Engineering Geology at the Cross Roads

Dhawan, Gopal
Executive Director (Geotech)
Sayeed, Imran
Chief (Geology)
NHPC Limited, Sector 33, Faridabad 121001, Haryana, India
Corresponding Author: sayeedimran2009@gmail.com

Abstract

With a lot of emphasis being placed on infrastructure development, which consists of large civil engineering structures both surface and underground, there is immense pressure on engineering geology. Challenges are simply enormous and if performances are not of a very high standard, a lot of impugn will come on engineering geology. The paper analysis the situation in detail and asks the readers to introspect and chose the path of success themselves, keeping in view the alternatives available. Besides the authors have tried to throw light on the popular term 'Geological Surprise' a terms which greatly offends most of the geologists and rightly so. However, in the paper we have advocated to use geological uncertainty and have come out with typical examples for the same.

1. Introduction:

The birth of engineering geology as a subject took place consequent to the St. Francis dam failure in California in the year 1928. Slowly the new kind of specialization, the engineering geology gained importance as geological advice started to be taken by the civil engineers engaged in construction of large structures, especially dams. Many countries or states enacted laws or formulated building codes wherein it was made mandatory to obtain opinions or advice from experts from different fields most notably from geology before embarking upon major construction activity. The science of engineering geology made rapid progress and subsequently rock mechanics, soil mechanics also got combined with engineering geology to become Geotechnics or Geotechnique which has a wider scope. Simultaneously or thereafter the Geotechnical Engineering also developed as a full fledged branch of Civil Engineering. In many cases the Geotechnical Engineer and Engineering Geologist had overlapping functions.

The modern engineering geology as it stands now flows from basic and in depth knowledge of several branches of conventional geology such as geomorphology, stratigraphy, petrology, structural geology and petrography in addition to all the applied aspects. An engineering geologist is for example supposed to be familiar with all forms of investigations and latest geo-engineering topics like rock mass classifications, rock and soil mechanics, construction materials and so on. Above all a minimum workable knowledge of civil engineering structures is also necessary. In the construction stage detailed mapping of dam foundations or rock classification in tunnels is required. Day to day advice on rock supports and remedial measures in case of unforeseen circumstances shall be necessary. Therefore, it is seen that in engineering geology, a host of activities related to different branches of science and engineering have to be performed. Such an expertise is not readily available from the universities. Professionals who are coming out of their studies have to be rigorously trained mainly at the work place.

Probably due to its origin, engineering geology is mostly remembered with failures but it rarely gets due accolades for a task well performed. After analyzing the current scenario it would not be out of place to say that Engineering Geology as it stands today, is at the cross roads particularly with respect to the Indian context.

"Geological Surprise" in terms of geotechnical engineering can be defined as a media that has been encountered suddenly and which was not predicted earlier. To qualify more, the same should have resulted in changed circumstances in dam foundation, abutments, spillways and energy dissipation structures, large or deep open excavations, underground openings and in tunnels. Such circumstances may or may not result in putting additional resources or changed construction methodology by the executing agency in turn affecting the completion time and cost of the project.

In order to understand the occurrence of the geological surprises it is necessary to understand the methodology of the investigations and appreciate what can be predicted and what cannot be predicted. This paper also attempts to describe the nature of geological surprises or uncertainties that are likely to be encountered in typical structures of river valley project and how much they affect the cost or time of completion.

2. Methodology of Geological Investigations:

Geological investigations are typically carried out for large civil engineering structures associated with the river valley or hydroelectric power projects in stages. They are linked closely with the stages of the project which may be Pre-Feasibility, Feasibility, Detailed Investigation (DPR), Construction and O & M Stages. In the pre-feasibilty stage when the project is conceived, generally available geological maps and literature is used. Selection of proper sites for main structures is important activity which has tremendous bearing on the future of the scheme conceived. However in the feasibility stage, focused geological mapping of the project area on the survey plans specially developed for the investigations is undertaken. This is followed by exploratory drilling and test tunneling. Some rock mechanic or soil tests are also undertaken.

In the feasibility stage based on geological information the lay-out of the project together with type of dam, tunnel alignment with number of adits and type of power house is decided. Moreover, based on preliminary geological findings, study of alternatives and site selection continues, particularly in the initial stages. Ideally at the culmination of feasibility stage investigations, a feasibility report should be able to establish overall technical as well as broad economic viability of all main structures of the project based on topographic, hydrological and geologic findings. A broad framework of geological and geotechnical investigations to be carried out in the detailed investigation stage has to be evolved in this stage itself so that proper estimate and time frame for DPR studies is developed.

In the detailed investigation or DPR stage, a definite investigation plan is followed. The media supposed to hoist different civil structures is thoroughly investigated with different methodologies for different structures.

2.1 Dam Sites:

The investigations for the dam sites includes preparation of topographic plans on 1:1000 or 1:500 scale followed by detailed geotechnical mapping and collection of rock quality parameters. The exploratory drilling and permeability tests are done all along the dam axis and also in the middle portion and at the dam toe. The river bed rock levels are ascertained by core drilling only which has to be of highest quality for correct interpretation of bed rock levels as well as its quality. In the abutments rock conditions are seen by tests tunnels followed by rock mechanic tests. Finally the bed rock levels in the river bed as well as in the abutments together with quality of rock help in detailed design and quantity calculations for the dam. Availability of construction materials also plays an important role in the decision regarding the type of dam as well as for costing of concreting works. The geological un-certainties or surprises that are associated with dam sites and that also cause delays and time overruns are
tabulated below:

Table No. 1
Typical Geological Uncertainties/Problems Associated with Dam Sites

Sr. No.	**Event**	**Possible causes**	**Impact on construction**	**Remedial Measures for avoiding Geological Uncert./ Surprises**
1	Encountering bed rock at deeper level than anticipated in tender/const. drawings in dam foundation	(i) Inadequate drilling at the dam axis/ middle potion/ dam toe. (ii) Improper interpretation of drilling results by geologists due to poor quality of drilling or poor core recovery. (iii) Survey errors. (iv) Changes in survey grid system during const. stage. (iv) Improper interpretation by geophysical surveys.	Depending on the deviation in bed rock depth it may result in increase in excavation depth, increase in concreting quantities, upsetting diversion arrangements because the time for excavation and concerting is now more than predicted earlier.	Increase no. of drill holes in invest. stage. Improve quality of drilling. Posting of adequate trained staff at site for geological mapping/ logging. Strict quality control in survey works. Grid system adopted for survey in investigation stage should not be changed
2.	Occurrence of weak zone, fracture zone or shear zone of width greater than 5m in the foundation which was not predicted earlier	(i) Typical causes are once again inadequate investigation or poor quality of drilling	(i) May cause delay as the weak zone needs to be treated. It the zones are not very wide, not much impact shall be there in cost or schedule (ii) In very rare or extreme case it may result in design changes	

			in the main structure	
3	Slope failures in dam abutments or spillway deep cuts due to sudden occurrence of unknown geol. conditions.	(i) Inadequate mapping, drilling or drifting (ii) Inadequate rock or soil testing (iii) Occurrence of shear zone or prominent discontinuity not predicted earlier (iv) Sudden occurrence of weak zone not predicted earlier **Following causes are not related to geological factors in slope failures but they are major contributors** (i) Inadequate understanding of geological reports (ii) Non availability of certain rock support elements in the BOQ in spite of known geological conditions and height or depth of slope excavation (iii) Non availability of adequate quantities of support elements in the BOQ resulting in under support of the slope face and subsequent failure. (iv) Changes in slope geometry after the DPR due to engineering requirement. (v) Changes in slope geometry after the DPR due to non-availability of land. (vi) Poor construction methodology may include poor to very poor blasting and delay in support installation, labor strikes resulting in stoppage of critical rock support activity which may prove to be catastrophic sometimes.	(i) Depending on the magnitude of failure causes no impact, small impact, medium impact or heavy impact on construction schedules. Requires mobilization of additional resources to overcome the problem	(i) Typical remedial measures include redesign of slope, drainages, addition of supports, introduction of new elements of support, pre-grouting, bio-engg. measures. Often treatment depends on the structure which is affected and long term necessity of stability. (ii) Training for engineers in geology and geologists in slope stability

4.	Occurrence of buried channels not predicted in DPR stage earlier	(i) Inadequate investigation. (ii) Not possible to reconstruct past geologic history or paleo-geomorphology of the area due to recent deposition. (iii) Bad site selection.	(i) Depending on the exact location of the buried channel may cause different impacts like depression in bed rock profile along the dam (rare). (ii) Occurrence of overburden in diversion tunnels may cause changes in tunneling and support methodology.	(i) May require addl. excavations in dam foundations. (ii) Steel supports in tunnels. (iii) Strengthening of the media in some cases if overburden owing to buried channels is encountered in diversion tunnels.

2.2. Tunnels:

In case of tunnels, geological surprises are being increasingly cited as reasons for delay and cost overruns. During the DPR Stage it is thus extremely important to investigate the geological environment in detail. Nothing can be substituted for a good and reliable engineering geological map. Generally the tunnel alignments are surveyed on 1:5000 and 1:10000 scale depending on the length of the tunnel. The most challenging part of geological investigation for river valley or hydroelectric power project schemes is mapping of long tunnel alignment in a rugged terrain where there is no accessibility. This also one of most neglected activity during the investigation stage as necessary resources are not available for undertaking such an exercise. For instance, construction of approach paths prior to geological mapping should become an integral part of the investigation activities.

Secondly for ascertaining the rock cover over the tunnel alignment especially at nallah intersections, or for the study of lineaments, shear zones, faults or any other geologic structure, all types of surface exploratory tools such as geophysical surveys, core drilling or test tunneling should be liberally used.

Finally the engineering geologist develops the geologic model through which the tunnel is anticipated to pass. This geological model is expected to contain description of major folds or faults, lineaments that will intersect the tunnel and rock units or litho units expected in the tunnel. However, for assessment of the tunneling media and ascertaining the support requirements which can be further co-related in the construction stage also, as the tunnel is excavated, there is no better system than rock mass classification. This is in *senso stricto* engineering characterization of rock masses. Thus the tunneling media is classified into various rock classes which have a definite meaning as far as tunneling conditions and application of rock supports for the stability of the tunnel is concerned. It needs to be clearly understood here that the estimation of rock classes is done from the surface outcrops, drill hole data and from the test tunnels which may be far away from the actual tunnel and hence there can be variations in the rock classes. This variation should be expected from a minor or negligible quantity to a substantial one in each and every tunnel.

The Geological Survey of India while giving clearance to one of the DPRs had categorically stated that the rock mass classification is based on assessment made from surface exposures and outcrops which are at a distance and therefore there can be variations in the same while tunneling. This (variation) shall not be construed as 'geological surprise'. In the Himalayan tunnels it is well known by experience that certain fractured zones or shear zones or weak bands or water charged strata shall be encountered for which certain treatment methods are also standardized. There is a need to formally include these treatment methods in the contracts so that during the construction time is not wasted in seeking fresh approvals and subsequent additional resource mobilization. Finally it has to be seen that the executing agency is prepared with the resources as well as specialists.

Overreactions such as putting steel rib supports in the entire tunnel or doing pre-grouting in the entire tunnel should be avoided as it is not a 'good engineering practice'. Another challenge which awaits the engineering geologists is the prediction of groundwater or water charged strata in the tunnels. The table given below is prepared keeping in view all the above points.

Table 2
Typical Geological Uncertainties/Problems Associated with Tunnels

Sr No.	Event	Possible Causes	Impact on Construction	Remedial Measures for avoiding Geological Uncert./Surprises
1.	Occurrence of weak zone, fracture zone or shear zone in the tunnels having a thickness of more than 1D to 1/2D of the tunnel and which was not predicted earlier	(i) Occurrence of litho-logical or structural weakness in the geology of tunnel which could not be predicted earlier or remained concealed under overburden (ii) Inadequate mapping, drilling or drifting	(i) May cause delay as the weak zone needs to be treated. If the width of the zones is not wide enough, impact shall be there minimal or negligible impact on cost or schedule (ii) In very rare or extreme case it may result in	(i) The most important remedy for avoiding such occurrences is to have provision of advance core drilling from the tunnel face which has to be judiciously utilized. (ii) Greater emphasis on remote sensing techniques for long tunnels followed by ground checks. (iii) Logistics for geological mapping need to

			design changes in the main structure	be improved by providing camping material, incentives for field work, drilling practices also need improvement. (iv) Avoid geologically weak or disturbed areas by suitably modifying tunnel alignment. (v) Develop capability for deep drilling along the tunnel alignment.
2	Presence of closely spaced multiple shears causing instability which was not foreseen earlier in the geological report/appraisal.	(i) Inadequate mapping, drilling or drifting	(i) Depending on the magnitude of failure causes no impact, small impact, medium impact or heavy impact on construction schedules. Requires mobilization of additional resources to overcome the problem.	(i) Greater emphasis on investigation. (ii) Reliance on remote sensing studies to pick up major lineaments followed by ground checks. (iii) Surface geological mapping to be followed by exploratory drilling. (iv) Probe all susceptible areas by core drilling demarcated by remote sensing or surface mapping, probe all areas on the basis of geomorphology.
3.	Water seepage (with or with out silt/slush)near the face within 20m with discharge exceeding 2000 lit/min which was not predicted earlier.	(i) Inadequate investigations. (ii) Ground water occurring as perched aquifer which is difficult to predict in hard rocks. (iii) Water occurring in confined state.	(i) Work may slow down or temporarily come to a halt (ii) Requires treatment of affected zone by dewatering or grouting	(i) Geophysical surveys on tunnel alignment wherever feasible. (ii) Lineament study for ascertaining secondary permeability. (iii) Advance probe drilling in tunnels: Provision in quantities as well

			depending on site conditions. (iii) May require dewatering arrangement depending on tunnel gradient	as in time schedule is required.
4.	Rise in temp. in the tunnel to more than 50° C not foreseen earlier	(i) Change in thermal gradient. (ii) Heat flow.	(i) Hampers construction activity (ii) Requires extra ventilation or other cooling arrangement.	(i) Thermal mapping of the deep bore holes on tunnel alignment. (ii) Avoid areas of high heat flow
5.	Encountering obnoxious gases not predicted earlier	Geological conditions are such that gases like methane occur	(i) Can have serious impact if the concentratio n crosses harmful levels	(i) Very cautious approach in suceptible geological environment. (ii) To maintain proper record during exploratory drilling (iii) Advance drilling from tunnel face.
6.	Encountering frequent stress induced failures or rock bursts which have not been predicted.	When tunnel passes below high cover in hard or strong /very strong rocks such events may occur.	(i) Impact on progress can be varied from small to very high resulting in stoppage of work if the rock bursts are violent and have potential to cause damage to equipment or human life.	(i) To avoid high cover zones by modifying tunnel alignment. (ii) Correct prediction of rock types in high cover areas. (iii) New geophysical techniques for deep investigations should be attempted.
7.	Encountering squeezing rock conditions not predicted earlier.	When tunnel passes below high cover in soft or weak rocks such events may occur.	(i) Impact on progress can be varied from small to very high resulting in stoppage of work if the squeezing is large and is	(ii) To avoid high cover zones by modifying tunnel alignment. (iii) Correct prediction of rock types in high cover areas. (iv) Advance core drilling from tunnel face.

			damaging the existing tunnel supports. Tunnel sect. may get reduced.	
8.		**Following causes are not related to geological factors in tunneling but they are major contributors for delays and higher costs** (i) Lack of understanding of geological reports (ii) Non availability of certain rock support elements in the BOQ in spite of known geological conditions and difficulty in tunneling (iii) Poor blasting methodology and delay in support installation. (iv) Lack of expertise in pre-support of known weak media. (v) Non availability of particular type of support element even though it is part of the BOQ (vi) Changes in tunnel alignment after the DPR due to engineering or environmental reasons. (vii) Labor strikes resulting in stoppage of critical rock support activity which may prove to be catastrophic sometimes.		

2.3 Underground Caverns:

There is a difference between the long tunnels and underground caverns in which investigations are more focused. Generally for underground caverns such as de-silting chambers or underground power house caverns, surge galleries etc exploratory drifts are made right up to the cavern and hence geological conditions are well known. Besides this, rock mechanic tests are also conducted inside the drift to ensure that correct parameters are assumed for the design of rock support in case of wide caverns. Rock support analysis by FEM is more important particularly when multiple caverns are planned in near vicinity. Traditionally because of the more intensive investigations and rock mechanic tests, underground power houses have not suffered major set backs or cost and time overruns in NHPC. However, in some cases modifications in the support systems were required when large deformations were noted by the instrumentations. Water seepage has been another cause for concern in the u/g caverns but same has also been largely controlled by the pumping arrangements. In a nutshell the geological surprises if at all encountered in the u/g caverns can be classified as follows:

Table 3
Typical Geological Uncertainties/Problems Associated with Tunnels

S. No.	**Event**	**Possible Causes**	**Impact on Construction**	**Remedial Measures for avoiding Geological Uncert./Surprises**
1.	Occurrence of weak zone, fracture zone or shear zone in the cavern having a thickness of more than 0.5 to 2m which was not predicted earlier.	(i) Occurrence of litho-logical or structural weakness in the vicinity of proposed cavern which could not be predicted earlier or remained concealed under overburden. (ii) Inadequate mapping, drilling or drifting.	(i) May cause delay as the weak zone needs to be treated. However, if the width of the zones is not wide enough, impact shall be there minimal or negligible impact on cost or schedule. (ii) In very rare or extreme case it may result in design changes in the main structure.	(i) The most important remedy for avoiding such occurrences is to have provision of exploratory drifting or test tunneling right up to the cavern followed by drilling from inside the drift to fully probe the local conditions around the excavation. (ii) Detailed geological mapping on 1:500 or 1:1000 scale is also mandatory. (iii) Logistics for geological mapping need to be improved by providing camping material, incentives for field work, drilling practices also need improvement. (iv) Avoid geologically weak or disturbed areas by suitable site selection.

2	Presence of closely spaced multiple shears causing instability which was not foreseen earlier in the geological report/appraisal.	(i) Inadequate mapping, drilling or drifting.	(i) Depending on the magnitude of failure, it causes no impact, small impact, medium impact or heavy impact on construction schedules. Requires mobilization of additional resources to overcome the problem.	(i) Greater emphasis on investigation. (ii) Surface geological mapping to be followed by exploratory drifting and drilling right inside the proposed cavern. (iii) Probe all susceptible areas by core drilling demarcated surface mapping.
3.	Water seepage (with discharge exceeding the assumed pumping capacity which was not predicted earlier.	(i) Inadequate investigations. (ii) Ground water occurring as perched aquifer which is difficult to predict in hard rocks. (iii) Water occurring in confined state.	(i) Work may slow down or temporarily come to a halt (ii) Requires treatment of affected zone by dewatering or grouting depending on site conditions. (iii) May require dewatering arrangement depending on seepage and head.	(iv) Geophysical surveys around cavern location wherever feasible. (v) Lineament study for ascertaining secondary permeability. (vi) Exploratory drilling and drifting right up to the cavern.
4.	Weakness in rock mass strength or large scale wedge formations which were not anticipated earlier. Such conditions cannot be supported by existing elements. Requires new items.	(i) Prominent changes in rock mass properties (ii) Significant changes in discontinuity patterns	(i) Hampers construction activity (ii) Requires additional mobilization of resources.	(i) Nothing is better than probing the proposed cavern by drift and drillings. (ii) Rock mechanic tests should be in representative media. (iii) Representative sampling for the laboratory testing.

5.		**Following causes are not related to geological factors in u/g caverns but they are major contributors for delays and higher costs** (i) Lack of complete understanding of geological reports (ii) Non availability of certain rock support elements in the BOQ in spite of known geological conditions and difficulty in tunneling. (iii) Poor blasting methodology and delay in support installation. (iv) Non availability of particular type of support element at site even though it is part of the BOQ (v) Changes in caverns location or dimensions after the DPR due to engineering or environmental reasons. (vi) Labor strikes resulting in stoppage of critical rock support activity which may prove to be catastrophic sometimes.		

3. Conclusions:

Large civil engineering structures such as dams, tunnels and power houses require sound foundation or tunneling medium to minimize their cost and time required for construction. As such thorough investigations and testing followed by up to date analysis is necessary. However modern construction techniques are also necessary to implement design decisions. This does not mean that large structures cannot be constructed in fair quality rock or good rock with problematic or weak zones. Such deficiencies in rock mass need to be brought out by thorough investigations. Even when weak zones or problematic areas cannot be indentified precisely it is experience has shown that typical problems occur in different types of formations. Meaning thereby even if fracture zones/shear zones have not been precisely delineated along the tunnel route it is well known that such zones are encountered particularly in the Himalayas. Characterization of such rock masses has been done many times earlier and therefore formulating remedial measures may not be farfetched. Often it has been seen even known difficulties cannot tackled owing to lack of modern technology and resources. Considering the vast experience of working in Himalayan projects and having faced problems the authors have tabulated the typical geological un-certainties structure wise. Perhaps in the next phase of work it is propose to further identify the problems on the basis of formations and document the successful stories in them. The present work would however help in finding many answers for arguments on geological surprises or more correctly uncertainties.

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