*Geotechnical Aspects of Underground Construction in Soft Ground – Viggiani (ed)*


# Underground car parks in Italian urban areas: Not an easy task!

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ABSTRACT: TREVI SpA has been involved for over 15 years in the field of underground car parks construction in Italian urban areas, offering a turn-key product named TreviPark. It is a cylindrical automated underground silo. This experience offered a comprehensive view about several aspects to be faced in order to come out with the final product. Among these aspects, we mention: human relations with job site neighbours, relations with the ancient heritage such as underground archaeological finding, the impact with the existing underground utilities, monitoring of the neighbouring pre-existing structures before, during and after the construction stage, relevant aspects of the design (soil investigation, loading, modelling of anticipated construction tolerances, impact on local hydrology and deformations behind the retaining wall), technological features in order to meet the design requirements like drilling verticality, walls and basement's waterproofing.

This paper would like to offer an overview of these aspects by focusing on some of them.

## 1 INTRODUCTION

For over 15 years, Trevi SpA, a worldwide leader in the field of special foundations, has been offering the private and public sector a mechanised, automatic, fully secure and unmanned underground car park that is commercially known as TreviPark (see Fig. 1). Civil and also mechanical components of the car park are designed, manufactured and installed by the Trevi Group; particularly the mechanisation is a Soilmec SpA product. The reduced sizes of the entry and exit bays (without entry ramps) make TreviPark's environmental impact negligible, the surrounding area may be maintained in its original conditions and urban facilities may be enhanced. The system can be successfully introduced and integrated into all urban environments, both historical and modern. All TreviParks are connected to a dedicated Control Centre that operates 24 hours a day, giving instructions to the client, operating thanks to a remote control system on the software which manages the electro-mechanical unit and by coordinating emergency reparations and maintenance systems.

The product is attractive because of its efficiency and pleasantness, and the experience gained over these years in the acquisition, management and construction stages allow us to emphasize some aspects that are usually underestimated and could be a real surprise for the Contractor, especially when operating in Italian urban areas. In the following paragraphs some of these aspects will be shortly described.

Figure 1. TreviPark construction sequence: secant piles retaining wall and excavation, placing of prefabricated internal structures, installation of car lift and final urban facilities.

## 2 DEALING WITH NEIGHBOURS

In order to successfully execute an underground car park, it might be useful to involve and make sensitive the public opinion to not only the advantages deriving from the execution of the intervention, but also to the performance of the various site activity phases. In agreement with what usually happens in other European countries, also in Italy, for the execution of some underground car parks, it has been possible to achieve a remarkable result by regularly informing the citizens about the works' progress, with forecasts about the final date of the works, the problems which had to be faced and solved and the various activities in progress (this is possible through press releases and other media, but also through illustrative panels placed outside the site). Citizens can be also invited, upon previous agreements, to visit the site so that they can personally realize what's going on and how works are carried out. Some sections of the fence around the site might be left open in order to allow residents and citizens to follow, day by day, the trend and the progress of the works.

The Italian law offers the residents living close to the car park a whole series of advantages in order to purchase or use the built car stalls, but despite these opportunities, in many occasions and especially in the starting phases, residents are likely to obstruct the execution of this type of works because they fear a consistent impact on the pre-existing physical and cultural structures, both during the execution and their following running. Districts' committees are then established and they can delay the issuing of the authorizations by the relevant Departments (it usually takes 3 ÷ 6 months but even 1 ÷ 2 years can be required). Anyway, our experience has shown, in many cases, that, once works were completed, those who were contrary to the project, realized then how good the initiative was and they even bought the built car stalls.

## 3 MONITORING OF EXISTING STRUCTURES

Before the site setting up for the car park execution, status surveys (legalized certificates) are usually carried out with regard to the buildings close to the car park to be constructed. This is in order to highlight their structural conditions at the time of the survey, that is, before the start of the works by means of photographs, assessments and measurements of the buildings' fissuring status, etc… .

At the same time, bench marks are installed for the topographic measurements to be performed in the most significant points of the buildings surrounding the areas interested by the car park construction. Level measurements are made and repeated along a significant time period (at least 6 months) before the works' start, in order to set the reference value and check that no deforming phenomena are in progress and also check the effect of the weather changes on the movements of the buildings and the optical measurements.

During the execution phases of the work, topographic measurements are carried out with variable frequencies per each type of phase. Warning threshold values are defined as adequate whenever they are exceeded and works in progress are to be interrupted in order to study the phenomena in progress and decide on the actions to undertake (i.e. the Aposa torrent, Via Finelli, Bologna).

These topographic readings are usually prolonged also after the completion of the car park, with a monthly frequency and for at least one year.

In some cases, in order to reassure the residents, and before starting the works, some dynamic monitoring surveys have been carried out in some buildings. In this way it was possible to detect the effects of environmental vibrations of the cars' traffic with no works in progress, 24 hours a day. Then, data were compared with the vibrations produced in the site, especially during the most critical phases of the car park construction (excavation, laying of the reinforcement cage, concreting, etc…). Results have highlighted that in the examined sites (i.e. Via D'Azeglio, Bologna) the vibrations induced by the works were of minor entity (maximum peak particle velocity ppv_max = 0.46 mm/sec), comparable to those of the normal environmental noise (ppv_max = 0.22 mm/sec), and, anyhow, within the limits set by the rules as per the type of controlled buildings (threshold for damage ppv = 3.0 mm/sec).

## 4 ANCIENT HERITAGE

In addition to the possible presence of architectonic, monumental and landscape limitations on the surface, there is a further element which must not be neglected, and precisely, the presence of archaeological finding in the underground.

By archaeological finding we mean any kind of finding linked to the past, also relating to not very long ago, on whose destiny the Department of Archaeological Heritage ruling on the area must decide, with reference to periods before the middle age, or the Department of Architectonic and Monumental Heritage for earlier ages. Since Italian cities are mainly historical cities which changed over the time due to subsequent stratifications, it's very common to find historical finding whenever the ancient part of the city is excavated.

Sometimes small and removable findings of minor importance are encountered, but it might happen to find more valuable remains: in this case the relevant Department will stop the works for a more or less long time (i.e. in Piazza Fabbri, Cesena, Figure 2,

Figure 2. Archaeological campaign at Fabbri square in Cesena (detail of a Roman mosaic 1st cent. A.D.).

for 6 months and in via d'Azeglio, Bologna, for 2 years) in order to ascertain, through an excavation campaign made by qualified personnel, the entity and the consistence of the findings, and then assess their destination.

In order to assess and estimate the costs involved by the archaeological risks, it is advisable to carry out preliminary archaeological surveys on the chosen area; these are carried out both on the basis of the documents and information available and by means of aimed core sampling (through drill holes) of underground materials, with following examination on the nature and the origin of the extracted fragments by specialized laboratories.

The mostly adopted solution consists in the execution of preliminary archaeological excavations, each on 10–20% of the intervention surface and for a depth that is at least equal to that assessed with regard to the most ancient traces, to be performed in some sampling points of the intervention area.

## 5 PRELIMINARY WORKS/EXISTING UTILITIES

One of the most demanding preliminary works in the execution of underground car parks is the determination and the re-location of the underground utilities sometimes intensively located under the city centres.

The time planning and the economic evaluation of the interventions are particularly difficult (i.e. Largo Pizzetti, Rome, the re-location of underground utilities required 8 months and 350.000€).

As for the determination, it is not always possible to get exhaustive and complete information, sometimes due to the lack of updated technical documents. As a matter of fact, while some institutions have already a complete set of documents, mainly on computer formats, for others it is necessary to patiently carry out researches in registers and also explorative core borings on the site are often required.

It should be also taken into account that the shifting is not easy for all utilities; in case of telephone systems, video-heating systems or sewerage manifolds with remarkable size, the deviation and the services' restoration costs involved can be sometimes so high to become, de facto, economic insurmountable obstacles for the execution of an underground car park.

If the car park must be executed in areas that are more sensible than others to the emission of dusts and noises, for example close to hospitals and schools, special precautions must be taken in order to fall within acceptable disturbance values as per regulations.

In order to mitigate the acoustic impact of the site, some provisions can be adopted, such as the fencing of the excavation area with elements characterized by high sound-absorbing features (with a full and continuous wall) and the same execution of the excavations is performed with methods suitable for exploiting, as adequately as possible, the requirements of sound waves' and vibrations' absorption by the ground and it will be possible to intervene on the noise produced by the used equipment by increasing their soundproofing. Moreover, excavation works, which are the noisiest phase, could be performed according to time schedules agreed with the municipal administrations and the district councils. In extreme cases, and for very limited periods, extensions to the noisy limits can be asked, and these will be issued by the Municipality upon previous agreement by the Supervising Authorities (i.e. via Finelli and via D'Azeglio in Bologna).

In order to contain the spreading of the air-dispersed dusts, efficacious measurements might be adopted, such as the use of dust-preventive cloth assembled on the trucks destined to the transport of inert matters and excavated materials and also the frequent wetting of the loading/unloading areas and access ways to the site—in order to maintain a condition of constant moisture of the materials which are likely to release dusts in their dry status.

During the site phase, it might be necessary to interrupt all or some parts of the traffic flows around the area interested by the intervention. These measures will have to be adopted for the strictly necessary period, envisaging all necessary requirements so that the works can be accomplished in quick times, with no interruptions, in order to limit to the minimum the traffic discomforts.

## 6 SOIL INVESTIGATION

Geological and Geotechnical investigations are the first steps in order to prepare the geotechnical model through which underground structures will be analysed. One of the main difficulties arising at this stage is the superposition of competences between the Geologist and the Designer. The conflict between geological and geotechnical reports must be avoided, particularly as far as soil properties are concerned, since these data must be evaluated by the Designer who chooses the foundation type. Unfortunately, the soil investigation is often performed by the Owner before appointing the Designer and this might imply additional soil investigations.

The new national technical code for the constructions (NTC) edited on 2008, considers the whole Italian country as a seismic land with different earthquake characteristics according to the geographic position and the local soil seismic behaviour. Soil classification is in function of the shear wave velocity parameter evaluated from ground level down to a 30 m depth. This means that the soil involved by the underground structures must be investigated for at least 30 m and, in any case, for such a depth where mechanical and hydraulic variations in the ground conditions may be anticipated.

Standard in-situ and laboratory tests are employed to evaluate static strength and deformation characteristics (un-drained and drained). In addition, some more sophisticated tests to define the dynamic behaviour of the soil, such as seismic cone penetration tests or down-the-hole tests in boreholes (field) and cyclic triaxial tests (laboratory), have to be carried out.

It is better to perform drilling for tests outside the footprint of the car park. In case some drillings must be performed in the area to be excavated, attention must be paid to the holes' sealing in order to prevent incoming water from flowing through a preferential path.

## 7 LOADS AND MODELLING

In most cases it is difficult to know the loading system from the surrounding existing buildings. Many times, these car parks are placed in down town areas and the plans of the buildings are often missed. Thus, information such as foundation type, foundation base elevation and characteristics of the foundation material are often not available. This leads to the subsequent need for foundations' core borings in order to take samples and complete surveys of the structure in order to have enough information (weights and plan distribution of loads) to complete the calculation model. These operations may be performed only with the authorization of the adjacent buildings' owner.

The calculation model must simulate all actions on the structure, from the natural loading (earth and water pressures, earthquake, etc.) to external overloads (buildings, traffic, etc.), internal reactions (capping beam, ring beams/wall, bottom slab, etc.). Interference might occur in case of multi car park systems (several shafts at reduced spacing) or other underground structures (metro). Possible anomalies on the theoretical cylinder shape within the construction tolerances have to be considered.

The vertically symmetric shape of the retaining wall shows several particularly favourable aspects:

- the circular shape under a more or less uniform radial loading (water and earth pressures) induces prevalent compression hoop stresses on the section which allow the use of high compression/low tension resistance materials like the concrete.
- the tendency to ovalization of the circular shape is opposed by the passive earth pressure; hence, it can be said that the system is self-centring.
- in case of loss of reaction at the diaphragm wall toe, the cylinder shape is self standing.

The most unfavourable loading conditions are usually due to un-symmetric actions such as localised overloads (adjacent buildings, operating equipment, etc), inclined ground level, seismic actions, etc... Figure 3 shows an example of the worst loading conditions matched with a localised shape anomaly. It is a plane view of ¼ of the retaining wall.

The plane $q$ pressure distribution on the car park shaft, due to a localised overload, is simulated by a sinusoidal equation, Equation 1, where $q'$ is the value of maximum pressure.

$$q = q' \times \cos(2 \times \alpha) \quad (45° \le \alpha \le 90°) \tag{1}$$

The pressure $q$ may be constant or variable on vertical direction.

The simplest way to simulate the seismic effects is to use an equivalent static loading $q_{eq}$ according to the Mononobe (1929) and Okabe (1926) or Wood (1973) proposal and to consider a variable

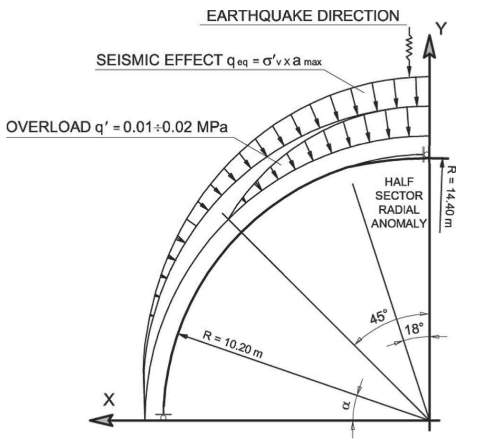


Figure 3. Example of loading condition on ¼ of the shaft—plan view.

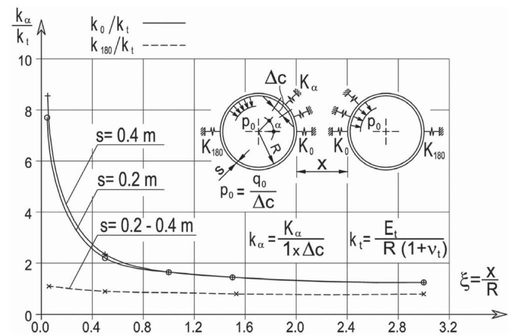


Figure 4. $k_\alpha/k_t$ versus $\xi = x/R$ graph.

loading distribution on the plane like that given by Equation 2:

$$q = q_{eq} \times \sin\alpha \quad (0° \le \alpha \le 90°) \tag{2}$$

Where $q_{eq} = \sigma_v \times a_{\max}$ = seismic horizontal pressure; $\sigma'_v$ = effective vertical stress and $a_{\max}$ = maximum horizontal ground acceleration.

The anomaly, with respect to the perfect cylinder shape, is simulated on an angle of 36°, with a vertical deviation of about 1%.

With regard to the interference between two or more shafts, the study performed by Alessi et al. (1993) summarised in Figure 4 is interesting.

The graph shows the variation of the normalised radial soil rigidity around a shaft $k_\alpha/k_t$ versus the normalised free distance between shafts $\xi = x/R$.

Where $k_t$ refers to the soil rigidity in case of a single shaft given by Equation 3:

$$k_t = E_t/\left[R \times (1 + \nu_t)\right] \tag{3}$$

While $E_t$ = Young modulus of soil; $R$ = radius of shaft; $\nu_t$ = Poison coefficient of soil; $k_\alpha$ = radial soil rigidity at a given $\alpha$ angle accounting for shafts interference; $k_0$ = radial soil rigidity at $\alpha = 0°$ (minimum distance between shafts); $k_{180}$ = radial soil rigidity at $\alpha = 180°$ (on the opposite side of the shaft); $x$ = minimum free distance between shafts' and $s$ = thickness of the retaining wall.

It can be seen that while the $k_{180}/k_t$ parameter is practically independent by the distance of shafts and about equal to 1, the $k_0/k_t$ ratio rises slowly from big spacing up to about $x = 0.5 \times R$, having then a sharp increase when the shafts become more and more close till a theoretical infinite rigidity when the shafts are in contact.

The new code for construction (NTC-08) require realistic simulation of the events hitting the structure, considering the complexity of model and loading conditions; this calls for the adoption of powerful calculation tools like 2D and 3D Finite Element Methods.

## 8 HYDROLOGY

The construction of underground car parks may change the local hydrology. A row of narrow-spaced underground shafts may create a barrier to the natural flow of the water in the ground, especially if a high hydraulic gradient is present. The effect is to induce an increase in the ground water level upstream the shafts and a decrease downstream. In order to avoid such a problem and to maintain the original hydraulic conditions, draining trenches may be envisaged between each shaft to increase the permeability locally.

Under seismic conditions, Westergaard (1933) approach may be used to evaluate the hydraulic thrust against the retaining wall.

## 9 DEFORMATIONS BEHIND RETAINING WALL

Either during the construction of the retaining wall, or during the excavation inside the shaft and after, under service conditions, deformations will be induced in the ground space around the car park. The high rigidity of the circular shape is such to guarantee very small deformations behind the retaining wall. Anyhow, if the existing structures (buildings) are very close to the shaft and are ancient and heavy, and the foundations are insufficient and/or deteriorated, some preliminary works may be required in order to increase the safety level of the work. In case it is necessary to increase the local stability (single panel excavation stability) during the construction of the retaining wall, a reticulate micropile wall (at least No. 2 rows of micropiles inclined on opposite directions parallel to the retaining wall) may be envisaged between the existing foundations and the single panel borings. If the real capacity of the existing foundations is close to the loading system, an adequate safety condition must be reached before the construction of the car park starts. The increase in the foundation capacity may be obtained through one of the following methods: by increasing the dimensions and strength of the existing foundations, by increasing the capacity thanks to deep foundations like micropiles or by improving the characteristics of the natural soil. In all cases it is a further problem.

## 10 AS-BUILT SHAFT CHECK VERSUS EXCAVATION

In order to take advantage of the cylindrical shape effect, it is fundamental to control the as-built retaining wall during the stage of soil excavation from the shaft and to check that the deviations measured on site are within the construction tolerances considered in the design.

Here below, there's an example of procedure that checks the construction tolerance of the cylinder retaining wall performed by secant piles. The control is focused on verifying two types of anomalies that will be solved in different ways: a local and an extended anomaly. The control is performed at pre-defined elevations, frequency increased with depth and amount of anomalies noticed. At each control elevation, the position of each pile is measured, supplying a set of data per pile that includes: radius $r_i$, radial deviation $\Delta r_i$ and tangential deviation $\Delta t_i$. Radii are placed on a bar chart as shown on Figure 5, theoretical and average values are drawn, but more than anything else, it is important to control the running curvature along the perimeter to emphasise the presence of local or extended anomalies.

The following relationship is used, Equation 4:

$$c_i = r_{i+1}\cos(360/n) - 2r_i + r_{i-1}\cos(360/n) \quad (4)$$

Local anomalies are further examined through the comparison of measured radial and tangential deviations and the envelope of admissible deviations as shown in Figure 6. If the actual position of the pile falls out from the referenced envelope, it has to be repaired (above ground water level: by local demolition and reconstruction; below ground water: several techniques may be used in order to reinstall the correct cylinder shape).

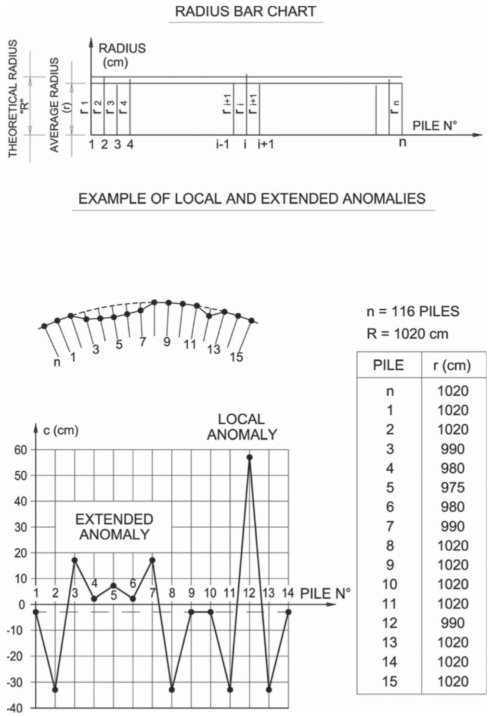


Figure 5. Example of local and extended anomaly detection.

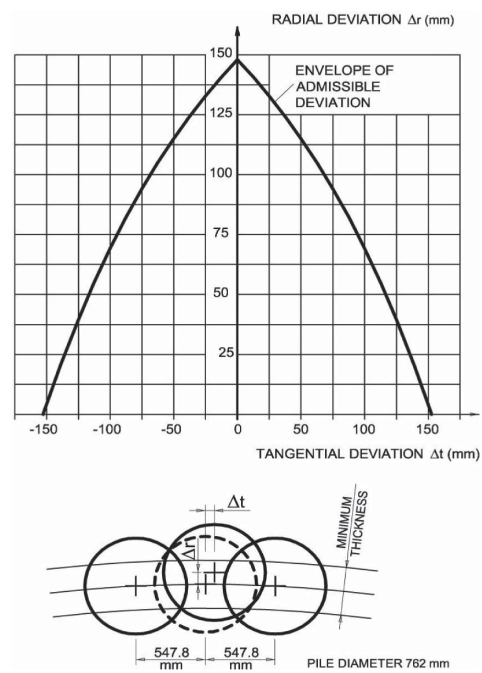


Figure 6. Example of local anomaly evaluation.

Extended anomalies usually call for much heavier corrective operations. The re-profiling of the internal surface of the shaft through a ring wall/beam could be a solution.

## 11 WALLS AND BASEMENT'S WATER-PROOFING

When the car park is constructed on a site where the soil profile is described as cohesion-less and highly permeable and the excavation will go deeper than the water table, great attention has to be paid in order to guarantee the waterproofing of the side retaining wall and the excavation bottom.

According to the cylinder shape of the shaft, no particular joints are usually necessary in order to avoid water incoming from the side because of the horizontal hoop pressure between adjacent elements that seal the wall.

The target to make the bottom of the excavation impervious is much more difficult and expensive. If the soil profile is such that, by increasing the depth of the retaining wall more than what it is strictly required by structural/stability reasons, it is then possible to fix the base of the wall inside a natural impervious soil layer, and at a reasonable cost, this condition is absolutely desirable. Otherwise an artificial bottom plug has to be constructed at such a depth to balance the underwater pressure with respect to the stabilising weight of the soil on the top. Injections and jet-grouting techniques are usually employed. But the most important and difficult aspect of this work is the check of the imperviousness of the plug and, in case, the definition of faulty positions in order to repair them, and this control has to be performed before the excavation stage.

Once there were techniques that required an hydraulic gradient to be established between the inside and the outside the shaft, but now a new technique developed by Texplor does not need any variation in the hydraulic natural equilibrium and is able to give a clear picture of the position of the existing faults either on the side or on the bottom of the shaft. The system works on the principle that the electric current flows easily where water is present, so, by inducing an electric field into the ground and by measuring the passage of current standing from the working platform, it can supply the position of the faults, if any.

## 12 SHAFT: TECHNOLOGICAL IMPLEMENTATION

The complex logistics of the underground car park construction (narrow spaces, pre-existing buildings nearby the excavations, restrictions as far as noise, vibration and environmental pollution are concerned and reduced time schedule) require the adoption of innovative technologies and equipments in terms of production, quality of the product and reduced environmental impact.

Implementing the well known Continuous Flight Auger (CFA) technique for the pile construction, the Cased Auger Piles (CAP) and the Cased Secant Pile (CSP) technologies were developed. A continuous flight auger is housed inside a casing on the piling equipment. Auger and casing are driven by two independent rotaries. They penetrate simultaneously in the ground during the excavation stage; then the auger is extracted while pumping the concrete and later the casing is withdrawn and reinforcements may be placed using a vibrator, if required. The side wall of the car park shaft is obtained through primary and secondary secant piles at a given spacing in order to get the required overlapping. For this application, special guide walls are requested to guarantee the correct plan position of the piles and the guide of the casing at ground level (see Fig. 7).

The main advantages of the CSP technique are:

- piles are constructed without using drilling fluids, in any kind of soil, above and below ground water table, thus the removed soil is at its natural state and may be disposed with no problem, at low cost;
- the casing gives high rigidity to the excavation system, minimizing the verticality tolerance. Vertical deviations in the range of 0.5%–0.7% were measured for the cased length of the piles;
- the drilling system allows the piles to cross very hard materials (from weak to medium rock, low reinforced concrete slab, masonry wall, etc.);
- the jobsite installation plant is minimised both with regard to space and time;
- noise, vibration and impact shocks are reduced to a minimum;

Figure 7. Guide walls and SoilMec equipment for CSP retaining wall construction.

– the casing allows the piles to be constructed nearby existing foundations, hence avoiding stresses' reductions during the drilling stage and with a minimum disturbance during the construction of the whole shaft.

SoilMec SpA of Trevi Group, a mechanical world leader in the construction of rigs for the execution of geotechnical works, have developed a range of equipments particularly dedicated to the execution of CSP in function of the geometric features of piles (diameter, cased length, total length, etc) and geotechnical characteristics of soils (www.soilmec.it).

## 13 CONCLUSIONS

The aim of this paper is to emphasize some aspects in the car park project that could be underestimated by the Contractor. Authors believe that the following themes may not be disregarded, especially if the job site is placed in the down town of Italian cities.

– As far as the success of car park construction is concerned, the establishment of good public relations with local authorities and people living nearby the area involved by the car park is extremely important;
– Taking into consideration the ancient history of Italian towns, any excavation in the down town has a high probability to encounter underground archaeological findings, with a consequent forced shifting of the time construction schedule;
– Preliminary works may be very time- and money-consuming, particularly the detection and re-location of existing utilities could be so difficult that the Contractor or the Owner might abandon the project;
– Environmental requirements about noise, vibrations and air-dispersed dust as well as local traffic interruption must be carefully planned;
– Monitoring plays an important role for quite all works in civil engineering, but this is particularly true when the behaviour of the structure depends on its shape (arc effect), and the impact on the neighbouring pre-existing buildings may be extremely remarkable;
– Finally, the new Italian technical code for the constructions (NTC) edited in 2008 requires realistic simulations of soil-structure interactions as well as loading conditions (seismic actions), therefore modelling and analyses of theoretical and as-built conditions must be performed using somewhat sophisticated calculation tools.

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