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Analysis of In Situ Test Data for Deformation Modulus of Weak Pyroclastic Rock Mass

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ABSTRACT

This paper discusses the deformability characteristics of pyroclastic rock mass by plate loading in the drifts and Goodman jack tests inside the drill-holes. These tests were carried out at Shwezaye project in Myanmar. Thirteen plate load tests were performed inside the exploratory drifts and 24 Goodman jack tests were carried out in NX size drill-holes upto a depth of 42.5 m from the ground surface. These drifts were excavated using the mechanical breakers, thus eliminating the effects of blasting on the rock mass properties. Results of rock mass deformability obtained by plate load and Goodman jack tests have been compared and reported in the present study.

Keywords: Modulus of deformation; Plate load test, Goodman Jack test

1. INTRODUCTION

Geological setting forms the basis for describing a material as soil or rock. Soils are materials that can be separated by gentle means such as agitation in water whereas rocks are harder rigid aggregates of minerals connected by strong bonds. Materials with unconfined compressive strength less than 1.0 MPa is termed as soil (Singh and Goel, 2011). Rock mass is comprised of rock material or rock substance and discontinuities. Mechanical behaviour of rock mass is influenced by presence of discontinuities which makes it different from the rock material. The deformation characteristics of rock mass are affected by the nature and extent of discontinuities apart from the composition and grain size and porosity. Laboratory tests conducted on small intact cores do not represent the actual rock mass as field conditions cannot be simulated in the laboratory. Behaviour of rock mass under stress is affected by properties of discontinuities such as orientation, spacing, persistence, roughness, wall strength, aperture, infill, seepage, number of joint sets, block size and shape etc. Hence, the field tests become important for assessing the stress-strain behaviour of rock mass and to facilitate engineering design of underground structures in or on rock mass.

Many methods are available for the assessing the deformability characteristics of rock mass. The simplest of all methods is plate loading test (PLT) with deformation measurements at the surface. Plate jacking tests with measurements inside the drill-hole with uniaxial loading is perhaps the best method since the deformations are measured beyond the blast affected zone. Other methods such as flat jack test and borehole Jack tests can also be used to determine the modulus of deformation of rock mass. Goodman jack test (GJT) is very good tool to determine the deformation modulus of rock mass inside the drill-hole. The test can be conducted upto 60 m depth using GJT. However, the area affected in GJT is much smaller as compared to plate load test.

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This paper presents deformability characteristics of weak pyroclastic rock mass along with a comparison between PLT and GJT. The paper focuses on the effect of loading area and the methodology on the modulus of deformation of rock mass.

2. GEOLOGICAL SETUP

Shwezaye multipurpose project situated in Monywa and Kalay districts of Sagaing division of Myanmar on river Chindwin (Fig. 1) has been envisaged within Plio-Pliestocene Ayerawaddy formations of Central Burma Basin. The central Burma basin is bordered to west by a sub-duction zone and on the east by active strike slip Shan-Sagaing fault.

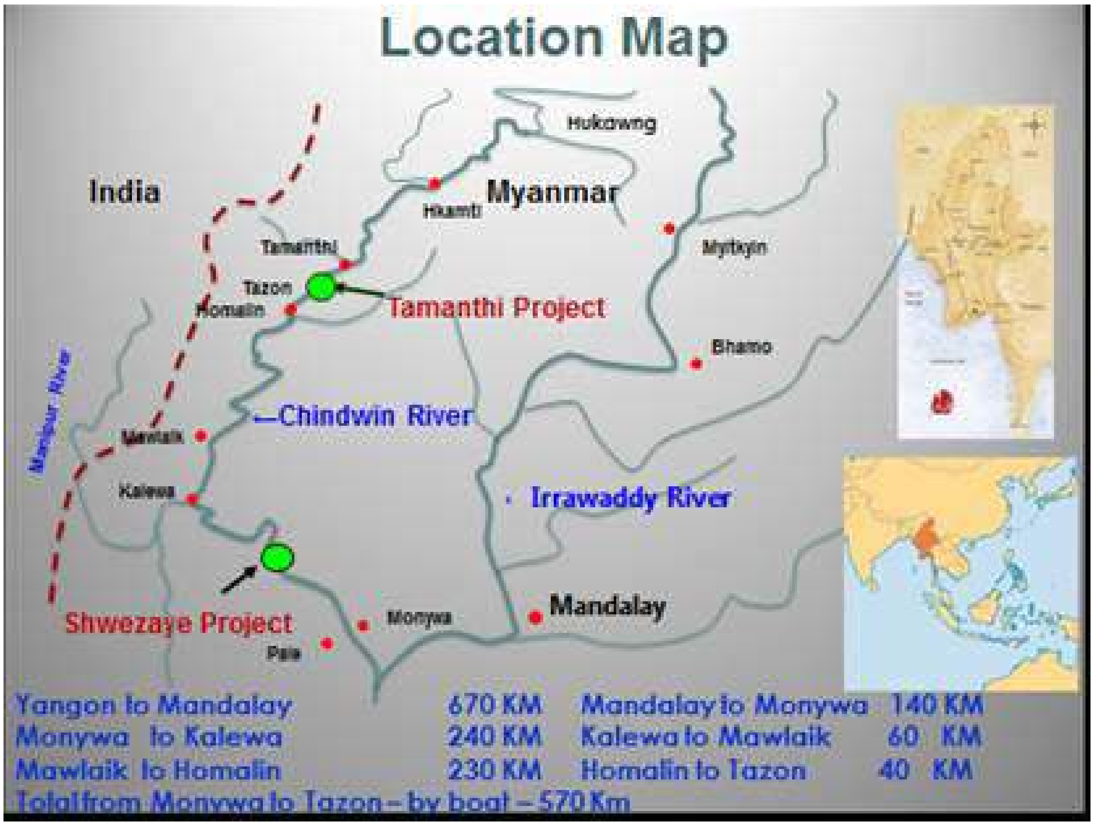

Fig. 1 - Location map of the project

The project lies on the western margin of a well-known volcanic arc which crosses river Chindwin near the proposed dam location as shown in Fig. 2. This volcanic arc presented by a chain of discontinuous volcanoes forms a broad belt (40 km wide), N-S through the Central Burma Basin and joins the volcanic arch in Andaman sea and Java and Sumatra. In close proximity of Shwezaye project, many volcanic craters occur on both banks of river Chindwin prominent being Twin Taung and Twin Ma located in the left and the right bank, respectively as shown in Fig. 2 and about 4 km away from the proposed project location near Shwezaye village.

The project area is occupied by sedimentary Ayeyrawaddy formations that have been affected by repeated volcanic activity over a period of time. These sedimentary formations are modified by river action/ change in river course. Two pyroclastic mounds define the right and left bank of the river forming the Shwezaye narrow gorge through which river Chindwin flows. Geological model of the project area is as follows:

- The river bed is occupied by heterogeneous medium of sand with intermittent gravel and mud which occurs beyond the drilled depth of around 150m in the river. A water column of around 30m exists above these sandy/ gravely deposits.

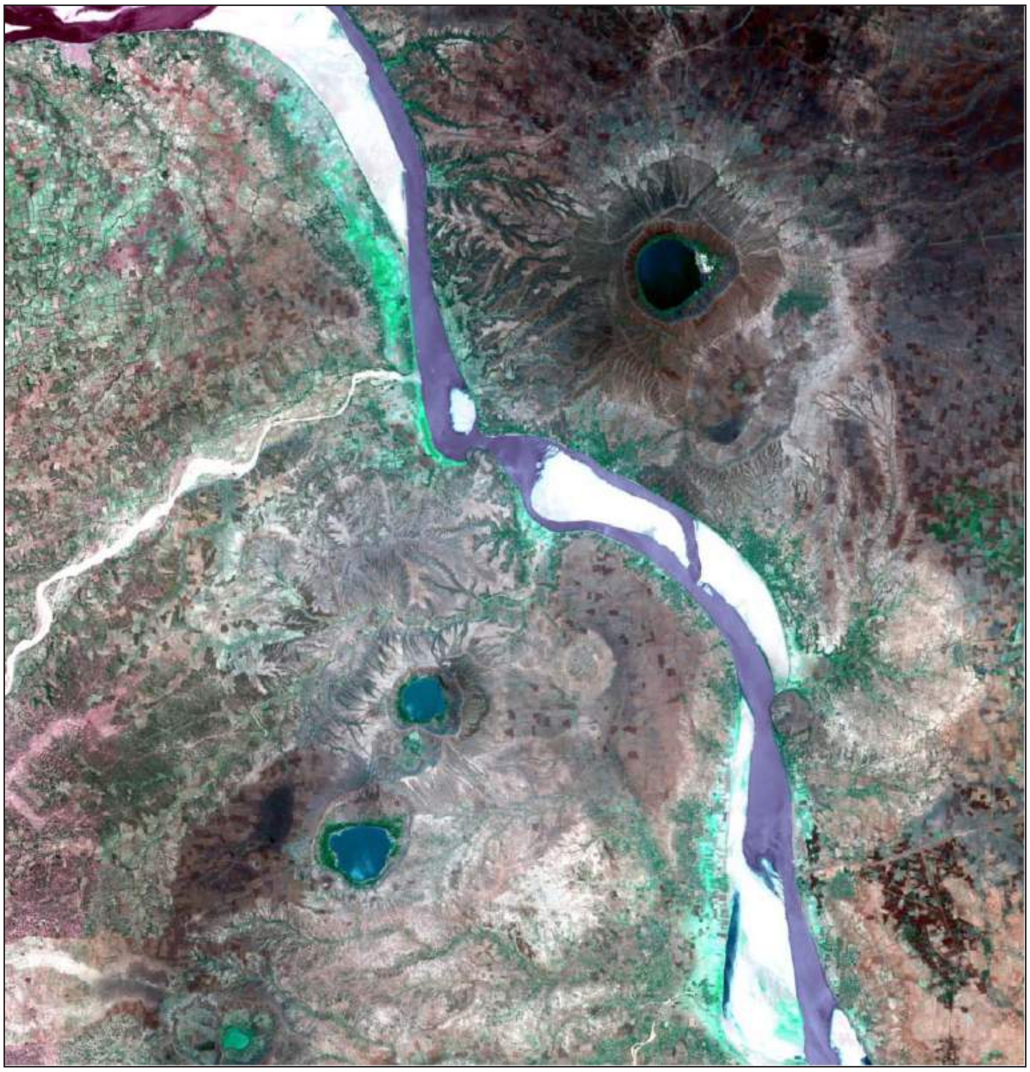

Fig. 2 - Google map showing volcanic craters and narrow gorge

- Both river banks are defined by weak, jointed pyroclastic rocks. The pyroclastic rocks consist of fragments of andesite and basalt cemented with tuffaceous sand and volcanic ash. Intercalations of sandstone/ mudstone alternations occur within the pyroclastic rocks. The pyroclastic layers are relatively compact and show discrete layering dipping sub-horizontally. These pyroclastic rocks are limitedly distributed around the river edges as shown by few boreholes drilled around the river edges. A 10 to 30 m layer of columnar basalt overlies these pyroclastic rocks on both the banks.
- Baring the pyroclastic mounds around the river edges high ground on both the banks is covered by deposits of volcanic ash ejected from the existing volcanic craters. These ash beds are coated with calcareous sinters and underlain by thick light brown sticky and stiff silty clay, gravel and sandy material of Ayeyrawaddy. At places these layers grade into weekly consolidated tuff, mud stone and sand stone (Ayeyrawaddy formation). This is shown by geophysical surveys and confirmed by several drill-holes that lead to recovery of wash samples of sand and gravel.

3. RESULTS AND DISCUSSIONS

3.1 Plate Load Tests

Plate load tests for the determination of modulus of deformation of rock mass were conducted using 60 cm diameter plate in accordance with provisions of IS 7317 (1993), ISRM (1981) and CBIP 1988). The tests were performed in 5 cycles of loading and unloading. A total of 13 tests comprising of 5 tests each in the right bank drifts DRB-1 and DRB-2 and three tests in left bank drift BLB-1, were conducted. Photograph of the plate load test setup is given in Fig. 3.

Fig. 3 - Test setup

The modulus of deformation for the loading cycle has been calculated by considering total deformation of a particular cycle whereas modulus of elasticity was calculated by considering only elastic deformation for the same cycle using the following equation:

$$E = \frac{Pm(1-\nu^2)}{\delta\sqrt{A}} \quad (1)$$

where

E = modulus of deformation/elasticity,
P = applied load,
ν = Poisson's ratio,
m = constant depending upon the shape of plate (m = 0.95 for square plate and 0.96 for circular plate),
δ = deformation corresponding to load, and
A = area of plate.

Modulus of deformation and modulus of elasticity were calculated for each cycle of loading and unloading respectively. Pressure was applied in five cycles viz. 1, 2, 3, 4 and 5 MPa.

First cycle of 1.0 MPa was repeated in each test. Modulus values were determined using the data from repeated first cycle and subsequent cycles. All the tests were considered while averaging the test results.

Five plate load tests were conducted in drift DRB-1 and DRB-2 on the right bank whereas three tests were conducted in DLB-1 on the left bank which was partially submerged into water.

Pyroclastic rock mass with various degrees of consolidation was encountered in all the three drifts and the two drill-holes. The average values of modulus of deformation from drifts DRB-1, DRB-2 and DLB-1 and considering all the 13 tests are given in Table 1. The average values of moduli of deformation at dam site considering all the thirteen test results were found to vary between 1.485 GPa and 4.668 GPa with an average value of 2.808GPa at an applied pressure of 5.0 MPa (CSMRS, 2012a). Similarly, modulus of elasticity varied from 1.773 GPa to 5.242 GPa with an average value of 3.516 GPa at an applied stress level of 5.0 MPa. The modulus ratio varies between 1.06 and 1.71 with an average value of 1.26 at an applied stress of 5.0 MPa. The values of modulus of deformation increase whereas moduli ratio decreases with increase in applied stress in all the tests. Pressure versus deformation plot for one of the tests is shown in Fig. 4.

Table 1 - Average values of moduli of deformation and elasticity by plate load tests

σ	E_d (GPa)			E_e (GPa)			E_e / E_d		
MPa	Min	Max	Av	Min	Max	Av	Min	Max	Av
1.0	0.617	2.688	1.184	0.824	7.848	2.117	1.08	7.92	1.93
2.0	0.677	2.364	1.322	0.955	3.885	2.231	1.22	3.37	1.71
3.0	0.954	3.652	1.891	1.190	4.557	2.874	1.19	1.89	1.52
4.0	1.261	4.612	2.481	1.505	5.765	3.457	1.18	1.85	1.41
5.0	1.485	4.668	2.808	1.773	5.242	3.516	1.06	1.71	1.26

<u>Notations:</u> σ – pressure; E_d- modulus of deformation; E_e – modulus of elasticity; Min – Minimum; Max – Maximum; Av - Average

The results from all the drifts along with overall average values have been graphically presented in Fig. 5. Slight variation in modulus of deformation of rock mass in all the three drifts may be seen. This may be attributed to the degree of consolidation and the grain size.

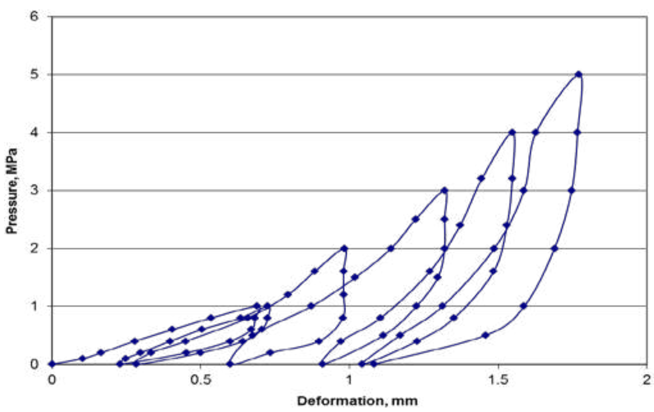

Fig. 4 – Stress vs deformation plot for one of the plate load tests

3.2 Goodman Jack Test

Twenty four Goodman jack tests were conducted inside two NX size drill-holes one each on left and right abutments. Tests were conducted during drilling of drill-holes. Pressure was applied in such a way so that transferred stress is comparable with those applied in plate loading tests. The volume of rock affected by the jack is about 0.028 m^3 (1cft.) and extends to about 114 mm into rock away from the borehole wall.

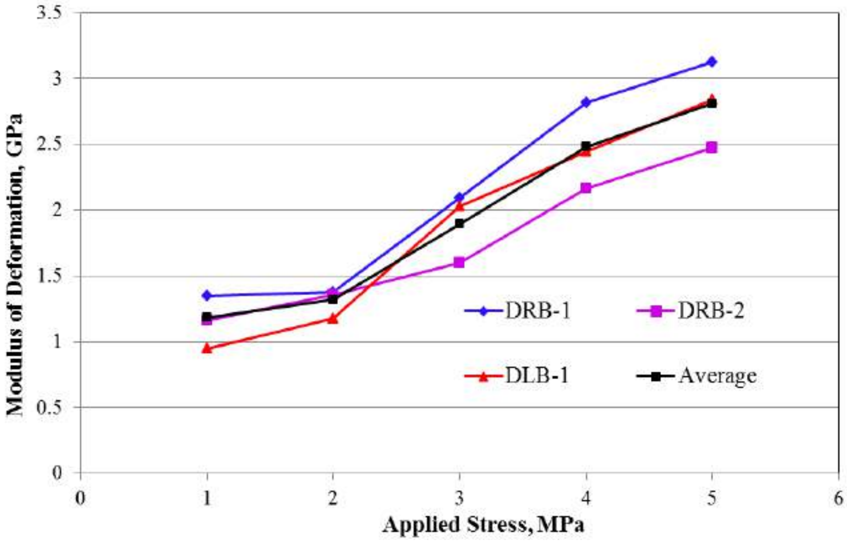

Fig. 5 - Modulus of deformation of rock mass by plate load test

Stress transferred to the borehole wall depends upon the particular model used for the tests and in the present case stress transferred to the borehole is 55% of the applied stress. The stress was applied in five cycles of 2, 4, 6, 8 and 10 MPa. First cycle was repeated in all the tests and the test results have been determined using the repeated cycle. Deformations at all the incremental pressures were observed during the loading and unloading cycles.

These tests were conducted in accordance with provisions of IS 12955 (1990 – Part 1), ISRM (1981) and CBIP (1988). Figures 6a and 6b show the tests in progress.

The modulus of deformation has been calculated using the Eq. 2 (Goodman et al., 1968):

$$E = 0.86\{\Delta P/\Delta D/D)\}\, K(\nu,\beta) \tag{2}$$

where

E = modulus of deformation/elasticity (MPa),
ΔP = stress increment (MPa),
ΔD = diametral displacement increment (cm),
D = diameter of Borehole (cm), and
$K(\nu, \beta)$ = constant depending upon Poisson's ratio (ν) and the angle of loaded arc (β).

Drill-hole DH-17 is located on the left bank of river Chindwin. Seventeen tests were conducted between 10.0 and 42.5 m depth. Water table in the drill-hole was noticed at 8.2 m depth. Drill-hole DH-04 is located on the right bank of river Chindwin. Seven Goodman jack tests were conducted in DH-4 between 10.5 m and 17.0 m depth in pyroclastic rock mass with minor variations in nature, colour and strength. Water table in the drill-hole was observed at 5.22 m depth.

(a) Drill-hole DH-17, left bank, dam axis (b) Drill-hole DH-04, right bank spillway

Fig. 6 - Goodman jack tests in progress

The average values of E_d and *Ee* from all the 24 tests are presented in Table 2. Average values of E_d considering all the twenty four tests ranges from 0.550 GPa to 5.635 GPa with an average value of 2.436 GPa at an applied stress of 5.5 MPa (CSMRS, 2012b), whereas values of *Ee* varied from 1.366 GPa to 8.196 GPa with an average value of 3.161 GPa at the same applied stress. Modulus of deformation increases with increase in applied stress, whereas modulus ratio decreases with increase in applied stress. Pressure versus deformation plot is shown in Fig. 7.

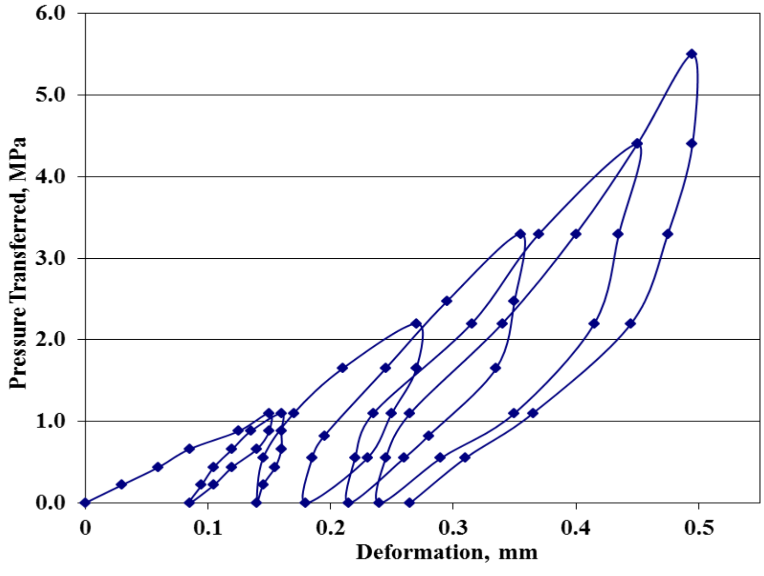

Fig. 7 - Stress versus deformation plot for one of the Goodman jack tests

Figure 8 shows variation in value of deformation modulus of rock mass in drill-holes DH-17 and DH-4 alongwith average deofrmation modulus plot. GJT-4 and GJT-14 in Fig. 8 refer DH-04 and DH-17 respectively. Slight variation in modulus of rock mass on both the banks was observed. It may be seen that values of deformation modulus in drill-hole DH-04 are comparatively less than those in DH-17.

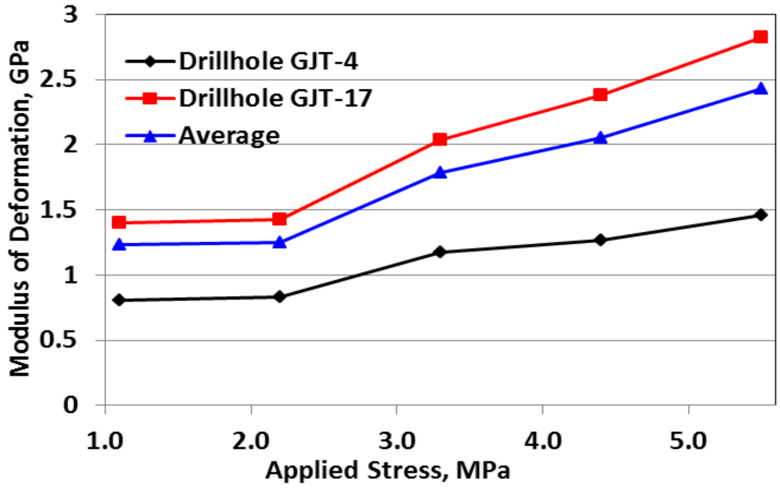

Fig. 8 - Modulus of deformation of rock mass by Goodman jack tests

Table 2 - Average values of modulus of deformation and elasticity by Goodman jack tests

σ MPa	E_d (GPa)			E_e (GPa)			E_e / E_d		
	Min	Max	Av	Min	Max	Av	Min	Max	Av
1.1	0.368	2.254	1.229	0.902	4.508	2.370	1.00	7.00	2.22
2.2	0.331	2.254	1.253	1.093	5.152	2.640	1.08	6.25	2.33
3.3	0.652	4.161	1.782	1.319	6.011	2.786	1.06	4.80	1.72
4.4	0.751	5.548	2.053	1.244	6.011	2.684	1.04	3.00	1.45
5.5	0.550	5.635	2.426	1.366	5.635	2.880	1.03	3.42	1.39

4. COMPARISON OF PLATE LOAD AND GOODMAN JACK TEST RESULTS

Pressure of 1.0, 2.0, 3.0, 4.0 and 5.0 MPa were applied in cycles in case of plate load tests, whereas in Goodman jack tests, pressure of 2.0, 4.0, 6.0, 8.0 and 10.0 MPa were applied in cycles. The stress transferred to rock in case of Goodman jack tests was of the order of 55% of the applied stress. Hence, transferred stress to rock mass in case of Goodman Jack tests in five cycles was of the order of 1.1, 2.2, 3.3, 4.4 and 5.5 MPa. Although the slight variation in corresponding stress level of plate loading and Goodman jack tests is there, modulus values obtained by both tests may be compared to see the effect of curvilinear stress application and the extent of loading area. Here, it would be appropriate to mention that both tests have distinct advantages. Plate load test covers larger area compared to Goodman jack and secondly the loading area may be varied using different sizes and shapes of the loading plates. However, Goodman jack tests are carried out deep inside the drill-holes.

Generally, the exploratory drifts are excavated by drill and blast method. Hence, the adjoining rock mass around the opening gets disturbed due the impact of the blast. The damage from blasting of the test-adit reduces the magnitude of modulus of deformation with a factor between 2 and 4 (Dev et al., 2000; Singh et al., 1994; Palmstrom and Singh, 2001). Even in an extensive in situ test programme in fairly uniform and good quality rock, deformability data may feature a deviation of 25% or as much as 10 GPa for an average in situ modulus of 40 GPa (Bieniawski, 1989).

Mechanical breakers, chisels and hammers were used for excavation of drifts at Shwezaye project, thereby eliminating the effects of blasting. Moreover, the tests were carried out in saturated conditions. The variation in average modulus of deformation of rock mass using plate load and Goodman jack tests is shown in Fig. 9.

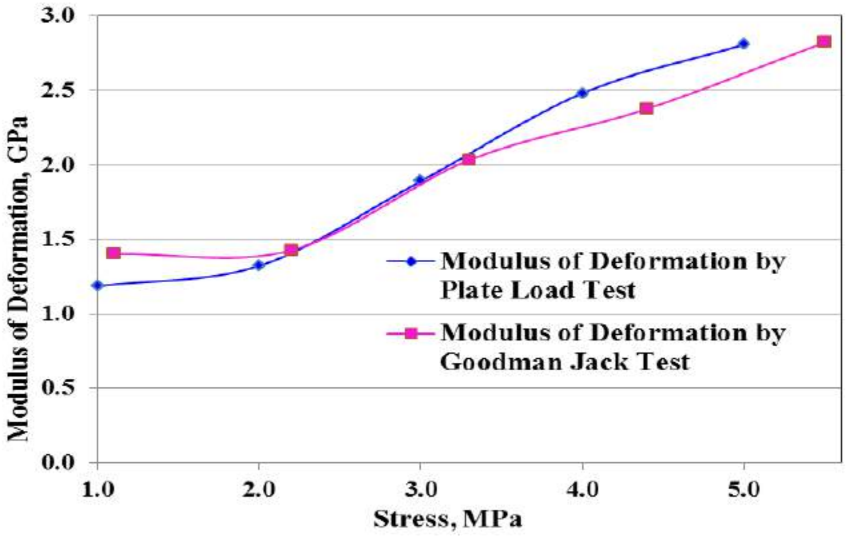

Fig. 9 - Comparison of plate load and Goodman jack test results

At lower applied stress of the order of 3 MPa, Goodman jack test results were quite comparable, whereas at higher stresses, the values obtained by plate load tests were slightly higher by 6-20% than that of the values obtained by Goodman jack tests. From the results, it may be inferred that modulus of deformation from plate loading and Goodman jack tests is comparable provided the field conditions are similar and rock mass is undisturbed. This may be attributed to the fact that drift was excavated using mechanical means rather than drill and blast technique. Both plate load and Goodman jack tests were performed in simulated conditions such as:

- Tests were performed immediately after drifting and drilling of fresh holes.
- Both the tests were carried out in saturated rock mass i.e. immediately after the monsoon period was over.
- Both the tests were conducted on similar rock mass.

5. CONCLUSIONS

The variation in modulus of deformation of rock mass by plate loading and Goodman jack tests is dependent on method of excavation, scale effect, weathering of rock mass and field conditions. At low stresses i.e., upto 3 MPa, modulus of deformation was either found to be higher in case of Goodman jack tests or it was similar. However, average modulus of deformation by plate loading tests was found to be 6-20% higher than Goodman jack tests at high applied stresses (>3 MPa). The phenomenon may be attributed to the fact that exploratory drifts were excavated using mechanical tools rather than drill and blast technique. The tests were carried out with minimum lapse of time in the drifts under saturated conditions. The Goodman jack tests were performed simultaneously during drilling operations. Effect of weathering in exploratory drifts and drill-holes was negligible. Both the tests represented the rock mass as a whole, since the tests were conducted on both banks at the dam axis using both the techniques.

Plate loading and Goodman jack tests have distinct advantages and applications. In the absence of exploratory drifts, drill-holes may be utilised to assess the deformation characteristics of rock mass using Goodman jack tests.

Care should be taken while excavation of exploratory drifts. Blasting should be avoided in soft rock mass and controlled blasting may be adopted in the cases of very hard rock mass. Tests should be conducted immediately after excavation of drifts and drilling for true representative characteristics of rock mass. At the Shwezaye project looking to the rock mass, the drift excavation was done by mechanical breakers, chisels and hammers to avoid blast damages.

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