La Lettre

Terrasol in the Middle East

terrasol
setec

Special Edition – August 2018

Editorial

For several years, TERRASOL has achieved around 25% of its turnover on projects abroad for local, international and French customers, covering a range of geotechnical services: assistance to owners, project management, assistance to contractors, etc.

The Middle East has been one of our major business areas for many years, with assignments connected with projects in virtually every country in the region, as illustrated by the map opposite and the references presented in this special issue of our Terrasol Newsletter.

Today, we are leveraging this experience to pursue our development in this region, as part of the international expansion of our activities. Terrasol's teams take care of our customers' geotechnical demands and also work within the Setec Group's multidisciplinary teams for operations on a global scale.

We hope you enjoy reading this issue dedicated to our activity in the Middle East,

V. Bernhardt

Terrasol and the Middle East

TERRASOL is highly involved in the Middle East and this year, we wanted to take advantage of this special issue of our TERRASOL Newsletter to illustrate some of our many references in the region.

We have recently contributed to several iconic projects such as the "Dubai Creek Harbour Tower", a cable-stayed tower that aims to be the highest in the world, the Riyadh Metro in Saudi Arabia, and the LNG storage tanks at the Al-Zour terminal in Kuwait.

We have focused on advancing our operations in the Middle East in several sectors since the early 2000s and to date, the most important of these are:

- Buildings: with issues related to foundations, shoring, or soil-structure interaction, in the framework of high-rise building projects, such as the Dubai Creek Harbour Tower or the Entisar Tower, as well as large buildings construction, such as hotels or company headquarters.
- Infrastructures: englobing urban public transport, the GCC railway project, civil engineering structures, or assignments for harbours and airport construction/extension.
- Energy and Oil & Gas, which are obviously hot topics in this part of the world: foundations for storage tanks, power stations or industrial facilities, impact of natural hazards on structures, as well as assignments for dam projects.

It is important to remember that seismic issues are omnipresent in the area, and dynamic calculations/checks are required on most projects.

The Dubaï Creek Harbour Tower - @DR

This special issue of our TERRASOL Newsletter presents a selection of some of these projects, and the above map illustrates all our missions in the region over the past 12 years. We have also added green logos on the map to show the countries in which the SETEC Group is permanently present or represented, with the Middle East being one of the major development areas for the SETEC group's international business.

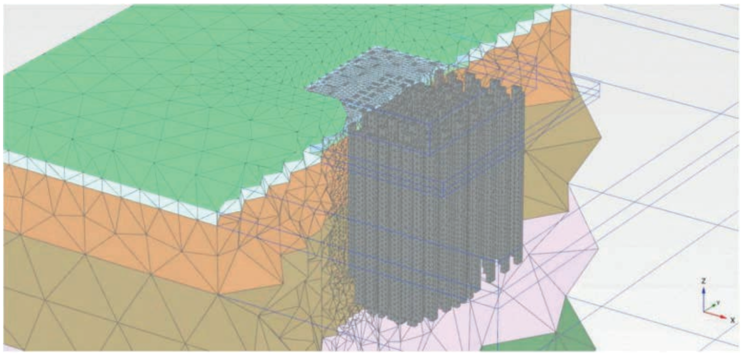
Finally, in addition to our engineering activities, we also distribute our full range of geotechnical calculation software products (TALREN, FOXTA, K-RÉA, STRATICAD) in the Middle East and provide training sessions (in French or English) dedicated to geotechnical modelling: application of standards, determination of soil parameters, use of software suites, output analysis, etc.

We now eagerly look forward to challenging new projects and opportunities with all stakeholders in the region.

V. Bernhardt and A. Abboud

Foundations of the Entisar Tower

Dubai, United Arab Emirates



At over 500 m in height, Entisar Tower will be one of the tallest buildings in the world. It is dedicated to both residential and commercial use. With a footprint of 60 m by 60 m, it is a very slender structure, inducing very high compression stresses on its base, and therefore requiring a specific deep foundation system.

SETEC was called on by ESEC to carry out a value engineering assignment, and TERRASOL was entrusted with the foundations design.

The geological context starting from the surface is the following:

- a slightly silty and shelly sand layer,
- interbedded carbonate and sandstone rock layers, with frequent beds of conglomerate rock layers,
- calcisiltite interbedded with mudstone/conglomerate rock layers
- soft rocks including Gypsum and Mudstone.

The foundation system consists of rectangular barrettes down to 80 m in depth, embedded in soft rock. The average stresses at the base of the raft (SLS permanent loads) are higher than 2.5 MPa at the core of the structure.

TERRASOL first carried out a preliminary design of the foundations and a technical analysis of the contractor's bids and of the foundations systems they proposed.

Finally, we prepared a geotechnical finite element model of the foundations system in 3D, at SOLETANCHE BACHY's request. This model was intended to analyse the foundations behaviour and to assess the soil stiffness for 4 load cases: dead loads, live loads, wind loads and seismic loads. The maximal displacement under dead load is reached in the north quarter of the core and does not exceed 6 cm. The stiffness of the deep foundations system has been assessed using several soil-structure interaction iterations. This process has allowed to optimize the foundations design, but also contributed to the structure optimization (with a better load distribution).

The execution of the foundations has been completed and the structure's construction has not started yet.

A. Bergère

Marriott Hotel in Manama

Bahrain

A large urban extension has been under development since the years 2000 around Bahrain Bay, in the north of Manama. This extension project includes the construction of a new Marriott Hotel on a reclaimed landfill plot. The execution works for the excavation retaining structures (excavation of approximately 80 m x 80 m, tangent piles with several levels of tie-rods) and the foundations for the building (concrete piles 800 to 1500 mm in diameter, 10 to 20 m long, anchored in a variably fractured limestone substratum), began smoothly, but were abruptly halted in 2006.

Photo Credit: SETEC TPI

The project was restarted in 2015, with a fundamentally revised design required by the new Architect GROUPE 6. In this new design, the position of the core of the 35-storey tower (height about 170 m) is shifted, the excavation is deeper and loads have been revised.

SETEC TPI asked TERRASOL to determine if the foundations of the initial structure could still be used and if it was feasible to make the excavation deeper. After analysing all the geotechnical input data and the load-bearing tests executed on the existing piles (static and dynamic tests), the bearing capacities of the various piles were readjusted. Checks on the retaining structures showed that the passive pressures needed to be increased by adding new ranges of tie-rods and the hydraulic embedment needed to be extended by additional grouting.

C. Bernuy

"Crystal Towers" project

Beirut, Lebanon

Photo Credit: SAYFCO

TERRASOL assisted 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 raft on piles 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 was combined with prior reinforcement against liquefaction by stone columns over a depth of 20 metres. The Foxta software was used for estimation of the foundations displacements and stiffnesses under static and seismic conditions, taking into account the group effect.

F. Cuira

Dubai Creek Harbour Tower

United Arab Emirates

Photo Credit: © Calatrava

This tower developed in Dubai by EMAAR is aimed to be the highest structure in the world, hence its name “The Tower”. It was designed by Spanish architect Santiago Calatrava, backed by the Australian engineering design company AURECON. This new monument located in the Dubai Creek Harbour area should be taller than the Burj Khalifa tower. The tower, in the shape of a “Fleur-de-Lys” and resembling a minaret, will host an observation area and will be inaugurated for the international exhibition in 2020. The design of the structure, which takes its inspiration from guyed masts, is a world first: the vertical structure of the tower, which has a constant diameter, is held at a height of 700 m by pre-stressed cables. The other end of these cables are anchored in foundation blocks.

In the framework of this project, TERRASOL has provided support for SETEC TPI, who participated in the Peer Review for the foundations and the superstructure on behalf of BUREAU VERITAS, who was appointed as Third party Reviewer for the project. Our assignment was to validate the overall behaviour of the foundations by checking the detailed design documents produced by SOLETANCHE BACHY, the contractor in charge of the geotechnical works. In particular, we examined the site investigation report produced by FUGRO, the O-Cell method loading tests, and the studies of the tower foundation barrettes and of the foundations for the cable anchor structures.

TERRASOL was also involved in assessing the geotechnical parameters in relation to the selected behaviour laws, as well as in designing the foundations using soil-structure interaction concepts (numerical models and analytical calculations). To check the tower foundation barrettes loaded beyond 100 MN, a 3D finite element model had to be created, which was used in particular to obtain the foundation stiffness matrices required for the structural calculation review model.

A. Guilloux and A. Abboud

Double excavation for the One Za’abeel projet

Dubai, United Arab Emirates

Photo Credit: APCC

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.

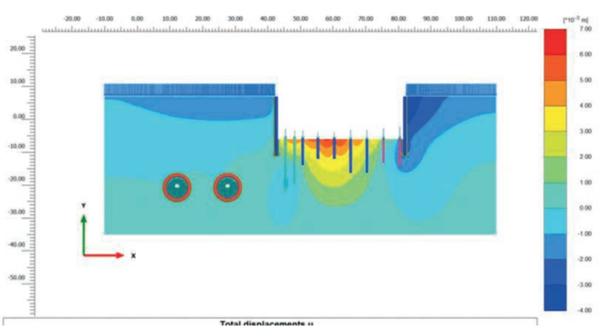
We have studied analytical and numerical models with hydro-mechanical coupling, and analysed a number of geometrical configurations, in 2D and in 3D, in order to meet the requirements of the project and enable the production of an optimized design. An analysis of the retaining structures under seismic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

The studies carried out by TERRASOL enabled a number of options to be proposed for optimization 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.

A. Abboud

Impact of a building construction on existing metro lines

Doha, Qatar



TERRASOL assisted ACES Qatar in the assessment of the impact of a building construction on two adjacent existing lines of the Doha metro. The building foundation system is a raft on piles designed as floating piles. Piles closest to the metro tunnels were equipped on the top 3 to 7 meters with permanent casings to reduce friction mobilization.

The objective of the study was to evaluate the displacements and internal forces of the tunnel structure during the different execution phases and in particular the pile loading phase which represents the application of the total building loads.

The analysis was performed using a Plaxis 2D finite-element model integrating the different construction phases including dewatering, a 13 m deep excavation, foundation pile creation and vertical loading. Model input data included the soil stratigraphy (Simsima Limestone, Midra Shale and Rus formation) represented using a Mohr-Coulomb behavior law, temporary shoring wall consisting of contiguous Ø600 or 700 mm piles, tunnel structures (plate elements) and foundation piles of various diameters and loads (embedded beam elements).

Model results showed that the tunnels are outside the construction influence zone with negligible displacement records. Comparison of force magnitudes between tunnel initial construction stage and pile loading stage also indicated negligible incremental axial loading.

The analysis also provided the vertical and horizontal displacement values at selected locations and depths corresponding to the instrumentation equipment (inclinometer and extensometer) implemented to monitor actual ground displacements during execution works.

A. Abboud

Riyadh metro – Lines 1 and 2

Kingdom of Saoudi Arabia

Photo credit: Photo FAST 2016

The Riyadh metro is an ambitious automatic metro-type mass transit system that is currently under construction and designed to serve Riyadh, the capital city of Saudi Arabia. The project consists of a total of 6 lines, 176 km of tracks and 85 stations.

Arriyadh Development Authority has entrusted the FAST Consortium, composed of FCC (leader), ALSTOM, SAMSUNG, STRUKTON, FREYSSINET SAUDI ARABIA, TYPSA, ATKINS, and SETEC, to design, build and deliver the Riyadh Metro Package 3, lines 4, 5 and 6. Within this consortium, SETEC is in charge of the project Management Office and of the design of the depots facilities. The two depots, one underground and the other at groundlevel, are integrally designed with BIM (Building Information Modeling).

Furthermore, ARUP engineering firm was entrusted with a Design & Build assignment for 5 underground stations included in the work packages for line 1 (Blue Line) and line 2 (Red Line). SETEC TPI, together with TERRASOL for geotechnical issues, carried out an "independent checker" mission to validate ARUP's studies from the preliminary phase (schematic design) up to the final phase.

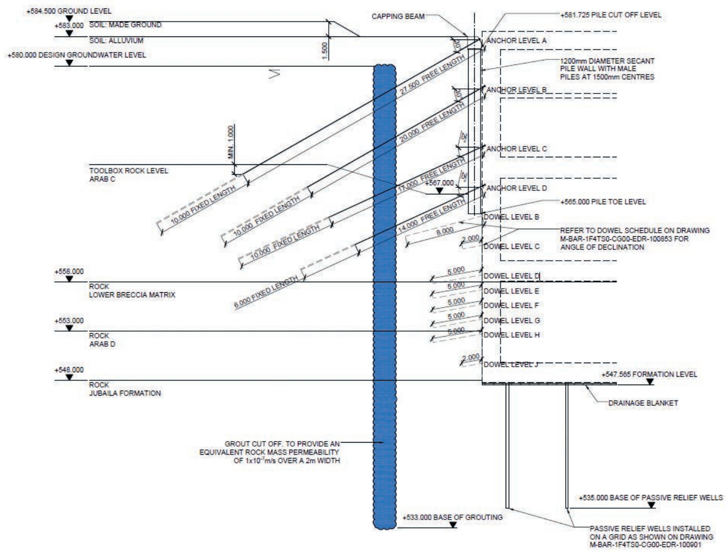
The geological context comprises loose backfill about ten meters thick covering a series of rocky horizons (limestone or breccia), with different levels of fracturing. The stations are built on a slab foundation at a depth of approximately 25 to 35 m depending on the station.

The retaining structures are generally made of secant piles, with anchors or struts over the height of the loose layers, and an embedment in the top of the rocky horizons. For hydraulic reasons, the bottom part of the wall is extended by grouting, down to 20 or 30 m below the base of the piles.

The selected design also includes the reinforcement of the fractured horizons using nailing or pinning techniques, as well as the execution of relief wells underneath the slab.

To check the design of the retaining structures, TERRASOL carried out independent calculations using K-Réa software, in some cases combined with finite element approaches (Plaxis calculations). The design of the nailing in the rock layers was checked using distinct-element modeling (UDEC calculations).

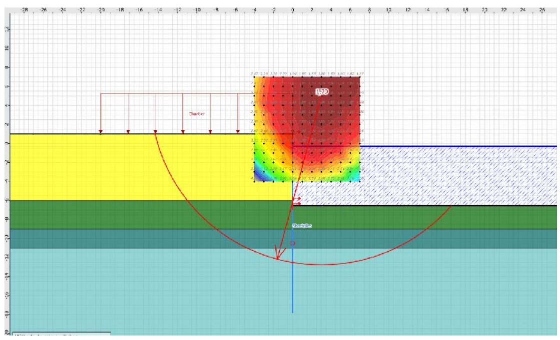
C. Bernuy



Pipe replacement at Port Said power plant

Egypt

In the scope of a GRP pipe replacement and repair works at the Port Said power plant, TERRASOL was entrusted with an external control mission by BALINEAU, the contractor in charge of executing the temporary shoring works consisting of strutted or anchored sheetpile walls.



The first stage consisted of analyzing the available soil data in order to accurately define the soil parameters for shoring wall analysis. Interpreted tests included field testing such as SPT, CPTu and vane shear, as well as lab testing such as identification and triaxial testing (CD, CU+u). The main focus of the analysis is the characterization of the 20 m thick fat clay layer encountered at 10 m depth below the upper silt and sand layers and which controls the stability of the sheetpile wall. The analysis enabled a fine estimation of the clay undrained cohesion cu as a function of the effective vertical stress and its variation with depth.

The second stage requested from TERRASOL was to perform side-checks of the shoring system which required the creation of dedicated models for the different studied sections. The critical aspects of the verifications are the safety on mobilized passive earth pressure which controls embedment depth, the equilibrium of vertical forces in light of negligible bearing resistance of the clay layer and the Kranz stability required to define the distance between the main wall and the reaction wall.

Global stability verifications were also performed using both drained and undrained soil parameters.

The results obtained allowed us to confirm the required section and length for the sheetpiles, determine support reactions for the design of tie rods and struts, and identify critical failure mechanisms.

A. Abboud

Third Bosphorus Bridge
Istanbul, Turkey

Photo Credit: © ICA IC Içtas-Astaldi

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.

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 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.

TERRASOL carried out the checking of the foundations design for SETEC TPI (Independent Checker for the project). As the first phase of this work focused on design analysis, TERRASOL also provided its advices for project optimization, with the stability checking of the rock foundations, using 3D finite element calculations.

Construction started in May 2013. The last deck element was installed in March 2016 and the bridge was inaugurated on August 26, 2016.

A. Guilloux

Railway project in Oman
Oman

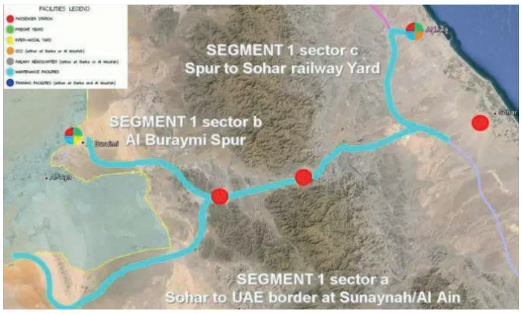


Photo Credit: Oman Rail

Still in need of a railway infrastructure, the Sultanate of Oman is considering a huge nine-phase construction programme for a 2135-kilometer dual-track national rail network. This network is intended to transport freight and passengers with trains travelling at 220 kph between 46 stations and 9 intermodal terminals. An international call for tenders was launched in 2014 with 18 candidate consortiums to carry out the construction works for the first phase. This first phase comprises three 200-km sections to connect the Sohar Port to Al Buraymi and the border with the United Arab Emirates, and includes 5 stations.

A multidisciplinary team from the SETEC group spent two months working intensely to contribute to the CCC / SAMSUNG / STRABAG civil engineering consortium's tender. TERRASOL participated in the analysis of the dossier, in the optimized design and feasibility of the civil engineering works, and in the preparation of the technical file for the tender.

Having acquired sound experience in recent high-speed line (LGV) projects in France, TERRASOL utilized these skills to scrutinise several complex structures: tunnels, viaducts, cut-and-cover structures, large earthworks, etc. This project enabled TERRASOL to showcase their skills for an international railway project.

KV. Nguyen

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 part of these tests has been directly controlled on the site. In the framework of the standard BS EN 1997-1, the analysis of these tests led to optimize the values of the safety factors for the pile bearing capacity.

Besides, TERRASOL has been involved in the design of foundation systems of three other constructions: the pre-boarding bridges and the maintenance building with general raft foundation and the boarding bridges with semi-deep foundation (massif pad foundation).

S. Burlon, M. Hocdé and A. Abboud

LNG tanks on rigid inclusion on the Al-Zour site

Kuwait

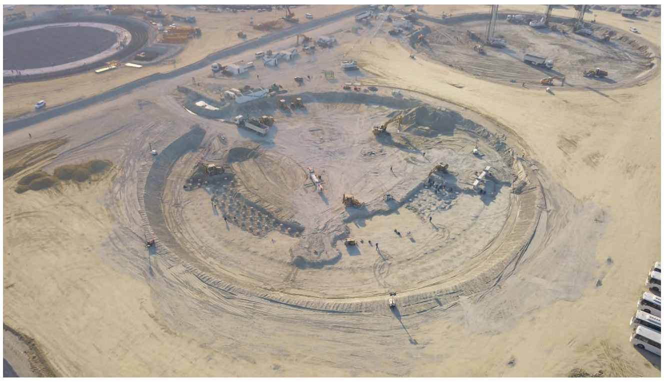


Photo Credit: © Kuwait Integrated Petroleum Industries Company (KIPIC)

To secure its imports and exports of Liquefied Natural Gas (LNG), the KUWAIT NATIONAL PETROLEUM COMPANY (KNPC) has launched the construction of a giant terminal on the Al-Zour site. The project, which must be completed in 2020, consists of building a regasification plant (USD 1.39bn) and 8 storage tanks with an individual capacity of 225,000 m^3 (USD 1.52bn), all located on a platform reclaimed entirely from the sea. This major "Design & Build" contract was won by HYUNDAI ENGINEERING & CONSTRUCTION, which entrusted the design to the Korean firm KOGAS TECH, specialized in engineering and maintenance of onshore and offshore gas facilities.

After consulting several international geotechnical engineering companies, KOGAS TECH entrusted TERRASOL with the design of the tanks foundations. These eight pre-stressed concrete structures, with a diameter of 96 m and height of 45 m, must in particular be able to satisfy strict differential settlement criteria (1/300 for settlements measured along the tank's diameter, and 1/500 regarding tilting), and to withstand strong seismic accelerations with a return period of 2475 years.

The project is located on a reclamation area. The lithology under the sea, before the execution of the embankment, consisted in a succession of sandy layers of increasing density along with depth, up until a bedrock located approximately 70 m under the sea level. In order to reduce liquefaction hazards, it has been decided to dredge the layers that had the weaker features prior to embankments works, at 6 to 7 m of depth. Hydraulic embankments are then put in place and their thickness is taken to approximately 20 m through the vibroflotation technique.

The solution adopted for this project's foundations consists in executing non-reinforced CFA (Continuous Flight Auger) rigid inclusions of diameter 0.8 m; and with a mesh of 2.80 x 2.80 m in the center of the tank, and of 2.40 x 2.40 m on the outside section. These inclusions are embedded 1 m in the layer of dense sand and are overlaid with a 2 m thick gravel layer. Under each tank 1128 rigid inclusions have been implemented, with a varying length of 20 to 25 m. At the project's scale, that represents over 200 km of inclusions, a distance equivalent to the one between Paris and Le Mans!

The tests carried out to verify both the local and global bearing capacities of the structures (at the tanks' level and under the tanks' outside section) as well as the overall stability (of the hydraulic embankment), conducted with the software TALREN (developed by TERRASOL), showed that the tank's overall stability was ensured without rigid inclusions. These tests were conducted for static phases as well as for seismic phases, considering a return period of 2475 years, with a nominal acceleration of 0.17 g. Failure mechanisms under seismic conditions have also been analyzed, as well as liquefaction hazards. Inclusions will therefore only reduce settlements (field 2 of ASIRI recommendations), but are nonetheless essential given the pressure applied by the tanks' heavy loads (up to 250 kPa during the hydro-test stage).

For the seismic justification, TERRASOL determined the seismic response of the site using SHAKE program, which enabled the dynamic impedances of the foundation system to be defined (using SASSI program) with the right degradation functions for the shear moduli. On this occasion, we called for Alain Pecker's expertise to calibrate seismic design spectra.

TERRASOL could demonstrate for this project that the innovative solution of rigid inclusions for the tank's foundations is technically and economically an interesting and convenient approach. ASIRI recommendations were a crucial contribution to this project given the fact that the strict criteria of deformations that had to be complied with could be verified following the design principles which are detailed in these recommendations, along with semi-analytical methods. ASIRI recommendations were thus able to prevail in the context of Oil & Gas projects that are historically oriented towards British or ACI standards.

J. Drivet, C. Bernuy and N. Frattini

Photo Credit: KIPIC

Oil & Gas complex in Das Island

Abu Dhabi, United Arab Emirates

Photo Credit: Cegelec

ADNOC is one of the largest national oil companies and one of the most advanced in terms of seismic analysis and recovery optimisation techniques applied to its oil fields, both onshore and offshore. Its subsidiary ABU DHABI GAS (ADGAS), specialising in the processing, marketing and distribution of LPG and LNG, has contracted CEGELEC OIL AND GAS for the construction of an eighth turbine (36 MW, Frame 6 type) on Das Island, which is located in the Persian Gulf about 110 km from the Emirate of Abu Dhabi.

In the framework of civil engineering studies, CEGELEC contracted TERRASOL for the geotechnical detailed design.

TERRASOL first worked on the definition and supervision of the on-site geotechnical investigations, in strict compliance with offshore safety and risk management procedures. We then designed the foundations of the various elements of the power plant (turbine, structural steelwork, chimney, buildings, etc), paying particular attention to the behaviour of the deep foundations under dynamic loading.

C. Bernuy

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

Janneh Dam

Lebanon

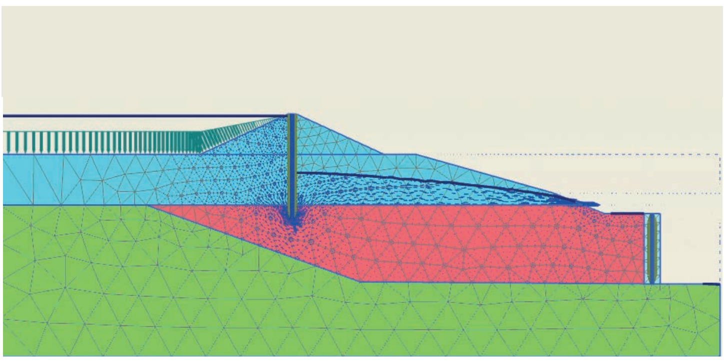
To prepare its response to a call for tenders launched by the Lebanese government, VINCI CONSTRUCTION GRANDS PROJETS contacted SETEC ENERGIE ENVIRONNEMENT (SETEC group) for technical assistance on this operation, with SOGREAH and KHATIB & ALAMI managing the project.

To satisfy the demand as accurately as possible, SETEC ENERGIE ENVIRONNEMENT teamed up with LOMBARDI (to design the dam body and provide the associated geotechnical engineering expertise) and TERRASOL (for the geotechnical design of the ancillary structures, upstream cofferdam, jet-grouting bulkhead, and downstream cofferdam).

The main structure is a 92-m high RCC (roller-compacted concrete) dam, with 62 m of replacement of alluvial material on the Narh Ibrahim river.

@DR

Crédit photo : VCGP



The upstream and downstream cofferdams consist of a dike with a deep grouted cut-off wall.

The bulkhead consists of an arc-shaped wall executed with the jet-grouting technique and acting as a retaining structure to enable the replacement works for the alluvial material under the base of the dam body.

TERRASOL's assignment consisted of:

- A review of the preliminary design,
- The study of an alternative solution proposed by VINCI CONSTRUCTION GRANDS PROJETS, which consisted of moving the upstream cofferdam (dike) further upstream, building the cut-off wall on the upstream side of the dike (rather than on its axis), and removing the bulkhead.

The result of this study clearly showed the advantages of the alternative solution:

- Solution 1 (without embedment of the cut-off wall in the substratum) does not provide enough safety,
- Solution 2 (with embedment of the cut-off wall in the substratum) presents a risk of overflow due to probable dam settlement, and requires extensive jet-grouting works, the stability of which is uncertain,
- Solution 3 (VINCI's alternative solution) minimizes the amount of geotechnical works (smaller cut-off wall and no jet-grouting) and reduces the volumes to be pumped.

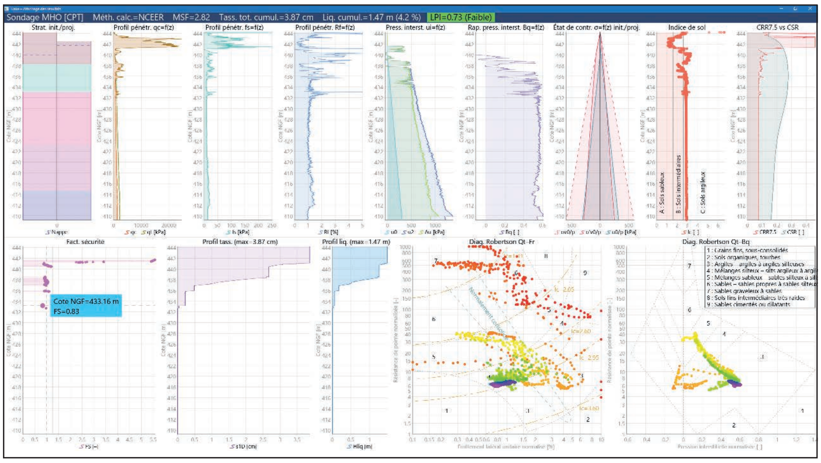
This comparative study was carried out using the PLAXFLOW module (PLAXIS software) for flow quantification. In addition, PLAXIS 2D was used to check displacements, as well as stresses and forces in the cut-off wall and the bulkhead.

J. Drivet

New "Liquefaction" tool

Scientific developments

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.

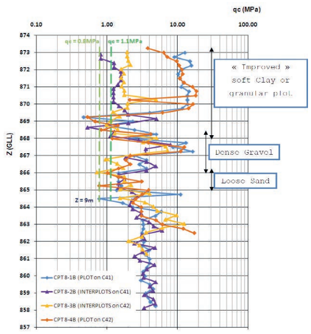
In addition, an assessment of seismic-induced settlements is presented using the semi-empirical Zhang and Brachman method (2002). This indicator, which will soon be extended to further options stemming from future developments, enables a spatial analysis and paves the way to multi-criteria analyses that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

M. Hocdé and M. Huerta

Water treatment plant in Zahle

Lebanon

TERRASOL’s mission on the Zahle wastewater treatment plant located in the Beqaa Valley of Lebanon was initiated in 2006 by a request from DEGRÉMONT SUEZ to perform a review of soil conditions. The geotechnical analysis of the initial ground investigations indicated the presence of a soft clay layer within the lacustrine sediments leading to large consolidation settlements under the facilities reaching 30 cm. In a second phase, complementary pressuremeter testing was analyzed and used to calculate total and differential settlements under clarifiers which confirmed the first findings.



TERRASOL was then entrusted by the general contractor BUTEC to study a soil treatment program based on dynamic replacement associated to wick drains. The spacing, diameter and depth of the gravel inclusions were defined to obtain an equivalent soil modulus for the reinforced clay leading to acceptable settlement values. A methodology was specified with definition of treatment targets. To validate the design, two trial zones were executed and followed closely by TERRASOL. The improvement was verified by pre- and post-testing using pressuremeter and CPT.

Photo Credit: BUTEC

The main zones were then treated and a careful final survey of dynamic compaction was performed. CPT profiles showed that the soil improvement increased the overall modulus to target value and all the zones reached the set criteria. Soil improvement works were covered by a compacted base course and subgrade layer before raft execution. TERRASOL assisted BUTEC during the execution period from 2008 to 2010.

Later in January 2013, TERRASOL performed a site visit at the request of BUTEC in order to validate the design of soil improvement works under the aeration tank based on the results of post-treatment CPTs. TERRASOL also reviewed plate load test procedures and results to validate the base coarse layers and redefine target specifications.

Finally, in 2014, TERRASOL performed the raft design under the recirculation sludge pumping station and filters and assessed expected settlements for these particular structures located below water table and below improved layers.

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