

Design of the foundations for the tallest tower in Africa: “Tour F” in Abidjan



Photo credit: @PFO

In the framework of our activities in Africa, and after completing the detailed design studies for the Mohammed VI Tower in Rabat (rising to a height of 250 m) in 2019, Terrasol last year carried out for Spie batignolles fondations and Besix the design studies of the foundation system for the tallest tower currently being built in Africa: “Tour F” in Abidjan (Ivory Coast), culminating at a height of more than 300 m.

This tower, whose footprint is similar to a pentagon circumscribed by a circle with a diameter of 40 m, has a foundation system comprising 70 barrettes whose tip is injected. The barrettes are 60 m long and have a section of 4.2 m² (1.5 m x 2.8 m). A raft with a thickness of between 2.5 and 3.5 m ensures the transfer of loads from the tower to the foundations.

The site essentially includes sandy-clayey soils with a groundwater level at a depth of about 25 m. One-metre clay lenses may appear irregularly. These soils were mainly characterised using Ménard pressuremeter testing, and two Osterberg cell tests were carried out on bored piles with a diameter of 1.5 m whose tip is injected using the same method as for the barrettes. These monitored tests have made it possible to optimise some of the calculation parameters, notably the axial friction and the tip resistance, and also to validate the injection procedure implemented by Spie batignolles fondations for the foundation base. For a net limit pressure of 4 MPa in the sands, the value of the apparent tip factor is significantly higher than 2.0 and can even reach 3.0.

The effects of the soil-structure interaction play a fundamental role in the design of the foundation system, both under vertical loading (total and differential settlements, rotations, internal forces, and loads) and horizontal loading (rotation and horizontal displacement, 2nd order effects). It was thus necessary to make an estimate of the barrettes stiffness that is as accurate as possible, taking into account the group effects that are involved and tend to soften their apparent stiffness (notably in the central part). Specific soil-structure interaction procedures were implemented associating three-dimensional finite element models with the Plaxis 3D software on the one hand, and hybrid models with the Tasplaq software developed by Terrasol on the other hand. These hybrid models – combining conventional numerical resolution methods, such as the finite elements method, with analytical approaches – enable considerable time savings during the calculation phase, and offer greater possibilities for proceeding with vast parametric studies.



Photo credit: @Spie batignolles fondations

Editorial

Building on the momentum generated at the end of 2020, the year 2021 confirms a record level of activity for Terrasol, and we are delighted to have been able to welcome several new recruits over the last few months to strengthen our teams – despite a context that continues to be difficult for everyone due to the lockdown and generalised Working From Home.

This growth phase also prompted us to reinforce our Top Management at the beginning of 2021, with the appointment of Fahd Caira as VP.

Our activity is of course being driven by our ongoing major projects (Grand Paris Express, London-Birmingham High Speed Railway HS2, Lyon-Turin TELT project, etc.), as well as many other projects and queries in France and abroad, on which we have worked during the first half. The articles in this issue offer you an overview of some of these projects, and the latest developments in the area of soil-structure interaction under seismic conditions (Fonds soil).

The news from the Software Department is also very rich, notably with the launch of Scage at the beginning of the year, and of Talren v6 in July.

We hope that the coming weeks will continue to see the “return to normal”, that we will be able get back to the office in growing numbers and see you, customers and partners, at the time of the various meetings and events once again scheduled in our diaries!

Wishing all our readers a wonderful summer and a great holiday.

Valérie Bernhardt

The use of a hybrid method thus made it possible to greatly speed up the necessary soil-structure interaction procedures and to facilitate the dialogue between the geotechnical and structural engineers. A complete 3D calculation was also carried out to confirm the results obtained. The confrontation of the numerical and hybrid models – with variations in the results of less than 5% – allowed to fully validate the reliability and robustness of the proposed design.

The soil-structure interaction studies conducted on “Tour F” project have led to the development of ever-more efficient methods for detailed design, enabling to quickly launch the construction works. The hybrid methods that Terrasol has been promoting for a number of years represent relevant and efficient alternatives to the numerical methods which still remain time-consuming regarding the preparation of the models and the calculations.

S. Burlon

Geotechnical expertise for the “Sizewell C” EPR project

United Kingdom



Photo credit: © EDF, EDF Energy, Edvance 2021

Sizewell C project deals with the construction of two new EPR reactors in Suffolk, United Kingdom. The site's geotechnical context is marked by the presence of deformable soils, requiring a fine-tuned processing of the effects of the soil-structure interaction under static and seismic actions.

Terrasol has been involved in several steps of this project. Firstly, our experts took part in the Expert Panel organised at an early stage by Edvance, where the goal was to identify optimisation opportunities regarding the soil-structure interaction (SSI) analyses with respect to the buildings' replication rates.

The static and dynamic SSI studies for the buildings of the nuclear island have been entrusted to the ICOSH consortium, of which the Setec group is a member. In the framework of this consortium, Terrasol

carried out the dynamic SSI studies for all the buildings of the nuclear island (site analysis, kinematic interaction, dynamic impedance functions), as well as the sensitivity analysis and external control studies for the static SSI aspects (non-linear elastic model using the Tasplaq module of the Foxta suite).

In parallel we were also entrusted with studies of the prestressing chamber (PSG), which have consolidated the expertise we gained at the time of the studies conducted for the Hinckley Point EPR project.

J. Pérez Herreros and A. Abboud

La Pallière dike: long-term monitoring of a dike on peat soil

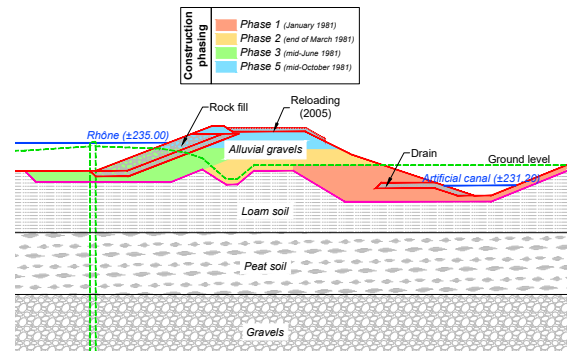
Ain, France

The “Digue de la Pallière” is a gravel dike situated on the right bank of the Lavours Dam (Ain department). This dike's key geotechnical characteristic is that it is built on a thick layer of peat stretching over a distance of several hundred metres. Since the dam was filled in 1982, the dike has undergone important settlements, subsiding by as much as 1 metre in some places, and is showing several signs of hydraulic malfunction.

Between 2007 and 2011, Compagnie Nationale du Rhône (CNR) entrusted Terrasol with a series of geotechnical missions aiming to establish, using numerical back-analysis, a diagnosis of the dike's mechanical and hydraulic condition in light of the results of a detailed monitoring programme including, notably, the follow-up of the settlements over more than 25 years. This diagnosis made it possible to determine the dike's long-term stability and establish a direct link between its hydraulic malfunction and the settlements observed. This subsidence has gradually led to a decompression of the core of the dike and consequently to a localised increase in permeability, which is impacting the flow regime in the body of the dike.

Recently, Terrasol has been called on again by CNR to analyse this dike's response during the transient phases of waterlevel variation. The analysis is being conducted using numerical modelling of the transient response of the dike's materials and of the surrounding existing ground. The results will be compared with those of the detailed monitoring of the movements observed at the time of the next lowering of the waterlevel.

F. Cuira



Cliets Tunnel

Haute-Savoie, France



Photo credit: @Campanon Bernard Centre-Est

The Cliets Tunnel is situated on the RD 1212 secondary road between the municipalities of Ugine and Megève, in the Arly gorges. The site is known as being the seat of frequent large-scale rockslides associated with a generalised outcrop bending movement of the rock mass, consisting of sericitous and quartz micaschists with subvertical foliation.

Further to a major rockslide in February 2019, involving a volume of about 8,000 m³ and blocking both portals of the existing tunnel, the Savoie District Council (Contracting Authority) decided to build a new 240-m tunnel, further towards the interior of the massif, in order to move away from the outcrop bending zones.

Terrasol carried out the detailed design studies (G3 mission) on behalf of Vinci Construction. The temporary support, consisting of radial bolting and sprayed concrete, and in the tunnel portal zones of HEB 180 steel arches, was validated by calculation approaches considering either discontinuous or continuous materials.

Specific verifications were carried out regarding the entrance portal, which is characterised by forepoling pre-support and arched profiles sections with enlargements on the Arly side: these elements were made necessary by the skewed attack and asymmetry of the loads.

The final lining is consisting of concrete poured in place behind the prefabricated walls for the sidewalls, and of sprayed concrete for the vault.

P. Antoniazzi, J.P. Janin and J. Drivet

New rail-bridge over the canal in Saint-Denis

Ile-de-France region, France

A new rail-bridge spanning the Saint-Denis canal has appeared on the scene in Paris 19th arrondissement. It is a combined structure with skew arches approximately 80 m long, built in the context of the Technical Terminal for the extension project on the RER E line to the West (TTEO phase 2).

Terrasol has been working with SNCF Réseau since this elegant construction's design phase (preliminary design, detailed design, tender and contracting phases), through to execution supervision, completed in the spring 2020 with the installation of the two arches by barge.

The Saint-Denis rail-bridge is a complex project owing to the requirements relative to the control of the new structure's deformations with respect to the century-old bridge that it adjoins to widen the railway platform (track V2E straddling the two structures). In a dense urban context, the use of a "forest" of micropiles, half of which are at an angle of 45°, was found to be inescapable: each of the two piers rests on a reinforced concrete mass supported by about 70 type IV micropiles. The abutments are built on groups of bored piles with a diameter of 1,000 mm. The modelling of these foundation systems was performed using the most of the capabilities of the Groupie+ module of the Foxta software suite.

A large number of temporary props were used to deal with the kinematics of the works. It should also be noted that the site was the subject of a vast campaign of injections into the Lutetian and Bartonian geological formations, presenting strong karstic hazards linked to the dissolution of anteludian gypsum.

M. Hocé and F. Cuir



Photo credit: @SNCF Réseau

New Laâyoune harbour

Morocco

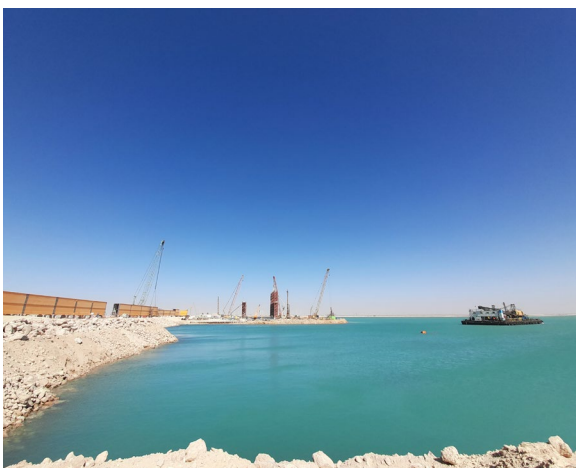


Photo credit: @Setec Maroc

For more than a year, Terrasol and Setec Maroc have been working together on behalf of Jesa Team Maroc which is accomplishing a general assistance and consulting mission for Phosboucraa, a subsidiary of the OCP SA group ("Office Chérifien des Phosphates"), for the construction of a new harbour in Laâyoune. This new facility will enable exploitation of the Boucraa phosphate deposits. The studies and works are being carried out by the Greek company Archirodon with support from the Danish company Cowi for the project management.

Terrasol's and Setec Maroc's missions are essentially focussed on the foundations of a maritime viaduct providing access from landside to the quays of the vast harbour zone. With a length of 3,170 m, this structure runs perpendicular to the coastline, and includes nearly eighty 40-m long spans. Each span is built on supports comprising 5 driven steel piles, some of which are inclined.

The design of the piles is based on a variety of compression and traction loading tests that were analysed by Terrasol and Setec Maroc. Optimisations were sought taking care, however, to guarantee a sufficient degree of robustness and reliability. Indeed, this structure – designed for an operating lifetime of 100 years – is subject to specific loading conditions owing to its exposure to a marine environment, which is always aggressive.

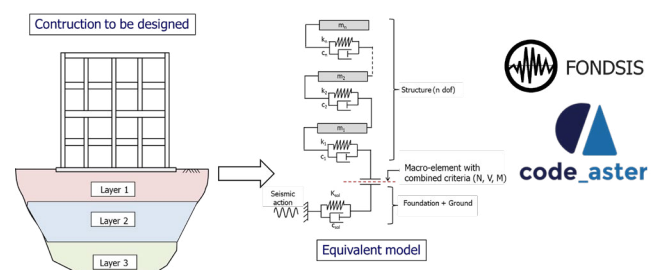
S. Burlon and A. Skali Senhaji

FONDISIS, a tool for the seismic design of shallow foundations

Scientific developments

Terrasol is frequently called on to design shallow foundations and foundation slabs subject to seismic loading. This may concern conventional structures or major constructions such as reservoirs or nuclear facilities. The checking of these structures relies on implementation of the Eurocode 8 standard which governs seismic design in Europe. The application of Eurocode 8, although it authorises the use of "displacements" approaches, is usually associated with "forces" approaches involving safety formalisms. For constructions with shallow foundations, these formalisms very often lead to conceptual dead-ends and obvious and unnecessary oversizing of the foundation systems.

In order to go beyond this conceptual dead-end, it is possible to use displacements analyses, which consist of determining the seismic limit state (sliding, bearing capacity, overturning) by directly quantifying the irreversible post-seismic displacements. These displacements analyses can be carried out directly using non-linear complete dynamic models in 2 or 3 dimensions: their complexity and the multitude of parameters make them generally incompatible with practical engineering applications. An alternative approach consists of using an equivalent analogical model: the structure is represented by a "skewer" model, where the foundation interacts with the ground via a macro-element integrating the non-linearities related to the separation, sliding and punching mechanisms at the soil/foundation interface. A software program, called FONDISIS, has been developed by Terrasol to allow for this analogical modelling and it has already proved useful and efficient in the framework of several seismic design studies that we conducted recently. In parallel, at the request and on behalf of EDF-TEGG, Terrasol has implemented the macro-element used in FONDISIS in Code_Aster, in the form of a new constitutive law called FONDA_SUPERFI, which is already available in the current version of the software.



F. Cuir, J. Pérez Herreros and C. Borely



Talren v6

A major new version

Here, we introduce you to version 6 of our historical software application Talren, dedicated to verifying the stability of geotechnical structures with or without reinforcing elements. This new version includes a new computation engine, several new functionalities as well as complementary modules making it possible to extend the software's application fields:

- **“Pile” module:** this complementary module is used to estimate more accurately the resistance contribution along a “nail” type reinforcing element representing a pile, an inclusion or a barrette working in flexion-shear.
- **“Flow” module:** this module makes it possible to perform an integrated calculation, under steady state conditions, of the pore pressure field to be considered for stability analyses. The calculation is based on a numerical resolution of the Laplace equation taking into account the multilayer and anisotropic nature of the soil.
- **Internal stability of a nailed soil mass:** Talren v6 now offers the possibility of specifying and/or automatically adjusting the forces on the nail heads required to verify the internal stability of a nailed soil mass, in line with the provisions of the new NF-P 94 270 standard dated October 2020.
- **“Sensitivity” module:** this module makes it possible to automatically conduct sensitivity studies to assess the influence of the model's various parameters on the stability of the structure being studied. It is also possible to carry out probabilistic analyses.
- **Seismic aspects:** Talren v6 allows you to automatically look for the destabilising seismic acceleration (the one leading to the limit equilibrium), which can be used as input data to an “Earthquake” wizard integrated in the software, enabling the empirical or analytical calculation of irreversible post-earthquake shifts (Newmark type model).

An **assessment version** is available and can be downloaded from our website.

Y. Abboud, M. Huerta and F. Cuira

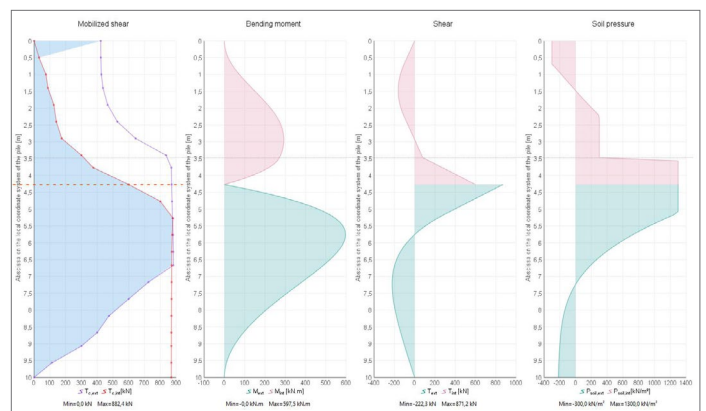
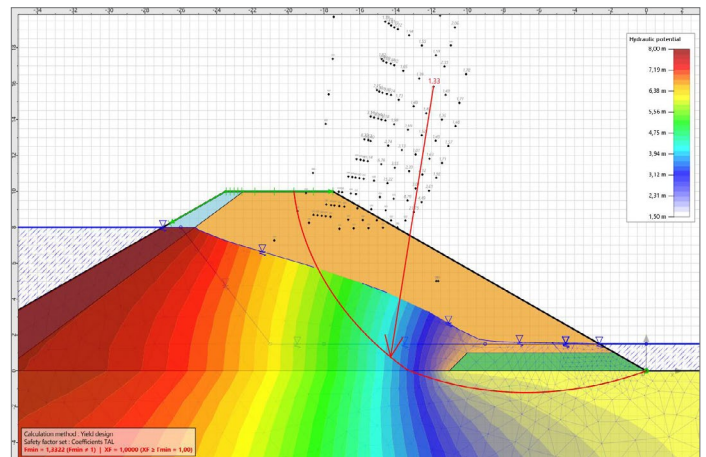
Foxta v4.1

New update

A new update for Foxta (v4.1) is available, offering new capabilities that will be of great use for calculating soil reinforcements by rigid inclusions: processing of a foundation with a limited footprint on rigid inclusions (MV3 approach), automatic adjustment of the negative skin friction thresholds, possibility of feeding t-z reaction laws from PMT tests, CPT tests or soil shear properties.

This update is free for users of version 4 of Foxta.

M. Huerta and F. Cuira



Training courses



Our 2021 training catalogue is available on our website. Please check it to get the complete list of oncoming training sessions.

And please do not hesitate to contact us to organise on-demand in-house training sessions.

Recent publications



- *“Exemples d'interaction sol-structure pour les fondations de deux très grandes tours”* (S. Burlon et F. Cuira) Solscope Mag n° 17, April 2021
- *“Prolongement de la ligne 11 du métro parisien : tunnel des Lilas”* (J.P. Janin, C. Dano and V. Villain) Revue Travaux n°969, June 2021
- *“Eole, une nouvelle cathédrale à la Défense”* (F. Asselborn, G. d'Ouinca, J. Pinto, S. Reynaud) Revue Travaux n°969, June 2021
- *“Ligne 15 Sud - Excavation du rameau 1702P dans un contexte défavorable”* (E. Peyrard, JF. Orefici, Y. Ben Dhaoui, A. Bachelier) Revue Travaux n°969, June 2021

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 : terrasol@setec.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 : terrasol@setec.com

Representation in Morocco

Setec Maroc
3 rue Abou Hanifa
Agdal
Rabat - Maroc
Tel : +212 (661) 16 20 78
Fax : +212 (537) 77 48 41
Email : ahmed.skalisenhaji@setec.com

Terrasol Tunisia

2, rue Mustapha Abdesslem
El Menzeh
2037 Tunis
Tunisie
Tel : +276 71 23 63 14
Fax : +256 71 75 32 88
Email : info@terrasol.com.tn