffolding and it is

¹³¹ See J.-B. Bodot, *Travaux du Pont de Kehl*, in *Nouvelles annales de la construction*, V, 1859, coll. 18–20. About the building of the bridge in Kehl see also Charles Alfred Oppermann, *Travaux du pont du Rhin à Kehl*, in *Nouvelles annales de la construction*, V, 1859, coll. 155–60; J. G. Schwedler, Hipp, *Der Rheinbrückenbau bei Kehl*, in *Zeitschrift für Bauwesen*, X, 1860, coll. 7–46.

¹³² About the technique of the pneumatic tube by Pott, and its relation with pneumatic system developed in Kehl, see Auguste Perdonnet, *Notions générales sur les chemins de fer*, Paris, Lacroix et Baudry, 1859, pp. 222–32.

poured and levelled in layers of about $\frac{1}{2}$ – $\frac{3}{4}$ feet thickness, into the highest timber enclosures.¹³³ When the caissons have reached the depth of about 20 meters under the riverbed, workers gradually fill the inside spaces with brick masonry work, and, after they leave the caissons through the pipes. These are later pulled out, and the remaining hollow cylinders are filled with concrete. The foundation of each pier finally consists of cast iron caissons filled with masonry work at a depth of about 20 m., and an enormous well, filled with concrete. (fig. 5.7.25)

In 1864, the only freestanding pier of the bridge over the Pregel in Königsberg is built using a single pneumatic caisson, which is similar to the caissons used in Kehl, and is therefore provided with a central pipe for the digging machine, and two lateral pipes for workers' access and air insufflation.¹³⁴ (fig. 5.7.26–30) The building site is surrounded with scaffoldings that house the cranes, the jacks and the engine that powers the digging machine, while the pump is in a shed on dry land and it is powered by a steam engine, which, at the same time, move the drums for the production of mortar and concrete, inside the same shed. (fig. 5.7.31–32) Unlike the case of Kehl, brick masonry work is used here to fill the space inside and over the caisson, while concrete is just used to fill the hollow spaces that remain once the pipes are extracted.

Pressurized circular bells, instead of caissons, are used to build the foundations for the freestanding piers of the bridges over the rivers Oder and Parnitz near Stettin that are constructed between 1866 and 1868, in the context of the already mentioned project for the improvement of the railway from Berlin to Stargard.¹³⁵ (fig. 5.7.33–34) The two bridges are almost similar and each consists of a central circular pier supporting a swing bridge, two freestanding piers standing on the riverbed, and two abutments. These last ones are built on ordinary sunken well foundations, each one being composed of three wells, except the left abutment of the bridge over the Oder, which is built on a stretch of the concrete foundation of the dock that had been built in 1844. The central freestanding piers of both bridges are built following the same procedure. The bell is suspended on scaffoldings by means of sixteen couples of chains made of metal bars connected one to each other, and hanging from the screws fixed in jacks. (fig. 5.7.35) The pressurized bell is provided with two pipes and no digging machine is installed. The well for the central pier of the bridge over the Oder reaches the depth of 42 feet from the medium level of gauge, whereas the one for the central pier of the bridge over the Parnitz reaches a depth of 25 feet. The wells over the bells are built in brick masonry work and they taper from the bottom to the top. Concrete is only poured onto the bottom of the bell after that the well has reached the desired depth, forming roughly $4 \frac{1}{2}$ feet high bases, while all others hollow spaces are filled with brick masonry work. A similar procedure is used to build the freestanding pillars on both sides of the circular ones. These ones, however, each stand on two wells, which are connected at the top by a masonry vault. (fig. 5.7.36)

¹³³ See Schwedler, Hipp, *Der Rheinbrückenbau bei Kehl...*cit., col. 26.

¹³⁴ See Löffler, *Die Fundirung der Eisenbahnbrücke über den Pregel in Königsberg*, in *Zeitschrift für Bauwesen*, XVI, 1866, coll. 517–36; Hagen, *Brunnen, Wasserleitung und Fundirungen...*cit., pp. 391–98.

¹³⁵ See Stein, *Erweiterungsbauten der Berlin-Stettiner Eisenbahn...*cit., pp. 6, 28–31.

Pressurized bells are also used to build the foundations of two freestanding piers (namely the first two next to the right abutment) of the bridge over the Rhine that is built between 1868 and 1870 in Hamm near Düsseldorf, along the railway connecting Düsseldorf and Neuss.¹³⁶ (fig. 5.7.37) A first plan suggests the use of two single and 9 feet high wrought-iron caissons, which are intended to gradually be covered with poured concrete inside enclosures. Since it is considered too demanding to build up and steer such caissons, this plan is set aside and two 26 feet-wide diving bells for each pier are used instead of caissons. (fig. 5.7.38) They are sunk down from usual scaffoldings housing materials and installations.¹³⁷ The wells over the bells are filled with brick masonry work, while concrete is poured inside the bells, once they have reached the planned depth. (fig. 5.7.39) Mortar and concrete are produced using cement from the Bonner-Portland-Cement-Fabrik mixed with *Trass*, and sand. Concrete is also poured underwater into the space between the two well foundations of each pier, which is closed along the major sides by means of sheet piles; and each pier essentially consists of two cylindrical pillars, each rising from a well, which are connected at the top by an arch. All other piers of the bridge in Düsseldorf are built on much more common foundations made of concrete poured by means of a pipe inside enclosures of sheet piles, apart from the foundations of the right pier standing on land, which consists of masonry work.¹³⁸

Besides the development of pressurized caissons and bells, a number of foundations are built adopting the technique of the ordinary sunken well at the turn of the 1870s. Again in the Oder valley near Stettin, the railway line Breslau-Schweidnitz-Freiburg is improved as of 1869, demanding the construction of five further bridges, among which, the one that crosses the Berlin-Stettin-Stargard railway line over the watercourse called Kleine Reglitz is partially built on sunken well foundations.¹³⁹ The bridge actually stretches over five spans, two of which are covered with masonry vaults, whereas the remaining three spans are covered with metal constructions. (fig. 5.7.40) The abutments stand on foundations made of concrete poured inside enclosures of sheeting piles, whereas the two piers in the central part of the bridge each stand on two sunken wells.¹⁴⁰ Several bridges along the railway connecting Berlin, Potsdam and Magdeburg are also built on sunken well foundations, namely the viaduct over the

¹³⁶ See Stahl, *Die Construction der Taucherglocken zur Fundirung der Rheinbrücke bei Hamm*, in *Zeitschrift des Vereins deutscher Ingenieure*, vol. XIII, 1869, coll. 185–88; *Mittheilungen aus Vereinen. Verein für Eisenbahnkunde in Berlin*, in *Deutsche Bauzeitung*, III, 1869, p. 135; Hermann Zwick, ed., *Jahrbuch über die Leistungen und Fortschritte auf dem Gebiet der practischen Baugewerbe*, vol. I, Leipzig, Carl Scholtze, pp. 324–27; Pichier, *Die Verbindungseisenbahn zwischen Düsseldorf und Neuss mit Ueberbrückung des Rheinstromes oberhalb Düsseldorf*, in *Zeitschrift für Bauwesen*, XXII, 1872, (coll. 237–50, 369–84), coll. 239–45.

¹³⁷ *Ibid.*, col. 241.

¹³⁸ *Ibid.*, coll. 244–45.

¹³⁹ They are the bridge over the large Reglitz, the bridge ove the small Reglitz, a tidal bridge close to the goods station, a bridge passing under the Road Stettin-Altdamm, and the bridge over the Parnitz; see Friedrich Eduard Salomon Wiebe, *Die Bauten der Breslau-Schweidnitz-Freiburger Eisenbahnm Oderthal bei Stettin*, in *Deutsche Bauzeitung*, IX, 1875, (n° 71, pp. 353–55, n° 73, pp. 363–65, n° 75, pp. 373–75), n° 73, pp. 363–65; Teichgräber, *Die Brücken im Oderthale bei Stettin...cit.*

¹⁴⁰ The piers of all other bridges in the Stettin Oder valley along the same railway line stand on timber piling foundations.

Schiffahrt canal in Berlin, and the bridges over the Elbe near Magdeburg, near Biederitz and near Gommern. The first has piers standing along the embankments of the canal, on foundations composed of three different wells in line, which are built in a shored up and partially artificially buried site. Concrete is poured onto the bottom of the well, in spaces that are dug by means of the already described Indian-spade. (fig. 5.7.41) Similar constructions made of pillars standing on three sunken wells in line are also built for the other mentioned bridges near Magdeburg, Biederitz and Gommern.¹⁴¹

The huge railway bridge that is built between 1868 and 1872 over the river Vistula and its tidal land, near the town of in Thorn (today Torun), is a further example of work partially realized on sunken well foundations. The bridge has two abutments and sixteen piers, ten of which are built, each on three wells in line. One stands in the riverbed of a minor branch of the Vistula, while all the others are built on the tidal land that stretches between the main course of the Vistula, and the just mentioned minor branch. (fig. 5.7.42) The wells are partially filled with concrete, and partially with brick masonry work. The piers standing straight in the Vistula are built on foundations made of timber piles rammed inside enclosures of sheet piles, and are covered with a bed of concrete, whereas the abutments are built straight on the soil. (fig. 5.7.43) Concrete is produced using cement taken from the Stettiner-Portland-Cement-Fabrik.¹⁴²

Dalmann also makes further use of sunken well foundations to build the new docks of the Grasbrookhafen, which is completed in 1876. (fig. 5.7.44–46) A railway turntable at the southwest end of the northern quay of the Grasbrookhafen is, instead, built on a circular foundation made of timber piles, the heads of which are enveloped in a ring of concrete. (fig. 5.7.47) And it is just to this kind of now well explored building technique, based on the use of timber piles covered by a concrete basement, that Dalmann turns to again when he, in 1875, designs the construction of the Strandhafen, which stretches straight along the Elbe.

5.8 Concrete for constructions above ground

The acknowledgement of the similarity between lean conglomerate and concrete, around the mid 1850s, brings in about a decade of the prevalence of concrete over lean conglomerate in constructions above ground. Two conditions favour such a change in the building culture: the spreading use of hydraulic binders, which are also recognized as appropriate for lean conglomerate mixtures, especially in the case of foundations and basements; and the awareness that Coignet in France, as well as British master builders, tend to reduce the amount of cement in concrete as much as possible when they

¹⁴¹ See Julius Ludwig Quassowsky, *Ueber Fundirungen mit Senkbrunnen nebst Beschreibung einiger Fälle aus der Praxis*, in *Zeitschrift für Bauwesen*, XXIV, 1874, (coll. 297–312), coll. 304–12.

¹⁴² See Anon., *Eisenbahnbrücke über die Weichsel bei Thorn*, in *Zeitschrift für Bauwesen*, XXVI, 1876, (coll. 35–54, 197–218), coll. 38–49.

build above ground, thus producing mixtures that are similar to the ones of the German lean conglomerate.

Some literary works express this change during its development. Seen in this light, the historical excursus about concrete constructions that Becker traces in his book about fireproof staircases from 1857 assumes particular relevance.¹⁴³ Becker tries to provide a unitary and synthetic vision of the history of constructions made of lime and cement-base conglomerate, from the ancient Roman ones to those of his time, including constructions belonging to the domain of hydraulic engineering, along with the buildings by Lebrun, Rydin, Prochnow, Leuchs, and the houses that the British army constructs on the Wight Island in the early 1850s. Becker's sources concerning the ancient Roman art of building are Rode's translations of Vitruvius' *De Architectura*, and Hirt's *Baukunst nach den Grundsätzen der Alten*. Thus, Becker describes the ancient way of building walls made of masonry faces and concrete filling, with a special regard for the *opus reticulatum*. He also mentions the Roman's skills in building concrete vaults and freestanding concrete walls by means of provisional centrings and formworks, besides the constructions of hydraulic works using the indispensable pozzolana.¹⁴⁴ Apart from the description of the different ways Romans used concrete, it is also interesting to observe that Becker considers ancient and modern concrete as essentially equivalent. "Both ancient and recent concrete," he writes in this regard, "consist in mixtures of mortar and all kinds of rubble, and sometimes in mixtures of gravel and lime-based mortar." "The ancients," he then goes on, "used it to build principally concrete walls, vaults, floors and hydraulic works," hinting, in this way, at the possibility of using concrete to build such kind of works anew.¹⁴⁵ Becker, however, wavers when he comes to write about the relation between lean conglomerate and concrete. He defines lean conglomerate as a kind of concrete lacking in rubble, and he shares the current conviction that lean conglomerate has prevented the spread of concrete use in construction above ground in Germany.¹⁴⁶ As examples of lean conglomerate constructions, he mentions the walls of a factory along the Schifffahrt canal in Berlin, close to the site of the Zoologischer Garten, which he describes as made of mortar (one measure of lime from Rüdersdorf and six measures of sand and gravel) poured and tamped in formworks. He furthermore reports that, on the same site, four columns have been built by pouring and tamping, in wooden formworks, a kind of concrete made of one measure of Portland cement and six measures of sand, gravel and stone rubble. These same columns

¹⁴³ See Becker, *Der feuerfeste Treppenbau*...cit., pp. 52–59.

¹⁴⁴ About the use of concrete in modern hydraulic engineering, Becker's main reference is Bélidor's *Architecture hydraulique* (see Becker, *Der feuerfeste Treppenbau*...cit., pp. 53).

¹⁴⁵ "Der Béton der Alten wie der der Neuern aus einem Gemisch aller Art klein geschlagener Bruch- oder Mauersteine mit Mörtel, zuweilen auch aus einer Mischung von Kies und Kalkmörtel. Hauptsächlich zur Aufführung von Mauern, zu Gußgewölben, zu Estrich, wie zu Wasserbauten wurde der Béton von den Alten vielfach verwendet" (Becker, *Der feuerfeste Treppenbau*...cit., p. 52).

¹⁴⁶ "Although the use of concrete over ground is known since fourteen-years, lean conglomerate has prevailed" ("In Deutschland ist die Anwendung des Betons zu Hochbauten seit etwa 14 Jahren im Gebrauch, doch im Allgemeinen seit dieser Zeit der Kalk-Sand-Pisé-Bau mehr in Ausübung gekommen" Becker, *Der feuerfeste Treppenbau*...cit., p. 59).

are covered with plaster and with a layer of oil painting, to give them the appearance of sandstone.¹⁴⁷ Although he is a major supporter of Portland cement, Becker praises “the great solidity of ordinary mortar, made with lime lacking any hydraulic property, and with much sand, like the one that it is used for buildings made of lean conglomerate.”¹⁴⁸ Becker’s historical excursus becomes, a few years later, the main source for an article dealing with concrete, lean conglomerate and artificial stones, which is published in 1864, in the *Zeitschrift für praktische Baukunst*, under the title of “The importance of artificial building materials”.¹⁴⁹

The book about concrete building by the Austrian-Hungarian hydraulic engineer Johann von Mihálik (1818–1892) also contributes to strengthen, in Germany, the arising concept that concrete is appropriate for extended uses, underwater and underground, as well as above ground; the second edition of Von Mihálik’s book is in fact published in Berlin in 1860, shortly after having been issued in Wien.¹⁵⁰ “Concrete,” Mihálik clearly states, “is suitable to build with advantages to all kinds of masonry works, underwater and above ground.”¹⁵¹

The most evident literary expression of how the concepts of lean conglomerate and concrete overlap each other is perhaps to be seen in the third edition of Engel’s book about lean conglomerate, which is published in 1865. Already in the preface, making reference to the use of lean conglomerate, Engel asserts: “This building method, which is closely related to the centuries-old use of lime-based mortar, may have been already known in antiquity, according to Vitruvius’ reports, which relate the Roman way of building walls by pouring lime and stone rubble (concrete) into box-shaped contraptions.”¹⁵² Hydraulic lime, Roman and Portland cements are now all described as possible components of lean conglomerate, and some kinds of concrete mixtures taken from Coignet are listed among the ones that are considered as appropriate for lean conglomerate, up to the point that Engel resorts to the expression “rammed, hydraulic, and lime-based mass” to briefly explain what concrete is.¹⁵³ Engel considers concrete as an appropriate material to build vaults, and mentions, as pertinent

¹⁴⁷ *Ibid.*, p. 56.

¹⁴⁸ “[...] welche große Festigkeit schon Mörtel gewöhnlicher Art, von Kalk ohne wesentliche hydraulische Eigenschaft, mit großem Sandzusatz, wie derselbe zum Kalk-Sand-Pisé-Bau verwendet wird” (Becker, *Der feuerfeste Treppenbau...*cit., p. 57).

¹⁴⁹ Anon., *Der Werth des künstlichen Baumaterials...*cit.

¹⁵⁰ Johann von Mihálik, *Praktische Anleitung zum Béton-Bau für alle Zweige des Bauwesens*, Wien, Joseph Stöckholzer v. Hirschfeld, 1859², Berlin, Theobald Grieben, 1860². Full name of Mihálik is János Mihálik von Madunycz, and he is born in Arad, which is today in Romania.

¹⁵¹ “Mit Béton kann Mauerwerk jeder Art, und zwar sowohl ober als unter Wasser” (Von Mihálik, *Praktische Anleitung zum Béton-Bau...*cit., 1860, p. 7).

¹⁵² “Daß diese Baumethode, welche im innigem Zusammenhange mit der seit Jahrtausenden bestehenden Anwendung des Kalkmörtels ist, schon im Alterthume bekannt gewesen sein dürften, beweisen die Berichte des Vitruv, nach welchen die Römer schon kastenartige Vorrichtung zur Herstellung von Mauern aus Kalk und Steinstücken (Béton) benutzt haben” (Engel, *Der Kalk-Sand-Pisébau und die Kalksand-Ziegelfabrikation...*cit., p. 3). Similarly to what already observed for Becker, Vitruvius’ *De Architectura* and Hirt’s *Baukunst nach den Grundsätzen der Alten* are Engel’s literary references for the art of building in the antiquity (see *ibid.*, pp. 3–4).

¹⁵³ “[...] Mauer aus Béton (hydraulischer Kalkstampfmasse)” (“walls of concrete (rammed hydraulic, and lime-based mass)” Engel, *Der Kalk-Sand-Pisébau und die Kalksand-Ziegelfabrikation...*cit., p. 67).

evidences, the ancient Roman concrete vaults, along with the much more recent examples of vaults built by Hoffmann, some other ones described by Mihálik, and the pointed vault of a little house for inspectors that the master builder Carl Ruland (1806–1871) builds between 1858 and 1859, along the river Isar, close to Munich.¹⁵⁴ (fig. 5.8.1) Apart from the in-between floor, Ruland's house is entirely made of a quite lean concrete (one measure of hydraulic lime and ten measures of sand and stone rubble), from the foundation to the vault forming the roof. This house is to be seen in relation with the already mentioned railway inspector houses made of lean conglomerate in the region of Hamburg, and it can also be considered one of the earliest examples of a concrete house built in Germany.

As of about the mid 1860s, a crucial period for the definitive acknowledgement of concrete as building materials for constructions above ground finds its beginning. The building of railways is once again a driving force. In 1865, the Dyckerhoffs' cement company, which has been entrusted with the construction of concrete floors for some stations of the Swabian railways, builds a 4 feet span concrete railway bridge. In the same year, the Dyckerhoffs experiment in their own factory with the construction of floors made of iron beams, placed 18 inches from each other, and concrete flat vaults as fillings. The kind of concrete that is used in both cases is made of one measure of cement, three of sand and four of stone rubble.¹⁵⁵

Between 1867 and 1868, concrete is used to fill the fields of the extraordinary iron floor that is built to construct a railway underpass along the Jacobsstrasse in Görlitz, which is 100 feet-long and 35 feet-wide.¹⁵⁶ (fig. 5.8.2–3) The underpass is divided into three aisles by two rows of eleven iron columns; the central aisle is 21 feet wide, and the lateral ones are each 7 feet wide. The columns bear eleven transversal girders, which are light-arched over the main aisle, and twelve minor girders in each of the ten fields formed by the major girders. This iron structure forms a horizontal frame containing one hundred and ten hollow fields, which are filled with concrete. The whole is finally covered with asphalt and gravel, forming the base for the rails.

In the wake of the example shown by Ruland, around 1867, the master builder Joseph von Schierholz (1817–?), who is engaged in the construction of the Swabia railways, takes into account the possibility of building houses for inspectors in conglomerate, seeing that, as he himself asserts, neither natural stones, nor large amounts of good quality bricks are easily available in the region, whereas hydraulic lime and cement are produced in several local kilns.¹⁵⁷ Schierholz rejects the use of aerial lean conglomerate (*Kalksand*), which he considers not good enough to produce rapidly solidifying masses,

¹⁵⁴ Ibid., p. 90; Joseph von Schlierholz, *Ueber Beton-Verwendung zu Hochbauzwecken, hauptsächlich zu ganzen Gebäuden*, in *Allgemeine Bauzeitung*, XXXV, 1870, pp. 260–65. About Carl Ruland, see Anon., *Zur Erinnerung an Carl Ruland, kgl. Regierungs- und Kreisbaurath a. D., Ehrenmitglied des Münchener Architekten- und Ingenieur-Vereins*, in *Zeitschrift des bayerischen Architekten und Ingenieur-Vereins*, IV, 1872, pp. 1–4.

¹⁵⁵ See Stegmann, *Das Bauunternehmen Dyckerhoff Et Widmann...cit.*, esp. pp. 27–31.

¹⁵⁶ See Anon., *Der Umbau des Bahnhofes zu Görlitz*, in *Zeitschrift für Bauwesen*, XX, 1870, (coll. 471–82), col. 474. The subway becomes known as Jakobstunnel, since it stretches along the Jacobsstrasse.

¹⁵⁷ See Schierholz, *Ueber Beton-Verwendung...cit.*; see also Dollinger, *Wärterhaus aus Béton*, in *Deutsche Bauzeitung*, IV, 1870, pp. 44–45.

and chooses, instead, to experiment with three different Roman and Portland cement-based concrete mixtures, being aware of Von Pettenkofer analyses, and of Von Mihálik and Becker's literary works. The construction of three test-houses, between Ulm and Blaubeuren, is therefore planned. Each house should consist of a basement covered with two barrel vaults, and an above standing main living space covered with a pointed vault, and divided into two levels by means of an in-between timber floor. (fig. 5.8.4) Apart from the in-between timber floor, all other bearing walls and vaults are intended to be built in concrete, to pour and tamp in formworks and on centrings. The construction begins in the summer of 1867, and it is achieved in the spring of 1868. Two houses are entirely constructed according to the plans, whereas the third one is covered with an ordinary roof and cement tiles, due to lack of time. At least one of these houses is built by Leube, specifically the one in Gerhausen.¹⁵⁸ (fig. 5.8.5) In the following years the Swabia railway administration orders the construction of further concrete houses, and, according to Schierholz, about ten are completed until 1870.

The increasing housing need that is caused by the industrial and urban development also gives occasions for experimenting with concrete construction above ground. The housing question is particularly serious in Berlin, where the effects of Reforms promoted in the early century by Heinrich Friedrich Karl vom und zum Stein (1757–1831) and Karl August von Hardenberg (1750–1822) make the phenomenon of urbanization even more critical. The population increases from 418000 to 702437 habitants, between 1859 and 1867, and the housing question gains such an importance that the master builder Franz Gustav Assmann, in a talk given at an assembly of the Berlin Architektenverein in 1872, states: "The housing question has now turned into housing crisis."¹⁵⁹ It is in such a context that the entrepreneurs Anton and Alfred Lehmann, based in the manufacturing area of Rummelsburg, plans to build a working-class neighbourhood, entirely composed of concrete buildings, according to British models they have heard about from the master builder Albrecht Konstantin Türrschmiedt (1817–1871).¹⁶⁰ In 1870, on behalf of the Lehmanns, the engineer Alexis Riese goes on a journey to England,

¹⁵⁸ See Anon., *Bahnwärterhäuser aus Gußmauerwerk*, in *Polytechnisches Journal*, XLIX, vol. CXXVII, p. 517; Breuss, Günther, Kaindl, Zrost, *175 Jahre Leube...*cit., p. 35.

¹⁵⁹ "Aus der Wohnungsfrage ist aber inzwischen eine wirkliche Wohnungsnoth geworden" (Franz Gustav Assmann, *Die Wohnungnoth in Berlin*, in *Zeitschrift für Bauwesen*, XXIII, 1873, (coll. 111–30), col. 111).

¹⁶⁰ See Lehmann, *Bericht über einen Versuch mit Konkretbau*, in *Verhandlungen des Vereins zur Beförderung des Gewerbeleisses in Preussen*, LI, 1872, pp. 37–38. About concrete houses in England see also Friedrich Wiebe, *Bauwerke aus Concret*, in *Deutsche Industriezeitung*, 1870, pp. 7–8, and in *Zeitschrift für Bauhandwerker*, XIV, 1870, pp. 61–62.

Friedrich Türrschmiedt founds in 1865 the *Verein für die Fabrikation von Ziegeln, Kalk und Cement* (Society for the manufacturing of bricks, lime and cement), together with the master builder Friedrich Eduard Hoffmann (1818–1900); about Türrschmiedt see Lämmerhirt, *Albrecht Türrschmiedt*, in *Deutsche Bauzeitung*, V, 1871, pp. 330–31. About the development of Rummelsburg and the early steps to the building of the worker settlement see Armin Niemeyer, *Ein Vorläufer des Betonbaues am Rande Berlins*, in Ulrich Großmann, Klaus Freckmann, Fred Kaspar, Ulrich Klein, ed., *Aus den Forschungen des Arbeitskreises für Haus- und Siedlungsforschung*, Marburg, Jonas, 1991, pp. 97–108; Christina Czymay, "Colonia Victoriastadt" in Berlin-Lichtenberg, in Berlin, Landesdenkmalamt, ed., *Beiträge zur Denkmalpflege in Berlin*, n° 12, Berlin, Schelzky und Jeep, 1997, pp. 60–63; Id., *Die Colonia Victoriastadt – Betonhäuser in Berlin Rummelsberg*, in Hartwig Schmidt, ed., *Zur Geschichte des Stahlbetonbaus. Die Anfänge in Deutschland 1850 bis 1910*, Berlin, Ernst & Sohn, 1999, pp. 11–15.

where he learns about how to produce and apply concrete, while the Lehmanns buy a roughly 20 hectare wide land plot, on the eastern side of Rummelsburg, where the new neighbourhood is intended to be built. According to Türrschmidt, it is through a contact with the British master builder "Wonnacott" that Riese learns about concrete. The master builder that Türrschmidt mentions could be Thomas Robjohns Wonnacott (1834–1918), who builds a concrete house in the first half of the 1870s in Grays in the county of Sussex.¹⁶¹ Once back in Berlin, Riese builds an experimental concrete house, composed of two levels and a basement. He uses a concrete mixture composed of Portland cement from Stettin, sand, pebbles from Rüdersdorf, rubble taken from the demolition of other buildings, and slags from a nearby gas manufacturing installation, which he pours into wrought-iron metal formworks of the type that Charles Drake has patented in the United Kingdom in 1867.¹⁶² Just like the metal formworks, the concrete mixture is also to be seen in relation to Riese's journey to England, since, as it is reported in an article from 1873 focusing on the construction of concrete houses, British builders mix "Portland cement and the most different materials that are affordably available, close to the building sites, like sea sand, coal ash, slags, gravel, rubble and so on," and the ratio between cement and other agglomerate varies between 1:7 and 1:13.¹⁶³ Such a kind of concrete is quite lean and therefore reminiscent of Engel's hydraulic, lime-base mass. Türrschmidt welcomes this construction with enthusiasm, claiming that concrete will make it possible to do without masons, who were striking in Berlin in that period.

The reliability of Riese's concrete test-house is verified and recognized by the Berlin *Baupolizei* and by the Berlin magistrate on a visit that takes place on November of 1871.¹⁶⁴ Meanwhile the Lahmanns found a building company, the Cement-Bau A.G., and once the Berlin *Baupolizei* has approved the use of concrete, the construction of the new dwellings begins.¹⁶⁵ The early houses that are built in 1872 (about 12) only have walls made of concrete, whereas the floors and the staircases are made of wood.¹⁶⁶ The following ones are, instead, almost entirely made of concrete, including staircases and floors. These ones consist of single flat vaults covering small rooms, whereas each larger room is

¹⁶¹ See Albrecht Konstantin Türrschmidt, *Berlin erstes Concretehaus*, in *Notizblatt des Vereins für die Fabrikation von Ziegeln, Kalk und Cement*, 1871, n° 3, n.p. About Thomas Robjohns Wonnacott and the concrete house he builds in Grays, see Peter Raby, *Alfred Russel Wallace*, Princeton, New Jersey, Princeton University Press, 2001.

¹⁶² Heike Hinz, "Berlin-Lichtenberg, Türrschmidtstrasse 17. Fruhe Betonhäuser in der Victoriastadt ab 1871. Zur Entstehung und Sanierung des Wohnhauses in der Türrschmidtstrasse 17", final report for "Aufbaustudiegang Denkmalpflege", Technische Universität Berlin, 2002; Anon., *Ueber die Anwendung des Beton zur Herstellung von Wohnhäusern...*cit., p. 28.

¹⁶³ "Zur Erzeugung des concretes sind in England in Mischung mit Portlancement die verschiedensten Materialien in Anwendung gekommen, wie solche in der Nähe von Baustelle eben am wohlfeilsten zu haben waren, Z.B. Meersand, Kohlenasche, Schlacken, Kies, Steinbrocken, u." (Anon., *Ueber die Anwendung des Beton zur Herstellung von Wohnhäusern*, in *Zeitschrift für Bauhandwerker*, XVII, 1873, (pp. 15, 28–31), p. 15; about concrete mixtures used in England see also Bernhard Liebold, *Zement*, Halle, Hendel, 1874, pp. 41–42, n. 1).

¹⁶⁴ See Hinz, "Berlin-Lichtenberg..." cit.

¹⁶⁵ See Niemeyer, *Ein Vorläufer des Betonbaues...*cit., p. 100.

¹⁶⁶ See Ernst Kanow, "Colonia Victoriastadt." Eine Berliner Wohnsiedlung mit mehr als hundert Jahren alten Wohnhäusern aus Beton, in *Architektur der DDR*, XXX, 1981, (pp. 50–53), p. 51.

covered with two flat vaults resting on two bearing walls and on a central iron double T beam. Chimneys are built as hollow pipes inside the walls, by putting provisional round poles in the formworks, at appropriate places, before concrete is poured.¹⁶⁷ The concrete mixture used to build the walls is quite lean, being composed of 10 % Portland cement, 15% sand, and 75% coal ash. The use of slags is thought to improve the healthiness of the houses, keeping walls dry. The mixture used to build the vaults contains a larger percentage of cement, about 14%, very probably as a precaution.¹⁶⁸ The strength tests that are carried out before works start prove that this kind of vaults can withstand 3750 kg/m² against an expected strain of 750 kg/m². (fig. 5.8.6) The neighbourhood is only partially constructed (about sixty buildings out of two hundred), and it is given the name of Victoriastadt, referring to the queen Victoria, a detail that reinforces the connection with the British culture.

In 1872, just as the construction of Victoriastadt begins, the entrepreneur Godhard Friedrich Julius Prüssing and the businessman Friedrich Planck found a cement factory in the town of Vorwohle, in the Duchy of Brunswick, which goes under the name of Vorwohler Portland-Cement-Fabrik. Shortly after the foundation of the cement factory, they contact the master builder Berhard Liebold (1843-1916), who is based in the nearby town of Holzminden, where he runs a private office, and is a teacher at the Holzminder Baugewerkschule.¹⁶⁹ Liebold already has some experience with cement pipes, since he has built a canalisation in a factory in Karlsruhe, and he is probably also aware of the concrete houses that are under construction in Berlin, through periodicals that are available in the library of the Baugewerkschule.¹⁷⁰ Together with Liebold, Prüssing and Planck found a building company, the Vorwohler Cement-Baugesellschaft Prüssing, Planck & Co., in 1873, with the evident aim of exploiting the Portland cement they produce.¹⁷¹ In the same period, Liebold conceives a group of dwellings for Prüssing and Planck to build in Vorwohle, for the workers of the local cement factory. They have foundations made of stone, walls made of sand-lime bricks and vaults of concrete. (fig. 5.8.7) The sand-lime bricks for the walls are produced using a mixture of seven measures of ash and one measure of slaked lime, according to instructions that Liebold himself develops, and they are moulded in a Bernhardi's press.¹⁷² Concrete for the flat vaults and for the staircases is more prudently composed of one measure of cement, two of sand and four of rubble.¹⁷³ The construction of the early vaults goes through a singular accident, which is probably once again due to the excessive belief in the adhesion between cement mortar and bricks. Liebold, in fact, at first draws concrete vaults that do not rest

¹⁶⁷ *Ibid.*, p. 52.

¹⁶⁸ See Anon., *Das Cementbau*, in *Zeitschrift für Bauhanwerker*, XVI, 1872, (pp. 187-88), p. 188; *Mittheilungen aus Vereinen*, in *Deutsche Bauzeitung*, VI, 1872, p. 385; Anon., *Versuch mit Concretbau*, in *Zeitschrift für Bauhanwerker*, XVII, 1873, p. 143; Liebold, *Zement...cit.*, pp. 76, 106.

¹⁶⁹ See Matthias Seeliger, *Betonbau in der Provinz - Die Vorwohler Zementbaugesellschaft*, in Uta Hassler, ed., *Häuser aus Beton. Vom Stampfbeton zum Grosstafelbau*, Tübingen, Berlin, Ernst Wasmuth, 2004, pp. 47-57.

¹⁷⁰ See Liebold, *Zement...cit.*, p. 85; Seeliger, *Betonbau in der Provinz...cit.*, p.48; see also Liebold, *Zement...cit.*, pp. 40-47.

¹⁷¹ See Seeliger, *Betonbau in der Provinz...cit.*, p. 49.

¹⁷² See Liebold, *Zement...cit.*, p. 54.

¹⁷³ *Ibid.*, p. 106.

perpendicularly on the sand-lime brick walls, but on banquettes of hard bricks and fat lime-based mortar forming angles of about 18 degrees with the imposts of the concrete vaults. Liebold believes that the brick masonry banquettes and the concrete vaults bind so much together that they act as monolithic elements. "In order to avoid a weakening of the walls," Liebold later relates in this regard, "I made building banquettes of well burnt bricks, according to the form shown in the section 23 [see fig. 5.8.8], since I thought that the concrete mass of the vaults could weld with the bricks of the banquettes".¹⁷⁴ Such construction of course fails, and, only with a second attempt, Liebold conceives vaults that lie perpendicularly on the banquettes, inside the walls.

Along with dwellings for the working-class, since the early 1870s, the construction of some concrete houses for entrepreneurs is also to be observed. The Stuttgart architect Otto Tafel (1838–1914) builds a villa for the train manufacturer Oskar Merkel in Esslingen am Neckar, around about 1873, while Liebold builds a number of further concrete buildings in the area between the river Weser and the Harz Mountains. In Vorwohle, he builds the local inn and a dwelling house for the local Asphaltfabrik between 1876 and 1877, in Holzminden he builds the residence of Planck in 1877, and, nearby in Kreiensen, he builds the Maigatter hotel.¹⁷⁵ (fig. 5.8.9–11) Being the residence of an entrepreneur involved in the production of cement and concrete, the house of Planck is considered a sort of exemplar building, conceived to test and to show the properties of cement and concrete. The considerable number of different kinds of vaults employed to cover the rooms and halls of the house are an evidence of such an aim. Particularly impressive is the groin vault forming the roof, which is originally even provided with a flat terrace in the central part of it. The concrete for the walls and for the upper vaults is composed of cement, sand and gravel, whereas for the inner vaults and for the staircase, it is made of cement, sand and coal slags.¹⁷⁶

In spite of such experimental works, the construction of buildings entirely made of concrete remains quite modest. In 1874, the *Verband deutscher Architekten- und Ingenieurvereine* (Associated Society of the German Architects and Engineers Societies) debates about the appropriate domains of application of concrete in architecture, realizing that concrete is just suitable for functional buildings without aesthetic requirements. Nevertheless, as the matter is again discussed ten years later, the number of concrete buildings in Germany is still extremely modest, even in the domain of the functional buildings.¹⁷⁷ The pretended unsuitability of concrete to provide aesthetic qualities is therefore no

¹⁷⁴ "Die Widerlager der Gewölbe liess ich, um eine Schwächung der Umfassungsmauern zu verhindern in nebenstehender Form, Holzschnitt 23, von gut gebrannten Mauerziegel herstellen, weil ich glaubte, dass sich mit diesen die Bétonmasse des Gewölbes gut und innig verbinden würde" (Liebold, *Zement...*cit., p. 100).

¹⁷⁵ See Anon., *Ein Beitrag zum Betonieren von Hochbauten*, in *Oeberösterreiche Bauzeitung*, II, 1897, (pp. 69–70), p. 69; Seeliger, *Betonbau in der Provinz...*cit., p. 56.

¹⁷⁶ See Bernhard Liebold, *Wohnhaus des Hrn. Kaufmann F. Planck in Holzminden*, in *Deutsche Bauzeitung*, XI, 1877, pp. 458–59.

¹⁷⁷ As in 1884 Schierholz carries out a statistical research about the number and the type of concrete realized in Germany, on behalf of the *Verband deutscher Architekten- und Ingenieurvereine*, he only finds 17 houses, 2 stables and

satisfying reason to justify the limited number of concrete buildings completed in Germany approximately in the third quarter of the century. The reason is rather to be found in the importance that the German building culture traditionally devotes to ordinary masonry. Concrete, instead, becomes part of the construction practices very gradually, mainly by replacing the masonry work in single parts of the buildings, namely where the extraordinary monolithic behaviour of it is considered particularly advantageous. The reference principally goes to vaults and flat vaults used as filling panels in iron floors. Besides the already mentioned examples, further ones are to be observed since about the mid 1870s. Among them it is worth mentioning the floors of the corridors of the Frankfurt Old Opera, which is built between 1873 and 1880. They consist of iron beams and concrete slabs. Concrete is poured on false-works, which are provided with provisional boxes on the surface, in order to give the ceilings the aspect of old panelled ones. And it is also worth mentioning the early use of concrete for the construction of bombproof floors in military shelters. These had traditionally consisted of iron beams, laid close to each other and supporting a high floor made of brick masonry work. In the summer of 1874, the *General Inspection des Ingenierus- Corps und der Festungen* tests, instead, on the firing range of Tegel in Berlin, a new kind of bombproof floor. It is made of a network of iron double T beams, the minors of which are placed extremely close to each other, the space between them being covered by means of little metal vaults; this armour of iron beams is covered with a bed of concrete, which is 60 cm high in the middle, and slopes towards the extremities. (fig. 5.8.12) "Henceforth, brick masonry work," it is asserted in the report following the tests, "is no longer to be used to build over the beams; concrete is instead to be poured over little metal vaults, and it should be as good as possible, produced with care, since the distribution of thrust produced by projectiles over the iron beams depends on the solidity of concrete, especially on the part of it that lies between the beams."¹⁷⁸

5.9 Further studies about Portland cement, and the regulation of its main physical features

Along with the previously observed development of building skills with concrete, during the third quarter of the century, the study of cement goes through further evolutions, by chemical analyses and strength tests. Following the model of Von Pettenkofer's researches, the *Württemberg Centralstelle für*

factories and some basins (Verein Deutscher Portland-Cement-Fabrikanten, ed., *Der Portland-Cement und seine Anwendungen im Bauwesen*, Berlin, Ernst Toeche, 1892, p. 185).

¹⁷⁸ "Für die Aus- und Anbemauerung ist fortan nicht mehr Ziegelmauerwerk, sondern Beton auf Wölbblechen zu verwenden, und ist der Herstellung eines Möglichst guten Betons besondere Sorgfalt zuzuwenden, da vornehmlich der Festigkeit der Betonmasse, insbesondere auch derjenigen zwischen den Balken, das Maß der Verteilung der Stoß und Sprengwirkung einschlagender Geschosse auf mehrere Balken abhängt" (General Inspection des Ingenierus- Corps und der Festungen, "Vorläufige Bestimmungen über die mit Rücksicht auf die Wirkung des gezogenen 28 cm Mörsers den Bombensicheren Eisendecken fortan zu gebende Construction" Berlin, den 11 Marz, 1875, ms. 667, in GStA IV. HA Preußische Armee, Rep. 16 Militärvorschriften).

Gewerbe und Handel (centre for manufacturing and trade)¹⁷⁹ takes into account three different kinds of English Roman cements, and one kind of Portland cement, around the mid 1850s.¹⁸⁰ The raw materials, the cement powders, as well as a hardened cubic specimen for each kind of cement are analysed, with the aim of comparing the different chemical compositions, and finding the modifications that occur during the different steps of the cement's production and use.¹⁸¹ The outcomes of these analyses are then compared with similar analyses of two kinds of local hydraulic lime taken from the town of Horb am Neckar, southwest of Stuttgart. In accordance with Von Pettenkofer's explanations, these comparisons show that local marls contain a lower amount of clay than the mixtures of lime and clay that are usually burnt to produce Portland cement, and that, moreover, local hydraulic lime is usually not burnt enough.¹⁸²

Approximately in the same period as these cement studies take place in Stuttgart, the chemist Georg Feichtinger from Munich carries out similar investigations.¹⁸³ He takes into consideration a kind of Portland cement from England and five different kinds of Bavarian hydraulic lime. He comes to agree with Von Pettenkofer about the origin of the different physical properties of Portland cement and Bavarian hydraulic limes. In particular, he emphasises the quality of the English Medway clay, which is usually taken to produce Portland cement, and, in this regard, he clearly states: "Bavarians need to search for a similar kind clay, if they aim at getting a Portland cement-equivalent product."¹⁸⁴

Apart from such comparative investigations, which essentially involve consequences on a local scale, some essential chemical studies are carried out during the 1860s, focusing the question of cement hardening, namely how water comes to combine with substances composing the cement. Such studies contribute to improve the general scientific knowledge about hydraulic limes and cements. The question of cement hydration, which is already recognizable in previous studies about hydraulic lime and mortar (John, Fuchs, Von Pettenkofer), takes a clear shape exactly in this period, giving rise to two different approaches to the matter. The first develops in the wake of Fuch's theory about the hardening of hydraulic lime, which Von Pettenkofer essentially considers as appropriate to also explain the hardening of Portland cement. This is therefore thought to occur by a combination that develops between lime and silica by means of water, once silica has been set free from the other silicates' components during the

¹⁷⁹ A public institution that has been founded in 1848 in Stuttgart, with aims similar to those of the Prussian Technical Committee.

¹⁸⁰ Carl Knauß, *Chemische Untersuchung einiger englischen hydraulischen Kalke*, in *Gewerbeblatt aus Württemberg*, 1855, n° 4, pp. 25–32, and in *Polytechnische Journal*, CXXXV, 1855, pp. 361–69.

¹⁸¹ The raw materials from which Portland cement had been burnt are, however, not available (Knauß, *Chemische Untersuchung...*cit., p. 362).

¹⁸² *Ibid.*, p. 369.

¹⁸³ See Georg Feichtinger, *Ueber die chemischen und physikalischen Eigenschaften mehrerer bayerischen hydraulischen Kalke im Vergleich mit Portland-Cement; zugleich ein Beitrag zur Theorie des Erhärtens der hydraulischen Kalke*, in *Polytechnisches Journal*, CLII, 1859, pp. 40–61, 108–18.

¹⁸⁴ "Wollen wir demnach ein dem Portland-Cemente ähnliches Product erhalten, so muß vor allem ein Thon gefunden werden, der in der chemischen Zusammensetzung ähnlich ist dem Thone vom Medwayflusse" (Feichtinger, *Ueber die chemischen und physikalischen Eigenschaften...*cit., p. 61).

burning of lime and clay. The second approach, instead, is based on the belief that the hardening process of Portland cement is essentially different from the one of hydraulic lime. The German promoter of this second approach is the chemist August Winkler, a scholar of the better-known Karl Jacob Löwig (1803–1890), who teaches chemistry at the university of Breslau.¹⁸⁵ Winkler divides hydraulic limes into two groups. One includes the Portland cements, the other the so-called Roman cements, namely all hydraulic limes that are producible by burning marls at moderate fire, besides pozzolana, Trass, brick powder and other similar materials. The first are thought to contain unslaked lime once burnt, and to harden according to the principles of Fuchs' theory; whereas the second are thought to contain no slaked lime at all once burnt, but a complex silicate made of alkali, lime, silica, silicic acid, clay and iron oxide, which is supposed to arise during the firing of lime and clay. Such a silicate is thought to undergo a decomposition process when it comes into contact with water, while some lime combines with silica and clay, and the remaining part of it, with carbonic acid.¹⁸⁶ Feichtinger does not agree at all with Winkler. He strongly maintains the applicability of Fuch's theory to explain the hardening process of Portland cement, which he further describes as a three step-process consisting in a preliminary reaction of water with all the components of cement, followed by the combination of silica and lime through water, and by the eventual combination between the residual hydrated lime and carbonic acid. Feichtinger and Winkler engage in a real quarrel over the hardening process of Portland cement, by way of articles that are published in the *Polytechnisches Journal* between 1864 and 1865, and they never come to an agreement.

In the wake of Winkler's explanation, the chemist Wilhelm Heldt (1823–1865), a Liebig scholar, develops a further contribution to the comprehension of the hardening process of Portland cement, through a research that he publishes in 1865.¹⁸⁷ Heldt asserts that, during the burning of Portland cement, lime combines with the main components of clay, silica and alumina, forming two compounds that he calls lime-aluminate and lime-silicate. These two compounds are then thought to once again be decomposed to their essential components by means of water, so that part of lime combines with silica and clay, while the remaining part of it combines with carbonic acid.

In such a framework, the Berlin chemist Wilhelm Michaelis (1840–1911) plays the critical role of connecting the theoretical achievement from the domain of chemistry to that of practical building needs. Michaelis studies chemistry at the university of Berlin and attends practical training in the Wildau cement factory near Eberswalde. Once he has achieved the training, he goes back to Berlin,

¹⁸⁵ See August Winkler, *Ueber hydraulische Mörtel*, in *Journal für praktische Chemie*, vol. LVII, 1856, pp. 444–62, and in *Polytechnische Journal*, vol. CXLII, 1856, pp. 106–21, (about the relation between Winkler and Löwig see in particular p. 108, n. 18).

¹⁸⁶ See Winkler, *Ueber hydraulische Mörtel*...cit.; see also Id., *Ueber Portland-Cement*, in *Chemisches Centralblatt*, III, 1858, pp. 481–83, and in *Polytechnische Journal*, vol. CXLIX, 1858, pp. 262–65; see also Friedrich Knapp, *Ueber Cemente*, in *Polytechnisches Journal*, CCXXII, 1876, (pp. 147–53), p. 148.

¹⁸⁷ Wilhelm Heldt, *Studien über die Cemente*, in *Journal für praktische Chemie*, XCIV, 1865, pp. 129–61, 202–37; see also Knapp, *Ueber Cemente*...cit., pp. 148–49.

where he further studies at the local Bergakademie (school of mines) and graduates in 1867 with a dissertation about Portland cement, which is then published in the *Journal für praktische Chemie*.¹⁸⁸ Two years later Michaelis publishes a comprehensive book about the essential components of hydraulic mortar, with special regard to Portland cement. He relates about its chemical features, focusing especially on the hardening process, but, unlike most chemists, he also describes how to manufacture and test cement, besides giving a synthetic account of the main physical features that a good kind of Portland cement is supposed to have. Considering the compositions of “a series of recognized good cements”, Michaelis establishes that Portland cement should contain approximately 25% silica, 69% lime, and a small amount of clay and iron oxide. He essentially believes that these substances form aluminate and lime silicate compounds during the burning, and he shares Winkler’s belief about the lack of unslaked lime in Portland cement once it has been adequately burnt. He justifies the typical phenomenon of lime slaking that is often observed, as the result of side factors like the presence of coal slags from the kiln, or the use of mixtures of lime and clay that have not been assembled accurately enough; but he rules out the idea that such phenomena could be part of the essential properties of cement. Again in accordance with Winkler, he also believes that the chemical principles of Roman and Portland cement hardening are different, and that the latter essentially hardens by simple combinations of its main components (aluminate and lime silicate compounds) with water. He admits the existence of other complex chemical reactions, but he considers these ones as secondary aspects of the hardening process.¹⁸⁹

Concerning the main physical features of Portland cement, Michaelis explains that it “should consist of powder that is as fine and homogeneous as possible, it should harden strongly but not too fast, except in a few cases (constructions in rough water, sealing of cracks in walls underwater, etc.), it should neither expand nor shrink, it should be homogeneously and agreeably light-grey coloured like a stone, without any brown spots, it should show strong cementation properties, bind with stones, tolerate the addition of sand, and it must be free from any adulteration [...].”¹⁹⁰

To verify the quality of Portland cement, Michaelis attributes great importance to strength tests on specimens made of pure hardened cement, and specimens made of cement-based mortar. In his book from 1869, he describes a long series of strength tests that have been carried out on specimens made of

¹⁸⁸ See Wilhelm Michaelis, *Ueber den Portland-Cement*, in *Journal für praktische Chemie*, vol. C, 1867, pp. 257–303.

¹⁸⁹ See Michaelis, *Die Hydraulischen Mörtel*...cit., pp. 186–188, 192–94; The exact proportions given by Michaelis are 80 “äquivalent” of silic acid, between 15 and 25 äquivalent of clay and iron oxide, and between 210 and 230 äquivalent of lime; the term “äquivalent” is used to mean “atom” at that time (see entry “Aequivalente” in *Herders Conversations-Lexikon*, vol. I, 1857², p. 54); see also Knapp, *Ueber Cemente*, pp. 149–50.

¹⁹⁰ “Portland-Cement soll ein möglichst feines und gleichmässiges Pulver darstellen; er soll stark, aber mit Ausnahme einiger weniger Fälle (Bauten in bewegtem Wasser, Dichten von Sprüngen in Wassermauern etc.) nicht zu schnell erhärten; er soll dabei sein Volumen nicht verändern, weder Contraction noch Volumvermehrung zeigen; er soll eine gleichmässige, angenehme, hellgraue Steinfarbe annehmen und durchaus keine braune Flecke bekommen; er soll stark verkittende Eigenschaften haben, stark am Stein haften und einen hohen Sandzusatz vertragen; er soll endlich frei von Verfälschungen sein [...]” (Michaelis, *Die Hydraulische Mörtel*...cit., p. 223).

different kinds of mortar since the early decades of the century in France, England, Denmark and Germany. Among the ones that have taken place in Germany, he mentions the flexural strength test that the Oberbergamt in Bonn carries out on specimens made of *Trass*-based mortar; the compression strength tests that Lentze carries out to verify the quality of the cement-based mortar he intends to use to build the piers of the bridges in Dirschau and Marienburg; the flexural strength tests that the professor Julius Manger of the Berlin Gewerbe-Institute carries out taking into account, inter alias, cement from the Stettiner Portland-Cement Fabrik; some compressive tests that are carried out in 1862 in Siegburg in Rhineland; the tensile strength tests that the Bauinspektor Dircksen carries out when he builds a further stretch of the already mentioned Verbindungsbahn in Berlin; and the tensile and flexural tests that the master builder G. Schwartz carries out using an appropriate machine that he conceives expressly for that purpose in 1867.¹⁹¹ This machine, which is essentially a second-class lever, can be set for tensile and for compressive strength tests. (fig. 5.9.1-2) Among the different kinds of possible strength tests, Michaelis considers the tensile one as the most appropriate to verify the quality of Portland cement.

In 1872 Michaelis founds, together with H. Früling and A. Rudeloff, a chemical-technical bureau equipped with a workshop to test building materials, and expressly conceives two machines to test the compressive and the tensile strengths. The first is a manual press, the second is a first-class lever, which is equipped with two stirrups to charge a specimen, and a special container, which can be filled either with sand, or with water. (fig. 5.9.2-3) Michaelis' workshop produces and sells such machines.¹⁹²

It is very probably on the basis of such knowledge and expertise that the *Deutsche Verein für Fabrikation von Ziegeln, Thonwaaren, Kalk und Cement* (Society of bricks, earthenware, lime and cement makers – below shortly mentioned as *Verein*), which has been founded in 1865 on the initiative of the previously mentioned master builder Türrschmiedt, entrusts Michaelis, in January 1875, with the writing of instructions, apt to verify and test the quality of Portland cement.¹⁹³ Such instructions are to be submitted to the *Verein*, and, if approved, they should be adopted as rules, in order to provide order in the domain of cement manufacturing and trade. Comparing the outcomes of several strength tests, especially referring to the experiments on the strength of cement that the British engineer of the London Metropolitan Boards of Works, John Grant, carries out as of 1858, in the context of the construction of a drainage system in South London, Michaelis draws seventeen theses. The first seven can be considered real prescriptions; they concern the weight, the minimal strength and the grain texture of cement. The other thirteen can be, instead, considered as advice for builders rather than instructions to prove the quality of cement.¹⁹⁴ Such theses are harshly criticized at the twelfth general assembly of the *Verein*, which takes place on January 1876, and, consequently, decidedly rejected. The

¹⁹¹ See Michaelis, *Die Hydraulische Mörtel...*cit., pp. 229-59. For the test by Manger see Julius Manger, *Der Stettiner Portland-Cement in Versuche und Erfahrungen dargestellt und beleuchtet*, Stettin, F. Heffenland, 1860; Id., *Untersuchungen über die Festigkeit von reinen und gemischten Cementen*, in *Zeitschrift für Bauwesen*, IX, 1859, coll. 523-34.

¹⁹² See Wilhelm Michaelis, *Zur Beurtheilung des Cementes*, Berlin, A. Seidel, 1876, p. 5.

¹⁹³ See Anon., *Die Cementfrage*, in *Thonindustrie-Zeitung*, I, 1876, pp. 2-3.

¹⁹⁴ See Michaelis, *Zur Beurtheilung des Cementes*, esp. pp. 45-46.

controversy essentially arises over the few strict prescriptions contained in the theses, namely the one imposing that cement should be sold by weight, the one establishing a correlation between the grain and the price of cement, and the one about the minimal required tensile strengths. The first two are considered as pertaining to the domain of business rather than that of technology, while the values of minimal required tensile strength are considered high and unrelated to customers' needs.¹⁹⁵ The opposition against Michaelis' theses is so great that some cement makers even come to mistrust their scientific reliability. In order to overcome the deadlock, the *Verein* entrusts a committee made of architects and exponents of the cement makers, lead by Hugo Delbrück (1825–1900), who is at that time the director of the Stettiner Portland-Cement-Fabrik, with the development of new instructions.¹⁹⁶ The committee produces a document made of six "resolutions", which take into account: the weight, the setting time, the grain-size, and the volume variation of cement, besides prescribing that the cementation capacity is to be tested by means of tensile strength tests on specimens made of cement-based mortar, using an improved machine by Michaelis. (fig. 4.9.5) The choice of the tensile strength test proves that the *Verein* mainly considers Portland cement as a binder for mortar, plaster and architectural decorations, rather than for the production of concrete. The resolutions are approved at the thirteenth general assembly of the *Verein*, which takes place on January 1877, and are adopted by the Berlin Architekten Verein (Berlin Society of Architects), by the Verein Berliner Baumarkt (Society of Berlin building market), as norms, being the first shared and compulsory rules to evaluate a building material. Shortly after the approval of the new resolution, a number of cement makers lead by Michaelis give rise to a new opposition, which has, however, no effective consequence. The norms are even submitted to the approval of the minister of trade and industry one year later, and rise from the domain of shared rules among professional associations, to the wider domain pertaining to national rules and laws.

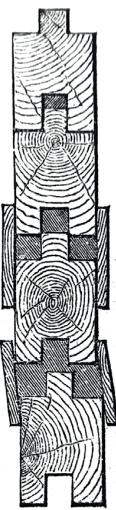
With the development and the approval of a regulation about the features that Portland cement is supposed to have, an essential chapter of the German construction history is achieved. It has involved the radical transformation of a building culture that used to exalt the quality of aerial lime and mortar, limiting the use of hydraulic mortar made of lime and pozzolanic materials to a few cases, to a building culture in which the use of hydraulic artificial cement is going to be prevalent. At the same time, essential skills to build with concrete develop, moving from the observation of foreign and more advanced expertise. The scientific approach to the study of lime and cement, and the effort to establish rules in the domain of construction, even for the empirical practice of strength tests, are crucial features of this evolution and will affect the following development of reinforced concrete. As a matter of fact, Joseph Monier's empirical method to produce objects and construction elements made of concrete and metal nets is studied on scientific bases specifically in Germany, in the first half of the 1880s, leading to a clear formulation of what reinforced concrete is, and providing an early mathematical model to

¹⁹⁵ See Anon., *Die Cementfrage*, in *Thonindustrie-Zeitung*, I, 1876, pp. 37–38.

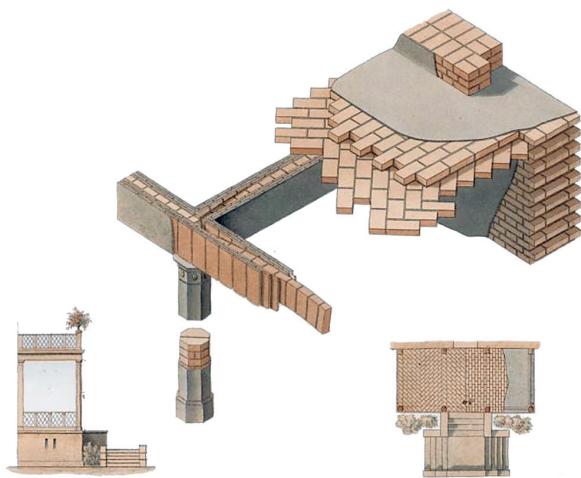
¹⁹⁶ *Ibid.*, p. 3.

calculate a reinforced concrete slab. This is the result of the evolution of knowledge and expertise about cement and concrete, that occurs approximately during the first three quarter of the 19th century.¹⁹⁷

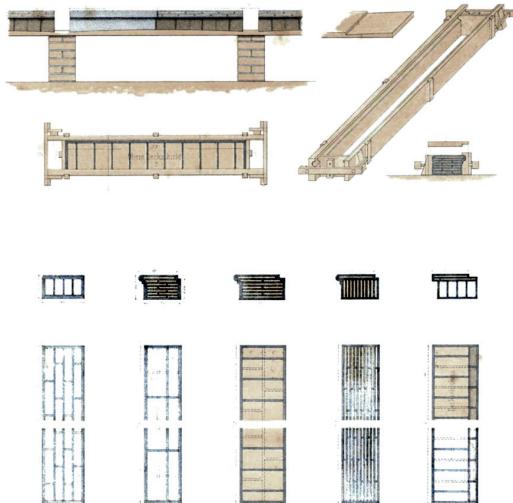
¹⁹⁷ In this regard, see as essential reference Gustav Adolf Wayss, *Das System Monier (Eisengerippe mit Cementumhüllung) in seiner Anwendung auf das gesammte Bauwesen*, Berlin, Seidel & Cie, 1887.



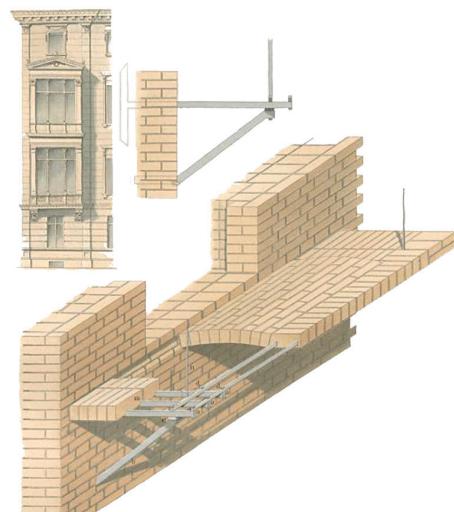
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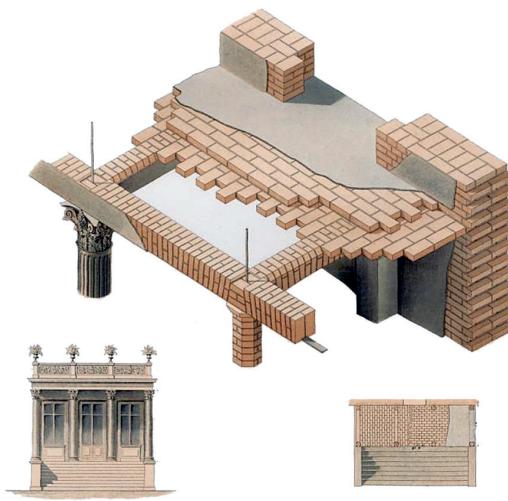
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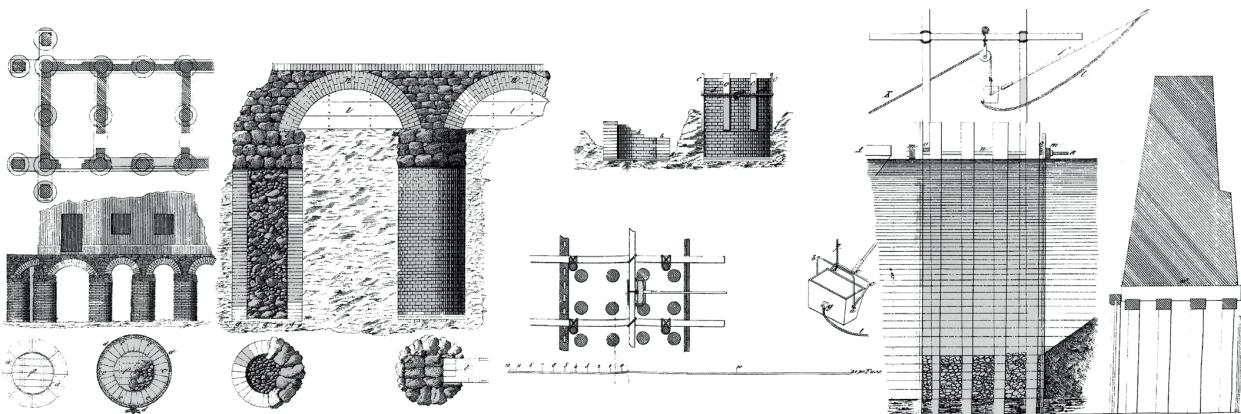


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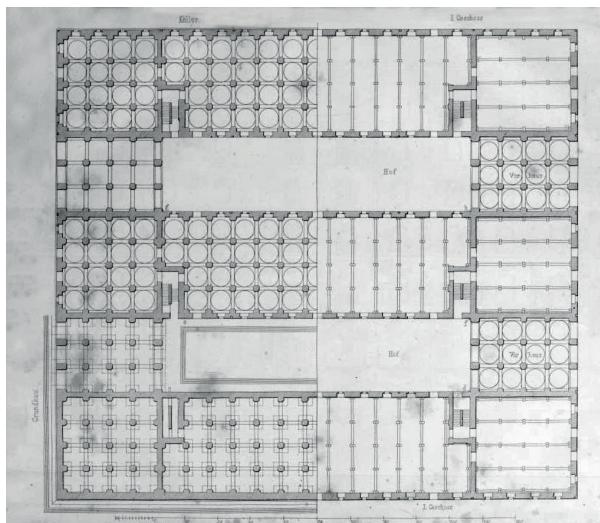


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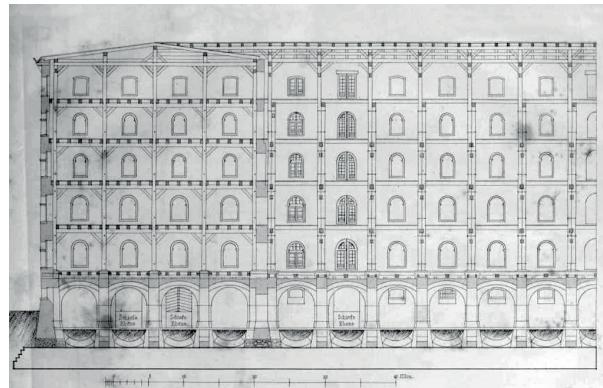
5.1.1. W. A. Becker, Cement-based mortar filling as a remedy for improper sheet piles ramming, Berlin-Spandau, 1849–50 (W. A. Becker, 1860). 5.1.2. C. L. Schüttler, balcony made of bricks bond with Portland cement-based mortar, Berlin, 1851 (W. A. Becker, 1860). 5.1.3. Prefabricated steps made of bricks and cement-based mortar (W. A. Becker, 1857). 5.1.4. Hahnemann, balcony made of bricks, iron bands and Portland cement-based mortar, Berlin, 1854 (W. A. Becker, 1860). 5.1.5. Riehmer, oriel windows made of bricks, iron bands and Portland cement-based mortar, Berlin, 1859 (W. A. Becker, 1860). 5.1.6. P. J. Lennée, artificial cave in the garden of villa Borsig in Moabit, Berlin, approx. 1849 (Becker, 1860).



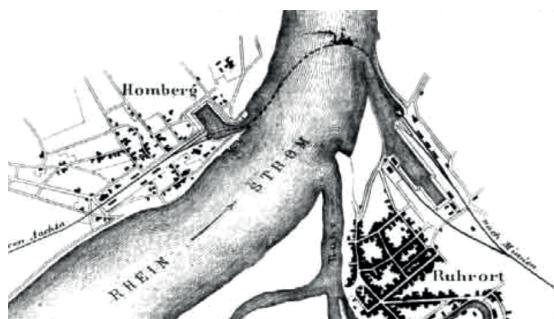
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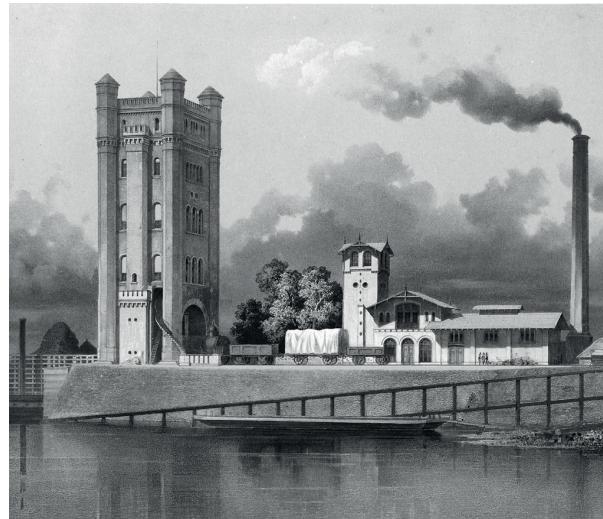
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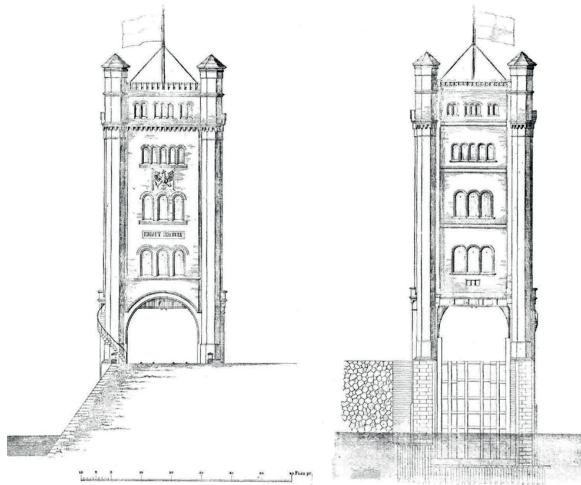


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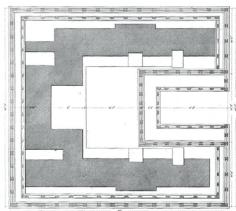


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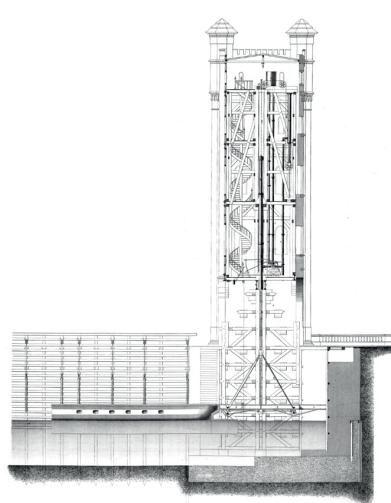
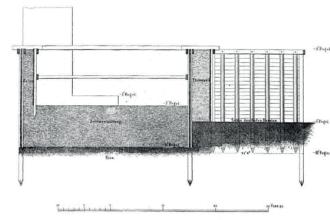
5.3.1. Sunken well foundations and the foundation of the dock along the Oder in Stettin from 1842–1844, according to J. C. Wedeke (1849). 5.3.2–3. Ch. A. E. Pötzsch, warehouse in Leizig on concrete foundation (1850), plan and cross section (Anon., 1853). 5.3.4. Elevator towers for freight wagons in Duisburg (1854–56), general planimetry to illustrate the connection by a steamboat from a river side to another, namely from the port of Ruhrtort to the one of Homberg (Weishaupt, 1857). 5.3.5. Elevator towers for freight wagons in Duisburg, view of the tower in Ruhrtort (Weishaupt, 1857).



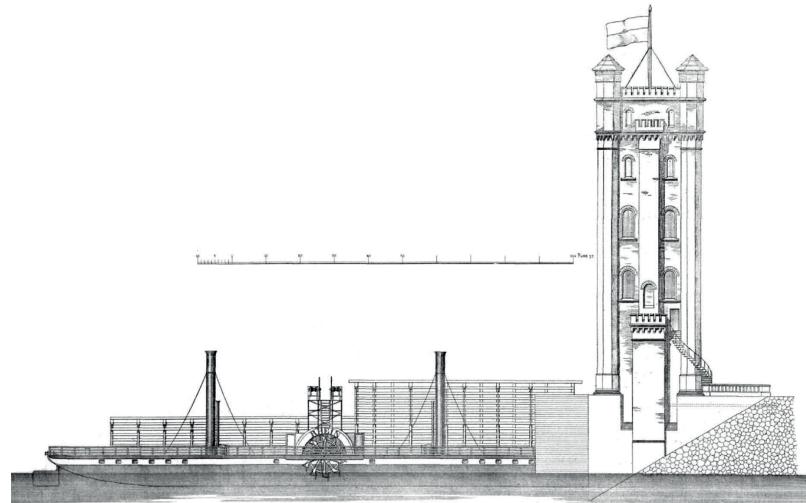
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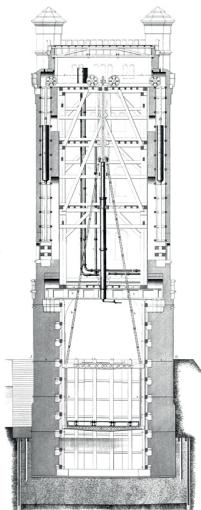
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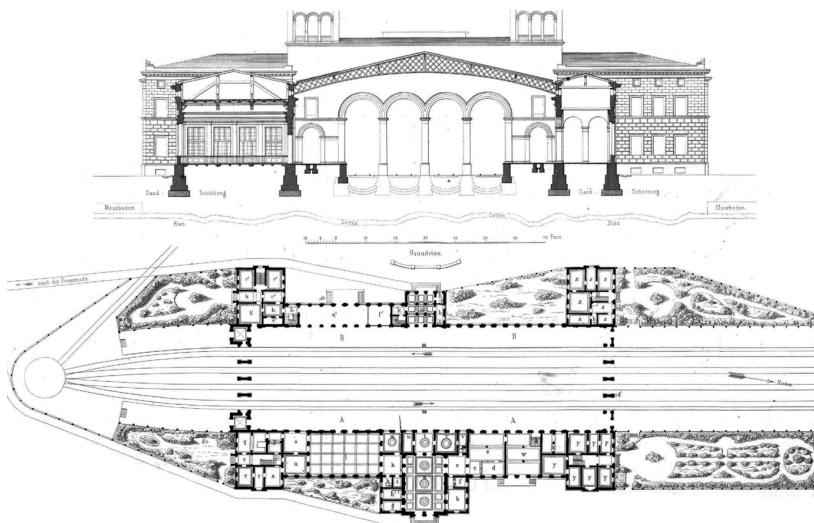


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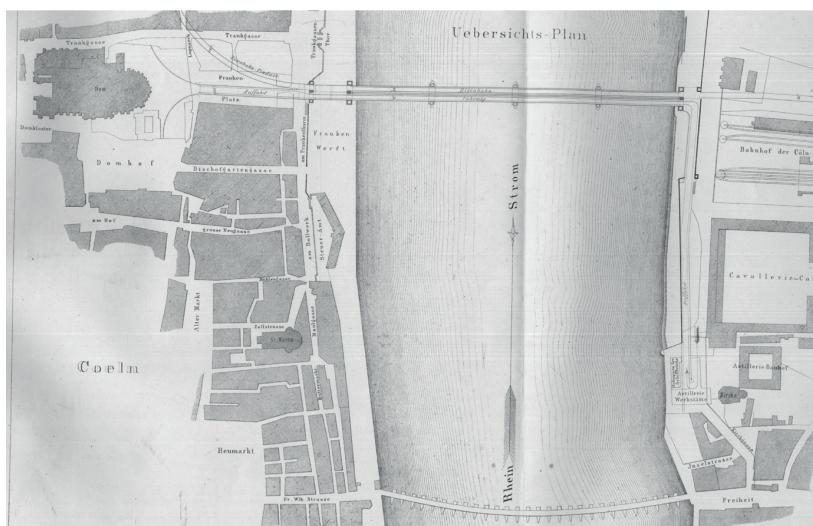


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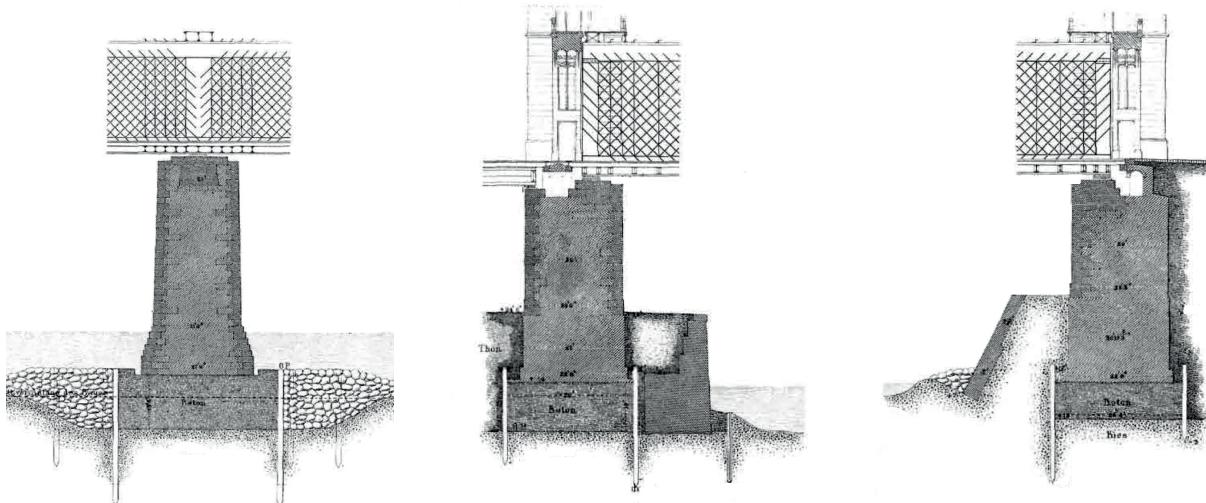
5.3.6. Elevator towers for freight wagons in Duisburg, front elevations, from the waterside and from the andside (Weishaupt, 1857). 5.3.7. Elevator towers for freight wagons in Duisburg, plan of the basement and section of the concrete foundation (Weishaupt, 1857). 5.3.8. Elevator towers for freight wagons in Duisburg, longitudinal section over tower (Weishaupt, 1857) 5.3.9. Elevator towers for freight wagons in Duisburg, side elevation (Weishaupt, 1857). 5.3.10 Elevator towers for freight wagons in Duisburg, cross section (Weishaupt, 1857). 5.3.11. Elevator towers for freight wagons in Duisburg, the tower in Homberg in a postcard, n.d..



5.3.12



5.3.13

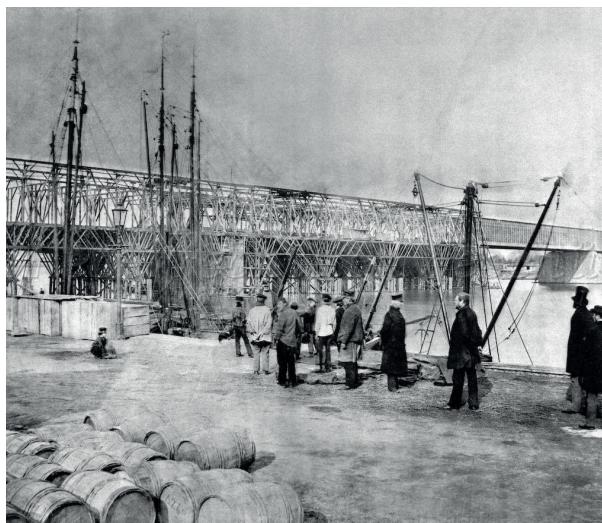


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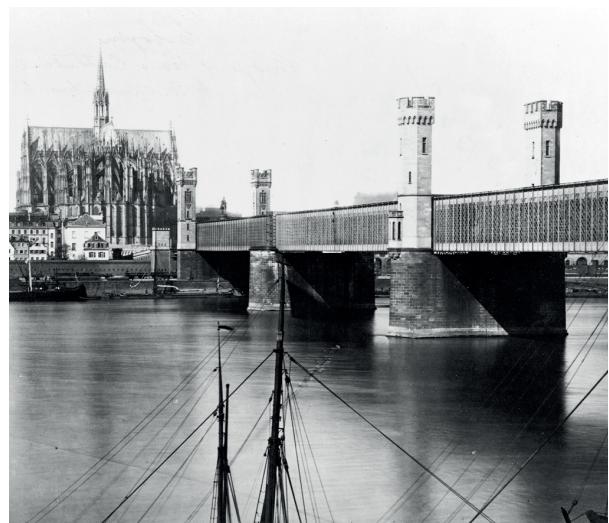
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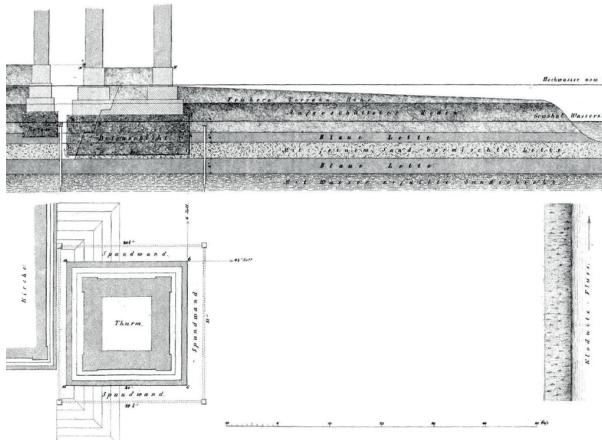
5.3.12. Thüringen railway station in Leipzig (1855–56), plan and cross section (Witzeck, 1860). 5.3.13. Chatedral Bridge over the Rhine in Cologne (1855–59), planimetry (Lohse, 1857). 5.3.14. Chatedral Bridge over the Rhine in Cologne, section of the freestanding pier, (Lohse, 1863). 5.3.15–16. Chatedral Bridge over the Rhine in Cologne, sections of the left and right land piers.



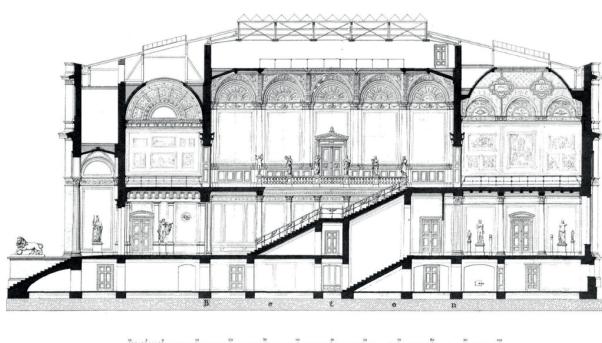
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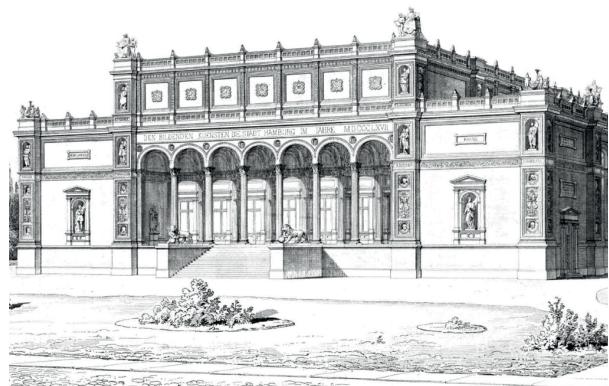
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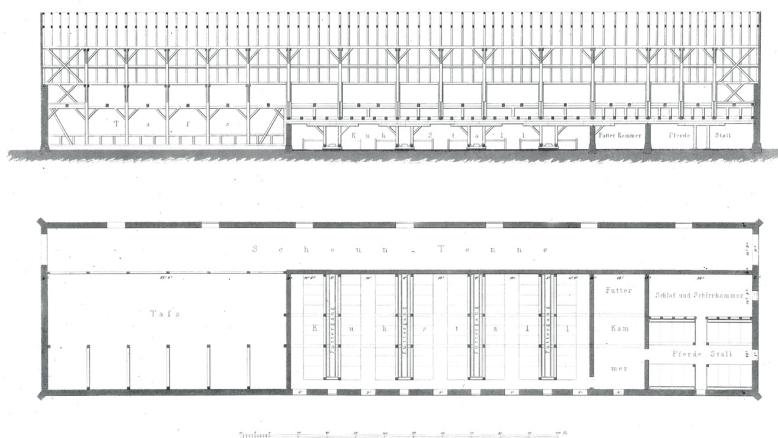


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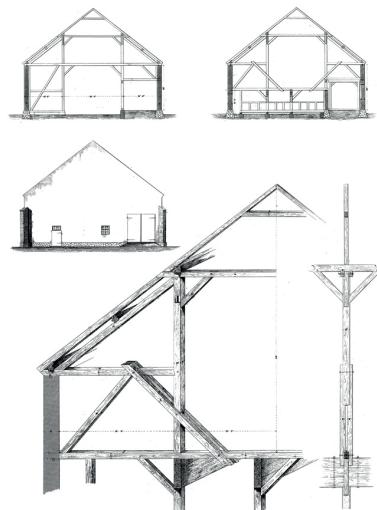


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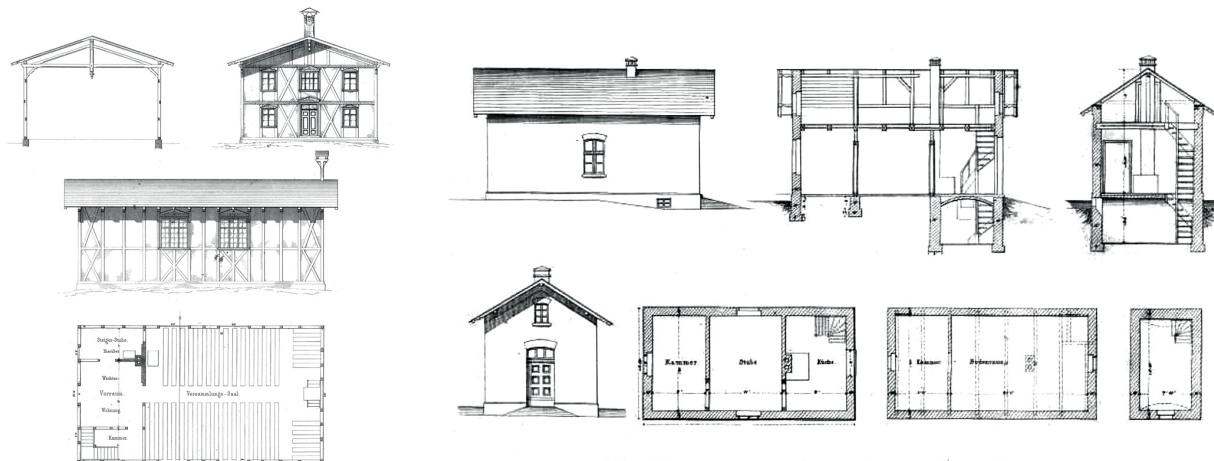
5.3.17. Chatedral Bridge over the Rhine in Cologne under construction, photography, 1857. 5.3.18. Chatedral Bridge over the Rhine in Cologne in a picture from 1900. 5.3.19. F. A. Stüler, church of Saint Barbara in Gleiwitz in Silesia (1855-59), plan of the tower and cross section over the concrete foundation (Assmann, 1863). 5.3.20-21. G. Th. Schirrmacher, H. v. der Hude, Hamburg art gallery (1864-69), cross section and perspective view (Von der Hude, 1868).



5.4.1

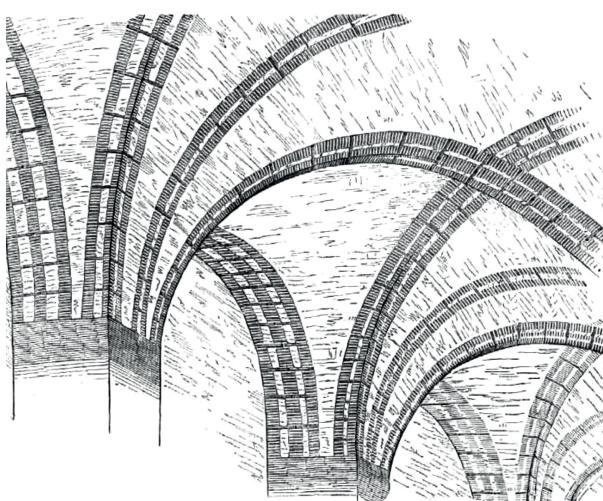


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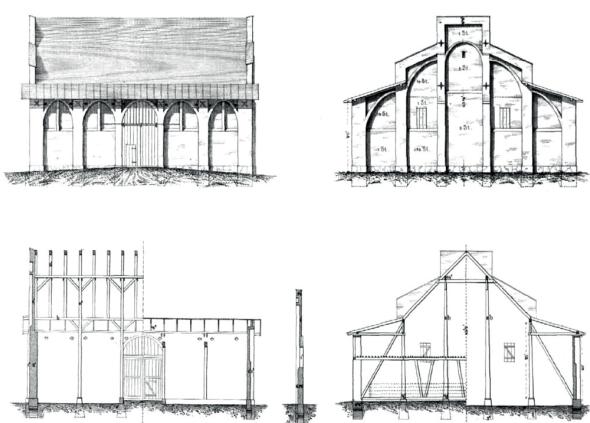


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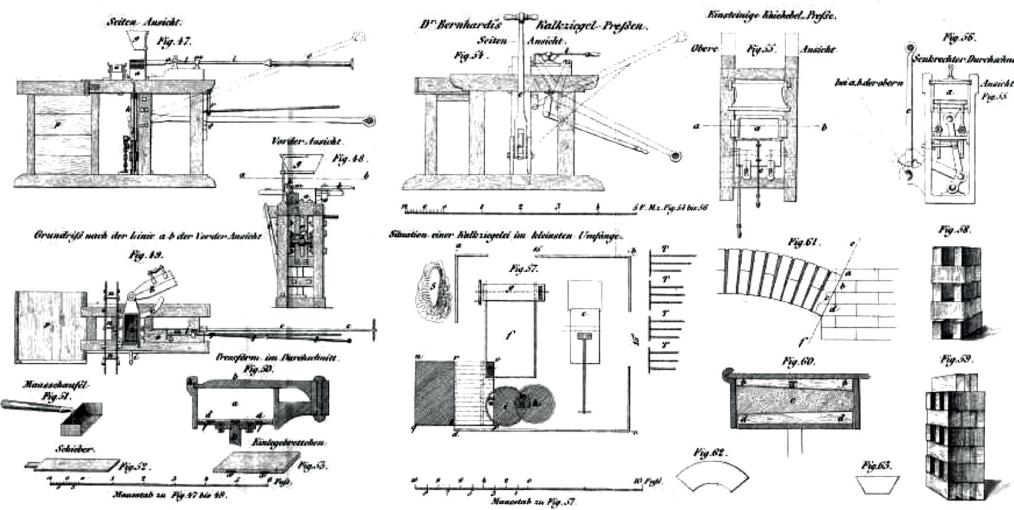


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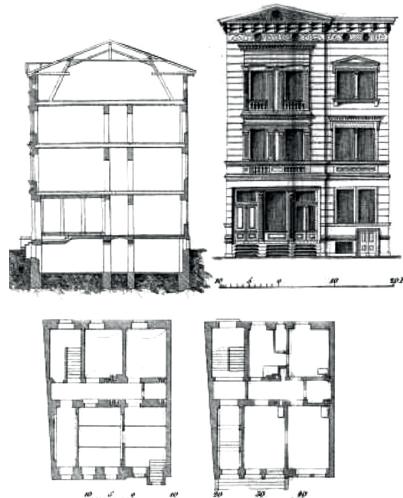


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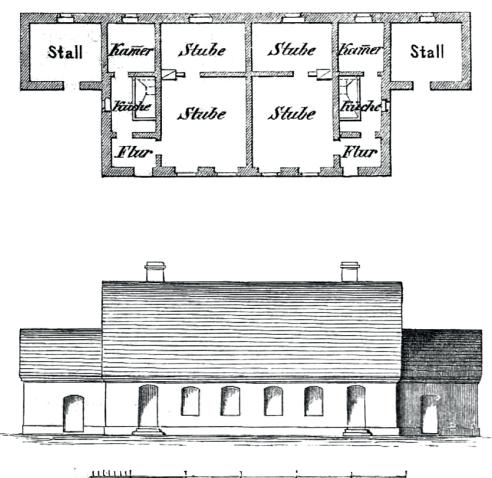
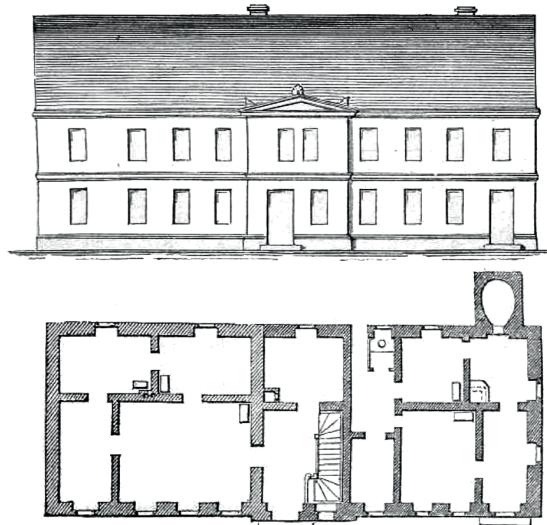
5.4.1-2. Barn with walls in lean conglomerate and interior timber framework structure, Stechow, Brandenburg (1853-54) longitudinal section, plan, transversal sections and side elevation (F. Engel, 1864). 5.4.3. Administrative building of a quarry company in Rüdersdorf, exposed timber framework structure with lean conglomerate filling, cross section, front and side views, plan (F. Engel, 1864). 5.4.4. Scheer, house for railway inspector along the line Altona-Kiel (approx. 1856), front and side views, sections, plans (Tellkampf, 1866). 5.4.5. W. Salzenberg, draft of the groin vaults of Baths of Diocletian, 1857. 5.4.6. E. H. Hoffmann, barn with lean conglomerate walls provided with discharging arches, western Prussia, (approx. mid 1850s), front and side views, sections (Hoffmann, 1858).



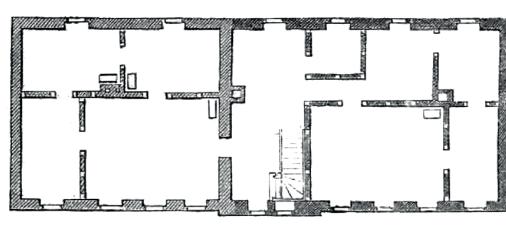
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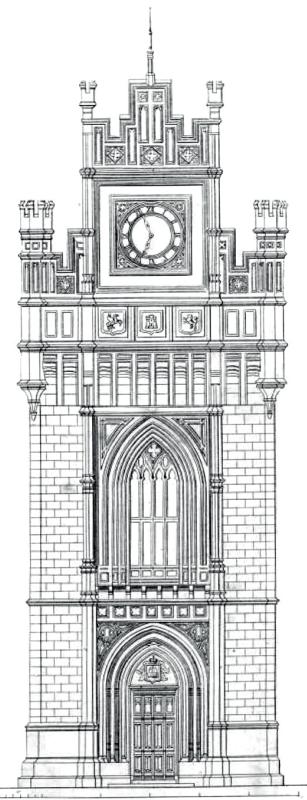


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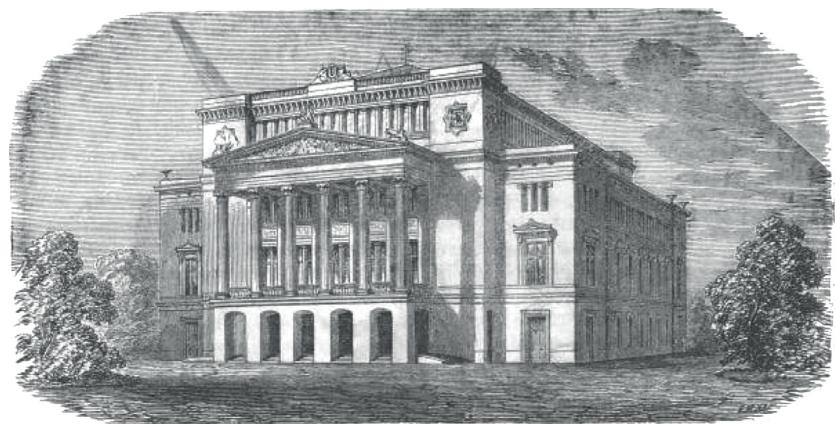


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5.4.7. F. A. A Bernhardi, cast iron press for sand-lime bricks, patent 1856 (F. Engel, 1865). 5.4.8–10. Houses with wall of sand-lime bricks, in Eilenburg, Jeseswitz [sic.], and Lüchow (F. Engel, 1865).



5.5.1



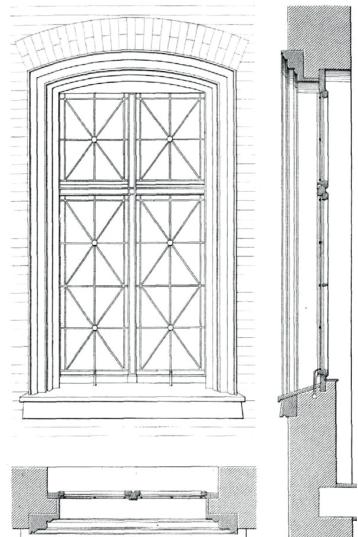
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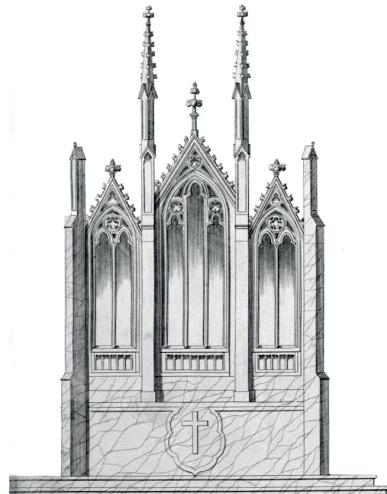
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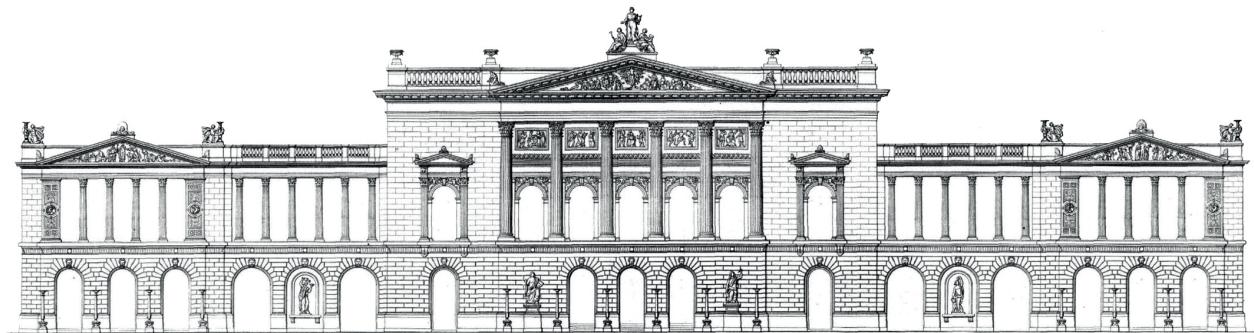
5.5.1. Beyne, Gildengebäude, Riga (1853–60), entrance tower (Anon., 1866). 5.5.2. L. Bohnstedt, Stadttheater, Riga, (1861–63), perspective view (Anon., 1866). 5.5.3. M. C. Ph. Gropius, hospital, Eberswalde (1862–65), front views (Gropius, 1869). 5.5.5. Gropius, hospital, Eberswalde, window with cement-based moulded cornices (Gropius, 1869).



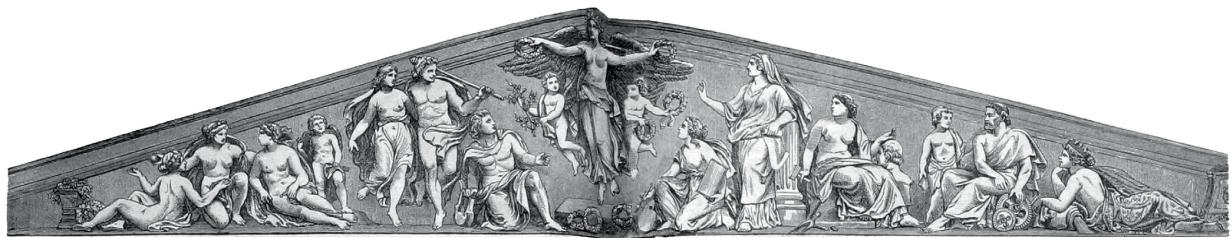
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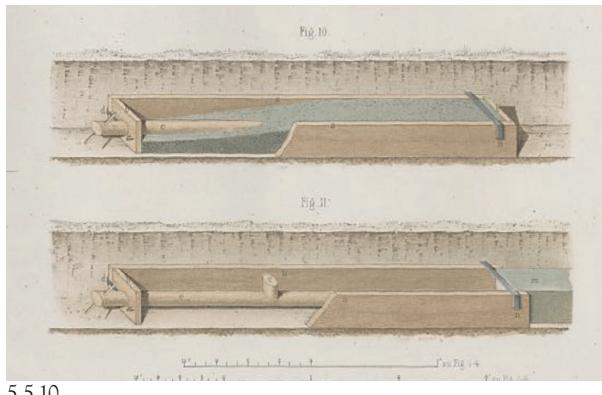


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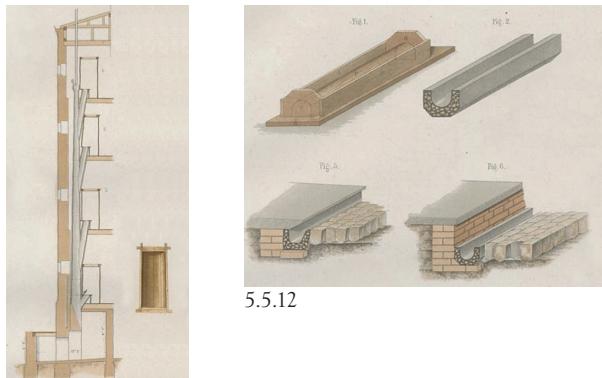


5.5.9

5.5.6. Loewer, altar in the Stephankirche, Garz, Pomerania, (uncertain date), front view, (Hermann, 1860). 5.5.7. Czarnikow, altar of the St. Marien church in Strasbourg in the Uckermark, (approx. 1865), front view, (Anon., 1866). 5.5.8. C. F. Langhans, Stadttheater, Leipzig, (1864–68), front view (Brückwald, 1870). 5.5.9. Hagen, Czarnikow, Stadttheater Leipzig, high relief of the pediment (Anon., 1868).

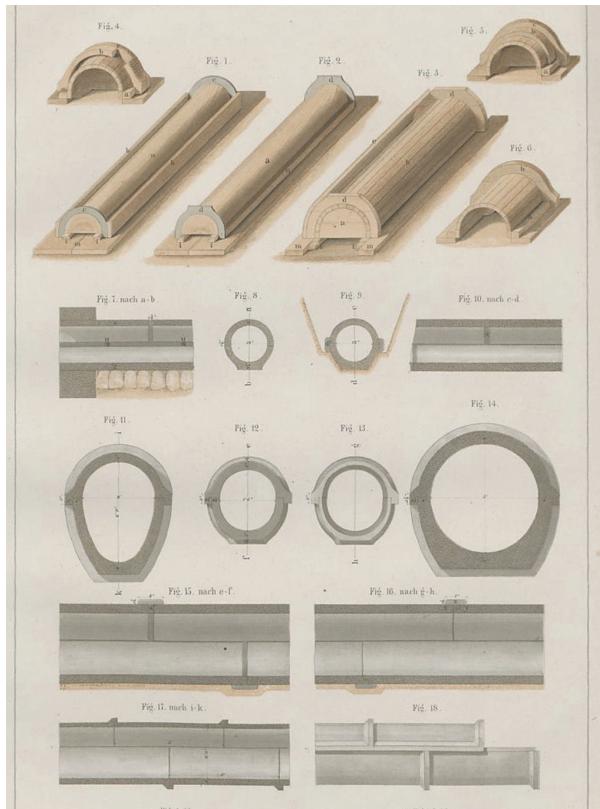


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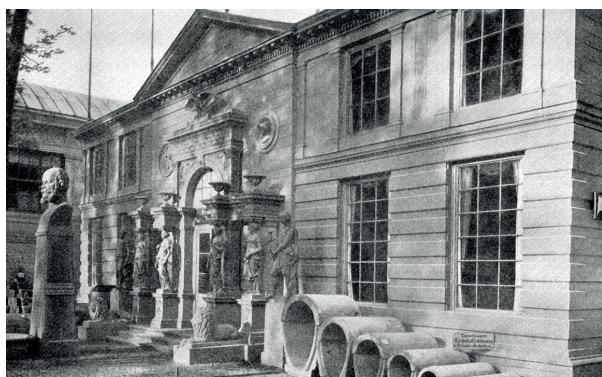


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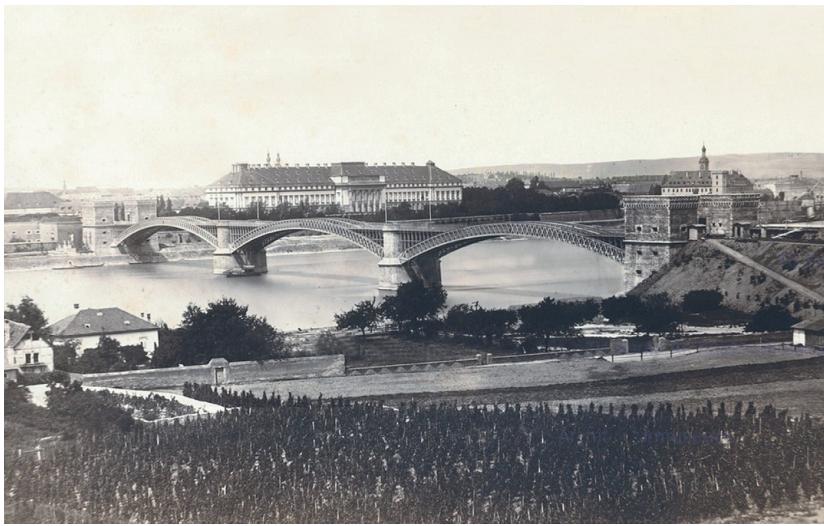
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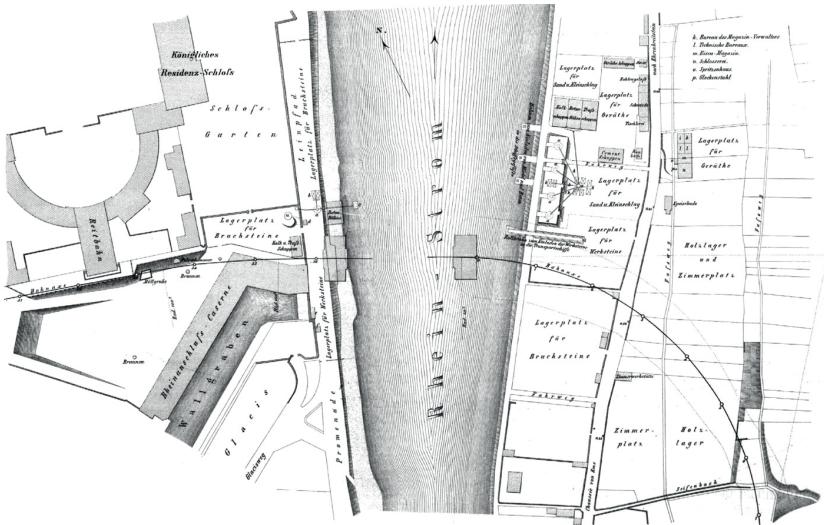
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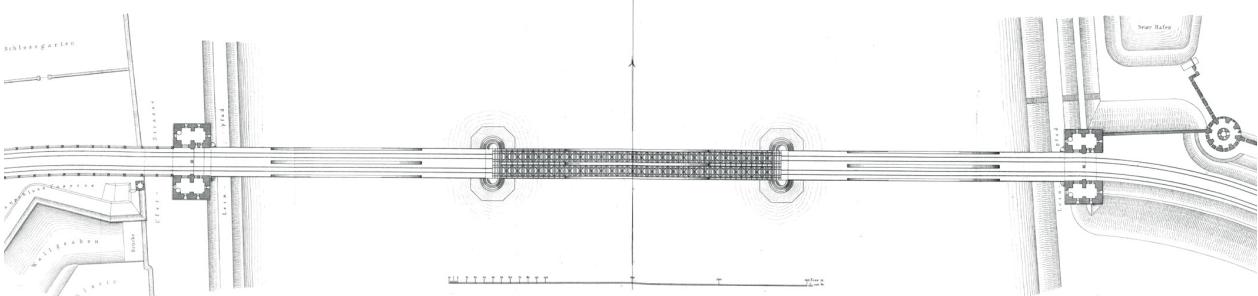
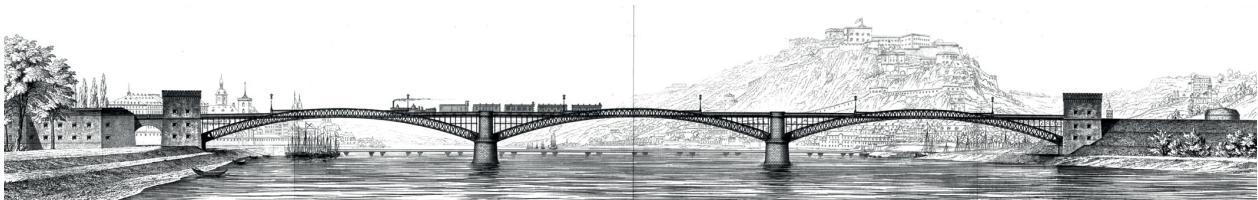
5.5.10. Concrete pipes to be produced in situ, (Becker, 1860). 5.5.11. Fehse, Eyffert, Garnison-Lazareth, Berlin (1851), concrete sanitary drain (Becker, 1860). 5.5.12. Concrete open-channel (Becker, 1860). 5.5.13. Concrete pipes for draining systems (Becker, 1860). 5.5.14. Concrete objects by the Company Dyckerhoff und Widmann at the International Exhibition of Wien, 1873. 5.5.15. Concrete objects by the Company Dyckerhoff und Widmann at the Exhibition of Art and Industry of Munich, 1876. 5.5.16. F. Moest, Dyckerhoff & Widmann, Galatheabrunnen, approx. 1869. 5.5.17. F. Moest, Dyckerhoff & Widmann, Eisenbahnbau and Eisenbahnbetrieb, 1876.



5.6.1

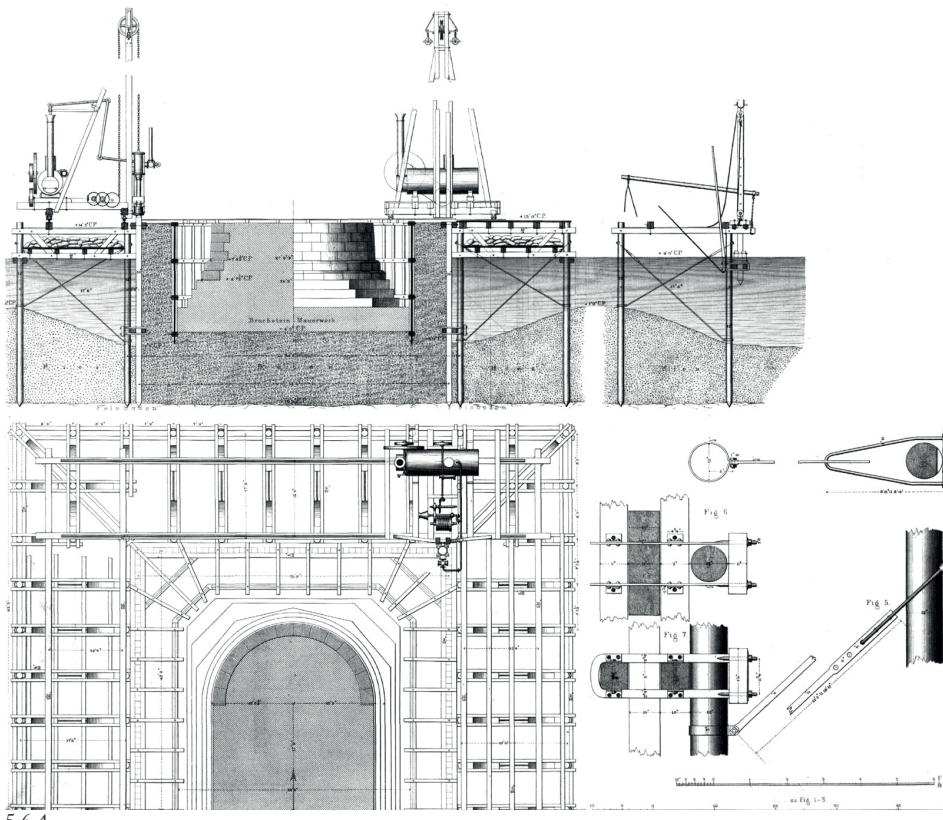


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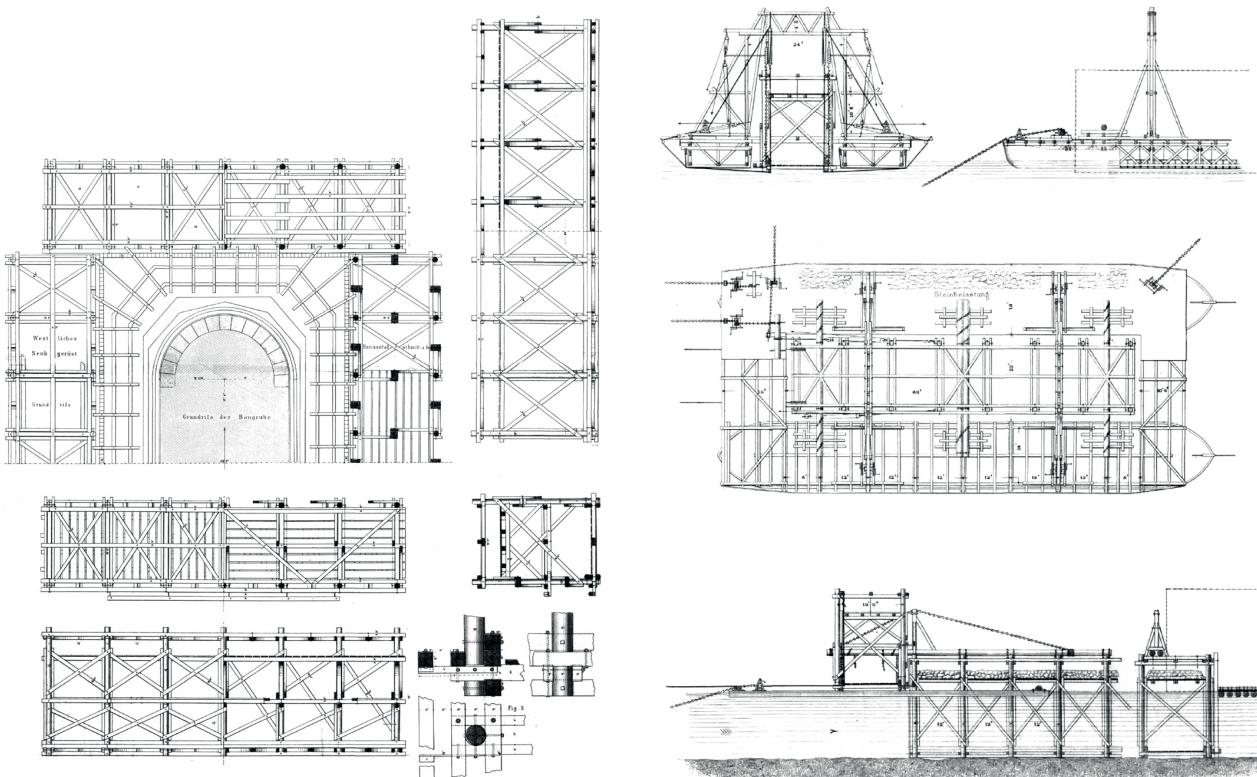


5.6.3

5.6.1. E. H. Hartwic, bridge over the Rhine in Koblenz, photography on paper. 5.6.2. E. H. Hartwic, bridge over the Rhine in Koblenz (1862-64), planimetry with indication of the installations for the building site. 5.6.3. E. H. Hartwic, bridge over the Rhine in Koblenz, front view from the South, and plan.



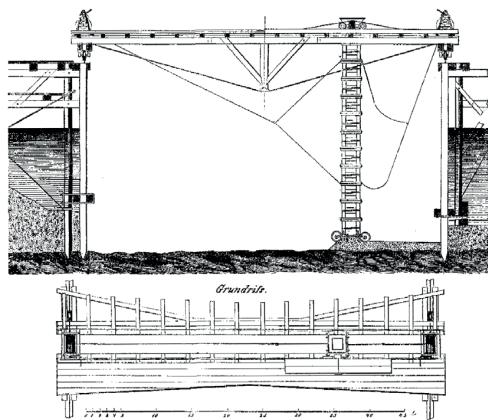
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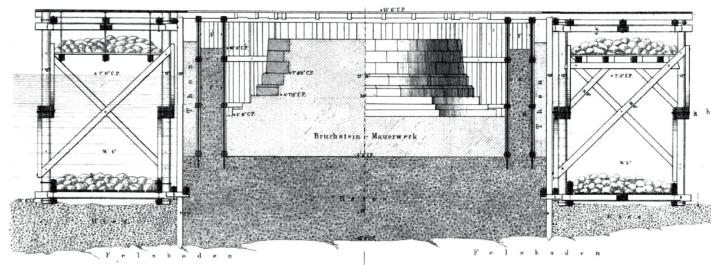
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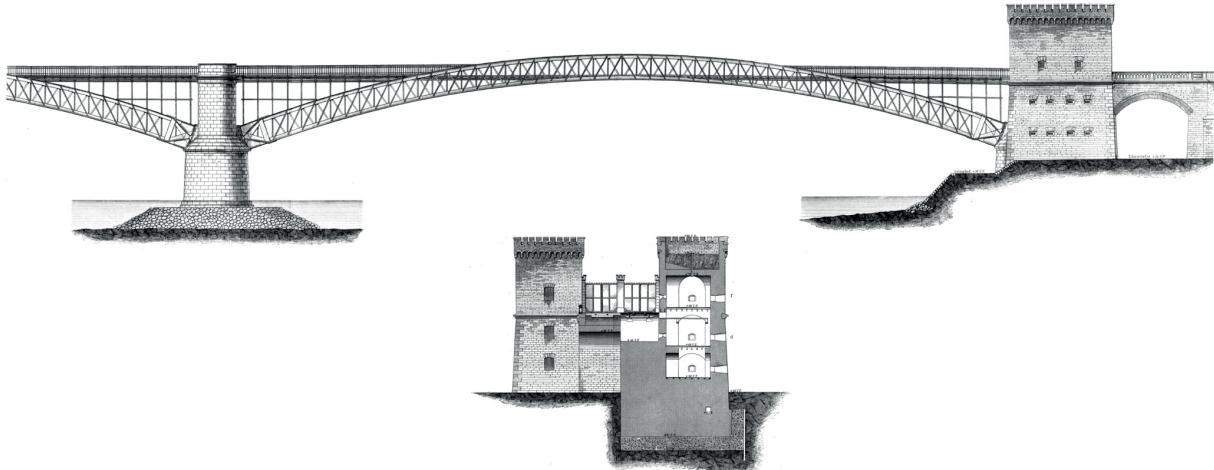
5.6.4. E. H. Hartwich, bridge over the Rhine in Koblenz, foundation of the left freestanding pier with built-on-site scaffoldings, cross section, partial plan, details of the coupling between the sheet piles and the scaffoldings. 5.6.5. E. H. Hartwich, bridge over the Rhine in Koblenz, foundation of the right freestanding pier with prefabricated scaffoldings, partial plan and partial front views of the scaffoldings. 5.6.6. E. H. Hartwich, bridge over the Rhine in Koblenz, foundation of the right freestanding pier with prefabricated scaffoldings; above: the system to transport and sink the longitudinal scaffoldings by means of barges; below: the system to transport and sink the longitudinal scaffoldings by means of rafts.



5.6.7



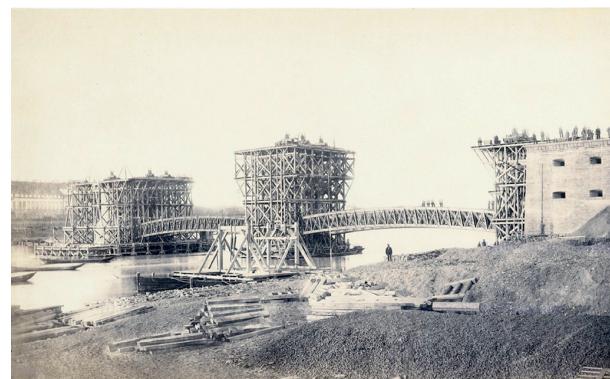
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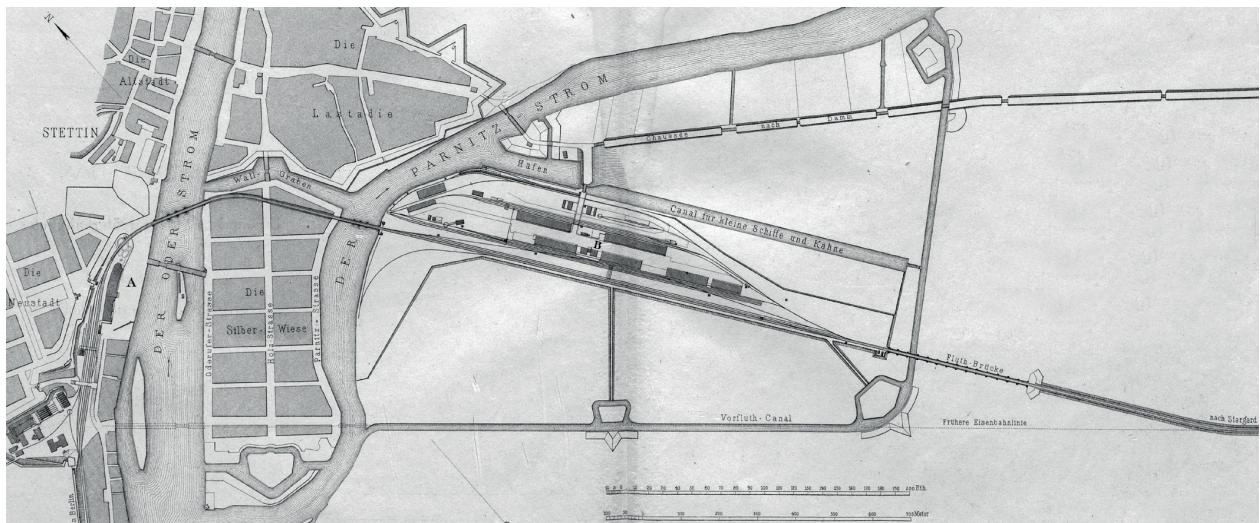


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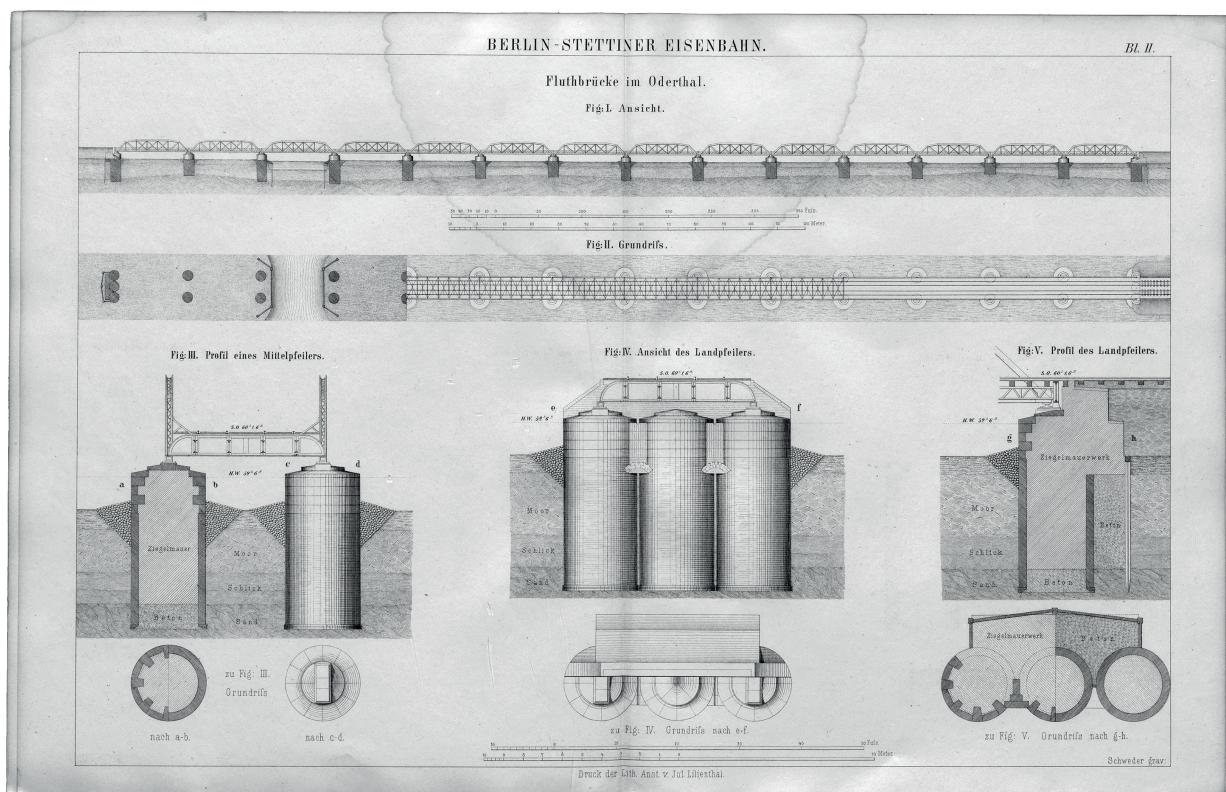


5.6.11

5.6.7. E. H. Hartwich, bridge over the Rhine in Koblenz, foundation of the left freestanding pier, concrete pouring. 5.6.8. E. H. Hartwich, bridge over the Rhine in Koblenz, foundation of the right freestanding pier, the construction of the lowest masonry layers. 5.6.9. E. H. Hartwich, bridge over the Rhine in Koblenz, front view of the left span from the North, and partial front view and partial section of the left land pier from the West. 5.6.10–11. E. H. Hartwich, the bridge over the Rhine in Koblenz under construction, photographies on paper.

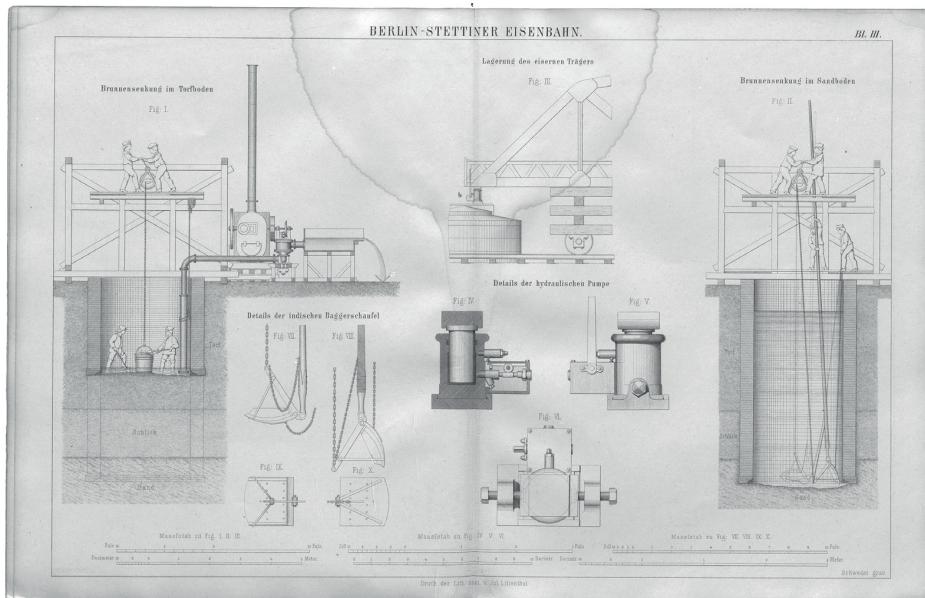


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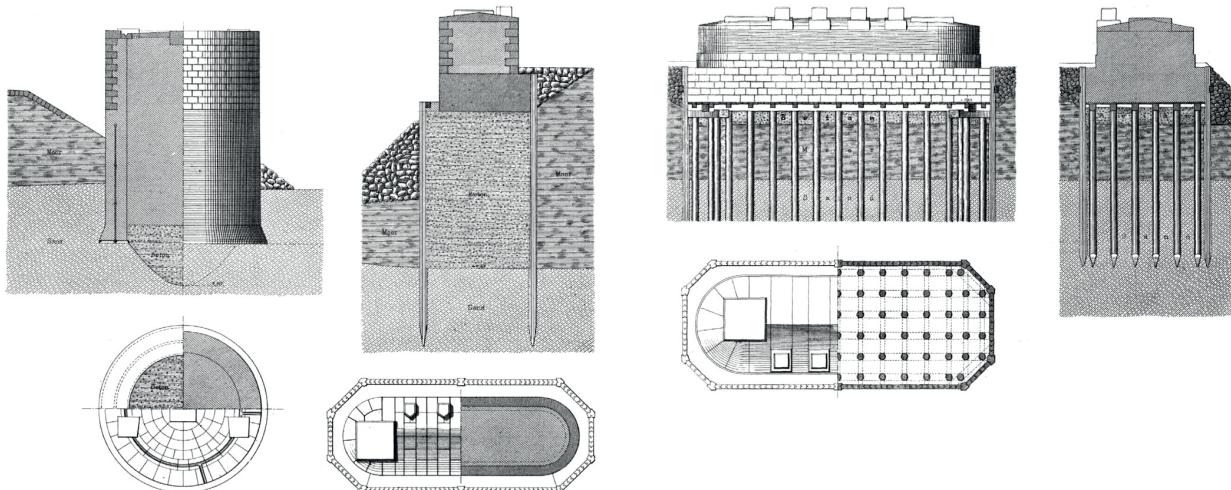


5.7.2

5.7.1. The improvement of the Stettin-Stargard railway line, 1864-69 (Stein, 1870). 5.7.2. The Fluthbrücke (bridge over the tidal land) in the Oder valley south of Stettin, front view, plan, front view, sections and plan of a freestanding pier, and of a land pier (Stein, 1870).

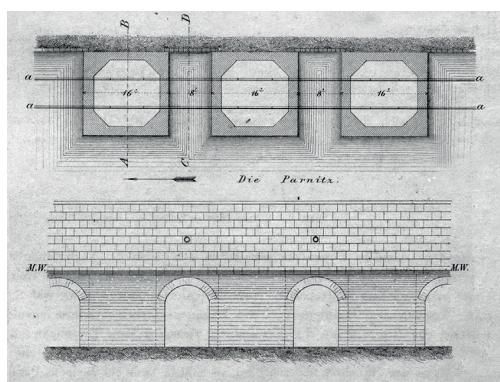


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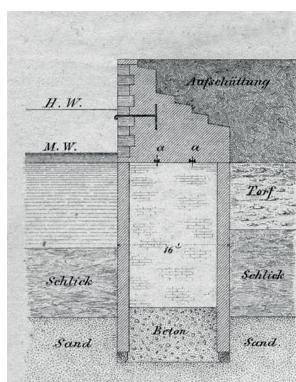


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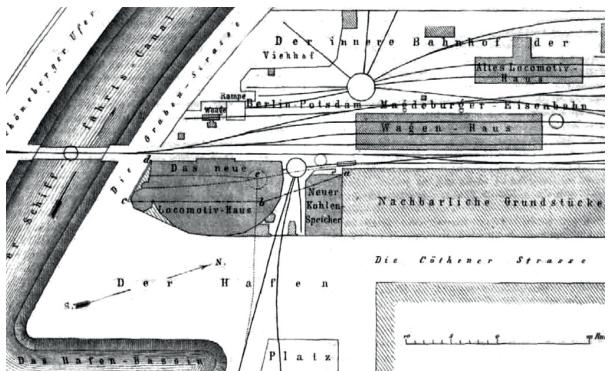


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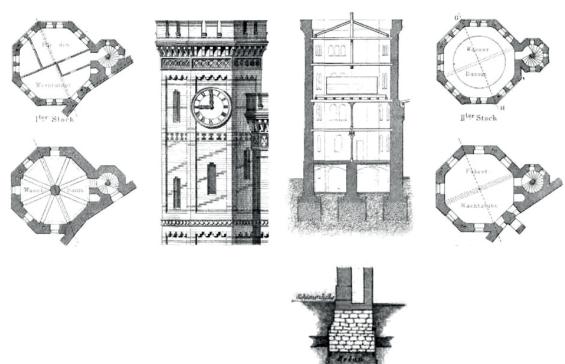
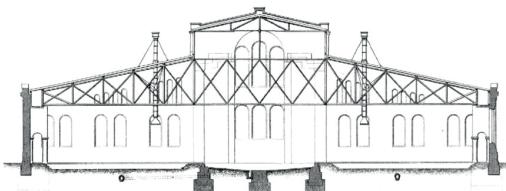
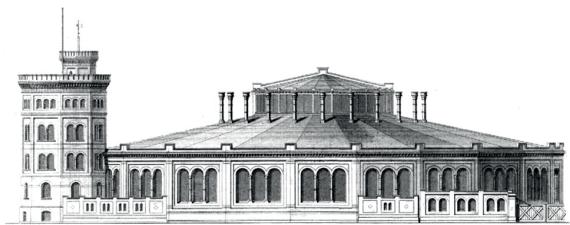


5.7.7

5.7.3. The bridges across the Oder valley near Stettin, the bridge over the tideland, drawings of the sinking technique with details of the pump and of the Indian-spade (Stein, 1870). 5.7.4 Bridge of Kahfahrt, south of Stettin, on the laft the central pier, partil section, view and plan at different levels; on the right, right land pier, section and plan at different levels (W. v. Haselberg, 1879). 5.7.5. Bridge over the Zeglin, south of Stettin, pier, longitudinal and cross section, plan at different levels (W. v. Haselberg, 1879). 5.7.6-7. Dock along the Parnitz, south of Stettin, foundation, plan, front view and transversal section (Stein, 1870).

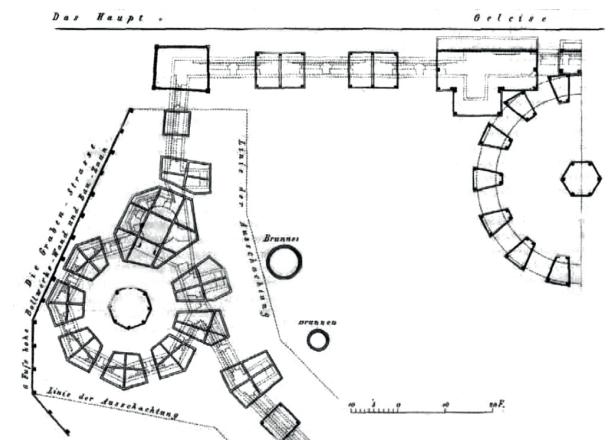
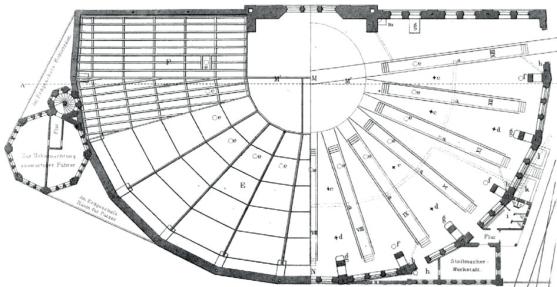


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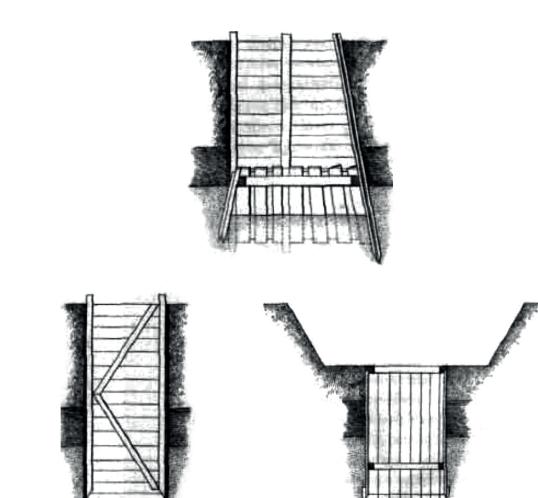


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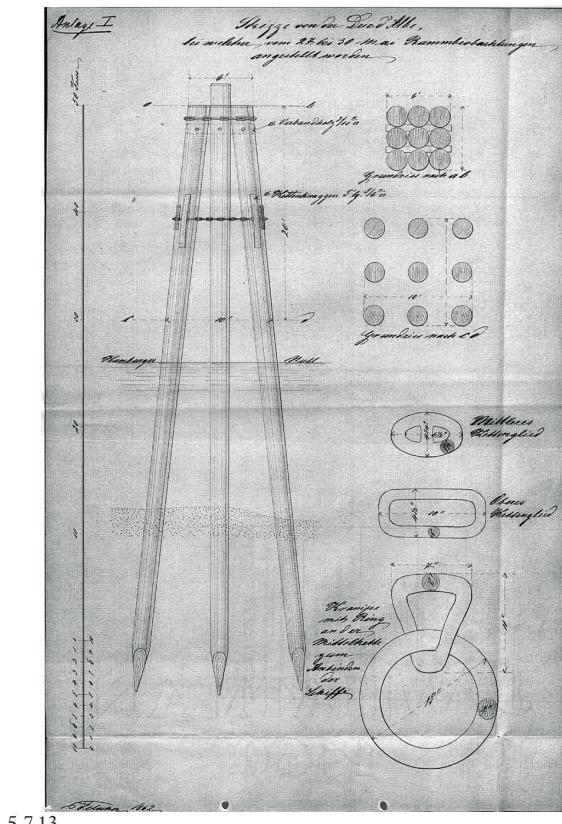


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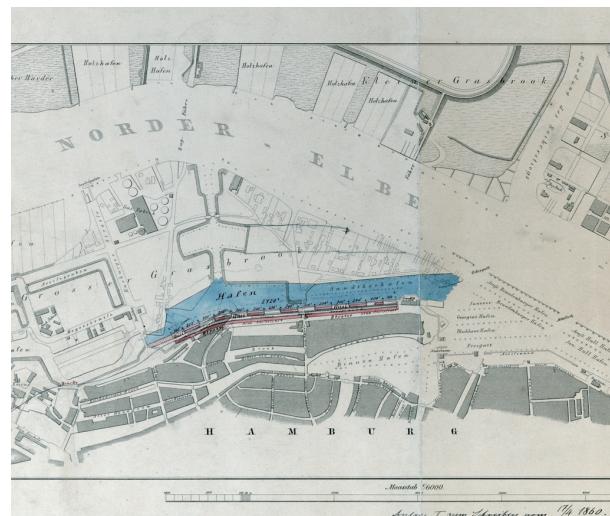
5.7.8. Railway works at the Berlin-Potsdam-Magdeburg railway station, Berlin (1863–64) (H. Weise, 1865). 5.7.9. Railway works at the Berlin-Potsdam-Magdeburg railway station, new locomotive shed, plan, section, front elevation from the street (H. Weise, 1865). 5.7.10 Railway works at the Berlin-Potsdam-Magdeburg railway station, front elevation of the locomotive shed from the side of the rails; partial front view of the staircase tower; section and plans of the main tower; detail of a footing (H. Weise, 1865). 5.7.11. Railway works at the Berlin-Potsdam-Magdeburg railway station, plan of the foundations (H. Weise, 1865). 5.7.12. Railway works at the Berlin-Potsdam-Magdeburg railway station, shoring methods for foundations; above: traditional shoring system for foundations along the side of the rails; below: first and second type of sinking caissons.



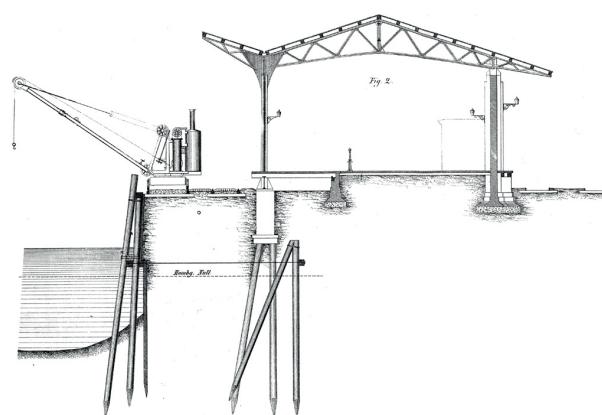
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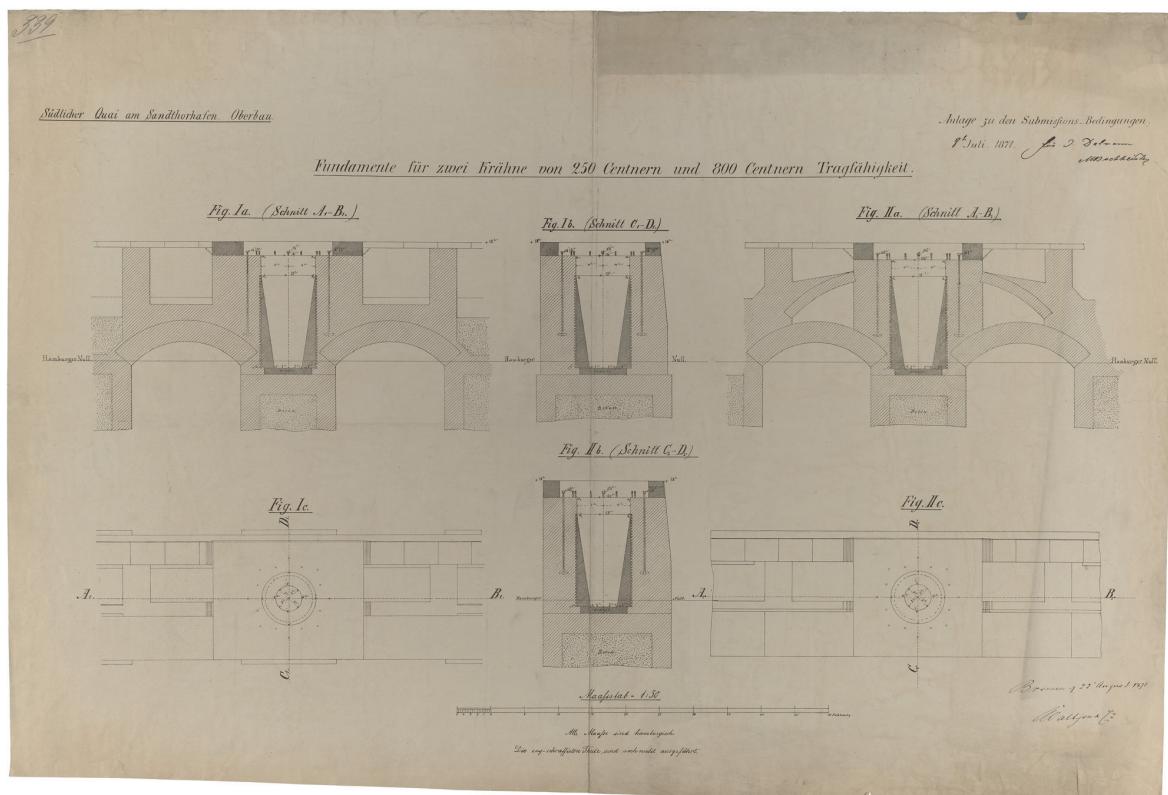


5.7.17

5.7.13–14. The prevalent use of timber structures in the port of Hamburg: drawing of a dolphin (1862); view of the port at the Ladungsbrücken, a ship fixed at a dolphin (1860). 5.7.15. J. C. W. Dalmann, plan for the Sandthor basin (1860). 5.7.16. J. C. W. Dalmann, drawing of the northern Sandthor dock with an above-standing shed, Hamburg (1861–66), section (1869). 5.7.17. View of the Santhor dock (1860).

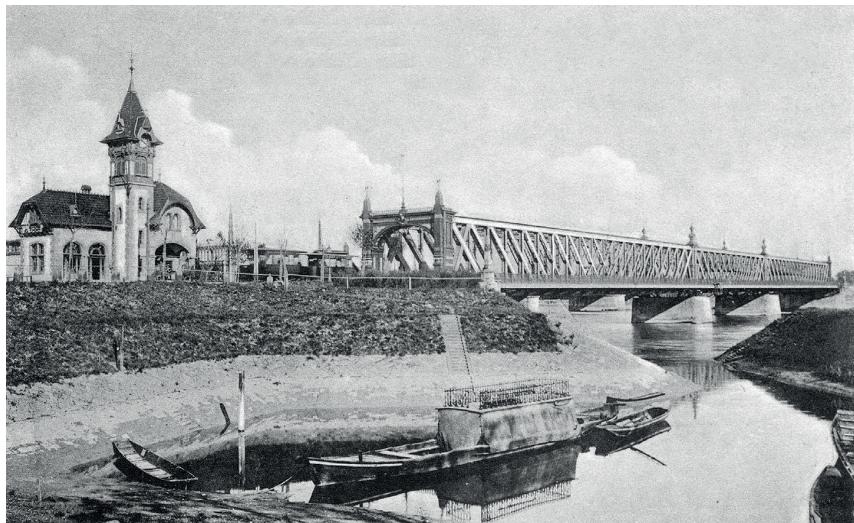


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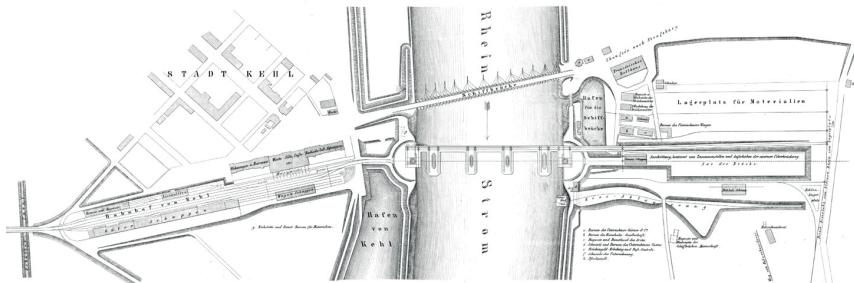


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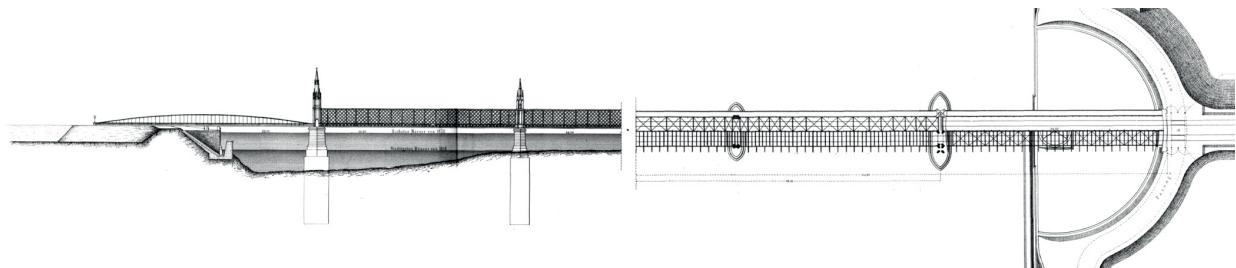
5.7.18. J. C. W. Dalmann, project of the southern Sandthor dock, Hamburg (1866–72), frontal view, sections, plan [s.d.]. 5.7.19. J. C. W. Dalmann, project of the southern Sandthor dock, Hamburg, the foundations of the cranes; on the left, foundation for “250 center” crane (125 centner of today); on the right, foundation reinforced with flying buttresses for 800 centner (400 centner of today); (1871).



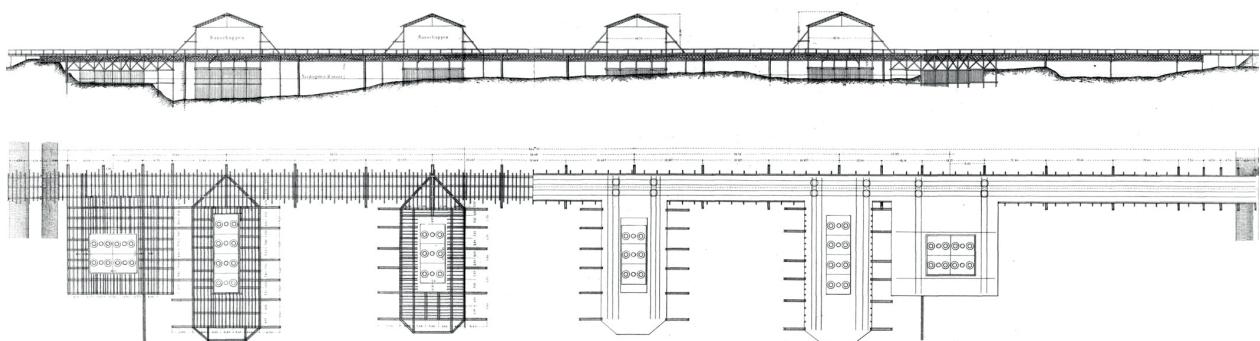
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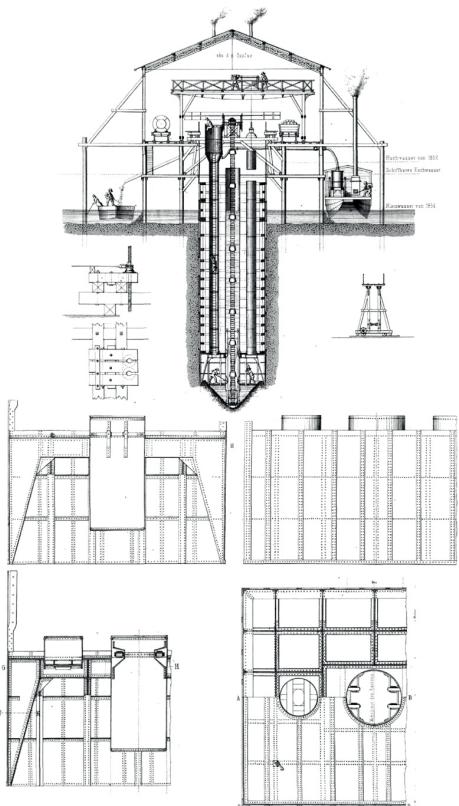


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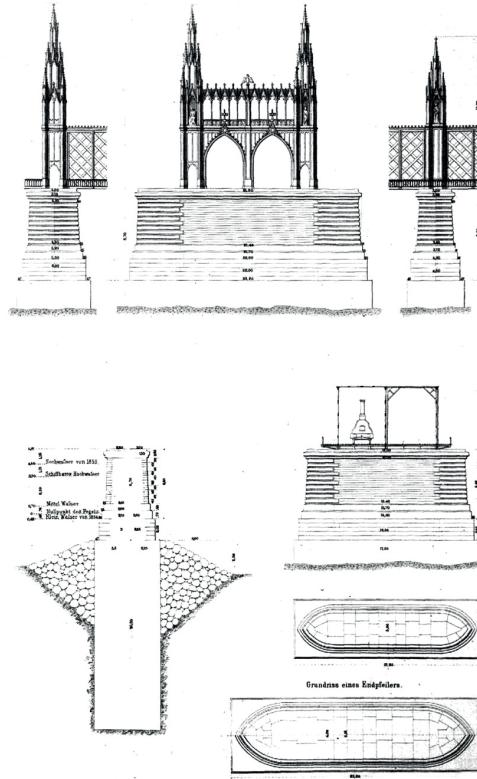


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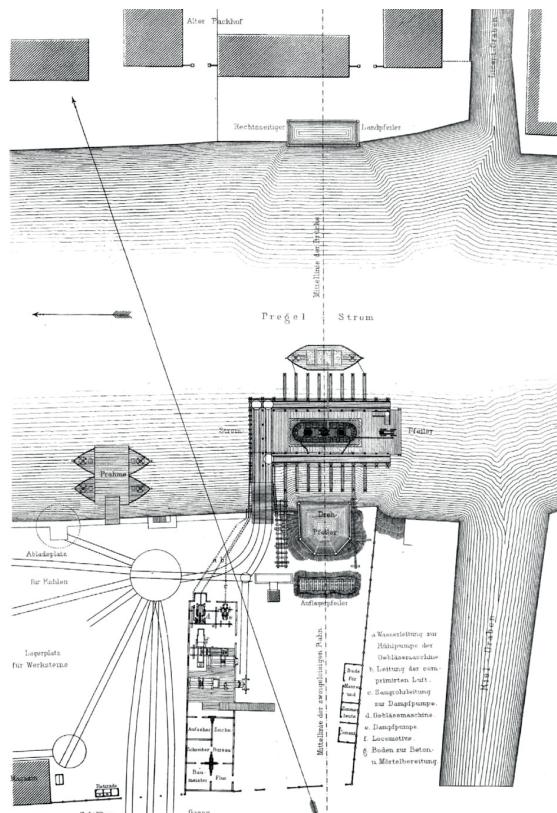
5.7.20. View of the bridge over the Rhine in Kehl (1858–61), (Schwedler, Hipp, 1860). 5.7.21. Bridge over the Rhine in Kehl, plan of the building site installations (Schwedler, Hipp, 1860). 5.7.22. Bridge over the Rhine in Kehl, half elevation, half plan, the two halves are symmetric (Schwedler, Hipp, 1860). 5.7.24. Bridge over the Rhine in Kehl; above, elevation of the scaffoldings under sheds for the construction of the piers; below-left, horizontal section of the scaffoldings for the construction of the foundations of the piers, the arrangements of the caissons for the construction of the foundation of each pier; below-right, plan of the scaffoldings for the construction of the foundations of the piers; (Schwedler, Hipp, 1860).



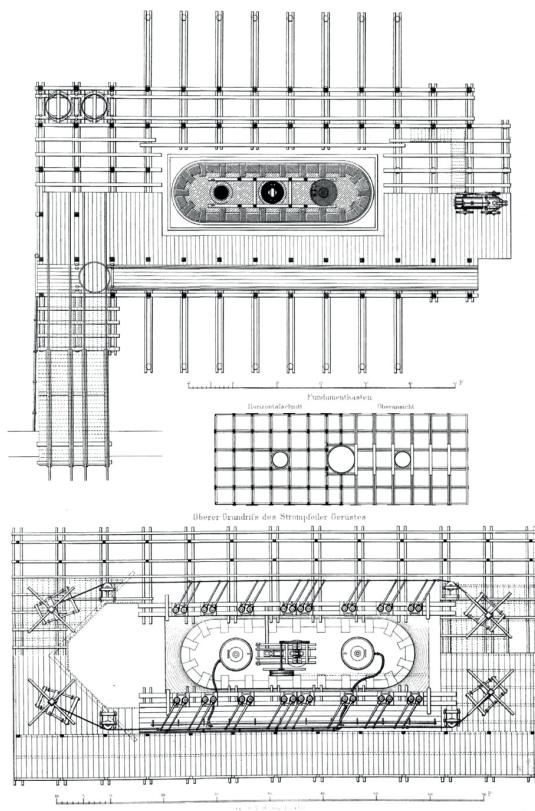
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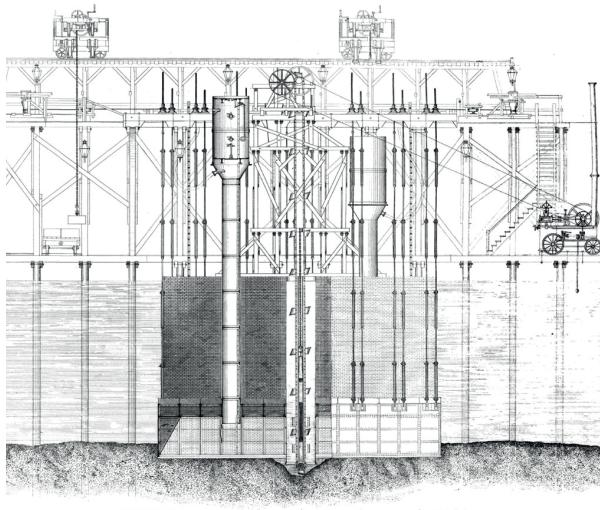


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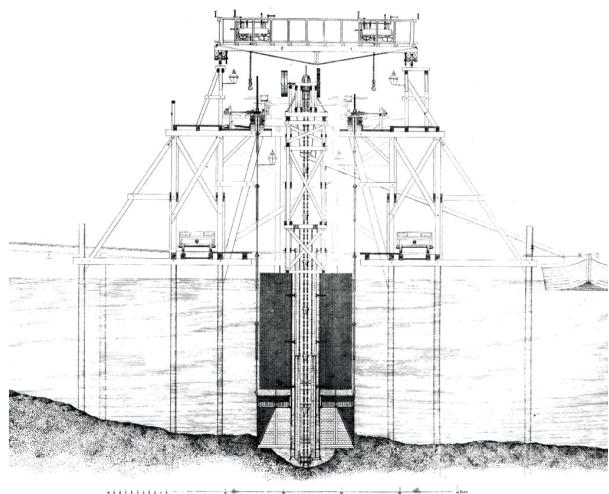


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5.7.24. Bridge over the Rhine in Kehl, above: transversal section over a foundation well under construction; in the middle-left, detail of a jack for suspending the caisson; in the middle-right, detail of a bridge crane; below, detail of the caisson, on the left transversal and partial longitudinal sections over the caisson, on the right partial longitudinal elevation elevation, partial view and section from above (Schwedler, Hipp, 1860). 5.7.25. Bridge over the Rhine in Kehl, side views and plans of a freestanding pier. 5.7.26. Bridge over the Pregel in Königsberg (1864), plan of the building site for the freestanding pier (Löffler, 1866). 5.7.27. Bridge over the Pregel in Königsberg, the construction of the freestanding pier, views from above of above (Löffler, 1866).



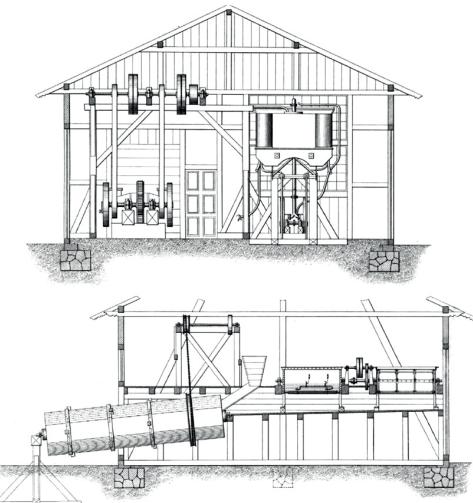
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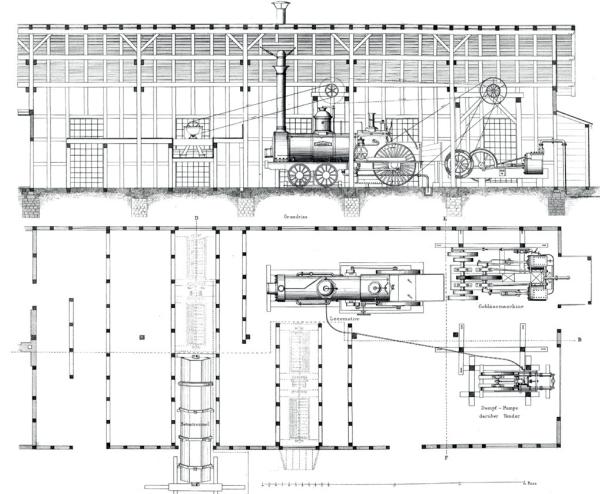
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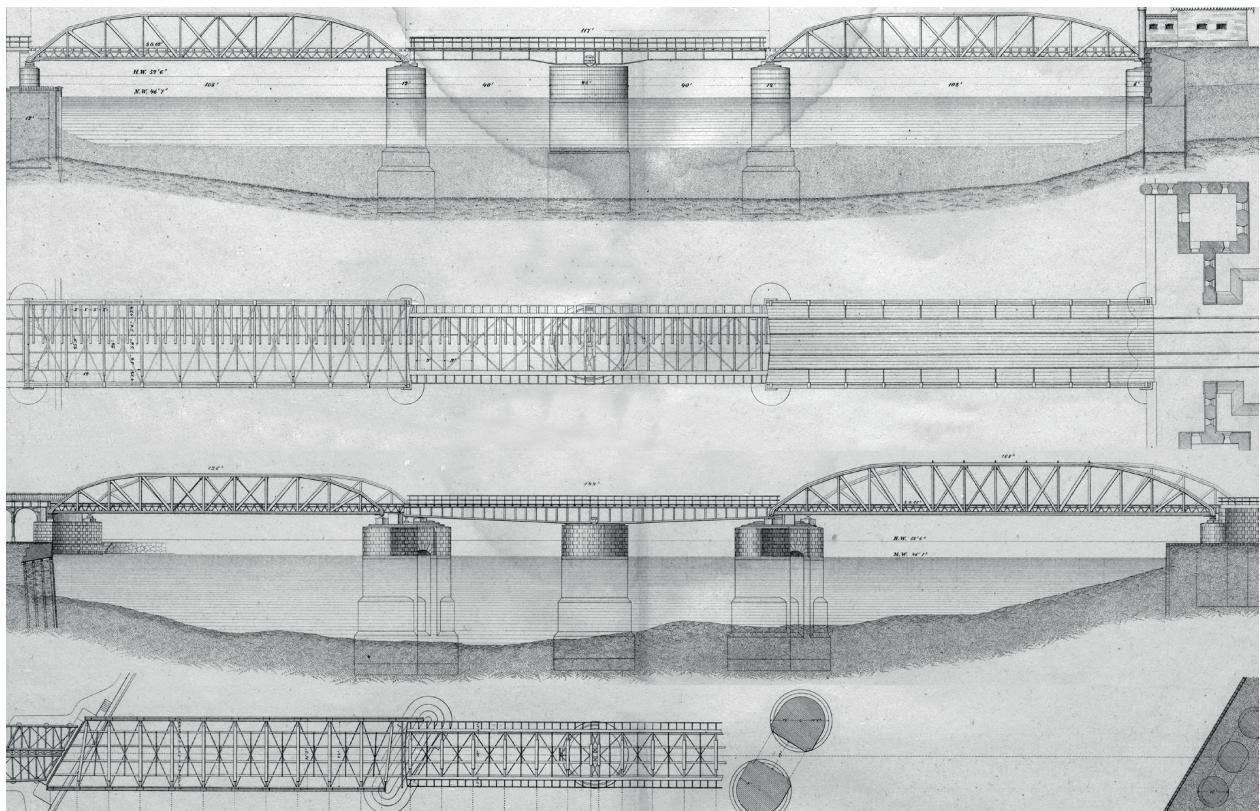


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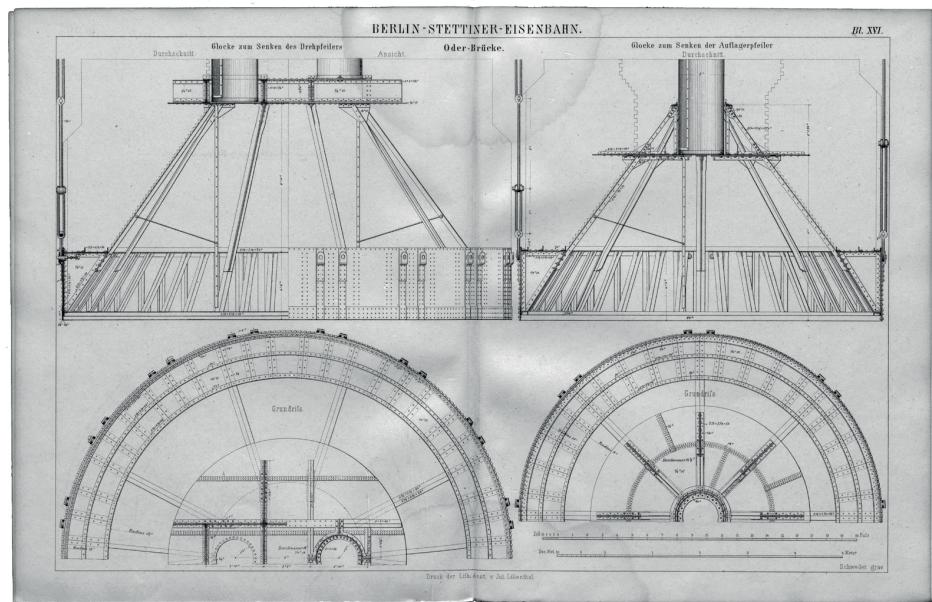


5.7.32

5.7.28–29. Bridge over the Pregel in Königsberg, the construction of the freestanding pier, transversal and longitudinal sections (Löffler, 1866). 5.7.30. Bridge over the Pregel in Königsberg, the construction of the freestanding pier, photo from the scaffoldings (Löffler, 1866). 5.7.31–32. Bridge over the Pregel in Königsberg, the mortar an concrete mill, sections and plan (Löffler, 1866).

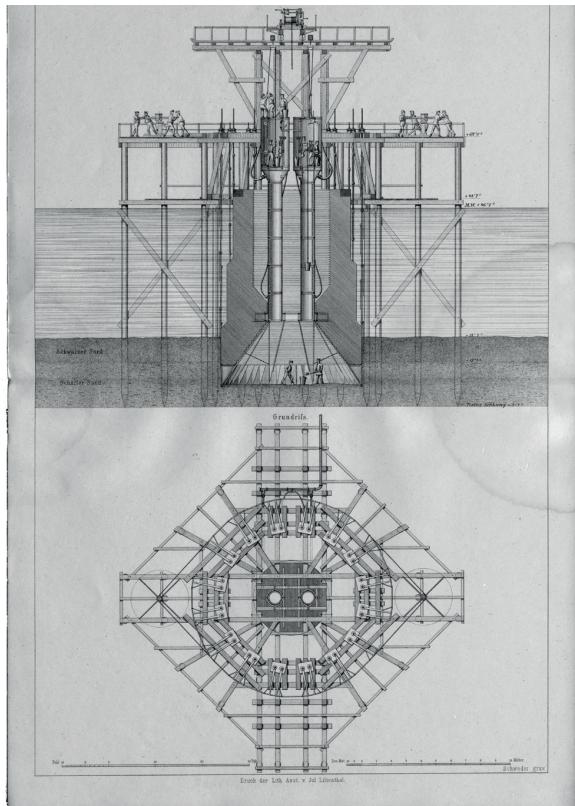


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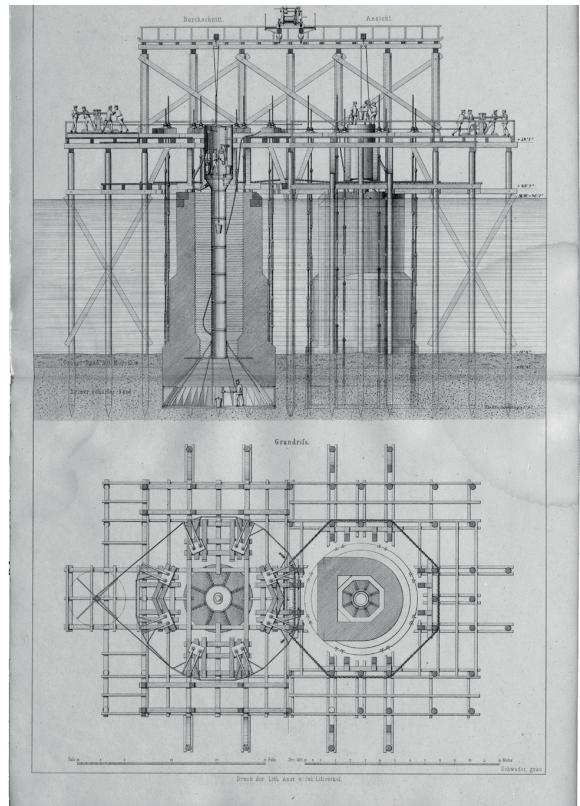


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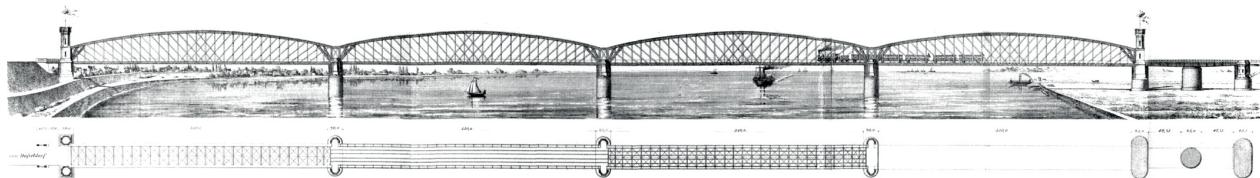
5.7.33. Bridges over the rivers Oder and Parnitz, Stettin (1866–68); above, elevation and plan of the bridge over the Parnitz; below, elevation and plan of the bridge over the Oder. 5.7.33. Bridges over the rivers Oder and Parnitz, Stettin, details of the pressurized bell, sections.



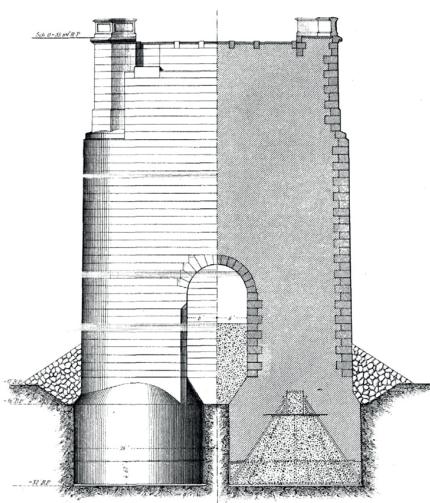
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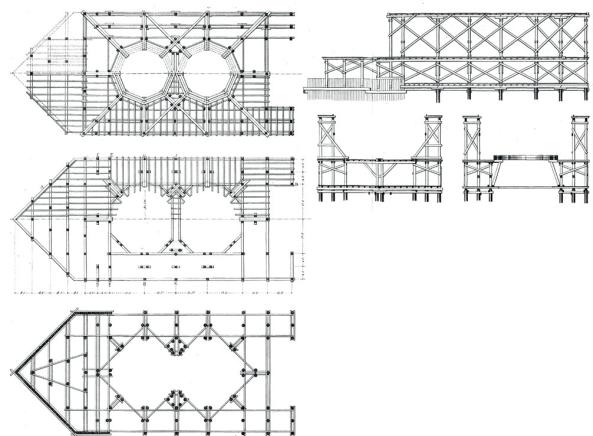
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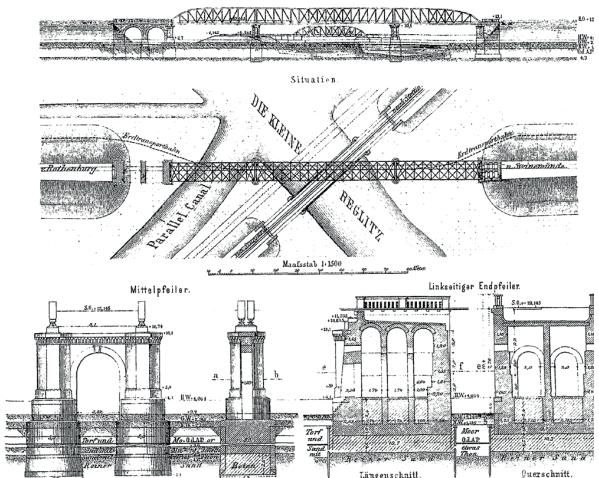


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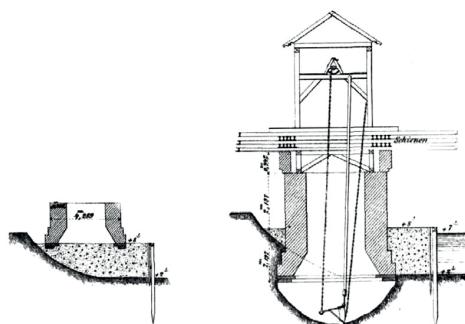


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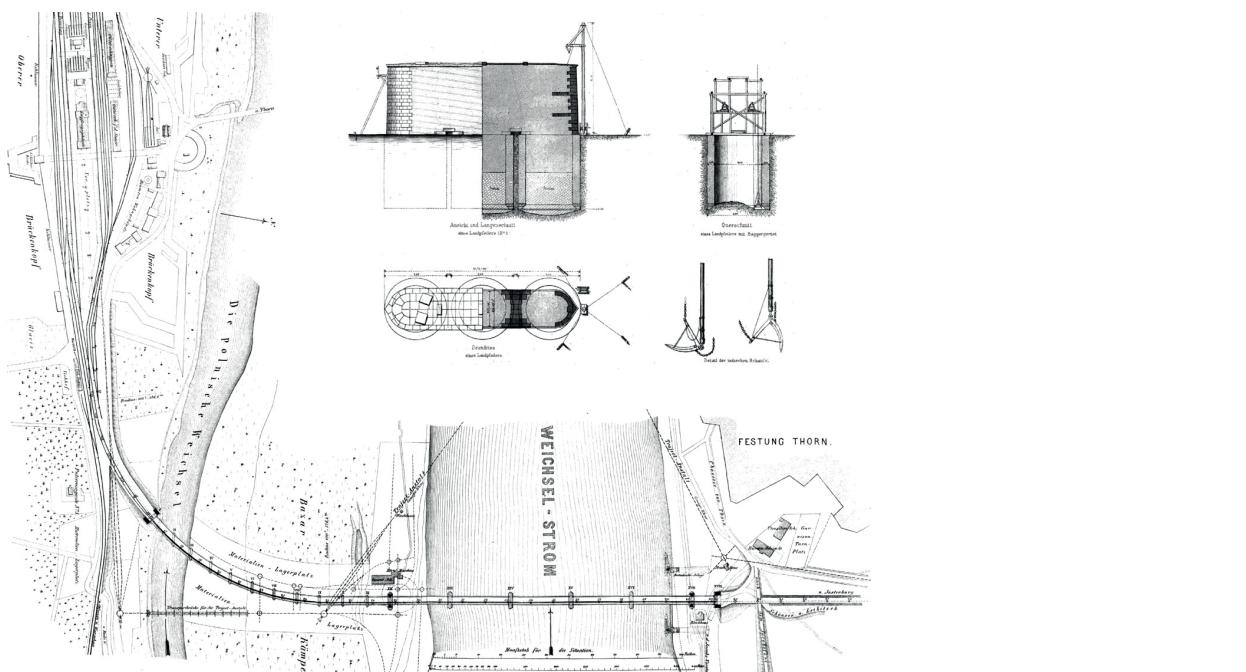
5.7.35. Bridges over the rivers Oder and Parnitz, Stettin (1866–68), the construction of the fudation of the central pier, cross section and plan. 5.7.36. Bridges over the rivers Oder and Parnitz, Stettin (1866–68), the construction of the fudation of one lateral freestanding pier, cross section and plan. 5.7.37. Bridge aver the Rhine, close to Düsseldorf (1868–79), elevation and plan at different levels (Pichier, 1872). 5.7.38. Bridge aver the Rhine, close to Düsseldorf, partial side elevation and partial section of one of the piers that are built on well foundations (Pichier, 1872). 5.7.39.Bridge aver the Rhine, close to Düsseldorf, plan at different levels and sections of the scaffoldings to build the foundation of the piers hat are built on well foundations (Pichier, 1872).



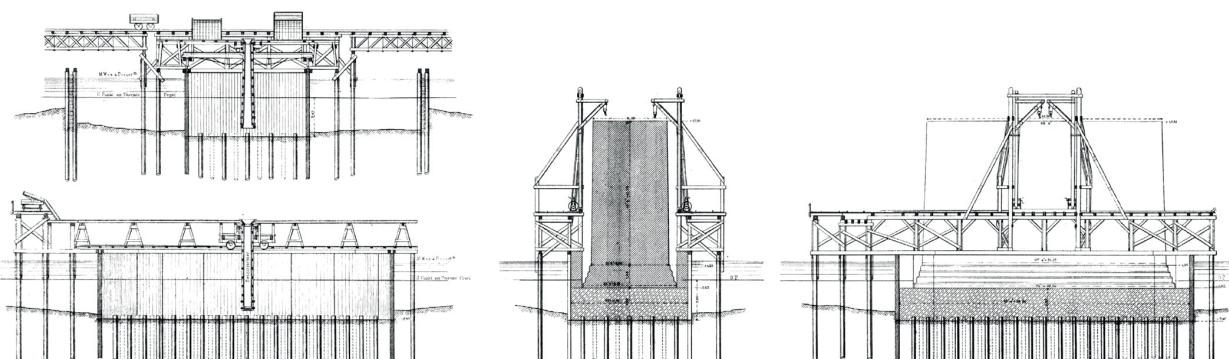
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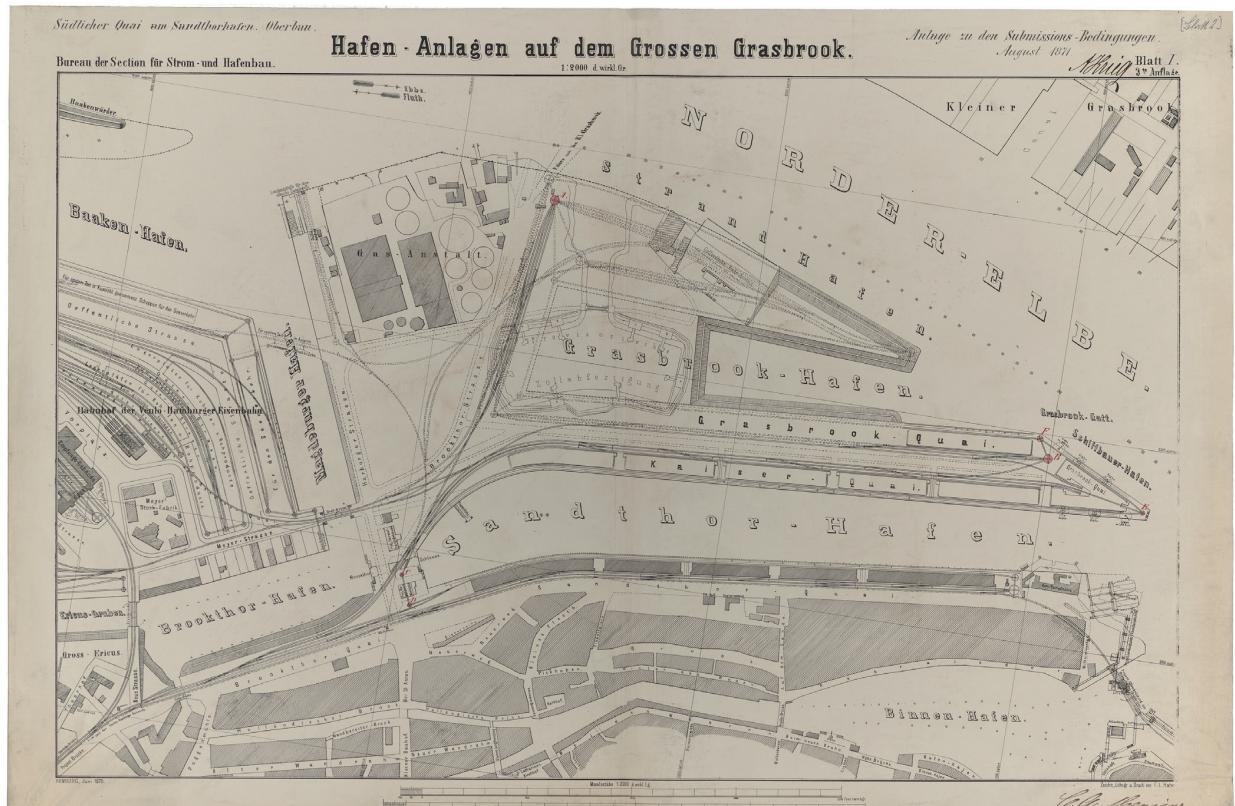


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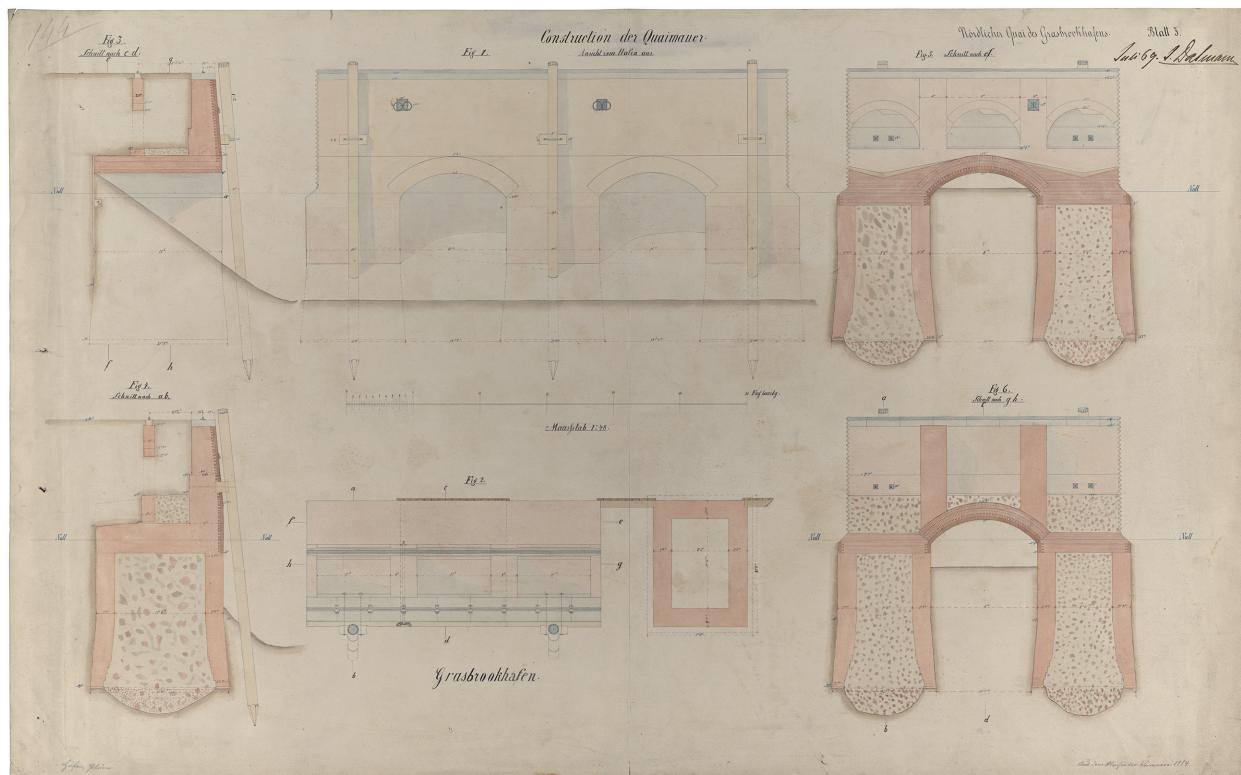


5.7.43

5.7.40. Bridges over the Kleine Reglitz along the Breslau-Schweidnitz-Freiburg railway line, Stettin (1869), elevation, plan, elevation and section of a freestanding pier built on two well foundations, longitudinal and transversal section of a land pier, built on a concrete foundation (Wiebe, 1875). 5.7.41. Bridge over the Elbe, close to Magdeburg, section of the construction of a well foundation (Quassowsky, 1874). 5.7.42. Bridge over the Vistula in Tourun, (1868-72), plan and drawings of the construction of a pier on well foundations, longitudinal section over the pier, section over a well under construction, plan, the shovel used to dig the soil inside the wells (Anon., 1876). 5.7.43. Bridge over the Vistula in Tourun, the construction of one of the piers that are built of concrete foundations, longitudinal and transversal sections (Anon., 1876).

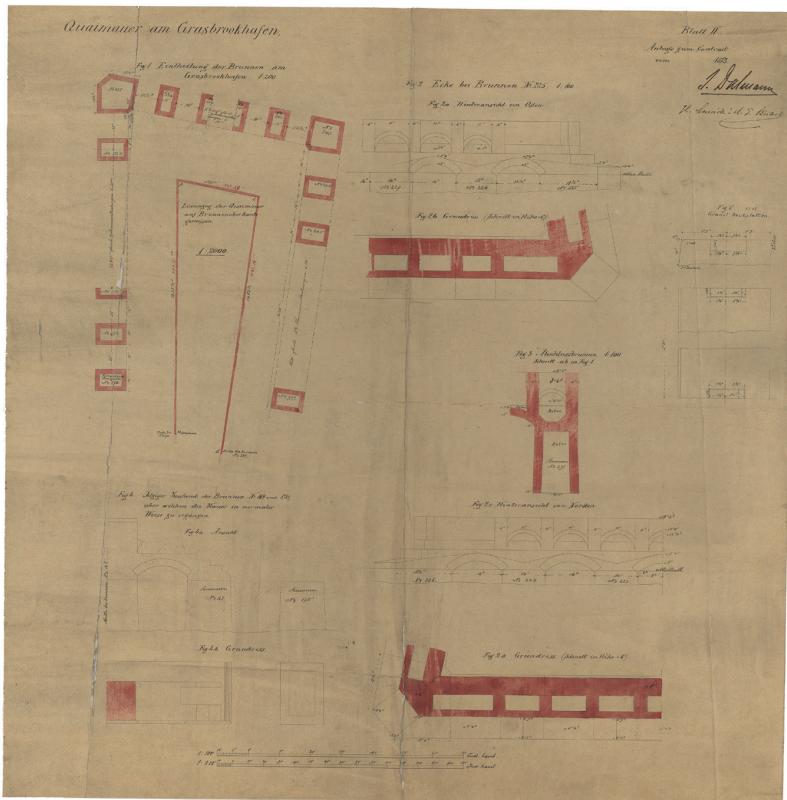


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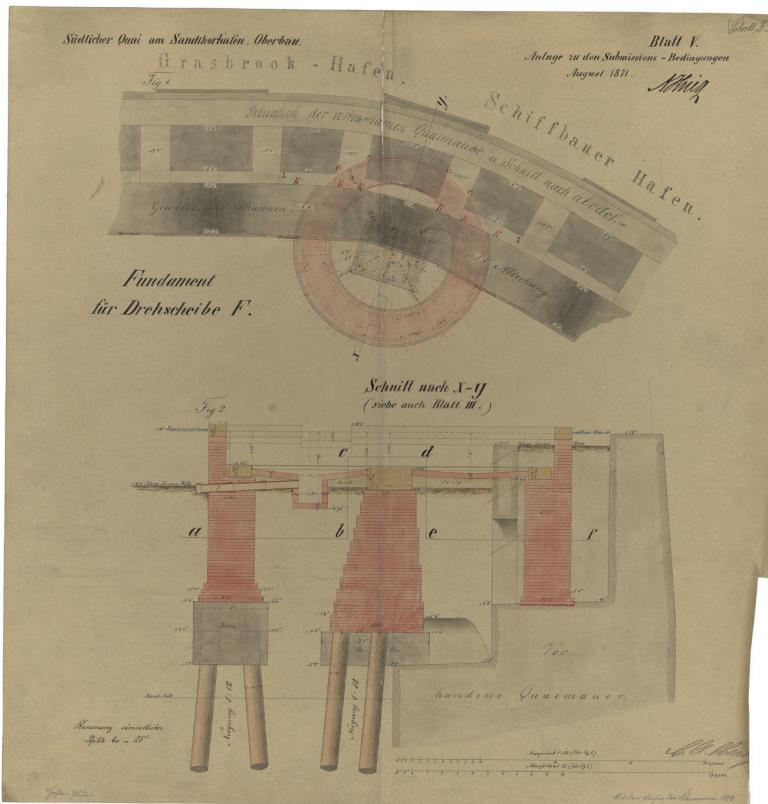


5.7.45

5.7.44. J. C. W. Dalmann, project of the Grasbrook harbour, Hamburg (1871-76), plan, 1871. 5.7.45. J. C. W. Dalmann, project of the Grasbrook harbour, Hamburg, views, sections and plan of the well foundations, 1869.

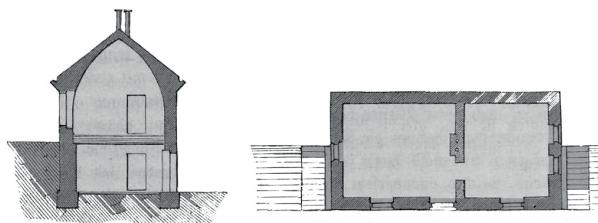


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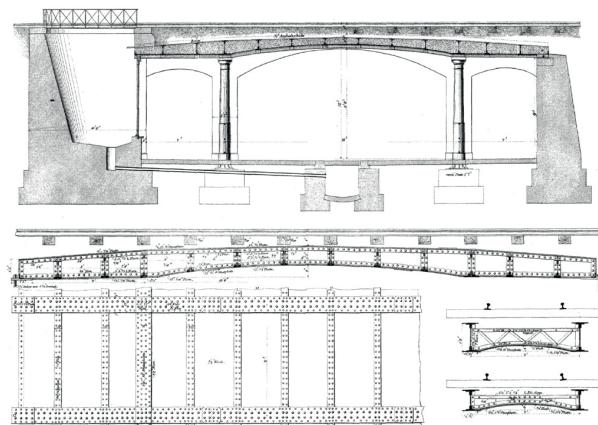


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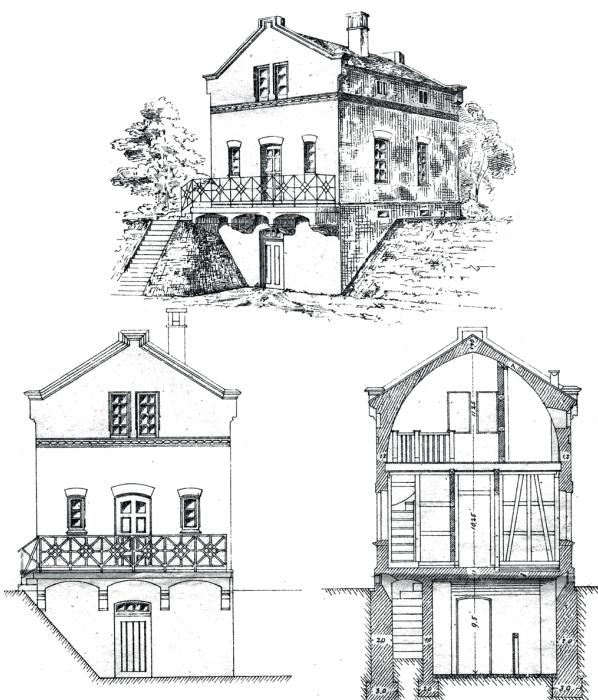
- 5.7.46. J. C. W. Dalmann, construction of the Grasbrook harbour, Hamburg, explanation drawings for a contract dating back to august 1873.
 5.7.47. J. C. W. Dalmann, project of the Grasbrook harbour, Hamburg, plan and section of a railway turntable to build on the dock, 1871.



5.8.1



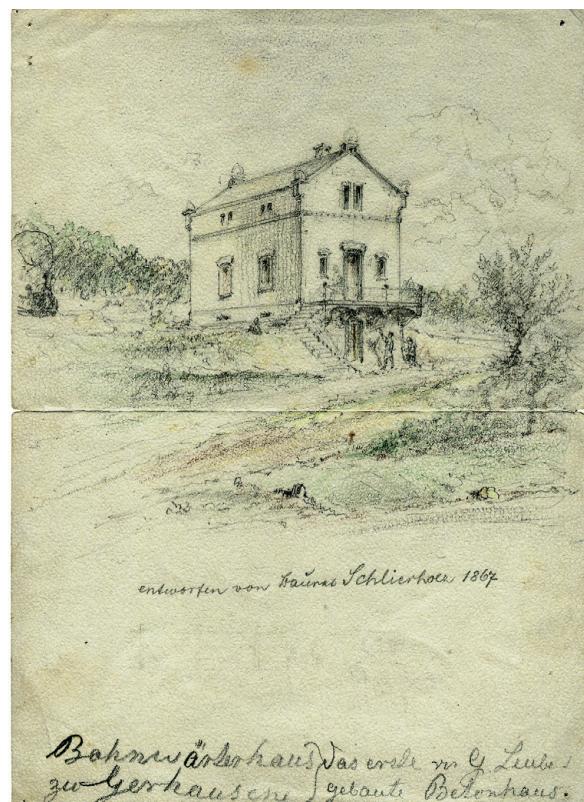
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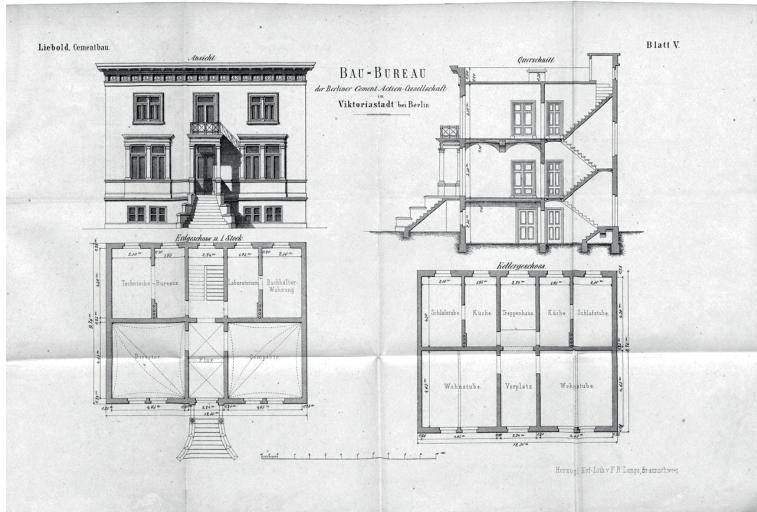


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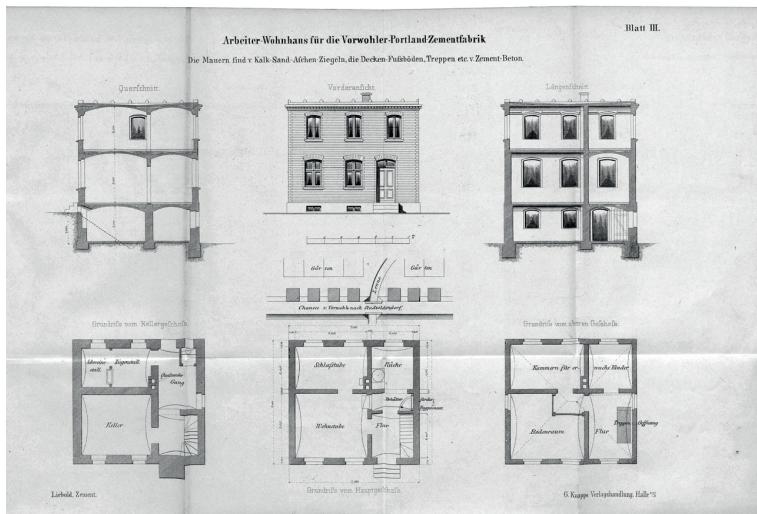


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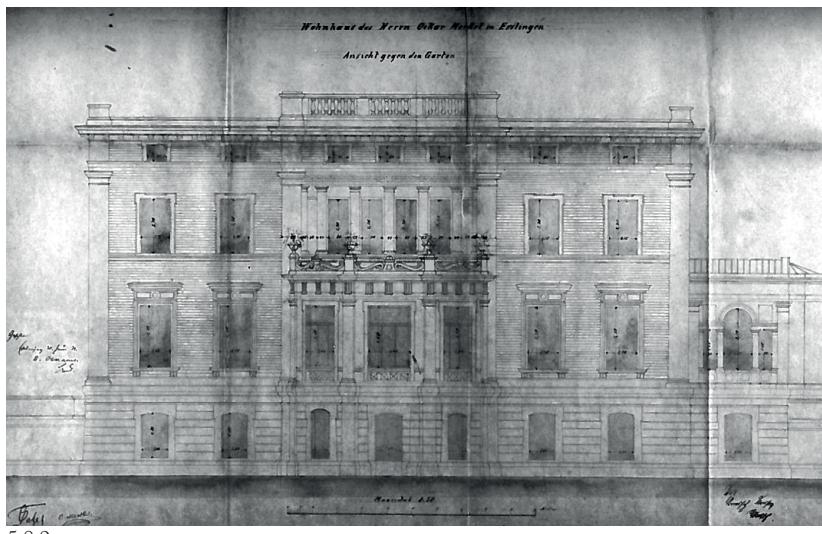
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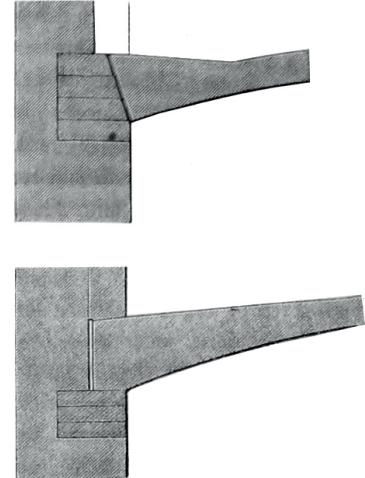
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5.8.9

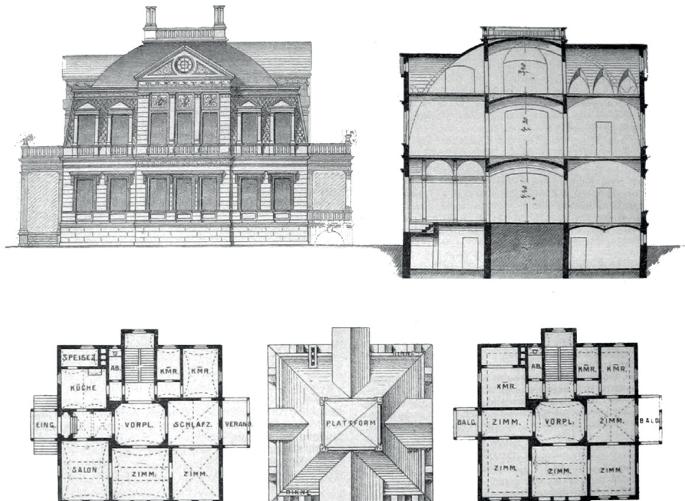


5.8.8

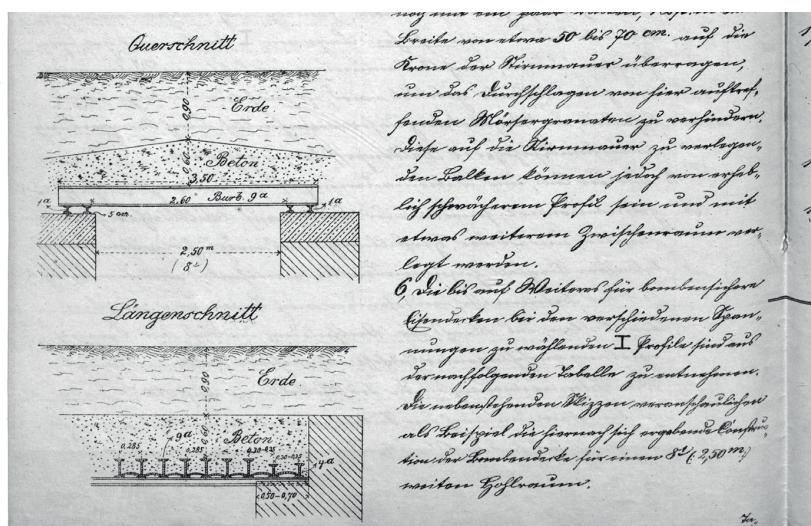
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5.8.10

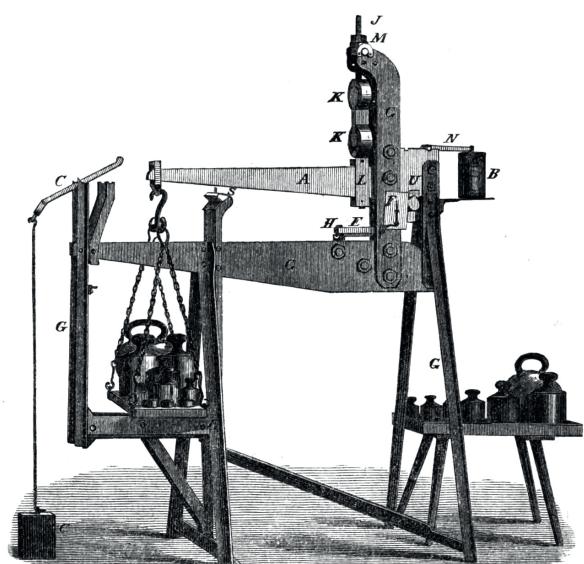


5.8.11

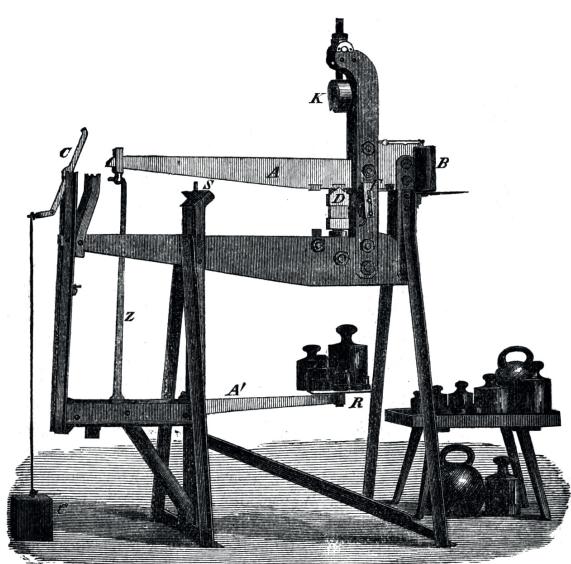


5.8.12

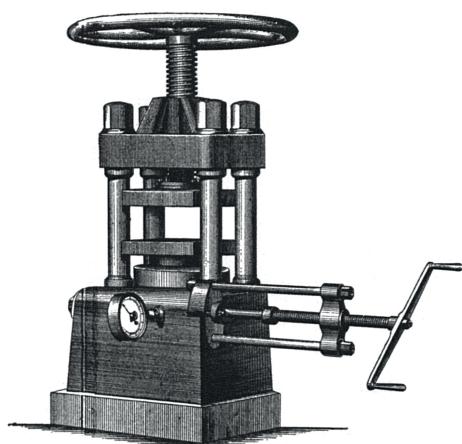
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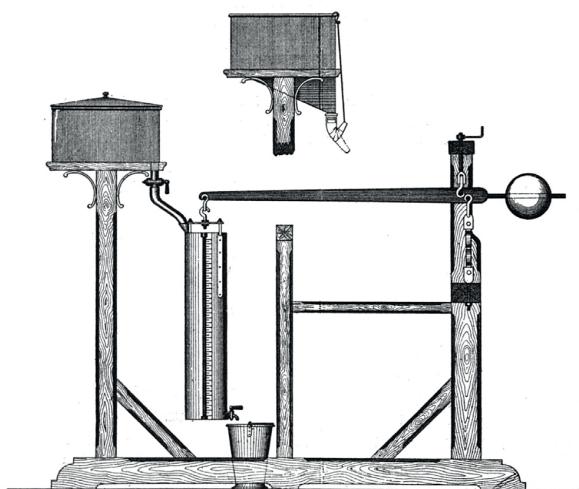
5.9.1



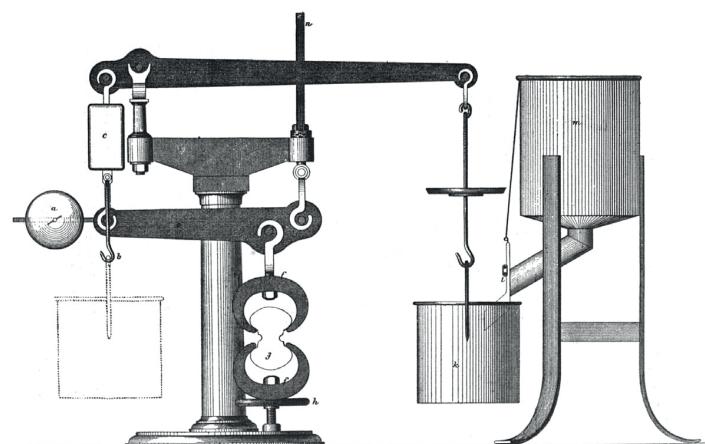
5.9.2



5.9.3



5.9.4



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5.8.10. G. Schwartz, machine to test cement-based mortar specimens, 1867, prepared for a tensile strength test (Michaelis, 1869). 5.8.11. G. Schwartz, machine to test cement-based mortar specimens, 1867, prepared for a compressive strength test (Michaelis, 1869). 5.9.3. Michaelis, Früling, press for compressive strength tests, 1872. 5.9.4. Michaelis, Früling, machine for tensile strength tests, 1872. 5.9.5. Michaelis, machine for tensile strength tests, 1876.

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The sequence, from periodicals, to books and to the archival sources, reflects the order that has been followed during the research activity, which has been essentially developed by considering, at first, printed sources dating back to the analysed period of time, in order to build up a global vision of the events, and later, the archival sources, which have been focused on the base of the previous analysis of the printed sources.

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Curriculum Vitae

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Architect (Member of the Society of Architects in Rome from 2005 to 2011).

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Studies

- 2015 PhD (Docteur ès Sciences) in History of Architecture.
École polytechnique fédérale de Lausanne
- 2004 Master of 2nd degree in history of architecture.
Università degli Studi Roma Tre and Accademia di San Luca, Rome.
- 2002 Degree in Architecture, cum laude and publication dignity.
Università degli Studi di Napoli Federico II, Naples.

Publications

- 2014 *Du conglomerat maigre au béton de laitier: expériences allemandes sur la composition du béton, 1840–1876*, in *Matières*, vol. 11, 2014, p. 103–15, 2014.
- 2014 *The early German production and use of modern hydraulic binders: between English influences and the search for a scientific approach, 1817–1839*, in *Proceedings of the First Construction History Society Conference*, Cambridge, 11–12th April 2014, pp. 1–8.
- 2012 *Les planchers en poutres de fer et Stampfbeton en Allemagne*, in Roberto Gargiani, ed., *L'architrave, le plancher, la plate-forme. Nouvelle histoire de la construction*, Lausanne, PPUR, 2012, pp. 529–36.
- 2006 *Corviale, un'idea di città*, in Flaminia Gennari Santori, Bartolomeo Pietromarchi, eds., *Osservatorio Nomade. Immaginare Corviale. Pratiche ed estetiche per la città contemporanea*, Milano, Mondadori, 2006.

Conferences

- 2015 Universität der Bundeswehr München.
Topic Zement- und Betonbau Entwicklung im 19. Jahrhundert, der Beton taucht aus der Erde auf.
- 2014 Fédération de l'Industrie du Béton, Meeting TG History of concrete structures, Dresden, 2014.
Topic Der Anfang von Zement- und Betonbau in Deutschland, eine neue Lesart.
- 2014 Construction History Society, Queens' College, University of Cambridge.
Topic The early German production and use of modern hydraulic binders: between English influences and the search for a scientific approach, 1817–1839.
- 2012 Colloque Béton, Ecole polytechnique fédérale de Lausanne, 2012.
Topic Invention, fabrication et emploi d'un ciment allemand sur le chantier du premier pont sur la Vistule à Dirschau.

- 2011 Colloque Béton, Ecole polytechnique fédérale de Lausanne, 2011.
Topic Le placement de l'armature dans une plaque en béton. Propositions de Wayss et Koenen, 1880-1887.

Professional trainings

- 2013 "Instructional Skills Workshop"
Teaching Support Center - EPFL.
- 2011 "Leading a team", course.
EPFL.
- 2009 "Project management", course.
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- 2006-2007 Project manager.
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- Activity Fundraising and development of projects to submit Calls for Proposals and Calls for Tender:
- ESTEEM, Enhancing Safety and security aspects in Transport research in the EuroMediterranean region. 7th FP.
- STEMOUT, STrengthening EuroMediterranean relationships On sUrface Transport research. 7th FP.
- ECODL, European Community of Disabled Learners.
- 2006-2005 Researcher.
Fondazione Adriano Olivetti, Rome.
Topic of interest: the social housing in Italy in the 1960s and in the 1970s, with special reference to the Nuovo Corviale by Mario Fiorentino.
- 2001-2002 Stage at architecture office.
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Work experience

- 2009-2015 Doctoral assistant.
Chair of History of Architecture, prof. R. Gargiani, EPFL, Lausanne.
- 2007-2009 Site Manager
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- 2005-2007 Independent Architect.
Activity Territorial analyses on behalf of RisorSa S.r.l., Sviluppo Lazio S.p.a., Rome.
- 2004-2005 Architect.
Comune di Roma, Ufficio Progetti Metropolitani.
Activity Design of master plans for university areas in the context of the Rome Zoning Plan of 2003.

