An approach in ground realization and spatial reconciliation of weak zones through core drilling

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Abstract

Utilization of underground space for infrastructure development is picking up the momentum day by day. Lot of Survey & Investigation is done to ascertain the feasibility of the projects and for preparation of Detailed Project Reports. But, in-spite of vast investigation activities carried out, the developers generally face problems during execution of any underground structure. The first step for investigation of underground structures after surface geological mapping is to conduct exploratory core drilling, because it provides the vital subsurface information. Obtaining maximum core recovery is of immense help to understand the subsurface geology. However, the significance of core loss is often more important than recovered core, because lost core may represent the worst conditions for design concepts. Core loss generally takes place due to the presence of weak features like sheared & fractured zones or in the very soft ground. During underground excavation negotiating through a shear zone or even partially encountering a shear seam of considerable thickness in overt portion sometimes pose critical problems. If a shear zone is encountered in a drill hole, generally the apparent thickness of shear zone is obtained along the drilling direction of the drill hole, however, the same data can be plotted in a cross section and the true thickness of the shear zone can be inferred. But, if the true thickness and disposition of a shear seam/zone is known in the initial stages at drilling site itself with the help of simple trigonometric method, it can be helpful in better understanding of the geological features and timely communication to the designers. In one hand where this exercise can be of immense help in understanding the subsurface weaker zones encountered during drilling, on the other hand in the highly disturbed regions with different stages of deformation this technique may be of least usage.

Himalayas being young folded mountains are mostly in deformed state with occurrence of intermittent sheared and fractured zones along various set of discontinuities. Proper interpretation of the shear zones and assessment of its true thickness may lead to suitable preparedness for the challenging ground situation while excavation of underground structures. Through this paper the authors are proposing simplified techniques to be implemented in the field itself to obtain the true thickness of any weak feature encountered in the drill hole using trigonometry. This paper also emphasizes on modern approaches in core logging for ground realization and spatial reconciliation of weak features like shear zones with a case study of Tawang H E Project located in Higher Himalayas of Arunachal Pradesh.

1. Introduction:

Core drilling is done to collect the insitu rock samples and for determining the extent of overburden in an area. The fundamental objective of core drilling is to collect subsurface samples in the shape of core and accompanying sludge material. The modern drilling techniques with digital data loggers (Geomonitor GM 1M data field logger, Rufco DL2 field logger) when synthesized with the advanced geospatial techniques can provide better results in 3D with exact information. The depth wise linear information collected from a single drill hole can be further extrapolated in the form of fence diagrams with the help of software (Rockware-LogPlot, WinLog) to obtain planar geological information of the area. Examination of cores & geological logging determine whether to carry out further investigation in that area or search a better alternative. Core drilling needs special emphasis because these data ultimately have direct impact in understanding the characteristics of the rock media for contemplating & firming up the design of any structure. However, presence of shear zones and its thickness also play important role in finalizing the underground structures. Shear zones are nothing but a structural discontinuity in the rockmass formed as a response to inhomogeneous deformation partitioning strain into planar or curviplanar high-strain zones.

In most of the cases the exploratory drill holes are done vertically unless specifically required otherwise. Generally, in such conditions the drill hole intersects the shear zones at an angle and the thickness observed is mostally apparent thickness of the shear zone. However, for designing appropriate support and to anticipate the difficulties in excavation we require the true thickness of the shear zone.

2. Objectives of Core Drilling:

Nowadays, drilling is carried out for all the major underground structures. This is a profusely used technique to collect subsurface information worldwide. The purpose of core drilling varies from organization to organization and even at different stages of investigation. For example during the feasibility & DPR preparation stage of Tawang HEPs the prime objective of core drilling were identification of variations in the litho units and assessment of weak features in the bedrock, whereas, while conducting drilling in construction stage main emphasis is given on identification of shear zone, characterization of sheared & fractured material, calculation of fracture frequency, RQD etc. Importance of survey and investigation in the initial stage of project development has been understood very well. Before conducting any exploratory drilling programme it is important to decide the purpose of drilling, sampling & the logging technique. Thus the objectives of core drilling can be broadly enumerated as follows:

1. To obtain geological characteristics:
    - Lithological information
    - Genesis (metamorphic / sedimentary environment)
    - Permeability / Porosity Correlation
    - Mineralogy/ Geochemistry
    - Grain density
    - Fracture frequency & pattern
    - Weathering effect
2. To examine extent of structural features like fold, fault, lineation etc.
3. Collection of rock samples for laboratory and insitu testing.
4. To conduct geophysical tests.

3. Achieving Ideal Core Recovery:

For a mining geologist the rock core is of ample use even if they are recovered in disturbed and fractured state whereas, an engineering geologist will appreciate the core samples obtained in minimum disturbed condition because the rock quality designation (RQD) is of utmost importance for designing of civil structures. An engineering geologist who has to evaluate the subsurface information from the core samples requires a high core recovery to eliminate the scope of guessing for the missing samples as far as possible. By achieving 100 % core recoveries it is easy to log the cores & interpret the subsurface geological information (picture 1).

Picture 1 100% Core recovery in gneissic rock of Sela group, Tawang HEP, Arunachal Pradesh, India

Whereas, poor core recovery produces many questions in our mind: whether the core loss is due to any week feature like shear zone, very soft & friable media or voids/ caving (picture 2). Obtaining ideal core samples are helpful to find out if there is any adverse geological condition which might impede the progress during construction stage.

Picture 2 Poor core recovery in sheared gneissic rock of Sela Group, Tawang, A.P.

The activity of diamond drilling is similar to many engineering projects where it is presumed that an investment will reap a reward. Planning for core drilling begins with listing the objectives of drilling keeping in view the regional and local geological setup. The key to a successful coring operation is planning, execution and communication. Hole size, angle and depth of the drill hole also influence selection of the coring tools. To achieve an ideal core recovery following measures should be taken while drilling:

1. Selection of Drill Machine should be done considering the type of rock mass, its mechanical properties and the extent of drilling.
2. The vibration of the machine needs to be controlled.
3. The intermittent torque and rotation variation tends in breaking of the core. In such condition the constant torque & bit rotation should be kept to obtain maximum core recovery.
4. The quantity of pumped water for cooling the drill bit and washing of fines should be optimized to reduce excess washing away of the cores.
5. In fractured or week zones the double tube or triple tube barrels should be used.
6. As the hole advances deeper, the penetration rate is also governed by the weight of the drill string, thus in depth the thrust must be comparatively less.

To obtain an ideal core recovery the key role is to be played by driller of drilling machine. An experienced driller should be given the responsibility to achieve maximum core recovery by implementing various drilling techniques as per the nature of rock mass, but unfortunately this aspect is generally not been taken care of during drilling operations. Similarly, the role of geologist is equally important. Before starting of drilling operation it is prime responsibility of the geologist to get associated with the driller and discuss about the objectives of drilling, tentative depth to be drilled, nature of rock mass to be encountered etc.

In Tawang HE project, Stage-I total drilling of about 2825m has been done out of this 606m has been done exclusively at the finally identified underground powerhouse site (table 1).

Table 1
List of drill holes in Power House site of Tawang HEP, Stage-I

S. No.	Drill Hole	Location	Ground El.(msl)	Drill Length (m)	Bed Rock	
					Depth (m)	Elevation (msl)
1	PDH-6	U/S Surge Shaft	2222	131.0	0	2222
2	PDH-7	Pressure Shaft Alignment	2120	62.0	43.5	2076.5
3	PDH-9	Pressure Shaft Alignment	1969	78.0	22	1947.15
4	PDH-4	Underground PH	1829	69.0	0.5	1828.5
5	PDH-5	Transformer Cavern	1759	185.3	30	1729
6	PDH-8	Tail Race Surge Gate	1714	81.5	24	1690.6

4. Core Logging:

Core logging needs special emphasis because these data ultimately have direct impact in understanding physiomechanical characteristic of rock media for contemplating & firming up design of civil structures. A geologist should not restrict its work upto logging of the recovered cores, in fact, observation at the time of drilling like the rate of penetration, colour of return water, sludge composition & characteristics, machine vibration & drill string rpm etc. are equally important. During core logging, a geologist records several outputs of core drilling to complete the standard format of drill hole logging. In addition to this if an abstract log of the drill hole is provided to the designers classifying the types of litho units encountered with similar characteristics (such as gneiss, schist, granite, sand stone, lime stone etc.) and the extent and disposition of weak features like shear zones, it would be more convenient for them to understand the media for which any underground structure has to be designed. An abstract drill hole log describes the broader categorization of geological environment of that area.

ABSTARCT LOG OF DRILL HOLE NO: PDH-5

LOCATION : Above Transformer Cavern
TOTAL DEPTH :185.3m
TYPE OF DRILL MACHINE:Dimec 262
STARTED ON :25-04-09
COMPLETED :10-06-09

COLLAR ELEVATION: 1759.15
CO-ORDINATES: E- 41189.06
N- 40112.58
ANGLE WITH HORIZONTAL: 75°
BEARING OF HOLE: N 56 E

DEPTH(M) From	DEPTH(M) To	MATERIAL	WEATHERING	STRENGTH	RECOVERY (%)	RQD (%)
0	30	Slope wash material comprising boulders and rock fragments of gneiss & leucogranite in the soil matrix	Slightly ☐ Moderately ☐ Highly ☐	Weak ☐ Medium Strong ☐ Strong ☐ Very Strong ☐	0 100	0 100
30	45.5	Gneiss with thin schist bands <5cm intermittently (Fractured zone encountered between 33.0 to 34.5 and 39.0 to 41.5.)	Slightly ☑ Moderately ☐ Highly ☐	Weak ☐ Medium Strong ☑ Strong ☐ Very Strong ☐	0 100	0 100
45.5	53.5	Leucogranite with intermittent schist bands of <5cm	Slightly ☑ Moderately ☐ Highly ☐	Weak ☐ Medium Strong ☑ Strong ☐ Very Strong ☐	0 100	0 100
53.5	85.0	Gneiss with thin schist bands <5cm intermittently	Slightly ☑ Moderately ☐ Highly ☐	Weak ☐ Medium Strong ☑ Strong ☐ Very Strong ☐	0 100	0 100
85.0	97.2	Leucogranite	Slightly ☑ Moderately ☐ Highly ☐	Weak ☐ Medium Strong ☑ Strong ☐ Very Strong ☐	0 100	0 100
97.2	108.5	Gneiss	Slightly ☐ Moderately ☑ Highly ☐	Weak ☐ Medium Strong ☑ Strong ☐ Very Strong ☐	0 100	0 100
108.5	112.5	Shear zone	Slightly ☐ Moderately ☐ Highly ☑	Weak ☑ Medium Strong ☐ Strong ☐ Very Strong ☐	0 100	0 100
112.5	185.3	Gneiss with intermittent bands of Schist & Leucogranite	Slightly ☑ Moderately ☐ Highly ☐	Weak ☐ Medium Strong ☑ Strong ☐ Very Strong ☐	0 100	0 100

Broadly, in engineering geology the main objective of core logging is to assess the rock quality of different litho units present in the area and to identify the weak features like sheared and fractured zones. Fundamentally the underground structures are placed in sound rock formation and if poor core recovery is obtained in such country rock the loss of core can be attributed to the weak features like shear zones, fractured zones or occurrence of intermittent soft bedrock etc. These weak zones can pose critical problems if encountered partially or in full span in the overt portion during underground excavation. Hence, shear seams and shear zones should be described in detail, including data such as the percentage of the various components (gouge, rock fragments) and the relationship of these components to each other. An accurate description of recovered core and a technically sound interpretation of poor or non recovery depths is the primary requirement of core logging. Identification of the start and end point of any weak zone should be recorded when the recovery is undisturbed (i.e. - before transportation of the core box/ immediately after retrieval of core barrel). The logger needs to remember that any interpretation, such as a shear zone, must be based on observed factual data to interpret the geometry of a shear zone.

4. Interpreting Geometry of the Shear Zone:

For an engineering geologist after core logging, the critical task is to interpret the geometry of the encountered shear zone. Softwares like LogPlot, WinLog etc can be used to obtain the 3-dimensional geological information of various litho units by extrapolating the data of one hole to another in the vicinity. This method of interpretation of the geometry of a shear zone can be best implemented for dam foundation, surface power house investigation or specifically for underground power house where the topography is almost flat.

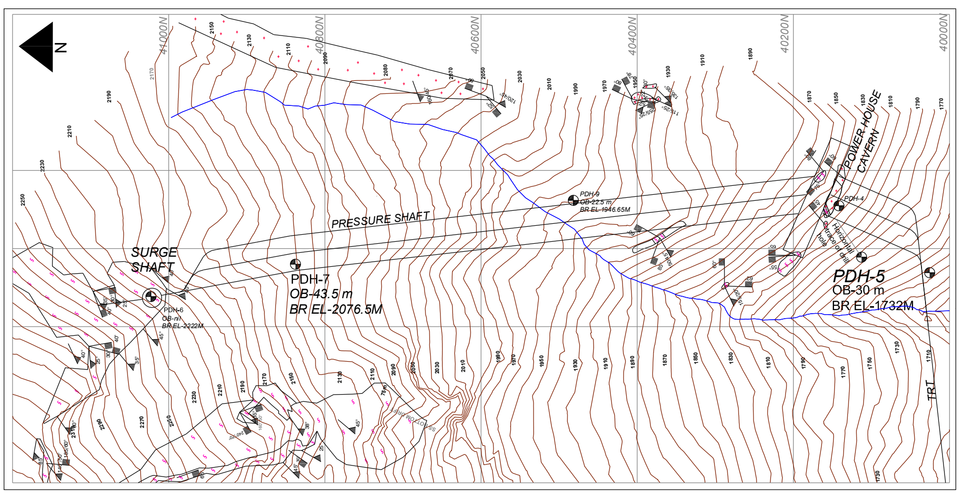


Figure 1 Plan showing location of drill holes in PH Complex of Tawang HE Project, Stage-I.

But when it comes to the undulatory - rugged hilly terrain and steep hill slopes like in Himalayas this method of joining lines of the similar litho units becomes unrealistic due to considerable difference in elevation (figure 1). In such cases the extrapolation of a particular bedrock or weak feature dies out due to considerably steep hill slope before it can reach upto the next drill hole location (figure 2). In hilly terrain although the aerial distance between two drill holes is less but the elevation difference between the two drill holes is high (table-1), which restrict the use of above mentioned software.

To overcome this impediment in hilly terrain for interpretation of the geometry of shear zone the individual drill holes have been studied in Tawang Basin Projects. The thickness of shear zones or any weak feature obtained from the drill hole are generally the apparent thickness, whereas, calculating the true thickness of a shear zone is very important in order to anticipate the difficulties during excavation of underground structures and for designing appropriate support.

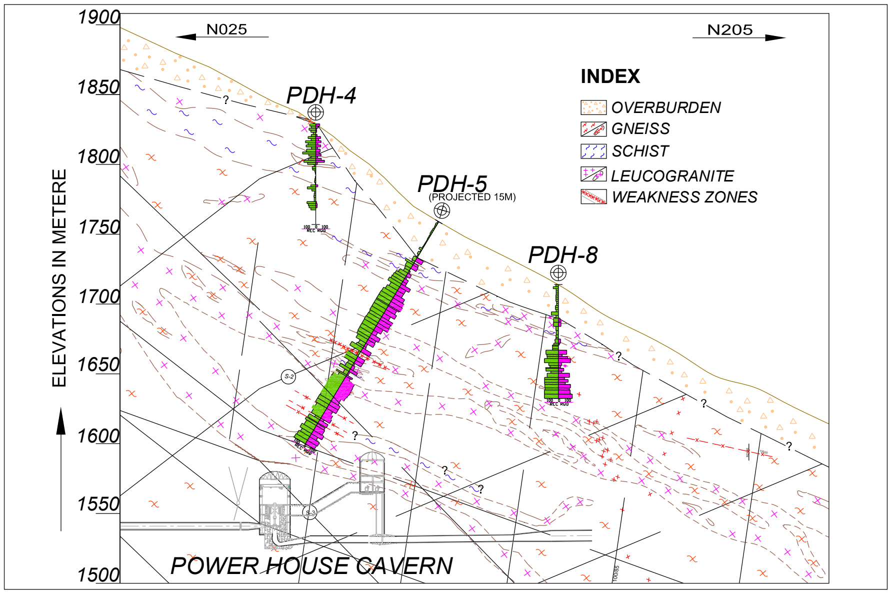


Figure 2 Geological section in PH Complex of Tawang HE Project, Stage-I.

An approach for ground realization and spatial reconciliation of weak zones through core drilling has been evolved for finding the true thickness of the shear zones running parallel to the foliation/ bedding plane. The precisely measured dip or inclination of drill hole, depths of variation in litho unit, variation in physical, chemical and mechanical properties of rock mass, recording start & end points of shear zones, general trend and inclination of country rock (picture 4) are helpful in interpreting the geometry of a shear zone. Here, the observed apparent thickness of the shear zones encountered in the drill holes have been converted into true thickness with simple trigonometric calculations and plotted in the drill hole section (figure 2).

Picture 4 Precisely measured inclination of foliation in the core samples

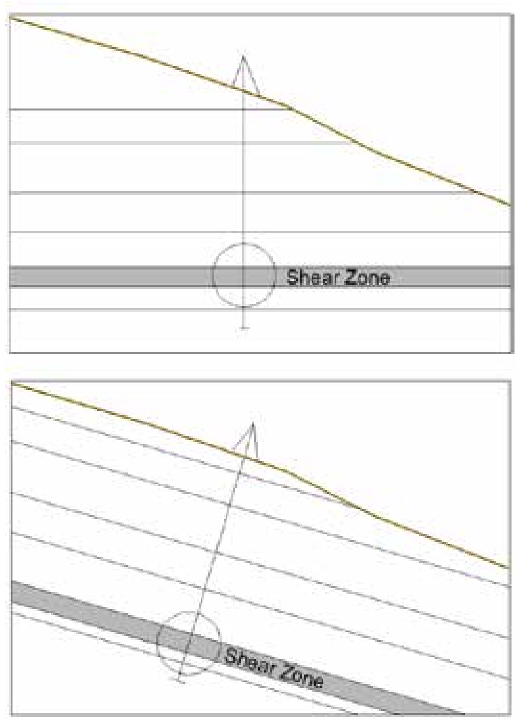
Worldwide, the drilling is carried out mostly in three conditions; the vertical drill hole, the inclined drill hole and the horizontal drill holes. Depending upon the correlation of attitude of drill hole and orientation/ inclination of the bedrock three different scenarios are illustrated:

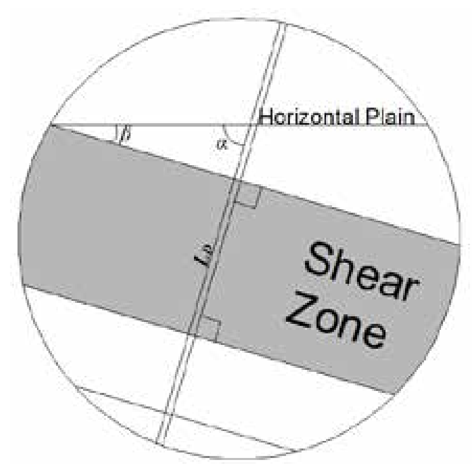
1. Vertical/ inclined drill hole puncturing the bedrock perpendicular to the foliation/ bedding plane.
2. Vertical/ horizontal drill hole puncturing the bedrock with inclined foliation/ bedding plane.
3. Inclined drill hole puncturing the bedrock with inclined foliation/ bedding plane.

Scenario-1:

In this case it is assumed that the drill hole is done perpendicular to the foliation or bedding plane of the bedrock and shear zone is running along the foliation or bedding plane. The starting depth and end point of the shear zone observed in the drill hole has to be recorded precisely, the difference between the end point and start point of the shear zone will give its true thickness (figure 3).

i.e, $L_D = T_T$





Here:
α = angle of inclination of drill hole.
β = angle of dip of the shear zone with horizontal.
L_D = Length drilled into the shear zone
T_T = True thickness of the shear zone

Figure 3 Schematic drawing showing drill hole puncturing shear zone perpendicularly.

However, this is a rare case during geological investigation for hydro projects in Himalayas.

Scenario-2:

In this case it is assumed that the vertical drill hole punctures inclined/ dipping bedrock with shear zone running along the foliation or bedding plane. If the dip of the shear zone (β) is known the angle between the drill hole and dip of the shear zone (Ω) can be obtained (figure 4). Simultaneously, by putting the values of LD and Ω in equation-(i) the true thickness (TT) can be derived from the following formula:

$$T_T = L_D \times \sin \Omega \qquad \text{------ equation (i)}$$

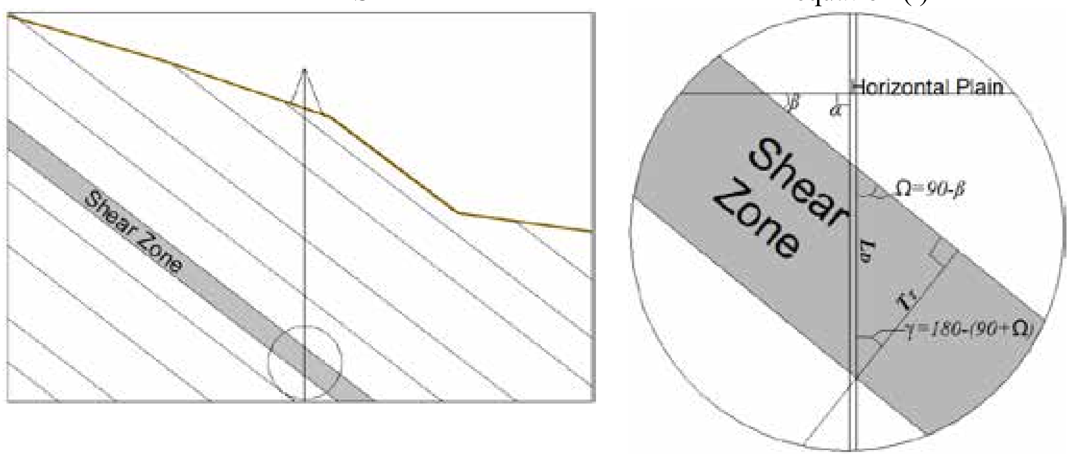


Figure 4 Schematic drawing showing vertical drill hole puncturing inclined shear zone.

Here:

α = angle of inclination of drill hole.
β = angle of dip of the shear zone with horizontal.
LD = Length drilled into the shear zone.
Ω = angle between the drill hole and dip of the shear zone.
TT = True thickness of the shear zone.

Scenario-3:

Spatial restrictions such as in mountainous region often necessitate drilling oblique to the strike. If an inclined drill hole is puncturing an inclined shear zone, oblique to the strike and none of the intersecting angle (α, β & Ω) will form a right angle.

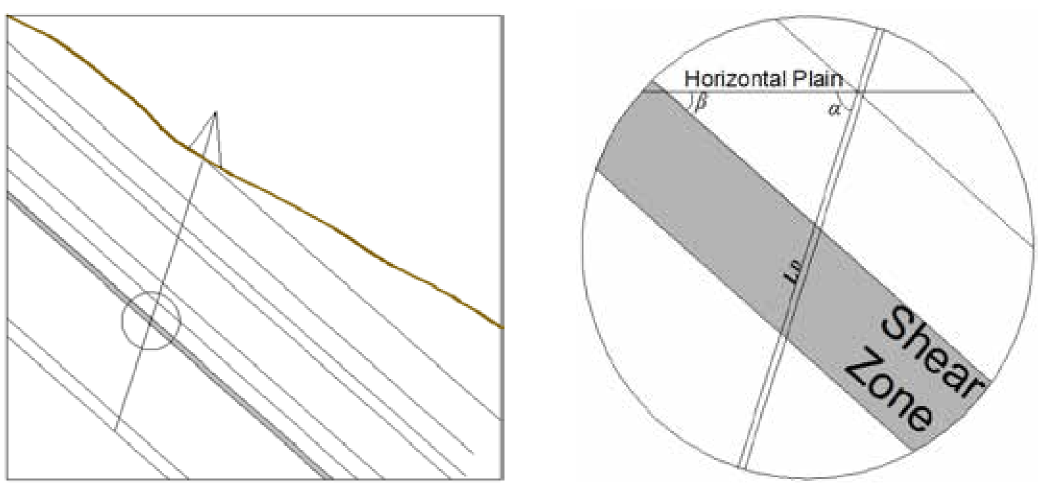


Figure 5 Schematic drawing showing inclined drill hole puncturing inclined shear zone oblique to strike.

Here:

α = inclination of drill hole
β = angle of dip of the shear zone with horizontal
LD = Length drilled into the shear zone
Ω = angle between the 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 LD (i.e.-starting and end points of the shear zone in a drill hole) and the attitude of the shear zone are known. Now, by multiplying LD with a standard thickness reduction factor **RM*** the true thickness of shear zone (TT) can be obtained.

$$T_T = L_D . R_M \qquad \text{------ equation (ii)}$$

RM*-Evolved by Friedrich-Wilhelm Wellmer, Manfred Dalheimer and Markus Wagner and published in their book "Economic Evaluations in Exploration" http://www.springer.com/978-3-540-73557-1.

RM can be derived from the geometric & trigonometric method or it can be expressed with the directly observable angles:

α - (angle of inclination of drill hole),
β - (angle of dip of the shear zone with horizontal) and
γ -(angle between the horizontal projection of the drill hole and the dip direction of shear zone).

Thus: $$RM = \cos\beta\,(\sin\alpha + \cos\alpha \times \cos\gamma \times \tan\beta) \qquad \text{------ equation(iii)}$$

In the present study the authors have used the directly observable method to derive thickness reduction factor RM.

The thickness reduction factor (RM) can also be obtained from the curve sets for RM for various drill hole inclination (Please refer: figure B1 to figure B4 at the Appendix B, pp-206 of Economic Evaluations in Exploration, Friedrich-Wilhelm Wellmer, Manfred Dalheimer, Markus Wagner).

5. Case Study:

Geologically, the major part of the Tawang HE Project, Stage-I is located in the rocks of Se-La Group belonging to Main Himalayan belt of early Proterozoic age. The major lithological assemblage of this group comprises rocks of high grade metamorphics & gneisses of Central crystallines. These rocks have undergone high grade regional metamorphism from amphibolites to granulite facies. The litho units are strongly deformed and are often associated with migmatites. The outcrops and the underground excavations like drifts in the area reveal the presence of intermittent shear zones of considerable thickness which may cause hindrance at the time of execution. To minimize the hindrances/ uncertainties an approach is being made to determine the true thickness of the shear zones through core drilling.

Out of total drilling of 2825m in Tawang HE project, Stage-I about 606m has been done at the finally identified underground powerhouse complex site (table-1). This approach of ground realization and spatial reconciliation of weak zones has been implemented in the drill holes at powerhouse site to find out the true thickness of the weak zones.

Case I: A vertical drill hole PDH-7 was drilled upto 62m at the pressure shaft alignment in the power house complex of Tawang HE project, Stage-I. This hole encountered a weak zone of around 3m from depth 54.0m to 57.0m. The general trend of the country rock is 140°/45°, thus the foliation is making an angle of 45° with the vertical drill hole. In this case Scenario 2 is most appropriate approach to find out the true thickness of the shear zones encountered along the foliation and can be derived by applying equation (i): $T_T = L_D \times \sin \Omega$

Here:

L_D (i.e. the apparent thickness of the shear zone along the length drilled) is 3m and

Ω (i.e. the angle between the drill hole and dip of the shear zone) is 45°.

Thus the true thickness (T_T) of the shear zone is derived to be 2.12m.

Case II: Similarly an inclined drill hole PDH-5 of 185.3m has been drilled adjacent to the underground powerhouse cavern. This 75° inclined drill hole is towards N57°E direction. The general trend of foliation in this area is 135°/50°. This inclined drill hole is puncturing an inclined shear zone, oblique to the strike and none of the intersecting angle (α, β & Ω) forms a right angle.

In this case Scenario-3 would be most appropriate approach to obtain the true thickness of the shear zones encountered. In order to obtain the true thickness of a shear zone intersected at depth 108.5 to 112.5m the directly observed values can be put in equation (ii) & equation (iii).

Here the directly observable values are:

- L_D - the apparent thickness of the shear zone along the drill line, (4m)
- α - the angle of inclination of drill hole (75°)
- β - the angle of dip of the shear zone with horizontal (50°)
- γ - the angle between the horizontal projection of the drill hole and the dip direction of shear zone (79°)

By putting the values in equation (iii) we can derive the thickness reduction factor R_M.

$$R_M = \cos 50 (\sin 75 + \cos 75 \times \cos 79 \times \tan 50)$$
$$= 0.642 (0.965 + 0.259 \times 0.191 \times 1.192)$$
$$= 0.657$$

Now by putting the value of R_M in equation-(ii)

$$T_T = L_D . R_M$$
$$= 4 \times 0.657 = 2.63\text{m}$$

Hence the true thickness of the shear zone encountered in drill hole PDH-5 between depths 108.5 to 112.5 is 2.63m.

To sum up the above exercise it is prudent to advise that, if all the above mentioned parameters are recorded judicially while drilling and core logging the true thickness of the weak features can be calculated at site itself and can be further conveyed to the designers for appropriate designing of underground structures and for estimation of support requirements.

6. Limitations:

This approach can be considered as the first step towards evolving a mechanism for interpretation of the true thickness of the shear/ weakness zones encountered in drill hole. The limitations in application of this approach for ground realization and spatial reconciliation of weak zones through core drilling are enumerated below:

i. Generally, loss of core recovery due to changes in the rock competency gives mere idea of start & end points of the shear zone and there are no obvious planes from which angle can be taken.

ii. The identification of the angle of shear plane would be difficult in the area of multiple deformations, where shearing has taken place along different sets of discontinuities.

iii. The deviation of drill hole is an obvious phenomenon in deeper drill holes and in region with mixed strength competencies of the bedrock. This aspect is yet untouched in this approach.

7. Conclusion:

Displacement in the rock mass occurred in the brittle zone of the earth crust sometimes results to criss-cross network of localized or small scale faults may be in centimeters scale which all together are termed as fracturized zones, whereas the similar phenomenon in the ductile zone results in formation of smoothly braided network of localized shear displacement which ultimately forms a shear zone. These fracturized or shear zones are weak features within the rock mass. Shear zones are planar and curvy planar features formed in the earth crust at the level of 10 to 15km and higher. These weak features when encountered during the excavation of underground pose difficulties in execution and hinder the progress. Early knowledge of the occurrence of such phenomenon can be helpful in anticipating the difficulties in excavation and for designing appropriate support to handle the weaker zone. If the severity of the weak zones is assessed at the earlier stage the modifications in the orientation & location of the underground structures can be done. The purpose of carrying out core drilling is to have an idea for go/no-go decision. In-spite of practical problems related to irregular behaviour of shear seams the core drilling provides a vital information at very early stage. This approach of ground realization and spatial reconciliation of weak zones is to utilize the vital data obtained from core drilling. This method would be a handy tool for the engineering geologist at the site for determining the true thickness of weak features and will also help the designers in taking appropriate decisions regarding designing of large underground structures.

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