

Soil-foundation interaction 10 years of scientific developments

Over the last few years we have carried out a number of scientific studies, in particular on the topic of soil-foundation interaction. These developments, all motivated by practical issues encountered in the geotechnical studies that we work on every day, have been applied through new calculation tools incorporated step by step into the **Foxta software suite**. Here is a brief summary.

The development of the Tasplaq module was a major step forward in the modelling of **rafts and slabs**, providing a practical calculation method breaking away from the "slab on springs" representation while avoiding the use of complete 3D finite-element processing. The method has demonstrated its effectiveness in a number of major projects (high-rise buildings at La Défense, EPR in the United Kingdom, etc.) and has benefited from several recent updates, such as the processing of a non-horizontal multilayer and the integration of unloading/reloading effects.

The lessons learned from the ASIRI research project have been used to extend the Taspie+ module, which applies a simplified approach to process the complex interactions involved in the behaviour of soil reinforced by **rigid inclusions**. The power of this method lies in its ability to account for the effects of soil/inclusion relative rigidity in the modelling of load transfer mechanisms. The latest update of the module incorporates edge effects in the case of a limited number of inclusions.

The general application of the "t-z" and "p-y" models as implemented in the Taspie+ and Piecoef+ modules provides a satisfactory and rigorous solution to the issue of **parasitic effects**, taking into account the soil-foundation interaction (negative skin friction, lateral thrusts, swelling, etc.). **Buckling** is another parasitic

aspect specific to the design of micropiles. The mathematical formulation of Piecoef+ provides a new approach for direct estimation of the critical buckling load, an approach that also evaluates the second-order effects in the case of a non-zero initial curvature.

The new Groupie+ module for **pile groups** enables easy processing of the 3D equilibrium of the pile/soil/foundation system in a single model, taking account of the non-linearities related to the soil behaviour. Development is continuing, with the aim of introducing the footing flexibility and processing pile/soil/pile interaction effects.

The recent development of **geothermal foundations** has motivated the development of a new module, Thermopie+, for evaluation of thermal-mechanical loads in a group of geothermal piles connected at the top by a structural element of any stiffness. The proposed approach accounts for the effects of pile/structure/pile interaction, unlike conventional modelling which is limited to an isolated pile with a single elastic connection at the top.

In parallel, the recent increased awareness of the challenges related to the **seismic risk** has encouraged us to work on additional analysis methods in order to take full account of the dynamic character of seismic loads. In this context, we are currently focusing on the following topics:

- **Piles under seismic conditions:** a rigorous treatment of the seismic response of a pile foundation necessitates taking into account the (dynamic) effects of pile/soil/pile interaction, which are ignored implicitly in the usual 'pseudo-static' analyses. This was the motivation for the initiation at the beginning of 2016 of a PhD thesis together with AP Consultants, Ecole Centrale de Nantes and IFSTTAR Nantes. This project is aiming to develop a "macro-element" able to represent the non-linear response of a pile group under seismic conditions, taking frequency-related effects into account.
- **Rigid inclusions under seismic conditions:** going beyond the calculation of internal loads under inertial and kinematic effects, the seismic design of a foundation on rigid inclusions requires the evaluation of the irreversible displacements related to the "fuse" effect played by the granular layer. A "generalised Newmark model", integrating the effects of soil-structure

Editorial

As we work through 2016, Terrasol teams are mobilised on all fronts:

- The construction phase kick-off for the major Paris transport projects: Eole station in La Défense in the autumn, and then Line 15 (South-West section). We are preparing to second part of our teams to these worksites, while continuing to fulfil our design and project phase contracts for the subsequent work packages.
- Reactive responses to all the requests for which we are contracted by our customers in France and abroad, at the same time as we are boosting our workforce assigned to the Paris projects.
- The expansion of our activities in fields such as wind power, geothermal structures, seismic design, port and airport structures, and the nuclear sector: this is supported by our in-house scientific developments.
- Our geotechnics training activity: it has experienced substantial growth, with more than 170 engineers trained in the first half of 2016.
- The supervision of two PhD theses, one on the modelling of exceptional retaining structures and the other on the seismic behaviour of deep foundations.

We are focusing all our energy and our know-how to meet these challenges, to the benefit of the projects and of our clients.

And we have been successful with some great projects won during the first six months of the year, both directly with our own clients and within the multidisciplinary teams of the Setec group: launch pad for Ariane 6 at Kourou, Le Havre harbour, offshore wind turbines at Fécamp, the CERN LHC project in Switzerland, and others.

And let's wager that new opportunities will come up during the 2nd semester!

I wish you all very enjoyable holidays, and look forward to getting back to you in September with a special issue of our Newsletter dedicated to the geotechnics of bridges and civil engineering structures.

V. Bernhardt

interaction, has been developed and subjected to practical evaluation as part of an on-going R&D partnership with Hyundai Engineering & Construction.

F. Cuira



Crystal Towers (Beirut, Lebanon)
Foundations designed with Groupie+ and Tasplaq

Casablanca Finance City Tower

Morocco

In the context of the construction of the Casablanca Finance City tower, BYMARO, the contractor in charge of the works, has contracted TERRASOL:

- to conduct geotechnical detailed studies related to the design of the temporary retaining structures, the drainage system, and the soil-structure interaction aspects,
- for the follow-up of the works.

The project, located on the site of the former Anfa airport (Casablanca), consists of a 25-floor tower with six underground parking levels (down to 20 m deep). The geology consists of loose formations some ten metres thick, underlain by a schist substratum. The phreatic level is expected at 8 m below the groundlevel. The temporary retaining walls consist of:

- a soil-nailed wall for the upper part, its stability checked with Talren calculations,
- a wall with rock bolts for the lower part, its stability checked with block calculations.

We also carried out the studies of the tower settlements, and of the control system for water under-pressures. The follow-up of the works on site was carried out by our Morocco-based geotechnician. It included the follow-up of the excavation operations: validation of the soil nails pull-out tests, checks during excavation, fractures survey, advice on project ad-hoc adjustments.

T. El Malki, J.F. Bruchon and J. Marlinge



Photo credit: CFC @BYMARO

Extension of quay TMDC 4

Montoir, France



The Grand Port Maritime de Nantes - Saint-Nazaire is proceeding with the downstream extension of the waterfront of general goods and container terminal 4 (TMDC 4). The contract awarded to the consortium BOUYGUES TPRF – COLAS – DTP TERRASSEMENT covers the construction of a reinforced concrete quay 350 m long, on driven metal pile foundations, backed by a platform formed by backfilling over alluvial deposits reinforced with rigid inclusions. The works also necessitated reprofiling of the bank by backfilling and dredging.

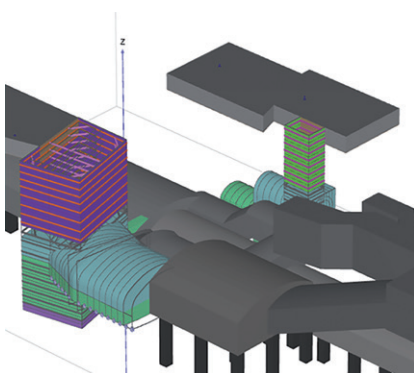
TERRASOL has worked with the consortium as geotechnical consultant since the tendering phase. In the construction phase, TERRASOL is producing the general geotechnical synthesis of the project, as well as the earthworks stability studies (Talren calculations), and pile driving studies. The pile driving study is conducted using numerical simulations based on the theory of wave propagation in a pile set in the ground. It covers the definition and adjustment of the driving criteria, and the verification of the load-bearing capacity obtained.

The works have been in progress since June 2015. All of the rigid inclusions have been completed, and 25% of the piles have been driven to date.

J. Marlinge and S. Benouis

Metro line 11 – “Mairie des Lilas” station

Paris, France



As part of the extension of line 11 of the Paris Metro to Rosny-Bois-Perrier, new secondary accesses have to be provided at Mairie des Lilas station, opened in 1937. The works consist in creating lined shafts from groundlevel, from which galleries will be excavated to intersect the existing structures (ticket hall, connecting passages, underground station).

The study had many challenges and objectives, set out by Paris transport authority RATP: define the phasing of the works, check the temporary support of the structures, assess the effects of the construction of the new accesses on the existing underground structures (Mairie des Lilas station and the line 11 tunnel) as well as on the surface buildings and roads, and lastly define a monitoring system.

Given the geometry of the structures, a three-dimensional numerical approach appeared to be essential in order to investigate correctly the complexity of the soil-structure interactions between the structures to be built and the existing structures, and consequently to be able to deal with the various issues mentioned above.

Two complex 3D numerical models were built, one for each access. They were used for detailed simulation of the works phasing and to design, during the RFP phase, the monitoring system that will be installed for application of the interactive design method during works execution.

J.P. Janin and H. Le Bissonnais

Seismic design of retaining structures

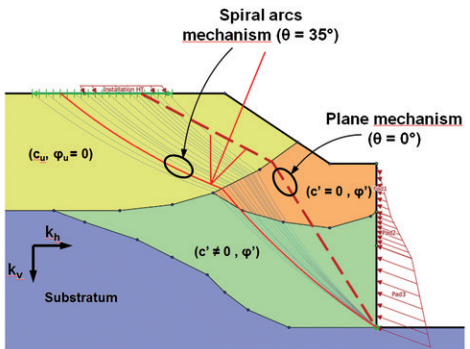
Yield design calculation

The kinematic method of the yield design calculation as implemented in Talren enables to assess the “dynamic” active/passive pressure diagrams to be considered for the seismic design of retaining structures. This goes well beyond the scope of validity of the usual analytical models such as the Mononobe-Okabe one extended to the case of cohesive soil (Okabe, 1924).

The results of a comparison made for a wall retaining homogeneous soil subjected to an earthquake characterised by $k_h = a_h/g = 0.3$ and $k_v = 0$ are given in the table opposite: the Mononobe-Okabe model leads to results strictly identical to the results of a yield design calculation restricted to plane kinematics ($\theta_{max} = 0$), which corresponds to the assumption introduced implicitly in the Coulomb’s problem from which the Mononobe-Okabe model is derived. However, this assumption leads to over-optimistic results when the cohesion term becomes predominant, with more than 20% under-estimation of the dynamic active pressure compared with a more sophisticated model analysing spiral arc kinematics.

This observation is confirmed by the example shown in the figure, dealing with the dynamic active pressure behind a wall retaining heterogeneous soil. Application of the yield design calculation with spiral arcs mechanisms leads to a resultant dynamic active pressure of around 980 kN/m, 50% higher than the value given by a calculation restricted to plane kinematics (660 kN/m).

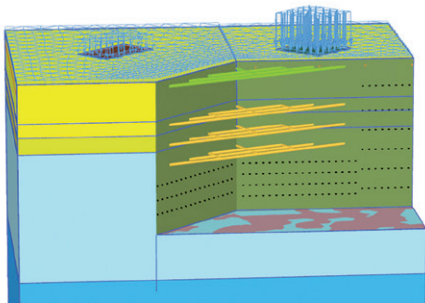
φ' (°)	Slope inclination (°)	Cohesion (kPa)	Mononobe- Okabe	Yield design plane kinematics	Yield design spiral arcs
30	0	0	570 kN/ml	570 kN/ml	570 kN/ml (+01%)
30	0	20	305 kN/ml	305 kN/ml	310 kN/ml (+02%)
30	16	20	450 kN/ml	450 kN/ml	500 kN/ml (+11%)
0	0	50	368 kN/ml	368 kN/ml	450 kN/ml (+22%)



F. Cuira

Double excavation for the Investment Corporation head office

Dubai, United Arab Emirates



As part of the Investment Corporation head office construction in Dubai (United Arab Emirates), TERRASOL was entrusted by contractor APCC with the geotechnical design of the retaining structures, in a sensitive context, according to British standards. The project comprises the construction of two towers located on each side of a road bridge that crosses the site. This existing bridge is sensitive to displacements. The two towers will rise to 305 m, over a six-level underground car park. The average excavation depth for each tower is about 35 m.

We have studied analytical and numerical models with hydro-mechanical coupling, and analysed a number of geometrical configurations, in 2D and in 3D, in order to meet the requirements of the project and enable the production of an optimised design. An analysis of the retaining structures under seismic conditions was also performed, supplementing the static calculations.

The studies carried out by TERRASOL enabled a number of options to be proposed for optimisation of the retaining structures, while meeting the design criteria and complying with particularly short study deadlines. One of our engineers was seconded to Dubai for a few weeks to work with our client, facilitating exchanges and increasing effectiveness.

U.S. Okyay

Roche Diagnostics building

Meylan, France



Photo credit: @Photec Production

The French subsidiary for Diagnostics activities of the Roche pharmaceutical group is building its new head office in Meylan, near Grenoble. The building will have a useful area of 11,000 m² on four storeys over two basement levels. Lead contractor LÉON GROSSE contacted TERRASOL early in 2015 following major displacements of the peripheral sheet piling observed during the first excavation operations.

The very particular geological and hydrogeological context (bedded and saturated silty clays) necessitated the definition and follow-up of additional soil testing (core drillings, triaxial tests, interstitial water pressure cells, etc). TERRASOL then analysed and summarised all the acquired data and defined a reliable geotechnical and hydrogeological model.

Six finite-element calculation profiles (Plaxis 2D) under undrained and drained conditions enabled us, in close collaboration with LÉON GROSSE, TRACTEBEL (Project Manager) and EG-SOL (responsible for the works follow-up), to design and check the reinforcement necessary for the continuation of the excavation, while controlling the displacements of

adjacent structures. Tangent piles reinforcing the abutment of some walls, combined with very dense bracing, were designed and installed. The excavation bottomed out in late-2015 with horizontal displacements conforming to the model predictions.

TERRASOL is currently continuing to monitor the displacements during the phases of struts removal and backfilling.

T. Rossi

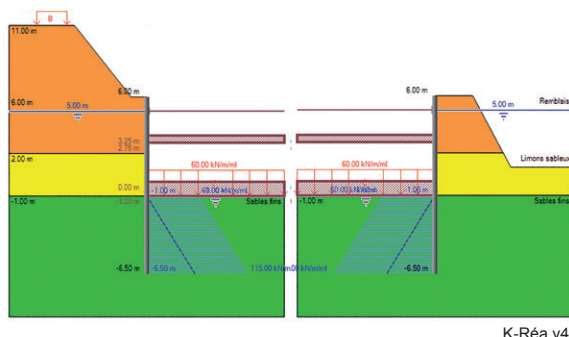
Software department



K-Réa v4

The new version 4 of K-Réa software was distributed in late-2015. The new features (refer to the previous issue of "La Lettre") have been a great success with our users. More than 50 geotechnical engineers have already received training on the new version, which extends the scope of application of K-Réa: large retaining structures for large-scale excavations with thick slabs (modelling with surface supports is possible), cylindrical shafts supported by circular beams, reinforcement of maritime quays (back-wall calculation if necessary), screening during motorway widening works, supports for bridge abutments or cofferdams, etc.

The latest update incorporates significant optimisation of calculation time and results loading time (in particular for projects with a large number of phases) and new wizards for selecting wall and anchors properties.



K-Réa v4

Foxta v3

We are currently working on a major update of Foxta which will incorporate significant improvements in both the user-interface and the calculation kernel. New features will include extension of calculation variants to all Foxta modules, edge effect processing in Taspie+ (case of a limited number of inclusions), introduction of the footing flexibility in Groupie+, and processing of thermal effects (geothermal foundations).

Talren v5

Talren v5 has recently been updated with a new feature further increasing its user-friendliness: reinforcement families. This option makes it easier to manage reinforcements by assigning them to families sharing the same characteristics (with nevertheless the possibility of managing exceptions). A new reinforcement generation tool is also available.

Trainings

We had an increasing training activity in the first half of 2016, with more than 18 training sessions in France, and about 170 engineers who attended these sessions (whether in-house sessions or group courses), which dealt with either stability of geotechnical structures (Talren), foundations design (Foxta), retaining walls design (K-Réa) or with Plaxis applications. Additional sessions are already scheduled for the end of 2016.

At the same time, we also develop our training programs abroad: these past months, we organized courses in Morocco, in the United Kingdom, in Algeria, as well as in Senegal. And we have plans for additional courses for instance in Senegal, Turkey and Morocco before the end of 2016.

Finally, our course programs go beyond the use of the software themselves: we train the participants more generally about the applicable standards, the calculation methods, and advanced design concepts in geotechnical engineering, with examples of real case histories. Our courses combine presentations, software handling and master cases, and are run by experienced Terrasol engineers and experts.

M. Huerta and F. Cuira



Group training session - Foxta v3 in Algiers

Recent publications and presentations

- « Les projets d'ouvrages géotechniques : apports de l'observation et de la modélisation » (A. Guilloix) – RFG, n° 146, 2016
- Influence of EPB-TBM heading confinement pressure on surface settlements: comparison between 3D FE numerical predictions and in situ measurements (JP. Janin, P. Renier, A. Bergère and H. Le Bissonnais) – The World Tunnel Congress WTC, San Francisco, April 2016
- « 2^{èmes} Rencontres Algéro-Françaises de la Géotechnique, du Forage et des Fondations », Algiers, May 2016
 - « Gestion, surveillance et suivi des glissements de terrains. Cas pratique : étude du point dur au PK176+800 (échangeur de Djebahia) » (M. Yahia-Aissa)
 - « Étude de sol en zone urbaine et exemple de fondations spéciales du Viaduc de Millau » (M. Yahia-Aissa)
- « Journées Nationales de Géotechnique et Géologie de l'Ingénieur », Nancy, July 2016
 - « Apports de la méthode cinématique du calcul à la rupture pour la conception des soutènements » (F. Cuira and B. Simon)
 - « Apports de l'interaction sol-structure dans la conception des fondations » (F. Cuira and B. Simon)
 - « Considérations pratiques autour de modèles numériques de certaines gares du futur Grand Paris » (G. Chapron, K. Nejjar, H. Le Bissonnais and F. Cuira)
 - « Fondation d'un IGH en environnement contraint » (E. Cazès, A. Bergère, F. Cuira and B. Simon)
 - « Modélisation d'un système d'interaction sol-pieu-structure pour un groupe de pieux géothermiques » (C. Borély, F. Cuira and US. Okyay)
 - « Analyse et rétro-analyse du comportement des fondations d'un ouvrage d'art de la LGV SEA » (KV. Nguyen, PL. Loriferne and F. Mathoniere)
 - « Conception et dimensionnement des fondations d'un IGH en milieu karstique – Le futur Palais de Justice de Paris » (A. Beaussier and P. Reiffsteck)



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