GEOTECHNICAL APPRAISAL OF FOUNDATION CONDITIONS OF DIBANG DAM, ARUNACHAL PRADESH, INDIA

Y K CHAUBEY, IMRAN SAYEED, SANKHADIP CHOWDHURY AND RAHUL KHANNA
NHPC Ltd, Faridabad, Haryana, India

THOMAS DIETLER
Pöyry Switzerland Ltd. (now part of AFRY)

ABSTRACT

NHPC is implementing Dibang Multipurpose Project across river Dibang in Arunachal Pradesh, Northeastern India with objectives of flood moderation and power generation (2880 MW). The scheme envisages construction of ±278 m high concrete gravity dam on a foundation of strong feldspathic gneiss with subordinate schist bedrock of Proterozoic age. Extensive investigation has been carried out by NHPC since 2002 prior to which federal agencies were also involved in feasibility studies. About 3800 m of core drilling and 725 m of exploratory drifts (test tunnels), several laboratory and in-situ rock mechanic tests have been performed. M/s Pöyry of Switzerland was engaged as expert consultant to review the geotechnical aspects. Their studies together with examination of site and investigation data have established the geological and geotechnical feasibility of founding a high dam at this site. The paper embodies details of investigation, feasibility studies and geotechnical appraisal of the foundation for the high dam.

1. INTRODUCTION

1.1 History of the Dibang Dam project

A high dam towards the lower reaches of river Dibang was conceived in early eighties by Brahmaputra Board. Two alternative locations were identified in this regard. Out of the two sites, the one located about 2 km upstream from the confluence of river AshuPani with Dibang near Munli was preferred for further investigations. In March 2002, a Pre-feasibility report (PFR) envisaging a 263m high concrete face rock fill dam at the Dam axis-I with 02 nos., 4 km long head race tunnels and a surface power house was prepared by Brahmaputra board. Based on the PFR findings, Government of India accorded Stage-I clearance to the project.

Project layout was reviewed in February 2003. Based on engineering constraints such as accommodation of surface spillway, the dam axis was shifted about 250m upstream of Dam axis–I indicated in PFR to Dam axis-II with E-W alignment (Fig. 1). A 263m high clay core rock fill dam with surface chute spillway was envisaged at this axis. NHPC completed about 921m of drilling and 176m of drifting at this dam axis. This location was also ruled out for founding the dam due to presence of significant depth of overburden of the order of 70 m. It was subsequently decided to explore a new alternative and accordingly, Dam axis-III, about 460m downstream of Dam axis-II, was selected as shown in (Fig. 1). Instead of surface power house, an underground power house was proposed towards the right bank inside the ridge facing Ashu Pani-Dibang confluence. The Dam axis-III was extensively investigated by geological mapping, exploratory drilling and drifting. Based on the investigation results, Geological Survey of India (GSI), recommended that the geological setting were favorable for the construction of a concrete gravity dam with spillway located within the dam body in order to avoid huge vertical cutting of 150-200m on right bank for locating spillway.

Subsequently, after evaluating the possibility of construction of a concrete dam at the proposed location with an underground power house, it was decided to consider a ±288m high (from deepest foundation) concrete gravity dam at this location. Comprehensive geological and geotechnical investigations were undertaken by NHPC in form of detailed geological mapping, geophysical studies, exploratory drilling and drifting supported by laboratory and in situ rock mechanic tests.

After detailed examination the techno-economic concurrence (TEC) was accorded by federal authorities to the project during January 2008 with a dam height of 288 m which was subsequently reduced by 10 m on recommendation of Forest Appraisal Committee, of Ministry of Environment Forests & Climate change (MOEF & CC), Government of India in September 2014

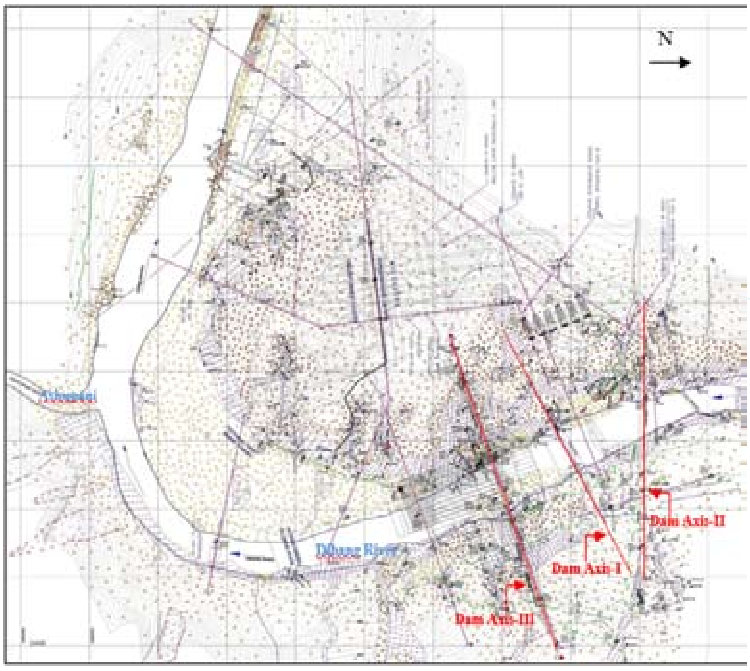

Fig. 1 : Layout Plan of the project area along with location of alternative dam axis.

As a prerequisite of TEC, certain supplementary investigations and tests were conducted along with appointing Poyry Energy AG as International geotechnical expert to carry out the geotechnical appraisal of the dam foundation. From January 2006 to March 2016, supplementary site investigations were carried out as per the recommendations of TEC and International geotechnical expert. During January 2017, expert from Poyry Energy Inc. visited the project area and also evaluated the entire site investigations conducted so far and submitted its appraisal in form of Final report titled "Geotechnical Appraisal of Foundation Condition of Dibang Dam" during March 2017. The project was accorded TEC for the second time with a dam height of ± 278 m.

1.2 Salient features of the project

Location		
State	:	Arunachal Pradesh, India
District	:	Lower Dibang Valley District
River	:	Dibang
Dam Site	:	1.5 km u/s of confluence of Ashupani with Dibang
		Latitude : 28°20'7" N; Longitude : 95°46'38" E
Reservoir		
Maximum Water Level (MWL)	:	El. 538.0 m
Full Reservoir Level (FRL)	:	El. 530.3 m
Minimum Draw Down Level (MDDL)	:	El. 489.2 m
Gross Storage at FRL	:	3247.9 M cum
Dam		
Type	:	Concrete Gravity Dam
Top Elevation of Dam	:	El. 540 m
Height of Dam above deepest foundation level	:	278 m
Length of Dam at top	:	798 m
Spillway		
Spillway Capacity at FRL	:	19000 m^3/sec
Lower level Spillway	:	6 nos.; Crest Elevation – El. 454.2 m
Upper level Spillway	:	5 nos.; Crest Elevation – El. 485.3 m
Water Conductor System		
Head Race Tunnel	:	6 nos.; 9 m dia. Horseshoe

Pressure Shaft	:	6 nos.; 7.5 m dia. Circular Steel Lined
Penstocks	:	12 nos.; 5.2 m / 4.0 m dia. Circular Steel Lined
Tail Race Tunnel	:	6 nos.; 9 m dia. Horseshoe
Power Generation		
Power House	:	Underground
Number of Units	:	12
Installed Capacity	:	2880 MW (12 x 240 MW)

1.3 Topography of Dam Site

The proposed dam site is located about 1.5 km upstream of confluence of river Ashu Pani with river Dibang. At the location of dam axis, the deepest riverbed level is El. ±292.0m. The width of the river channel is about ±135m at the dam axis. The topography at the proposed location is defined by a moderately narrow asymmetrical valley with moderately sloping banks having rock exposures on the river edges. At the dam axis, the river course is aligned almost in NW-SE direction. The left bank slope is of the order of 38° to 45°. The right bank slope is of the order of 40° to 45° upto El. 360 m from the river edge and becomes steeper at 65° to 75° above El. 360 m upto El. 490 m. Above El. 490 m the slope is at an angle of 45° to 60°. Flowing further downstream the river takes sharp bend around a hill ridge towards the right bank following NE-SW course. The slope of the river in vicinity of project is about 1V:250H.

1.4 Dam Section

Based on the outcome of geotechnical investigations the dam cross section was reviewed closer to a trapezoidal section while the original dam cross section was close to a right triangle. As such upstream and downstream face of dam has multiple slopes. The base width of the highest non-overflow block and overflow block (spillway) is ± 355 m and ± 400 m respectively.

This modification has beneficial effect on the stress distribution in both the dam body and the foundation. Also due to the modified cross section the sliding stability of the dam is significantly improved. Due to multi sloped upstream faces the entire foundation interface is kept in compression and shear stresses along the foundation interface are distributed more evenly. The tendency of tensile stresses and large shear stresses getting generated at the upstream heel and the downstream toe respectively is greatly reduced by the modified cross section. The estimated effective vertical stresses at foundation grade under the highest dam blocks are of order of 3-4 mpa (compression) for normal condition and 4-6 mpa (compression) for unusual conditions.

1.5 Location and general geology of the project area

The proposed dam (N28°20' 07"; E95°46'38") is located on river Dibang, about 1.54 km u/s of river confluence of Ashu Pani with river Dibang, in Lower Dibang Valley district of Arunachal Pradesh. The project site falls within Mishmi hills within rocks of Bomdila Group belonging to Proterozoic age (GSI Records, vol. 145-146 Part-4, 2013). According to the geological succession proposed by Geological Survey of India (Mahanta et al., 2012), the rocks of Bomdila Group are in tectonic contact with the quartzites of Boleng Group towards downstream of the project, which are thrusted over the Siwalik in further south. However, in the north (towards upstream), Bomdila Group is in contact with Dibang Group. The geological succession is given in Table 1 below:

Table 1 : Geological Succession of Dibang valley after GSI (Mahanta et.al, 2013)

Lithology	**Formation**	**Group**
Sand stone/ Silty Shale	Undifferentiated Siwalik rocks	Siwalik
Biotitegranite/Pegmatite/Diorite-Granodiorite-Granite/Basic-Ultra basic/Garnetiferous granodiorite		Lohit Granitoid Complex
Peridotite-serpentinite/ Metagabbro-amphibolite/ Basic schist/ Actinolite-tremolite schist	Mayudia Complex	Dibang Group
Crystalline Limestone/ Limestone	Hunli	
Serpentinite/ Chlorite schist with Carbonates, Phyllite and Carbonaceous phyllite	Tidding (Yang Sang Chu)	
Orthoquartzite/ Hornblende schist	Ithun	
Conglomerate-pebbly orthoquartzite/ Pink orthoquartzite	Silekorong	Boleng Group
Green quartzite-phyllite/ Pink orthoquartzite	Bomdo	
Garnetiferous mica schist/ Biotite gneiss-hornblende gneiss with calcareous quartzite		Bomdila Group

Several synclinal and anticlinal fold axes are also present within the project area indicating the intricate folding of rock mass. Dibang river course is inferred to be developed along the axial trace of an overturned anticline, at the dam site. The foliation is very prominent, dipping in directions varying from North to NE and further towards East (Fig.2).

Fig 2 : Foliation joints with highly varying dip directions exposed towards left bank upstream of dam axis.

The most important structural elements are Tidding Suture (±5Km North), Lohit Thrust (±16 Km North).The rocks of Boleng Group are thrusted over Siwaliks through MBT which is located about 10 Km downstream. NHPC carried out Megnatullertic (MT) survey through Indian Institute of Geomagnetism (IIG), Mumbai during 2008 which ruled out existence of any major thrust/fault zone near the dam site.

2. FIRST STAGE GEOLOGICAL AND GEOTECHNICAL INVESTIGATIONS

Detailed geological and geotechnical site investigations were carried out with inputs from GSI, CSMRS, NIRM, IIGM etc. Detailed topographical survey of the entire project area was undertaken. Geological mapping covering about 4.5 Km^2 area was conducted and important geotechnical details were collected on 1: 2000 scale. Preliminary desk studies were carried out to identify major unstable slopes around the dam site and other project areas utilizing IRS 1C/1D LISS III Geo-coded FCC's on 1:50,000 scale. Geophysical survey was conducted by NHPC at the dam site in form of seismic refraction profiling of 610m towards the left bank to delineate bed rock contact. One seismic profile of 100m length was carried out by CSMRS earlier also towards left bank. In-situ shear wave velocity study was conducted in one of the drill holes DDH-32 of 30m depth towards the left bank to determine dynamic and static elastic parameters of bed rock.

Exploratory drilling and drifting was carried out at both dam axis-II & III respectively to assess the subsurface geological conditions. Dam axis-II was dropped from further investigations due to presence of significant depth of overburden leading to deep open excavation on left bank. Three nos. drill holes undertaken along surface spillway indicated overburden of the order of 33m while four nos. drill holes towards the left abutment indicated overburden ranging from 34 to 70m.

During stage 1 of investigations at dam axis-III (Fig.3), foundation and both abutments were explored through 15 nos. drill holes (Fig.4) and 5 nos. exploratory drifts (Fig.5). Exploratory drilling included 4 nos. holes in the river bed also (Fig. 6) along with 5 nos. groutability test holes undertaken towards left bank. The cumulative length of exploratory bore holes and drifts at dam axis-III has been 1117.50m and 495m respectively. Detailed geological logs of drill holes as per IS 4464 (India Standard Code) and 3-d geological logs of exploratory drifts were prepared. The above data was utilized for constructing a geological model of the dam area and also for planning of investigations further and to re-adjust the design details.

Fig 3 : Downstream view of the dam axis-III.

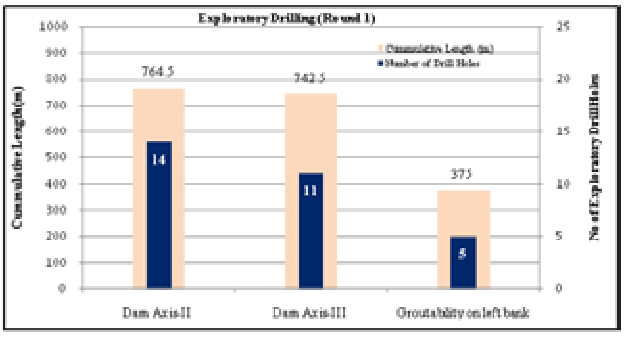

Fig 4 :.Exploratory drilling in round-1at the dam area.

Fig 6 : Exploratory drilling in the river bed to explore dam foundation condition.

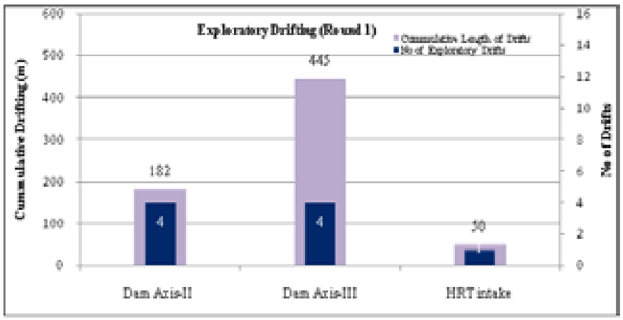

Fig 5 :. Exploratory drifting in round-1at the dam area.

Attitudes of about 2500 nos. of joints collected from the exploratory drifts located on both left and right banks were plotted separately in form of rose diagram and stereo plots (Fig.7 and Fig.8).

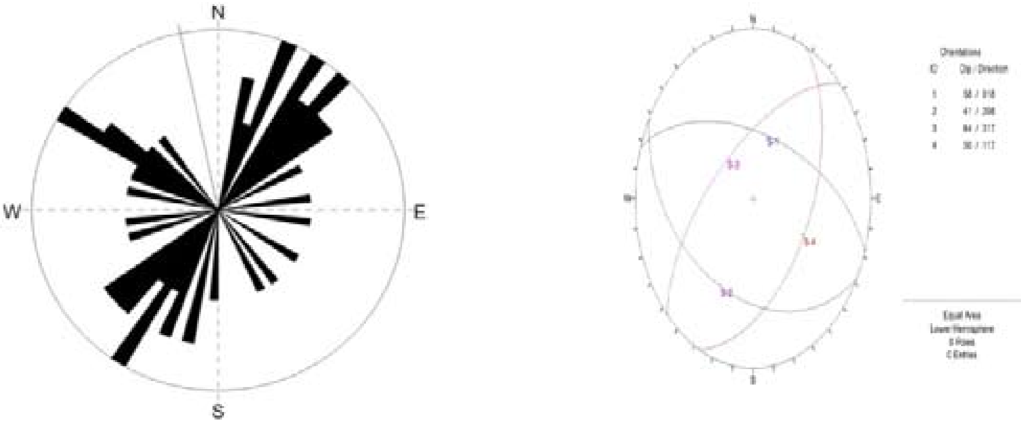

Fig 7 : Rose diagram and stereo plot of major discontinuities towards left bank

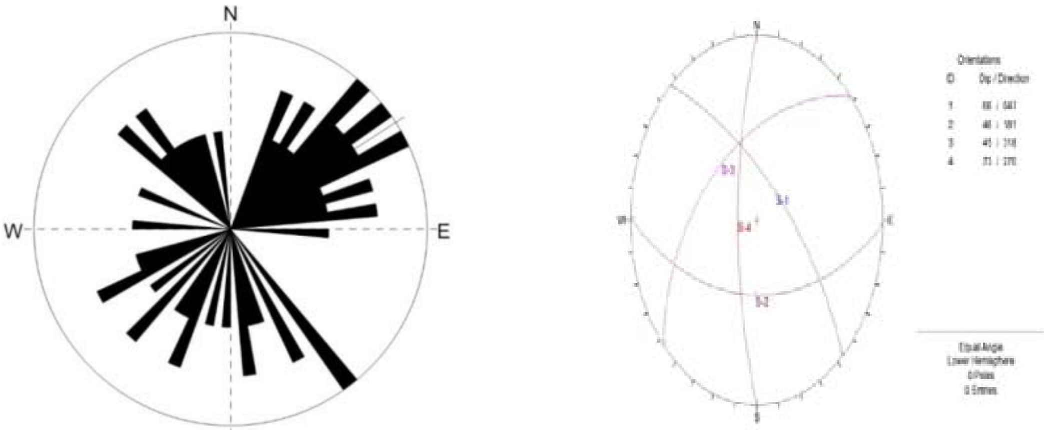

Fig 8 : Rose diagram and stereo plot of major discontinuities towards right bank

It is observed that dip direction of the maximum no. of joints are oriented in NE to SW direction which corresponds to foliation joints. The majority of the joints are aligned oblique to the dam axis (N071° –N251°). The rock mass is dissected by four major joint sets. Most prominent is foliation (S1) joint which is dipping moderately to steeply (40°-75°) towards northeast (NE) to east (E). At higher elevation there is a swing in foliation trend towards north-easterly direction. Based on the stereo plot analysis, average orientations of the four major discontinuities (S1, S2, S3 and S4) has been worked out for both left and right banks respectively. The same are plotted on stereo net and also given in Table 2 below:

Table 2. Major discontinuities identified towards left and right banks

Discontinuities	Average Orientation (Dip Direction/Dip Amount)	
	Right bank	Left bank
S_1	$047^0/66^0$	$018^0/58^0$
S_2	$181^0/46^0$	$208^0/41^0$
S_3	$318^0/45^0$	$317^0/64^0$
S_4	$270^0/73^0$	$117^0/50^0$

Laboratory rock mechanics tests were conducted on core samples collected from various drill holes located in dam foundation and abutments through NIRM. Elastic properties viz., UCS, Young's modulus, Poisson's ratio, tensile strength, shear strength (C&Φ) etc. were determined for dry and saturated conditions from intact rock samples.NIRM in association with CSMRS also conducted in situ rock mechanic tests for determining in-situ rock deformability and shear strength parameters (C&Φ) of the rock mass in the middle and upper level drifts on both the banks at alternative-III dam axis. Groutability tests were conducted towards the left bank dam axis adopting single line test method i.e. using a line of drill holes along the proposed grout line. Four primary holes and two nos. secondary holes were done to check the efficacy of grouting in the foundation rocks. Petrographic study on rock samples were conducted through Dibrugarh University.Department of Earthquake Engineering (DEQ), IIT-Roorkee worked out site specific seismic design parameters for the project. Based on the results of round-1 investigations, Detailed Project Report (DPR) was submitted during December 2005.

3. FIRST STAGE GEOTECHNICAL APPRAISAL 2008

3.1 Introduction

At the end of the first site and laboratory investigations round, the developer NHPC mandated Pöyry Energy Switzerland Ltd. (today part of AFRY) to review and comment on the results of these investigations. The scope included the following assignments:

- Review of the dam design using state of the art approach with regard to the safety and stability of the dam considering the prevailing foundation conditions. The design shall include a study covering the possibility of locating the power house in the dam body.
- Review and substantiation, if applicable, of the strength parameters of the foundation material to be used in stability and stress analysis of the dam under different load combinations.
- Review and substantiation, if required, of design criteria to meet the International Standards of safety requirements.
- Review of safety and stability of the slopes of the abutment and plunge pool excavation.
- Suggestions of engineering measures to improve the rock mass properties of the foundation.

3.2 Methodology of the appraisal

The dam and geotechnical expert of the Reviewer inspected the project site for two days in association with NHPC. All existing exploratory drifts in both abutments of dam were visited and inspection of the drill core boxes was carried out in detail to evaluate general and detailed geological-geotechnical conditions at site.

At the corporate office of NHPC, the data assessment started with wrap-up meetings and discussions about the dam design and the geology in place. Having reviewed all the relevant geotechnical reports and documents, the evaluation of the findings from the investigations was conducted taking into considering geology, lithology, bore hole logs (CR, RQD), evaluation of RMR, shear strength, stresses in foundation, settlements to be expected and the executed grouting tests. Finally, additional meetings and discussions took place, as well as further data collection for finalization of the appraisal at home office (Pöyry, 2008).

3.3 Conclusions from the appraisal of 2008

The main issue is the general assessment of the foundation conditions at the Dibang site, in particular the judgement of the safety and stability of the ±288m high gravity dam. For such a high structure one would clearly desire sound, hard and competent rock in the entire foundation. However, the foundation rock consists of highly metamorphosed and partly altered rock, of sedimentary origin.

From the geotechnical point of view the formation comprises essentially gneiss, schist and phyllite. Gneiss as such is a hard durable rock as observed over considerable stretches e.g. along the right river bed. But often the gneiss has a narrow foliation and is highly jointed. The schist is considered to be quite weak. The phyllites are to be classified as poor rock.

One important factor for the correct judgment of the dam foundation is the quality of the cores obtained by the bore holes performed. Often the core recovery is quite low and the quality of the bore cores obtained is low which was not corroborating with observations from site. It was observed that the quality of drilling needed improvement to achieve good core recovery to reflect the actual in-situ rock mass condition which was judged to be of better quality. It was concluded that in general the proposed dam site meets the requirements with respect to foundation conditions although adjustments and further improvements may need to be considered at detailed design stage.

Consequently, complementary explorations were recommended as essential for arriving at a objective assessment of dam foundation for conclusively establishing its feasibility for a high concrete gravity dam. These additional investigations comprised the following activities:

- Galleries/Drifts and exploratory drillings in the both lower abutments.
- Drilling of at least one 200m deep hole.
- Water pressure tests and tests by Goodman jack performed systematically to the maximum depth possible. The latter tests are important to obtain more conclusive information on the deformation characteristics of the foundation rock.
- Geophysical borehole logging.
- Complementary drill holes equipped with Piezometers.
- Complementary grouting tests.
- Of particular importance was to obtain by the new drillings complete core recovery and good quality cores. This requires modern and powerful equipment and a very experienced drilling crew.

4. SECOND STAGE OF INVESTIGATIONS

Another round of additional/supplementary geological and geotechnical site investigations were carried out between January 2006 to March 2016, after submission of Detailed Project report in order to comply with the conditions stipulated under Techno Economic Clearance (TEC) accorded by Central Electricity Authority (CEA) and also to fulfill the recommendations given by the international geotechnical expert of Poyry Energy Inc.

4.1 Exploratory drilling and drifting

During this supplementary investigation carried out in stage 2, overall 27 nos. exploratory drill holes with cumulative length of 2604.05m were completed in the project area. Out of this, 24 nos. drill holes were carried out in dam area having cumulative length of 2405.55m (Fig. 9). Therefore, including both round-1 and round-2 of investigation a total of 52 nos. of drill holes with cumulative exploratory drilling of4486m has been completed in the dam area. As recommended by international geotechnical expert, a 200m deep vertical drill hole DDH-40 has been drilled towards left bank to explore the foundation rock (Fig.10). This drill hole intercepted moderately jointed, good quality bed rock in form of feldspathic gneisses with bands of dark amphibole and pegmatite gneiss.

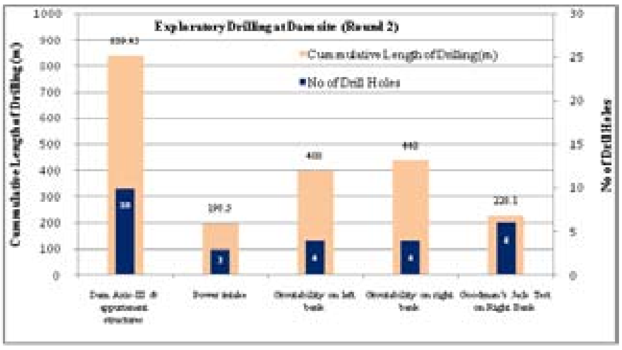

Fig 9 : Exploratory drilling in round-2 at dam area.

Fig 10 : Good quality core pieces recovered from drill hole DDH-40 having depth of 200m

Fig 11 : Exploratory drifting in round 2 at dam area.

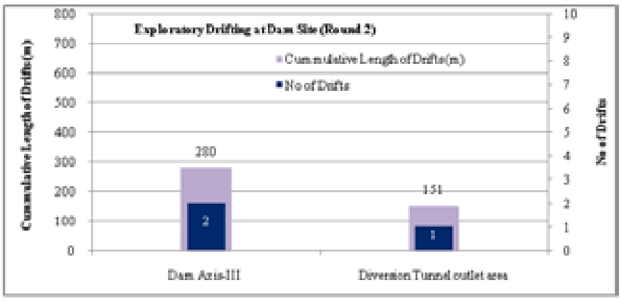

Fig 12 : Lower level exploratory drift towards left bank on dam axis-III

The 2006 revision of BIS Code-IS 15662 recommended three levels of exploratory drifts for dams having height more than 100m. Therefore, as stipulated in TEC conditions and recommended also and for evaluating foundation condition, two lower level drifts at dam axis, one each on either bank having cumulative length of 280m were excavated during round 2 investigation stages (fig.11).Overall, dam area has been explored with 11nos of drifts having cumulative length of 1470m.

Based on the recommendations of GSI and International geotechnicalexpert, groutability tests were carried out on both banks in the dam foundation with triangular pattern in accordance with IS 6066. By successively drilling and grouting three nos. 110m deep drill holes located on the vertices of an equilateral triangle of 3m long sides and one 110m deep check hole at centre of the triangle so as to check the efficacy of grouting. The groutability test indicated that the foundation rock intermittently shows high permeability in initial level down to 60-70m depth in fracture/jointed zones where permeability reaches up to 15 to 60 lugeons. However, the post grouting permeability values were reduced below 5 lugeons, indicating foundation rock is amenable to grout.Therefore, grouting will play a significant role in foundation treatment as well as for desired permeability reduction in dam foundation.

4.2 Establishment of a geological model of dam area

Based on the above site investigations including exploratory holes and three levels of exploratory drifts, a geological model for the dam area has been prepared (Fig.13) after correlating all data. This model explicitly depicted expected quality of rock mass based on geomechanical classification (Bieniawski, 1989). The rock classes II (Good), III (Fair) and IV(Poor) anticipated are 12.43%, 79.56% & 8.0% for left bank and 13.33%, 79.72% &6.94% for the right bank respectively. Zones of fractured/sheared rock mass expected to intercept the foundation grade has also been shown. Overburden material along with zone of weathered rock mass which need to be removed during excavation has been worked out based on geological mapping, exploratory drilling and drifting.

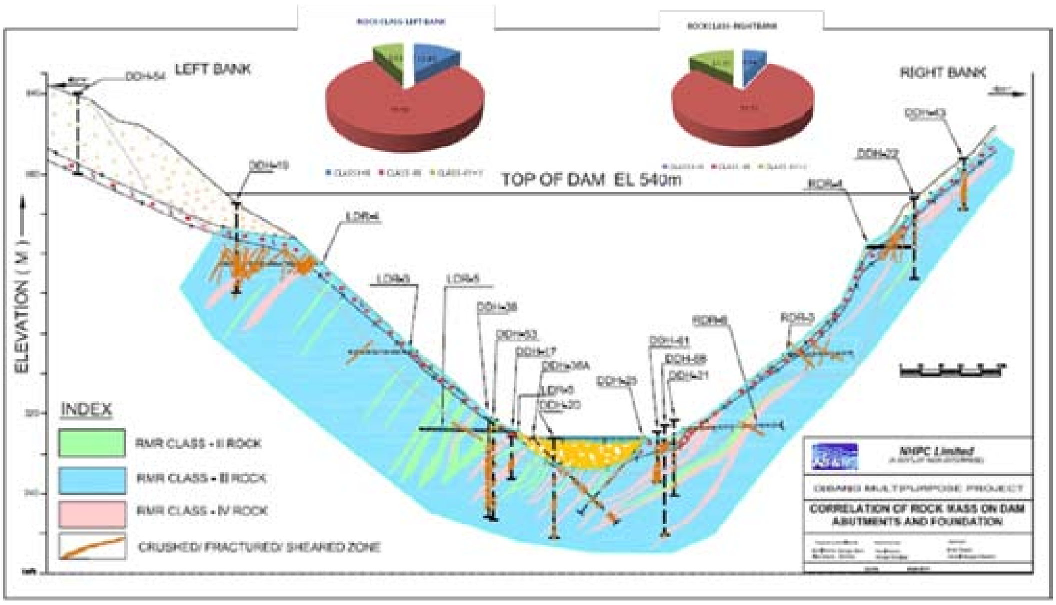

Fig 13 : Geological model based on geotechnical investigations in form of cross section at dam axis.

4.3 Rock Mechanics Testing and analysis of test results

During round 2 investigations also, laboratory rock mechanics testing was performed through Indian School of Mines (IIT-ISM), Dhanbad for various engineering properties of intact rock. For assessment of the dam foundation, the deformation modulus of the founding medium is very important. The important insitu tests conducted for deformability measurement are (i) Plate Load test; (ii) Plate Jacking Tests, (ii) Goodman Jack Tests and (iv) Dilatometer Tests. As suggested by international geotechnical expert, insitu rock mechanic tests to determine shear strength parameters and deformability were conducted through NIRM during 2011 in both the lower level drifts viz., LDR-5 & RDR-8. Beside 5 nos. deformability tests were also conducted using dilatometer by NIRM in the 200m deep drill hole no DDH-40 located about 100m d/s of dam axis towards the left bank. Further, during 2015-16, CSMRS conducted insitu tests again in both lower drifts in form of shear and plate load tests, followed by Goodman Jack tests in five nos. drill holes (DDH-59, 60, 61, 62 & 63) located on right bank. The details of insitu tests performed are given in Table 3 below:

Table 3 : Insitu Rock Mechanic testing during round 2 at dam area.

Insitu Tests	Left bank – lower drift (LDR-5)		Right bank – lower drift (RDR-8)	
	NIRM	CSMRS	NIRM	CSMRS
Deformability (Plate Load Test)	5(2011)	5(2016)	10(2011)	5(2015)
Direct Shear Test (Rock to Rock)	5(2011)	4(2016)	5(2011)	5(2015)
Direct Shear test (Rock to Concrete)	------	5 (2016)	------	5(2015)
Dilatometer Test (NIRM 2011)	5 nos. tests in DDH-40		--------	
Goodman's Jack Test (CSMRS 2016)	---------		28 nos. tests DDH-59-63	

The results w.r.t. deformation moduli submitted by various agencies werefound to be highly variable. Therefore, in order to workout representative values, geotechnical memos summarizing all thetest results and interpretation of deformability characteristics w.r.t. the foundation rockcondition as encountered in exploratory drifts at three levels and applied stress levels were prepared. The results of this analysis are discussed below:

Left bank: A perusal of rock classification data from all the three drifts on the left bank indicates that majority of rock mass is of Class-III (80%), whereas Class-II (12%) and Class-IV (8%) contribute small portion only. Test locations along with the respective rock classes as encountered in left bank drifts is shown in Figure 14. Average values of all deformability tests conducted at various level drifts on the left bank are plotted against stress levels (Fig. 15). Accordingly at Stress levels 6,8 and 10 MPa, deformation modulus of 3.72, 5.54 and 6.75 GPa has been worked out. After stripping of weathered portions, it is estimated that approx. 6% of Class-IV rock will still remain in foundation. The values given above represent Class II/III conditions which are anticipated in about 92% of the rock mass. For values pertaining to Class IV rock mass condition separate evaluation has been carried out for both the banks.

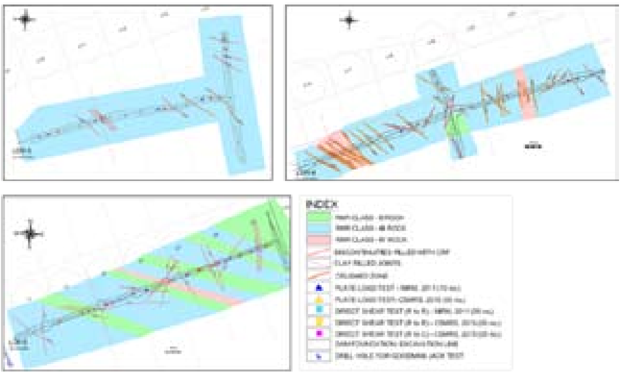

Fig 14 : Locations of insitu rock mechanics test shown along with estimated rock classes in the exploratory drifts towards left bank.

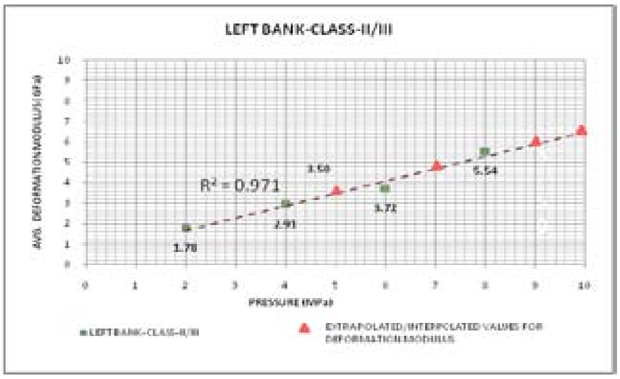

Fig 15 : Average values of all deformability modulus obtained in Class-II/III rock mass at left bank.

Right Bank: Rock mass data from all the three drifts on right bank also indicates that a majority of rock mass fall in Class-III (80%) category. However in case of right bank Class IV constitute 13% while Class-II is 7%. Test locations along with respective rock classes as encountered in right bank drifts is shown in Figure 16. Average values of all deformability tests conducted at various level drifts on right bank for Class-II/III rock mass (87%) are plotted against stress levels (Fig. 17). The deformation modulus values obtained from Goodman Jack tests undertaken in the two horizontal drill holes DDH-62 and 63 inside lower most drift on the right bank are also considered while averaging. It is however, difficult to ascertain rock classes from the drill-hole data.

The lower drift (RDR-8) has encountered 26% of Class-IV media which is mainly occupying initial 70m of the drift portion. Incidentally, the testing carried out by NIRM covers Class-IV rock at four locations. However, it is also seen from dam excavation section that about 45m of the right bank portion will be excavated. As the remaining 25m also encompasses majority of Class IV rock with a number of shear zones/seams has been recommended to increase the stripping corresponding to 70m in RDR-8 drift. If this portion is stripped then the percentage of Class-IV is expected to come down. However, it may be appreciated that inherent Class-IV bands (other than outer periphery owing to weathering) will continue to remain in foundation which are overall expected to be approximately 10% of the media on right bank.

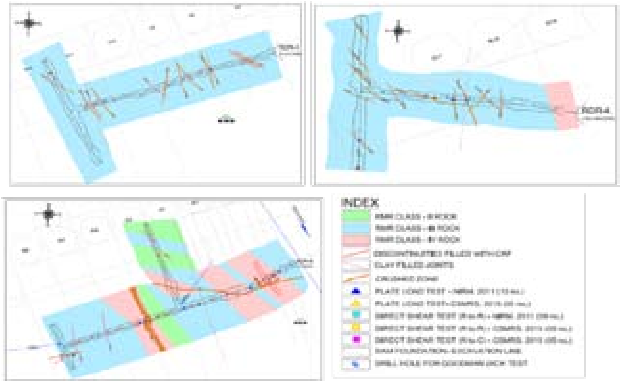

Fig 16 : Locations of insitu rock mechanics test shown along with estimated rock classes in the exploratory drifts towards right bank.

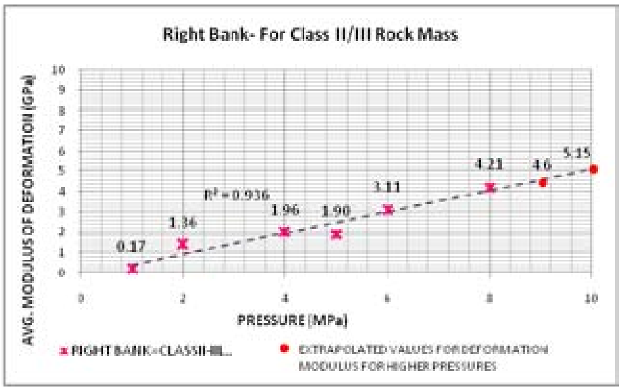

Fig 17 : Average values of all deformability modulus obtained in Class-II/III rock mass at right bank.

From the complete tests carried out in all Class-IV rock having RMR 27-40, the average value of deformation modulus for Class-IV is estimated to be 1.28 GPa at 6 MPa and 1.42 GPa at 8 MPa respectively (Fig.18). These values for Class-IV rock have been adopted for left bank also. It is pertinent to add that the thickest band of Class-IV rock found inside RDR-8 is 7m wide.

River Bed: In order to have the assessment of rock foundation in river bed portion, deformability values obtained from Dilatometer test conducted by NIRM during 2011 in vertical drill hole DDH-40 towards the left bank and Goodman Jack test conducted by CSMRS in three nos. vertical drill holes towards the right bank are considered.On analysis of the deformation modulus values obtained from Goodman Jack test, average deformation modulus values of 2.74, 3.29 & 3.6 GPa at 6, 8 and 10 MPa pressures respectively are obtained.It is presumed from all investigation data that after reaching the foundation grade nearly 10% of all the media shall be of Class-IV category in river bed. After removal of weathered rock etc. this percentage is expected to come down to 8% for which values as given for the right bank may be adopted.As discussed earlier also dilatometer test has given a value of 4.74 GPa at 5 MPa stress level on the left bank. It further strengthens the interpretation that rock mass on left bank is better when compared to right bank. This position is also expected to be reflected in the river bed. Based on the above analysis, the recommended values for deformation modulus are shown in Table 4 below:

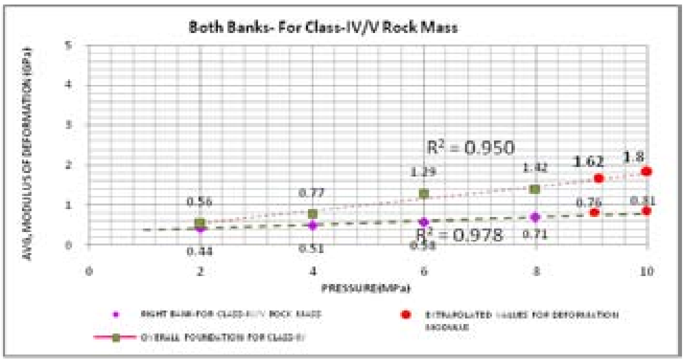

Fig 18 : Average values of all deformability modulus obtained in Class-IV/V rock mass at both banks.

Table 4 : Recommended values of deformation modulus for dam foundation

Location in Dam Area	Stress Level (MPa)	Recommended Values of Deformation Modulus (E_m) in GPa	
		Class-II/III rock mass	Class-IV rock mass
Left Bank	6.0	3.72	1.29
	8.0	5.54	1.42
	10.0	6.75	1.80
Right Bank	**6.0**	**2.80**	**1.29**
	8.0	3.83	1.42
	10.0	4.60	1.80
River Bed	6.0	3.06	1.29
	8.0	3.67	1.42
	10.0	3.96	1.80

4.4 Hydrogeological study and permeability contours for dam foundation

At the instance of International geotechnical expert, a hydro-geological section has also been prepared by NHPC at the dam axis (Fig. 19). This section depicts the measured permeability test results from various boreholes along with contour lines of permeability values. The section also included the groundwater levels measured in the various boreholes.

Suggestions of International geotechnical expert including geophysical logging and monitoring of water levels in boreholes is being undertaken in the dam area during pre-construction stage.

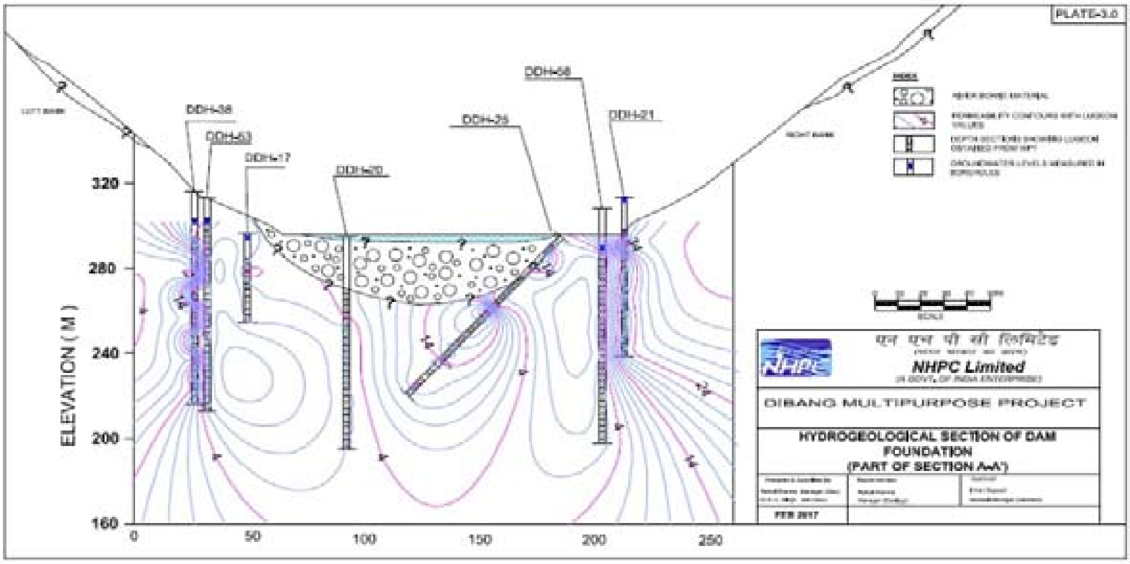

Fig 19 : Hydrological Section depicting permeability contours along dam axis.

5. SECOND STAGE OF GEOTECHNICAL APPRAISAL 2017

5.1 Introduction

After execution supplementary geological-geotechnical investigations, NHPC,during 2017,again mandated Pöyry Switzerland AG. (Presently part of AFRY) with the consultancy on the geotechnical appraisal of the foundation conditions of Dibang Dam with following Scope of Work:

- To study, analyse and review the results of additional investigations and geotechnical tests.
- To study, analyse and review the results of the entire investigations and geotechnical tests carried out so far.
- To provide geotechnical appraisal of the rock mass, its properties and behaviour, its strength and weakness etc., qualitative as well as quantitative, with reference to safety and stability of the high concrete gravity dam.
- To suggest measures required to be undertaken during design and engineering and construction, if any.
- Overall final review of the report “Geotechnical Appraisal of Foundation Condition of Dibang Dam, October 2008” (Pöyry 2008) in light of the above review, if required.

5.2 Methodology

As during the appraisal in 2008, the second round in 2017 took place on project site (3 days) and in the NHPC’s corporate office in Faridabad outside New Delhi (2 plus 3 days).

The focus during the site visit was on detailed inspections of all old and new exploratory drifts in the left and right abutments, as well as all core boxes of the newly drilled exploratory boreholes. Finally a wrap-up discussion with all participants, including the Director (Technical) of NHPC, was held for a common understanding of the site conditions and the geotechnical interpretation of them.

The document review in the developer’s office assessed the new results and findings from the second round of investigations and put them into relation to the earlier investigation results and Pöyry’s appraisal in 2008.

5.3 Next project steps

Geophysical logging of selected drill holes and monitoring of water levels in boreholes are being undertaken in the dam area during pre-construction stage for refining the estimates rock mass characterization of dam foundation and establishing the transient groundwater flow behaviors in the foundation rock mass.

5.4 Conclusions from the appraisal 2017

The appraisal of the geological-geotechnical foundation conditions at Dibang Dam Axis can finally be summarized as follows:

- Extensive site and laboratory investigations have been conducted in two phases by NHPC and various external organisations. All the important supplementary investigations have been executed as requested. All results are very well documented and structured in the DPR September 2016 Volumes.
- The site inspection 2017 revealed that in the left abutment the geological-geotechnical conditions are more favourable than in the right abutment. Furthermore, it became obvious that a considerable portion of the poor quality of drill cores and excavated drift walls is due to mechanical impact during drilling and blasting, as well as due to stress relieve and weathering after core recovery and excavation.
- Thus, the real conditions can be stated as in a certain grade more favourable than indicated by the apparent quality of drill cores and drift excavations. The DPR documents reflect the conditions at site very well and they can be assessed as reliable, although they have to be taken rather on the conservative, safer side than too optimistic. Assessing the results from the rock mechanics in-situ tests (in drifts), it has to be stated that these values have also to be considered as rather conservative, since the relatively large disruption zone around the drift excavation has affected them.
- From the geological and engineering point of view no further site investigations were required for the technical clearance of the DPR.
- It is strongly recommended to plan, execute and monitor the rock mass excavation for dam foundation properly and by smooth and controlled blasting to affect the remaining rock mass in the foundation as little as possible.

6. CONCLUSIONS

6.1 Final conclusions from the geotechnical investigations and the appraisal of their results

1. The 2017 assessment of the site conditions and the performed investigations revealed that no further site and laboratory investigations were required.
2. The assessment indicates that the undisturbed rock mass quality is assumed to be better in some extends than apparent from the inspection of the drifts and the drill cores.
3. The resulting geotechnical parameters from the in-situ and the laboratory tests indicates estimates which makes the foundation condition manageable for safe construction and operation of a ±278 m high concrete gravity by deploying proper design and construction methodology. However, studies (Palmström and Singh, 2001) in the Himalayan mountains show that with Plate Jacking Tests more realistic in-situ values would be resulting, which are in average by a factor of 2.5 higher compared to those received from the Plate Load and Godman Jack Tests performed at Dibang Dam site. This shows that the geotechnical parameters obtained from the in-situ and laboratory tests are on the conservative side and the real conditions are more favourable. Thus, the geotechnical parameters as suggested in DPR for use are reasonable and will result in a more conservative than in an optimised design.
4. Basically, such type and size of dam would require Rock Mass Class II (Good Rock) for safe foundation. However, approximately 80% of the Dibang Dam site rock mass is classified as Class III (Fair Rock); only around 10% are to be classified as Class II. However, with maximum of class V/IV rock comingunder stripping during excavation, the percentage of Class-II/III rock mass shall increase. This aspect has been adequately addressed in the up-dated dam design 2016 by adjusting the cross section of the dam body to limit stresses transferred to the foundation.
5. To summarize, the modification of the dam section considerably improves sliding stability and seismic resistance of the dam as well as the compatibility of the deformation behaviour of the dam and the deformation behaviour of the foundation.
6. Analysis showed that for the highest dam section, assuming fair rock properties (Class III), the allowable bearing capacity is not exceeded. The smaller section with a height of 120 m, applicable for higher foundation levels on both abutments, was investigated in respect to the presence of combination of fair and poor rock qualities and was found to withstand the resulting static loads (such as dead load, water load and uplift forces).
7. To enhance the compatibility of deformation behaviour of the dam body and the foundation rock mass, zoning of the dam should be considered, i.e. concrete with higher strength should only be applied where necessary, e.g. at the faces and in the upper sections, and lower strength concrete should be used wherever possible. This would also help to reduce thermally induced stresses.
8. Roller Compacted Concrete can have significant lower modulus of elasticity compared to conventional vibrated concrete, and should be considered for the Dibang Gravity Dam due to the more compatible deformation behaviour.

9. The test grouting revealed that the rock mass can be improved regarding water tightness and to some extend also regarding consolidation of the rock mass.
10. To improve the foundation rock as far as possible, the following appears important:
    (a) Adequate excavation of rock mass, and where required replacing by dental concrete.
    (b) Extensive consolidation grouting to improve the remaining rock mass.
11. To estimate the required excavation and grouting volume (for consolidation and curtain) and thus the final concrete volume for the dam body, a thorough assessment of the Rock Class, Lugeon-value and Ground Water Level distribution in the dam foundation area has to be prepared.

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