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# A bridge over the Gambia River

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Gambia is a country located along the border on the river with the same name, and virtually divides Senegal from West to East, thereby making travelling by land between Casamance and the capital complicated. Until now, the Gambia River was crossed by a ferryboat allowing only a limited flow of traffic with haphazard reliability. For this reason, various studies for a crossing have been undertaken since the 1970s with an initial ground investigation campaign (by BCEOM in 1972), in parallel with economic and layout studies.

These studies were resumed by the Gambia River Basin Development Organization (OMVG) in 2010 with funding from the African Development Bank, which led to a call for tenders for the construction of this structure. A consortium composed of STUDI INTERNATIONAL and SETEC TPI, together with TERRASOL, is the tenderer appointed for the project management during the construction phase.

The tender file defines the crossing structure as a pre-stressed segmental bridge, 942 m long between abutments, with access embankments of approximately 600 m and 900 m on either side.

The geological setting consists of fine alluvium deposits in the river bed, with compressible areas of mangrove for the accesses. The ground investigation highlighted the following issues: low compacity of the fine alluvial deposits in the first few metres of the river bed, and compressibility of the foundation soils below the access embankments (organic clays).

Therefore, the following solutions were considered:

- Long piles under the bridge supports, executed using driven steel tubes,
- Consolidation of the soil layers below the low embankments,
- Lightweight embankment (polystyrene) below the highest embankments.

The technique specified to execute the piles was actually applied in the construction phase, because it seemed to be the most suitable technique considering the geotechnical setting and the available construction resources available locally.

For the access embankments, the contract originally included the validation of the technical solutions by executing an instrumented test embankment. However, due to the site's organizational difficulties, the test embankment could not be executed until very late on, and the interpretation of the measurements obtained (controlled by TERRASOL) concluded that the consolidation times would be lengthy, and could lead to postpone the commissioning date for the structure. As the Owner did not want to delay the commissioning (a toll will be applied so any delay would result in operating losses), the decision was taken with the contractor to switch to access piers supported by driven piles.

Throughout the construction engineering process, TERRASOL handled various project management assignments:

- Verification and validation of the assumptions and calculations provided by the Contractor,
- Contribution to adaptations and technical changes to the project,
- Expertise on soil/structure interaction with complex soil behaviour (pile groups under vertical, horizontal and torsional loading; soil consolidation with creep behaviour), using Foxta software.

TERRASOL engineers are proud to have played their part in this major cross-state mobility project in West Africa.

J. Drivet

# Editorial

Terrasol experienced intense activity during the 1st six months of 2018, and this pace is expected to continue throughout the rest of the year. Therefore, we have expanded our teams accordingly over the last few months, with many recruitment actions since the beginning of the year in Paris and Lyon. We currently employ over 70 people, and this workforce has steadily grown over the years.

Our on-site teams are also becoming progressively larger, as works begin for the different work packages for the "Grand Paris Express", soon with 8 engineers on-site with the project management teams. Furthermore, two of our engineers are currently working with the Setec team in Birmingham, England, on the "High Speed 2" railway project.

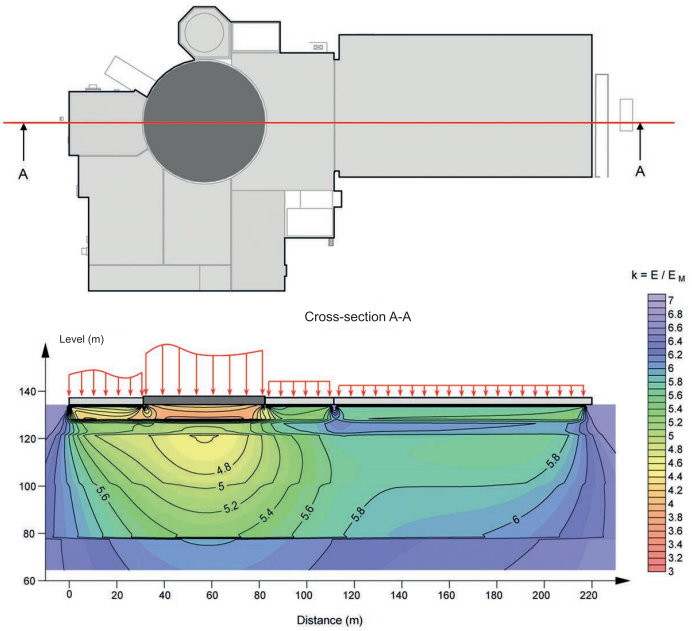
And what's more, the "French Days for Geotechnical and Engineering Geology" (JNGG 2018), which were held in Marne-La-Vallée in June, were a good indicator of the enthusiasm and technical expertise of our teams, as Terrasol published and presented more than 10 papers: these papers concerned geotechnical projects to which Terrasol has contributed, or covered our latest scientific developments (calculation methods, software, etc.).

This issue of the Terrasol Newsletter continues on the same theme, illustrating the diverse aspects of our activity to serve our customers and partners.

V. Bernhardt

# How to better account for soil/structure interaction

## Scientific developments




*Accounting for the variation of the modulus with the strain level in the Tasplaq program. Example of a nuclear power plant unit. Map of the E/EM ratio in each point of the ground soil (where EM is the Menard pressuremeter modulus)*

Foundations and structures (buildings, towers, bridges, etc.) are currently designed based on Eurocodes, combining various sets of partial factors to provide an appropriate overall safety factor for both serviceability limit states and ultimate limit states. Therefore, all construction projects rely on these texts to ensure an acceptable level of reliability and robustness.

In most cases, the design of foundations and supported structures is checked separately due to the artificial division between structural and geotechnical engineers. Besides, the navigation through the various existing normative texts (Eurocode 1 for actions, Eurocode 2 and 3 for reinforced or pre-stressed concrete and steel, Eurocode 7 for geotechnical design and Eurocode 8 for seismic design) remains difficult. In this context, in many cases, structural and geotechnical engineers provide their own design verifications without necessarily taking into account the interactions between structures and foundations.

In the last few years, TERRASOL has tried to bridge this gap between structural and geotechnical engineers in order to deal with the design of foundations and supported structures in the same time. For each project, principles of soil-structure analysis are promoted and the results obtained by this approach are highlighted. The overall design of the structures can thus be largely optimized and this results in cost-effective projects with increasing levels of reliability.

Soil-structure interaction implies the calculation of displacements for both the structure and the foundations. In this aim, TERRASOL is developing a complete range of software suites to calculate both vertical and horizontal displacements of foundation systems. All the programs are based on hybrid calculation methods that combine the behaviour of both ground and structure and are dedicated to specific applications. They permit to reduce calculation times making it possible to quickly perform sensitivity analysis, which are recommended for all projects. This approach avoids the systematic use of general numerical modelling methods that remain complex to handle.

For a long time, the calculation of foundation settlement based on the theory of elasticity has been problematic. If poorly handled, this theory often leads to pessimistic results for the assessment of settlements. To go one step further, TERRASOL has initiated new developments in the programs of the FOXTA software suite, as part of the ARSCOP French national research and development project (“New approaches of ground investigation and geotechnical design with pressuremeter tests”) in order to account for the specific small strain behaviour of ground. By considering this type of behaviour, settlement predictions can be improved, meaning that foundation design can be significantly optimised beyond the safety factors.

In the specific case of the TASPLAQ module, the aim is to define the soil deformation modulus (often measured by pressuremeter tests) as a function of the strain or stress level.

F. Cuira and S. Burlon

# Extension of the RER E railway line to the West of Paris

## Paris, France

TERRASOL is currently conducting VISA (control) and DET (works supervision) geotechnical assignments, within SETEC TPI teams, in the framework of the project management for the extension of the RER E railway line to the West of Paris (EOLE project). Our assignment focuses on the structures in the "La Défense" sector: tunnels (traditional excavation method), new station below the CNIT building, together with ancillary and connecting structures. TERRASOL is responsible for the on-site geological and technical supervision of excavations and geotechnical works, and for the follow-up of displacements. The project is entering its second year of full activity.

The underpinning operations are taking shape: the foundation shafts for the Régnault car park are being excavated on the eastern tunnel side; for the future station itself, 90% of the 1560 micropiles designed to temporarily underpin the internal structures of the CNIT building have been completed, and 10% of the columns loading have been transfered. The execution of the final underpinning structures (slab and shafts) will begin in the summer.

In the East, a shaft and 50 linear metres of the main tunnel have been excavated, requiring a major drawdown of the water table. For the tunnel to pass underneath the EXALTIS tower (sensitive structure), compensation grouting is planned: the conditioning and pre-lifting phases were completed in April 2018. In the West, the diaphragm walls of the cut-and-cover and of the open-cut are finished, after localized grouting was employed to seal the ground following significant mud losses.

The structures are planned to be commissioned in 2022.

F. Asselborn and J. Marlinge

# A building with very sensitive rafts

## Les Mureaux, France

For the construction of the assembly facilities for the future Ariane 6 launch vehicle, TERRASOL joined forces with VINCI CONSTRUCTION FRANCE on a co-design project for ARIANEGROUP, to take on an extraordinary challenge.

The N80 building, which is located on the southern banks of the River Seine in Les Mureaux, will be dedicated to the manufacturing of the oxygen and liquid hydrogen tanks for the future launch vehicle. The heavy equipment to mill and weld the tank components requires foundations that limit differential settlements to a few dozen microns! This exceptional requirement will enable processes to be automated, thereby drastically reducing costs and increasing current launch frequencies.

TERRASOL has produced several 3D finite element models (with PLAXIS), with a very high level of accuracy, to study foundation solutions for this N80 building. The final solution involved piled rafts to comply with the operational requirements: the first raft measuring 53 m x 12 m x 4 m is founded on 315 piles, whereas the second raft measuring 11 m x 4 m x 2 m is supported by 14 piles. Acceptance testing is in progress and the first measurements are consistent with the expected results.

This immense technical challenge was made possible through the collective work of all the disciplines involved, coordinated by ARIANEGROUP.

C. Babin, Y. Abboud and P. Kuhn

# A high-speed railway line between London and Birmingham

## England


The HS2 project consists in the construction of a high-speed railway line linking London to Birmingham (phase 1) and then to Manchester and Leeds (phase 2) in the North of England.

Phase 1 of the project, which is currently underway, involves a 200-km section between London and Birmingham. It has been divided into 7 work packages that have been allocated to several consortia.

Two of these work packages were awarded to Eiffage-Kier, which entrusted the DJV composed of SETEC, ARCADIS and COWI to perform the design of the C2 and C3 central work packages, which cover a distance of 80 km, including 17 viaducts, 3 cut-and-covers, and major earthworks (embankments up to 14 m high, and cuttings nearly 30 m deep).

TERRASOL is part of the SETEC team on the project platform in Birmingham; this multidisciplinary team is involved in the earthworks studies for both the C2 and C3 work packages: geotechnical studies, drainage, environment, landscaping, BIM, etc.

B. Madinier

# Cigéo project for Andra

## Bure, France

For the Cigéo project, TERRASOL has been commissioned by ANDRA (French National Agency for the Management of Radioactive Waste) to develop an engineering approach for the design of tunnel segments with compressible material planned to be used as the internal structure for the galleries and cavities that will be excavated in the Callovo-Oxfordian layer, a geological formation with deferred behaviour, for future deep geological facilities for the disposal of radioactive waste in Bure.

The study initially focused on an exhaustive analysis of the measurements provided by the Meuse/Haute-Marne underground research laboratory (LSMHM) and in particular, measurements taken from the GRD4 gallery that was excavated with a road header TBM in 2013. The analysis of 4 years of measurements taken by the sensors installed within the argillite and segments enabled to adjust the computation model developed with FLAC numerical code in order to model the construction of the gallery and the behaviour of the whole system during the first years. An extrapolation to 100 years was then produced using different sets of calculation parameters to evaluate the sensitivity of the results and the robustness of the proposed design for several excavation diameters, structure orientations and excavation methods (Tunnel Boring Machine or traditional method).

TERRASOL is currently continuing these design studies on compressible material segments as part of a new assignment applied to the access galleries leading to high-level waste cavities. Additional thermal loading caused by the packages will be taken into consideration.

At the same time, TERRASOL is carrying out geotechnical supervision of galleries excavations at the LSMHM laboratory for EIFFAGE (see picture here above).

H. Le Bissonnais and J.F. Bruchon

# Software department

## New "Liquefaction" tool

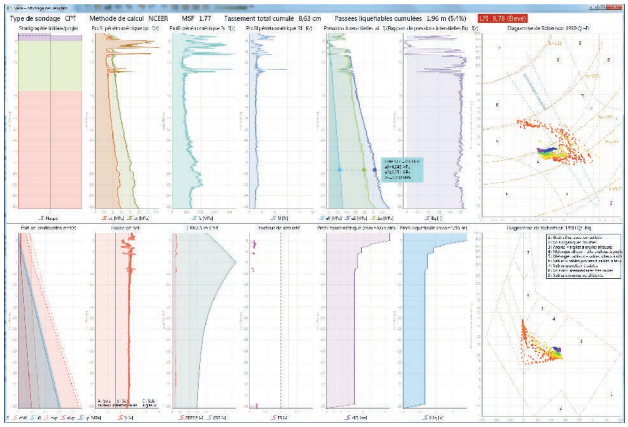
TERRASOL is currently in the process of finalizing the development of a new calculation tool that is dedicated to the quantitative analysis of the risk of soil liquefaction under seismic loading.

In its initial version, this tool strictly implements the direct semi-empirical "NCEER" method (Youd and Idriss, 2001), which is currently accepted worldwide. It introduces safety factors based on the comparison between the project earthquake-induced shear stress (CSR) with the cyclic shear resistance of the site materials (CRR), issued from in-situ CPT (u) or SPT testing results. Specific attention is paid to the calculation assumptions (seismic assumptions, hydrogeological conditions for greenfield site and project conditions) and to raw data importation (CPT (u) and/or SPT testing).

This user-friendly tool can also be used to carry out sensitivity analyses on all critical parameters (water table levels, acceleration/magnitude properties, etc.) by managing "scenarios" that are associated with the analysis of a borehole or a group of boreholes.

In addition, an assessment of seismic-induced settlements is presented using the semi-empirical Zhang and Brachman method (2002). This indicator, which will soon be extended to further options stemming from future developments, enables a spatial analysis and paves the way to multi-criteria analyses that do not limit liquefaction studies to just safety factors.

M. Hocdé and M. Huerta



*Liquefaction analysis using CPT results*

## Training

The following training courses are already scheduled up to the end of the year:

- Foxta v3 in Rabat (Morocco) on July 3rd and 4th 2018
- Foundations design in Dakar (Senegal) from July 23rd to 26th 2018
- Talren v5 in Lyon on October 12th 2018
- K-Réa v4 in Lyon on October 13th 2018
- Foxta v3 in Lyon on October 14th and 15th 2018
- Plaxis 2D in Paris on November 12th, 13th and 14th 2018

Furthermore, we remain at your disposal to respond to your requests for in-house training courses on the modelling of geotechnical structures.

M. Huerta

# Recent publications and presentations

- "Solution de remblai renforcé par géotextile – Projet de mise à niveau du tronçon Lakhdaria – Bouira (33kms)" (**M. Yahia-Aissa, P. Brossier,** A. Hadjaze and M. Khelifi) – Algerian Conference on Geosynthetics, Algiers, February 2018
- Radar interferometry as an innovative solution to monitor the construction of the Grand Paris Express – First results (F. Koudogbo, A. Urdiroz, J. Garcia Robles, **G. Chapron**, G. Lebon, V. Fluteaux and G. Priol) – WTC 2018, Dubai, April 2018
- "Des réservoirs de GNL sur fondations spéciales au Koweït" (**C. Bernuy** and **N. Frattini**) – Solscope Mag n°9, April 2018
- "Instrumentation avancée de la gare Fort-d'Issy–Vanves–Clamart : fibre optique et cellules de pression pour ausculter la paroi moulée" (**K. Nejjar**, **H. Le Bissonnais** and **F. Cuira**) – Solscope Mag n°10, June 2018
- "Méribel – Fondations d'une résidence Pierre & Vacances sur inclusions rigides" (**A. Beaussier**, T. Boizard and P. Roze) – Travaux magazine n°942, June 2018
- "Parlons géotechnique !" (**V. Bernhardt**, L. Chalard, F. Depardon and J. Robert) – Travaux magazine n°942, June 2018

**European Conference on Earthquake Engineering, Thessaloniki, June 2018**

- Macroelement based seismic analysis of a raft foundation (**Y. Abboud**, **S. Burlon** and JF. Semblat)
- Significant seismic ground motion parameters for the macroelement based design of shallow foundation (**Y. Abboud**, **S. Burlon** and J.F. Semblat)

**"Journées Nationales de Géotechnique et de Géologie de l'Ingénieur", Champs-sur-Marne, June 2018**

- "Apports de l'interaction sol structure dans le dimensionnement des groupes de pieux sous séisme" (**J. Pérez**, **F. Cuira**, P. Kotronis and S. Escoffier)
- "ONERA : Soufflerie de Modane - Avrieux (France) – Renforcement de sol en milieu gypseux" (B. Mazaré, P. Wagner, C. Brouillat-Fargier and **J. Voiron**)
- "Prise en compte de l'ISS dans la justification de la portance sismique d'un radier général" (**Y. Abboud**, **F. Cuira**, **S. Burlon** and J.F. Semblat)
- "Calcul probabiliste tenant compte de la variabilité spatiale des sols pour la justification d'un remblai" (**H. Pillard**, **A. Bergère**, **F. Cuira** and JJ. Fry)
- "Estimation de la surface comprimée des fondations gravitaires annulaires en statique" (**JF. Bruchon**, **C. Borély**, **F. Cuira** and E. Palix)
- "Mise en place d'une instrumentation avancée de la paroi moulée de la gare Fort d'Issy Vanves Clamart" (**K. Nejjar**, D. Dias, **G. Chapron**, **F. Cuira**, **H. Le Bissonnais** and V. Fluteaux)
- "Dimensionnement de 8 réservoirs GNL fondés sur inclusions rigides selon les recommandations ASIRI" (**N. Frattini**, **C. Bernuy** and **F. Cuira**)
- "Estimation du rapport E/EM : application aux radiers de grandes dimensions" (**MT. Hoang**, **F. Cuira**, D. Dias and P. Miraillet)
- "Les Argiles Plastiques de l'Yprésien et leur comportement capricieux" (**A. Bergère** and **F. Ropers**)
- "Quelques considérations pratiques autour de l'utilisation de la méthode « NCEER » pour l'étude du risque de liquéfaction des sols" (**M. Hocdé**, **F. Cuira** and **F. Ropers**)
- "Etude du comportement en déplacement de micropieux en traction" (L. Toubassy, **F. Cuira**, V. Darras and J. Habert)

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