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Displacement-based numerical back analysis for estimation of rock mass parameters in Siah Bisheh powerhouse cavern using continuum and discontinuum approach

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ABSTRACT

Back analysis as a modern observational method is a helpful technique for evaluation of soil and rock mass parameters and prediction of their mechanical behavior. Most back analysis techniques in geotechnical engineering problems are based on the methods that utilize the monitored data of stresses, strain and displacements. This technique is one of the prominent processes in design and evaluation of the stability of caverns that reveals the shortcoming of supports design and in fact is essential for evaluation of design parameters. Siah Bisheh pumped storage project with complex geometry, changeable geological formations and diverse geotechnical properties of rocks, is under construction on the Chalus River at the north of Iran. The underground complex consists of three main caverns placed near each other. In this study displacement based direct back analysis using continuum and discontinuum numerical modeling were applied and geomechanical properties of rocks, stress ratio and joints parameters were identified and then calculated parameters were compared with the initial design parameters. Both continuum and discontinuum modeling results were in a good agreement with measured displacements which confirm the numerical modelings correctness and back analysis results.

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1. Introduction

Siah Bisheh Pumped Storage project is located in 125 km north of Tehran, in the vicinity of Siah Bisheh village. This plant is designed to produce a rated capacity of 1040 MW peak energy. In this project, two concrete face rock fill dams are under construction in Chalus valley for the water storage. Siah Bisheh powerhouse cavern (PHC) with 24.5 m width, 46.5 m height and 131 m length is one of the largest underground power plants of its kind in Iran. Transformer cavern (TRC) with 16.1 m width, 28.4 m height and 160 m length and guard gate cavern (GGC) with 5.5 m width, 10.5 m height and 90.7 m length are the other main underground openings in this project. The powerhouse cavern was excavated at a depth of about 260 m (Fig. 1).

Back analysis techniques as a practical engineering tool are nowadays often used in geotechnical engineering problems for determining the unknown geomechanical parameters, system geometry and boundary or initial conditions using field measurements of displacements, strains or stresses performed during excavation or construction works.

From the mathematical point of view, displacement measurements are not greatly influenced by typical local effects. By comparison, stresses and strains are differential quantities, whose validity is limited to local regions (scale effect). Therefore, the observation at several successive points will be necessary to obtain a distribution over a sufficiently large area (Oreste, 2005). On the other hand, displacements of rock masses induced by excavation can be measured easily and reliably. Therefore, extensive studies have been conducted to develop different models of displacement-based back analysis (Sakurai and Takeuchi, 1983; Gioda and Locatelli, 1999; Swoboda et al., 1999; Feng et al., 2004; Zhang et al., 2006; Akutagawa et al., 2000; Sakurai, 2003). Back analysis techniques also have been used based on field measurements of strains or stresses (Kaiser et al., 1990; Zou and Kaiser, 1990).

The main purpose of this study is to use displacement-based direct back analysis approach in order to evaluate the geomechanical parameters of rock masses in Siah Bisheh PHC and compare them with adopted design parameters. The instruments used are inclusive extensometers, load cells, convergency pins and geodetic points. Rock mass parameters selected for design of powerhouse cavern have been based on laboratory tests and conventional rock mass classification methods (Lahmeyer Co., 2005a,b).

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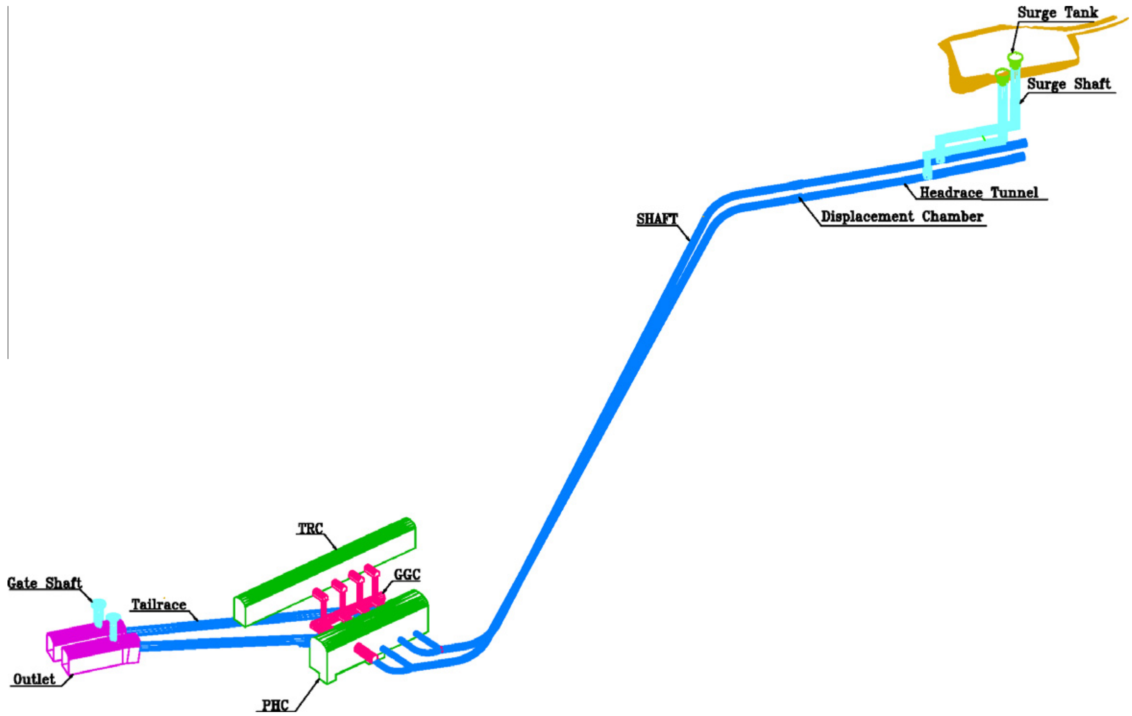

Fig. 1. A 3-D model of Siah Bisheh underground openings.

2. Project description

2.1. Geology and engineering geology

The Siah Bisheh pumped storage project is located at the Alborz Mountains, mainly folded and formed during the Alpine orogenic phase. Geomorphologically, Alborz is a young Mountain with deep and narrow valleys and active tectonics. The most important tectonic phenomenon of Siah Bisheh area are the fault called as the Main Thrust Fault (MTF), with a dip/dip direction of 78/028 and an almost *E–W* trend and the reverse fault of Chalus, which is parallel to the Chalus River in Siah Bisheh area, which must be taking into consideration in terms of seismicity. Powerhouse and transformer caverns are generally under construction at the Permian Formation. In this area, Permian formations mainly consist of quartzitic sandstone, siltstone and shaly siltstone, dark and red shale and igneous rocks. Thickness of these layers varies from some centimeters to 3.5 m (Lahmeyer Co., 2005a,b).

The influence of groundwater on the behavior of rock mass surrounding a tunnel is very important and has to be taken into account in the estimation of potential tunneling problems. When the water is not drained, it reduces the effective stresses and thus the shear strength along discontinuities and finally, in all cases, the strength of the rock mass. In addition, it is particularly important when dealing with shales, siltstones and similar rocks in which they are susceptible to changes in moisture content, which directly affect their strength.

There are uniform bedding layers throughout the powerhouse area with deep and dip direction of 55/195. It is noteworthy that during excavation of the powerhouse pilot at chain ages 40, 81 and 89 of the right wall, three shear zones, with an almost 40–50 cm thickness were encountered. All of these features are parallel to the bedding planes. The azimuth of powerhouse cavern is N152°E and all of the existing faults in the powerhouse area have an appropriate distance from cavern walls and without any intersection.

Rock mass consists of Bedding planes and 5 main joint sets in powerhouse area (Table 1). Based on surveying along the pilot tunnel at the center of powerhouse crown, the rock joints have different lengths of almost 3–10 m and their spacing is between 200 and 600 mm (Lahmeyer Co., 2005a,b).

Table 1
Discontinuities' orientations at powerhouse cavern [10].

Discontinuity	Dip direction (°)	Dip (°)
Bedding	191	55
Joint J1	030	56
Joint J1-1	018	81
Joint J1-2	009	66
Joint J1-3	305	80
Joint J2	078	82

2.2. Geotechnical parameters

Considering the large length of powerhouse cavern, various types of geological properties are present. Due to the fact that most of the geological properties could not be directly measured for this site, they had to be estimated by empirical and theoretical methods. For this purpose, generalized Hoek–Brown failure criterion was utilized. The results showed various geological zones at the power house cavern region and therefore, the area were initially divided into two zones. Likewise to determine the strength characteristics of the rock masses, the uniaxial compressive strength tests were carried out. Moreover, the large flat jack tests and dilatometer tests were performed to determine the deformability characteristics of the rock masses. Also using the field surveys, the RMR value at the related zones was obtained 45 with fair rock class IV. Table 2 shows the mechanical characteristics of different rock types adopted from rock mass classifications and in situ experiments (Lahmeyer Co., 2005a b).

A joint mapping program with 414 measurements was conducted in the exploratory vault adit indicating five major joint sets and one bedding plane.

The shear parameters of $\phi = 25°$ and $c = 0$ were assumed on bedding planes. Also, based on the assumption of 10 cm thick shear

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