Reappraisal on the Field Tests for Determination of Rock Mass Characteristics for Open Terrain (s)

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Abstract. For site investigations pertaining to hydropower project(s), often the suitable in-situ testing protocols are limited in open terrains due to constraints in carrying out them on rock masses. Such scenarios necessitate the utilization of available resources to the best possible extent, in carrying out sampling procedures required for evaluation of design parameters like shear strength (concrete over rock; rock over rock) and deformability characteristics of rock mass. In order to carry out these tests, it is mandatory to get enough upward reaction for the expected structural loads (which are usually of higher magnitude), for better engineering judgements. These loads will have to be compounded to the conservative side, by at least 1.5 to 2 times of the expected design loads. In order to meet this requirement, particularly in drift areas (small audits), the crown reaction due to cover is sufficient. However, in most of the open terrains, the reaction is provided by relying on Kent-ledge arrangement by providing sufficient loading arrangement such as sand bags, concrete blocks etc., a time taking process involving considerable risk. The current manuscript deals with instances encountered under difficult open terrains in carrying out required tests, and suggests suitable site specific solutions with available resources within the working area. The authors believe that, the proposed solutions presented in this manuscript will benefit the practicing engineers and stake holders working in the geotechnical investigations pertaining to in-situ rock testing.

Keywords: In-situ tests; Open terrain; Kent-ledge loading; Rock mass; Reaction loads.

1 Introduction

The sub-soil investigation of any site plays an important role in the stability and structural integrity of any structure founded on it [4 & 5]. Usually, tests pertaining to sub-soil investigation are carried out as part of reconnaissance survey. In most of these cases, the tests are to be conducted in confirmation with Bureau of Indian Standards (BIS). Meeting the requirements laid forth by relevant standards in carrying out in-situ testing, is not possible due to complex terrain characteristics, non-availability of skilled manpower, material and testing equipment. Furthermore, mobilizing the same to the proposed testing site becomes a challenge due to logistics involved. The various shortcomings in meeting the BIS testing protocols [6 & 7] in actual field scenario for open terrains are listed below:

i. The test site shall be selected such that the geology at the test location is representative of the geology of the area loaded by the proposed structure to be built.
ii. Even though a level uniform surface is preferred for proposed in-situ testing, in majority of the cases, the open terrain comprises of steep slopes with water logged areas.
iii. For uneven terrains, in order to carry out in-situ block shear test, concrete walls on either side of base for the open trench having 2.5 m width usually do not rest on same level.
iv. Non availability of materials, machineries and manpower to arrange the kentledge loading as specified by the BIS codes. Logistics associated with shifting the testing equipment to the site is challenging.
v. Usually, for a given site, a minimum of about four tests are to be carried out. During this phase, the shifting of the test arrangement (Kent-ledge loading) from one location to another location is an arduous task and consumes considerable time and results in delayed project scheduling.

The sampling procedures required for evaluation of design parameters like shear strength (concrete over rock; rock over rock) and deformability characteristics of rock mass include 'in-situ block shear test' [6] and 'uniaxial jack test'[7] respectively. In order to carry out these tests, it is mandatory to get enough upward reaction for the expected structural loads (which are usually of higher magnitude), for better engineering judgements. Furthermore, the testing loads will have to be compounded to the conservative side, by atleast 1.5 to 2 times of the expected design loads [7].

In general, the 'in-situ block shear test' and 'uniaxial jack test' require testing to be carried out in drifts, tunnels or underground openings for convenience to get sufficient top reaction load(s) based on loads coming from proposed structures to be built [9]. In the absence of such facility, the tests may be conducted on open Terrain(s) close to the proposed foundation or abutments. Usually, the size of the open trench in which these tests are to be carried out shall be kept as small as required for testing, so as to reduce the length of heavy 'I sections' and minimize the number of packing plates or the size of the intervening 'C channels' that are usually placed across the open trench. The size of the open trench shall be such that the distance between the loaded area and a restrain supporting concrete pedestals/walls surface should be at least equal to the radius of the loaded area so that any restraint does not affect the calculated moduli (deformability modulus; elasticity modulus; permanent deformation modulus etc.,) [8] significantly. This is particularly true in the case of site investigations pertaining to hydroelectric projects. Usually, for such projects the minimum size of the open trench required for convenient testing is about 2.5 m wide and about 1.8 m high [10]. The excavation of the open trench shall be made in such a manner that it causes minimum disturbance to the underlying rock. Care should be taken to avoid blasting during final preparation of the test site.

In the present work, the author(s) present a typical case study pertaining to 'kentledge' loading arrangement adopted for the characterization of in-situ rock mass at spillway site of Polavaram Irrigation Project, Andhra Pradesh, India. The manuscript presents details pertaining to site specific loading arrangement developed on complex open terrain having inclined topography exhibiting characteristic water logging.

2 Details Pertaining to Proposed Study Area

Indira Sagar Multipurpose Project, Polavaram, envisages construction of two no's of earth and rock fill dams totaling 2454 m length across the river Godavari and spillway with 48 radial gates of size not less than 16 m x 20 m including electrically operated hydraulic hoist, pilot channel, approach channel and spill channel to facilitate impounding of 194.60 TMC of water for generating 960 MW of hydro power. The existing rock type along the spillway axis of the site is observed to be Granite. Layout plan of Polavaram Irrigation Project (PIP) [1 & 2]] is shown in Fig. 1.

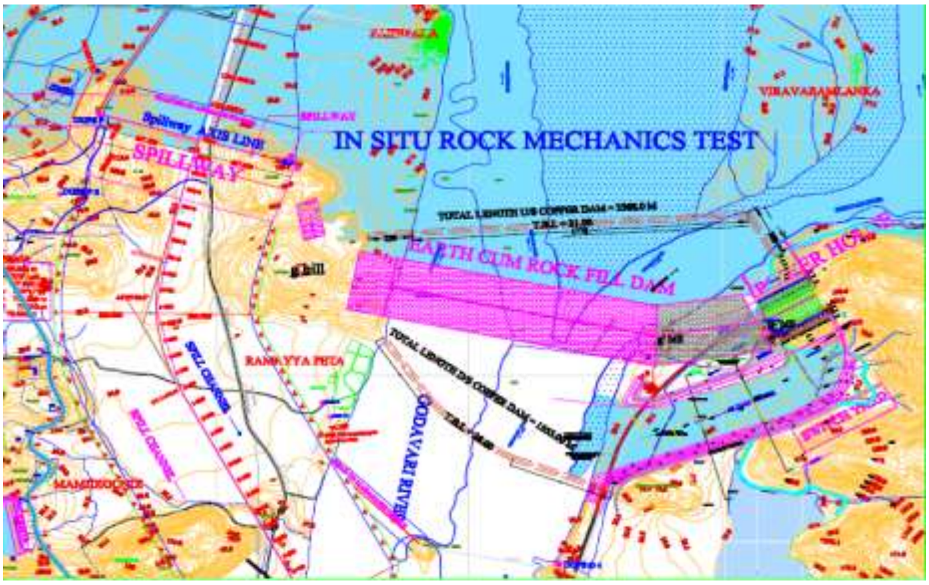

Fig. 1. Characteristic Layout of the Proposed Study Area [10]

2.1 Geology and Subsurface Conditions of the Spillway

The study area is located in the Precambrian mobile belt known as Eastern Ghat Belt of Andhra Pradesh, India. This is considered to be younger and linear metamorphic belt. It runs almost parallel to East Coast, trending along NE-SW direction, for a length of 900 m extending into Madhya Pradesh and Orissa in the North and Ongole in the South. The Spillway is located across the saddle between Muthyalamma Konda hillock and small isolated hillock (unnamed) on the right bank of the Godavari. A brief account of the geology along the proposed study area i.e., alignment (Ch 0.00 – Ch 481.00m) of spillway revealed that, the proposed reach forms left hillock with maximum elevation of +90.00m. This reach exhibited moderate to steep slopes occupied by Khondalite suite of rocks covered with lateritic soils at some places. Both Garnet-Biotite-gneiss and Garnet-sillimanite-gneiss (Khondalite) were found to be present along the alignment considered.

3 Site Selection and Preparation

The authors visited the Polavaram Irrigation Project site on right and left flanks of the proposed spillway as shown in Fig. 2. Upon preliminary investigation, it was noted that, both banks exhibited highly weathered characteristics above the ground level with limited overburden height. It was concluded that, it was technically not feasible to make any drift at the spillway foundation level for conducting in-situ tests. Geologically, the location of trench was considered favorable for determination of shear strength parameters of rock mass which may be used for foundation design. Accordingly, in-situ shear tests at spillway foundation of the project were proposed to be conducted in open trench at left flank (Ch 0.00 – Ch 481.00m). Further, it was decided to carry out five block shear tests on concrete over rock interface and five block shear tests on rock over rock interface in open trenches excavated along with left flank of spillway axis.

Fig. 2. Photograph of site preparation at Study Area

3.1 Open Trench Excavation

The excavation process commenced with mechanical breakers, chisels and other appropriate cutting tools. The trench was excavated in the fresh rock and it was 2.5m wide, 30m long and 1.8 m deep parallel to dam axis. The gap between upstream side reaction pad to face of the testing block was maintained at 0.75 m. Abutment on either side of the block was ensured to be at same level. A minimum gap of 1m was maintained between two adjacent blocks.

The progress was periodically monitored and site preparations were completed for the initial investigation. Since, rock over rock interface shear blocks require enormous time for cutting and finishing, it was decided to prepare one set of rock blocks and one set of concrete blocks to determine shear strength parameters of rock mass at proposed left flank of spillway axis. Concrete and Rock blocks of 70 x 70 x 35 cm for in situ shear tests and maximum 5 cm thick cement pad for Plate load was prepared in accordance with the provisions of IS code of practice [6,7 &8]. Rock face on the upstream side of the block or concrete reaction pads were cast for applying the shear load.
The support walls of the trench and concrete blocks were prepared by M20 grade concrete without any reinforcement as shown in Fig. 3. The preparation of side walls was carried out in two stages. In order to maintain the uniform platform, the existing rock mass was chiseled in stepped manner with respect to the existing site slope so that horizontality of the loading platform is maintained (Fig. 3). It is worth mentioning that, proper care was taken to ensure that the stepped abutment was located in such a way that, the location of center of gravity of loading platform did not fall at the center of any given shear block as seen from Fig. 3. In the eventuality of not maintaining this suggested specific arrangement of stepped abutment, it would become virtually impossible to perform the test at that desired location. This will eventually lead to unnecessary delays for the testing program. The authors believe that, adopting to similar methodology for works which necessitate identical loading arrangement will result in significant cost savings.

Fig. 3. Photograph of open trench excavation and shear test locations [10]

4 Loading Arrangement Adopted

In this project, proposed height of the spillway above deepest foundation level is approximately above 60 m. IS 7317 suggests that the maximum load at which the test is to be conducted shall correspond to 1.2 to 1.5 times the anticipated maximum stress expected to be developed because of the proposed structure. For this, Kent-ledge loading arrangement with sufficient load for application of normal load in shear as well as plate load tests with approximately 120 tonnes load to cater to the design requirements have been adopted. Plate load tests were conducted up to a maximum applied stress of 3MPa with respect size of the test plate/block.

The top reaction loading was prepared with Kent-ledge which was made by preparing a loading plate using mild steel (MS) girders. ISMB 250 girders more than 3.5 m in length were used considering the stability and safety aspects as well as for meeting expected higher loads. Further, to overcome the expected bearing failure, MS plates (20 mm thick) and sand bags were also used under the load bearing girders, so as to transfer the dead load over a larger area. Later, $1m^3$ concrete cubes were placed over this MS plate (20 mm thick)) to obtain a total load of around 120 tonnes, so that the loading unit remains intact and acts as one unit as seen from Fig 4. Detailed testing procedures can be referred from ISRM (1981), CBIP (1988), IS 7746 (1991) and IS 7317 (1993).

Fig. 4. Photograph of open trench showing Kent-ledge loading arrangement [10]

4.1 In-situ Shear Test Procedure

A set of 5 blocks were cast each for rock/rock and concrete/rock interface. Each shear block was tested for a particular normal stress which was kept constant during the test. Proper care was taken to keep the top and side reaction pads concentric with the block. Horizontal reaction pad was prepared such that it did not yield during the application of horizontal thrust. Vertical load was applied using a 200 T capacity hydraulic jack and aluminum alloy/MS hollow cylinders were used to fill up the gap between the top reaction pad and the hydraulic jack. Shear force was applied by another 200 T capacity hydraulic jack from the side reaction pad. Normal loads of 20, 24, 32, 40 and 60 T were applied for five tests, respectively. The shear load was applied at an angle of 15^0 with the horizontal so that the shear plane coincides with a plane of weakness in the rock i.e., a joint, plane of bedding, schistosity or cleavage, or with the interface between concrete to rock. This was achieved by two wooden wedges placed across the jack. The applied shear force and corresponding displacement of blocks were measured and recorded during the test. The normal and horizontal displacements of the block produced during the test were measured by seven dial-gauges. Out of these seven dial gauges, four were used to measure normal displacement and the other three for shear displacement. The observations were recorded till failure and continued even after the failure at which no further rise or fall in shear load was observed with increasing shear displacement to get the information regarding residual resistance. Figure 5 shows the in-situ shear test assembly in open trench at different location of the site.

Fig. 5. Photograph of test set-up for shear

4.2 Plate Load Test (PLT) Procedure

At the test site, the rock surface at the bottom of the trench was smoothened by chiseling to obtain parallel face of 65 cm diameter. Though the bottom surface was made smooth by careful chiseling, a thin layer of sand was spread to take care of minor undulations. The top reaction loading was prepared with Kent-ledge as mentioned in section 4.0, and setup is shown in Fig. 6. Both the top and bottom surfaces were kept parallel to each other. The testing equipment was assembled with 2.5 cm thick and 60 cm diameter MS plates at the bottom followed by 45 cm and 30 cm diameter plates. Thereafter, a hydraulic jack of 200 T capacity was placed. The gap between top pad and jack was filled with aluminium alloy pipes. At the top of aluminium pipes, MS plates of 30 cm and 45 cm diameter having 2.5 cm thickness were placed. To remove small gap(s) and complete the assembly packing, the plunger of the jack was moved upward. The load was applied by means of jack and pump and the test was completed in five cycles of (14.14, 28.27, 42.41, 56.55 and 70.69 T) loading and unloading. The deformations were recorded by using 4 dial gauges with an accuracy of 0.01 mm installed diagonally on the bottom plate.

Fig. 6. Setup of plate load test assembly [2]

Throughout the testing process, the abutments on either side of open trench exhibited remarkable structural integrity and behaved as single rigid unit. This observation was further corroborated by the constant readings observed from installed dial gauges during the course of testing. Further, the top reaction load coming from kent-ledge system consisting of concrete blocks of size $1m^3$ with proper anchoring system demonstrated excellent structural integrity. Owing to proper reaction system, even at high peak loads, the concrete blocks didn't exhibit yielding.

5 Conclusions

In-situ tests are of significant importance as these can closely simulate the realistic field conditions consisting of actual discontinuities at the project site. Such experimental simulations are of immense value for design and analysis of structures to be constructed in or on jointed rock-mass. However, such in-situ tests require careful site preparation before actual test so as to avoid erroneous results as well as accidents during testing. There are situations when site specific problems cannot be accounted for while preparing the test site. This paper highlights such difficulties by means of a case-study of in-situ block shear test and uniaxial jacking test in an open trench. The authors have addressed the issue with regards to applying suitable reaction loading arrangement by means of innovative Kent-ledge loading procedure. The Kent-ledge loading procedure adopted in field was proven to be very effective. Relying on the description provided by the authors, it is believed that, similar analogous solutions can be arrived at for other terrains as well.

6 Practical Importance of the Proposed Study

The authors have presented a case study pertaining to hydroelectric project near Polavaram irrigation project spillway Site. The authors are of the opinion that, the proposed loading arrangement aids in the utilization of available resources to the best possible extent, in carrying out sampling procedures required for characterization of rock mass. The authors are hopeful that the site specific method presented in the manuscript is quicker and reliable and even meets the standards laid forth in relevant BIS code(s).

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