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POTENTIAL OF SHELL STRUCTURES MADE OF LINEAR MANUFACTURED UNIAXIALLY CURVED SANDWICH PANELS

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1. INTRODUCTION

Today lightweight steel constructions made of sandwich panels are a common solution for roof and wall claddings. Due to the excellent weight to load ratio, their good heat insulation, their high load-bearing capacity as well as the economical manufacturing and erection process, sandwich constructions are build frequently. Besides the mentioned advantages the linear manufacturing process of sandwich panels, normally limits the possible building cubature to rectangular shapes.

Another construction form coming with an even lower ratio of weight to load are shell structures. In the 20th century, many of these structures were built, following the technical and scientific progress of that time. Disadvantages of most realized structures were that large and unique temporary constructions as well as large installation expense was necessary. In times of growing importance of construction time, the growing costs of construction site equipment and wage, building an economical efficient structure requires high levels of prefabrication and short assembly times.

In an interdisciplinary project, architectural, civil engineering and mechanical engineering institutes of Technische Universität Darmstadt are working on combining the advantages of these two forms of design. The research is aimed on the development of a concept to build shell structures out of linear manufactured uniaxially curved sandwich panels. This paper focuses on presenting the work status of the Institute for Steel Structures and Materials Mechanics, which consists of research on the load-bearing capacities of these structures.

2. STATE OF THE ART

In 1970, Otto Jungbluth presented a lightweight construction dome made of sandwich panels [2]. The shell structure has a span width of 45 m and was built of 120 panels. Each panels is uniaxially curved, has a variable width und was produced by Hoesch AG in single item fabrication.

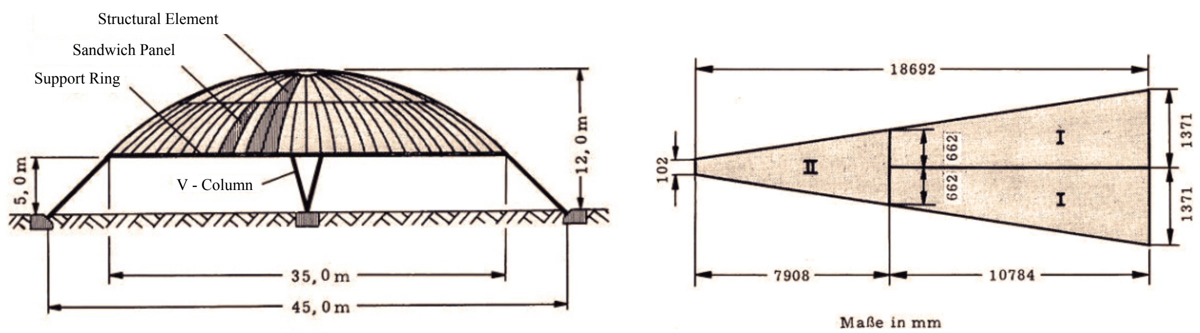

Fig. 1: Dome by O. Jungbluth and a Structural Sandwich Element. Figs. 1 and 2 in [2].

The panels with a length of approx. 8 m or 11 m are approx. 0.1 m to 1.4 m wide (see Fig. 1) and have metal faces with a thickness of 1 mm and polyurethane foam core in between the face sheet with a thickness of 150 mm. The structure is joined by pop rivets and bolted connections, which causes high local stresses in the face sheets.

On the site, 40 structural elements were merged to a shell structure (see Fig. 1), assembled by three sandwich panels, each. The connection of the panels to the structural elements as well as the connection of the elements had to be foamed after fixing them with the mentioned fasteners in situ.

After several reconstruction works, the dome is today the Information Center of Hannover Fairs. Taking into account that, according to German codes, facilities have to be designed to operate up to 50 years, it can it be concluded that the dome is a permanent light-weight shell structure with viable performance efficiency. However, despite its high performance a structure like the dome of Otto Jungbluth can hardly be built economically, considering todays boundary conditions.

Nevertheless, in 2010 Klaus Berner reported about established hall structures built with a roof structure made of linear manufactured uniaxially curved sandwich panels in Italy [1]. In this context, he also reminded of the structural potential of arched structures, which let expect a larger span of the panels.

3. ASPIRED DESIGN FORM

This research work is aiming on solutions realizing shell structures out of linearly manufactured uniaxially curved sandwich panels with plane face sheets and a polyurethane core taking advantage of their high load capacity and high level of prefabrication. This includes developing a design tool, a manufacturing process as well as the determination of the load bearing performance of these structures.

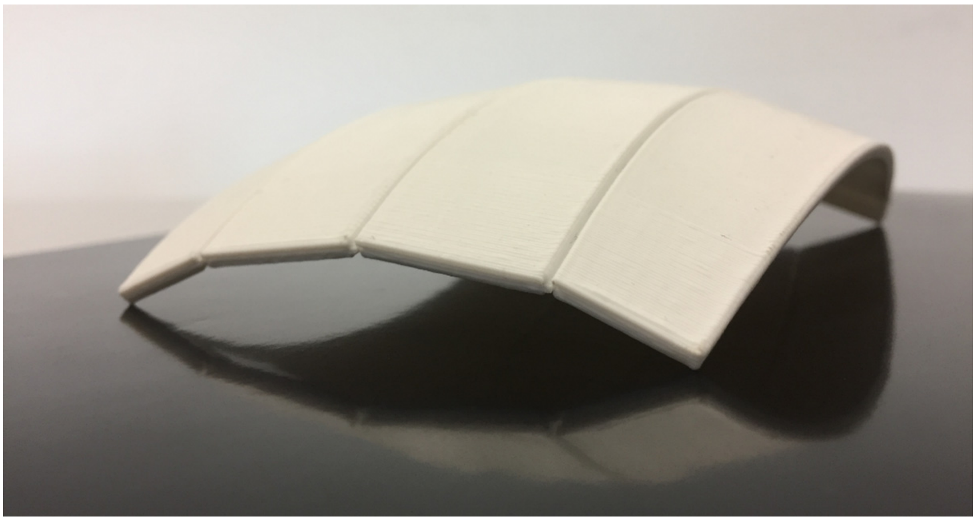

Fig. 2: Exemplary Design Model – Spherical Segment.

As an example, a roof structure could be designed as a spherical segment. Along the longitudinal direction, the panels are curved and in transverse direction, the curvature is approximated by a polygon. This design principle requires that the sandwich panels are produced with variable width as well as inclined joint planes. All features of the panels can be pre-engineered in computer models. The design tool will be targeted on holding the basic information for the manufacturing as well as the static model. Thus an integral design process is developed, which allows a close cooperation between architectural design, structural engineering and the manufacturer.

4. POTENTIAL OF LOAD-BEARING CAPACITIES

At this time, preliminary investigations on the load bearing capacity of arched sandwich beams indicate their high structural potential compared to single span sandwich beams. The load bearing capacity of these two kinds of structure was determined by loading them with the same unit dead load cases. Single span as well as arched sandwich beams, with different ratios of radius of curvature to span, have been loaded over their entire length respectively over half of their length. They were analysed in two-dimensional numerical models using the finite element method. Following up the model of the arched sandwich beam is described in detail.

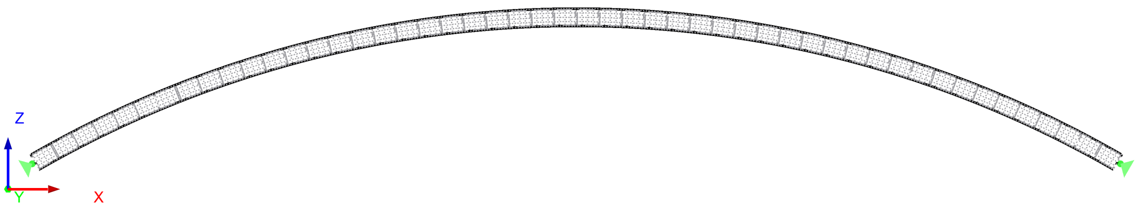

Fig. 3: 2D Finite Element Model.

The supports of the two-hinged arch where modeled by rigid beam elements connecting the two face sheets of the sandwich cross section similar to an end-plate connection (see Fig. 3). The end-plates them self were simply supported in the centroid of the sandwich cross section (see Fig. 4). The steel face sheets of the sandwich panels were modeled with curved beam elements using a common ideal-elastically isometric material with a Young's modulus of 210000 N/mm² and a Poisson's ratio of 0.3. The core of the sandwich panel was modeled using shell elements. Taking into account the simplified two-dimensional model, the core material was modeled ideal-elastically isometric as well. Deviating from the material of the deck layers the shear modulus of the core was defined as 2.5 N/mm² or 4.0 N/mm² and in consideration of a Poisson's ratio of 0.25, the belonging Young's modulus was calculated, isotropic material behavior presumed. The Poisson's ratio of the core material was set according to [3].

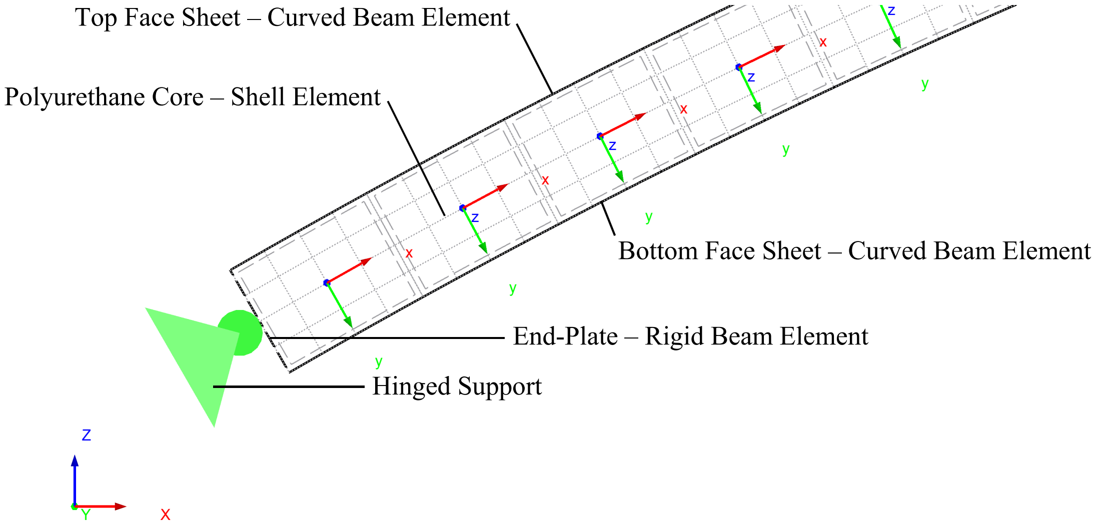

Fig. 4: 2D Finite Element Model – Detail at Support.

Since the material parameters of the core are defined vertically to the member axis, the plane of the core is modeled by trapezoidal shell elements which approximate the curved form like a polygon. According to [4] the limit values for the length of these elements are determined as the depth respectively twice the depth of the sandwich panel. The axis of each shell element is aligned with the longitudinal axis of the sandwich panel at the associated location. The axis and the mesh of the shell elements can be seen in Fig. 4.

To compare the load bearing capacity, the normal stresses in the face sheets of the two structures, resulting from the corresponding load cases, have been determined. They were compared to the yield stresses of usual face sheet material, as well as the wrinkling stress belonging to the modeled face sheets. Wrinkling stresses were calculated according to equation 8.50 in Stamm & Witte [5].

The comparison showed that the load bearing stresses of many two-hinged arch sandwich beams are significantly lower than in the single span beam. The actual amounts of stresses in the arched beam are essentially depending on the relation between the radius of curvature and the span of the sandwich panel. For example, sandwich beams were the radius of curvature and the span have approximately the same amount, are showing the highest potential of load bearing capacity.

5. CONCLUSIONS

Almost 50 years ago, Otto Jungbluth built a dome using lightweight sandwich panels, which have been produced in single item fabrication. Although his structure has a high potential of load bearing capacities, it seems not be possible to build a similar shell structure economically these days.

In a current project, three institutes of Technische Universität Darmstadt are working on a new design principle to build shell structures using economically manufactured sandwich panels with a high level of prefabrication.

A preliminary study showed that arched sandwich beams have a high potential regarding the load bearing capacity. The comparison between an arched and a single span sandwich beam showed that, even for asymmetric load, resulting bearing stresses in the arched beam are significantly lower than in the single span beam.

In the course of the project it is planned to produce uniaxially curved sandwich panels and verify the results of the numeric models with full scale tests. Based on the results further numeric studies will be carried out taking into account realistic load cases. Wind, snow and temperature loads are supposed to be considered, giving special attention to asymmetrical loads.

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