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Comparison between plate jacking and large flat jack test results of rock mass deformation modulus

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ABSTRACT

The results of two types of loading tests for the determination of the in situ rock mass deformation modulus (E_m), namely, large flat jack (LFJ) and plate jacking tests (PJT), which were carried out side by side during the exploratory phase of the Karun 3 hydro-electric project in Iran, have been compared, correlated and analysed. The comparison includes sixteen PJTs and twelve LFJ tests. PJT moduli obtained from displacements measured in depth are much higher than the LFJ moduli and are sometimes even higher than the modulus of the intact rock material. However, this investigation has proved that they can be well correlated with the corresponding LFJ results and reduced by factors established in this comparison. The analyses showed that uncertainties connected to PJT results are caused by the restraining effects of the adjoining rock, and the disturbing effects of blast damage, and also that the scattering of results occurs due to insufficient volumes of rock mass tested. A new empirical relationship for indirect estimates of E_m based on the RMR classification scheme is made from field data presented in this investigation and other reliable published data.

1. Introduction

In any analysis of rock mass mechanics, the deformation modulus is an important input parameter. The modulus of deformation describes the relationship between load (applied stress) and resulting deformations (strain) that include elastic and inelastic behaviour.

The determination of the modulus is still a major problem in the field of rock mechanics and usually the rock mass deformability is determined by only using laboratory test results of intact rock specimens and extrapolating these results to the rock mass based on parameters that can be obtained at low cost from field observations. The empirical correlations for indirect estimates of rock mass deformability are usually based on classification schemes such as the Rock Mass Rating (RMR) [1], the Geological Strength Index (GSI) [2], the Tunnelling Quality Index (Q) [3] and the Rock Mass Index (RMi) [4].

In situ test methods for direct measurements of rock mass deformability are performed rarely, since they are time-consuming, expensive, difficult to conduct and the reliability of the results is sometimes questionable [5,6]. In this regard Bieniawski [7] said "Unfortunately, few projects to date have featured a sufficient number of different tests to allow a meaningful comparison of in situ test data. Very different in situ results may be obtained depending on the test method. This means that it is difficult to rely on any one in situ method alone: two or more methods should be used to crosscheck the results."

For the design of important expensive structures (concrete dams, large underground caverns, large foundations and tunnel linings) to be built on or within rock masses, the rock mass deformability has to be determined by in situ tests. Furthermore, most of the existing empirical correlations have been made on data obtained by in-situ tests. This is why in developing empirical relationships it is important to use reliable field data that have been accordingly verified, e.g. by using different in situ test methods on the same location.

A plate loading (PLT) or jacking test (PJT) is the most common in situ test [6] among large test methods for the determination of the rock mass deformation modulus. Both PLT and PJT are often named the plate bearing test as well. They are performed in test adits with a height of 2.0–2.5 m and a span of 2 m. Test adits are usually excavated by the drill and blast technique. The main disadvantage of the plate test lies in the fact that the rock surface that is loaded is more or less disturbed by blasting and furthermore, in many cases the tested rock mass volume is not representative for the rock mass [8,9]. The PLT version measures displacements only on the rock surface, while the PJT with a central instrumentation hole and multiple position borehole

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extensometers (MPBX) measures displacements at different depths in the rock mass as well. Unfortunately, the addition of the MPBX did not solve the problem of unknown stress distributions in the zone influenced by the surface loading [10]. Due to large scatter in PJT data, the interpretation is often a difficult task and becomes a matter of good engineering judgement.

A large flat jack test (LFJ) was devised by Rocha [11] with the aim to eliminate drawbacks of the plate bearing test. This method was used in several large dam sites in Portugal and some other countries. While the method gave reliable results, it was expensive and therefore, has not been used in recent years [6]. The LFJ test method has the advantage over other methods of testing insofar as it investigates the deformability of the rock mass in an almost undisturbed state [12].

Large flat jack (LFJ) and plate jacking (PJT) tests were applied during geotechnical investigations for three large hydro-electric projects in Iran during the 1990s. These valuable field data have been revisited in order to reinterpret PJT data utilizing the least-squares method and formulae derived for a rigid circular plate as defined in detail by Unal [13]. Originally, the PJT data were interpreted using the ISRM Suggested Method [14]. Different PJT moduli, obtained in the reinterpretation, have been compared and correlated with reliable LFJ moduli.

The aim of this paper is to present the results of the comparison between PJT and LFJ test data which, in the opinion of the authors, can help plate jacking test users to properly use as well as treat and interpret the test data. It has been proved that PJT results calculated from displacements measured at extensometer points in depth can be well correlated with corresponding LFJ results and reduced by factors established in this comparison. Also, a new empirical relationship for indirect estimates of E_m based on the RMR classification scheme is made from field data presented in this investigation and other reliable published data.

2. Geotechnical investigations

Geotechnical investigations for three large hydro-electric projects on the Karun river in Iran, namely, Karun 3 HEPP, Masjed-e-Soleiman HEPP and the extension phase (powerhouse cavern) of the Shahid Abbaspour dam (Karun 1), were carried out by the Croatian company Geotehnika during the 1990s.

The Karun 3 (K3) Dam is a 205 m high, double-curvature concrete arch dam and it is located in the western Zagros mountain range, in the north-east of the Khuzestan Province. Its construction was completed in 2004. Asmari and Pabdeh are the dominant geological formations in the area and they consist of folded Oligocene and Miocene sedimentary rocks. The first formation comprises strong, thickly bedded limestone and marly limestone and the other weak to moderately strong marlstone and marly limestone interbeds. The most important geological feature in the site is the Keyfmalek anticline, whose core is made of the Pabdeh formation. The dam foundations are located in Asmari limestones within the anticline ridge's flank. Geotechnical parameters of the rock masses at the Karun 3 site are shown in Table 1 [15]. In order to determine the deformability characteristics of the rock masses in the left and right abutments, an extensive in situ testing programme has been carried out. Six exploratory adits were excavated where four of them were located in the right abutment and two in the left one. The in situ deformability testing comprised twenty-two plate jacking (double-sided plates, forty-four tests), twelve large flat jack tests, and thirty-nine flexible dilatometer tests in boreholes, the results of which are described in detail in the test reports (Geotehnika Co., Zagreb, Croatia (1993): Karun 3 Development Project, Iran Water and Power Resources Development Company, Tehran—Iran, Final reports on plate load and large flat jack tests).

The Shahid Abbaspour Dam, also known as Karun 1 (K1), is located 120 km downstream of the Karun 3 Dam. It was completed in 1976 as the first of a series of dams planned for development on the Karun river. It is also a double-curvature concrete arch dam with the height of 200 m. Originally there was a power station on the dam site located on the ground surface with a capacity of 1000 MW. In the 1990s the decision was made to extend the capacity for another 1000 MW through the excavation of an underground powerhouse cavern (145 m long, 26 m wide and 52 m high). Geotechnical investigations for that purpose comprised the excavation of an exploratory adit and performing in situ deformability tests: six plate jacking tests (double-sided plates, twelve tests) and ten flexible dilatometer tests in boreholes. Corresponding results of plate jacking tests are given in the test report: Geotehnika Co., Zagreb, Croatia (1994): Shahid Abbaspour Dam (Karun 1), Underground Powerhouse No. 2, Iran Water and Power Resources Development Company, Tehran—Iran, Final report on plate load tests. The cavern is located in the Asmari formation, which is comprised of thick beds of limestone. The average compressive strength of intact rock is 100 MPa.

The Masjed-e-Soleiman Dam (Godar-e-Landar) is also located on the Karun river, 26 km downstream of the Shahid Abbaspour Dam. It is a rockfill dam with a vertical clay core and height of 177 m. The underground powerhouse cavern (267 m long, 30 m wide and 50 m high) and the transformer cavern (110 m long, 14 m wide and 21 m high) are located in the right abutment. These caverns lie predominantly in the Bakhtyari formation that is divided into more than ten units in this area. The powerhouse cavern is located in units IV and V that consist of conglomerate, sandstone, siltstone and claystone. The laboratory test results on intact rock samples taken from the Bakhtyari formation are presented in Table 2 [16]. Geotechnical investigations in the area comprised the excavation of an exploratory adit, drilling of boreholes and performing in situ deformability tests: five large flat jack tests and 50 flexible dilatometer tests in boreholes. The LFJ results are detailed in the report: Geotehnika Co., Zagreb, Croatia and Interfels GmbH, Bad Bentheim, Germany (1993): Masjed-e-Soleiman (Godar-e-Landar) HEPP, Iran Water and Power Resources Development Company, Tehran—Iran, Report on extra large flat jack tests.

3. Plate jacking test

Plate jacking tests at Karun 3 and Karun 1 projects were carried out in test adits using double-sided rigid circular plates with a diameter of 1 m (Fig. 1). The equipment was produced by Interfels

Table 1
Geotechnical parameters of the rock masses at the Karun 3 site [15].

Geotechnical parameter	Limestone	Marly limestone	Marlstone
UCS dry (MPa)	70–90	60	20–25
UCS wet (MPa)	60	50	15
RMR	40–70 (aver. 58)	23–60 (aver. 49)	12–45 (aver. 38)
Karstification	High	Medium	Low
Durability	High	Medium to low	Low

Table 2
Laboratory results on intact rock samples taken from the Bakhtyari formation [16].

Geotechnical parameter	Conglomerate	Sandstone	Siltstone	Claystone
UCS (MPa)	56–57	53–67	39–43	23
Ei (GPa)	25–45	18–25	11–13	8