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Hydraulic soil failure due to artesian ground conditions during the construction of a hydro electrical power plant on Sakarya river

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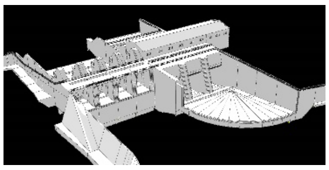
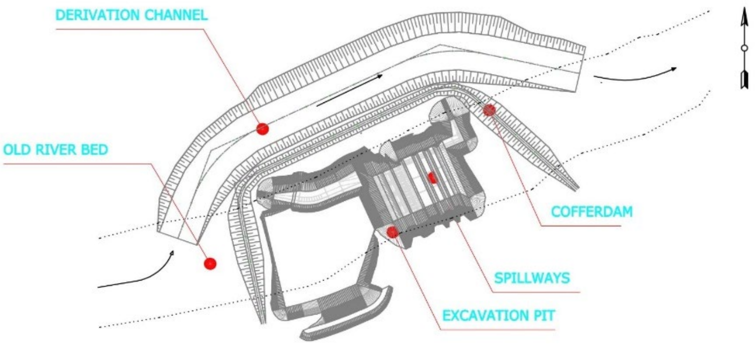
1. Introduction

A run-of-the-river hydro electrical power plant was constructed in 2018/19 on Sakarya river in Turkey. In the previous years, geotechnical ground investigations were carried out and the complete design project of the hydro electrical power plant was established.



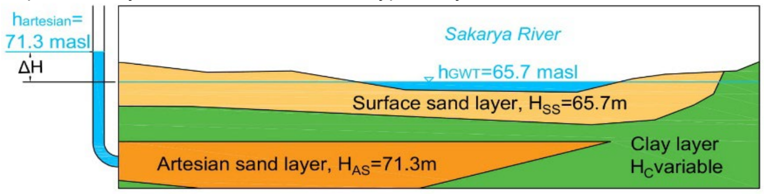
The project included the derivation of the river by means of a cofferdam in order to dry the old riverbed. In that place, an excavation of an area of 40x40m and 5.5m depth was foreseen in order to build the foundations for the spillways. However, during the construction works, additional soil investigation was made and an artesian aquifer was detected. Such conditions had not been considered in the design project. If the project was carried out as initially foreseen, the risk of hydraulic soil failure due to the artesian conditions was judged very high. In order to avoid the difficult ground conditions, the entire hydro electrical power plant was relocated towards a zone where the artesian aquifer was not present.



This master thesis includes an analysis of the initial project without relocation of the plant which results in hydraulic soil failure. Thereafter, two alternative technical solutions in order to deal with the artesian conditions are suggested.

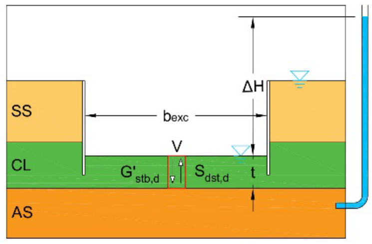
2. Hydraulic soil failure analysis of the initial project

The soil is of alluvial origin and consists of sand and clay. The clay layer (CL) acts as a confining unit for a subsurface sand layer (AS) which contains an artesian aquifer characterized by a higher total head *H* than the surrounding soil layers. The artesian pressures cause seepage through the clay layer. When an excavation is made in these soil conditions, the pit bottom can experience hydraulic heave which is a type of hydraulic soil failure.



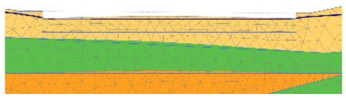
Analytical approach

The situation is checked by the equilibrium of destabilizing seepage forces *S* and stabilizing buoyant soil weight *G'* within a soil volume *V*. The initially foreseen excavation of the entire surface sand layer (SS) of 5.5m depth leads to failure. Only a maximum of approximately 1m depth can be excavated in stable conditions.

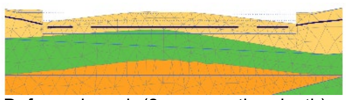


Numerical approach

A numerical 2D model is created by the FE-software Plaxis. A stepwise procedure consisting of various excavation steps is applied. At the first step (1m depth), stable conditions are obtained. At the second excavation step (2m depth), hydraulic heave of the pit bottom occurs. The numerical model confirms the analytical analysis.



Deformed mesh (1m excavation depth)

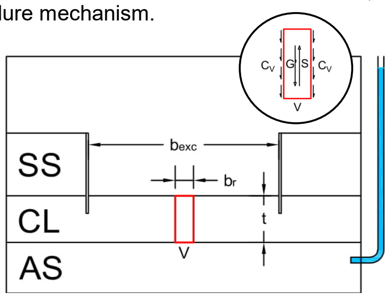


Deformed mesh (2m excavation depth)

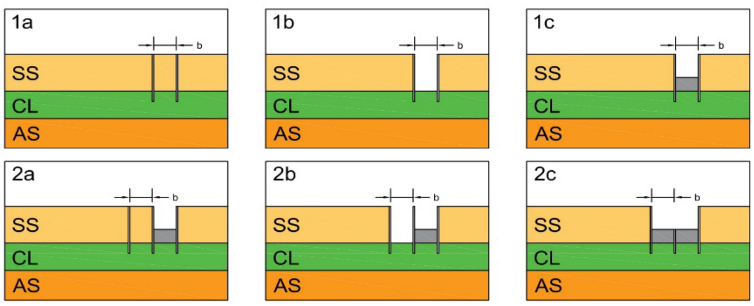
3. Consideration of the beneficial effect of cohesion as a technical solution of the hydraulic soil failure problem

Usual design approaches for hydraulic heave compare seepage forces *S* to buoyant soil weight *G'*. In a new design approach presented by Wudtke & Witt, additional resisting forces from cohesion can be considered. In cohesive soils, wedge shear failure is the prevailing failure mechanism.

On a reference volume *V* in the clay layer, cohesion acts laterally on the shear body. The importance of cohesion depends on the failure body width b_r: the wider the volume, the lower the influence from cohesion. All possible failure bodies must be checked for hydraulic heave. The most unfavorable case is when the failure body width b_r is equal to the excavation pit width b_{exc}.

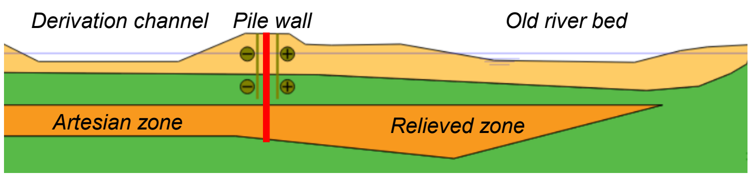


In order to mobilize cohesive resisting forces, only small excavation pits can be excavated. Therefore, a stepwise excavation procedure is suggested. A small excavation pit of width *b* which is stable due to cohesion is excavated and the foundation is built (1a – 1c). The pit can then be extended stepwise by the same stable width *b* (2a ff.). Further extension steps are applied until the total excavation width is reached.



4. Local relief of the artesian soil conditions as a technical solution of the hydraulic soil failure problem

The artesian aquifer probably stretches out beyond the area around the power plant. It is impossible to remove artesian pressures from the entire aquifer, but a local relief under the construction site is conceivable. In order to separate the relieved zone from the artesian aquifer, a hydraulic barrier consisting of a sheet pile wall can be inserted.



The numerical analysis shows that if the relief is achieved efficiently, the initially foreseen excavation of 40m width and 5.5m depth can be carried out in stable conditions. Even if the pile wall is not deep enough to separate the relieved zone completely from the artesian aquifer, the analysis gives stable results.

5. Conclusion

Artesian soil conditions lead to very difficult conditions for excavation works. Removing soil and lowering the groundwater table leads to less stabilizing soil weight and increased seepage forces. Hydraulic soil failure is likely to occur. A thorough soil investigation in a preliminary project phase in order to detect and characterize the artesian aquifer is therefore crucial.

The initial project of the power plant on Sakarya river did not take into account these conditions and had to be relocated due to the high risk of hydraulic soil failure. In this thesis, two alternatives to relocation of the plant are presented. The effect of cohesion can be used in a stepwise excavation process in order to obtain a stable pit bottom. However, for large excavation pits, this solution leads to a time consuming and extremely cumbersome process. The solution of locally relieving the artesian conditions yields more efficient results. However, the exact soil layering, permeabilities and artesian pressures must be known beforehand in order to obtain a correct model.