Geotechnical and Geophysical Site Characterisation 5 – Lehane, Acosta-Martínez & Kelly (Eds)
 ISBN 978-0-9946261-2-7

Investigation the results of Plate Load Test using rigid plates in weak rock masses (Case study)

M. G. Nik
School of Railway Engineering, IUST University, Iran

B. Abrah & E.G. Samani
MSc, Rock Mechanics, Azmune Fulad Consulting Engineering Co., Iran

ABSTRACT: The most important parameters for designing and numerical modelling are deformability modulus, cohesion, friction angle, poison's ration and stress ratio, among which the modulus of deformation is of paramount importance. Plate loading test using rigid plates is one of the large scale tests for determining de-formability modulus of rock masses. This test has been used for measuring the aforementioned modulus of low quality rock mass at the left abutment of Karun2 dam in Iran. Care should be taken in interpretation of test results due to existence of fractures and porosities in weak rock masses. In this paper, analysing the re-sults of the experiments has been performed with three methods, i.e., ASTM, ISRM and UNAL and there has been a big difference between the out coming results of ASTM and ISRM methods with UNAL method.

1 INTRODUCTION

Plate load test is one of the in-situ rock mechanics experiments for determining deformation modulus of rock masses. In this test, for measuring the deformability characteristics of rock mass, loads are applied through a flexible jack or a pair of circular and rigid steel plates on the reciprocal surfaces in a small gallery or access tunnels. The induced deformation due to loading are measured in the boreholes behind the loading plates. The required data for calculating deformation modulus in loading-unloading cycles are achieved with increasing and decreasing the loads. Figure 1 shows schematic view of the method of conducting a flexible plate load test.

2 GEOLOGY OF KARUN 2 DAM SITE

The dam site is locating about 70 km far from Izeh city in Khuzestan province and has laid on the north eastern crest of Pabdeh anticline. Pabdeh and Asmari formation have been investigated in the vicinity of dam location. Engineering geological profile of dam axis has been shown in figure 2.

3 EQUIPMENT FOR CONDUCTING PLATE LOADING TESTS

This equipment consists of a pair of rigid plate having a weight of 750 kg and external diameter of 100 cm with a 14 cm central hole, steel spacers with different lengths for filling the gaps between rigid plates, 12 MPBX with related sensors, hydraulic jacks with the capacity of 250 tons and related pumps, data logger system, mechanical packers and related aluminum rods. Figure 3 shows the equipment for this tests in set up procedure. Two boreholes are drilled at behind the plates with the length and diameters of 6 m and 76 mm, in each 5 extensometers are installed.

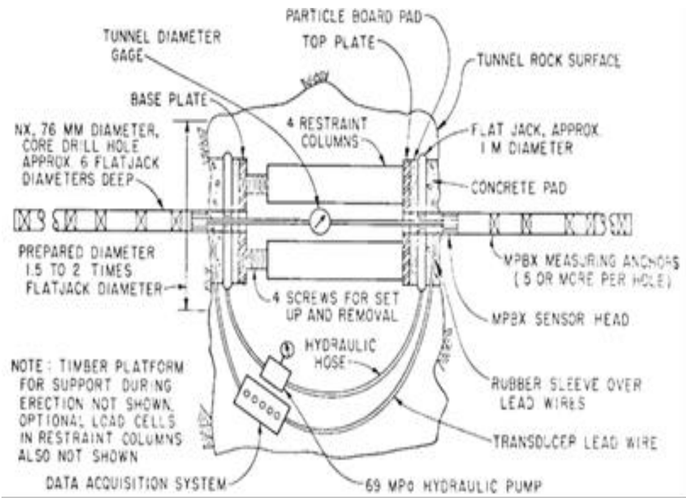

Figure 1. Typical setup for flexible plate loading test [4].

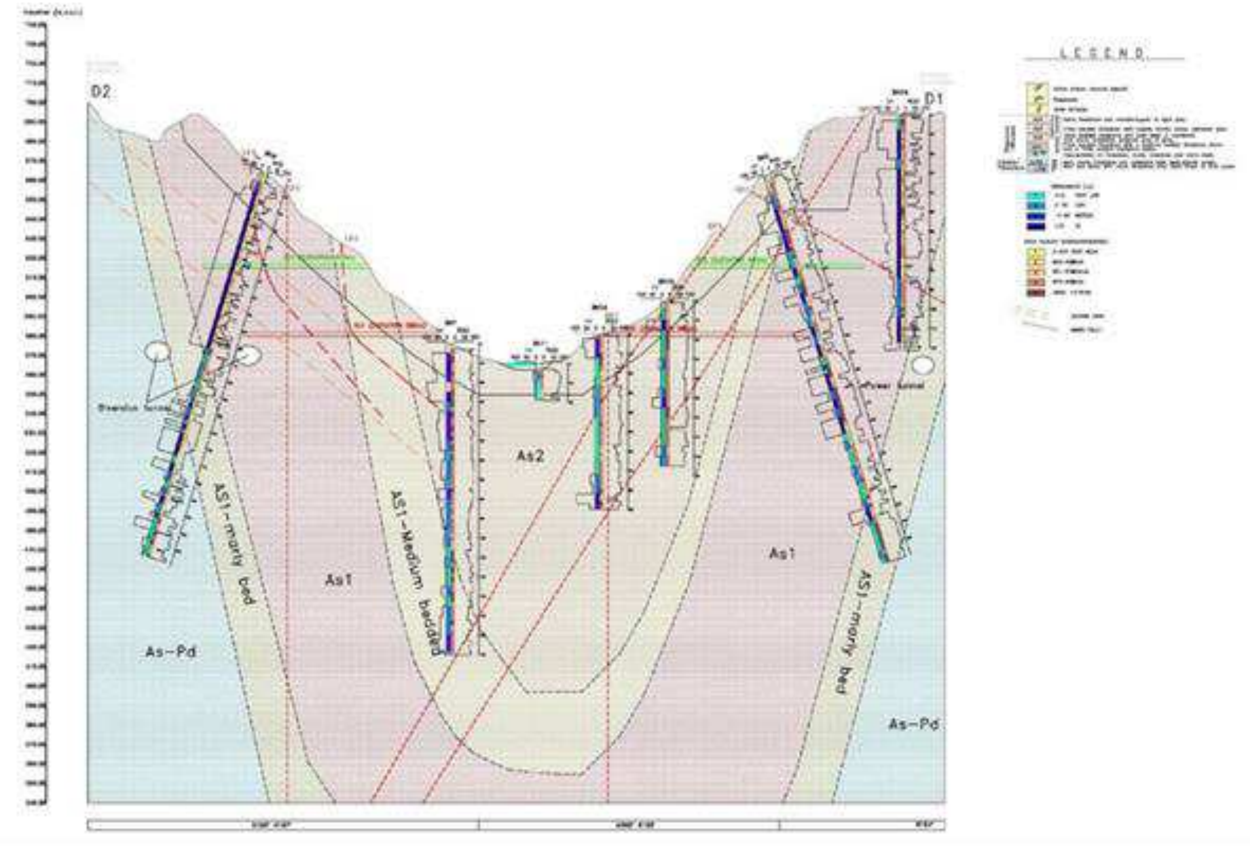

Figure 2. Engineering geological profile of Karun 2 dam axis [4].

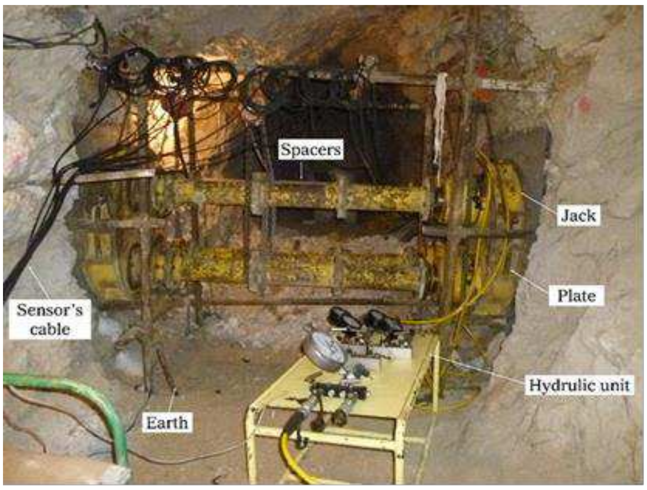

Figure 3. Equipment for conducting Plate Load Test [4].

4 GEOLOGICAL DATA ACQUISITION

Before placing rigid plates on the rock surface, chipped and smoothened surfaces have been mapped precisely (figure 4). These surfaces have then been paved with a layer of cement and a borehole has been drilled at the centre of each surface. Figure 5 shows a series of cores brought out of one of the boreholes.file.

5 SOLVING THE PROBLEMS AND INSTRUMENT INSTALLATION

One of the problems encountered in this project was the method of installing instruments in boreholes. Existing numerous voids and cavities of small (tens of cm) to large (more than 1 m) types, open discontinuities and fractured rocks enhanced the possibility for instruments to be stuck so that in one of the tests there was not possible to install the extensometers due to existing of voids up to 2 m wide. Also positioning the packers in points such as joints or other discontinuities in the rock mass could create doubts in validity of data. For these reasons, a borehole camera was used for determining the true position of the voids, open joints, fractured zones and appropriate location for extensometers to be installed. Since the camera showed a number of cavities, voids and weakness points in most of the boreholes, it was decided the voids in boreholes to be filled with soil and plaster grout (figure 6) and re-drilled with a single core barrel through the plaster grout which has filled the voids and cavities at the borehole walls and therefore resulted in making a smooth surface for installing the packers of extensometers. The merit of filling the voids with soil and plaster grout is that the modulus of deformability is not changed accordingly.

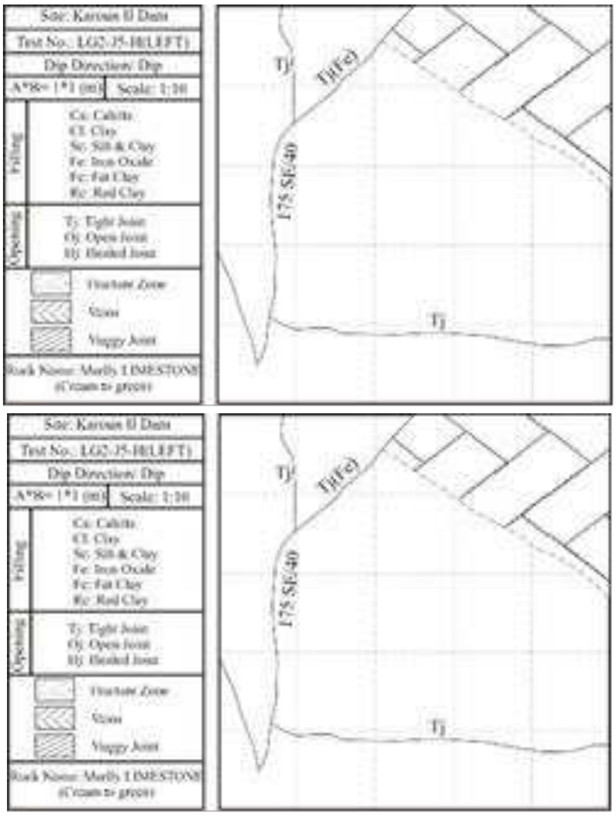

Figure 4. Mapping left and right chipped and smoothened surfaces before a test [4].

Figure 5. a sample box containing cores of a borehole in one of the tests [4].

As an example of encountered problem due to defects of rock mass in this project, the test number LG2-J5-H may be referred as a witness. The test has to be conducted in 5 cycles with maximum pressures of 2, 4, 6, 8 and 10 MPa. Due to the voids and clayey interlayers in the rock mass, the prepared rock surface could not bear the full pressure of the test and was deformed in 8 MPa obliquely (figure 7). With regard to the deformation on the right edge of loading plate and horizontal set up of the test, it was stopped at the end of the forth cycle to prevent the risk of injuries due to falling a very heavy steel column (figures 8 and 9).

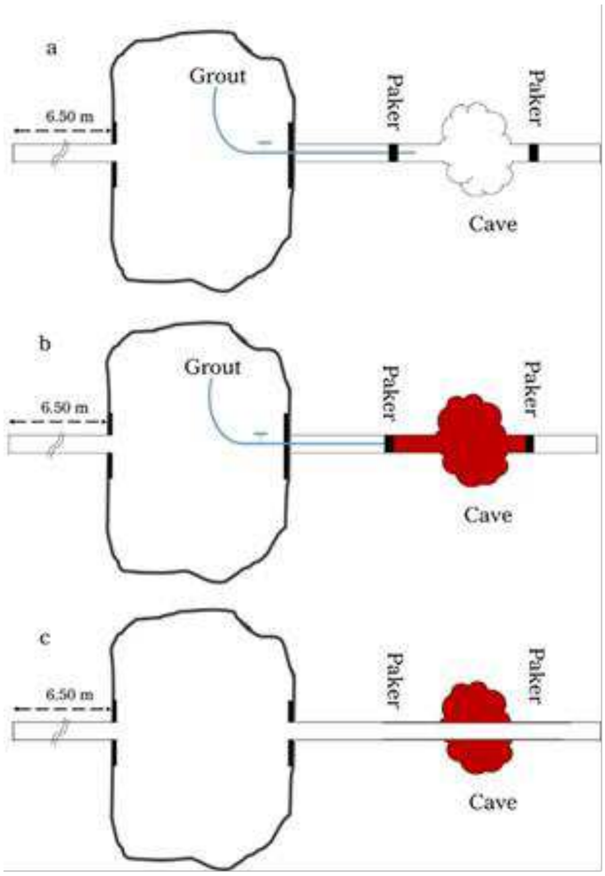

Figure 6. The procedure of filling voids and cavities in extensometer holes [4].

Figure 7. Dis-harmonic deformation in loading surface in a test [4].

6 CALCULATIONS

Three methods of calculations modulus of deformability, i.e., ISRM, 1981, ASTM, 2008 D4394-08 and UNAL, 1997, have been used in this project in order to compare the results obtained from these methods of calculations.

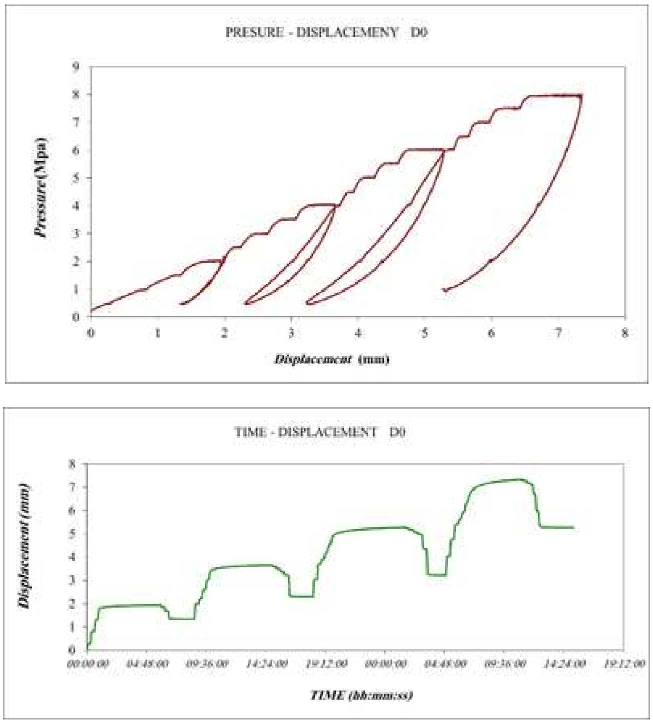

Figure 8. Pressure-displacement and Displacement-time curves [4].

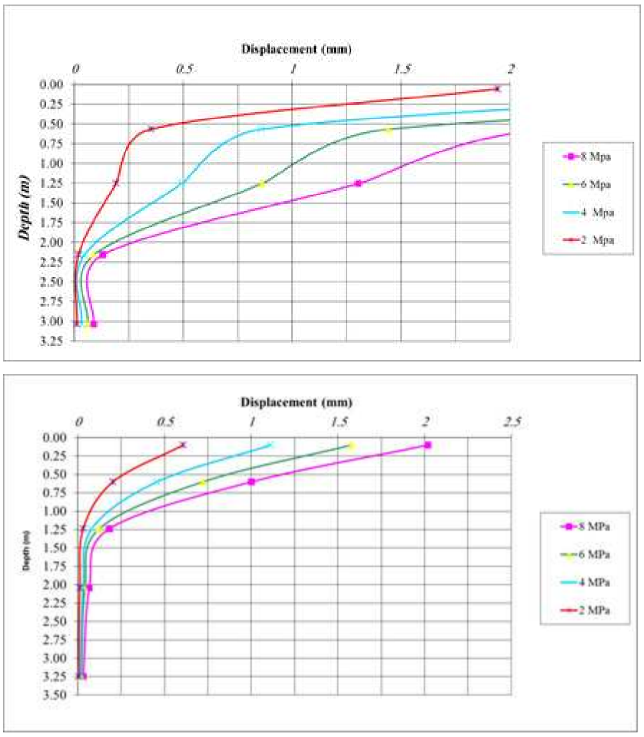

Figure 9. Displacement –depth for left and right plates [4].

6.1 *ISRM, 1981*

The relations used in this method are based on elastic solution for uniform loading (constant stress) on a circular surface of isotropic elastic semi-infinite media. As the rock mass under pressure has not conformity with these assumptions, the structural specifications of the rock mass and the parameters effective on the results should be considered in using the results of the tests. The Poisson's ratio used for calculation of deformability modulus in all the tests has been obtained from laboratory experiments on the cores came out from the related boreholes and has been equal to 0.25.

In the case of using flexible flat jack and having displacement amount in depth of Z in relative to loading surface, instantaneous deformability modulus is determined from relation 1:

$$E = \frac{2Q(1-\nu^2)}{W_z}[(R_2^2+Z^2)^{0.5}-(R_1^2+Z^2)^{0.5}] + \frac{QZ^2(1+\nu)}{W_z}[(R_1^2+Z^2)^{-0.5}-(R_2^2+Z^2)^{-0.5}] \quad (1)$$

Where, E is deformability modulus (MPa), Q is the pressure applied on loading surface (MPa), υ is Poisson's ratio of the rock mass, R_1 is the diameter of central hole of loading plate (m), Z is depth of the measuring point to loading surface (m), R_2 is the diameter of loading plate (m) and W_z is displacement of depth of Z (mm).

It should be mentioned that despite the extensive use of the relation proposed by ISRM for analysing plate load test results, this equation has been presented for experiments with flexible type of loading surfaces.

6.2 *ASTM, 2008*

Calculation the deformability moduli of rock mass in this method has been done based on proposed relation of ASTM, 2008 standard. This relation for determining deformability modulus of rock mass at the points in the extensometer borehole behind the rigid circular loading plates is as relation 2:

$$E = \frac{(1+\nu)P.R}{2W_Z}[(2-2\nu)arcSin\left(\frac{R}{(R^2+Z^2)^{0.5}}\right) + \frac{R.Z}{(R^2+Z^2)}] \quad (2)$$

Where, E is deformability modulus of rock mass (MPa), P is the pressure applied on loading surface (MPa), υ is Poisson's ratio of the rock mass, R is the diameter of loading plate (m), Z is depth of the measuring point to loading surface (m) and Wz is displacement of depth of Z (mm).

6.3 *UNAL, 1997*

Determination of instantaneous, average and total deformability modulus of rock mass is possible by means of the relation proposed by UNAL. Engineering judgment is required for selection of appropriate modulus. The relation is as:

$$E = \frac{Q_{ave}.R}{2W_Z}[2(1-\nu^2)arcCot\,Z + (1+\nu)\frac{Z}{Z^2+1}]$$

If: (3)

$$K = \frac{R}{2}[2(1-\nu^2)arcCot\,Z + (1+\nu)\frac{Z}{Z^2+1}]$$

Then:

$$E = K.\frac{\Delta Q_{ave}}{\Delta W_Z}$$

Where, Q_{ave} is average stress applied on loading plate (MPa) and R is the diameter of loading plate (m). It should be mentioned that instantaneous moduli has been used in this project. The calculated results from the above mentioned methods have been shown in table 1.

Table 1. Calculated results from three methods

Test Results Summary

Project: Karoun II Dam	Test No: LG2 - J5 - H	Test orientation: Horizontal	Date: 2014	By: B. Abrah

RIGHT Plate

			Anchor Depth (m)														
			3.035			2.155			1.255			0.565			0.055		
	Anchor No :		D4			D3			D2			D1			D0		
	Pressure (Mpa)		Modolus (GPa)			Modolus (GPa)			Modolus (GPa)			Modolus (GPa)			Modolus (GPa)		
	From	To	ISRM	ASTM	UNAL	ISRM	ASTM	UNAL	ISRM	ASTM	UNAL	ISRM	ASTM	UNAL	ISRM	ASTM	UNAL
Loading (MPa)	0.5	2	16.6	16.5	32.1	14.9	14.8	27.7	2.5	2.4	4.0	2.4	2.3	2.9	0.7	0.6	0.6
	0.5	4	14.2	14.1	27.5	13.9	13.8	25.8	2.3	2.3	3.8	2.4	2.2	2.9	1.2	1.1	1.1
	0.5	6	13.0	12.9	25.1	11.6	11.6	21.6	2.1	2.1	3.5	2.3	2.1	2.8	1.5	1.3	1.3
	0.5	8	12.3	12.3	23.9	11.1	11.0	20.6	2.0	1.9	3.2	2.1	1.9	2.5	1.4	1.2	1.3
	0.5	10															
Unloading (MPa)	0.5	2	21.6	21.5	41.8	20.0	19.9	37.2	3.6	3.5	5.9	3.4	3.1	4.0	2.4	2.1	2.2
	0.5	4	18.3	18.2	35.4	16.7	16.6	31.0	2.9	2.8	4.7	2.9	2.7	3.5	2.3	2.0	2.1
	0.5	6	14.9	14.8	28.9	13.2	13.0	24.4	2.6	2.5	4.2	2.7	2.5	3.2	2.4	2.1	2.1
	0.5	8	12.8	12.7	24.8	11.5	11.4	21.4	2.4	2.3	3.9	2.5	2.4	3.0	2.7	2.3	2.4
	0.5	10															

LEFT Plate

			Anchor Depth (m)														
			3.25			2.04			1.24			0.6			0.1		
	Anchor No :		D9			D8			D7			D6			D5		
	Pressure (Mpa)		Modolus (GPa)			Modolus (GPa)			Modolus (GPa)			Modolus (GPa)			Modolus (GPa)		
	From	To	ISRM	ASTM	UNAL	ISRM	ASTM	UNAL	ISRM	ASTM	UNAL	ISRM	ASTM	UNAL	ISRM	ASTM	UNAL
Loading (MPa)	0.5	2	56.9	56.7	110.9	29.7	29.5	54.7	16.2	15.9	26.4	4.1	3.8	5.0	2.3	1.9	2.0
	0.5	4	31.6	31.5	61.6	22.2	22.0	40.9	13.7	13.4	22.3	4.8	4.5	5.9	3.8	3.2	3.4
	0.5	6	37.8	37.6	73.6	28.0	27.7	51.4	14.4	14.1	23.4	5.1	4.8	6.3	4.4	3.8	3.9
	0.5	8	22.8	22.7	44.4	17.4	17.2	32.0	11.8	11.6	19.2	5.0	4.7	6.1	4.7	4.0	4.2
	0.5	10															
Unloading (MPa)	0.5	2	31.6	53.6	104.9	31.6	31.4	58.2	19.0	18.6	30.9	7.8	7.3	9.5	6.3	5.4	5.6
	0.5	4	22.8	30.1	58.9	22.8	22.6	42.0	14.9	14.6	24.3	6.8	6.4	8.4	5.9	5.1	5.3
	0.5	6	26.1	26.0	51.0	20.1	19.9	36.9	13.4	13.1	21.7	6.4	6.0	7.9	6.0	5.2	5.4
	1	8	23.9	23.9	46.7	18.2	18.1	33.5	12.3	12.1	20.1	6.3	5.9	7.8	6.5	5.6	5.8
	0.5	10															

7 CONCLUSIONS

Conducting experiments in weak rock needs special measures such as:

- In order to prevent the instruments to be installed on the voids, cavities, open joints, etc., the location of installation should be precisely controlled. It is achieved by means of a borehole camera.
- In this kind of rock mass the wall of the extensometers borehole is likely full of voids, cavities, open joints and crushed rocks. Therefore, various types of extensometers is difficult to be used. A method of treatment the walls suggested in this work is filling the voids with mixture of soil and plaster grout.
- With regard to the calculations and achieved results using three proposed methods, it was decided to use the data from sensors number 2 and 3 for calculation the deformability modulus as design parameter in all tests using ISRM 1981 and ASTM 2008 standards. In the meantime, the data obtained from one of the experiments has been used for calculating deformability modulus of rock mass with two aforementioned plus UNAL methods. Big discrepancies have been observed from comparison of the results of ISRM and ASTM with UNAL method

8 REFERENCES

ISRM, 1979 "Suggested methods for determining in situ deformability of rock – Part 1: Suggested method for deformability determination using a plate loading test (superficial loading)", Int. J. Rock Mech. Min. Sci. & Geomech. 16: 197-202.

ASTM, 1998 "Flexible Plate Loading Method" [D 4395 – 04].

ASTM, 2008 "Standard Test Method for Determining In Situ Modulus of Deformation of Rock Mass Using Rigid Plate Loading Method", Annual Book of ASTM. 04.08.

Report of geology of Karun 2 dam site, 2005.