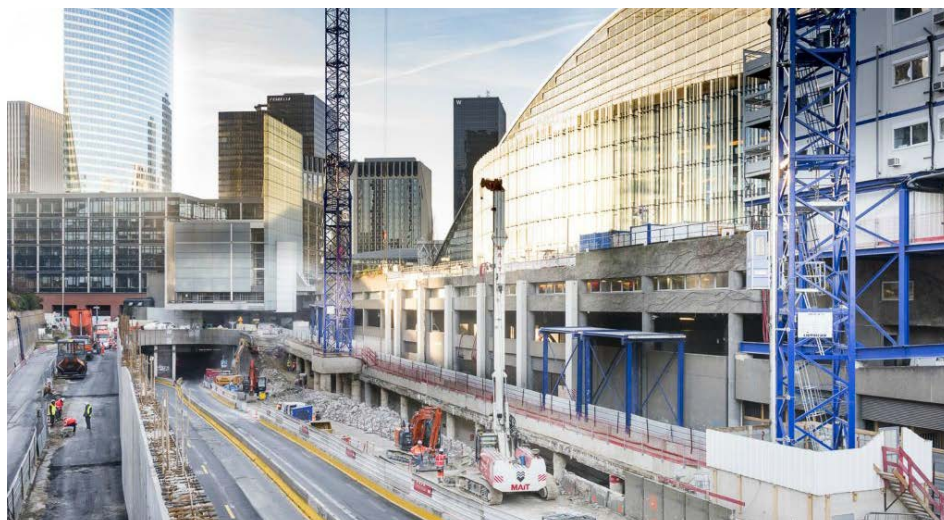


## Trinity Tower in La Défense, Paris



Soletanche Bachy - @ Cédric Helsly

As part of the Trinity Tower project, TERRASOL has designed the tower foundation system, on behalf of UNIBAIL-RODAMCO (SCI Trinity Défense), and has carried out an assignment of works follow-up during the execution stage, within the project management consortium SETEC/CROCHON CBA/ARTELIA BÂTIMENTS ET INDUSTRIES.



© SCI TRINITY DEFENSE (UNIBAIL RODAMCO) / Crochon Brüllmann + Associés / L'autre Image Production

The foundations for this 33-floor building must satisfy several conditions which are specific to the particular site of La Défense (Paris): limited floor space, underground space occupied and preloaded by the parking lots and foundations of the CNIT and Coupole buildings, necessary control of the deformations induced below neighbouring buildings. In addition, their implementation must be performed without interrupting the traffic of the RN192 main road, located under the future tower. They are anchored in the Lutetian marls and stones layer, immediately above the coarse limestone slab and the Ypresian clayey layers, the behaviour of which has an impact on the long-term settlements of the tower. These constraints have resulted in the design of a foundation system comprising four rows of micropiles (marked A to D) and a

row of buttress piles (close to row A) to take up the horizontal loads. There are a total of 994 micropiles and their length vary from 9 to 27 m, depending on the rows.

The design of the foundations (2012-2014) was based on the pile testing method, which recommends carrying out compliance tests before the execution phase. The studies took into account the soil-structure interaction via the development of a flexibility matrix which links the displacement at the top of each support zone to the load distribution for the whole project. These results are extracted from a PLAXIS 3D modelling, in which the behaviour of the foundations could be finely calibrated thanks to preliminary calculations performed with FOXTA software. Together with SETEC TPI's structural model, the flexibility matrix enables to determine with one single iteration the final reactions of the supports.

TERRASOL carried out the VISA phase from the end of 2015, checking the documents produced by BATEG company (VINCI group). And works began in early 2016. The micropiles were executed by VIPP (subcontractor) between March 2016 and June 2017, with several interruptions due to the project phasing in order to guarantee traffic continuity. 12 compliance tests certified the good quality of the marls and stones layer and of the coarse limestone, as stated in our reports. 18 control tests validated the successful execution of the micropiles and the design of the foundation system proposed by TERRASOL. Only 6 micropiles (out of 994 executed) required a non-compliance report (due to layout or quality/quantity of grout).

## Édito

In 2017 TERRASOL has been active on all fronts: "Grand Paris Express" and general urban transport projects, towers and exceptional buildings, port and airport facilities, industrial installations...: all these works require extensive geotechnical analysis, in order to ensure both their safety and optimization. We would like to deeply thank our team who worked hard and addressed these many topics!

Nevertheless, the year 2018 also promises to be full of new challenges: at this very moment, due to increasing demand, we are expanding and strengthening our team so that we can meet all our customers' requirements: geotechnical syntheses; design assignments (including complex 3D modelling); works supervision services (either within project management teams, or together with the contractors); all of which are fields in which TERRASOL has a strong expertise.

This TERRASOL's Newsletter issue illustrates some of our ongoing projects here in France and overseas, as well as some of the scientific developments we are currently working on.

The whole TERRASOL team wishes you a very happy New year !

V. Bernhardt

In line with the CNIT sensitive structure, the row A is the deepest one: an excavation 130 m long and 10 m deep was executed in the marls and stones layer, supported by a parisian retaining wall on its whole height, and anchored at 2 levels. Earthworks, retaining structures and foundations works in this zone were brought to completion between July 2016 and February 2017.

To date, sidewalls are finished and the slab is under construction. Ongoing monitoring of the retaining structures displacements shows good results, as measures are within the thresholds defined by TERRASOL and BATEG: vigilance threshold is at half of the value predicted by the calculation; alert threshold is at 80%; interruption threshold is at 100%. Targets were to be installed under the core of the tower this November in order to set the settlements initial state.

The Trinity Tower delivery is scheduled for the first term of 2019.

A. Bergère, KV. Nguyen and E. Cazes



## A new terminal for Male Airport

### Maldives



Photo credit: Thinkstock

As part of a Design & Build contract for the construction of a new terminal for the Maldives airport, SETEC group works along SAUDI BEN LADEN GROUP, contractor to which the construction was awarded, on the two main study phases: preliminary design and detailed design.

TERRASOL worked on this project within SETEC teams: during the first phase, we defined the soil investigations program, and prepared the specifications for this testing, adapting them at best to the specific site context, to the soil layers and characteristics, and to the resources available locally.

Following the analysis of the soil investigations results, TERRASOL proposed and studied several solutions for the terminal foundations (shallow, deep, by soil improvement or reinforcement). We finally oriented the design towards a solution of deep foundations, well adapted to the stratigraphy presenting sandy deposits on a substratum of coral sedimentary rocks.

During the detailed design phase, TERRASOL also ensured the review of the solution of driven piles made of pre-stressed reinforced concrete, which were being executed, carrying out the analysis of the implementation method, of the calculation reports and of the dynamic loading tests reports.

A. Abboud

## Aisne-Meuse dams

### Picardy, France

The project to modernize Aisne's and Meuse's dams consists of the replacement of "needle" dams, built at the end of the 19<sup>th</sup> century, with automatic dams equipped with water-inflatable sealing, in order to improve navigability, to secure agents, as well as to optimize and to increase the reliability of the current rivers management.

The Design & Build consortium COREBAM (several companies of VINCI CONSTRUCTION FRANCE) entrusted TERRASOL with the detailed design of the temporary and permanent sheetpile retaining structures for 9 of these new dams, located between Revin (08) and Verdun (55), as well as in the Soissons commune (02).

The dams studied by TERRASOL each consist of:

- A fish pass to ensure fish continuity,
- Two/three steps of the dam water-inflatable sealing system,
- One/two river piles and two connecting abutments (one on each bank),
- A technical room accommodating the equipment control devices for the operation of the water-inflatable sealing.



Photo credit: Corebam

The studies carried out allowed us to propose various solutions for the retaining structures construction, as well as technical optimizations, while taking into account the soil layers heterogeneity and execution constraints (limited space, presence of existing structures, sheetpile driving limit, ...).

KV. Nguyen and A. Preotu

## Spatial variability: application to earth dams

### Scientific developments

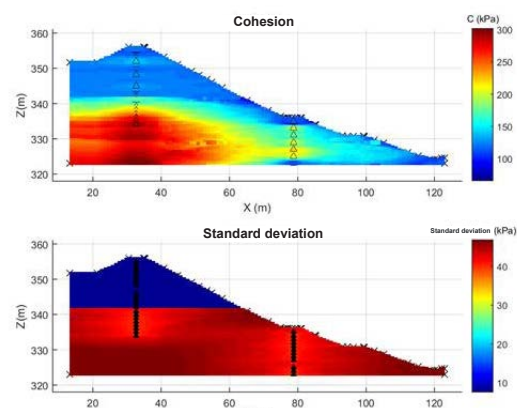
Geotechnical structures verifications generally follow deterministic approaches and take into account partial or global safety factors. These safety factors are evaluated so that for standard cases, the safety level of the structure respect failure probabilities (or reliability indexes) imposed by normative documents. A standard uncertainty on the input data is considered for the calculation.

We are presently developing at TERRASOL, in collaboration with EDF / CIH, an approach that enables to assess the spatial dispersion of the design parameters in association with the failure index. The position of the geotechnical input data is used to optimize calculations so that natural dispersion is no longer considered as a true measurement uncertainty, but rather as additional information to be included in the calculation.

The method consists in defining distances and models of spatial correlation for the geotechnical parameters. The model is then divided into independent macro-elements, with sizes equivalent to correlation distances. We chose to use Kriging method here. It is an interpolation method that integrates spatial correlation, which is able to evaluate the error expectation and standard deviation for each macro-element according to the position of the data. The standard deviation is then the lowest at the position of the data. The Kriging method is associated with the probabilistic Response Surface Methodology, or RSM. Fast and reliable, this method makes it possible, with a limited number of deterministic calculations, to accurately calculate the structure's reliability index  $\beta$ .

This method has been tested on a real earthworks project and provides encouraging results. A higher level of safety is ensured for this project due to the accuracy provided on the location of the critical soil areas, when compared to standard deterministic or probabilistic methods.

A. Bergère, H. Pillard and F. Cuira



## 5-star residence "L'Hévana" at Méribel les Allues France

In the heart of the Méribel les Allues ski resort, PIERRE & VACANCES equips itself with a prestigious residence composed of 95 apartments.

The execution of the foundations and retaining structures of this architectural complex, built on top of four levels of underground parking, has been attributed to FRANKI FONDATION with an alternative solution which replaces the piles of the initial project design with shallow foundations (footings and rafts) supported by stiff inclusions.

FRANKI FONDATION entrusted TERRASOL with an assistance assignment, and we contributed with our geotechnical expertise by providing the design and verification of the foundations of the alternative solution:

- Definition of geotechnical calculation models in a heterogeneous context: located in Doron's axis (the Doron is a stream canalised and backfilled in the 80s), the site is composed of relatively compact fills of fluctuating thickness overlaying moraines of variable thickness.
- Definition of inclusions meshes and adjustment of the geometry of the rafts and footings foundations in order to control deformations taking into account the heterogeneous geotechnical context and loading conditions. This step required multiple iterations with the structural design office.
- Geotechnical verifications of the foundations system.

A. Beaussier

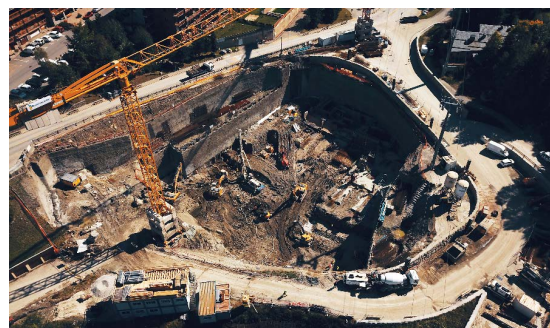


Photo credit: Franki Fondation

## Liquefaction hazard analysis Scientific developments

TERRASOL is frequently called on for liquefaction hazard analysis (by SNCF, EDF, CEA, etc.). Nowadays, these are systematically conducted using the semi-empirical procedure known as «NCEER», formalized by Youd and Idriss (2001) after the NCEER / NSF workshops in 1996/1998: this procedure consists in the introduction of safety factors by comparing the project earthquake-induced shear stress (CSR) with the cyclic shear resistance of the site materials (CRR), based on in-situ testing results.

This is an opportunity for us to identify the ambiguities, and/or inadequacies, of the specific recommendation guides and the existing normative frameworks.

Regarding this matter, TERRASOL is conducting a review about the main sticking points of the NCEER procedure implementation in the normative framework applicable to the various categories of structures, and in connection with the initial assumptions of the validity domain defined by its authors. These considerations have resulted in the ongoing development of a dedicated software.

This tool will incorporate additional indicators existing in the scientific literature: spatial arrangement of cumulative liquefiable thicknesses, liquefaction potential index, severity index with respect to liquefaction. Together with the evaluation of seismic-induced settlements, they will allow to provide spatial perspective to the analysis which is limited to safety factors, offering the prospect of multi-criteria hazard mapping.

M. Hodge and F. Cuira



Photo credit: 松岡明芳

## Regional Express Train in Dakar Senegal

The construction of the Dakar regional express railway line is part of the Senegal's economic development plan. Its two main functions are to provide services for the Dakar suburbs, replacing the existing "Petit Train de Banlieue" (PTB), and a connection with Blaise Diagne International Airport (AIBD).

The Dakar TER project is divided into two phases. Phase 1 covers the development and widening of the existing infrastructure between Dakar and Diamniadio stations (36 km), and phase 2 consists in the construction of a new line between Diamniadio station and AIBD airport (19 km).

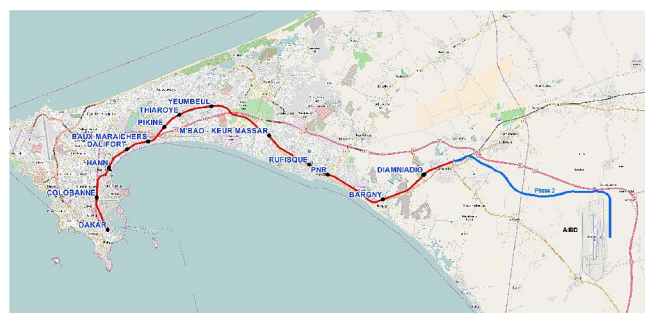
EIFFAGE entrusted the SETEC group with the project studies and with technical assistance throughout the works phase. Within the SETEC project teams, TERRASOL is responsible for the geotechnical analysis of the foundations of the structures along the whole of the alignment. Approximately a hundred structures are concerned: road bridges, railway bridges and footbridges.

The geology varies greatly along the alignment. Essentially, the project can be divided into three distinct geological sectors:

- Sector 1: 21 km at the Dakar end, comprising dune sands between 15 and 40 m thick;
- Sector 2: around 20 km in the central part, with marly and marly-limestone layers, overlain by a clayey layer;
- Sector 3: the last 14 km at the airport end, with sandstones, clays and laterite deposits.

One of the major challenges of this project is its schedule, since the railway should be ready to operate by January 14, 2019. To date, studies for Phase 1 have been completed and those for Phase 2 are in progress.

S. Delattre and KV. Nguyen





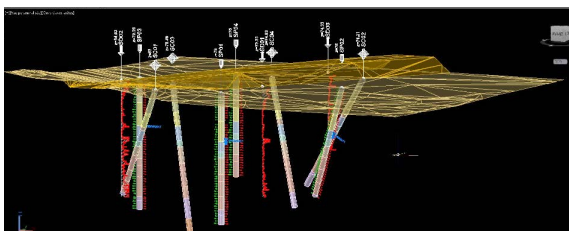
# Software department



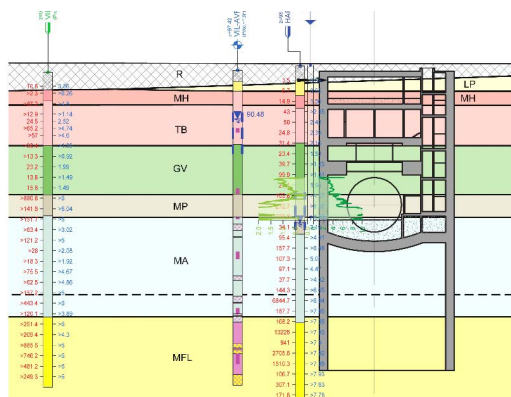
## Stratcad v2.0

For quite some years, TERRASOL has been developing and marketing Stratcad, a module specially designed to draw geotechnical data using C.A.D software. It includes layout tools and borehole log creation tools, all of which are largely user-customizable.

The new v2.0 version is a major evolution. In addition to the basic features, it now allows to build and implement 3D borehole logs. Volumetric objects are perfectly handled.



Soil investigation data can be represented in the 3D model in the form of volumetric objects, taking into account the possible boreholes inclination. The data is projected onto one or more cross-sections which, in turn, enable the elaboration of a geotechnical profile.



M. Anic-Antic

## Conferences

Terrasol has recently participated in the following conferences:

- International Conference on Soil Mechanics and Geotechnical Engineering (ICSMGE), Seoul (South Korea), September 2017
- 8<sup>th</sup> edition of the African Geotechnical Days, Lomé (Togo), November 2017
- International AFTES Conference, Paris, November 2017
- Géorail International Symposium, Marne-La-Vallée (France), November 2017
- 2017 IGC Conference (Indian Geotechnical Conference), Guwahati (India), December 2017

Geogrup, our distributor in Turkey, also represented us during 2 events in Turkey:

- 3<sup>rd</sup> International Soil-Structure Interaction Symposium, October 2017
- 7<sup>th</sup> Geotechnical Symposium, November 2017

## Training

You are more and more participants each year to attend our training sessions (whether public or in-house).

The sessions are a great opportunity to focus on different geotechnical topics, going much further than discussing our geotechnical software themselves.

The next sessions scheduled in France are the following:

- Talren v5 in Paris on March 27<sup>th</sup> 2018
- K-Réa v4 in Paris on March 28<sup>th</sup> 2018
- Foxta v3 in Paris on March 29<sup>th</sup> and 30<sup>th</sup> 2018

But we also plan sessions in Morocco, Senegal, and many more countries.



Training for the Roads Authority in Morocco (Oct 2017)

M. Huerta

## Recent publications and presentations

- "Bases de l'interaction sols-structures sous séisme : principes généraux et effets inertiels" (S. Brulé and **F. Cuira**) – Fascicule C251 des Techniques de l'Ingénieur, July 2017
- "Pratique de l'interaction sol-structure sous séisme" (**F. Cuira** and S. Brulé) - AFNOR Éditions, December 2017

### International Conference on Soil Mechanics and Geotechnical Engineering (ICSMGE), September 2017

- Deep foundation systems of ultra-rise buildings: the Entisar tower in Dubai (G. Pereira, H. Poulos and **A. Bergère**)
- "Etat de l'art sur les méthodes de calcul d'un pieu et d'un groupe de pieux sous chargement sismique" (**J. Perez Herreros**, **F. Cuira**, P. Kotronis and S. Escoffier)
- "Approche simplifiée par calcul semi-analytique pour le dimensionnement d'inclusions rigides sous semelle" (**N. Frattini**, **F. Cuira** and B. Hor)
- "Apport des éléments finis dans le dimensionnement d'écrans de soutènement par rapport aux méthodes classiques : étude de cas Gare Fort D'Issy Vanves Clamart" (**K. Nejjar**, D. Dias, **G. Chapron**, **F. Cuira**, **H. Le Bissonnais** and V. Fluteaux)
- "Glissements sous-marins fréquents au niveau de Cap Lopez au Gabon en Afrique de l'Ouest" (E. Green, **B. Simon**, **C. Babin** and **KV. Nguyen**)

### International AFTES Conference, Paris, November 2017

- "Méthode 3D simplifiée pour la prévision des tassements générés par le creusement d'un tunnel au tunnelier pressurisé" (**JP. Janin**, P. Renier and **H. Le Bissonnais**)
- "La ligne 15 Sud-Ouest du Réseau de Transport du Grand Paris : conception et enjeux géotechniques du tronçon T3C" (**H. Le Bissonnais**, **G. Chapron**, P.L. Veyron, G. Pons and V. Fluteaux)
- "Apports de la modélisation aux éléments finis des excavations profondes dans l'Argile Plastique dans le contexte particulier du projet Grand Paris" (**K. Nejjar**, **F. Cuira**, **G. Chapron**, **H. Le Bissonnais** and D. Dias)
- "Conception technique de la gare RER sous le CNIT à Paris-La Défense : maîtrise des risques constructifs dans un environnement complexe" (L. Canolles, **J. Marlinge**, L. Berend, F. Lanquette and M. Pré)
- "Méthodologie de détection des zones déstructurées et des cavités dans les terrains gypseux parisiens le long de la ligne 16 du Grand Paris Express" (E. Egal, C. Kreziak, A. Saitta, **J. Marlinge** and G. Priol)



Scan this QR code with your smartphone

### Head Office

Immeuble Central Seine  
42-52 quai de la Râpée  
75583 Paris Cedex 12  
France

Tel: +33 (0)1 82 51 52 00  
Fax: +33 (0)1 82 51 52 99  
Email: [info@terrasol.com](mailto:info@terrasol.com)

### Rhône-Alpes office

Immeuble le Crystallin  
191/193 cours Lafayette  
69458 Lyon Cedex 06  
France

Tel: +33 (0)4 27 85 49 35  
Fax: +33 (0)4 27 85 49 36  
Email: [lyon@terrasol.com](mailto:lyon@terrasol.com)

### Representation in Morocco

Setec Maroc  
3, rue Abou Hanifa  
Agdal  
Rabat-Morocco

Tel: +212 (661) 25 53 89  
Fax: +212 (529) 03 64 00  
Email: [t.elmalki@terrasol.com](mailto:t.elmalki@terrasol.com)

### Terrasol Tunisia

2, rue Mustapha Abdesslem  
El Menzeh  
2037 Tunis  
Tunisia

Tel: +276 71 23 63 14  
Fax: +256 71 75 32 88  
Email: [info@terrasol.com.tn](mailto:info@terrasol.com.tn)