Strategy for Site Investigation of Tunnelling Projects

ITA Working Group 2
Research

N° ISBN: 978-2-9701013-3-8

ITA REPORT N°15 / MAY 2015

ASSOCIATION
INTERNATIONALE DES TUNNELS
ET DE L'ESPACE SOUTERRAIN
AITES
ITA
INTERNATIONAL TUNNELLING
AND UNDERGROUND SPACE
ASSOCIATION

“If you do not know what you should be looking for in a site investigation, you are not likely to find much of value. What you look for should be suggested by the natural environment, and by the nature of the construction problem to be solved. Thus, a detailed programme of investigation cannot be decided on day one and adhered to, and the engineer who in the long run is responsible for the solution of the construction problem should not expect to order a site investigation and then dismiss the matter from his mind until a report is placed upon his desk.”

R. Glossop, 8th Rankine Lecture

ITA Report n°15 - **Strategy for Site Investigation of Tunnelling Projects** - N°ISBN: 978-2-9701013-3-8 / MAY 2015
Layout : Longrine – Avignon – France – www.longrine.fr

Strategy for Site Investigation of Tunnelling Projects

ITA Working Group 2 Research

This study of site investigation for tunnelling projects began with a request from the Executive Council Meeting held in Kyoto, Japan on November, 2001 led by Professor André Assis, former President of the International Tunnelling Association (ITA).

As it is not possible to predefine the ground conditions in detail before a tunnel is constructed geological risks exist on any tunnelling project. The purpose of site investigation is to provide adequate and reliable information in early stages of the project in order to improve the knowledge of the subsoil, assess various design options and choose construction methods that better cope with the identified potential risks.

Site investigations have to be conducted within the global strategy of project risk management (see "Guidelines for Tunnelling Risk Management ", WG2, 2004) and should follow the ALARP (as low as reasonably practicable) principle to reduce risks - namely geological, geotechnical and hydrogeological risks.

The level of acceptable risk as defined by the ALARP principle can be specified in different ways depending on the design stage, and the site investigation strategy should take cognisance of this. The effort required during a site investigation (in terms of the scope of investigation and related cost) will vary with the project development, and has to focus on progressively improving the level of knowledge. The effort required at any stage will depend upon the complexity of the project and will have a direct impact on risk mitigation and project cost.

This document presents the strategy for site investigations based on international best practice, with the aim of maximising the benefit in terms of acquiring knowledge at the right project phase, while avoiding common misleading approaches in terms of investigation effort and responsibility. It is hoped that this document will be a useful guide for future tunnelling projects.

As Animateur and Vice-Animateur of ITA Working Group 2, Research, we wish to acknowledge the important contributions of the following persons: Eric Leca as former Animator and current WG2 Tutor who previously led this study; David Chapman, Elena Chiriotti, Giorgio Höfer-Öllinger and Emmanuel Humbert who drafted the text; all the WG2 Members who contributed to collect the relevant case histories and to finalise the document, the WG2 reviewers Ron Tluczek, Conrad Felice and William Hansmire, and the ITA reviewers Harvey Parker, Amanda Elioff , and Robert Galler. A special thank goes out to Randy Essex, a member of WG3, who gave valuable comments on geotechnical reports in preparation of this recommendation.

Chungsik Yoo, Animateur of WG2
Elena Chiriotti, Vice-Animateur of WG2

>> TABLE OF CONTENTS

1 >> General

Because the three-dimensional engineering geology for tunnelling and underground projects cannot be entirely defined prior to construction, there are more unknowns, and hence risk, in these projects than those involving superstructures such as bridges and buildings.

The need for good geological knowledge and engineering geology is essential for an underground project, and it should dominate investigations from the very beginning. Geology affects every major decision to be made in designing and constructing a tunnel, determining its cost, and even the performance of the final product.

Careful site investigation is essential to a successful tunnelling project. A thorough programme will not only include collecting and collating all information and data, but evaluating design parameters to be used to assess the project's feasibility, deciding on a reasonable and optimum alignment, designing the ground support and/or lining, and evaluating the construction method and resultant construction program.

More importantly, it should provide a baseline for bidding and predict possible construction difficulties so as to ensure safe and economic performance, and assess the impacts of the tunnel construction on the environment, local residents and surrounding structures.

1.1 SCOPE

The aim of this report is to share and disseminate existing approaches on site investigation for tunnelling projects in order to improve international practices by reviewing and assessing the geotechnical information required for design, while considering environmental and construction issues. This report provides a general guide for site investigation procedures which may be adapted to address the specific needs of each project which may include technical risks, local regulations, contractual framework, etc..

Since in-situ conditions may not be fully defined until they are encountered directly from within the tunnel, the site investigation programme must be phased to match the objectives of the subsequent design phases so that each phase reveals more data on specific uncertainties or queries. This guideline deals with the various phases which are required for site investigations from design stages prior to the start of construction, through to the systematic updating of the geological, geotechnical and hydrogeological model during construction.

The scope of site investigation should not be limited to geotechnical aspects, but must also consider the environment in the locality of the proposed tunnel and identify any associated potential risks.

This report will discuss the benefits of phasing the site investigation, while comparing known conditions vs uncertainties, and the value of additional information versus cost implications. This document sets out a general strategy on how to obtain the required site information to assist the client, engineer and contractor to meet the project goals. As each underground project will have individual requirements, as well as different risks and geotechnical profiles, these general guidelines will have to be developed and adapted to meet the specific project requirements.

The practical and technical details of conducting a site investigation (e.g., the boring methods, sampling methods, methods available for conducting in-situ testing and laboratory testing, the interpretation of the data and how to characterize, classify and analyse the various parameters obtained from the site investigation) are not covered by this document and the reader is advised to refer to specialized technical standards and books.

2 >> Key Reasons for Undertaking a Site Investigation

2.1 PURPOSE OF SITE INVESTIGATIONS

Site investigations should be viewed as an integral part of the risk management process of a tunnel project. Without sufficient data or information from site investigations, the inherent risks in construction and operation of the tunnel or underground works may be unacceptably high. Site investigations should therefore be considered to be the foundation on which the risks associated with the project are identified.

Through each phase of the site investigation for a project, the collected and interpreted data will form the basis for achieving the following design objectives:

- assessment of the technical and economic merits of alternative schemes;
- selection of the most suitable alternative and alignment;
- preparation of an adequate and economical design for the tunnel(s) and underground structure(s);
- selection of appropriate construction methods with low inherent risks;
- identify difficulties or risks that may arise during construction and assess potential mitigation measures
- assess impact on the environment, local residents and existing structures;
- evaluate the re-use or disposal for excavation material;
- predict productivity, schedule and cost;
- predict a geotechnical baseline or reference conditions for bidding.

All site investigations should be initiated by interrogating all existing data with respect to, the history of the site, the predicted geology, existing structures and their foundations, utilities in the area, historical geotechnical investigations, etc.

The information to be obtained should include geology, geomorphology, seismicity, hydrogeology, geotechnical laboratory and field testing results. This information must establish in three dimensions the geological structure, the succession and character of the strata present, the groundwater conditions and the presence of any special hazards. The array of data to be collected will be dictated by the specific construction and performance requirements of the proposed tunnel or underground structure.

An effective site investigation is best achieved by carrying out the work in various phases. Each phase aims to fill gaps in the existing knowledge of the site or to confirm or correct earlier predictions.

A rigidly prescribed programme should not be followed; the philosophy for the planning and execution of the site investigation should be:

a) to decide what information to look for – this will be derived from an appreciation of the geotechnical needs of the project with an understanding of the general geology, character and previous use of the area, compared to the detailed knowledge gained to date;

b) to design the site investigation to provide this additional information utilising the most suitable methods – while being alert to variations or anomalies which may occur that may require changes to the planned investigation.

And last, but not least, the reliability and robustness of the data should be continuously reviewed as new information is obtained, so that the investigation effort is maximised by adapting the programme to the encountered conditions. The detailed knowledge gained at each phase should be utilised to update the ground model and reduce the level of uncertainty, and to plan the scope of further investigations.

2.2 FACTORS INFLUENCING SITE INVESTIGATIONS

The following factors are identified as influencing the extent, reliability and development of Site Investigations:

- **Geology, hydrogeology and geomorphology**

As more complex ground conditions are encountered, extra effort will be required in order to attain a suitable level of confidence in the reliability of the data. This may be hampered in remote areas where in-situ investigation may be difficult to obtain and remote sensing techniques and/or geophysical investigations may be required.

- **Project characteristics**

The scope and focus of a site investigation will be defined by the constraints and geometry of the project (i.e., depth and layout of underground work, tunnel(s) and related ancillary works, such as cross-passages, egress and/or ventilation shafts, adits, galleries, etc.), as well as its locality (i.e. urban or high mountainous regions, complexity of portal or shaft construction and access, etc.).

- **Project use**

Each project will have individual needs as well as a unique risk and geotechnical profile which will dictate specific requirements, e.g. nuclear waste repository, mining exploitation, tunnelling beneath urban environments, etc.

- **Project stage / Investigation phase**

The effort to be put in site investigations has to be consistent with the scope of the project stage. The detailed knowledge gained at each phase of the site investigation should be then utilised to update the ground model in order to plan the scope of further investigations required to reduce the residual level of uncertainty in the next stage of the project.

- **Construction method**

Once appropriate construction method(s) are defined, additional field and/or laboratory investigations may be required to obtain design parameters for mechanised vs. conventional tunnelling.

- **Environmental considerations**

Environmental factors may trigger the type and extent of specific investigations that may be required with regard to the natural environment (e.g., groundwater quality, pollution factors) and/or the urban environment (e.g., noise, air quality, existing buildings, wetlands).

After considering all the above-mentioned influencing factors, at each stage of a specific project, it will be possible to define the optimum scope of investigation required. The level of site investigation required to reach specific goals may vary considerably. Even preliminary studies may require a non-negligible initial investment when the project risk and geotechnical profile are complex and may impact the feasibility of the underground work. Depending on the size and complexity of the project exploratory galleries/shafts may be excavated to achieve a sufficient level of information.

It is the Owner's responsibility to approve the scope of the site investigation and consent to the associated programme and cost. However, contingent factors often exist, which may influence the Owner's decisiveness which will have an impact on the optimum sequencing and effectiveness of the investigations. On the one hand this may be part of the Owner's role and responsibility.

However, on the other hand, the Owner must be fully informed and made aware of:

- the impact that his decision(s) may have on the robustness of knowledge gained;
- the risk related to insufficient investigation;
- the residual uncertainties that will be maintained;
- the level of risk his project will be exposed to.

2.3 STAKEHOLDERS

During the process of development of a tunnel project the following stakeholders are involved:

- **the Owner**
- **the Engineer** as the Owner´s Designer
- **the Contractor,** and his Designer depending on the contractual framework

Third parties, which include:

- owners / Managers of utilities, public underground structures and public surface structures which may be influenced by the tunnel construction;
- owners of land, buildings or housing which may be influenced by the tunnel construction;
- people who live/work within the zone of influence of the tunnel alignment;
- those who may benefit or be disadvantaged during and after construction of the tunnel.

2.4 ROLES AND RESPONSIBILITIES

The Owner, the Contractor and the Designers have different levels of responsibility with regard to the development of a project, and all have to fulfil their obligations and contribute – to different degrees – to the control of the project cost and schedule, and to the preservation of the environment.

The tasks and responsibilities of the different parties involved with the site investigations during the development of a tunnel project will be dependent on the contract model chosen for the project. However, it is recommended that the Owner retains the final responsibility for the ground conditions, irrespective of the contractual framework that is chosen for the project.

As stated in the “Geotechnical Baseline Report for Construction - Suggested Guidelines”, ASCE, 2007:
“In traditional contracting, the Owner and his design Engineer will address the full scope of geotechnical investigation and design including exploration of subsurface conditions along the project alignment. Under DB (design and build) method the Owner may seek to transfer the responsibility for portions of this effort to the DB team, whether to achieve schedule efficiencies, transfer subsurface risks, or other reasons.

It is recommended that the same level of exploration be carried out in advance of DB procurement as would be accomplished under traditional method.
To “economize” on the amount of subsurface information provided in advance of DB proposals increases the risk that the Designer will have insufficient information upon which to base a reliable design”.

These are strong statements which are generally shared among the technical community and should draw attention to the following aspects:

- The Owner retains the final responsibility for the accuracy of information on the ground conditions.
- The Owner has the final responsibility in approving the extent of investigations to be implemented at each stage of the design, which may be in conflict with what would ideally be required by the Designer. His or her decision has a direct influence on whether additional costs are incurred upfront during site investigations in order to minimise the uncertainties, or whether the costs of the effect produced by such uncertainties on the project will be potentially covered as a provisional sum for risk.
- Generally, it is far more cost effective to carry out the appropriate site investigations at the right project timing, rather than try to make provisions for investigations and risks at a later stage of the project.

In fact, in the former case the majority of uncertainties linked to the ground conditions are resolved prior to construction, which assists in preparation of an economical design and selection of appropriate construction methods with low inherent risks. Adequate information on the ground conditions contributes to the development of a proactive and positive relation among all parties involved in the project and control of the schedule and costs.

In the latter case, bigger residual uncertainties can lead to conservative design approaches, higher provisions for risks, or higher exposure to the risk of contractual claims.

- The Owner should allocate sufficient time, funding and resources to the Engineer to develop and coordinate the investigation programme, to interpret the results of investigations, to assess the residual uncertainties and to develop the design accordingly.
- The site investigation works should remain under the responsibility of the Owner, and they should preferably be excluded from the Engineer's contract. It is recommended that they are carried out through a dedicated bid for execution only. This allows avoiding the following negative effects that could be related to site investigation costs being included in a lump-sum engineering service contract:
  - the bidders for the position of Engineer may propose reduced investigation to remain competitive; as a consequence, the extent and quality of the site investigation could be insufficient;
  - the responsibility for the collected data could be shifted to the Engineer, while it has to remain with the Owner who has to approve and consent to the scope, programme and costs of site investigations.

Any apparent economy in terms of cost and/or technical involvement by the Owner could result in an overly conservative (or even too optimistic) design, bigger residual risks and/or unidentified geological/ geotechnical risks.

- The risk related to ground uncertainties should be properly managed, and may be shared among the Parties, in particular between the Owner and the Contractor. The frequently encountered practice among Owners worldwide of attempting to transfer the total geotechnical risk to Contractors, especially in DB contracts, does not facilitate the proper management of risks and does not liberate the Owner of his final responsibilities. This transfer of geotechnical risk – especially when accompanied by a reduced initial effort in ground investigations – maybe eventually paid by the Owner in terms of either conservative design and/or increased risk of contractual claims, revised design and schedule overruns.

Consequently, the best practices should take into account the following:

- the strategy employed for site investigations should, as far as possible, be independent of the contractual framework;
- information takes time to be obtained and design changes due to late availability of geological and geotechnical data will have more negative impact if they occur in the latest stages of the project;
- a concerted effort should be made to gather the maximum amount of information during the preliminary design stage, with the objective of completing the majority of the investigations prior to commencement of the detailed design stage;
- as the reliability of the data and knowledge of the ground conditions depends upon the amount of site investigations and the quality of interpretation, it is considered prudent to establish an appropriate contractual risk sharing framework (see § 4).

3 >> Strategy for Site Investigation at Various Stages of the Project

3.1 GENERAL

The scope and extent of any site investigation will depend on the status of the project design and on the associated investigation phase. With regard to underground work, the duration of a site investigation campaign from the time it is conceived, through procurement, execution and interpretation is – at each stage of the design – of the order of months to years.

Simple investigations will typically take 3 to 6 months but more extensive investigations can extend to one year or more, depending on the complexity and variability of ground conditions along the tunnel and associated underground structures. In extreme cases the investigation may extend for several years if exploratory galleries/shafts are recommended. Hence, not only the full scope and extent of the site investigation needs to be appreciated, but also its duration within the overall schedule of each project.

The following sections outline typical components, the various phases of site investigations and their purpose.

3.2 COMPONENTS OF SITE INVESTIGATIONS

Typical components of ground investigations are as follows:

- **Desk study**, i.e., literature search and collection of existing information, such as:
  - regional maps (topographic, geological, geophysical, hydrogeological, natural hazards, seismicity, etc.);
  - aerial photos, satellite images;
  - technical literature, studies and existing reports about ground conditions;
  - data related to neighbouring and/or similar projects;
  - existing land use and environmental factors;
  - seismic, climatic, rainfall and hydrological data.
- **Field mapping** and reconnaissance
  - geomorphological mapping;
  - geologic field mapping, geotechnical outcrop mapping, sampling;
  - hydrogeological mapping, water management survey, sampling.
- **Field investigations**
  - direct investigations: trial pits, boring and sampling, in-situ testing (i.e. in-situ stress tests, lugeon or permeability tests, etc.);
  - indirect investigations: geophysical methods, airborne surveys;
  - surveys: topography, building conditions and foundations, utilities, environmental, water wells;
  - monitoring: geotechnical, hydrogeological monitoring, monitoring of existing surface and underground structures.
- **Laboratory tests**
  - identification and classification tests (including mineralogical and petrographic tests, if required);
  - rock / soil mechanical laboratory tests to define strength and deformability properties, time-dependent behaviour, hardness, abrasivity, etc.;
  - hydrochemistry.
- **Exploratory/investigation** tunnel or shaft, which may include field trials for grouting, rock bolts installation, etc.

Further information on the technical details and test procedures for these methods may be obtained from existing standards and references.
Examples of typical information and data that can be collected through the above mentioned components are given in Annex 1.

3.3 PHASED INVESTIGATION OF PROJECTS

The flowchart in Figure 1 demonstrates how the various phases of a site investigation interlink or correlate with the design stages of a tunnel project. Three design phases are considered prior to construction:

- **feasibility studies** (including pre-feasibility, technical feasibility and conceptual design when applicable);
- **preliminary/basic design** (including any designs for permit applications or approvals, when applicable), referred to as preliminary design in the text;
- **detailed/final design**, referred to as detailed design in the text;

Furthermore, specific site investigations can be carried out during the construction stage. More detail on each of these investigations is discussed in following sub-sections.

The flowchart also illustrates the scope of work to be undertaken at each phase of the site investigation, namely:

- **feasibility studies:** to collect enough data to confirm the feasibility of the project;
- **preliminary design**: to determine quantitative characteristics of the ground so that technical solutions may be developed to a point where reliable costs and duration can be established;
- **detailed design:** to reduce the residual uncertainty and inherent risks to a level as low as reasonably practicable.

Since the scope and extent of site investigations depends upon the level of uncertainty and the complexity of the ground conditions, the flowchart gives a basic framework that may be adapted to suit each project profile.

The reliability and robustness of ground model has to match at each phase the design objectives defined in §2.1. This may require an iterative process of data collection, assessment, re-evaluation and redefinition of investigations within the same design phase. In complex projects where exploratory galleries/shafts are required, the results from such investigations become available progressively during the preliminary and detailed design phases, requiring additional design review phases. Although this data is collected for the duration of the design, the exploratory work should be complete prior to concluding the detailed design. In general, the earlier the exploration is made the greater the potential for savings and for cheaper and much better project.

Reference can be made to Annex 2 where various case histories are listed.

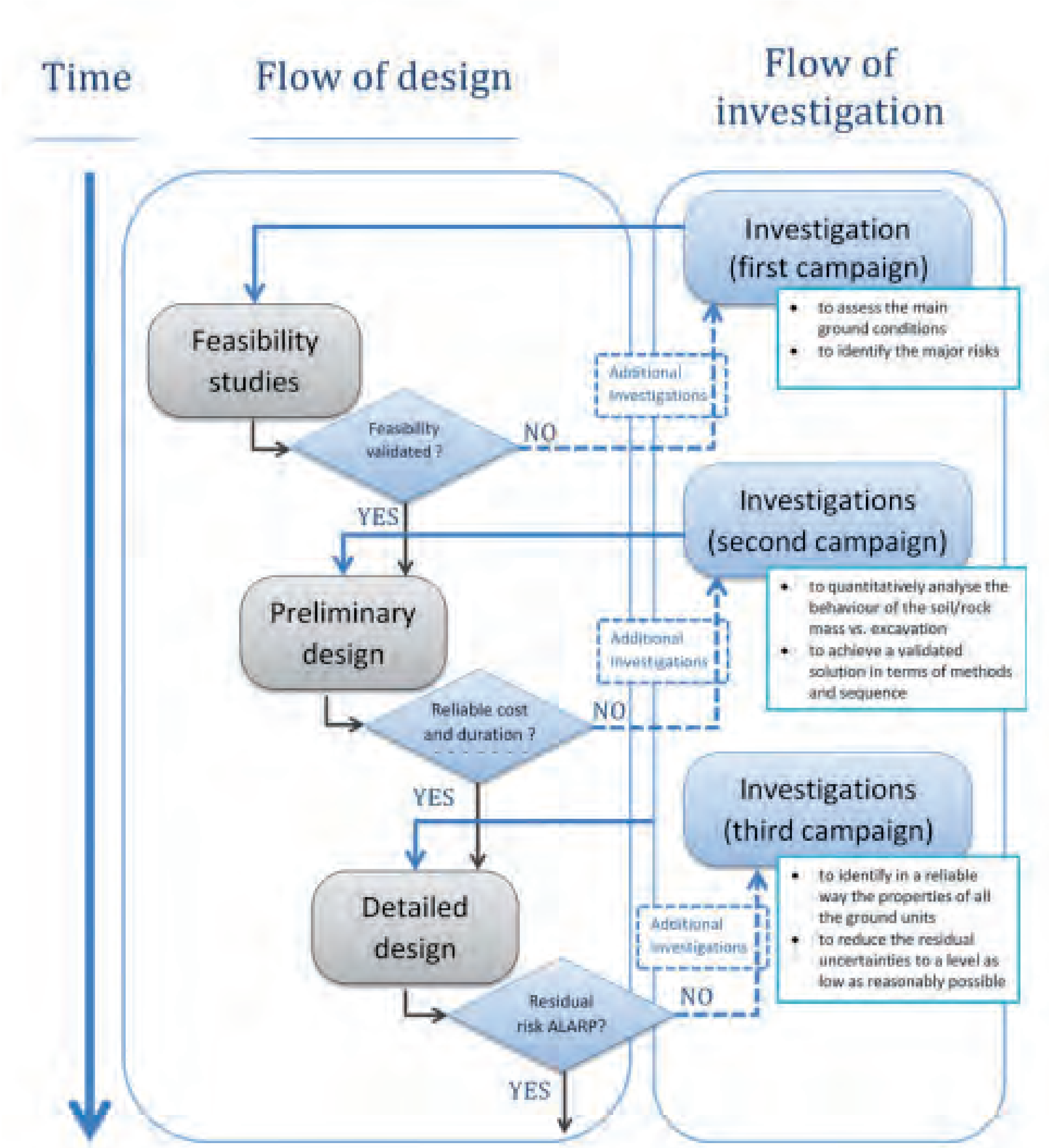


Figure 1 – Recommended phased strategy and scope of site investigations in relation to the design stages of a tunnel project.

3.3.1 Investigations for feasibility studies

Initial studies should be carried out to achieve the following goals:

- to assess the general suitability of the location of the site/tunnel;
- to achieve the best interpretation of the ground conditions based on existing data;
- to assess the technical and economic merits of alternative alignments and their respective ground conditions;
- to make conceptual level estimates of cost and schedule;
- to identify major risks and/or fatal flaws and propose a Risk Register;
- to assess the ground conditions and risks, if any, which could determine the feasibility itself.

3.3.2 Investigations for preliminary design

Design investigations should be carried out to achieve the following goals:

- to develop a 3D model of geological conditions which quantitatively characterises the ground and the hydrogeological regime to a level that permits:
  - selection of the most suitable alignment;
  - preparation of an adequate and economical design together with preliminary cost estimate;
  - selection of appropriate construction methods with ALARP inherent risk, including predicting the behaviour of the ground versus excavation method, determining the different temporary support classes and their distribution along the tunnel alignment, together with a possible range of variation, and to design the ancillary works and portals;
- to define the extent of the zone of influence and to estimate the impact this may have on adjacent structures or land forms;
- to quantitatively identify the risks, to assess their impact on the cost and potential delays to the schedule, and to decide on design measures to reduce the risk ;
- to give a reasonable range of probable cost and duration;
- to assess the level of residual uncertainty so that the need for additional ground investigation can be identified;
- to provide information for the EIA (Environmental Impact Assessment), depending on the legal requirements.

Project stage	Expected results	Investigation means
Feasibility study	Geological and hydrogeological maps. Natural risk map, when appropriate. Longitudinal geological profile. Longitudinal geotechnical and geomechanical profile with the qualitative identification of ground behaviour classes and the identification of the major hazards (with qualitative assessment). Preparation of Risk Register.	Regional topographic, geological, hydrogeological/ groundwater, seismic hazard maps. Information from field surveys and/or adjacent similar projects. Geophysics may provide useful information. Limited site investigations to confirm extremely critical geological or groundwater conditions (e.g., faults, karsts, aquifer , if needed.

Table 1 – Investigations for feasibility studies.

Project stage	Expected results	Investigation means
Preliminary design	Longitudinal geological profile (1:5000 to 1:2000). Longitudinal geotechnical-geomechanical profile (1:5000 to 1:2000) with the quantitative characterisation of ground behaviour classes and identified hazards. Geological and geotechnical cross-sections at the portals (1:500 to 1:200) Geological and geotechnical sections at access/ ventilation shafts Preliminary characterisation of the hydrogeological regime. Update of Risk Register	Geophysics and boreholes at the portals and shafts Boreholes along the alignment. Water sources and groundwater monitoring. Laboratory tests. Outcrop and surface mapping In situ stress measurements and permeability tests, when appropriate. Exploratory galleries / shafts, if needed.

Table 2 – Investigations for preliminary design.

3.3.3 Investigations for detailed design

Design investigations shall be carried out to achieve the following goals:

- to reduce the residual uncertainty to a ALARP level;
- to plan and execute the field and laboratory investigations to confirm the geotechnical and hydrogeological properties of the various ground units;
- to develop a reliable 3-dimensional geotechnical and hydrological model so that the construction method(s) can be validated and justified by calculation and detailed in terms of specifications; to obtain the full set of design parameters (including their potential range of variation) in order to finalise the dimensioning of all elements of the design;
- to achieve a final, accurate assessment of cost and duration;
- to update the risk register, re-assess the level of residual risk, and confirm mitigation measures in order to reduce the non-acceptable risks to a ALARP level;
- to identify requirements for the collection of additional geological, hydrogeological and geotechnical information during the construction phase, including the necessary full scale field trials, if any.

Project stage	Expected results	Investigation means
Feasibility study	Longitudinal geological profile (1/2000 to 1/1000). Longitudinal detailed geotechnical and geomechanical profile (1/2000 to 1/1000) with the quantitative characterisation of ground behaviour and support classes, identified hazards, distribution of support sections and controls during construction. Geological and geotechnical cross-sections at the portals, shafts and along the tunnel (1/200 to 1/100) Definition of detailed set of design parameters and their variability. Detailed characterisation of the hydrogeological regime. Update of the Risk Register Specifications for investigations during construction	Additional boreholes both at the portals and along the alignment. Laboratory and field tests. In specific cases/locations, geophysics may provide useful information. Excavation of experimental sections along the tunnel alignment, if needed. Continue the monitoring program of water sources and groundwater

Table 3 – Investigations for detailed design.

3.3.4 Investigations during the construction phase

At this phase, investigations should be carried out for the following purposes:

- to validate the 3-dimensional geotechnical and hydrogeological model using face mapping, investigations ahead of the tunnel face (e.g. probe drilling, geophysics), TBM performance data, etc.;
- to monitor the ground, ground support and groundwater behaviour;
- to systematically update the 3D ground model in order to predict ground and groundwater behaviour in the subsequent section to be excavated, and to adjust the design / construction method(s) accordingly;
- to analyse the excavated material and assess its potential re-use, or spoil characteristics taking into account environmental constraints;
- to record the condition of structures/ buildings that may be affected by the excavations, and to monitor ground movement and settlement.

3.3.5 Further use of investigation results

The results from all phases of the investigation should be collected, centralised and maintained during construction and, in some cases, during the operation of the facility. During construction, the data should be reviewed to verify design assumptions and to assist in contractual issues, if needed. At a later stage, the data may be utilised when modifications or upgrades are to be implemented or when problems are realised in the maintenance or operations. This data would be continuously updated with monitoring data from geotechnical and environment instrumentation.

It is recommended that a GIS-based model be established to organise and store the project "geo" data in a geo-referenced system. This is especially important for complex projects where a significant amount of information is generated and validated data have to be quickly available and shared among different stakeholders. It is advisable that the Owner initialises and maintains the system throughout the life cycle of the project.

3.4 REQUIRED SITE INVESTIGATION EFFORT

Tunnels demand for a comprehensive investigation which requires considerable time and expenses. Adequate site investigations play a fundamental role in implementing a global strategy of project risk management (see "Guidelines for Tunnelling Risk Management ", ITA WG2, 2004). In addition, the insurance industry requires that the project to be insured is covered by comprehensive and adapted investigation (ITIG, 2012).

Consequently, the Owner has to be aware that investigation should be planned on the basis of needed information and not on the basis of cost, and that sufficient time and budget have to be devoted. Economies on the investigation phases could apparently save time on the design and/or tender schedule, but would generally not allow to achieve the best and most economic project, to define a proper share of risk when setting the contractual conditions between the Owner and the Contractor, and to improve the control of project cost and schedule during construction.

As already mentioned, site investigations should be executed in various phases, and conceived as an iterative process with specific goals at each stage.

At the beginning of the project, generally the ratio of knowledge gained to effort expended is high. Field mapping and desk studies are relatively inexpensive and yet they yield much information. The "knowledge vs. cost curve", shown schematically in Figure 2, is therefore steeper at this stage. Consequently, this phase is of paramount importance and it should be provided for at the very beginning of the studies.

During the preliminary and detailed investigation phases (e.g. with core drilling, field and laboratory tests, etc.), there is still a lot of very important information obtained for tunnel design and risk management. Although the cost to obtain this information is higher than in the previous stage, it makes a significant contribution to improving the reliability of the knowledge of the ground conditions. This phase is therefore vital to the development of the project. The corresponding cost generally ranges between a few percent of the cost of the project construction. Case histories of site investigations for tunnels in the U.K. indicate that the cost for this phase of the investigation is generally less than 3% of the construction cost and may exceptionally go as low as 0.5%, generally depending on the overall cost of the project.

However, it should be borne in mind that the higher the risks of a project and the more complex the ground conditions, the more money will have to be spent to gain reliable data. Investing less than 1% in site investigations at the preliminary design stage is generally considered to be risky.

On completion of a large or major project, a budget for the site investigations of about 3% (potentially increasing up to 8-10% depending to the complexity and depth of the underground work, the need for exploratory galleries/shafts, or the use – such as nuclear or hazardous waste) of the project construction cost should be considered as normal.

The U.S. National Committee on Tunnelling Technology (USNC/TT) in 1984 recommended that "expenditures for geotechnical site exploration should be increased to an average of 3 % of estimated project cost for better overall results". In addition, in case of urban tunnels "The level of exploratory borings should be increased to a level of 1.5 linear feet of borehole per route feet of tunnel alignment for better overall results".

The data collected in Annex 3 give some references which support the percentages mentioned above.

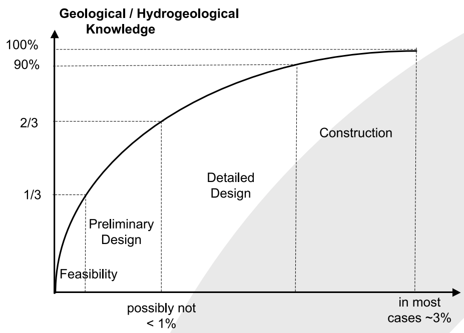


Figure 2
Schematic knowledge vs. cost curve

As requested by the ITIG Guidelines (2012), “the Ground Reference Conditions shall be issued to tenderers as integral and formative information on which tenders shall be based and the Client shall take responsibility for the information so issued […]. Ground Reference Conditions […] shall form part of the Contract and shall provide the basis for comparison with ground conditions encountered in relation to those assumed and allowed for at the tender stage by the Contractor. The Ground Reference Conditions shall provide the baseline against which encountered conditions can be assessed and compared. The Ground Reference Conditions shall also identify hazards appropriate to the site and ground conditions established from the investigations to permit associated risks to be assessed and catered for at time of tender, consistent with the Contract Documentation requirements”.

Hence, the results of site investigations have also to be used for allowing the Contractor to bid and for defining contractual conditions. The following sections illustrate the principles on which investigation results are used form a contractual point of view in the international practice.

4.1 INTRODUCTION

The factual and interpreted data collected during the various phases of the site investigation will have varying degrees of significance when utilised in contract documentation. Thus when considering the needs of a site investigation, one not only has to consider the technical content on which the tunnel design and construction will be based, but also how this information will be utilised in contracts and in the procurement process, in particular on how the geotechnical risk is handled.

Past experience gained from major construction projects, especially tunnelling projects, has highlighted some fundamental principles:

- the integrity and reliability of all types of factual information (“data”) has to be maintained throughout the life cycle of the project;
- interpreted information from desk studies, or interpretations made from the factual data gained during the project’s site investigations must be distinguished from the factual data;
- whatever the method of procurement or the form of contract, geotechnical risk is best managed when the knowledge of the subsurface has been adequately developed before contracting construction services (whether traditional contracting forms, lump-sum, fixed price design or build contracts), and when an agreed model of ground conditions is introduced and made contractual.

An agreed ground condition model provides a sound basis for negotiation in case of changed conditions and this is formalised in different countries in various ways (Geotechnical Baseline Report in the Anglo-Saxon approach; Plan de Management des Risques in the French approach; etc.).

4.2 SITE INVESTIGATION REPORTS

Examination of worldwide practice indicates that four types of reports are generally produced, each having its own specific function. These are namely reports providing:

- factual data (e.g., Factual Report or Geotechnical Data Report, in the Anglo-Saxon approach; Cahier des Données Factuelles, in the French approach);
- interpreted information in terms of geotechnical behaviour (e.g., Geotecnical Interpretative Report or Geotechnical Memoranda for Design, in the Anglo-Saxon approach; Mémoire de Conception, in the French approach);
- the contractual reference for the geological, hydrogeological and geotechnical model (Geotechnical Baseline Report, in the Anglo-Saxon approach; Mémoire de Synthèse, in the French approach; etc.;);
- data collected during construction (Post-Construction Geotechnical Report, in the Anglo-Saxon approach; Dossier de Suivi Géotechnique d’Exécution, in the French approach; etc.;).

It is necessary that the first two documents are completed and/or updated at each phase of the project. The relevance of each report will depend on the contractual framework adopted for the project. This will vary from country to country and examples are given in Annex 4.

Factual data

The report should contain only factual information, data and objective considerations that have been gathered during the different stages of a Project. This report does not include engineering interpretations. The data contained in this report underpins all the other reports. This report often becomes a Contractual Document. Note that factual data include boring logs and soil/rock classifications which are prepared by experienced professionals.

The factual data report includes:

- the list and extracts of all the geological maps used;
- the description of the site exploration programme (dates, localisation, methodology, description of procedures employed, etc.);
- groundwater information;
- the logs of all borings, trenches, and other site investigations;
- the results of all field investigations and laboratory tests (in many cases the data may come from processed laboratory test results, following standard procedures; the final calculated test value is considered a factual information);
- the reported experience of any exploratory gallery/shaft/adit, if existing;
- the references of the bibliography used and the sources of information that provide relevant data (data from similar works, regional geological literature, history of land use, etc.);
- plans and sections indicating summarised borehole information and geological structure.

Interpreted data

These reports include subjective considerations and comments by the Geotechnical Team, in accordance with his understanding, critical evaluation and interpretation of the factual data. The interpretative report presents the geotechnical and engineering interpretation of the data and defines the parameters characterising the geotechnical/geomechanical behaviour of the ground and its variability. This report may be part of the bid package but is not given the status of Contractual Document.

The interpretative report addresses project related issues, it highlights possible impacts on the adjacent facilities and potential problems as well as risks for the various design options and construction methodologies; it indicates the requirement for further site investigations or observations before or during construction.

The interpretative report can also include design analyses, such as rock-mass interaction analyses where ground characterization is used to predict the ground behaviour, response, and support requirements.

Contractual baseline data

Specific contractual documents have to be produced when contracting the project. The geotechnical documents are generally presented in the form of baselines upon which a tender would be prepared and risk sharing would be agreed. As such, in the Anglo-Saxon approach the Baseline Report is a contractual document and is meant to be as objective as possible.

The report states the anticipated (or to be assumed) ground conditions to be encountered during underground construction upon which bidders may rely. Risk associated with conditions consistent with or less adverse than the baselines are allocated to the Contractor, and those materially more adverse than the baselines are be accepted by the Owner.

It establishes the envelope of geological, hydrogeological and geotechnical knowledge relevant to the project, defines the expected geotechnical conditions and highlights all the identified uncertainties. To the maximum extent possible, baseline statements are best described using quantitative terms. Qualitative descriptions, if required, should be clearly defined.

Data collected during construction

The Post-Construction Geotechnical Report (or similar in other national approaches) is intended to form a final record of all “geo” information gathered during the course of the project. It will also constitute a living document into which all future monitoring results are included and any modifications to the project are recorded.

The report should ideally include the following:

- as-observed records of geology and ground conditions;
- monitoring results both during and post-excavation (i.e. groundwater levels, deformation measurements, survey, etc.);
- records of all investigations carried out during construction, including probe drilling and monitoring of performance;
- a record of construction experience, incidents and expedients;
- a full set of site investigation reports, plans, sections, and other records and documents, kept for reference purposes;
- as-built records of the structure, including boreholes and temporary excavations, and of subsequent alterations made in the course of repairs or modifications.

5 CONCLUSIONS

Good geological knowledge and engineering geology are of paramount importance for the successful execution of a tunnelling project. The required information can be obtained from a well executed site investigation program which includes collecting and collating all information and data as well as evaluating design parameters.

Site investigation provides important information that is required for reducing the risks associated with tunnel construction and constitutes an essential component of modern tunnel engineering. As such, site investigation should be viewed as one key component of the global strategy for project risk management in terms of reducing geological, geotechnical and hydrogeological risks.

This document has been prepared by Working Group 2 of the ITA, and aims at consolidating updated information on key aspects of site investigation principles and practices that may assist stakeholders in their approach to tunnelling projects. The document, which is based on international best practices, can be used as a general guide for the site investigation strategy which may be adopted to address the specific needs of each project.

Working Group 2 would welcome comments from users, as to the contribution of this approach to serving Member Nations needs and facilitating the dissemination of site investigation knowledge and general practice at an international level.

6 REFERENCES

Codes, guidelines and recommendations

ITA WG2, 2004, Guidelines for Tunnelling Risk Management

ITIG, 2012, A Code of Practice for Risk Management of Tunnel Works, 2nd edition

AFTES Recommandation, (2012), Characterisation of geological, hydrogeological and geotechnical uncertainties and risks, GT32R2A1

ASCE (2007), Geotechnical Baseline Reports for Underground Construction, the Technical Committee on Geotechnical Reports of the Underground Technology Research Council.

Austrian Society of Geomechanics, (2010), Guideline for the Geotechnical Desing of Undeground Structures with Conventional Excavation, Salzburk.

British Standards Institution, Code of Practice for Site Investigations, BS5930:1999. BSI, London.

Eurocode 7 – Geotechnical design – Part 2: Ground investigation and testing

FHWA - Federal Highway Administration (2002), Evaluation of Soil and Rock Properties, FHWA-IF-02-034

Geotechnical investigation and testing, ISO/TC 182/SC 1

ICE - Institution of Civil Engineers, (2001), Managing Geotechnical Risk, Clayton C.R.I, London.

ÖNORM B 2203-1, (2008), Undeground works - works contract. Part 1: Cyclic driving (conventional tunnelling), Österreichisches Normunginstitut.

Technical papers and books

Glossop R (1968), The rise of geotechnology and its influence on engineering practice, 8th Rankine Lecture, Geotechnique 18, pp105 – 150.

Komatsuda S, Doshitsu Chosa no Kiso Chishiki (1989), Basic Knowledge of Site Investigation, Kajima Institute Publishing Co., Ltd

Doshitsu Chosa no Hoho to Kaisetsu (2004), Guide for Geotechnical Site Investigation Methods, 2004. Japanese Geotechnical Society

Clayton C.R.I., Mathews M.C and Simons N.E (1995), Site investigation, Second Ed., Published by Blackwell Science, Oxford.

Simons N, Menzies B and Matthews M. A (2002), Short course in Geotechnical Site Investigation, Published by Thomas Telford Ltd., London.

Parker H.W. (1996), Tunnel Engineering Handbook, § 4 - Geotechnical Investigations

West G, Carter P.G., Dumbleton M.J. and Lake L.M. (1981), Rock Mechanics Review, Site Investigation for Tunnels, Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. Vol. 18, pp. 345 to 367 (1981)

ANNEX 1 >> Elements of a Site Investigation

The following is a list of important elements associated with a tunnel project, and on which Site Investigations should be focused:

1. **Topography**, status of the land usage and accessibility conditions
2. Location and condition of **existing surface** structures, such as buildings, and underground structures such as basements, foundations, utilities, pipelines, etc.
3. **Water** use, water rights and water management requirements
4. **Accessibility** to the investigation site(s)
5. **Geomorphology**
   a. Soft rock fillings of valleys and glacial / glacigenic relicts
   b. Landslides and deep-seated gravitational slope deformations
   c. Rockfall, mudflow, avalanches, flooding etc.
6. **Field geology**
   a. Geological model – a three dimensional model of strata, folding, faults, joint characteristics (ground conditions)
   b. In-situ stress conditions
   c. Geological data relevant to design and construction method(s)
7. **Fault zones** and related characteristics
8. **Seismology**
   a. Neotectonic regime
   b. Active faults
   c. Volcanic zones
9. **Hydrogeology**
   a. Aquifers, aquitards and aquicludes (extension, geometry and properties)
   b. Groundwater levels and related seasonal changes
   c. Discharge of groundwater and flow direction
   d. Drainage network: main receiving water, feeders
   e. Water balance
   f. Chemical and physical water properties
   g. Karst phenomena and sinkholes
10. **Contamination**
    a. Natural, such as hazardous gases
    b. Man-made
11. **Geothermal activity**
12. **Radioactivity**
13. **Geotechnical** and **geomechanical** characteristics
14. **Meteorological** and climatic data
15. **Excavation** material
    a. Reuse (e.g. lithology, grain distribution, etc.)
    b. Disposal (asbestos contents, etc.)
16. In case of **immersed** or **under sea** tunnels, the followings should also be investigated
    a. Depth of water
    b. Tidal conditions including current and wave condition
    c. Navigation and ship traffic condition.

01 KUHTAI HYDROELECTRIC POWER PLANT, AUSTRIA

• PROJECT IDENTIFICATION

Location
Kühtai, Tyrol, Austria, Europe

Construction period
Scheduled: 2014 - 2017

Owner
TIWAG – Tiroler Wasserkraft AG
Eduard-Wallnöfer Platz 2
A- 6020 Innsbruck

Designer(s)
Technical Design: TIWAG
Geological Layout: Geoconsult ZT GmbH

Contractor(s)
Still not defined
Investigation gallery: ALPINE Bau GmbH

• GENERAL PROJECT DESCRIPTION

TIWAG – Tiroler Wasserkraft AG plans to extend the Sellrain-Silz HEPP that has been in operation since 1981.

This extending contains the construction of an additional reservoir with further water supply lines from the central and eastern Ötztal valley and the upper Stubaital valley and will result in a considerable improvement of the present energy production in the project area. Central features of the power plant are:

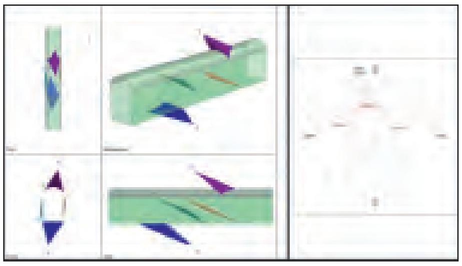
- reservoir in the upper Längental valley with an available storage capacity of about 31.1 million m and a dam height of about 113 m (rockfill dam with a clay core),
- the power plant Kühtai 2 with an output of 140 MW, connecting plant reservoir with the existing Finstertal valley reservoir
- and the 25.5 km water supply line from the upper Stubaital valley to the plant reservoir.

The addition of the Kühtai 2 power plant to the existing Kühtai pumped storage hydro power station is to be achieved by constructing a headrace tunnel between the Kühtai and Finstertal Valley reservoirs.

The turbine building is located entirely in a cavern at a depth of around 175 m in the right-hand side of the valley where the future abutment of the dam will be situated.

The additional water catchment area extends from Fernaubach brook in the upper Stubaital valley to Fischbach brook and Winnebach brook in the central Ötztal valley. The impoundments are situated at approx. 2,090 to 2,410 m above sea level.

• TUNNEL CHARACTERISTICS



Total Tunnel Length
25,5 km (headrace drive),
~ 15 km (all other tunnels like access tunnel, penstock and caverns)

Boring diameter
see below

Overburden(min-max)
30 – 1.063 m

Characterization scheme
NATM

Excavation type
NATM, TBM (see below)

Contract model
B2203-1, B2203-2

Headrace
25.5 km, Ø 4.2 m, 30 to 1063 m, TBM

Penstock
1.225 m, Ø 4.8-5.8 m, NATM (possibly TBM)

Penstock
375 m, Ø 6.1-6.7 m, NATM

Cavern of Power Plant
83.000 m^3, NATM

Drainage gallery
700 m, Ø 5.5-6.0 m, NATM

Investigation gallery
735 m, NATM

Cavern
(Length-Whith-Height) 64 x 31.5 x 50 m

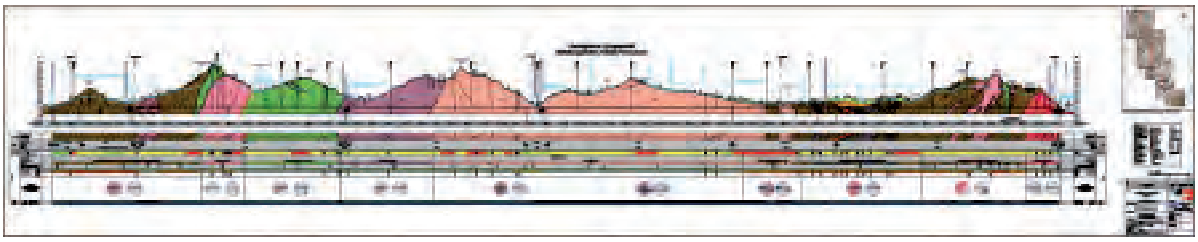
• ENVIRONMENTAL AND GEOLOGICAL CONDITIONS

The project area between Kühtai and the upper Stubaital valley is located in the north-western Stubai Alps and is predominantly high alpine in character. The area under investigation is almost exclusively above 2,000 m above sea level, the highest peaks in this area reaching over 3,000 m, parts of this area are glaciated.

In geological terms, the project area lies in the Ötztaltal-Stubai Crystalline Complex. Orthogneisses and paragneisses predominate in the region of the planned structures, as well as migmatites, amphibolites and mica schists. The Ötztal valley complex is bounded to the East by the Brenner Line and extends northward to the Inntal valley. It forms the border of the Engadine Window in the West and is intersected by faults and fracture zones in the South. In the South, the Ötztal-Stubai Crystalline Complex extends without interruption to the Periadriatic Lineament.

Morphologically, this alpine region is characterised by glacial erosion. The pronounced cirques indicate the previous extent of the glaciers. Massive rock glaciers and moraines also testify to the earlier glaciation. Almost all tributary valleys and cirques have deposits resulting from glaciation recession

• GEOLOGICAL PROFILE



Geological longitudinal section of the 25.5 km headrace gallery.

• SITE INVESTIGATION TARGETS

Geological Setting
- Bedding
- Quarternary soils covering the hard rock mass
- Permafrost related structures like rock glaciers

Ground Types / Characteristics
- Types of gneiss, migmatites, amphibolites
- Joint spacing

Structural Geology
- Orientation of joints
- Folding
- Fault zones and orientation

Fault Characteristics
- Geometry
- Filling

Alteration / Weathering

Hydrogeology

Geothermal Situation

In-situ Stress
- At the cavern location

Gravitative Mess Movements
- Deep landslide in a near-to-slope situation of the headrace gallery.
- Possible landslide in an abutment situation of the proposed dam (which figured out as stable rock mass with the investigations).

• MEASURES

Desk Study
- Feasibility study
- Studies from existing constructions (former HEPP's)
- Studies of regional geological literature
- Orthophotos
- Laserscan Images

Mapping
- Site visits of the headrace galleries of the existing HEPP
- 1:10.000 geological mapping all over the surface (ca. 110 km²)
- 1:5.000 geological mapping at reservoir site
- 1:2.000 geological mapping at water impoundments and dam site
- 1:10.000 hydrogeological mapping all over the surface
- 1.5.000 laserscan image geohazard process mapping

Drillings
- 26 core drillings from surface
- 11 core drillings from exploratory tunnel (at cavern site)

Geophysical Methods
- 21 seismic profiles
- 5 geoelectric profiles
- geophysical borehole tests in all drillings (acoustic / optical borehole image)

Field Tests
- Trial pits
- Lugeon tests in boreholes
- Lefranc tests in boreholes
- Pump tests in boreholes
- SPT tests in boreholes in soils
- Boreholes have been developed as monitoring wells (standpipes)
- One borehole has been developed as inclinometer
- At cavern site (from exploratory tunnel):
  - Radial press (two tests) in 2 m diameter caverns
  - Dilatometer tests in boreholes
  - Hydro fracturing test in borehole
  - Lugeon tests in boreholes
- Hydrogeological field measurements (discharge, temperature, electrical conductivity)

Laboratory Tests
- Soil tests (186 samples): Grain distribution
- Rock tests (74 samples): Modal analysis (thin sections)
- Water analysis (ion balance, stable isotopes, Tritium)

Exploratory Tunnel
- 1 exploratory gallery ~ 735 m at cavern site (realized in 2010/2011)

Monitoring
- Hydrogeological monitoring at springs, gauges and monitoring wells
- Inclinometer
- Geotechnical monitoring in exploratory gallery

02 GOTTHARD BASE TUNNEL, SWITZERLAND

• PROJECT IDENTIFICATION

Location
Switzerland

Construction period
1993 - 2016

Owner
AlpTransit Gotthard Ltd (until 2016)
Swiss Federal Railway (operator)

Designer(s)
Lombardi Engineers Ltd.
Amberg Engineering Ltd.
Pöyry Ltd.
Gaehler & Partner Ltd.
Rothpletz Lienhard Ltd.
Gruner Ltd.
CES

Contractor(s)
Murer / Strabag Implenia / Frutiger / Bilfinger Berger/Pizzarotti Implenia/Hochtief/Alpine/ Impregilo

Engineer's)
See Designers

• GENERAL PROJECT DESCRIPTION

The Swiss New Rail Link through the Alps (NRLA) is creating a fast and efficient railway link. Its core piece is the 57.1 km long Gotthard Base Tunnel, the longest railway tunnel of the world when it will start the commercial operation in 2016. The new railway link crosses the Alps with minimal gradients and wide curves at only 550 metres above sea level creating the first flat railway through the Alps.

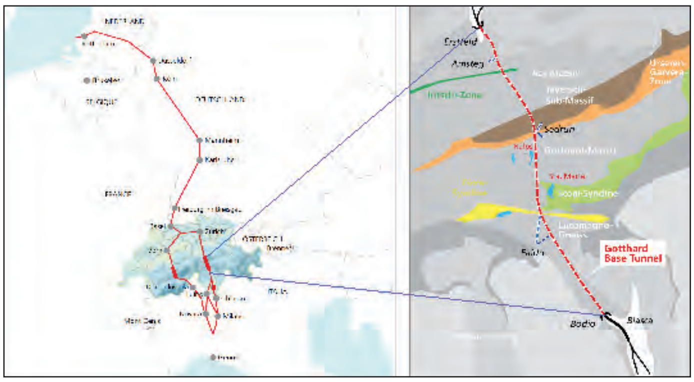
The flat railway allows efficient rail transport of goods as well as shorter journey times in national and international passenger traffic. The new routes cut passenger travelling times substantially. The new Gotthard route is a high-speed rail link. Passenger trains can traverse it at maximum speeds of up to 250 kilometres per hour. Nevertheless the main purpose of the new railway infrastructure is to shift a major part of the heavy transalpine goods traffic through Switzerland from the road to the rail.

The Gotthard axis of the NRLA is Switzerland's largest-ever construction project. With construction of the new Gotthard rail link, the country is implementing one of Europe's largest environmental protect ion projects.

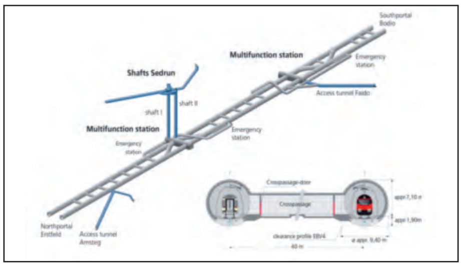
The Gotthard Base Tunnel consists of two 57-kilometres-long single-track tubes. These are connected together every 312.5 metres by cross passages. Including all cross-passages, access tunnels and shafts, the total length of the tunnel system is around 152 km. It joins the north portal at Erstfeld to the south portal at Bodio. With a rock overburden of more than 2300 metres, the Gotthard Base Tunnel is also the world's deepest railway tunnel constructed to date.

Two multifunction stations at Faido and Sedrun divide the two tubes into three approximately equally long sections. The multifunction stations each contain emergency stop stations and two track crossovers. In case of an incident such as a fire in the train or a fault in the Gotthard Base Tunnel, whenever possible the affected train travels out of the tunnel into the open air. If this is not possible, the driver stops the train at an emergency stop.

For construction purposes, the Gotthard Base Tunnel was subdivided into five main sections. Access adits provided access to the underground construction sites for workers, materials and machines. To save time and costs, construction work proceeded on the various sections simultaneously. For construction of the Sedrun section, access from the surface was through a 1-kilometre-long horizontal access tunnel and two 800-metres-deep vertical shafts. From there, the two tubes were blast-driven to the north and south. Because the deep overburden in bad ground conditions (squeezing rock) high stresses threatened to deform the tunnel on a distance of 1. Kilometres. Special supporting means were necessary in this zone. The engineers developed an innovative new concept with flexible steel rings (TH-profiles), which partly closed under the rock pressure. The rock pressure could finally be to a technically manageable degree reduced by allowing large deformations.



• Tunnel characteristics



Total Tunnel Length
Nominal length 57.1 km
System length 151.8 km

Boring diameter
8.8 / 9.4 / 9.5 / 11

Overburden(min-max)
100 – 2'350 m

Characterization scheme
2 single track tubes, connected with cross links every 312.5
2 multifunction stations
3 acceess galleries
2 vertical shafts (800 m)
1 bypass gallery
1 inclined ventilation shaft

Excavation type
TBM 98.1 km
Conventional 53.7 km

Contract model
Unit price contracts for civil work based on design bid build approach

The Gotthard Base Tunnel crosses the Alps in mainly hard crystalline rock masses, with a high uniaxial strength and a brittle failure mode.

Weak ground conditions with a ductile failure mode were expected on less than10 per cents of the total tunnel length.

The main ground related hazards were:

- rock fall, caused by the joint systems
- rock burst, mainly in zones of high overburden
- convergences or high rock pressure
- face instabilities
- combined scenarios.

Nearly two thirds of the total length of the 151.8 kilometres long tunnel system were excavated with TBM's.

One third of the total length was excavated by application of conventional tunnelling methods.

Logistics for was the main challenge for the contractors.

Depending on the general construction schedule railway (inner lining in parallel to the excavation) or conveyer belt systems (inner lining followed the excavation) were used for the transportation of the muck.

One of the biggest stories of success was the use of the spoil for the production of concrete aggregates of the rock support and the final lining. 100% of the concrete gravel for the tunnel construction has been produced from excavated rock material with origin from the TBM-drives and the conventional drives. No quality failure related to the concrete aggregates occurred on he entire inner lining.

The environmental requirements were generally fulfilled on a high level, also in the eyes of the public and the environmental organisations.

The Swiss Federal Office of Transport required in the project specific standards a lifetime of 100 years for the civil work. No major rehabilitation work with significant operational limitations is allowed during this time.

The solution to achieve this high requirements was a double lined tunnel with the provisional rock support as outer lining (first lining) and the permanent, in the minimum 30 cm thick, inner concrete lining (second lining).

• Environmental and Geological Conditions

The Gotthard Base Tunnel crosses the following main tectonic units from north to south:

- **the Aar massif**
- **the Gotthard massif**
- **and the pennine Gneiss Zone**

The Aar massif and the Gotthard massif are the backbone of the Swiss Alps. Both massifs consist mainly of gneisses and granites. These rocktypes showed generally a brittle failure mode. Under special circumstances squeezing was observed in the crystalline rock masses.

Younger sedimentary rocks are wedged in between the three main tectonic units. Some these rock masses are massively fractured, especially in the Tavetsch intermediate massif. In this rock mass types the phenomenon of squeezing was observed on a distance of 1 km.

The main ground related hazards were:

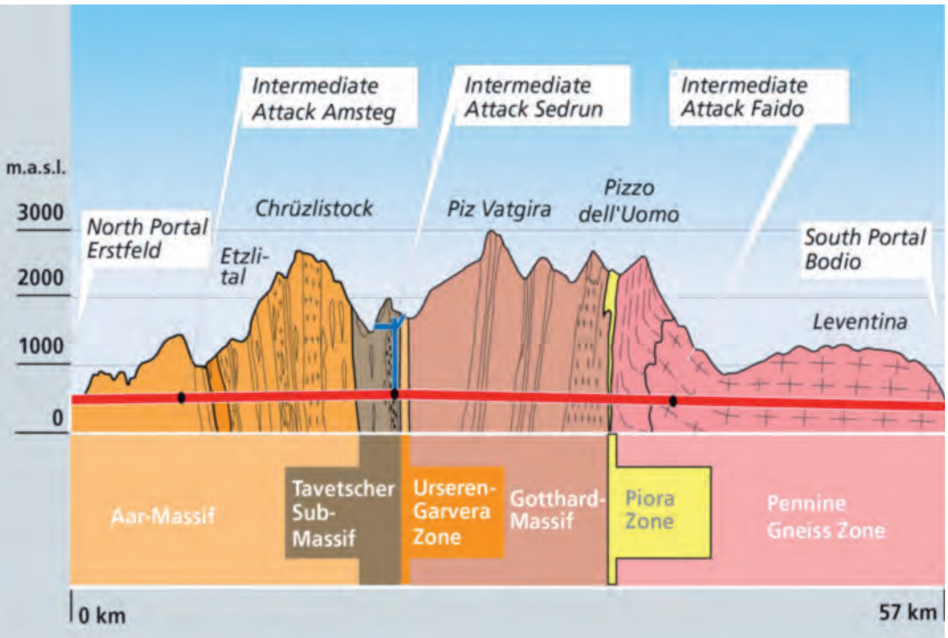
- rock fall, caused by the joint systems
- rock burst, mainly in zones of high overburden
- convergences or high rock pressure
- combined scenarios

The tender design assumed that more than 90% of the excavation could be done in good ground conditions without any bigger difficulties.

High rock or ground water temperatures and high initial ground water pressures caused by the high overburden had to be taken into account.

A maximum groud temperature of around 50°C was expected (highest temperature measured 46°C)

• Geological Profile



Geological longitudinal section of the 25.5 km headrace gallery.

• Project Stage(s)

Construction period 1993 - 2016

Prefeasibility Study
1. / 1993

Feasibility Study
2. / 1995

Variant Study
3. / 1989

Authoritie's Permissions Project
1. / 1995 – 1999 for 4 of 5 main lots
2. / 1995 – 2006 for 1 lot

Tender Design for Owner
1. / 1997 - 1999

Tender Design for CC
2. / -

Post Contract respectively Construction Design
3. / 2001 - 2014

Other
4. / none

• Site investigation targets

Geological Setting
• Tectonic situation

Ground Types / Characteristics
• Highly diverse rock mass types had to be traversed during the construction of the Gotthard Base Tunnel.

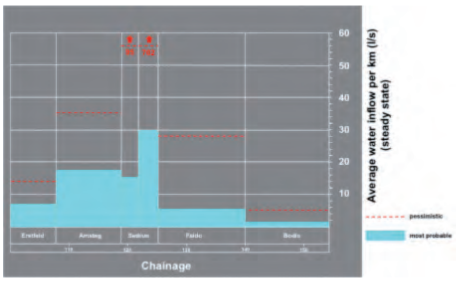
• They range from the tough Gotthard granites, through the highly-stressed pennine gneisses of the Leventina, to soft rocks of the Tavetsch intermediate massif.

Structural Geology
See geological profile

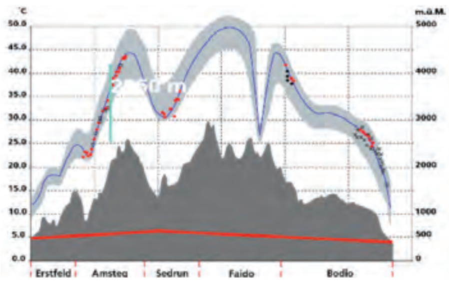
Fault Characteristics
• Kakeritic faults
• Ductile shear zones (mylonites)
• Brittle fault zones

Alteration / Weathering
• No special effects

Hydrogeology
• Forecast of probable water inflows with high pressure and high temperature (steady state)



Geothermal Situation
• Forecast of ground temperatures with numerical model



In-situ Stress
• in direct correlation to the overburden

• horizontal stresses similar normally in the same magnitude as the vertical stresses

Gravitative Mess Movements
• no

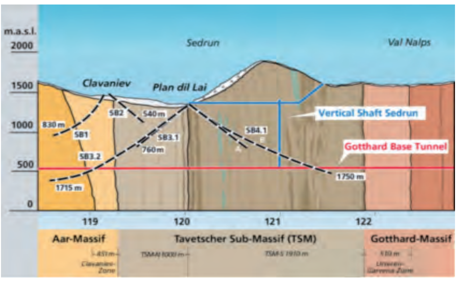
© figures from AlpTransit Gotthard
text AlpTransit Gotthard and Heinz Ehrbar

- **MEASURES**

Desk Study
- yes

Mapping
- yes

Drillings
- yes, long inclined core drillings in the Tavetsch Intermediate Massif



- extended core drillings in the Piora Zone (see below)

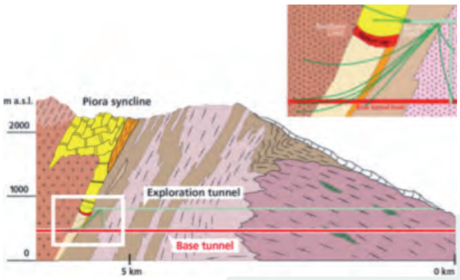
- systematic exploratory drillings (percsussion drillings) during the excavation in the conventional drive and the TBM-drives, mainly in both tubes
- core dillings in special cases (squeezing rock zones and during the excavation close to the Nalps concrete arch dam)

Geophysical Methods
- yes, in few special cases with only limited information for the excavation due to the inhomogeneous ground conditions

Field Tests
- bore hole tests
- various in situ tests in order to classify the muck for its reuse

Laboratory Tests
- yes, mainly triaxial tests, abrasivity tests
- various in situ tests in order to classify the muck for its reuse

Exploratory Tunnel
- yes, Piora exploratory system, tunnel of 5.3 km length



Monitoring
- yes, 3 D deformations (in all drives)
- extensometers in special cases
- monitoring of surface deformations during 15 years throughout the whole year (also winter time!) in order to detect dangerous deformation trends to the nerby concrete arch dams

© figures from AlpTransit Gotthard
text AlpTransit Gotthard and Heinz Ehrbar

03 CITYRINGEN, DENMARK

• PROJECT IDENTIFICATION

Location
Copenhagen, Denmark

Construction period
2011 – 2018

Owner
Metroselskabet I/S

Contractor(s)
Copenhagen Metro Team I/S

• GENERAL PROJECT DESCRIPTION

The Cityringen project is a new fully underground metro system with 17 stations, 2 crossovers and three construction and ventilation shaft structures interconnected by 2 single track tunnels of 16.5 km in length.

The geology in the Cityringen project area is characterised overall by a typically 1-5m thick fill layer. This is underlain by typically 10-25m thick quaternary layers. These deposits are highly variable and comprise a recognised sequence sand/gravel and clay till layers. At a number of locations extensive meltwater sands and gravels are deposited directly on the limestone, in particularly in the northern part of the alignment, whereas in the south-western part of the alignment the quaternary layers mainly consist of clay till.

The quaternary layers are underlain by Copenhagen limestone. The limestone is uniformly bedded, with extensive flint beds and bioturbated zones. The upper 0-4 metres of the limestone is locally glacially disturbed and heavily fractured.

• TUNNEL CHARACTERISTICS

Total Tunnel Length
33 km

Boring diameter
5.8 m

Overburden(min-max)
35 m

Excavation type
Earth Pressure Balance TBM

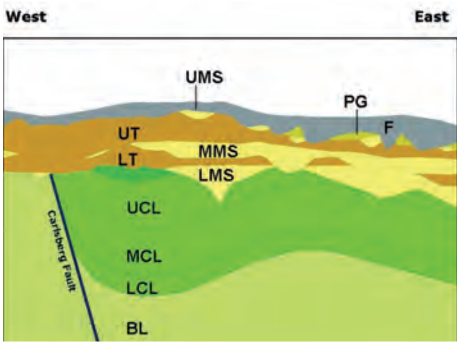
• ENVIRONMENTAL AND GEOLOGICAL CONDITIONS

Geologically the project area is featuring 2-5m of fill layers. This is underlain by 10-25m of quaternary layers, mainly consisting of glacial till and meltwater sand and gravel. The meltwater deposits are highly variable, consisting of fine-grained sand and coarser-grained sand and gravel, often with larger boulders. The coarse sediments usually occur in the lower part of the meltwater units and may possess very high permeabilities.

The quaternary layers are underlain by Copenhagen Limestone from the Danian period. The limestone is fractured to a varying degree, however, it is mostly severely fractured in the uppermost few meters. The induration and fissuring in the limestone is generally highly variable.

The eastern part of the Cityringen alignment passes the inner city of Copenhagen where many buildings are old and sensitive to variations in groundwater levels. For this reason the municipality of Copenhagen has in this area prohibited any groundwater lowering outside the construction zones unless appropriate measures are taken to keep the groundwater level within natural limits. The western part of the alignment passes through a catchment for domestic water supply at Frederiksberg where a key issue is protection of the groundwater resource in terms of quantity and quality, with chemical parameters of interest being salinity/chloride, nickel and sulphate. Numerous contaminated sites - typically originating from former dry-cleaning shops, petrol-filling stations and mechanical workshops - are located close to the planned construction sites.

- **GEOLOGICAL PROFILE**



Geology is comprised fill (F) and post-glacial deposits (PG), glacial till (UT - Upper till, LT - Lower till), meltwater sand/gravel (UMS - Upper, MMS - Middle, LMS - Lower) and limestone (UCL - Upper, MCL - Middle, LCL - Lower, BL - Bryozoan)

- **PROJECT STAGE(s)**

Prefeasibility Study

Feasibility Study

Variant Study

Authoritie's Permissions Project

Tender Design for Owner

Tender Design for CC

Post Contract respectively Construction Design

Other

- **SITE INVESTIGATION TARGETS**

Geological Setting

•

Ground Types / Characteristics

- Geology in site investigation boreholes, with the aim of establishing af full geological model along the alignment

Structural Geology

•

Fault Characteristics

•

Alteration / Weathering

•

Hydrogeology

- Identification of depth to flow zones/ waterbearing zones. Estimation of total transmissivity. Groundwater quality

Geothermal Situation

•

In-situ Stress

•

Gravitative Mess Movements

•

- **MEASURES**

Desk Study

- Collection of existing non-project data, e.g. earlier boreholes and pumping tests

Mapping

•

Drillings

- Project investigations before tender:
- 130 geotechnical boreholes (shell&auger in quaternary layers, core drilling in limestone) at stations, shafts and along the alignment.
- 80 hydrogeological boreholes (DTH drilling throughout the entire drilling depth) at stations and shafts, with several screens, for use in pumping tests and continuous groundwater monitoring.

Site investigation method	Approximate number
Borehole	500
Geophysical log, including flow log	250
Short duration pumping test	600
Long duration pumping test	33
Groundwater chemical sampling	350
Seismic survey	13 km
Groundwater level monitoring	250 wells

- In total 500 borings
- Average spacing 40 m
- 13 km seismic survey
- Total length of site investigation borings 17 km
- Cost of site investigations are 2,5% of construction cost

Location of borings along aligenment.

Geophysical Methods

- Geophysical logging in selected deep boreholes, including gamma, density, porosity and flow logs. In some boreholes OATV logs have been undertaken

Field Tests

•

Laboratory Tests

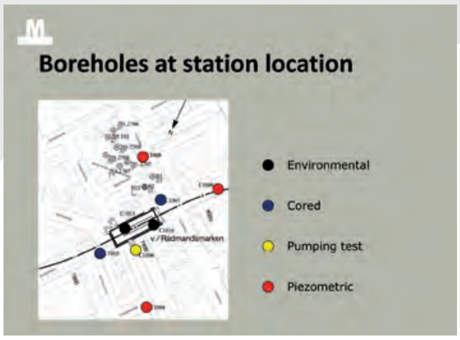
•

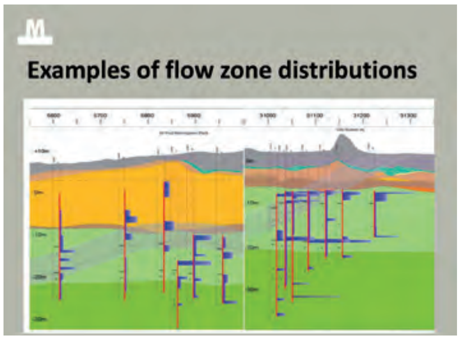
Exploratory Tunnel

- N.A.

Monitoring

- N.A.





04 PORCE III HYDROPOWER PROJECT, COLOMBIA

• Project Identification

Location

Amalfi, Department of Antioquia, Colombia.

Construction period
2006 – 2012

Owner
Medellin Public Utilities Company (EPM)

Designer(s)
Ingetec, Bogota, Colombia

Contractor(s)
CCC Porce III Consortium:
Construçoes Camargo Correa
Conconcreto S.A.
Coninsa – Ramon Hache S.A.

Engineer(s)
Ingetec, Bogota, Colombia

• General Project Description

Porce III Hydropower Project features a 151 m high, CFRD dam, which impounds 3,756 km² catchment area of the Porce River and tributaries into a 170 hm³ reservoir; a 730 m long open channel spillway with a discharge capacity of 11,350 m³/sec, controlled by four radial gates; a headrace conveyance system, composed of a 12,452 m long upper tunnel, a 159 m long vertical shaft and a 274 m long lower tunnel; an underground power station houses four vertical-shaft Francis turbines coupled to four synchronous three-phase generators, yielding a total 660 MW, or 4,254 GWh/year.

• Tunnel Characteristics

Total Tunnel Length
12,726 m (upper and lower headrace)

Boring diameter
8.5 m

Overburden(min-max)
30 - 550 m

Characterization scheme
Geotechnical characterization was performed using Barton´s Q System, Bienawski's RMR System and

Excavation type
Drill-and-blast

Contract model
Design + Construction

• Environmental and Geological Conditions

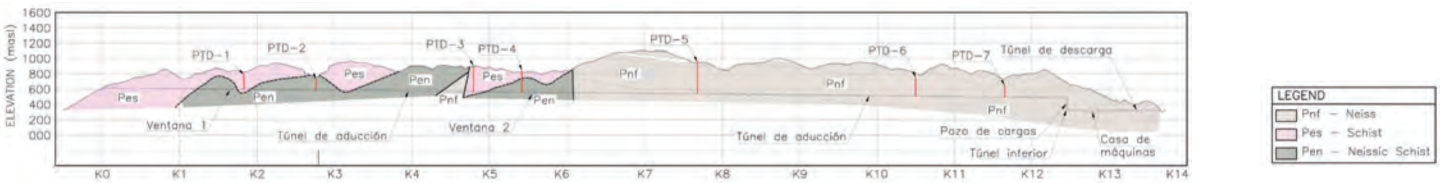
The surface of the area where the project´s headrace tunnel was excavated is covered 80% by residual soils and colluvium deposits. The lithologic units present correspond to Paleozoic rocks constituted by schist of varied composition and quarz-feldspar and aluminic gneiss. The rock is folded in a northerly direction along the tunnel alignment and is affected by faults, joints and shear zones.

The predominant geomorphologic units along the tunnel alignment correspond to High Mountain Schist and High Mountain Gneiss. Schist is composed of quartz, mica (sericite, muscovite, biotite and hornblend) and graphite, whereas neiss is composed of both, quarzic feldspar gneiss and aluminic gneiss. The main geologic structures defined correspond to a series of tight folds with a general N-S direction: the Castillo and Primavera Faults, and El Roposo shear zones.

The headrace tunnel was excavated along the left bank of the Porce River, through metamorphic rocks composed 11% by schist, 36% by gneissic schist and 53% by gneiss.

The project was developed within the deep canyon environment of the Porce River, which runs north through a tropical rain forest, were wildlife is abundant, including a wide variety of birds, reptiles and mammals. The owner was therefore quite demanding regarding the preservation of the pre-existing natural environment and stringent regarding the restotation of the environment affected by project construction.

• Geological Profile



Geological longitudinal section of the 25.5 km headrace gallery.

• SITE INVESTIGATION TARGETS

Geological Setting

The general geological setting of the project corresponds to metamorphic rocks (basically neiss and schist), of paleozoic age, highly weathered at the surface, mostly fresh and competent at depth (at tunnel level).

Ground Types / Characteristics

Ground types were defined in the technical specifications for bid as well as for construction and contractual purposes. The headrace tunnel involved basically five types of ground:

- Type I: competent, hard, massive, slightly fractured, stable rock, where excavation may advance without the need to install support, and only localisez shotcrete and/or bolts could be required;
- Type II: moderately hard to hard, moderately folded, fractured to moderately fractured rock, in which spalling over time may occur and therefore support is required;
- Type IIIA: medium to low strength, folded, fractured to highly fractured rock, which discontinuity planes are altered, and spalling may occur at the excavation face, therefore immediate installation of support is required;
- Type IIIB: friable and/or crumbly material, fault or shear zones composed of gouge or highly fractured material, including residual soil in the portal area;
- Type IIIC: higly fractured rock, cohesionless, where excavation shall be performed in three stages or sections: upper, mid and lower. Squeezing phenomena expected.

Structural Geology

Along the headrace tunnel alignment, the main geologic structures correspond to a series of tight folds, with a general N-S direction, El Castillo and Primavera Faults, and La Primavera and El Reposo shear zones.

A series of faults, with orientation N20° - 25°E are El Roble anticline, El Roble sincline, the Hondoná anticline, and El Totuno sincline. These folds affect the quartzic schists of variable composition.

La Primavera shear zone has direction N15 – 20°E/40°SE, and was defined base don Drillholes PCP-1 AND PCP-2, as well as on seismic refraction conducted during previous studies.

El Reposo shear zone was defined based on drillholes performed during previous studies.

Fault Characteristics

The headrace tunnel is affected by two geologic faults: El Castillo and El Salado Faults. The first is a reverse fault, oriented N40°W, dipping SW, affecting metamorphic rocks. It is located around K4+600 in the tunnel, and at the surface, it is covered by loose rock fragments, along a 100 m wide alignment. The fault material is 10 to 20 m thick and is composed of greenish grey milonite, gneiss and schist fragments embedded in a silty clay and brown sand matrix. RQD varies between 0% and 17%.

El Salado Fault is located 1.3 km east of El Castillo Fault, and crosses the tunnel at about K6+100. The fault´s direction is N20° - N30°W, dipping vertically. It is composed of highly fractured to crushed rock fragments 10 – 20 m wide, and an influence zone of some 100m that narrows with depth.

Alteration / Weathering

The alteration/weathering phenomena was observed in exploratrion galleries excavated in the dam´s left abutment and along the main and access roads. A significant thickness (some 30 m) of moderately to highly weathered rock had to be entirely removed to construct the CFRD dam.

As for the headrace tunnel, such weathered material was evident at the tunnel's and tunnel adits' portals, as well as along the first 30 or 40 meters of tunnel, excavated in poor ground and supported with streel sets.

In-situ Stress

In-situ stress measurements were carried out for the headrace tunnel, prior to commencemenet and during construction. The target of such tests was to investigate the magnitude of the minor principle stress (σ_3) in certain key locations of the tunnel, and compare such values to the internal pressure of the tunnel, in order to determine whether modification in the tunnel alignment or the installation of a steel liner would be necessary, in order to prevent hydraulic fracture phenomena that could generate leakage from the tunnel to the ground surface or into the powerhouse.

Four such locations were selected and hence, four corresponding sets of hydraulic fracture tests were conducted: the first two sets, prior powerhouse and headrace excavation, were performed, respectively, from an exploration gallery that ended near the future powerhouse, and from the surface, at a location of relatively low overburden (110m) due to a topographic depression; the third set, from within the tunnel, near the intersection with the vertical shaft, to check for effective overburden at such elbow; and a fourth set, performed near the intersection of the bottom of the shaft and the lower headrace tunnel, in order to check for effective minor principle stress values as the pressure tunnel approached the underground powerhouse surface.

The results of such tests allowed to optimise the design in the following ways: a) at the location of the low overburden due to the topographic depression generated by the running creek, the original tunnel alignment was displaced some 90m further into de mountain, to gain vertical overburden; b) as regards the elbow's optimum location, hydrofracture tests indicated the need to displace the elbow and the shaft 60 m further upstream, to gain lateral overburden; c) the test results indicated the need to steel-line the full length of the lower headrace tunnel that splices into the powerhouse.

Gravitative Mass Movements

Based on the results of the investigations, the dam´s left abutment required extensive tieback installation, and the tunnel´s adit portals required stabilization measures, including shotcrete, bolts, revegetation with native grass species and adequate drainage.

• MEASURES

Desk Study

Desk studies went through a step-by-step process, according to each stage of the project:

- a conceptual and prefeseability stage, in which different scenarios or alternatives for the project´s optimum location and layout were proposed, during which preliminary geological and geotechnical investigations were conducted;

- a feasibility stage, in which the selected alternative was studied and developed in much further detail, along with a significant number of drillings and other geotechnical investigations were performed as well as corresponding costs;
- a third stage, in which the detailed studies, drawings, technical specifications and contractual documents were prepared for bidding purposes.

All field investigations performes prior to, and during such stage, constituted the necessary parameters for such detailed office design of the project.

Mapping

The project involved topographical mapping and geological mapping. Topographical mapping was used to optimize the location and design of the project along its various stages. Three scales of maps were used: the first two, 1:25000 scale, which was the general scale of the project encompassing the basin, and the 1:10000 scale, covering the reservoir are, were both aerial photograph-based restitution scales; the third scale, 1:2000, was used for all detailed design of project's components, including the dam and appurtenant works, the access roads and the headrace tunnel's portals as well as its three adit's portals.

On the other hand, geological maps corresponding to the above-mentioned topographic maps were prepared, to the same scales, that is, general geological and geomorphological maps of the basin and reservoir areas, and detailed geological maps of the surface and underground works, including the headrace tunnel and powerhouse, for bidding purposes. In addition, a 630m long exploratory gallery, referred to ahead, was excavated, the end point of which was close to the future underground powerhouse which allowed detailed geological mapping of this project component.

During excavation of the headrace tunnel and underground powerhouse, detailed geological maps were drawn of the actual geology encountered, following each blast of the tunnel face, drawn at a 1:200 scale, not only to provide as-built records, but to assist in the design of the tunne's permanent lining: shotcrete, concrete or steel.

Drillings and pits

There were seven drillings performed from the surface along and over the headrace tunnel alignment, spaced between 1.0 km and 3.0 km, (1.5 km on average), depending on the degree of difficulty of the access to each drilling site, plus drillings at the inlet portal, and in two adit tunnels to the main tunnel, thus covering the full length of the tunnel. The following table summarizes the drillings and corresponding lengths

Headrace Tunnel Drillholes	Length (m)	Projected Station In Tunnel
PTD-1	110	K1+575
PTD-2	145	K2+700
PTD-3	340	K4+675
PTD-4	275	K5+400
PTD-5	420	K8+350
PTD-6	250	K11+325
PTD-7	160	K12+375
Adit Tunnel 1 (L=558 m) Drillholes	**Length (m)**	**Projected Station In Adit**
P-V1-1	55	K0+170
P-V1-2	34	K0+080
P-V1-3	15	K0+020
Adit Tunnel 2 (L= 649 m) Drillholes	**Length (m)**	**Projected Station In Adit**
P-V2-1	40	K0+165
P-V2-2	35	K0+070
P-V3-3	23	K0+015
Adit Tunnel 3 (L=705 m) Drillholes	**Length (m)**	**Projected Station In Adit**
P-V3-1	50	K0+240
P-V3-2	40	K0+130
P-V3-3	10	K0+010
Inlet Portal Pits	**Depth (m)**	**Location**
AP-V2-1	3.4	Portal area
AP-V2-2	3.0	Portal area
AP-V2-3	3.0	Portal area

Geophysical Methods

Geophysical methods included seismic refraction lines along the tunnel alignment,

Field Tests

A numer of field tests were conducted in order to establish basic design parameters. The most outstanding tests were in the area of hydraulic fracture, in order to determine the magnitude of the minor principle stress at key locations alongthe headrace tunnel alignment (see above).

Laboratory Tests

In order to establish the statigrapgy and the physical properties of the rock for the headrace tunnel, and as a complement to the field

work performed, a core drilling program was conducted, from which samples were retrieved for a variety of tests in the laboratoty. Lab tests were performed on soil and rock. Soil tests were performed almost entirely on surface samples and on samples obtained form pits excavated in the vicinity of the inlet portal.

Soil tests were basically: Atterberg Limits, specific gravity, hydrometric analyses, water content, Proctor compaction, following ASTM and AASHTO Standards. The table below summarizes such tests.

Rock tests were executed both pon surface as well as on cores retrieved form drillholes. Tests included: Grading of granular materials, compaction, direct shear, tensile strength, wave propagation velocity, triaxial, slake durability and petrography. The table below summarizes the type and number of tests perfomed.

Exploratory Tunnel

In 2004, a 635m long exploratory tunnel, 2.5m x 2.5m, was excavated between the Porce River left bank and the future underground power station, in order to investigate detailed golgical and geotechnical conditions for the powerhouse, regarding its orientation and temporary as well as permanent support requirements.

Monitoring

The design included the installation of a series of instruments for monitoring the behaviour of diferent project components once placed in operation, for long-term monitoring. A set of instruments, among which are inclinometers, piezometers and accelerographs were placed in the dam.

In the headrace tunnel, monitoring during construction included the installation of tape extensometer rings and pressure cells for longterm monitoring.

DATA COLLECTED FROM FRENCH ROAD TUNNELS

The five case histories presented below regards roads tunnels which where design and constructed between 2003 and 2014. Data were collected and actualized in 2010 by CETU, the Centre of Tunnel Studies of the French Ministry of Public Works.

The tunnel construction costs include the civil works only and they are those announced at the bidding stage. No major claims where observed after the completion of the works.

The quantity of site investigations were obtained from the tender documents (factual data reports). To assess the cost of site investigations, boreholes and in-situ test only were considered. The costs of geophysics and exploratory galleries (when present) were initially excluded from the analysis. For the case of Bois de Peu Tunnel, the cost of site investigation is given with and without the exploratory gallery.

Tunnel	Start of the works	Type	Total Length	Cumulated length of boreholes	Cost of explorations / cost of tunnel	Invest. Cost [M€]	Constr. method
Saint Vallier	2002	Road	178 m	225 m	2,6 %	1,26	D&B
Schirmeck	2003	Road	550 + 150 m	704 m	3,7%	1,01	D&B
Bois du Peu	2004	Road	2*600 + 90 m	885 m	2,2% Excluding costs for exploratory gallery	1,09	D&B
Peute Combe	2009	Road	2*600 + 120 m	1219 m	3,85%	0,95	D&B
Saint Béat	2010	Road	110 + 310 m	1586 m	2,1%	1,12	D&B

DATA COLLECTED FROM FRENCH TRAMWAY AND METRO TUNNELS

Tunnel	Start of the works	Type	Total Length	Cumulated length of boreholes	Cost of explorations / cost of tunnel	Invest. Cost [M€]	Constr. method
Tramway C2V	2010	Tramway	1500+90m	1902	N/A	1,20	EPB TBM
Paris Line 4 extension	2007	Metro	460m	380 m	N/A	0,83	D&B
Lyon line B extension	2010	Metro	1470m	2078 m	N/A	1,42	Slurry TBM
Paris Line 14 extension Lot1	2014	Metro	3620m	3475 m	N/A	0,96	TBM
Rennes Line B	2014	Metro	8100m	7679 m	N/A	0,95	EPB TBM

Assumptions on costs [€/m]:
- *Pressiometric borehole: 300;*
- *Subhorizontal and/or inclined core recovery boreholes: 1000;*
- *Vertical core recovery boreholes: 800;*
- *Destructive boreholes: 150*

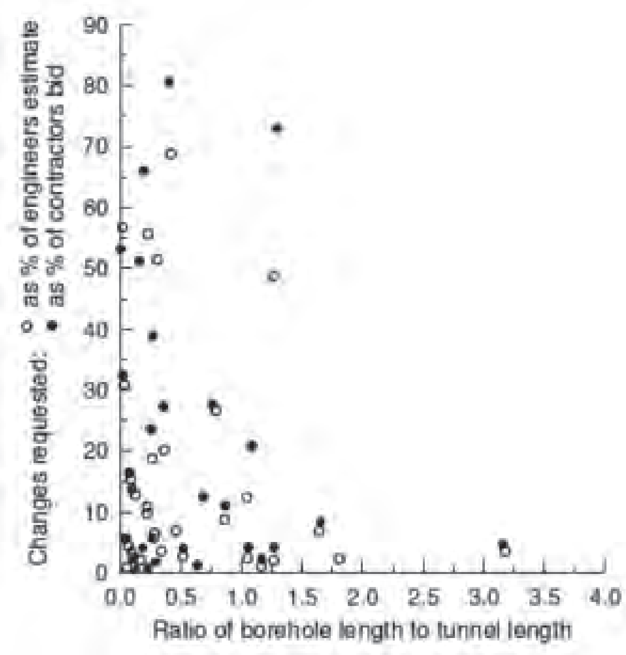
D&B = drill and blast

DATA COLLECTED FROM EUROPEAN LONG AND DEEP TUNNELS

Tunnel	Start of the works	Type	Total Length	Cumulated length of boreholes	Cost of explorations / cost of tunnel	Invest. Cost [M€]	Constr. method
Lötschberg	1994	Railway	34,6 km	N/A	2,8 %	N/A	Gripper TBM / DB
Gothard	1998	Railway	53,9 km	N/A	1,4 %	N/A	TBM / DB
Brenner	2011	Railway	57,0 km	~ 36 km	8,7 % I ncluding exploratory galleries	0,63	
LTF	Detailed design phase	Railway	57,1 km	~ 62 km	8,9 % ncluding exploratory galleries	1,08	
Koralm Base Tunnel	In construction		33 km	~ 21 km	1,9 %	0,64	N/A
Semmering Base Tunnel	In construction		27 km	~ 38,5 km	1,7 %	1,43	N/A

DATA COLLECTED FROM U.S. NATIONAL COMMITTEE ON TUNNEL TECHNOLOGY

Data were collected by the U.S. National Committee on Tunnel Technology (USNCTT 1984) by interviewing the Owners, Engineers and Contractors of 84 different tunnel projects.



Country	Factual Data	Interpreted Data	Contractual Data	Data collected during construction	Ref. document(s)
FRANCE	Cahier des Données Factuelles	Mémoire de Conception	Mémoire de Synthèse	Dossier de Suivi Géotechnique d'Exécution	AFTES (2012), Characterisation of geological, hydrogeological and geotechnical uncertainties and risks, GT32R2A1 NFP 94500 (2013), Missions d'ingénierie géotechniques – Classification et spécifications
KOREA	Geotechnical Data Report				KTA(2015) Standard Specifications for Tunnel
SWITZERLAND					SIA 198 (2004), Construction d'ouvrages souterrains SIA 199 (1998), Etude des massifs rocheaux pour les travaux souterrains
USA / UK (Anglo-Saxon approach)	Factual Report or Geotechnical Data Report	Geotechnical Interpretative Report or Geotechnical Memoranda for Design	Geotechnical Baseline Report	Post-Construction Geotechnical Report	ASCE (2007), Geotechnical Baseline Reports for Underground Construction

longrine 04 90 14 48 48 - (21200 - 05/15)

ITA Secretariat c/o EPFL - Bât. GC - Station 18 - CH - 1015 Lausanne - Tel. : + 41 21 693 23 10 - Fax : + 41 21 693 41 53
Email : secretariat@ita-aites.org - Web : www.ita-aites.org