La Lettre

Bridges and viaducts

terrasol

setec

Special release / August 2016

Editorial

Civil engineering structures have always been a major factor in the development of Terrasol. The geotechnical problems are varied (foundations, soil reinforcement, slope stability, rock or soil mechanics, hydraulic or mechanical stability of the bottom of excavations, retaining structures, etc.) and are often a major issue for the projects with respect to control of costs and completion dates.

This special issue of the Terrasol Newsletter presents some "historic" references (Poncin viaduct, Millau viaduct, Vasco de Gama bridge and others), together with more recent structures, major challenges with regard to their geotechnical aspects, such as the Bouregreg viaduct with its shallow foundations covering an area equivalent to a tennis court, or the Grande Ravine bridge with its 10 m shafts embedded in the rim of the ravine sides. Terrasol has also been extensively involved in the many civil engineering structures, whether standard or exceptional, built in France over the last few years as part of road or railway projects.
And although major civil engineering structure projects are becoming rarer in France, international projects give us the opportunity to broaden the scope of our action, as illustrated by the examples of the third bridge over the Bosphorus in Turkey or the bridge over the Wouri in Cameroun.
Terrasol's objective is to remain a reference when an innovative solution has to be found for the foundations of exceptional or more conventional structures.

H. Le Bissonnais

Geotechnics for civil engineering structures from past...

La Truyère viaduct (France)

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The bridge of La Truyère on the A75 motorway was designed by architect Alain Spielmann to fit into the landscape of the well-known Garabit railway bridge, built by Gustave Eiffel in the 1880s, the two bridges spanning the very steep-sided valley of the Truyère river. The motorway bridge is a portal bridge with a total length of 308 m, and legs inclined at 45° set into the valley slopes. Construction of the central span necessitated the installation of temporary piles capable of supporting 11,000 tons, and was completed in 1993.

TERRASOL was involved in 1990 for the DUMEZ-GTM consortium, at the construction design stage, providing assistance with the follow-up of foundation works and earthworks.
The Truyère valley cuts deeply, over 80 m, into a gneiss and mica-schist massif with many microgranite veins, highly jointed and with hydrothermal alteration. The design of the excavation slopes for the access tracks and platforms and of the foundations was guided to a large extent by a structural analysis of the rock, together with an assessment of the stiffness of the rocky massif. The final supports, legs and abutments are supported by shallow foundations on the rock, while the temporary piles are founded at mid-slope on Morrocan shafts 4.2 m in diameter and 10 m deep to take up the horizontal forces.

A. Guilloux

... to present

Cable-stayed bridge across Oued Bouregreg (Morocco)

ADM (Autoroutes du Maroc) had for a long time wished to realize a cable-stayed bridge for the Kingdom of Morocco. After a first draft planed over the Oued Sebou, close to Fès which reached the stage of pre-detailed draft with a team composed of SETEC TPI, MAROC SETEC, the architect Hervé Vadon (STRATES) and TERRASOL, a second opportunity occurred on the highway bypassing Rabat as an alternative to classical viaduct with concrete segments.

The same team presented an ambitious project with exceptional dimensions: total length of 952 m with a central span of 375 m, 100 m deck height and two main piles of 200 m height with an architecture inspired by the Arts of Islam.

The geological and geotechnical context is characterized by the presence of metamorphic ground (Carboniferous shales) covered by sedimentary formations (calcarenites, limestones, mudstones). The quality of the soils below the main pillars led to favor a supporting solution with shallow foundations, however with impressive dimensions (25x30m, about the size of a tennis court).

TERRASOL carried out various missions between 2008 and 2014: definition and follow-up of soil investigations, foundations pre-design, geotechnical assistance during works (earthworks, foundations), and control of detailed design.
The contractor in charge of the works was a Chinese consortium (COVEC and MBEC).

The bridge named "Mohammed VI", presently the longest cable-stayed bridge in Africa, was inaugurated on July 7, 2016 by the King of Morocco.

H. Le Bissonnais and J. Marlinge

Photo credit: Olivier Panier des Touches

Millau viaduct

France

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The Millau viaduct is a 2460 m long cable-stayed road bridge (with a metal deck) crossing the Valley of the River Tarn. Its high piers (240 m for the highest, itself topped by a 87 m high metal pylon) make this viaduct exceptional. Regarding the site geology, the foundations are laid mainly on limestone in the north part of the site, and on marls on the south part.

The semi-deep foundation system for each pile, adjusted to local soil conditions, is composed of a square footing with a thickness of 3.5 to 5 m. The footing is connected to four shaft foundations of 5 m in diameter and 12 m deep (on average).
The abutments C0 and C8 lie on a 1 m thick raft foundation connected to two lateral footings. It should be noted that due to geotechnical conditions of the site discovered during earthworks, abutment C0 is partially founded on a shaft, a necessary adjustment of the project to ensure the structure stability during the installation of the deck.

After its participation to the call for tender for construction and operation with EIFFAGE, TERRASOL was entrusted by SETEC TPI with a project management assignment, including the on-site follow-up of earthworks and foundations works, and also the checking of the design reports relating to the stability of geotechnical structures.
The foundations settlements were a major concern for the structure and interactive design was applied to follow-up displacements and be able to react if necessary. The monitoring results showed that settlements and rotations remained small and acceptable.

A. Bergère

Vasco de Gama bridge

Lisbon, Portugal

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The Vasco de Gama bridge over the Tagus in Lisbon was opened to traffic in 1998 after 44 months under construction, a remarkably short time for such a structure: total length 12.3 km, divided into eight sections, with a cable-stayed main bridge 829 m long.

TERRASOL was involved, in support of the consortium coordinated by CAMPENON BERNARD SGE, for the design and follow-up of the foundations, a major technical challenge of the project: in an estuary with wide tidal ranges and strong currents, 856 piles 1.7 to 2.2 m in diameter were installed to depths down to 85 m (loads of 3000 tons), with a production rates of two driven piles and one bored pile per day.

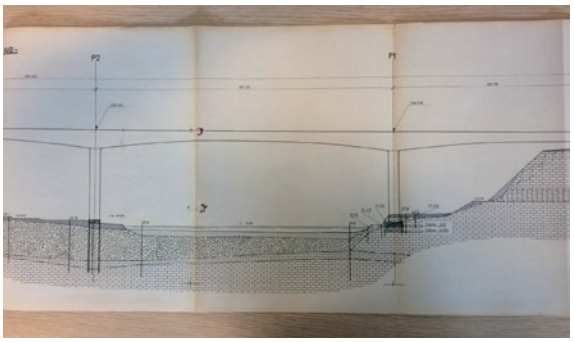
In an alluvial sequence up to 75 m thick, consisting of muddy loose sands at the surface down to compact coarse sands at depth, the realisation of soil testing boreholes and the choice of piling techniques were complex.

Nine full-scale loading tests, 7 vertical and 2 horizontal, enabled to validate the design parameters and highlighted the positive effect of tip grouting for the bored piles, but also the reduction of lateral friction and the absence of plug formation for driven piles, leading to modification of their execution and monitoring methods.

A. Guilloux

Poncin viaduct on the A42 highway

France



The first viaduct which TERRASOL studied, in 1979, was the Poncin viaduct on the A42 motorway, for SCETAUROUTE (acting as Project manager), during the design studies.

It is a curved box girder bridge built by the cantilever method. It comprises 6 spans, and its length is 567 m, with a main span of 155 m over the river Ain. This “exceptional” structure for the time was the first single segment-girder viaduct of its width.

The Ain valley is characterised by a Jurassic limestone substratum, with an alluvial cover about 20 m thick. The viaduct foundations are shallow for the supports on the rock, and deep, after grouting of the very coarse gravelly alluvia, for the two piers in the areas with thick alluvial cover: circular caisson with diaphragm walls 12.5 m in diameter for P2, and H-section barrettes for P3, because of the slope of the rocky substratum.

The structure was completed in 1986, and was the first major reference of TERRASOL for major civil engineering structures.

A. Guilloux

Structure shifting under close surveillance in Givors

France

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Within the development of the area around the Givors train station, BEC FRÈRES SA was awarded the construction of an underground passage under the railway track. The structure planned is a prefabricated frame. As the stoppage time imposed by SNCF was 72 hours to excavate, install the structure and refill, the construction company suggested an installation of the structure by shifting.

This shifting work was subcontracted to Freyssinet who recommended to use a shifting technique with air cushions and skidways. This consists in implementing hydraulic jacks outside the frame, under concrete 'tabs', to lift the structure. Under these jacks, a distribution plate allows them to slide on metallic skidways by means of an air cushion (pressurised nitrogen). The total weight of the structure is 1,080 tons, and the load per jack 108 tons.

The mission entrusted by BEC to TERRASOL covered several aspects:

- Analysis of the results of the additional soil testing and confirmation of the feasibility of the air cushion shifting,
- Calculation of the deformations and stresses in the skidways et recommendation of additional actions if necessary.

The analysis of the results of the additional investigations showed two weak zones likely to jeopardise the feasibility of air cushion sliding. The first, on the structure prefabrication zone, could possibly lead to major deflections in the skidways from the very beginning of the shifting. Therefore, TERRASOL recommended (as substitution was not feasible in this location) to preload the soil below the skidways using the lifting jacks. A second area was considered as hazardous, and a substitution recommended.
These checks were carried out with Plaxis 2D, in short and long term conditions, by applying a phasing of the loads modelling the construction progress.
The shifting operations were performed successfully on August 29, 2009.

J. Drivet

Raymond Barre Bridge

Lyon, France

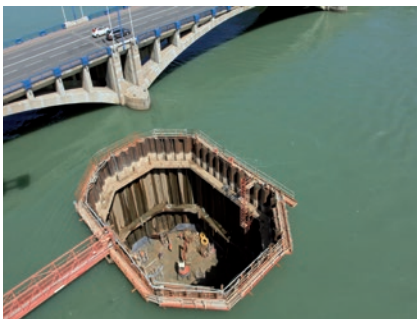


Photo credit: Balloide/SYTRAL

Marking the South entrance of the city of Lyon, the Raymond Barre Bridge across the Rhone presents a modern architecture featuring two outward-leaning arches. Working alongside the Project Manager, TERRASOL was entrusted with the study of the foundations of this structure, which is part of the project to extend tram line T1, and later with the follow-up of the geotechnical works.
The 3-span bridge has a pier in the river (P1) and a pier on the edge of the bank (P2). Both piers will be founded on piles. The soil is composed of river alluvia becoming compact at depth before encountering the bedrock consisting of granite sand associated with the facies of the Jardin des Plantes.

The problems raised by the project essentially concern:

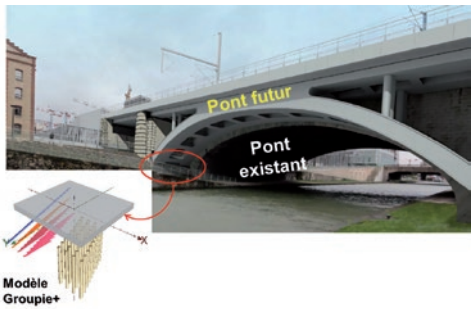
- the complex load distribution of the structure (asymmetry of the deck inducing considerable transverse forces for the foundations;
- compliance with river traffic, which requires the area covered by the foundations to be restricted;
- difficulties related to construction in a river with a water depth of approximately 12 metres at pier P1.

The calculations for the deep foundations of the piers were performed using the FOXTA software, making it possible to account for the behaviour of a pile group subjected simultaneously to transverse and axial loading.
The construction works were entrusted to the BOUYGUES TP/MATIÈRE/ZWALHEN & MAYR consortium. The first stone was laid on the 24th of November 2011. The works began in April 2012 with the construction of the cofferdam for pier P2 and of the piles for abutment C3. The large cofferdam of pier P1 required the execution of sixteen 1600 mm piles to support this pier on which the steel structure has been embedded. The construction was finished by September 2013.

T. Rossi

Widening an existing railway bridge

Saint-Denis canal, France



TERRASOL has been contracted by SNCF RÉSEAU for the design of the foundations system of a composite-structure skew arch bridge on the Saint-Denis canal. The bridge structure is eventually intended to support two additional railway tracks by widening an existing masonry arch railway bridge. The operation as a whole is part of the EOLE project (extension of RER line E west of Paris).

The foundation principle which was chosen comprises a group of grouted micropiles capable of absorbing a resulting load inclined at 45° from horizontal. The extremely demanding settlement criteria imposed on the structure (due in particular to a new track straddling the existing and future bridges) led us to recommend a design taking account of soil-micropile-structure interaction effects in order to ensure strict consistency between the supports stiffness and the loads transmitted by the superstructure.

Application of the new capabilities provided by the Groupie+ module of the Foxta software developed by TERRASOL enabled easy analysis of the three-dimensional behaviour of all the micropiles interacting with the superstructure that they support.

F. Cuira

Renewal of the Nantes - Saint-Gilles railway lines

France

As part of the French railway system upgrade plan, SETEC group was mandated by RFF (French Railway Infrastructure Manager) as Project Manager for the studies and the works for the complete renewal of the railway tracks between Sainte-Pazanne and Pornic and between Sainte-Pazanne and Saint-Gilles-Croix-de-Vie, a total length of 84 km. These works, intended to enable improvements including an increase in operating speeds, necessitated the replacement of the decks of a viaduct and six standard civil engineering structures built in the 1910s.

TERRASOL was involved from the preliminary design phase for the definition and design of the reinforcements to be implemented to ensure that the external stability of the abutments complies with current regulations under the future loading, which includes the new deck, the increase in operating speed and changes in train loads. Given the uncertainties on the abutment geometries, the following solutions were selected:

- Abutment reinforcement by soil nailing, enabling the checking of the geometrical assumptions and an easy adjustment of reinforcements during works,
- Vertical micropiles taking up the additional vertical loads, supplementing nailing for structures with inadequate load-bearing capacity,
- Anchoring of the fixed support of the structure by inclined micropiles, taking up the horizontal loads generated by the deck.

During the works phase, TERRASOL continued its involvement, with the checking of the detailed design and the follow-up of the works on site, including reinforced monitoring during the preparatory works in order to validate the anchors installation methods prior to the works, for which time constraints were very demanding.

A. Beaussier and A. Bachelier

Grande Ravine

Île de la Réunion, France

Photo credit: Olivier Panier des Touches

The Grande Ravine viaduct is one of the four exceptional structures along the Route des Tamarins, between the towns of Saint Paul and l'Etang Salé. The SETEC TPI /SPIELMANN consortium was awarded the full project management for the design and construction of this spectacular engineering structure (crossing a 320 m wide and 170 m deep breccia). This consortium entrusted TERRASOL with the design of the foundations and the monitoring of the earthworks, within a delicate geotechnical context (breccia slopes made of alternating metric beds of basalt and medium grade scoria).
The foundations of the supports include a 10 m diameter shaft embedded over 20 m height in the slope, connected to a counterweight bridge abutment. The earthworks for the bridge abutments and shafts were performed between August 2006 and June 2007. The final junction was made on October 28th 2008. This principle of foundation, validated using 3D finite element calculations, allowed obtaining displacements of the bridge abutments smaller than one centimeter during the deck sliding phases.

H. Le Bissonnais

A89 motorway - Balbigny/Viollay section

Loire, France

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Works on the A89 motorway section between Balbigny and the Viollay tunnel started in 2009.

Within the scope of constructing these 14.5 kilometres of motorway that include three viaducts and 15 standard civil engineering structures, TERRASOL, having carried out the geotechnical part of the preliminary and detailed designs, and prepared the tender documents, provided geotechnical assistance during the site works phase to SETEC TPI, project manager for earthworks and standard civil engineering structures, and owner assistant for the viaducts within a Design and Build contract.

The geological context, essentially highly tectonised volcanic rock, required a few minor adaptations during the works phase to take into account large variations of substratum alteration and fracturing over very short distances.

For example, it was necessary to rebuild the slope under a structure abutment as it presented an erratic alteration that endangered the structure stability.

These adaptations were carried out very rapidly, and in coordination with the group of contractors and the project manager, in order to avoid perturbating the works schedule. TERRASOL's reactivity contributed to maintaining the schedule.

J. Drivet

High Speed Railway Line “Bretagne - Pays de Loire”

France

Photo credit: Setec

The Brittany – Pays de la Loire High Speed Railway Line project extends the existing Atlantique HSR line Paris – Le Mans inaugurated in 1989. It will enable to reduce the travel time between Paris and Rennes by 37 minutes. In the framework of a Public-Private Partnership contract, the EIFFAGE group is responsible for the construction of the project, followed by line maintenance and renewal over a 25 year period : 182 km of new high speed line, 32 km of connection lines, around 200 civil engineering structures including more than ten viaducts.

Within the special project management group, comprising SETEC FERROVIAIRE (contract leader), SETEC INTERNATIONAL and SETEC TPI, TERRASOL was responsible for the management of the geotechnical surveys during the preliminary design phase as well as for the geotechnical studies for the civil engineering structures over a distance of approximately 120 km including 11 viaducts and 149 standard structures.
The survey campaign began in April 2011 and was completed in January 2012. An additional two month survey was subsequently launched in March 2012. Geotechnical studies began in October 2011, before all soil testing results were available, with a constant concern to seek the best technical solutions while simultaneously optimising the project in terms of quantities, costs and schedule.

To comply with the preliminary design completion dates, TERRASOL mobilised a team of over ten engineers. By the beginning of 2012, we had almost completed the geotechnical studies for all the structures, with a rate rising up to 20 structures / week. The review phase then allowed for the incorporation of new data (laboratory results, additional surveys), of the various external control remarks, and of the exterior control comments. Our strong mobilisation was maintained up to May 2012, date of the official preliminary design release.
We then also performed the detailed design, and seconded an engineer on site to follow-up the geotechnical works.

A. Bergère

South-Europe-Atlantic High Speed Railway Line

Tours - Bordeaux, France

The Tours-Bordeaux South Europe Atlantic (SEA) HSL is the first High-Speed Line project based on the Public- Private Partnership (PPP) model in France. It involves 340 km of new line, including 302 km of high-speed line and around 40 km for connection to the existing line. With the aim of commissioning in 2017 for a concession period of 50 years, various preparatory works and studies necessary for the first construction operations started in 2010.

TERRASOL has been taking part in this project since the summer of 2011 on several geotechnical construction missions to assist various teams in the design and construction sub-group COSEA:

- Standard (52) and specific (4) civil engineering structures of section B (work sections 3 & 4);
- Viaducts (4) with prefabricated segments crossing the Auxance, the Indre and the Claix rivers (with taking into account of the karstic context);
- Hydraulic retention tank in Ambarès-et-Lagrave;
- Soil reinforcement under the Dordogne Valley embankments.

The commissioning of this High Speed Line is scheduled mid-2017.

K.V. N’Guyen

Nîmes – Montpellier Railway Bypass

France

Photo credit: Oc’Via - Yannick Brossard

TERRASOL has been working on the Nîmes - Montpellier railway bypass since 2010, first of all on the occasion of the response to the proposal by the OC’VIA Construction group (BOUYGUES), followed by the project (preliminary and detailed) design studies. For these studies, TERRASOL, alongside SYSTRA, had defined the geotechnical testing programmes, then carried out the geotechnical design studies for the standard engineering structures of the “Gard” works package, and lastly took part in the studies of the Lez Viaduct and of the Manduel cutting). A total of nearly a hundred structures have been studied.

As part of the detailed geotechnical works design, the OC’VIA Construction group subsequently contracted TERRASOL to update and optimize the geotechnical design studies for the engineering structures of works packages “Hérault” and “Gard”. Worth mentioning in particular is the grade separation carrying the future track V2 of the Lattes connection over the existing Tarascon-Sète line. This structure is located in a difficult geological context: the limestone massif, subcropping in the South zone of the structure, plunges abruptly and to great depth in the North zone of the structure. In addition, karstification processes are affecting this limestone substratum. The foundation techniques consequently chosen for the structure combine karst treatment grouting, shallow foundations, piles anchored into the rock and fl oating piles in the tertiary formations.

In parallel, TERRASOL worked actively on site. In the spring of 2014, a first engineer worked in the geotechnical unit of the technical department and then a second engineer was seconded to the Works Management team on site for 18 months. Among all the geotechnical issues encountered:

- Problems related to the karsts and to their backfilling.
- Monitoring and checking of the foundations of the engineering structures, and in particular the piles: a real challenge in view of the 1200 piles that were executed.
- Monitoring of the challenging jet-grouting operations under the existing SNCF (French Railways) tracks for the Manduel cutting.

G. Chapron, B. Madinier and F. Asselborn

Riviera Marcory viaduct

Abidjan, Ivory Coast

For Ivory Coast, the construction of the third bridge in Abidjan was one of the most symbolic projects of the 21st century. It was finished in 2014.

This 1,500 m long viaduct with 30 piers crosses over the large Ebrié lagoon and, as such, forms part of the global project linking the Marcory and Riviera districts. The project was carried out by BOUYGUES TRAVAUX PUBLICS and will be operated by the SOCOPRIM concession-holding company within the framework of a construction/concession contract.
On request from BOUYGUES, TERRASOL became involved early on in the project for the definition of the geotechnical surveys and an assignment to monitor the soil investigations carried out on site in November 2011. These works were followed by the definition and analysis of static pile loading tests as well as by the preliminary and detailed design.

Given the depth of the boreholes that exceeded 80 m and the difficulties inherent in a lagoon environment, the soil testing campaign proved to be particularly complex. As a result, it was necessary to modify the initial programme which provided for at least one piezocone sounding per support and replace them with destructive and pressuremeter testing. The viaduct is founded on 2 m diameter piles bored using hollow augers. These piles are more than 80 m deep in the central part of the lagoon in order to be embedded into a layer of compact sand laying under a considerable thickness of muddy clay deposits. This compact layer also includes a layer of deep clay with a lesser bearing capacity that required a precise definition of its stratigraphy, a definition made difficult by the erratic sedimentation conditions and the problems encountered during the investigations.

Pile tests using an Osterberg cells were carried out to confirm the proposed assumptions, particularly insofar as the pile tip bearing capacity is concerned. This highly depends on an execution methodology that includes pile tip injections to recompress the soil.

B. Simon

Cable-stayed bridges in Oyala

Equatorial Guinea

Photo credit: BBGE

TERRASOL was entrusted with foundation studies within the design-construction project of two triple span cable-stayed bridges over the river Wele at the entrance of Oyala, in central Equatorial Guinea. Bridge no.1 is located upstream, about 1 km away from bridge no.2. Both bridges are identical, except for vertical leveling.
The local geological context is composed of:

- alluvia of the river Wele on the surface, with mediocre mechanical characteristics,
- a layer resulting from in situ alteration of the crystalline substrate (lateritic profile),
- the granitic or gneissic substratum with an upper part of alteration reaching sand consistency.

The conditions of access to the site, as well as low availability of laboratories and boring machines in the country, resulted in a difficult soil testing campaign. Evaluating the soil mechanical characteristics was delicate because of the disparity of values measured, requiring a range-based approach for design.

The design of the foundations of the two structures in this lateritic geological context led to executing 44 micropiles of 10 to 15 m long for each pylon and abutment foundation, anchored by 4 m minimum in the gneissic substratum. These micropiles work mainly through friction in the rock, as the contribution of upper layers remains low. About ten micropiles are tilted by 15° to take up horizontal loads.

Later on, in 2013, TERRASOL was entrusted again with the studies of the foundations for Oyala bridge n° 7.

A. Bergère

Expertise on the Jacqueville bridge

Ivory Coast

The Jacqueville bridge links Jacqueville with the mainland across the Ebrié lagoon west of Abidjan (Ivory Coast). This structure has 16 supports (2 abutments, 14 piers), 13 of which are built in the lagoon. Works started in 2012 with the boring of large-diameter (1.20 m) piles, at depths down to more than 50 m in some cases. Investigations performed on the piles after construction showed bearing capacity defects on a large number of supports. After attempting to reinforce the deep foundations by grouting on three supports without reaching the target result, the owner (AGEROUTE) called upon TERRASOL for the following tasks:

- Detailed analysis of the geotechnical context of the supports concerned (P4, P14 and C16),
- Validation/proposal of a method for modification of the foundation system by addition of extra piles,
- Calculation of the new foundation system.

Addition of piles under the headers raised the problem of the proximity of the abandoned piles, which disturbed the friction and the tip behaviour of the piles, but also the question of the capacity of the new piles under horizontal loads in this complex environment. Several bracketing calculations were performed using the Fondprof, Taspie, Tasneg, Piecoef and Groupie modules of the FOXTA program in order to determine the behaviour of the foundation and validate the repair principle. These calculations enabled to proceed with the works on site, while globally maintaining the geometry of the planned headers.

J. Drivet and U.S. Okyay

Brazzaville Corniche

Congo Brazzaville

Photo credit: CRBC

The project consists in building a road link alongside the river Congo to improve access to downtown Brazzaville. The Congo government awarded the construction contract to the Chinese company CRBC. The SETEC TPI / SGI consortium was entrusted with the control of the project, and asked TERRASOL to deal with the geotechnical aspects: revision and adaptation of the geotechnical synthesis, checking the contractor's calculation reports for the foundation aspects, geotechnical stability, soil/structure interaction, geotechnical recalculations using Foxta and Talren software, signing off the contractor's documents (procedures, calculation reports, summaries), assistance to SGI's local control team.
The project, 2,5 km long, had to overcome a number of geotechnical difficulties:

- alluvial environment of the river banks necessitating soil reinforcement,
- cable-stayed structure with heavy loads, necessitating deep foundations of large diameter,
- presence of compressible and changing materials.

The works included a major cable-stayed bridge, and embankments on compressible soils.

All the structures have been founded on deep piles of large diameter because of the poor characteristics of the superficial materials and the need to account for strong horizontal loads. The embankment sections have necessitated the use of retaining walls on reinforced soil (stone columns), and the high embankments the use of rigid inclusions in order to meet the stability and deformation criteria.
The project also involved slopes protection against erosion and a hydraulic structure 200 m long below a high embankment.

Construction lasted from 2013 to 2016.

J. Drivet

Radès-La Goulette bridge

Tunisia

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TERRASOL with its branch TERRASOL TUNISIA has been the geotechnical consultant for the Japanese company TAISEI CORPORATION during the construction of the Rades - La Goulette bridge, crossing Tunis lake. This bridge includes a main cable-stayed bridge, as well as access viaducts with their access embankments. Its outstanding character lies specially in the geotechnical context, with compressible muds of a hundred meters thick, which lead to the following solutions:

- The two main piers of the viaduct are founded on 9 piles (diameter 2000 mm), which were originally planned to 100 m depth; due to the difficulties to drill such piles and after two full-scale load tests, the depth of these piles could be reduced to 80 m.
- The multiple piers of the access viaducts are founded on precast piles (reinforced concrete) 25 m deep, driven down to a thin sand layer.
- Access embankments, whose heights reach 8 m with pre-loading, could be built without any instability; vertical drains installed in the first more compressible layer have enabled to achieve consolidation in 3 to 4 months approximately, with settlements reaching 1.50 m!

Adequate soil testing, complemented by design studies accounting for the specific soil behaviour encountered on site, allowed anticipating this unusual behavior in a satisfying way, which could be confirmed by on-site monitoring.
The bridge was inaugurated in March 2009.

A. Guilloux and K. Zaghouani

At the edge of a delta: the second bridge over the Wouri

Cameroon

As part of the construction of the second bridge over the river Wouri in Cameroon, TERRASOL carried out an expert assessment assignment for contractor SOGEA-SATOM to study the construction of the embankments and their interaction with the bridge supports. The structure under construction includes five road traffic lanes and a railway line. It is 800 m long with 135 m major spans. The site is located in the Wouri river delta (equatorial climate). The top soil layers consist of highly-compressible estuarine clays and sands, with local deposits of organic content.

In this context, settlements leading to a level difference between the abutment and the access embankment may occur after a few years of operation, and it is important to properly predict this settlement, particularly in the transition and connecting zones.

In practice, it was necessary to ensure compatibility of settlements between the rigid structure (bridge) and the flexible structure (embankment). The selected solution was ground reinforcement by rigid inclusions. This technique limited differential settlements without involving preloading, which would have complicated the construction phasing. Conversely, the preloading technique was applied to the standard part of the embankment. A test plot was used for precise evaluation of the magnitude and development of the settlements in an extremely unfavourable geological context.

Started in 2013, the construction of the second bridge over the Wouri is scheduled for completion in September 2016.

U.S. Okyay

Third Bosphorus Bridge

Istanbul, Turkey

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 Virlogeux. 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 has also provided its advices for project optimisation, with the stability checking of the rock foundations, using 3D finite element calculations.

Photo credit: © ICA IC Içtas-Astaldi

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, as well as in the final phase, under the effect of deck tipping and seismic actions. Construction started in May 2013. The last deck element was installed in March 2016 and the bridge was inaugurated on August 26, 2016.

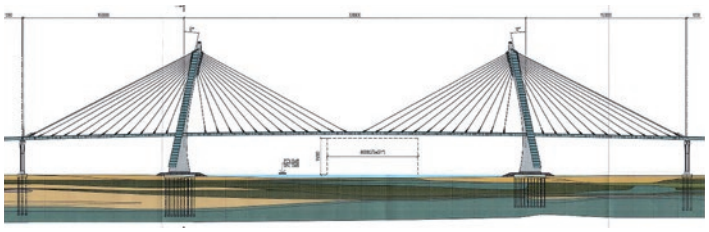
A. Guilloux

Saint-Petersburg bypass

Russia

As part of the verification of the design of two major bridges planned along the Saint-Petersburg bypass, SETEC TPI awarded TERRASOL the contract for verification of the deep foundations of the two bridges:

- a cable-stayed bridge over the Bolshaya Neva (Korabelny channel, 620 m long, main span 320 m long, composite deck) with substantially-inclined main pylons;
- a double-deck bridge over the Morskoy canal (734 m long, 7 spans of length up to 168 m).



The local geology consists of a sequence of alluvial deposits 25 to 30 m thick overlaying Proterozoic clay. The water table is expected a few metres below groundlevel.

The piers of the bridges will be supported by groups of bored piles, the tips of which, anchored in the Proterozoic clay, will be widened using reaming tools. The design of these foundations has been carried out using the Taspie, Piecoef, Tasseldo and Groupie modules of the FOXTA software. TERRASOL has also supplied the horizontal and vertical stiffness values necessary for the structural calculation.

M. Brun

Hong-Kong - Zhuhai - Macao bridge

Asia

The Hong-Kong - Zhuhai - Macao connection will boost trade between the Macao and Hong-Kong special administrative regions and Guangdong province in the Pearl River delta zone. This six-lane dual-carriageway road link, with a total length of 42 km, comprising viaduct sections as well as a tunnel section between two artificial islands, will link the former Portuguese and British trading posts in 45 minutes, compared with four hours at present by sea.

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As part of its construction contract for the 9.4 km of viaduct in the territorial waters of the Hong-Kong SAR, the BOUYGUES/CHINA HARBOUR consortium contracted TERRASOL for assistance with the design of the foundations of three of the component viaducts located in the airport ship channel.

In a potentially-faulted near-shore geotechnical context, composed of sub-consolidated marine deposits overlaying weakly-compacted fine alluvia, coarse alluvia, and a granitic substratum showing a fringe of very advanced alteration, the TERRASOL mission consisted in defining the geotechnical models of the viaducts, and the static and dynamic soil/structure interaction parameters of the support foundations, as the structure is being built in a seismic environment. This mission was conducted in conformity with the geotechnical codes in effect in Hong-Kong.

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