La Lettre

TERRASOL

Special release ICSMGE 2013

From modelling to works supervision

Edito

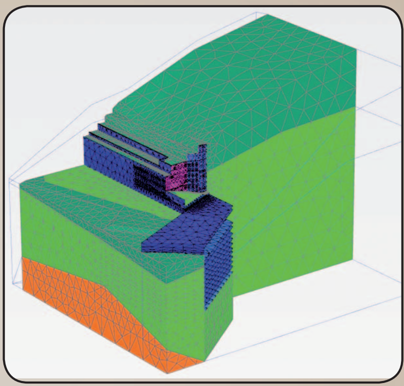
On the occasion of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, we propose this special issue of "La lettre Terrasol" with a compilation of some of our best papers published in this newsletter during the past 4 years.
It will give you an overview of our geotechnical know-how, and of the way it has been developed for recent projects in France and abroad, for any kind of construction: tunnels, bridges, buildings, industrial facilities, highways and railways, etc.
It also emphasizes our strong involvement in Research and development, both for new geotechnical approaches and for software development.
I hope it will give you a chance to get to know Terrasol better, and encourage you to come and visit us in our exhibition stand n° 34.

Alain GUILLOUX - CEO

3D modelling of geotechnical structures

Finite element calculations

More and more often, large-scale projects require complex stress-strain modelling for a better understanding of soil-structure interaction.
For a number of years, TERRASOL has been carrying out 3D finite element modelling for structures as varied as retaining structures (the Odeon Tower in Monaco, see opposite), foundations of complex buildings (the Louis Vuitton Foundation for Creation, the new High Court in Paris), underground works (the extension of Paris metro line 14), foundations of civil engineering structures (the Third Bosphorus Bridge), etc.



Let's consider 2 recent cases:

- The new High Court in Paris in the Batignolles area (a 160 m high building): the aim of the 3D modelling was to understand the behaviour and interaction of the deep foundations of the three building cores with the complex Paris geology. This model made it possible to better estimate the settlements and the load transfer within the piled-raft foundation system.
- The dismantling chamber for the metro line 14 TBM : this underground excavation is located below old buildings in the 8th Paris district. The 3D model was to prove that the compact shape of the structure and the chosen construction methods helped to limit settlements.

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.

A. Beaussier, P. Reiffsteck & A. Martin *(n°22, June 2013)*

Bretagne - Pays de Loire High Speed Railway Line

The Brittany – Pays de la Loire High Speed Railway Line project extends the existing Atlantique Paris – Le Mans HSR line inaugurated in 1989. Its objective is to significantly improve the service to Brittany and the Pays de la Loire and increase their accessibility. It is anticipated that the travel time between Paris and Rennes will be reduced by 37 minutes (to less than 1h30).

The PPP (Public-Private Partnership) contract was signed between RFF and the EIFFAGE group in the first quarter of 2011. The EIFFAGE group is responsible for the implementation of all aspects of the project, followed by line maintenance and renewal over a 25 year period. The main key figures are: 214 km of new line (82 km of high speed line and 32 km of connection lines), around 200 civil engineering structures including more than ten viaducts, and an estimated cost of 3.4 billion €. As the schedule is particularly tight, preliminary design surveys began in April 2011 and the studies have been completed by July 2012. The preparatory works began in July 2012.
Within the special project management group, comprising SETEC FERROVIAIRE (contract leader), SETEC INTERNATIONAL and SETEC TPI, TERRASOL was responsible for the management of the geotechnical surveys during the preliminary design phase as well as for the geotechnical studies for the civil engineering structures over a distance of approximately 120 km including 11 viaducts and 149 standard structures.

The survey campaign began in April 2011 and was completed in January 2012. An additional two month survey was subsequently launched in March 2012.
Geotechnical studies began in October 2011, before all soil testing results were available. To comply with the preliminary design completion dates, TERRASOL mobilised a team of over ten engineers. By the end of January 2012, we had almost completed the geotechnical studies for all the works, with a rate rising up to 20 structures / week. The review phase then took place between January and mid-May. This allowed for the incorporation of new data (laboratory results, additional surveys), of the various external control remarks made by Mr. Guilloux and Mr. Simon, and of the exterior control comments. A strong mobilisation of TERRASOL engineers was maintained up to 15.05.2012, date of the official preliminary design release. Since then, we have participated in the Visas phase, and in the follow-up of works on site.

This new experience in large infrastructures was acquired within a new contractual context given that we designed the project as well as participated in its construction. Our constant aim is to seek the best technical solutions while simultaneously optimising the project in terms of quantities, costs and schedule.
This experience will be particularly useful for the other high speed railway line PPP projects on which we are currently working such as the LGV SEA (between Tours and Bordeaux) where TERRASOL is carrying out the geotechnical works studies on several sections for VINCI, and the LGV CNM (between Nîmes and Montpellier) where the SETEC group forms part of the project management team alongside BOUYGUES.

A. Bergère & N. Li *(n°20, June 2012, updated in July 2013)*

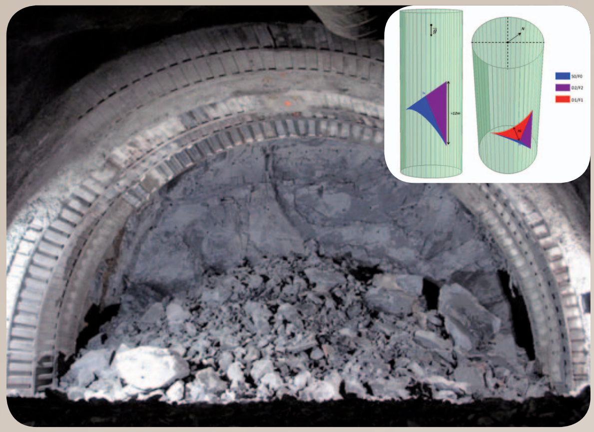
Chooz laboratory

Ardennes, France

// Excavation of cavern and shaft completed in 2012

Within the scope of the "Double Chooz" scientific experiment aiming to study the behaviour of neutrinos, the GUINTOLI - SOLETANCHE BACHY TUNNELS group of contractors is currently building an underground laboratory on the site of the Chooz nuclear power plant in the Ardennes region of France on behalf of CEA and CNRS, with project management by EDF. The detailed design was awarded to the TERRASOL (contract leader) – SETEC TPI group.

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 works, 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 *(n°20, June 2012)*

The Excavation of the Croix-Rousse Tunnel

Lyon, France

// Excavation completed on Sept 15, 2011

The Croix-Rousse urban tunnel (a single-tube structure 1,753 m long) connects the Eastern and Western halves of the Lyon conurbation. This is an outdated structure that does not comply with current regulations. As part of its full renovation and the work required to bring it into compliance with European directives, a safety tunnel (known as the "North Tube") needs to be built. This tunnel will also allow to provide a link between the Rhône and Saône rivers for soft transport modes (pedestrians, cycles and buses).

Within the grouping represented by Dodin Campenon Bernard, and as part of work package 3 (Design and Integrated Project Management) managed by SETEC ALS, TERRASOL took care of geotechnical aspects at every stage of the project, not only with regard to design (preliminary studies during the invitation to tender, project design and external control of the detailed design), but also during the works phase when it came to the earthworks required at the tunnel portals and to the tunnel excavation itself.

The excavation of the North Tube began in September 2010 and ended on September 15, 2011. The excavation works, which covered a distance of 1,726 metres, therefore took approximately one year: the construction of the portals, in loamy sand soil from the Miocene period, required the use of a roadheader and the installation of a heavy support structure (steel arches beneath forepoling that was not renewable on the Saône side and renewable over a distance of a hundred metres on the Rhône side). The remaining excavation work, which passed through a granitic and gneissic bedrock, was conducted with explosives (emulsion) and supported with a light bolted-shotcreted support. No major geological anomalies were encountered.

The project, which was executed in a sensitive urban environment, also benefited from a significant amount of monitoring work. In particular, an automated instrumentation system was installed on the Rhône side, allowing surface deformations at the site to be measured. The settlements, which totalled less than a centimetre, were shown to be as predicted.

B. Madinier & J. Voiron *(n°19, December 2011)*

Compensation grouting for underground crossing

Toulon, France

// Excavation completed on March 3, 2011

The second tube of the Toulon undercrossing was expected to be a much challenging project, due to the very sensitive urban environment and extremely complex tectonized geology. The experience of the 1st tube, built at the end the 1990s, proved it if needed. The passage under two 8 storey buildings was identified particularly difficult, as they had already undergone the digging of the 1st tube, and are located in the "worst" geology.

In spite of a very rigid support with face reinforcement by jet grouting columns, one of the buildings responded significantly with cracks in its finishing when the excavation approached it. Excavation was stopped. Several possible solutions were considered and it was decided to use compensation grouting.

The first phase consisted in pre-lifting the building by 12 to 15 mm, in order to "catch up" on the settlements that had already occurred. Excavation could then resume, by activating the compensation devices. With daily injections of 2000 to 3000 liters, building settlements were fully controlled in the range of ± 1 mm. A « first » in France, which allows considering using this method for other sensitive projects.

H. Le Bissonnais *(n°17, December 2010, updated in July 2013)*

Riviera Marcory viaduct

Abidjan, Ivory Coast

The construction of the third bridge in Abidjan will be one of the most symbolic projects of the 21st century in Ivory Coast.
This 1,500 m long viaduct with 30 piers is being constructed by BOUYGUES TRAVAUX PUBLICS and will be operated by the SOCOPRIM concession holding company. On BOUYGUES request, TERRASOL was involved early on in the project for the definition of the geotechnical surveys and an assignment to monitor the soil investigations carried out on site in November 2011.

The viaduct will be founded on 2 m diameter piles bored using hollow augers. These piles will be more than 80 m deep in the central part of the lagoon in order to be embedded into a layer of compact sand laying below a considerable thickness of muddy clay deposits.

This compact layer also includes a layer of deep clay with a lesser bearing capacity that required a precise definition of its stratigraphy, a definition made difficult by the erratic sedimentation conditions and the problems encountered during the investigations.
Indeed, given the depth of the boreholes that exceeded 80 m and the difficulties inherent in a lagoon environment, the soil testing campaign proved to be particularly complex.

These works were followed by the definition and analysis of static pile loading tests by Osterberg cell, as well as by the preliminary and detailed design.

T. Perini ***(n°20, June 2012, updated in July 2013)***

Raymond Barre Bridge

Lyon, France

Marking the South entrance of the city of Lyon, the Raymond Barre Bridge across the Rhone was designed in harmony with the entrance of the Confluences Museum, with a modern architecture featuring two outward-leaning arches. Working alongside the Project Manager, TERRASOL was entrusted with the study of the foundations of this structure, which is part of the project to extend tram line T1.

The 3-span bridge has a pier in the river (P1) and a pier on the edge of the bank (P2). Both piers will be founded on piles. The geotechnical context does not present any particular problems; the soil is composed of river alluvia becoming compact at depth before encountering the bedrock consisting of granite sand associated with the facies of the Jardin des Plantes.

The problems of the project essentially concern:

- the complex load distribution of the structure, due in part to the asymmetry of the deck which is embedded on the piers, inducing considerable transverse forces for the foundations;
- compliance with river traffic, which requires the area covered by the foundations to be restricted;
- difficulties related to construction in a river with a water depth of approximately 12 metres at pier P1.

Credit: balloide/SYTRAL

The calculations for the deep foundations of the piers were performed using the FOXTA software, its various modules making it possible to account for the behaviour of a pile group subjected simultaneously to transverse and axial loading.
The construction works were entrusted to the Bouygues TP/Matière/Zwalhen & Mayr consortium. The first stone was laid on the 24th of November 2011. SETEC ALS, with TERRASOL's assistance, carries out the works and studies Project Management for the civil engineering. The works began in April 2012 with the construction of the cofferdam for pier P2 and of the piles for abutment C3. The large cofferdam of pier P1 has now been completed and is awaiting the construction of the sixteen 1600 mm piles necessary to support this pier on which the steel structure will be embedded.

T. Rossi & B. Aksoy ***(n°21, December 2012)***

Third Bosphorus Bridge

Istanbul, Turkey

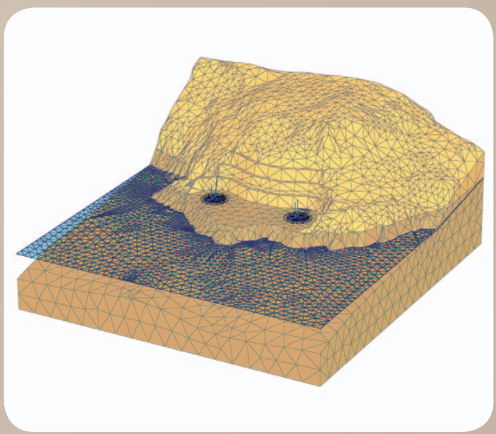
The Third Bosphorus Bridge is a cable-stayed suspension bridge with a single span of 1400 m linking the European and Asian shores of Istanbul (Turkey). Built by the Turkish-Italian consortium Içtas-Astaldi, its design was assigned to T-Ingénierie in collaboration with Michel Virlojeux. TERRASOL is currently carrying out the checking of the foundations design for SETEC TPI (Independent Checker for the project). As the first phase of this work focuses on design analysis, TERRASOL has also provided its advices for project optimisation, with the stability checking of the rock foundations, using 3D finite element calculations.

Constructed in a particularly demanding seismic context, the bridge lays on both shores on a rocky formation composed of andesite and conglomerates.
Each end of the bridge is composed of:

- A 15 m deep anchor block;
- A block comprising 2 m deep shear keys enabling anchoring of the cables;
- 4 piers;
- 2 shafts (20 m in diameter and 20 m deep) to anchor the 320 m high pylons.

These pylons will exert considerable forces in the construction phase, under the effect of the wind and during the installation of the deck, and in the final phase, under the effect of deck tipping and seismic actions.

B. Aksoy ***(n°22, June 2013)***



The Odéon Project

Monaco

// Excavation completed in 2013

The Odéon tower project in Monaco is exceptional, both by its height, 160 m, the tallest building in Monaco, and the depth of excavation required, planned to reach about 70 m maximum:

- 30 m temporary support: anchored "micro" soldier-pile wall then soldier-pile wall to create a horizontal platform at the superstructures base level,
- then 40 m diaphragm walls for the infrastructures, in top/down construction.

Within this project, carried out by the Vinci Construction France/Solétanche-Bachy pool, TERRASOL was entrusted with geotechnical consultancy on the soil testing, foundations... but also and mostly with the implementation of two 3D FE models to analyze notably the influence of the excavations on the surrounding buildings.

Built-up with the CESAR-LCPC and PLAXIS 3D software, these models are particularly "heavy". For instance, the CESAR-LCPC model includes explicit modeling of 366 prestressed anchors (adjustable in length), 48 micropiles, 22 piles, and over 500 m diaphragm walls and barrettes, as well as the structural elements of the underground levels, to which 57 computation phases must be added, with excavations per passes, activation of supporting elements, and gradual application of the tower's load ! Computing the entire model takes 36 hours.

A challenge for modelling engineers, taken up successfully thanks to the perseverance of our team !

A. Guilloux *(n°17, December 2010, updated in July 2013)*

Credit: Cédric Helsly for Soletanche Bachy

Fondation Louis Vuitton pour la Création

Paris, France

The « Fondation Louis Vuitton pour la Création » is a great project currently being constructed at the Jardin d'Acclimatation in Paris.

Its construction was entrusted with the architect Frank Gehry, author of many prestigious projects, including the Guggenheim museum in Bilbao.

More modestly for the geotechnical part, it is still an exceptional building, both by its structure and size, imposing very strict constraints on the foundations, and because it is built inside a 7500 m2 and 15m deep excavation.
This excavation is protected by diaphragm walls and was completed without any particular difficulties. However, the design of the raft foundation is more sensible, due to the presence of deformable clay layers (Sparnacian, False Clay and Plastic Clay), located 6 m below the raft foundation.

Although stresses are globally balanced between excavated earth and loads transfered by the building, the structure induces load concentrations exceeding initial stresses, whereas other zones are unloaded.

This is a new opportunity to develop 3D numerical modeling for accurate settlements analysis, where time effects must be considered. A geotechnical issue not much different from that of the nearby towers in La Défense.

Credit: Fondation Louis Vuitton – N. Borel

The observational method was developed during the construction, confirming the predictions of the models, especially a delayed but continuous heave of the raft, reaching about 1 cm. The main structure is now almost complete.

A. Guilloux *(n°14, June 2009, updated in July 2013)*

Note : The « Grand Prix National de l'Ingénierie » was awarded in 2012 to Claude Maisonnier (Setec Bâtiment, Setec group), Louis-Marie Dauzat (Quadrature Ingénierie), Marc Chalaux (RFR) and Matt King (T/E/S/S), for the « Fondation Louis Vuitton pour la Création ».

"Crystal Towers" project

Beirut, Lebanon

TERRASOL is assisting its local partner STS Consultants in the design of the foundation system for two towers (30 and 20 storeys) near Antelias Bridge in Beirut (Lebanon).

The geotechnical context of the site is marked by the highly variable top level of the bedrock (from 20 to 50 metres deep) and the presence of a loose silty sand horizon at the surface with furthermore a risk of seismic liquefaction.

These conditions justified the choice of a piled-raft foundation system with reinforced concrete piles 1.2 metres in diameter anchored to a depth of 3 to 5 metres in the bedrock. This system is combined with prior reinforcement against liquefaction by stone columns over a depth of 20 metres. The FOXTA v3 software was used for estimation of the foundations displacements and stiffnesses under static and seismic conditions, taking into account the group effect.

F. Cuira *(n°21, December 2012)*

Credit: SAYFCO

ALSTOM thermal power stations

Worldwide

Since the beginning of 2009, Terrasol led numerous geotechnical studies for thermal power stations worldwide on behalf of ALSTOM, a specialist in turn key facilities for power station projects.
In 2006, TERRASOL was first entrusted by ALSTOM with an expertise of the Tucuman site, Argentina, to identify the cause of disorders (settlements). Then, we worked in 2007 on the evaluation of the seismic input data for the Cycofos project in Fos-sur-Mer (France).

Since 2008, ALSTOM has regularly called upon TERRASOL's expertise for assistance in preparing bids, and many projects followed at the construction stage: Fos-sur-Mer (France), Terga (Algeria). Ghannouch (Tunisia), Tanjung Bin (Malaysia), etc.
As an example, the power station in Ghannouch, built for STEG (Tunisian company for Electricity and Gas), is characterized by heavy loads at ground level and an unfavourable geotechnical context marked by the presence of a loose fill layer downto 11m deep.
In order to limit settlements to allowable values, we proposed a piled-raft foundation with concrete precast driven piles (0.45m*0.45m) bound to the raft. The foundation system was designed using TASPIE+, and the design led to over 900 piles driven below the main buildings. Finally, finite element models allowed to validate the settlements under the structures and the impact of earthworks and water drawdown close to existing buildings. In addition, Terrasol provided geotechnical support during the construction of the driven piles and temporary supports.

J. Drivet & A.-L. Fauroux *(n°14, June 2009, updated in July 2013)*

Shah Deniz phase 2

Baku, Azerbaijan

The Shah Deniz phase 2 project is intended to extend the existing Sangachal land-based gas processing and oil production terminal operated largely by BP. The terminal is located on the banks of the Caspian Sea, 50 kilometres south of Baku in Azerbaijan. The new gas and oil refinery will be adjacent to the existing one.
The extension will include in particular a new gas production platform with a capacity of 16,000 billion m3 per year, with two additional auxiliary gas processing trains. It requires the construction of seven hydrocarbon product storage tanks.

The particularity of the site lies in the presence of "collapsible" soil with a thickness of 6 to 8 m. This surface layer mainly consists of sand grains bound in a silty-clayey matrix. The composition also includes volcanic compounds. This layer presents the distinctive feature of containing a lot of void and being sensitive to water addition. Wetting this layer causes it to collapse on itself with or without extra load. Conversely, in the natural state, this layer is protected by a crust and presents what could be described as good quality mechanical characteristics.

During the construction and operation of the extension, the protective crust may be damaged and the surface layer may thus get wet. Accidents, which have already occurred in the past on the existing terminal, may also cause wetting of this surface layer. To limit future settlement problems, the storage tanks will therefore be founded on piles reaching the lower layers.

Credit: ENTREPOSE Projets

In this special and rare context, ENTREPOSE PROJETS SAS entrusted TERRASOL with the geotechnical part and SETEC TPI with the structural aspects of the detailed design of the storage tank foundations.

C. Babin *(n°22, June 2013)*

Protection of a gas pipeline from erosion

Yemen

Transporting gas from the Marib' deposits in the middle of the country to Bahlaf on the coast of the Gulf of Aden, a YEMEN LNG "pipe" runs across almost 320 kilometres of sandy, stony and occasionally very mountainous deserts.
A 5 km section, permitting the passage from a high plateau reaching up to an altitude of 1,700 m to a plain lying 800 m below, is subject to hard geotechnical conditions: surrounded by high dolomitic cliffs that occasionally see massive rockfalls and located in a barely stable slope, this section also crosses over a series of oueds that, during the monsoon season, erode everything lying in their path.
Following an expertise assignment carried out in 2010 concerning the damages linked to this torrential erosion, TERRASOL was once again called on by TOTAL in March 2012, this time to send a TERRASOL engineer on site for a one month period. The works concerned:

- Supervision of works on a gabion and rockfill hydraulic structure,
- An expert assessment of all the redevelopment works carried out to date.

A. Beaussier *(n°20, June 2012)*

Algeria: the East-West Motorway

Algeria

TERRASOL has been extending its activity in Algeria and Maghreb for several years.
One of the major projects we dealt with in this region is the Centre part of the East-West Algerian motorway. The Project Owner is the Direction des Projets Neufs de l'Agence Nationale des Autoroutes (DPN/ANA). In this project, TERRASOL acted as representative for the SETEC group, and was entrusted with the management of technical assistance and external check by the Chinese contractor CRCC.

TERRASOL teams worked with CRCC in an unusual context: very prompt decision-making was required to achieve the works in a very tight schedule. And this was a true challenge considering both the international combination of cultures and techniques, and the geotechnical issues expected (and indeed met) in the Algerian mountains, among which serious instabilities of slopes and embankments.
7 sections were delivered in 2009, and one more key section through the mountains South East of Algiers (including two tunnels) was delivered in 2010, due to delayed land availability and postponing of soil testing campaigns and initial design.
This project was an opportunity for CRCC to demonstrate its ability in handling very large public works projects, and for TERRASOL to manage a multidisciplinary team with SETEC experts in roads, engineering structures, hydraulics, equipment and safety, etc.

P. Brossier & M. Yahia-Aissa ***(n°21, December 2012, updated in July 2013)***

Credit : Mur et viaduc - Lot M5 - Djebel Guantas

South Europe Atlantic High Speed Railway Line

Tours - Bordeaux, France

The Tours-Bordeaux South Europe Atlantic (SEA) HSL is the first High-Speed Line project based on the Public-Private Partnership (PPP) model in France. It will involve 340 km of new line, including 302 km of high-speed line and around 40 km for connection to the existing line. With the aim of commissioning in 2017 for a concession period of 50 years, various preparatory works and studies necessary for the first construction operations have been underway since 2010. TERRASOL has been taking part in this project since the summer of 2011 on several geotechnical construction missions (G3) to assist various teams in the design and construction sub-group COSEA:

- Standard (52) and specific (4) civil engineering structures of section B (work sections 3 & 4);
- Viaducts (4) with prefabricated segments crossing the Auxance, the Indre and the Claix rivers (with taking into account of the karstic context);
- Hydraulic retention tank in Ambarès-et-Lagrave;
- Soil reinforcement under the Dordogne Valley embankments.

K.V. Nguyen ***(n°21, December 2012)***

Dordogne Valley embankments

The SEA line passes through the Dordogne Valley near Saint André-de-Cubzac, a location known to geotechnical engineers for the experimental embankments built on soft organic clay, which have been the subject of numerous publications by the LCPC since the 1970s. The detailed soil-testing campaigns for the SEA project showed that it was also necessary to take into account the presence of a metre-thick peat layer for at least two of the three embankments to be built. The option chosen is to build these embankments on driven prefabricated rigid inclusions combined either with small concrete caps or with geogrids. At BALINEAU's request, TERRASOL carried out the pre-design of these various solutions with the aim of installing experimental plots equipped with instruments to compare the performances obtained and validate the design methods.

B. Simon ***(n°21, December 2012)***

East-European High-Speed Line

Saverne, France

Works on section H of the LGV EE (East-European High-Speed Line), from Danne-et-Quatre-Vents to Vendenheim (East of France), took an important step forward in 2011: all work packages were allocated and started, while work also commenced on the most emblematic structure of this second phase, the Saverne tunnel. Work packages 43a/43b, covering "Standard section", made the most of a favourable year for performing earthworks. "Viaduct" work packages 48 and 49 will enter the active work phase in early 2012.

Work package 47 involved earthwork at the tunnel's east portal to allow excavation of the first tube to commence in early November 2011.

Together with SETEC, Terrasol is actively participating in the Project Management of the different work packages: the Visa assignment led by the Parisian teams, plus the secondment of two engineers to the site to monitor the works covered by work package 47: the Saverne tunnel and the special engineering structures.

P. Legrand ***(n°19, December 2011)***

// Tunnel excavation completed in February 2013

East European HSL project - Credit: For the contractors group package 47
Photographer: JM BANNWARTH for Balloïde photos

ASIRI, a successful long-term project

2011 saw the successful completion of the national ASIRI Project devoted to soil reinforcement using rigid inclusions. It was launched in 2005 after various exploratory studies conducted as of 1999 with the support of the IREX and the RGCU. TERRASOL was involved in this collaborative research project for over 11 years, with Bruno Simon in charge of its coordination and technical management from the very outset.

Strong commitment on the part of all 41 partners allowed the project to keep within the initial budget (2.4 million euros) while meeting its objectives: better understanding of behaviour mechanisms and drafting Recommendations for the design (see opposite), execution and monitoring of these works (document published at the end of 2011 by Presses des Ponts). Events held in Lyon, Paris, Toulouse and Nantes to present these Recommendations highlighted the interest of this project by attracting over 400 participants.

TERRASOL's investment in this project has been considerable: in addition to the scientific management and coordination of experimental and numerical actions, we performed numerous studies to assess the data from test sites, took part in benchmarking exercises, and developed new calculation methods. Part of this work led to update the Foxta Taspie+ and Piecoef+ calculation modules. We also published several papers to present simplified but effective calculation methods.

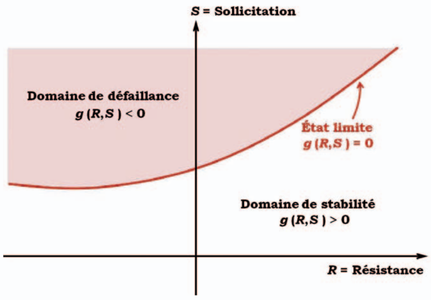
This project provides an exemplary illustration of what national research projects can bring to geotechnical engineering: the field of foundations is very much open to innovation insofar as it is able to benefit from experimentation and players with complementary skills.

B. Simon *(n°19, December 2011, updated in July 2013)*

Uncertainties and risk analysis in geotechnical engineering

Taking uncertainties into account is a constant concern in geotechnical engineering. Everyone involved in the profession seeks to reduce these uncertainties and their effects, by proposing for example:

- Actions aimed at reducing uncertainties concerning geotechnical data and anticipating more effectively the means to react to these uncertainties. These include for example two recent evolutions relating to standards: the publishing by French Tunneling Association of recommendation GT32 on the characterisation of uncertainties and geological, hydrogeological and geotechnical risks, and the current updating of French Standard NF P 94-500 which defines the geotechnical missions and minimum geotechnical investigations to be carried out in the frame of each project. TERRASOL took part in the working groups in both these cases;
- Actions enabling these uncertainties to be taken into account more effectively in the structures design; this is the issue which we have chosen to develop here, in connection with the Eurocodes in particular.



Since 2009, TERRASOL has undertaken research and development work focusing on risk analysis techniques and their applications in the design of geotechnical structures. This is in answer firstly to high demand from project owners faced with ageing infrastructures and a relatively undeveloped body of technical expertise in this area in France, and secondly to requests from construction companies for optimisation of projects in increasingly complex contexts, such as concessions for example. These techniques are based on a probabilistic approach derived from the reliability theory and are used to define the safety level with respect to a failure mechanism given in the form of a probability of failure or collapse of the structure.

Thus, in this approach, the geotechnical properties are random variables described by a probability distribution with a mean value and a standard deviation. Compared to conventional design by a deterministic or semi-probabilistic approach, the use of reliability engineering techniques enables to ensure a structure is safe when the geotechnical properties present significant scatter, or to optimise its design when the scatter is limited.

This work resulted in the development of a risk analysis tool based on the approximate method known as the "Response Surface Method" (RSM) which has proved to be effective in its applications on geotechnical structures. This tool will be progressively implemented in TERRASOL's calculation software in the form of a "reliability engineering design" wizard. This wizard will evaluate the probability of exceeding a limit state predefined by the user (bearing capacity, sliding, settlement, thrust, etc). The probabilities thus obtained are to be compared with the target probability values defined by Eurocode 0 for ultimate or service limit states.
The method which has been developed is also intended to clarify the application of the Eurocodes when numerical methods such as the finite element method or the finite difference method are used for the structures design.

F. Cuira & B. Simon *(n°22, June 2013)*

Geotechnical engineering and rehabilitation of structures

Rehabilitation projects for buildings or civil engineering structures include a geotechnical engineering component which must simultaneously meet technical requirements and provide an answer to Sustainable Development needs. This leads to re-use as much as possible the existing foundations to limit demolition and reconstruction work and minimise consumption of new materials.

Geotechnical issues are different from those of new projects and require different methodologies:

- investigations of existing foundations in order to check how they can be re-used;
- reinforcement of the existing foundations or creation of new ones, with loads redistribution questions;
- application of new regulations to old foundations which served their purpose for decades;
- selection of unusual and innovative construction techniques well adapted to these specific projects.

TERRASOL is currently committed to these goals both in a research project entitled Rufex (Re-Use of EXisting Foundations) aiming to develop the use of Soil Mixing with a retractable tool (Solétanche-Bachy process) for reinforcement of railway platforms and existing foundations of buildings, and in various building renovation projects in the Paris region.
Rehabilitation projects involve a desire to incorporate an element of the past in the buildings of the future and oblige us to rethink our engineering know-how.

A. Guilloux & T. Perini *(n°21, December 2012, updated in July 2013)*

Software Department

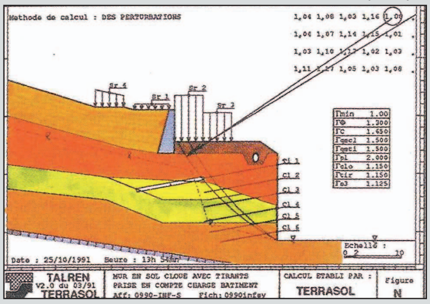
TERRASOL has been developing software ever since its creation in 1979. The development and distribution of advanced user-friendly geotechnical software has since become one of our significant activities, with a permanent team also providing support and training. Here's a short summary of the key facts for each of our software.

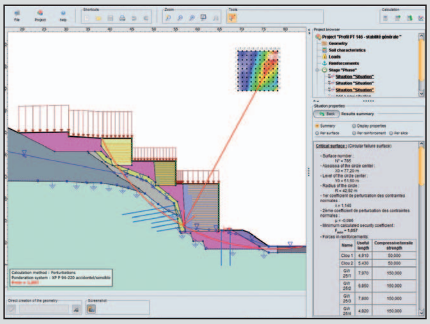
TALREN

***First version**: v1 in 1980*
***Latest version**: v5 in 2013*
***Number of licenses**: 1400*

The latest design tool for checking the **stability of geotechnical structures with or without reinforcements**: natural slopes, cut or fill slopes, earth dams and dikes, reinforced or anchored walls, etc. It takes into account various types of reinforcements, such as: anchors and soil nails, piles and micropiles, geotextiles and geogrids, steel and polymer strips.

Talren v2 (1991)

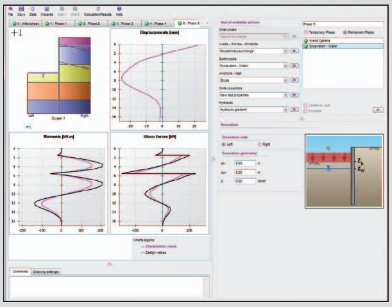




Talren v5 (2013)

K-REA

***First version**: v1 in 2004*
***Latest version**: v3 in 2012*
***Number of licenses**: 300*

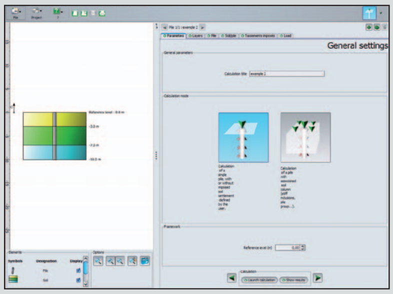


Retaining walls analysis using the subgrade reaction method: diaphragm walls, sheetpile walls, soldier pile walls, double-walls, cofferdams. K-Rea includes Eurocode 7 partial safety factors and ULS checks.

FOXTA

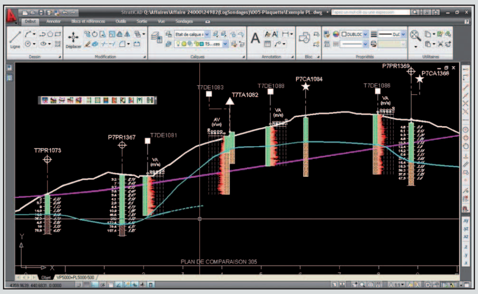
***First version**: v1 in 2000*
***Latest version**: v3 in 2012*
***Number of licenses**: 300*

Software suite for the design of foundations: shallow and deep foundations, interactions between several foundations, piled-raft foundations, stiff inclusions, pile groups... Foxta is composed of 8 modules, which can be combined or used in standalone mode.



STRATICAD

***First and latest version**: v1 in 2010*
***Number of licenses**: 15*



CAD module for geotechnics, enabling the semi-automatic processing of geotechnical data within drawings. Straticad combines efficiency, simplicity and graphical quality, providing significant time savings even when dealing with a small number of boreholes.

Recent publications: please ask for a USB stick on our stand n°34 for all our papers published in the past years

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