# Planning and Phasing of Detailed Geotechnical Investigations for Underground Structures

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**Abstract**

*Geo-technical Investigations plays a dominant role in deciding design parameters, construction methodology including cost assessment for underground structures such as tunnels, power house cavern during preparation of Detailed Project Report (DPR). As every project has got unique engineering components, a detailed understanding of Geological and Geomorphological features including stress field conditions of the area surrounding the proposed project site are of utmost importance rather than adopting a cook book approach.*

*It is experienced in past that geological surprises encountered during construction, causes delays and disputes during and after construction.*

*A well-planned exploration, if undertaken at investigation and design stage is always helpful in evaluating feasibility, safety, design and economics of the project in more systematic and reliable manner.*

*In the engineering project areas located in complex geological set up like Himalayas the cost and feasibility parameters are being dominated by Geological factors. To overcome this challenge a comprehensive knowledge of regional geology including structural geology of the area and its inter-relationship with cavern axis must be known. There must be adequate Geological / Geo-technical information including "Stress Field Conditions" to support the preparation of the "Geo-technical Design Summary Report (GDSR) forming the part of Contract Document.*

*In order to forecast anticipated geological problems a detailed sub-surface exploration programme including drilling of boreholes and Geo-physical survey is to be worked out on the basis of detailed Geological walk over survey and maps prepared with help of satellite imageries.*

*On the basis of the results obtained from surface / sub-surface explorations, the Rock Mass Quality (RMQ) is determined. Based on this a suitable geological model is prepared depicting distribution of reach wise Rock Mass Quality (RMQ) of anticipated rock types, ground water conditions and proposed method of excavations including ground support system. The final Geo-technical report that supports the Contract document has received considerable attention in recent past because of its legal significance to construction contract document. This is due to the fact the sudden occurrence of fault / shear zones requiring complete change in excavation method, support system, results in delay in project schedule and cost escalation, leading to legal complications on later date.*

## Introduction

Geology plays a significant role in choice of alignment, design and deciding construction methodology of tunnels and other underground structures. The unanticipated geological problems always create delays, escalation of cost and disputes between construction agency and client. It is experienced in the past that the tunnels thoroughly investigated during early phase has lesser cost and lesser disputes.

The most fundamental aspect of the Geo-technical Investigation for tunnels/ underground cavities is that, earlier the explorations made, the owner and designer has flexibility for optimization of alignment and deciding the construction methodology.

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The experience shows it is not advisable to go for design and construction before certain levels of explorations are completed. In fact it is also experienced in past that it is better to have no data or knowledge rather than to have misleading data.

## Challenges faced in geo-technical investigations for underground works

The challenges faced for Geo-technical Investigations required for underground projects located in the area having complex geological set up are due to the following facts:

- The Cost and Feasibility of the project is dominated by Geology.
- Every feature like drilling and Geophysical investigations of Geological Investigation is more demanding than traditional foundation engineering projects.
- There may be variation in regional geology and tectonic set up of the area.
- Change in engineering properties of rocks conditions, such as time, rate and direction of loading etc. These properties some time changes drastically.
- Ground water is most critical parameters to predict as it creates problem during construction, requiring provision of additional elaborate drainage arrangement before advancement.
- Change in in-situ structural conditions depending upon the tectonic setup of the area.

## Planning of investigation

The Geo-technical/Geological data collection and evaluation should begin early conceptual planning stage of any project and should continue through out construction and even after construction to document as built behavior of tunnel. The governing principle in setting scopes of phased field and laboratory investigations should be that all exploratory holes and tests should have the specific purpose of obtaining information of direct relevance to the design and construction of tunnel scheme.

The stages and methods of acquisition of Geo-technical information for tunnels can be summarized as:

- Route Corridor Identification
- Desk Study
- Site Reconnaissance
- Preliminary Ground Investigations (if required)
- Main Ground Investigation Field Work including Detailed Geological Mapping and drilling of exploratory boreholes.
- Main Ground Investigation Laboratory Work
- Interpretation of Main Ground Investigation findings
- Supplementary Ground Investigations (if required)
- Interpretation of Supplementary Ground Investigations
- Establishment of Geo-technical Design / Parameter values
- Preparation of Reference Ground Condition Report
- Review of Geotechnical Interpretive Report during construction

## Desk study and site reconnaissance

A desk study of available literature maps, aerial photograph, utility plans, existing ground investigations etc. should be carried out for all schemes. The existing information can be made available from the published literature about the area from national agency like Geological Survey of India, National Remote Sensing Agency and concerned State Govt. departments. These studies attain more importance where the project is proposed to be located in difficult terrain area.

Although recent technology advances have led to the availability of Satellite Imageries, which are updated frequently, there is no substitute for conducting a site reconnaissance along proposed corridor to get the best feel for final corridor selection and identification of locations of potential working for adits / shafts and work sites.

Normally this activity takes the form of a walk over survey, which also provides the opportunity to examine exposures of the ground and to confirm the reliability desk study data.

## Field investigations

### Selection of method of investigations and scope of work

There are number of field and laboratory investigations and testing methods of direct relevance to tunnel schemes, the method and scope of investigations applicable to any particular scheme will be governed by many factors related to specific project. Glossop (1968) has expressed valuable principle.

"If you do not know what you should be looking for in a site investigation, you are not likely to find much of value".

This is the important principle for strategy of site investigations, defining a specific purpose for every single exploratory hole collection or soil sample, or rock core, samples, field test and laboratory test. This should ensure that optimum value for money has been obtained from Sound Engineering consideration.

A phased Geo-technical Investigation programme is of great benefit in following these principles. The findings of preliminary investigation enable the main investigations to be better tailored to suit the expected surface and sub-surface conditions, while a supplementary investigation can be planned to sweep up remaining doubts and knowledge gaps left after assessing the results of main investigations. On the other hand, early boreholes may, with economy, serve the purposes of a later phase, for example some boreholes can be utilized for installation of piezometers.

Although each project site is unique, there are no rigid rules which can be applied for every project, but following aspects must be considered for planning the detailed Geo-technical Investigations.

- Character and Variability of ground
- Nature of the Project .
- Need for and scope of a Preliminary Investigations.
- Location and Spacing of Exploratory holes.
- Depth of Exploration s.
- Purpose of exploratory hole.
- Type of field in-situ and Laboratory tests.

It is important to take boreholes to an adequate depth below proposed invert level, both because subsequent design changes could cause lowering of alignment, and secondly the zone of influence of the tunnel may be extended by nature of the ground at a greater depth.

## Ground appreciation link between investigation and design

The ground appreciation, in other words, the interpretation of investigation data, forms essential link between factual information derived from desk studies, field and laboratory investigations and commencement of tunnel lining design process itself. Interpretation involves the definition, description and quantification of the ground conditions in a form that is relevant and readily available for tunnel lining design team. This imperative report may contain following:-

- Brief about Scheme.
- Description of Route Corridor.
- Finding of Desk Study and Site reconnaissance.
- Identification of route and alignment options.

- Summary of Ground Investigation Works.
- Hydrology including discussions on ground water
- Interpretation of ground conditions in relation to Design and proposed construction methodology
- Recommendations for design, construction and further ground investigations

The required Geo-technical design parameters should be worked out in Geo-technical Interpretive Report, dealing with interpretation of ground conditions in relation to design and construction. These are based on the description of rock including their structural conditions, and results of In-situ and laboratory tests.

The following table shows Geo-technical parameters that are normally required to be applied to tunnel lining design.

For design of tunneling and selecting method of excavation, it is necessary to obtain sufficient information on Geo-technical Design parameters. The amount of information required will vary from one site to another, depending upon the geological setup of the area.

The degree of detail study will also be guided by nature of design analysis. Establishing, the Geo-technical properties of some Geological strata can be undertaken with confidence, arising either from previous tunneling experience within same strata or from the fact that these strata are established to be relatively uniform. For example when the Geological mapping indicates uniformity of the strata fewer number of boreholes will be required, on the contrary the area having complex geology will require more detailed explorations and number of boreholes may be increased. The success of even a carefully planned boring programme also depends greatly on quality of, on site inspection during drilling operation.

It is not uncommon for Geo-technical Investigations even one investigation programme based on the most rigorous and comprehensive survey, fails to reveal actual ground conditions. In many cases, remarkable departure is observed within actual excavation conditions during construction, than the interpreted data based on exploratory holes. The interpretative report

| Sl. No | Type of Test. | Parameters Obtained | Tunnel Design Applicability |
|---|---|---|---|
| 1. | Bulk Density | Unit Weight | Over burden pressure |
| 2. | Maximum and Minimum Density | Maximum and Minimum Density | Over burden pressure of ground |
| 3. | Moisture Content | Moisture Content | Type and State of Ground |
| 4. | Specific Gravity | Specific Gravity | Over burden pressure |
| 5. | Plasticity | Liquid and Plastic Limits, Plasticity Liquid / Index | Type and State of Ground |
| 6. | Particle, Size Distribution | Properties of Soil Composition | Type of Ground |
| 7. | Unconfined Compression | Unconfined Compressive Strength (UCS) | Rock Strength |
| 8. | Point Load Strength | Point Load Index Strength, Unconfined Compressive Strength | Rock Strength |
| 9. | Undrained/ drained triaxial compression | Undrained Shear Strength | Soil / Rock Strength |
| 10. | Consolidated Undrained/ drained triaxial compression | Effective Stress Shear Strength | Soil Strength |
| 11. | Shear Box | Angle of shearing resistance | Frictional strength of soil grains and rock joints |
| 12. | Odometer / one dimensional consolidation | Co-efficient of compressibility vertical drains deformation | Soil stiffness |
| 13. | Laboratory Permeability | Co-efficient of Permeability | Soil Permeability |
| 14. | Poisson's ratio | Poisson's ratio | Ground stiffness |
| 15. | Chemical analysis | PH Value Sulphate and Chloride Contents | Lining Durability |
| 16. | Abrasion | Abrasion | Excavatability |

must endeavour to consider as thoroughly as possible a clear picture of ground conditions as a whole. On the basis of experience it may be concluded that variation in interpreted data and actual strata encountered during tunnel operations is controlled by following geological factors like:-

- Presence of ground water bearing or layers of granular material within cohesive strata.
- Cavities in rocks, solution features in limestone, sometimes partly or fully in filled with gravels, sands, silts and clays.
- Sudden appearance of artesian conditions not intercepted in boreholes during investigations.
- The presence of sudden aquifers in limestone was experienced way back in 1970, in Sundernagar, Satluj (SST) part of Beas Satluj link project in Himachal Pradesh. This problem was tackled by making pre-drainage arrangement.
- Deviation in interpreted location of weak zones such as fault zones, shear zones at tunnel grade. This is attributed mainly due to folded nature of strata in geologically complex area.
- Sudden occurrence of methane / other hazardous gas bearing strata.
- Variation of rock stress conditions as per rock cover.

## Need of explorations vis-a-vis size of cavern

The need of Geo-technical explorations varies with dimensions of underground excavation. The larger the cavity more the additional explorations, as the cavities / tunnels of larger dimensions may experience more construction difficulties. Frequently method of construction changes with increase in size of cavern and risks during construction stage are greater so different Geo-technical field as well as laboratory tests may be required to support increasingly more detailed Geotechnical Synthesis.

## Cost of explorations

U.S.National Committee on Tunnelling Technology in 1984, has recommended

(a) The site exploration budget should average 3.0% of Estimated Project Cost.

(b) Boring footage should average 1.5 linear feet of borehole per route feet of tunnel.

These recommendations were made on the basis of experiences that sometimes even 2% for Geo-explorations was obviously too low, as compared with average 12% expenditure incurred in project cost, that were for payment against variation clause. This is usually due to unexpected adverse Geological condition causing higher cost and delay in completion of project.

## Constraints/errors made for geotechnical investigations

- Detailed studies not taken up well in time. This leads in proper location of boreholes hence information collected sometimes is not useful.
- Detailed Surface Geological Mapping and Structural Analysis not undertaken timely.
- Not enough time is given (usually administrative pressure) for detailed exploration as per site specific requirement.
- Not enough money but more will be paid later. This is a casual approach and ultimately leads to collection of limited data for design creating problem in later date.
- Tendering of construction works before the Site Investigation is completed. This approach sometimes to disastrous and leads to tremendous problem and even causes change in route/alignment.

The tender finalisation of documents and award of contract of construction of tunnels in Railway line project linking Katra and Srinagar, has resulted to design of tunnel portals without adequate supports. This resulted collapse in tunnel portals at many places and forced the project authorities to take a decision to change the alignment.

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