La Lettre

Tunnels & underground structures

terrasol

setec

Special release

Editorial

Since TERRASOL was established in 1979, underground works have become a major focus in the development of our geotechnical engineering consultancy activities, under the impetus imparted by Alain Guilloux. With more than 250 underground structures analysed over 35 years, TERRASOL is an undisputed leader in this area. We have for example contributed to the development of tunnel calculation methods, in particular the use of finite element calculations (first High Speed Railways tunnels, Paris RER line E, Paris metro line 14) and are also heavily involved in the implementation of new excavation techniques (jet grouting for the motorway tunnel in Les Hurtières, pre-support and reinforcement of the tunnel face for the Tartaiguille HSL tunnel, compensation grouting in Toulon, microtunneling, etc).

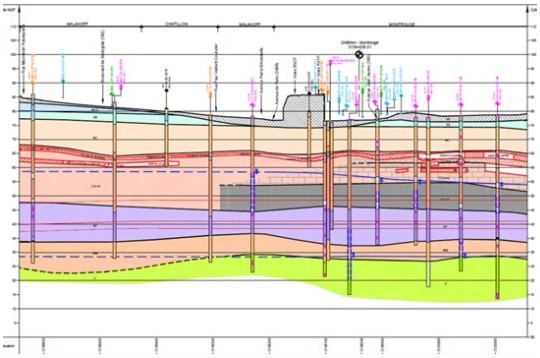
This special issue of the TERRASOL newsletter describes some projects carried out in this area in recent years which illustrate the extensive competencies of our teams, whether in the design phase (supervision/ analysis of soil testing campaigns, selection and design of construction methods) or in the construction phase (detailed design, works supervision, expertises).

Wishing you a pleasant reading !

H. Le Bissonnais

From design…

Greater Paris - Line 15



Line 15 between Pont de Sèvres and Noisy ("South Red Line") will be the first link in the Greater Paris Public Transport System, with construction starting in 2015 for a scheduled in-service date in 2020. The SETEC/INGEROP consortium is the Project Manager for the design of section T3 between the future stations at Pont de Sèvres and Villejuif - Louis Aragon.

TERRASOL is in charge of the coordination of the geotechnical studies along the whole length of the section, including in particular the interpretation of the soil testing campaigns, the production of the geological and geotechnical longitudinal profile, and the design of structures interacting with the ground (tunnel, ancillary structures, retaining walls in the stations, etc). The 12.5 km-long section can be divided into four geological units: the Seine valley (3.2 km), with a tunnel excavated in the chalk below the Seine alluvia; the Vanves-Clamart-Arcueil plateau (6.4 km); the Bièvre valley crossing; then the climb up to the Villejuif plateau (2.5 km).

The Vanves-Clamart-Arcueil sector is characterised by the presence of old quarries of coarse limestone (both underground and open-pit) over nearly 6 km, leading to a tunnel alignment running under these quarry levels, with a face located primarily through the lower coarse limestone or through the Ypresian formations ('fausses glaises', plastic clay). These geotechnical difficulties require the generation of complex models in the preliminary design phases (2D and 3D finite element calculations) in order to optimise the alignment and the boring constraints.

G. Chapron and H. Le Bissonnais

… to construction

St-Martin-la-Porte

The Saint-Martin-la-Porte decline is one of the first completed structures of the Lyon-Turin railway link. Designed initially as an exploratory gallery, this 2.4 km-long tunnel will subsequently provide access and ventilation for the future works of the base tunnel, which explains its substantial dimensions (excavated section around 100 m^2). Starting in 2002, TERRASOL produced detailed design studies and provided geotechnical assistance for the consortium formed by RAZEL, BILFINGER-BERGER and PIZZAROTTI. Excavation started in May 2003, and the tunnel reached a length of 2400 m in June 2010, after having encountered a scree cone, sedimentary soils (limestone, marl and dolomite), the coal face (anhydrites and gypsums) and the productive coal (sandstone and coal shale).

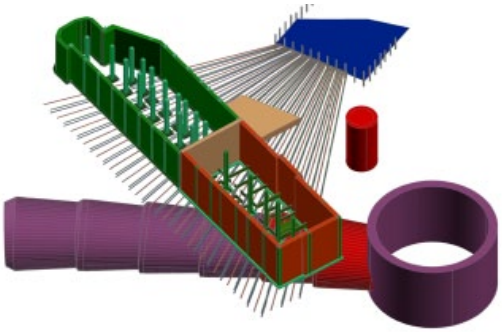
The main features of the project are the limited experience of boring large tunnels in these rocks at high depths (up to 600 m) and the presence of extremely deformable layers. The latter issue required, for the design studies, characterisation of soils on progress (using back-analysis), monitoring of the structure behaviour, and a continuous adjustment of excavation and support methods with respect to observations and new data.

One of the lessons of this project is the confirmation of the structural limits of a rigid support in deformable rocks under deep cover. Boring using a flexible method (dense bolting, shotcrete, sliding arch supports) applied from 1200 m length required a very thorough monitoring of the deformations, with metre-scale convergences.

B. Madinier and H. Le Bissonnais

Compensation grouting in Toulon

Var, France



From the initiation of the studies for the second tube project of the Toulon underground crossing, the passage under the Esplanade and Scheherazade buildings in the Marchand sector, in the central part of the tunnel, was identified as being particularly difficult.

Indeed, these two 8-floor buildings had already undergone the digging of the first tube, and soil testing showed the presence of soil with particularly poor quality (soft clay pockets issued from dissolved gypsum).

From the beginning of the excavation starting from the intermediate attack of the Marchand shaft, the Esplanade building responded significantly with cracks in the finishings of the buildings, in spite of a still relatively low level of surface deformation. Excavation was stopped due to the anticipation of deformations very close to the limit of the acceptable thresholds after passage of the tunnel. After considering the possibility of reinforcing the building's structure, it was finally decided to use compensation grouting to stabilize the building.

This method consists in injecting small quantities of grout to lift the building and compensate for settlements generated by tunnel excavation. These injections were performed from 3 layers of 20 subhorizontal drillings equipped with tubes-à-manchette, making up 5300 injection points. A large-size measurement system, made of topographic measurements from automated theodolites, electro-level chains, borehole extensometers and tiltmeters, allowed for continuous check of absolute and differential settlements.

A first phase before resuming excavation consisted in pre-lifting the building by 12 to 15 mm, in order to "catch up" the initial settlements already acquired. This phase also allowed to calibrate the system and validate the volumes of grout to inject by manchette. Excavation could then resume, by activating the compensation device. With daily injections of about 2000 to 3000 liters, settlement were fully controlled, with an accuracy of about 1 mm.

H. Le Bissonnais

A tunnel through coral

Miami, USA

TERRASOL was called upon by BOUYGUES to help them analyse the geotechnical conditions for the excavation of a tunnel under a sea channel in the Port of Miami. This 11 m diameter twin-tube road tunnel passes approximately 15 m below the channel bottom and through extremely heterogeneous corraline ground, including one layer with very poor properties.

No tunnel of this size had been built in Florida through this kind of geological formation, which is extremely difficult to investigate and test given the high fragility of some layers. A tough challenge for French (geo) technics!

The tunnel was opened in August 2014 after an intensive campaign of soil treatment in aquatic environment.

A. Guilloux

Credit: Daniel Azoulay

Saint-Béat tunnel

Haute-Garonne, France

The upgrading of the RN 125 main road between Saint-Béat and Arlos in the French Pyrenees will enable to bypass the village of Saint-Béat by means of a tunnel through the Cap de Mount mountain. The village is renowned for its quarrying of white marble, the formation constituting most of the massif through which the tunnel is built.

The GUINTOLI – SOLÉTANCHE-BACHY – SOLÉTANCHE-BACHY TUNNELS – PIZZAROTTI consortium has contracted TERRASOL and BMCI (a subsidiary of SETEC TPI) for the geotechnical and civil engineering detailed design of the tunnel. The 1018-metre-long tunnel was excavated by the traditional method using explosives, with a support mainly comprising bolts and shotcrete.

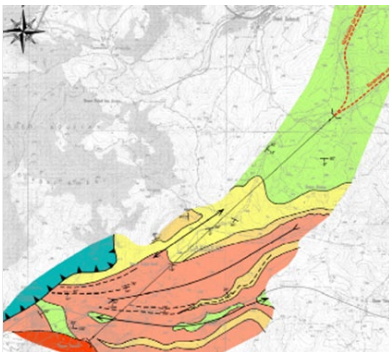
Despite a geology favourable to tunnelling (Marmorean limestone and good-quality marble, with limited fracturing), the works gave rise to some surprises: karsts at the northern portal, and substantial water inflow at the southern face. The main difficulty of the project, clearly identified by the first explorations, was the interception by the northern safety tunnel of a glacial furrow filled with alluvial materials. The analysis of additional explorations from the tunnel and from the surface resulted in the proposal to cross this geological irregularity by means of an arched support reinforced by forepoling. The excavation of the main tunnel was completed in December 2013.

H. Le Bissonnais

Ganntas tunnel

Algeria

In the context of its contract with CCECC, contractor in charge of the construction works for the doubling of the railway track with alignment adjustment between the El Affroun and Khemis Miliana stations (east of Algiers), TERRASOL produced the Ganntas tunnel detailed design. This is a 6.7 km twin-tube tunnel through Djebel Ganntas, peaking at about 800 m, between Oued Zebboudj to the north-east and Ain Soltane to the south-west. It has a section of 41 m² and a maximum cover depth of 390 m. It was excavated using the traditional method.



Even before the start of works, TERRASOL was mobilised to update the longitudinal profile, given the geological uncertainties revealed during the preliminary design phase. TERRASOL performed a parametric analysis using a finite element approach (CESAR) to approximate the behaviour of the surrounding rock according to the geological context (variation of the layers encountered, depth), and the excavation methods/ phases. On completion of this study, TERRASOL compiled a catalogue of support types to be used according to the observations made during excavation works.

Works monitoring, with geological recording, convergence measurements as well as soil testing on progress, enabled to adjust the calculation assumptions and to adapt the methods in the fault area expected in the southern part of the tunnel. By August 2014, works had progressed to more than 60% of the length.

M. Yahia-Aissa, P. Brossier and F. Binet

East European High-Speed Line

Saverne, France

Works on section H of the East European High-Speed Line, from Danne-et-Quatre-Vents to Vendenheim, were completed early in 2014 with the successive handover of both tubes of the Saverne tunnel (works package 47) to the railway equipment teams. These handovers, ahead of the initial schedule thanks to the record boring of the second tube, followed on from the delivery of the railway platforms of the adjacent works packages: standard section (works packages 43a and 43b) and viaducts (works packages 48 and 49).

Credit: JM BANNWARTH for Balloïde photos

TERRASOL actively participated with SETEC in the Project Management for the various packages: checking of the detailed design by the Paris teams, and on-site secondment of two engineers for the supervision of the works of the package 47 (Saverne tunnel and non-standard structures).

Through this assignment, TERRASOL contributed to the success of the project to resolve the various issues related to the construction of the tunnel and of the foundations of the various viaducts.

P. Legrand

Alpine South Corridor Phase II (renovation)

St-Marcel lès Valence – Moirans, France

The railway lines linking the conurbations of Valence, Grenoble and Chambéry constitute what is commonly called the “South Alpine Arc”. Phase II of the project consists of electrification of the lines between St-Marcel lès Valence and Moirans, connection of the line to the HSL (South operation) and electrification of the lines between Gières and Montmélian (North operation).

Credit: ©Tes 237

The consortium (ALSTOM – Contract leader, SPIE BTP, COLAS RAIL, NOUVETRA and SETEC) is working on the South operation in the frame of a design and construction contract. The 80 km line runs along the terraces of the Isère Valley and cuts through a few rocky outcrops, which justified the excavation of 3 tunnels (Têche, Poliénas and Rochefort).

As part of this project, TERRASOL, within SETEC’s integrated Project Management team, participated in the project design and in the works supervision:

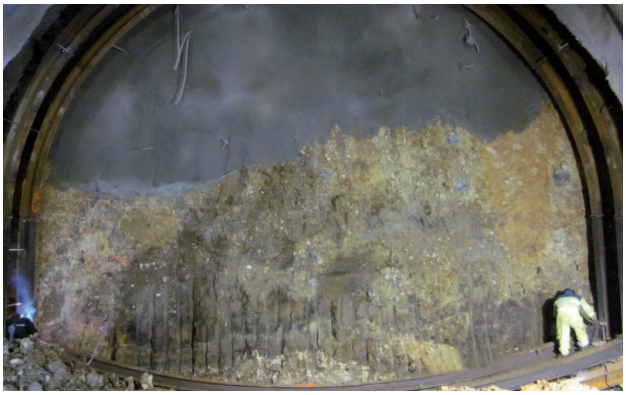
- line electrification (catenary, line substations, construction of a new substation);
- railway line connection to Valence HSL station (3.5 km of new line, 1 road bridge, civil engineering and track works);
- demolition of 6 standard structures, construction of 4 road bridges and 2 railway bridges;
- clearance upgrade for the 3 tunnels of the line: a thorough sensitivity analysis on various parameters was performed during the design phase using finite element calculations for the Têche tunnel, and instrumentation equipment was installed during construction to monitor displacements in the tunnels and on the external walls following grouting and excavation works on the central platform;
- installation of noise barriers in urban areas (≈ 6.4 km).

The works started in 2012, and the line was opened in December 2013, with electric train services starting in 2014.

C. de la Salle

Jenner tunnel

Le Havre, France



The Jenner tunnel is a 535 m long two-track underground structure for the first tramway to be built in Le Havre, linking the lower part of the city to Place Jenner located in the upper part. It is constructed in parallel with and fairly close to the existing road tunnel.

The overburden varies in depth from 35 m to 6 m for an excavated section of around 60 m². The tunnel is excavated with the “traditional method” using a cutter machine equipped with a milling head weighing several tons: excavation took place between January and November 2011. SPIE BATIGNOLLES commissioned TERRASOL to carry out an additional geological survey and geologically monitor the tunnel excavation.

The main concern about the excavation phase was the installation of heavy supports (steel ribs, sprayed concrete, umbrella arch and face bolts, as well as local counter ribs on raft) to compensate for unfavourable geological conditions (karstic or weathered areas) anticipated over most of the route while it may be assumed that the facies being crossed is largely compact chalk considered as a rock. The tunnel is located next to a plateau dug out from Cenomanian chalk, covered over a decametric thickness by Tint clay and, locally, plateau loam. The beginning of the excavation confirmed the presence of largely sound chalk, although with the presence of small karsts requiring “forepoling” type pre-support.

H. Le Bissonnais

Croix-Rousse tunnel

Lyon, France

Credit: Anne Claude Barbier

The Croix-Rousse urban tunnel is a two-way single-tube linking the east and the west of the Lyon conurbation. Its particularly dilapidated condition meant that it had to be upgraded to comply with European directives. The works consisted of:

- The construction of a safety gallery able to accommodate soft transport modes and public transport,
- The complete renovation of the road tube and its ventilation plants.

TERRASOL handled the geotechnical part of the whole project, from design to construction, with an old, densely urbanised environment as a major constraint.

The entrance at the Rhône end required the construction of a complex retaining structure with strict limitations of deformations in order to ensure the integrity of existing structures (old buildings, major galleries network-fishbone type, highly vulnerable church, etc).

With the same objective, the first 100 metres at the Rhône end through the Miocene sandy loam formations were excavated using a road header and supported using renewable forepoling.
In addition, an extensive instrumentation system was installed to monitor the impact of further excavation using explosive (emulsion) at shallow depth in urban environment, in the crystalline granite or gneiss bedrock.

J. Voiron and B. Madinier

Rennes metro

France

The project of Rennes Metropolitan area metro consists of the construction of a second metro line crossing the Rennes conurbation along a north-east/south-west axis and supplements the existing line A. Works package 1 of the project covers the construction of a tunnel 8 km long, 9 stations and 5 shafts.

The contract was awarded last autumn to the consortium mandated by DODIN CAMPENON BERNARD.

This project is located in a difficult urban environment with buildings of various levels of sensitivity in the immediate proximity, and involves excavation of stations up to 30 m deep, including in the central core of the old town. The geotechnical context is complicated given the feedback from existing line A and the geotechnical variability of the Rennes schists.

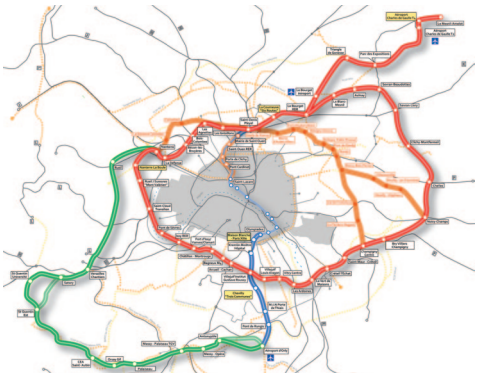
In close liaison with a reinforced monitoring mission, TERRASOL is entrusted with the definition of the various geotechnical assumptions related to the stations as well as with the supervision of the soil testing, the excavation of the stations, and the TBM excavation, with secondment of an engineer on-site.

P. Legrand

The «Grand Paris» and parisian transport projects

France

Essentially linked to the need to provide new public transport infrastructures (tramway, metro, regional express railway, train), a particularly large number of underground works projects are currently being studied in the Paris region. TERRASOL, thanks to its historic presence in Paris, its considerable knowledge of the region's geology and geotechnics, and its expertise in underground constructions, is particularly involved in a large number of projects. These are either exclusively geotechnical assignments or project management missions in association with various companies of the SETEC group.



Credit: Société du Grand Paris

Concerning metro lines, these projects include the extension to line 4 (2nd phase, from the Montrouge town hall to Bagneux) with a "second geotechnical evaluation" mission for RATP during the studies and works phases. A similar mission is currently being carried out during the detailed design (PRO) phase for the extension of line 12 up to the Aubervilliers town hall (2nd phase). TERRASOL is also present in the extension to line 14, considered a priority project for RATP to reduce the passenger load on line 13 between Saint-Lazare main line station and the Saint-Ouen town hall station.

Concerning the RER (Regional Express Railway) lines, the major project in the near future will be the extension of Eole (automatic metro) to La Défense with, in particular, a new station under the CNIT building (project management by SETEC / EGIS). It is also worth mentioning the doubling up of the tunnel for lines B and D between Châtelet and the Gare du Nord main line station, for which a feasibility study is presently being carried out.

Finally, the project that will call for a vast amount of energy in terms of studies and then works over the next few years is, of course, the Réseau de Transport Public du Grand Paris (Greater Paris public transport network). TERRASOL carried out the preliminary studies for the Villejuif – Saint Cloud section (south-west arc – the "Red" line) with SETEC TPI and SYSTRA, and is now participating in the geotechnical project management of the west section of this line, between Pont de Sèvres and Villejuif Louis Aragon, within SETEC/INGEROP teams. TERRASOL also carried out the feasibility study concerning the "Orange" line between Noisy and Saint-Denis, and the preliminary design of the south extension to line 14 to Orly airport.

H. Le Bissonnais

Extension of metro line 14

France

TERRASOL carried out missions G12 and G2 for the extension of Paris metro line 14 to Mairie de Saint-Ouen, on behalf of SYSTRA Île-de-France. This project is mainly intended to relieve congestion on metro line 13 and assist in the development of large-scale urban development zones located in the 17th Paris district and in the neighbouring cities of Clichy and Saint-Ouen. This entirely underground extension will be excavated with a Tunnel Boring Machine (TBM) over a distance of 5.8 km (plus approximately 500 m of connection tunnel to the maintenance site) and also includes the construction of four new open-air stations with a depth of 23 to 34 m, and a number of related structures with various functions (safety, ventilation, TBM dismantling structure, etc). This extension is located in the well-known Paris soil series, ranging from Ludian infra-gypsum marl to Lutetian coarse limestone, with a risk of gypsum dissolution.

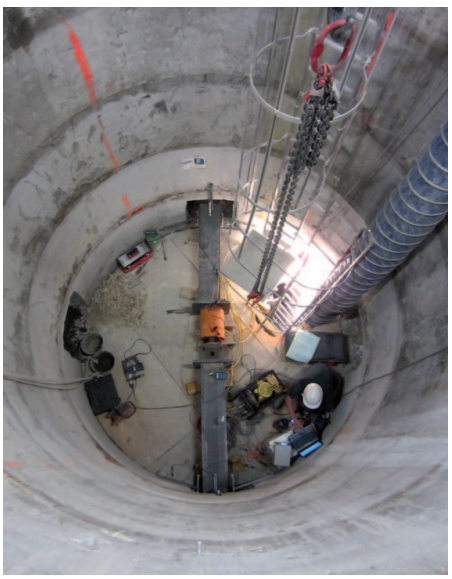
TERRASOL's assignment combines follow-up of geotechnical soil-testing and drafting of geotechnical synthesis reports, from the preliminary project phase to the invitation to tender. TERRASOL also works on additional specific issues, such as the 3D modeling of the TBM dismantling structure.

M. Hocdé and H. Le Bissonnais

The structures of the extension of RER E at La Défense

France

In the framework of the project management of Regional Express Railway line E (Eole) to the west of Paris, TERRASOL is carrying out the geotechnical studies of the structures in the La Défense district on behalf of SETEC TPI. The mission includes the definition of the soil testing campaigns, the follow-up of these campaigns, the preparation of the geotechnical analysis report, and the design of some of the structures. Especially, the new station to be built in the La Défense district, under the CNIT building, will comprise a main part built under existing structures, extended by two underground connecting tunnels. It is located in a particular geological context raising demanding technical challenges. Substantial soil survey works have been undertaken from the building's deepest basement levels, with project management ensured jointly by SETEC TPI and TERRASOL



A dedicated exploratory shaft with a diameter of 4 m was excavated by conventional means to a depth of 25 m. It enabled the rocks to be viewed at full scale and plate loading tests (horizontal and vertical loadings) and vibration tests to be performed at several levels. The programme is supplemented by conventional geotechnical surveys, including core drilling (used for a number of logging measurements), in situ geotechnical tests (SPT, pressuremeter, dilatometer and cross-hole tests) and laboratory tests. Full-scale permeability tests were performed as well.

The works, performed between June and December 2013, provided data that enabled to establish an exhaustive geological, geotechnical and hydrogeological analysis adapted to the context and to the complexity of the project, to define the calculation parameters for the detailed design phase, and to propose appropriate construction methods for the construction phase.

J. Marlinge and H. Le Bissonnais

Hydraulic gallery for the LNG terminal in Dunkerque

France

The methane terminal in Dunkerque includes the following constructions:

- 3 tanks of liquid gas (LNG) each containing 190,000 m³,
- a harbour terminal for gas transportation ships (wharf), for about 80 methane tankers per year, with a capacity up to 270,000 m³ each,
- a regasification unit,
- a water inlet tunnel from the CNPE in Gravelines to the tank area (tunnel of 3.0 m inner diameter and 5000 m long), to heat liquid gas.

TERRASOL was entrusted as an assistant to the project owner (EDF through its subsidiary DUNKERQUE LNG SAS) with the design of the water inlet tunnel and of the tunnel shaft.

The gallery is constructed underground over 5 km, using an earth pressure TBM, and remaining in the same geological layer at all times (Flanders clay). The overburden will be about 45 m on the Gravelines side. The tunnel will cross the West outer harbour. Access to the tunnel is provided by a 16 m diameter and 45 m deep diaphragm wall shaft.

TERRASOL presently carries out the G4 mission (geotechnical follow-up of works) for the excavation below Gravelines nuclear power plant and for the connection between the tunnel and the water intake vertical shafts.

H. Le Bissonnais and A. Bergère

Chooz laboratory

Ardennes, France

Within the scope of the “Double Chooz” scientific experiment aiming to study the behaviour of neutrinos, the GUINTOLI - SOLÉTANCHE BACHY TUNNELS group of contractors built between 2011 and 2013 an underground laboratory on the site of the Chooz nuclear power plant in the Ardennes region of France on behalf of CEA and CNRS, and with project management by EDF. The detailed design was carried out by the TERRASOL (contract leader) – SETEC TPI group.

Credit: Cédric Helsly for Solétanche Bachy

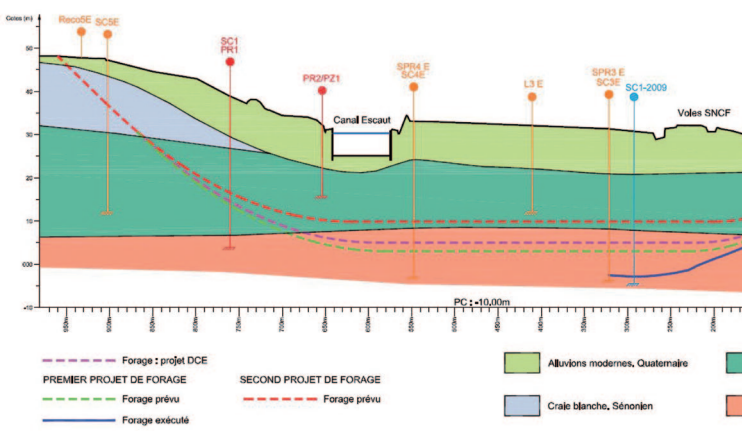
TERRASOL carried out the design of supporting structures for the laboratory access (trench – 90 m long, and access tunnel – 20 m² section, 145 m long), for the underground cavern (95 m² section, 30 m length) and for its vertical shaft required for the experiment (13 m excavation depth, 9.5 m diameter). The studies for the structures, excavated in shale/sandstone materials, combined a structural approach (analysis of the stability of blocks cut out by bedrock fracturation) and finite element calculations in an equivalent elasto-plastic environment (estimation of deformations and stresses using 2D and 3D modelling).

J. Marlinge

Directional drilling under the Escaut river

Neuville-sur-Escaut, France

In 2009 TERRASOL conducted an expert assessment in the context of a 980 m-long directional driling under the Escaut for the installation of the GRT gaz SNET pipeline. The project consisted in laying a DN 500 mm gas pipeline by directional drilling under SNCF railway tracks and under the Escaut canal at “Les Trois Muids” in Neuville sur Escaut.



Because of the risk of encountering flint in the chalky layers, the contractor had chosen an alignment located mainly in the Turonian marl formations.

A first drilling was halted after 341 metres in the marls, following unacceptable pressure surges of the drilling mud in the annular space (clogging). It was finally decided to raise the profile of the drilling to stay in the chalky levels. The second attempt succeeded with no particular difficulty.

A. Guilloux and H. Le Bissonnais

EDF water development project in Gavet

Isère, France

TERRASOL is conducting a global geotechnical expertise assignment for the new Romanche-Gavet water development project in Isère, with the participation of Alain Guilloux on the Technical Committee. This development consists of an adit (9.3 km long, 4.7 m diameter), a surge chamber (180 m high), a penstock of 163 m, and an underground power plant equipped with two production units which will replace the six existing plants on the river Romanche and will allow production capacities to be increased by 10%. The Romanche-Gavet project is the largest water project currently being developed by EDF (French National Electricity Board) in France.

Credit: Dodin Campenon Bernard

In parallel, TERRASOL is providing hydrogeological and geotechnical assistance during the works of the downstream release structures: a cofferdam was built to enable an excavation of 100 m by 30 m down to a depth of 12 m. TERRASOL was entrusted with the definition and follow-up of the geotechnical soil-testing campaign at the beginning of 2012, and the preparation of the geotechnical assumptions report. TERRASOL then carried out external control of the cofferdam detailed design documents.

In addition, it is necessary to lower the water table below the excavation level in the event of a 10-year flood, and thus to design the relevant pumping solution. TERRASOL carried out a 3D hydraulic modelling to simulate as accurately as possible the real project conditions, i.e. irregular stratigraphy and the presence of a deep confined water level. A parametric sensitivity study (flow and position of pumping wells) enabled us to optimise the pumping system.

C. Bernuy and Y. Bagagli

Tabellout dam

Texenna, Algeria

The Algerian National Dams and Transfers Agency (ANBT) has awarded to the GEIE/RAZEL/CMC/RAVENA consortium the contract for the Tabellout dam project construction near the city of Texenna, about 70 km south of the Jijel wilaya (district), in Algeria.The project as a whole comprises the construction of a roller-compacted concrete (RCC) dam 366 m long and 112 m high (reservoir capacity 294 hm^3) and a transfer tunnel 4.3 m in diameter (finished diameter 3.5 m) and 13 km long, for which a Tunnel Boring Machine (TBM) is being used.

From the start of the work, in March 2010, a number of geotechnical problems have been identified, in particular a landslide on the left bank of the dam, but also extensive degradation of the tunnel lining segments with the development of a collapse, and blocking of the TBM for more than 6 months.

At the request of the consortium, given the complexity of the geological context and the insufficiency of geotechnical data, TERRASOL has been providing since July 2012 technical assistance and consultancy services to the consortium on the various geotechnical aspects, including for prediction of the behaviour of the massif during the tunnel excavation, and in particular the behaviour of the Numidian clays and the zones of toppling suspected of being the source of the problems encountered (blockage of the TBM, collapse in the tunnel, important degradation of the voussoirs). In this context, TERRASOL defined a new program of soil investigation in cooperation with the consortium and the Project Manager. Deep boreholes should be carried out from groundlevel in order to adjust, if necessary, the longitudinal geotechnical profile. Mechanical tests are also to be executed from a gallery excavated laterally in the zone of the tunnel collapse.

M. Yahia-Aissa and A. Guilloux

Water Supply Project

Melamchi, Nepal

This project is intended to provide a safe and effective drinking water supply in the Katmandu valley, to improve sanitary conditions there and thus to help the economic development of the valley. It includes a tunnel about 26 km long, three access tunnels (adits) and structures for diverting the river upstream of the valley. The tunnel and the adits are excavated using explosives in the Precambrian massif of the Himalayan complex, characterised by rock formations with high metamorphism. The strata concerned by the tunnel excavation are the gneiss, quartzites and schists. The support selected by the Project Manager consists mainly of radial bolts and shotcrete. Steel arches are to be considered in the areas where the rock is most degraded.

Works began in April 2010 with a first contractor, but were suspended in September 2012. In June 2013 a new contract was signed with CMC (Cooperativa Muratori e Cementisti di Ravenna). CMC requested the engagement as consulting expert of Marc PANET, who asked TERRASOL to assist him in his on-site assessment in April 2014. The aims of this assessment were to analyse the structures already completed (a total of about 6 km of adits and part of the main tunnel) and to put forward recommendations for the completion of the sections still to be excavated.

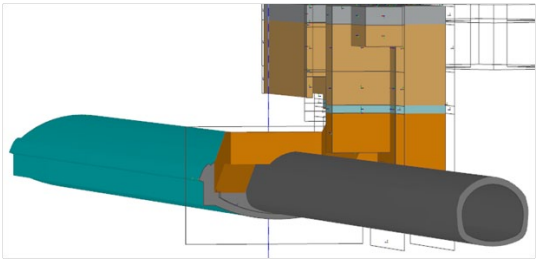
The assessment concluded that the short-term stability of the completed tunnel sections was satisfactory. However, works must be scheduled to improve the existing tunnel support in order to ensure the long-term integrity of the structure. In particular, systematic checking of the thickness and the quality of the shotcrete was recommended. Other recommendations covered the management of the geological difficulties likely to be encountered during the remaining excavation, and the optimisation of the works cycle and of the support/lining to be installed.

J.P. Janin

3D modelling of underground structures

Finite element calculations

The construction of an underground structure is a clearly three-dimensional problem. This is all the more valid for projects involving complex geometries, phased excavation methods or interactions with nearby structures.



Over the last few years TERRASOL has carried out several 3D finite element models of underground structures in order to optimise the resolution of the various issues arising in such projects: displacements generated at groundlevel and below nearby structures, design of the temporary support and the permanent lining, reinforcement of existing structures, etc. Here are 2 recent examples:

- Future extension of Paris metro line 14: the 3D modelling of the disassembly chamber of the Tunnel Boring Machine confirmed that the geometry defined for the structure and the selected excavation method enabled compliance with the settlement limits required for surface buildings.
- Metro station «Olympiades» (Paris line 14): a 3D model was built to investigate the effects on the existing structure of the construction of a new secondary access. This model was used to identify the areas of the station impacted to the greatest extent by the works and to define an appropriate monitoring system.

Through these numerous cases, we have developed our know-how, and determined the limits of such modelling. We are thereby able to propose relevant 3D approaches in accordance with specific issues and design progress of each project.

JP. Janin

Technical committees for underground structures

Frequently, for major underground structures projects, those involved in the works implement technical committees or expert committees in charge of monitoring work performance, with an outside view. These committees are implemented, either by one of the parties - project owner, project managers or construction companies - or jointly by several of these parties.

This is how I participated in several of these committees over the last few years:

- Metros: line B in Toulouse (France), line B in Lyon (under-river tunnel in Oullins, France), Cairo (Egypt), line B in Rennes (France);
- Roads: Lioran and Bois de Peu tunnels (France), La Bussière and Chalosset tunnels on the A 89 motorway (France), Miami tunnel (USA)
- Railways: Hallandsas tunnel (Sweden)
- La Praz – LTF decline - France

These committees help site managers in choosing major options in terms of methods and design, as well as in facing any difficulties encountered during the works. And this detached from daily constraints of the project, offering higher vision, and by engineers who have handled many projects in various contexts, therefore able to offer broad feedback. A role which seems to offer real added value, as these committees tend to multiply.

A. Guilloux

Recent publications and presentations

- « Mise en place de la méthode observationnelle pour la construction d'une tête de tunnel (LGV Est lot 47) » (O. Bril, E. Ducoin, R. Bourget and **S. Perrot-Minot**) – JNGG 2012 – Bordeaux, July 2012
- Keynote lecture: Management of settlements for an urban tunnel, Toulon, France (**A. Guilloux** and H. **Le Bissonnais**) – Geotechnics for Sustainable Development – Geotec Hanoi 2013
- 2D and 3D numerical analysis for the design of a TBM dismantling cavern to be excavated under sensitive buildings for Paris metro line extension (**JP. Janin**, A. Martin and O. Gastebled) – NUMGE 2014 – Delft, June 2014
- South Toulon tube : 3D numerical back-analysis on in situ measurements (**JP. Janin, H. Le Bissonnais, A. Guilloux**, D. Dias, R. Kastner and F. Emeriault), 8th International Symposium on Geotechnical Aspects of Underground Construction in Soft Ground, Seoul, August 2014
- « Puits de reconnaissance et essais en vraie grandeur pour une nouvelle gare RER à La Défense » (**J. Marlinge**, T. Perini, A. Martin and **H. Le Bissonnais)** – JNGG 2014 – Beauvais, July 2014
- « Tunnel de Saverne (LGV Est) : Déroulement des études géologiques et géotechniques en phase conception et travaux dans le cadre d'un processus de maitrise des risques » (**H. Le Bissonnais, P. Legrand,** PL. Veyron, A. Lacroix et A. Cuccaroni) – AFTES congress, Lyon, October 2014
- « Prise en compte des effets différés dans les ouvrages géotechniques enterrés » (**G. Tzimas**, **H. Le Bissonnais**, R. Witasse) – AFTES congress, Lyon, October 2014

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