View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Missouri University of Science and Technology (Missouri S&T): Scholars' Mine

Missouri University of Science and Technology
Scholars' Mine

International Conference on Case Histories in Geotechnical Engineering

(2013) - Seventh International Conference on Case Histories in Geotechnical Engineering

01 May 2013, 2:00 pm - 4:00 pm

# Determination of In-Situ Stress at Desilting Chamber of Punatsangchhu Hydroelectric Project (Bhutan), to Reconfirm Its Orientation Influenced by Topography — A Case Study

D. S. Subrahmanyam
*National Institute of Rock Mechanics, India*

S. Sengupta
*National Institute of Rock Mechanics, India*

R. K. Sinha
*National Institute of Rock Mechanics, India*

G. Shyam
*National Institute of Rock Mechanics, India*

Follow this and additional works at: https://scholarsmine.mst.edu/icchge

Part of the Geotechnical Engineering Commons

## Recommended Citation

Subrahmanyam, D. S.; Sengupta, S.; Sinha, R. K.; and Shyam, G., "Determination of In-Situ Stress at Desilting Chamber of Punatsangchhu Hydroelectric Project (Bhutan), to Reconfirm Its Orientation Influenced by Topography — A Case Study" (2013). *International Conference on Case Histories in Geotechnical Engineering*. 18.
https://scholarsmine.mst.edu/icchge/7icchge/session01/18

This Article - Conference proceedings is brought to you for free and open access by Scholars' Mine. It has been accepted for inclusion in International Conference on Case Histories in Geotechnical Engineering by an authorized administrator of Scholars' Mine. This work is protected by U. S. Copyright Law. Unauthorized use including reproduction for redistribution requires the permission of the copyright holder. For more information, please contact scholarsmine@mst.edu.

# DETERMINATION OF IN-SITU STRESS AT DESILTING CHAMBER OF PUNATSANGCHHU HYDROELECTRIC PROJECT (BHUTAN), TO RECONFIRM ITS ORIENTATION INFLUENCED BY TOPOGRAPHY- A CASE STUDY

**D S Subrahmanyam**
Scientist, National Institute of Rock Mechanics,
Dooravaninagar, Bangalore, Karnataka, India, 560075
Ph: +918025619697, Fax: +918025612795,
E. mail: subbu3268@gmail.com

**S Sengupta, R K Sinha, G Shyam**
National Institute of Rock Mechanics,
Dooravaninagar, Bangalore, Karnataka, India, 560075
Ph: +918025619697, Fax: +918025612795.

## ABSTRACT

Punatsangchhu Hydroelectric Project stage-I was conceptualized in Wangdue- Phodrang district of Bhutan for harnessing the hydro-power potentiality of Punatsangchhu River. Regionally the project area is located within a part of a gneissic terrain of Tethyan Belt of Bhutan Himalayas. The project envisages construction of 195m high concrete gravity dam across the river Punatsangchhu. For Desilting chamber and Powerhouse, it is always desirable to carry out in-situ stress measurement in such huge underground openings for designing of the support types. The stability of the underground cavern gets enhanced if the long axis of the cavern is oriented along or sub-parallel to that of maximum principal stress. National Institute of Rock Mechanics, a premier Research Institute under Ministry of Mines, Government of India, carried out stress measurements at RD 100m and RD 150m inside an exploratory drift approaching towards desilting chamber with a rock cover of 100m. This test was required to freeze the orientation of desilting chamber vis. a vis. orientation of maximum compression ($\sigma_H$) which was found to be N 150$^o$. As it was only 100 to 150 m away from the portal, a topography effect on the orientation of ($\sigma_H$) was not completely ruled out. So when the adit to Desilting chamber reached at RD 360m with a rock cover of 410m, it is necessary to carry out stress measurement at RD 360m to confirm the results of earlier tests at RD100m and RD 150m to find out the influence of topography on which the present paper is based was primarily for determination of in-situ stress measurements. The stress orientation as evaluated at RD 360m reconfirms the orientations revealed from earlier stress measurements at RD 100 and RD 150m.Thus it is recommended to freeze the direction of Desilting chamber along N 150$^o$. It also confirms that the earlier stress measurement results do not suffer from topography related influence.

## INTRODUCTION

Punatsangchhu Hydroelectric Project (PHEP) was conceptualized in Wangdue- Phodrang district of Bhutan (Figure.1) for harnessing the hydro-power potentiality of Punatsangchhu River. The project envisages construction of 195m high concrete gravity dam across the river Punatsangchhu. Four underground Desilting Chambers have been proposed on the left bank between E.L. 1129m and 1158m. The size of each chamber is 431m long including transition zone, 16m wide and 27m high to divert the water through Head Race Tunnel to an underground Power House for the generation of 870 M.W. of power. The rock cover gradually increases from the inlets towards the end of the chambers. The orientation of longitudinal axis has been worked out as S35$^o$E on the basis of orientation and intersection of joints forming wedges.

It is always desirable to carry out in-situ stress measurement in such huge underground openings for designing of the support types as the stability of the cavern gets enhanced if the long axis of the cavern is oriented along or sub-parallel to that of maximum principal stress.

Water and Power Consultancy Service (WAPCOS) India Ltd. has been entrusted to prepare the Detailed Project Report (DPR) of PHEP stage-1 by the Royal Government of Bhutan (RGOB) for finalizing the design, cost and schedule of construction of this project. In view of the above WAPCOS India Ltd engaged National Institute of Rock Mechanics (NIRM) India, to carryout in-situ stress investigations inside an exploratory drift to the proposed Desilting chamber.

In-situ stress measurements were conducted in two phases in the span of six months. The first phase of experiments was conducted inside two NX size (76mm) boreholes at RD 100m and RD 150m initially. As the drift progressed further deep into 400m, the second phase of in-situ stress measurements were conducted at RD 360m to confirm the results of earlier tests at RD100 and RD 150m to find out the influence of topography

FIRST PHASE OF INVESTIGATIONS

Scope of the work

In-situ stress measurements by Hydrofrac method using HTPF method (Hydrofrac Test in Pre-existing Fractures) inside NX size boreholes at RD 100m and 150m inside the adit to Desilting chamber and analysis of the data using software to evaluate complete stress tensors

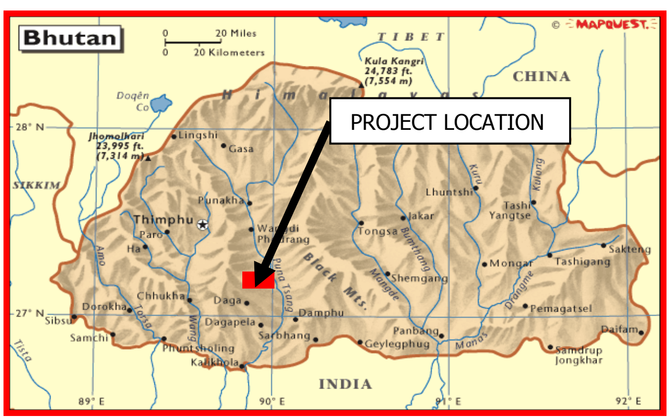


*Fig. 1 Location map of the Punatsangchhu Hydroelectric Project, Bhutan.*

Regional geology

Regionally the PHEP area is located within a part of the Tethyan Belt of Bhutan Himalayas. The rocks of Thimpu Group in general is characterised by coarse-grained quartzofeldspathic biotite-muscovite gneiss, with bands of mica schist, quartzite and concordant veins of foliated leucogranite, migmatites with minor metabasics and interbedded limestone. Garnet crystals and porphyroblasts are also seen within this gneiss.

On the basis of study of Aerial Photographs by Geological Survey of India (GSI), three sets of Lineament have been picked up trending (i) N-S (ii) NW-SE and (iii) NE-SW. The N-S trending lineaments aligned parallel to $90^0$E ridge, which is reported to be neo-tectonically active mainly in the Bay of Bengal. The Punatsangchhu River probably flows along one of such sympathetic north-south trending lineaments at the dam site. The other two sets of lineament are less in abundance. A few NE-SW/NW-SE trending lineaments picked up from the aerial photographs appear to be faults as indicated by the shifting of main river course. The traces of N-S lineaments in colluvial deposits along the valley slope marked by linear topographic elements of varying relief suggest probable active neo-tectonism in the area. The Main Central Thrust (MCT) in the Lesser Himalayan region is situated around 50 km south of Wangdue-Phodrang. However another small splay of the MCT is located around 8 km WNW of Wangdi in the Central Himalayas. (Figure. 2).

Three major faults are present in nearby areas. The most prominent is almost along the course of Punatsangchhu parallel to the $90^o$E line and traced from ~35 km south of Wangdi towards south upto the Bhutan-India border. Another minor fault runs almost parallel to Punatsangchhu river course (NW-SE) located around 25 km southeast of Wangdi. Another NW-SE trending fault located 35 km south of Wangdi was picked up on the Right Bank Hill of Punatsangchhu River.

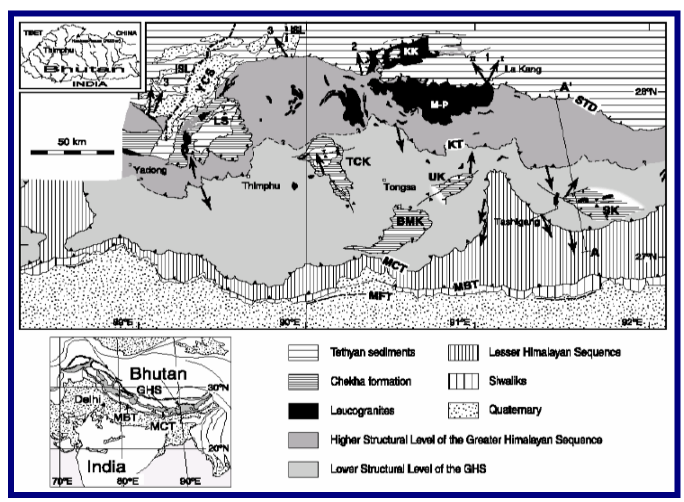


*Fig. 2 Simplified geological map of Bhutan*

Local geology at the desilting chamber

At the proposed desilting chamber, rocks of Sure Formation of Thimpu Group of Precambrian age are exposed. The bedrock exposed is represented by garnetiferous, biotite bearing quartzo feldspathic gneiss showing a general foliation trend N10$^o$E to N40$^o$E and dips 20$^o$ to 40$^o$ towards ESE to SE. At places, the rocks exhibit broad warps as evidenced from the swing in foliation from N40$^o$E to N-S and even upto N 10$^o$W-S 10$^o$E.

Technical borehole data

Two boreholes of NX size were drilled inside two niches at RD 100 m (7 m X 2.5 m X 5.5 m) and RD 170 m (7m X 3.5m X 5.5 m) specially excavated at the downstream side of the exploratory drift (Figure. 3) to the desilting chamber to carryout stress measurement. The important technical borehole data are summarised in Table 1.

Table. 1 Technical borehole data

| Borehole Number | Direction | Finished Diameter mm | Depth of Borehole in meters | RD Reference |
|---|---|---|---|---|
| | | | | |
| BH1 | Vertical Down | 76 (Nx – Size) | 30 | 100 m |
| BH2 | Vertical Down | 76 (NX Size) | 30 | 150 m |


*Fig. 3 Portal of the exploratory drift to desilting chamber, Punatsangchhu H.E. Project.*

Hydraulic fracturing set-up and stress measurement procedure

This method is intended for the determination of stress measurements in a borehole hole at desired locations (each location will have one borehole, normally consisting of three or more zones at different depths). For stress measurements at greater depths the zones can be accordingly decided to reach a logical conclusion as per site-specific requirements. Results of the stress measurements give both direction of maximum horizontal stress and the magnitude of principal stress tensors at a particular depth.

Equipment

The Inflatable Packers, Australia manufactured hydrofrac assembly with steel reinforced packer elements (67mm OD) were used for fracture initiation and extension. The test interval length was 500 mm. The length of each packer element was about 1200mm. In the case of hydrofrac experiments in the 76 mm diameter boreholes at Punatsangchhu Hydroelectric Project Stage - I, the tool was operated by quick connecting tubes (Aluminium tube with Brass coupler, 3m length, 25.4 mm ID, max. operating pressure 85 MPa) which were used for both moving the hydrofrac system inside the boreholes and also for injection. The high pressure inflation tube (max. operating pressure 52 MPa) was used for packer inflation. The maximum injection rate of the electric pump was 10 l/min using water for pressurisation. Packer and interval pressures were monitored up hole by pressure gauges. All the events of injection were recorded in continuous real time digital mode in a Dell Pentium Computer. (Figure. 4 to 6).

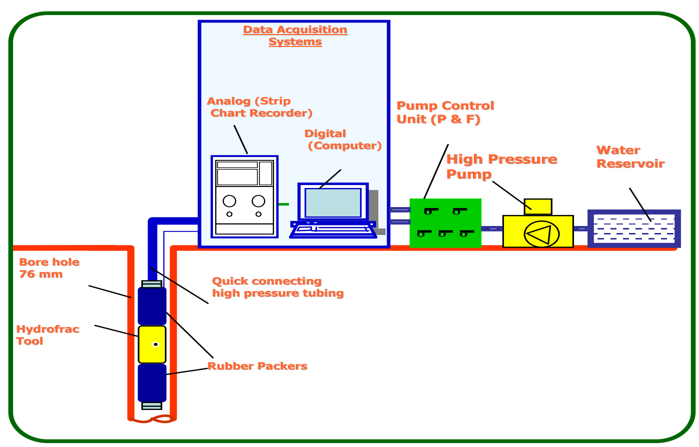


*Fig. 4 Schematic diagram of Hydrofrac Experiment Set-up*

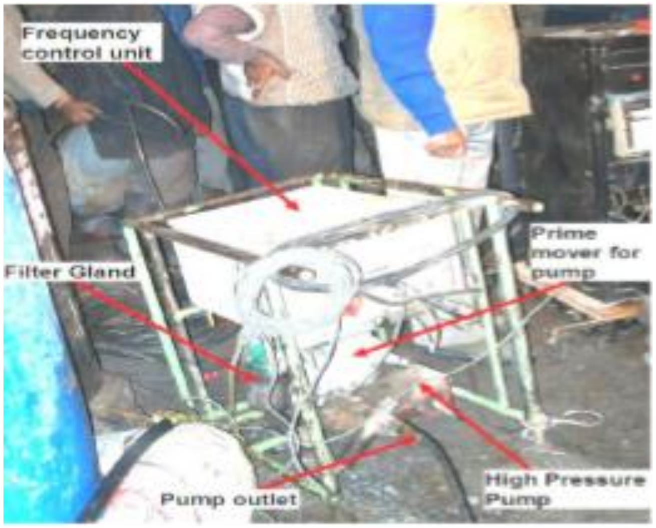


*Fig. 5 High Pressure Pump used for Hydro fracturing test*

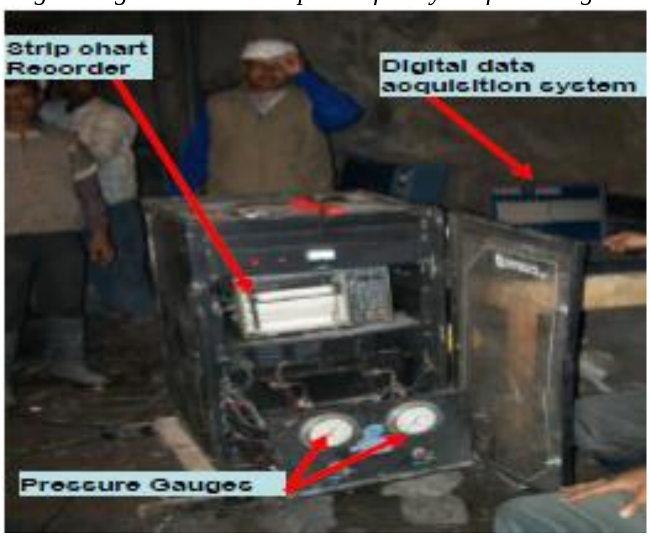


*Fig. 6 Digital data acquisition system used for hydro fracturing test*

Investigation Procedure

After the hydrofrac assembly was positioned at a pre-determined test section (selected on the basis of core inspection), the injection pressure was increased until a hydraulic fracture was initiated or a preexisting fracture was reopened. Subsequently, two to three refrac-cycles were conducted. Between the injection cycles the system was vented. The back flow from the fracture into the interval section was observed by short valve closures during the venting phase. Finally, the packers were deflated and tool was moved to the next test section. After all the hydraulic fracturing tests were conducted in all the boreholes, an impression packer tool with a soft rubber skin was run into the holes to obtain information on the orientation of the induced or opened fracture traces at the borehole wall. (Figure. 7)


*Fig. 7 Impression packer to know the fracture orientation*

Data acquisition system used during the test

During the course of hydraulic fracturing stress measurement at the site under consideration, the following data acquisition systems were used:

In real time mode on hard disk of a pentium computer, under the control of the program PICO Log, 16 bits (PICO Technology Limited).

Software used in data analyses

Two data analyses programmes are used in the analyses. They are Plane and Gensim.

The *software Plane* incorporates the impression data with the compass data as input parameters and gives the strike, dip and dip direction as the output known as fracture orientation data.

*The Software Gensim* computes the stress field on the basis of measured shut in pressure and fracture orientation data. Assumption is that the vertical stress is a principal stress and is equal to the weight of the overburden. The powerful Gensim programme requires only the shut in pressure and the orientation of an induced or pre-existing fracture. As a result the role of breakdown pressure and fracture reopening pressure are nil as far as stress computation is concerned.

EXPERIMENTAL RESULTS

The description of the borehole is given in Table 2. The average rock cover over the hydrofrac site is 100 m. Only eight zones could be selected by core inspection. The hydro fracture stress measurements were conducted in the borehole at different depths. The shut in pressure derived from the

Pressure-Time plot ranged between 2.35 MPa to 6.05 MPa. The shut in pressures derived from the plots and the orientation data of the hydrofractures derived from analyses by software plane for the vertical borehole are listed in Table 3.1. The determination of shut-in-pressure is straight forward and is picked up from pressure – time plot, when a sharp breakup is observed after fast pressure decline following pump shutoff. We calculated the shut-in-pressure from the third cycle of the pressure-time curve.

Table 2 Pressure and fracture orientation data derived from hydrofrac stress measurements inside boreholes BH1 and BH2 (Combined) Depth 10 m to 25 m

| S.No | Fracture inclination (deg.) [90°=vertical | Fracture strike (deg.) [N over E] | Shut in pressure (σn) (MPa) |
|---|---|---|---|
| | | | |
| 1 | 30 | 040 | 6.03 |
| 2 | 70 | 170 | 4.27 |
| 3 | 80 | 115 | 6.05 |
| 4 | 50 | 070 | 4.95 |
| 5 | 73 | 105 | 4.27 |
| 6 | 75 | 170 | 2.35 |
| 7 | 70 | 175 | 2.35 |
| 8 | 45 | 060 | 4.35 |

<u>Stress evaluation procedure and results</u>

The in-situ stress measurement inside two vertical boreholes drilled at the proposed powerhouse cavern were conducted with the following situations:

Pronounced topography.
Presence of anisotropic rock.
Presence of excavation induced stress.

Due to the above aspects a medium to large scatter in fracture orientation data were noticed which negated the use of classical simple hydrofrac hypothesis suggested by Hubert and Wills (1957). Therefore data analysis required a more sophisticated method, namely the interpretation of measured normal stress acting across arbitrary oriented fracture planes.

In this method the shut-in pressure $P_{si}$ is used to measure the normal stress component under the assumption that the vertical is a principal stress axis and the vertical stress $\sigma_V$ is equal to the weight of the overburden.

The analysis program *GENSIM* was used to calculate the magnitude and the direction of principal stresses on the basis of the following equation:

$$\sigma_h = (P_{si} - n^2 . \sigma_V) / (m^2 + l^2 . \sigma_H/\sigma_h) \quad (1)$$

Where, l, m, n is the cosines of the direction of the induced fracture plane related to the principal stress axis.

The calculations were done by using all shut-in pressure data as given in Table 3.2 derived from the measurements in the borehole and varying the ratio $\sigma_H/\sigma_h$ and the strike direction of $\sigma_H$ in the horizontal plane. The stress tensor is given in Table 3.

Table 3 Principal stress tensors as evaluated from two boreholes drilled inside the exploratory drift to the desilting chamber (RD 100 m and RD 150 m)

| | |
|---|---|
| Vertical Stress ($\sigma_v$) in MPa (Calculated with a rock cover of 100 m and density of rock = 2700 kg/m$^3$) | 2.64 MPa |
| Maximum Horizontal principal Stress ($\sigma_H$) in MPa | 07.14 MPa |
| Minimum Horizontal principal Stress ($\sigma_h$) in MPa | 2.38 MPa |
| Maximum Horizontal principal Stress direction | N $150^0$ |
| $K = \sigma_H/\sigma_v$ | 2.70 |

DISCUSSION AND FINAL CONCLUSION

High K value in the order of 2.7 is normal at such condition. The vertical stress is assumed to be overburden.

The stress configuration $\sigma_H > \sigma_v > \sigma_h$ corresponds to strike slip faulting.

The major joint set runs from N$10^0$ to N$50^0$, perpendicular to this joint set orientation is N$100^0$ to N$140^0$ the average being N $120^0$. However, the direction of major compression is N$150^0$. Thus it is advisable to orient the long axis of the underground excavation in between N $120^0$ and N $150^0$ i.e. N $130^0$ (Figure. 9).

Orientation of stress vis – a – vis structural lineament as seen on satellite image is shown in (Figure. 8).

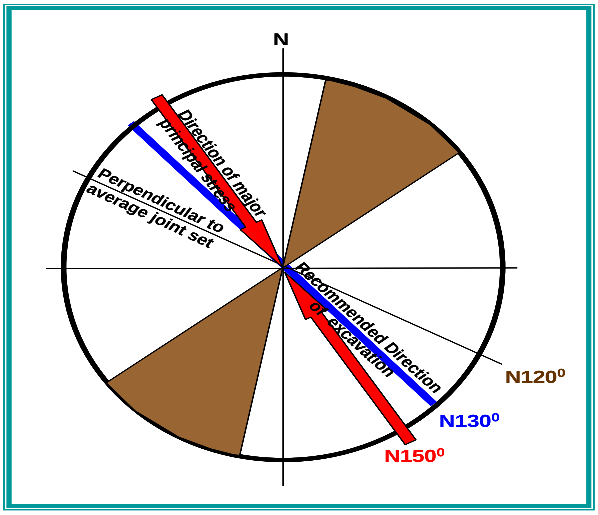


*Fig. 8. Orientation of stress vis – a – vis joint Sets and our recommendation.*

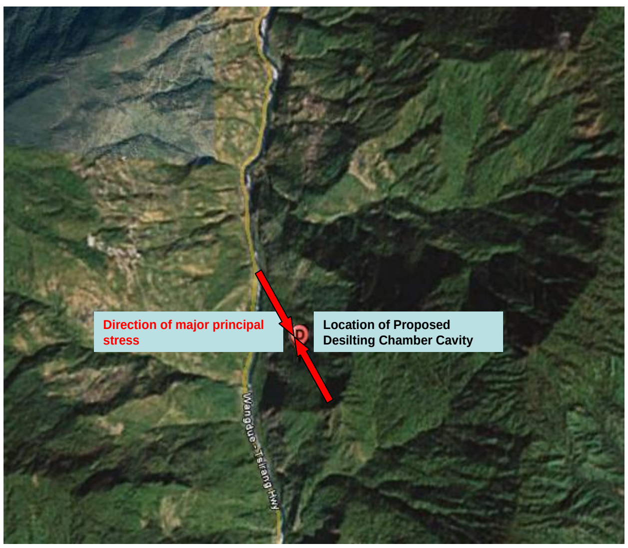


*Fig. 9. Orientation of stress vis – a – vis Structural lineament and the river*

SECOND PHASE OF INVESTIGATIONS

Summary

A stress measurement program was undertaken at Punatsangchhu H.E. Project stage-I during Jan/Feb 2010 inside desilting chamber for the determination of in-situ stress tensor by hydro fracture method. This test was required to freeze the orientation of desilting chamber vis. a vis. orientation of maximum compression ($\sigma_H$) which was found to be N 150$^o$. The hydrofrac test was carried out at RD 100 and RD 150 inside an exploratory drift at dam-axis and approaching towards desilting chamber with a rock cover of 100 m. As it was only 100 to 150 m away from the portal a topography effect on the orientation of ($\sigma_H$) was not completely ruled out. So when the adit to desilting chamber reached at RD 360 with a rock cover of 410 m, our client made a request to carry out stress measurement to confirm the orientation of maximum compression ($\sigma_H$). The in-situ stress and permeability measurements at RD 360 were undertaken to confirm the results of earlier tests at RD100 and RD 150.

Scope of the work

In-situ Stress measurement by Hydrofrac (HTPF) method to confirm the orientation of *($\sigma_H$)*

In-situ stress measurements by Hydrofrac method using HTPF method (Hydrofracture Test in Pre-existing Fractures) inside a specially drilled NX size borehole at RD 360 with rock cover of 410 m inside the adit to Desilting chamber.

Analysis of the data using software to evaluate complete stress tensors

Technical borehole data

A single borehole of NX size was drilled inside the niche at RD 360 m (7 m X 2.5 m X 5.5 m) specially excavated at the upstream side of the adit to the desilting chamber to carryout in-situ stress measurement by hydrofrac method.

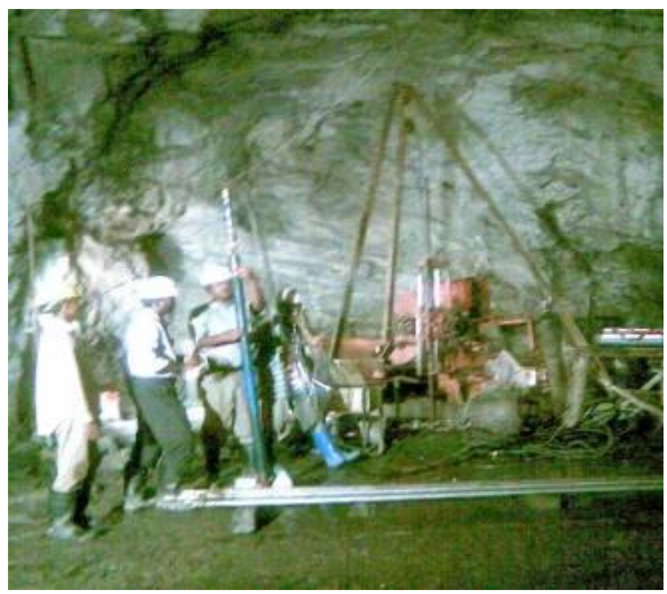

*Fig.10 Stress measurements at borehole DC 1 (RD 360m)*

Hydraulic Fracturing Set-Up and Stress Measurement Procedure

The average rock cover over the hydrofrac site is 410 m. Only three zones could be selected by core inspection. The hydro fracture stress measurements were conducted in the borehole at different depths. The shut in pressure derived from the Pressure-Time plot ranged between 10.6 MPa to 19 MPa. The shut in pressures derived from the plots and the orientation data of the hydrofractures derived from analyses by software plane for the vertical borehole are listed in Table 4. The determination of shut-in-pressure is straight forward and is picked up from pressure – time plot, when a sharp breakup is observed after fast pressure decline following pump shutoff. We calculated the shut-in-pressure from the last cycle of the pressure-time curve.

*The same type of procedure carried out to conduct Hydrofracture test in second phase also (Figure.10) as explained in First phase of investigations.*

Table 4. Pressure and fracture orientation data derived from hydrofrac stress measurements inside the borehole DC 1, Depth 31 m to 39 m

| Depth (m) | Fracture inclination (deg.) [90°=vertical] | Fracture strike (deg.) [N over E] | Shut in pressure ($\sigma_{si}$) (MPa) |
|---|---|---|---|
| | | | |
| 31 | 51.04 | 46.51 | 19 |
| 33 | 90.00 | 129.06 | 15 |
| 39 | 61.49 | 61.50 | 10.6 |

RESULT

It is confirmed that the orientation of maximum principal horizontal stress is N150$^o$. It also confirms that the earlier stress measurement results do not suffer from topography related influence (Table 5)

Table 5. Results of Principal stress tensors as evaluated from one borehole drilled inside the adit to the desilting chamber (RD 360 m)

| | |
|---|---|
| Vertical Stress ($\sigma_v$) in MPa (Calculated with a rock cover of 410 m and density of rock = 2700 kg/m$^3$) | 10.85 MPa |
| Maximum Horizontal principal Stress ($\sigma_H$) in MPa | 17.25 MPa |
| Minimum Horizontal principal Stress ($\sigma_h$) in MPa | 11.50 MPa |
| Maximum Horizontal principal Stress direction | N 150$^0$ |
| $K = \sigma_H/\sigma_v$ | 1.50 |

DISCUSSION AND FINAL CONCLUSION

The stress orientation as evaluated at RD 360 confirms the orientations revealed from earlier stress measurements at RD 100 and RD 150.Thus it is recommended to freeze the direction of desilting chamber along N 150$^o$

REFERENCE


Cornet, F.H., (1986) Stress determination from hydraulic tests on pre-exiting fractures – the HTPF method. Proc. Intl Symp, Rock stress and rock stress measurements, CENTEK Publ., Lulea, pp. 301-311

Mesy's Gensim and Plane software manual (1992)

Mindata, Australia, operating and analysis manual

Internal reports and communications of Pipalkoti H.E. Project.


ACKNOWLEDGEMENTS


We are highly grateful to late Mr. S. R. Nath, Project Director, WAPCOS for entrusting the job to NIRM. We also thankfully acknowledge his association right from the contract stage to the final execution stage. We held many important discussions regarding the technical aspects with, Mr. Amit Gupta, Project Manager, Mr. D.V.S. Murthy and Mr. K.P.S. Tyagi, Sr. Engineer which greatly helped us during execution of the project.

The management of the Punatsangchhu Hydroelectric Project Stage I is also thankfully acknowledged for extending all the facilities during the course of fieldwork.

Contribution of Director, NIRM is thankfully acknowledged, for going through the project report and providing valuable feedback.