Decisive Parameters for the Design of Power Plant Caverns

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Abstract

The demand on pumped storage plants for energy storage and covering peak current has been increasing significantly during the last years. Simultaneously, standards for environmentally and ecologically friendly design of power plants are set at higher levels. As a consequence power plant cavern with cross-sectional areas of >1500 m² are executed by an increasing number.
From a rock mechanics perspective, challenges concerning excavation and support systems for such caverns arise. Even though preferred geological boundary conditions in sound rock may be given, plastic zones in rock are developing causing rearrangement of stresses and thus deformation up to several centimeters. This tendency is supported by the tight arrangement of tunnels, galleries and shafts required for operation and maintenance as well as the distance between powerhouse and transformer caverns, which shall be as small as possible. Still, the rock pillar between the two caverns has to fulfill design requirements in terms of strength and stiffness.
In this technical note, some dependencies with respect to decisive parameters for the design of power plant caverns are presented. The dependencies include size of the cavern, geology, excavation and support measures and resulting deformation. The data on which the dependencies are based on result from data collected in design project of ILF as well as from literature.

Introduction

With the increasing demand on renewable energies the requirements of pumped storage plants (PSP) are growing. Already today's power production requires certain availability of storage capacity due to the time lag between production and demand. However with increasing capacity of renewable energies, such as solar and wind power plants, the requirements concerning production and storage capacities of PSP rise. Therefore the number of PSP under construction is growing. In order to design economically and to consider all required boundary conditions, it is common practice to place machines and transformers in underground caverns. As a consequence of the above mentioned tendencies in terms of capacity, the requirements concerning size of caverns grow simultaneously. From a rock mechanics perspective, this implies that excavation and support of caverns in rock get more challenging. This is not only due to the size of caverns or complexity of access tunnels but also due to tighter schedules for design and construction. When starting a project, in order to get a first idea of requirements and deformation tendencies, it would be useful to have a tool for a first assessment of geometry, support and deformation behavior of the required power cavern.
In this paper, some correlations concerning decisive parameters for the preliminary design of power caverns are presented. These correlations may provide a first idea concerning required size of a cavern as a function of the required capacity as well as concerning support as a function of

rock properties.

Decisive Parameters and their Influence on Cavern Design

Parameter Identification

The main parameters taken into account in this study are summarized below:

- total capacity of the PSP: Here, the maximum capacity for power production is considered
- length (L), width (W) and height (H)
    - area of the cavern (W x L)
    - cross-sectional area of the cavern (W x H)
    - volume of the cavern (W x L x H)
- overburden h above the cavern
- stiffness rock and rock mass: Limited by the availability of the number of data sets, here the properties of rock and rock mass considered are E_{int} and E_{rm} where index *int* denotes intact rock and *rm* denotes rock mass.
- strength of rock and rock mass: In analogy to the stiffness, the unconfined compression strength (UCS) of intact rock and rock mass are denoted by UCS_{int} and UCS_{rm} respectively.

Although the anisotropy of the rock mass is considered to be important, this parameter has not been considered due to the lack of available of data.

Shape of Cross Section

The most common shapes for the design of caverns are shown in Fig 1.

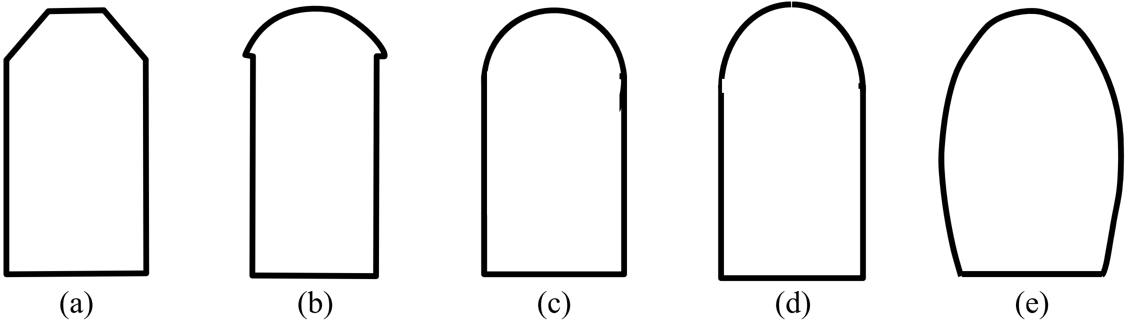
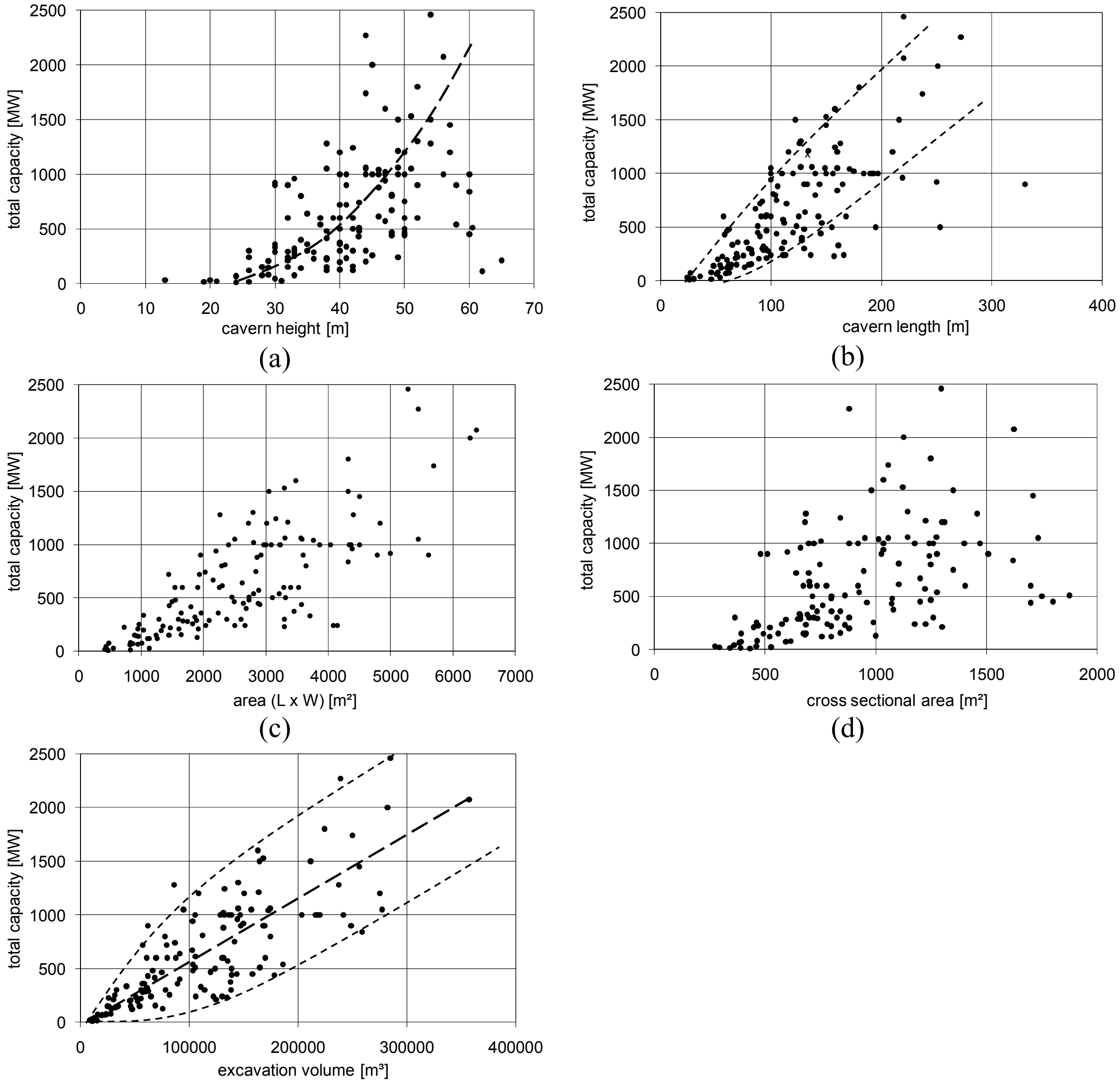


Figure 1: Common shapes of caverns; (a) trapezoidal; (b) mushroom; (c) circular shape; (d) bullet shape; (e) horse shoe

The choice of the shape to be considered for a particular cavern cannot be related directly to the above mentioned parameters. Neither the height nor rock strength shows a clear correlation with the cavern shape. In fact the optimum shape of the cavern is the one with minimum moment in the concrete lining. A correlation might be found when relating anisotropy to the vertical stress and strength of rock mass. At this stage, the database is not sufficiently filled to return significant results.

Correlations between Capacity and Cavern Dimensions

In the first place, correlations between capacity and geometry of the cavern have been analyzed (see Fig. 2). While correlation of cavern height may be correlated from the capacity, it has been found that for the cross sectional area (B x H) and the area of the cavern (L x B) dimensions cannot be correlated separately. Then again, the correlation between the capacity and the entire volume of the cavern is promising. Therefore, the remaining parameter may be derived from this correlation.

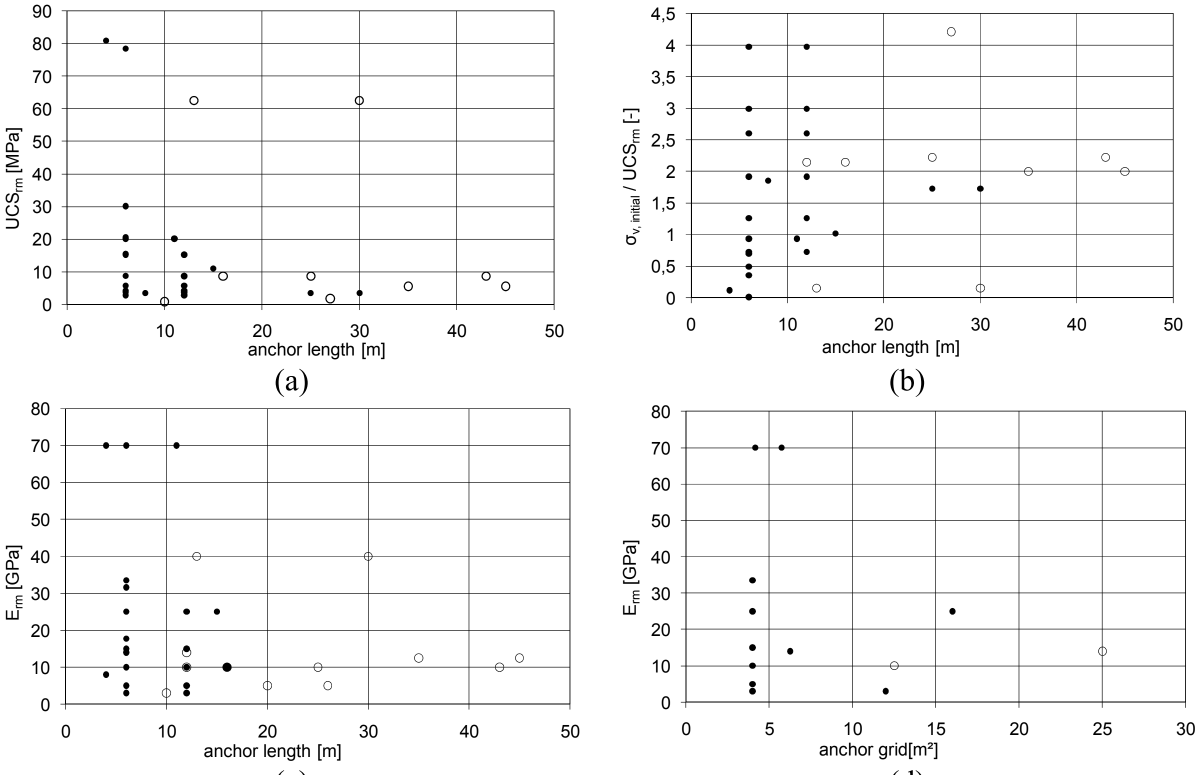


(a) (b) (c) (d) (e)

Figure 2: Correlations between total capacity and dimensions of PSP caverns. Dots represent data from literature and own projects, lines denote interpretation of mean values and ranges.

Correlations between Rock Properties and Support

Some correlations between stiffness and strength of rock mass and the anchor grid size and anchor length are shown in Fig. 3. Black dots denote passive anchors whereas white dots represent prestressed anchors.



(a) (b)

(c) (d)

Figure 3 (a)-(d): Correlations between of the rock mass properties and supporting anchors

Correlation between Rock Properties, Cavern Dimensions and Deformations

In Fig. 4, vertical deformation normalized by the width of the cavern is plotted against the stiffness and the strength of rock mass, respectively.

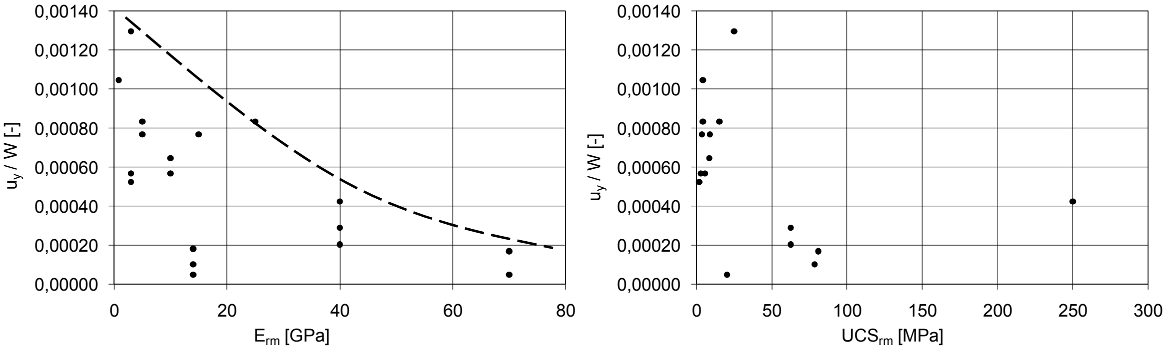


Figure 4: Vertical deformation u_y normalized by the width W of the cavern plotted against the stiffness (a) and the strength of rock mass (b).

Conclusion

Based on literature and own projects, a data set to evaluate decisive parameters for power plant caverns is presented. Some dependencies and correlations between decisive parameters have been investigated. Correlations between total capacity and geometry of the main cavern may be used as a first assessment at an early design stage for power storage plants or may serve to cross check defined geometries.

Furthermore, correlations between geometry and rock properties have been analyzed with respect to expected deformation (i.e. convergence). Some dependencies between support of shotcrete, anchor length and grid are presented as function of rock properties and cavern size.

Due to the decreasing number of available data sets with increasing complexity of parameters and results the significance of resulting parameters is decreasing. The data shown here represent an overview of possible dependencies and is a first step towards a more detailed study. Continuous collection and implementation of decisive parameters, in particular rock properties, support systems and measured deformation, into the database will further increase the significance of the dependencies.

The authors are aware of the fact and would like to point out that the presented correlations will never replace a fundamental analysis of each particular cavern design. However it may be useful to get a first idea and to check the cavern design at an early stage of a project.

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