Ground realization and characterization of rock mass through core drilling

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Abstract. The increasing demand of power day by day in the country put power sector to Himalayas to harness the power potential. Utilization of underground space for infrastructure development is picking up momentum day by day. Every infrastructure project requires significant geological and geotechnical investigation for timely completion of projects. Lots of survey and investigation is carried out to ascertain the geological and geotechnical feasibility of the hydro projects and for preparation of DPR. Construction of large caverns for power house presents challenges in terms of geotechnical engineering. Due to large size structure needs to ascertain behaviour of subsurface rock mass. The exploratory core drilling and exploratory drifts provide vital subsurface information. The subsurface exploratory drilling data provide immense help to understand subsurface information and reveals the subsurface behaviour of rock mass. The prior knowledge of weak feature can provide opportunity to prepare proactive solutions to mitigate these issues and structure design.

Authors are proposing simplified techniques to be implemented to understand ground realization and spatial reconciliation of weak zones/features with modern approaches in core logging with special core studies of Sunni Dam and Luhri Hydro Electric Projects Stage-II in Higher Himalayas of Himachal Pradesh.

1. Introduction
The in-situ samples are being collected through core drilling. The fundamental objective of core drilling is to collect subsurface samples in the shape of core besides sludge material. The depth wise linear information collected from a drill hole can be extrapolated through software’s available in the market to get planar geological information of the project/area. Geological examination of the cores and by logging we decides whether to carry out further investigations or search for other alternate sites. In most of the cases the core drilling is being carried out vertically, however presence of shear zones and its thickness sometimes warrants angular holes also in order to determine exact thickness which merely depend on the attitude of the discontinuities present in the area.

Sunni Dam HEP (382MW) is proposed on the river Sutlej and falls in District of Shimla and Mandi of Himachal Pradesh. The project is located in the inner Lesser Himalaya between Dhauladhar range in the south and Higher Himalaya in the north. The project envisages construction of a concrete gravity dam 83m high from deepest foundation level across river Satluj near Khaira village on State Highway-22. Co-ordinates of the dam axis are E 31°14’53””, N 77°12’39””. The underground power house and its appurtenant structures are proposed on right bank.

In order to evaluate the ground, the geotechnical investigation has been carried out. The geotechnical investigation includes core drilling, drifting, Physico-mechanical rock core samples for further studies etc. Among which core drilling has been carried out at dam, power house and its appurtenant structure to understand the ground.
2. Objective of core drilling

The purpose of the drilling is to collect subsurface rock mass which reveals nature of underground. The purpose and Type of core drilling varies from organization to organization & even different stages of investigation for example in case of Sunni Dam Project of SJVN, the core drilling is carried out for DPR preparation stage in order to know variations in Lithology & assessment of weak structure/features in the bed rock. This objective of core drilling can be broadly enumerated below

A) Genesis of the rock mass.
B) Bed rock information.
C) Depth of overburden
D) Permeability and Porosity.
E) Grain Density
F) Fracture/ Joint frequency
G) Nature of Weathering
H) Collection of rock core sample to carry out Physico-mechanical tests.
I) to examine disposition of structural features like faults, folds, schistosity /lineation
J) carry out soundings

3. Methodology and Planning: -

The methodology of core drilling involves study of the area geologically in order to define types of drill holes over various components of the project and first-hand information is available in the form of Geological map of the area. On the basis of geological map/data of the area, the number of holes and their direction decided and accordingly drill hole plan developed by marking holes in the contour plan of the area. Getting full recovery of the drill core is most important and depending on the rock mass strata available, the type of drilling decided for getting 95% to 100% core recovery. On getting full core of the run it is easy to log and interpreted the subsurface geological details.

Similarly, poor core recovery emanates doubts and questions i.e. whether the core loss is due to any week feature like shear zone, soft & friable medium, absence of the core warns presence of voids or cavernous nature of the rock as shown in figure 2 below. The structural behaviour of the rock mass/ overburden is studied by carrying out Water percolation tests, Standard penetration tests mainly. The core is studied after every run of the drilling and logged for interpretation purpose. In the case of Sunni Dam hydroelectric project, the drill hole plan was devised along dam axis, power house area and all appurtenant structure. The project area has been drilled by 29 number drill holes with a total depth of 2473m. The location of various drill holes are marked on the Layout Plan-Drill Holes (Plate-1).

| Table 1. The detail of exploratory drill holes at Power house, Sunni Dam |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| SN | Hole No | Name of the component | Location | Ground EL(m) | Depth (m) | Orientation of the drill hole |
|----|---------|------------------------|----------|--------------|-----------|-----------------------------|
| 1  | PHV-1   | Main PH                | On the surface of PH location | 878.57       | 60        | Vertical                    |
| 2  | PHV-1   | Inside Drift PH        | Inside PH Drift At 351 m RD  | 671          | 60        | Vertical                    |
| 3  | PHH     | Inside drift           | RD 448   | 672.5        | 50        | Horizontal                  |

4. Importance of Core logging

Each figure should have a brief caption describing it and, if necessary, a key to interpret the various lines and symbols on the figure. The core logging of drilled core is important part and geologist record lithological description, joint details, weathering nature, RQD, core recovery and penetration rate etc. In addition to this, Geologist may also record day to day activities of drilling and should record the same in the logs. i.e., rate of penetration, colour of return water, jamming of barrel etc. The RQD reveals the
subsurface rock quality by calculating equals to or more than 10cm core pieces in each run. All details are enumerated in the log sheet as per IS codes shown in the abstract drill hole log below in Table -2 of Power house of Sunni Dam.

The main objective of core logging is to access the rock quality of different litho units and to identify the weak feature like shear zone and fractured zones. Since underground structure are placed in sound rock. Thus geologist log should mention weak feature which can pose critical problem to place the component underground which ultimately required redesigning etc. Hence shear seams and weak zones should be described in detail, including gouge, fracture zone and rock fragments etc.

An accurate description of recovered core and a technically sound interpretation is the primary requirement of the core logging. Identification of start and end points of weak zone /fractured zone should be recorded before transportation of core boxes. Loggers/ Geologist should be well versed with the local and regional geology of the area. so that better interpretation be carried out.

The photographs given below in Plate-3a showing more than ninety percent core recovery which is recorded in most of the drill hole drilled at various locations in Sunni dam HEP and Figure -3b showing poor core recovery in the power house of Sunni Dam HEP. An engineering Geologist who has to evaluate subsurface conditions from the core samples requires a high core recovery to eliminate the scope of guessing work.

Figure 1. Showing more than ninety percent core recovery, Sunni Dam HEP

Figure 2. Showing poor core recovery, Sunni Dam HEP

where poor core recovery brings many questions in mind viz. Core loss due to weak feature like shear zones, very soft and friable media or voids. obtaining ideal core samples are helpful to find out adverse geological conditions prevailing in particular place.

5. Interpreting geometry of shear / fracture zone.

After core logging, the critical task is to interpret. the geometry of the encountered shear zone. The method of interpretation of the geometry of shear & fractured zone can be best implemented for dam foundation, surface power house and underground power house. In the hilly terrains where the topography undulating and rugged and steep hills as in the case of Sunni Dam and LHEP Stage-II project SJVN. The interpretation is not simple in folded topography. Thus in the case of hilly terrains due to considerable difference in elevations the projection may varies in components. The Interpretation of geometry of shear zone for the individual drill hole has been studied in Sunni Dam power house and LHEP-II dam foundation and the geological L section and cross section of Dam axis and underground power house Sunni Dam HEP are drawn on the basis of rock mass encountered in respective drill hole and emphasize is given to measure true thickness of weak feature like shear zone and Fractured zone. Actual thickness of shear zones or weak feature obtained from the drill hole are generally apparent thickness, whereas, calculating the true thickness of these zones are very important in order to anticipate the difficulties during excavation and for designing appropriate support.

6. Scenarios of core Drilling

Worldwide the drilling is carried out mostly in three conditions i.e., vertical drill hole, inclined and horizontal drill holes depending upon the structural position of the discontinuities present in the rock
mass and accordingly drill holes are planned to puncture the bed rock perpendicular to the foliation/Bedding etc. and scenario are illustrated below:

**Scenario 1.**
In this case drilling is carried out in the horizontal or angular which will be perpendicular to the bed and actual drilled length in the shear zone is true thickness of the weak feature i.e. \( T_t = L_d \) as below in the figure 3.

**Figure 3.** Schematic drawing drill hole puncturing shear zone perpendicularly. The true thickness of the shear zone calculated by subtracting from start point and end point of the shear zone.

**Scenario 2.**
In this case the vertical drill hole punctures inclined/ dipping bedrock with shear zone running along the foliation or bedding plane. If the dip of shear / fractured zone is \( \beta \) is known the angle between the drill hole & dip of shear Zone \( \Omega \) can be obtained, Figure 4 below. Simultaneously, by putting the values of \( L_d \) i.e. drilled length into shear /fractured zone and \( \Omega \) (angle between the drill hole and dip of the shear zone) in the equation below:
The true thickness (Tt) can be obtained i.e. \( Tt = Ld \times \sin\Omega \) …….equation (1)

**Scenario 3.**
Spatial restrictions such as in mountainous region generally necessitate drilling oblique to the strike. If an inclined drill hole is puncturing inclined shear zone, oblique to the strike and none of the intersecting angle (\( \alpha, \beta, \gamma \& \Omega \)) will form a right angle.
In this scenario it is assumed that thickness of weak/shear/fractured zone along the drilling direction i.e. \( Ld \) and attitude of the shear zone are known. Now, by multiplying \( Ld \) with standard thickness reduction factor i.e. TRM, which is derived from the geometric & trigonometric method or can be expressed with the directly observable angles.

Here,
\( \alpha = \text{inclination of drill hole} \),
\( \beta = \text{angle of dip of the shear zone with horizontal} \),
\( \gamma = \text{angle between the drill hole and dip of the shear zone} \),
\( Ld = \text{Length drilled into shear zone} \),
\( \Omega = \text{Angle Between drill hole and dip of the shear zone} \).
In this scenario it is assumed that the apparent thickness of shear zone along the drilling direction is \( Ld \) and the attitude of the shear zone are known. Thus, by multiplying \( Ld \) with a standard thickness reduction factor i.e. \( Rm \), the thickness of the shear zone (\( Tt \)) can be obtained by the equation
- \( Tt = Ld \times Rm \) ……………. equation (2)
whereas TRM can be derived from the trigonometric & geometric method & expressed with observable angles i.e., $\beta$, $\gamma$ & $\Omega$, thus

- $R_m = \cos \beta (\sin \alpha + \cos \alpha \cos \gamma \tan \beta)$ ----- equation (3)

In the above scenario it is assumed that apparent thickness of the shear zone along the drilling direction (L.d.) and attitude of the shear zone are known now by multiplying L.d. with a standard thickness reduction factor.

6.1. Case study
Geologically the major part of the Sunni Dam HEP located in the rock of Shali group comprises of Quartz arenite-carbonate sequence which is divided into eight formations. The sequence overlies the Sunder nagar Group and is intruded by Dolerite dykes. The basal part of the sequence is characterized by evaporate deposit (salt beds). There is profuse development of stromatolites in the carbonate rock sand occasionally there is some karst development. Sedimentary structure s such as mud cracks, ripple marks and cross bedding are extensively seen in arenite of the Khaira Formation. The outcrop and the underground excavation like drift in the area reveals the presence of intermittent shear zone of considerable thickness. In order to avoid the uncertainties an approach is being made to determine the thickness of the shear zone through drilling. The total core drilling of 2586m have been carried out in the Sunni Dam HEP in order to assess the weak zone in the power house cavern & other appurtenant structures.

6.2. CASE-I
A vertical drill hole PS-2 drilled up to 90m depth in the pressure shaft at the right bank of Sunni Dam HEP. This hole encountered a weak zone with 3.70 m thickness from depth 25.00m to 28.70m depth. The general foliation of the rock is 280°/25° thus foliation making an angle of 65° with the vertical drill hole. Thus in this case scenario 2 is suitable approach to calculate true thickness of weak zone encountered along the foliation & can be derived by applying equation ....(1)

$$T_t = L_d \times \sin \Omega$$ ........equation (1)

Here:

- $\alpha$ = inclination of drill hole i.e. vertical
- $\beta$ = angle of dip of the shear zone with horizontal 25°.
- $L_d$ = (apparent thickness of the shear zone along the drilled length) is 3.66m.
- $\Omega$ = Angle Between drill hole and dip of the shear zone 65°.

Thus, true thickness($T_t$) of the shear zone is derived to be 3.35 m

6.3. CASE -II
Similarly, inclined drill hole at Dam axis of Luhri stage 2 i.e. LHEP 2 drilled from the left bank in inclined direction of N44°W for 90m at an angle of 75° to explore Dam foundation having shear /Shattered zone, the general trend of the foliation/bedding at the Dam site is 040°/30°. This inclined drill hole is puncturing an inclined shear zone, oblique to the strike and none of the intersecting angle ($\alpha$, $\beta$ & $\Omega$) forms a right angle.

In this case scenario-3 would be most appropriate approach to obtained the true thickness of the shattered/shear zone encountered. In order to obtained the true thickness of the shattered/ shear zone intersected at depth 25m to 40.5m depth their fore directly observed values can be put in equation (2) & equation (3)

In this case, scenario-3 would be most appropriate approach to obtained the true thickness of the of the shear zone encountered. In order to obtain the true thickness of the shear zone intersected at depth 25.0m to 40.5 m depth the directly observed values can be put in equation (2) & equation (3):

- $L_d$ = (apparent thickness of the shear zone along the length drilled) is 15.5 m.
- $\alpha$ = inclination of drill hole (75°),
- $\beta$ = angle of dip of the shear zone with horizontal (30°),
- $\gamma$ = angle of profile between horizontal projection of the drill hole and dip direction of the shear zone (84°)

Thus, true thickness ($T_t$) of the shear zone is derived by putting the values in equations (3) we can derived thickness reduction factor $R_m$
\[
R_m = \cos 30 \left( \sin 75 + \cos 75 \times \cos 84.0 \times \tan 30 \right) \\
= 0.866 \left( 0.965 + 0.258 \times 0.104 \times 0.577 \right) \\
= 0.849
\]

Now putting value of the \( R_m \) in equation-(2)

\[
T_t = L_d \times R_m \\
= 15.5 \times 0.849 = 13.16 \text{ m}
\]

The above-mentioned parameters are recorded properly while drilling and core logging the true thickness \( (T_t) \) of the weak/shear zones can be calculated at site itself and can be further conveyed to designer for appropriate designing of underground structure for estimation of support system and further avoid variation in claims which ultimately effect schedule of the project and warrants time cost overruns.

However, there are limitations in application of this approach for ground realisation of weak features through core drilling i.e, Loss of core recovery, deviation of drill holes, in folded strata determining angle of shear plane is difficult.

**7. Conclusion**

The early knowledge of the weak features during investigation of the project is very helpful in projecting the feature and anticipating the difficulties in excavation for designing appropriate support to handle the weaker zone. If the severity of the weaker zones is assessed at the earlier stage of the project before construction it will help in orienting the components /underground structures effectively. Drilling thus helps in identifying practical problems to be encountered during construction. Their fore purpose of carrying out drilling is greatest tool for engineering geologist and designers for designing underground structures.

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