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Triaxial creep tests and back analysis of time-dependent behavior of Siah Bisheh cavern by 3-Dimensional Distinct Element Method

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Dedicated to Ali Sharifzadeh who lost his life due to the consequence of tragic car accident during the preparation of this research.

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ABSTRACT

Time dependent effects or creep behavior of rocks has great importance in further development of knowledge in the field of rock mechanics. An increase of pressure on support system due to creep behavior of rock is one of the most important issues in underground structure with weak surrounding rock mass. In this contribution a time-dependent behavior analysis of Siah Bisheh pumped storage powerhouse cavern with complex geometry being under construction on the Chalus River at the north of Iran were investigated. The cavern surrounded rocks containing Shale, Limestone, Sandstone and igneous rock in major parts is located in Alborz Structural Zone. The cavern is being built in a region that is highly prone to sheared and faulted zones. Therefore, it is essential to analyze and design underground structures to prevent any serious long-term damages in this region. The rock mass may exhibit continuous or discontinuous deformations due to excavation of large underground openings; therefore, deformation include shearing of joints and creep deformation of rock material. Because of the fractured and jointed rock mass, the Discrete Element method used to back analysis the time-dependent behavior of the Siah Bisheh cavern. In addition, triaxial creep tests were performed on rock specimens in order to estimate the time-dependent behavior of rock around the cavern. The creep tests and in situ measurements were employed to estimate parameters of power constitutive creep model being able to model the primary and secondary creep regions of rock masses implemented in the 3-Dimensional Distinct Element Code. Simulation results show good agreement with monitoring data. By excavating the lower stages of the cavern, some instantaneous deformation occurs in displacement–time curve of the crown.

1. Introduction

Time dependent deformation of rocks has significant effect on stability of underground structures. In order to study the stability of the underground structures and designing their support system, time dependent deformations should be highly considered (Shalabi, 2004; Tsai et al., 2008). Therefore, time-dependent behavior of underground structures as well as predicting the long-term behavior, is of great importance. Squeezing may occur in two main types of rock masses, namely, 'massive' (or intact) incompetent or weak (ductile, deformable) rocks and 'particulate materials' (or heavily jointed) rocks (Nilsen and Palmstrom, 2000), and may take place in two stages named instantaneous and secondary or creep type squeezing which depends on the tangential stress level, rock mass properties and tunnel shape. However, the fundamental mechanisms of squeezing are not fully understood (Barla, 2001; Kovari, 1998). Since a reliable constitutive model able to interpret creep phenomena is required in underground structures, indeed, the prediction of time-dependent behavior would not be easy to determine (Boidy and Pellet, 2000). It is also well known that rock properties measurements based on laboratory tests cannot be directly extrapolated in field scale without due precaution (Boidy et al., 2002) because the mechanical properties of discontinuous rock mass strongly depend on the properties and geometry of joints. Therefore, it is essential to use numerical analysis for simulating time-dependent behavior of rock mass and comparing with measurements obtained from monitored cavern over a long period.

As a practical engineering tool, nowadays, back analysis techniques are used in geotechnical engineering problem 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. Back analysis based on displacement, strain and stress measurements have been used for solving various geomechanical problems (Sakurai and Takeuchi, 1983; Kaiser et al., 1990; Gioda and Locatelli, 1999; Swoboda et al., 1999; Feng et al., 2004; Boidy et al., 2002; Zhang et al., 2006).

This paper presents the back analyses of time-dependent behavior of Siah Bisheh pumped storage cavern instrumented over

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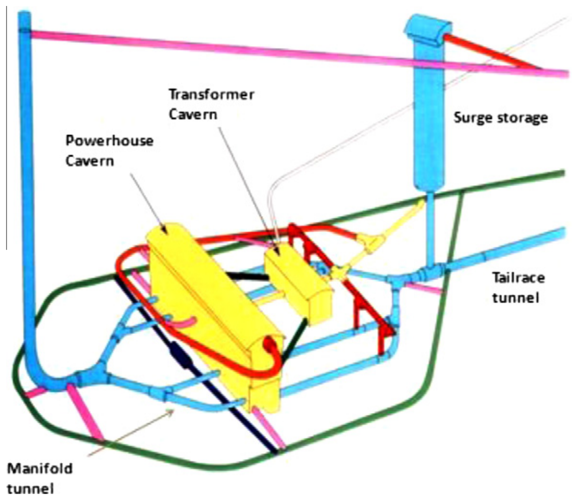

Fig. 1. A 3D model of Siah Bisheh underground opening.

4 years. The powerhouse cavern with 132 m length, 25 m width and 46.5 m height is the main underground structures in Siah Bisheh project. The powerhouse is constructed at a depth of approximately 250 m below surface. The total generating capacity of the scheme would be 1000 MW.

Siah Bisheh powerhouse cavern is located in discontinuous media and the failure of rock mass is mainly controlled by the discontinuity distribution. The study concerns the first 80-m part of cavern located mainly in red shale and quartzite sandstone. A 3D layout of the Siah Bisheh underground opining is shown in Fig. 1.

2. Siah Bisheh pumped storage powerhouse

Siah Bisheh pumped storage powerhouse is under construction on the Chalus River, north of Iran. Two dams will be constructed in Chalus valley for the water storage. Both dams are designed as concrete faced rockfill dams. Powerhouse cavern is located near the lower dam reservoir and its crown is more than 30 m below the lower dam maximum lake level.

Table 1
Discontinuity orientations at powerhouse cavern area (Lahmeyer-Iran Water and Power sources Co., 2005).

Discontinuity	Dip direction (°)	Dip (°)
Bedding	195	55
Joint J1	030	56
Joint J1–1	018	81
Joint J1–2	009	66
Joint J1–3	305	80
Joint J2	078	82

2.1. Geology and engineering geology

The Siah Bisheh pumped storage project is located at the Alborz Structural Zone being mainly formed and folded during the Alpine orogenic phase. The most important tectonic phenomenon of Siah Bisheh area is the fault called as the Main Thrust Fault (MTF), with a dip/dip direction of 78/028 and an almost E–W trend. Meanwhile, the reverse fault of Chalus, being parallel to the Chalus River in Siah Bisheh area, is another fault, which must be taken into consideration in terms of seismicity. The site of powerhouse caverns is generally located at the Permian Formation part. 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 few centimeters to 3.5 m (Lahmeyer-Iran Water and Power Resources Co., 2005).

The orientation of the bedding planes has no considerable changes in dip and dip direction. There are uniform bedding throughout the powerhouse area with deep and dip direction of 55/195. The azimuth of powerhouse cavern is N152-E and none of the existing faults in the powerhouse area crosses with proper distance from it. Rock mass consists of bedding planes and five main joint sets in powerhouse area demonstrated in Table 1. Based on surveying along the pilot, joints have different lengths of almost 3–10 m and their spacing is between 200 and 600 mm (Lahmeyer-Iran Water and Power Resources Co., 2005).

2.2. Excavation, support system and monitoring of powerhouse cavern

For excavation of powerhouse cavern, first, a pilot was excavated at the center of crown and then slashing the crown was carried out. After that, benching was performed with 3 m depth per stages until powerhouse floor (Ghorbani and Sharifzadeh, 2009). The support system in powerhouse cavern consists of shotcrete with wire mesh (20 cm in sidewalls and 25 cm in roof), grouted rock bolts (temporary support system) and double corrosion protection tendons (permanent support system). After each cycle of blasting, the exposed roof and walls was immediately shotcreted. Bolt installation had sometimes delayed. At present, many drainage holes with 4 m lengths and a 4_4 m pattern have been performed at roof and side walls of powerhouse cavern (Fig. 2) (Ghorbani, 2008).

Six instrumentation stations were set up along the axis of the powerhouse cavern at chainages of 26, 49, 67, 87,105 and 121. These arrays consist of grouted rod extensometer in the roof and sidewalls, convergency points, piezometer, pressure cell as well

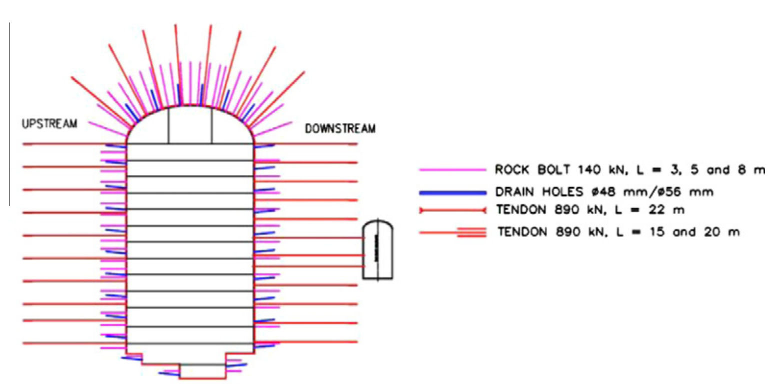

Fig. 2. Typical support system installed in the powerhouse cavern and excavation stages with drainage holes at roof and sidewall.