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EFFICIENT SCREWING : last developments and Korean experience

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SYNOPSIS : The auger and screw piles have known an important evolution during the last decade. Besides the large success of augercast (CFA) piling systems, new systems have been developed combining, to a variable extent, the classical extraction auger with especially designed displacement tools in order to develop screw piles with partial or total lateral soil displacement.
These last developments cover the whole range of lateral soil displacement and are more difficult than ever to compare. The authors present the latest evolutions in auger piling systems and compare them with respect to penetration performances, bearing capacities and amount of spoil generated. A special focus is given to a new efficient system: the OMEGA(Ω) pile in use in Korea since 1997. The results of the Hongcheon site are presented where this Ω system was applied for a new investment of the Korean National Housing Corporation (KNHC). This first important experience, with the execution of some 1,500 Omega piles with diameter 410 mm, is presented. The piles were installed through loose silty sands down to very dense sands and layers of gravel. The results of full-scale load tests are analysed and show the conformity with requirements of the clients.

KEYWORDD : OMEGA(Ω) Pile, CFA, full-scale load test

1. Introduction

Since their introduction some sixty years ago, augercast in place piles have known an increasing success for more than thirty years now. Major environmental concern regarding absence of vibrations and reduction of noise during pile installation mainly explain the important development and preferred use of vibration-free technologies such as augercast and screwed piles (instead of driven piles). Moreover, steadily improving installation techniques made it possible to gradually compete with driven displacement piles as far as the load-settlement behaviour is concerned. For all auger pile types however, there is a much greater need for careful control of the installation parameters.

In the field of the deep foundation techniques, the conventional classification of piles relates to the effects of the penetration of the drill head / auger in the soil, an effect that directly determines the bearing capacity of the piles. Two main types of piles are thus distinguished: displacement piles and non-displacement piles. When applied to screwed piles, this distinction entirely relates to the following aspects: the geometry of the auger tool, the installation procedure and the load-settlement behaviour of the pile, the three being closely linked with each other.

It is important to point out that the well-known, above-mentioned classification in the terms of displacement and non - displacement is under evolution. Because displacement is influenced by many aspects really, the terms themselves should be interpreted with relativity: some effects indeed, such as the presence of spoil, must not automatically lead to the conclusion of absence of displacement and / or vice versa. Recent technological advances, particularly in the field of soil testing, lead to new trends tending more towards a classification also defining soil displacement in terms of soil site parameters (i.e. measurement of change of soil stress conditions and soil stiffness) after installation of the pile. This will lead to a more explicit and unambiguous concept of displacement (and finally allow its quantification). This topic has been addressed by i.e. professor W.F. Van Impe during the XIVth ICSMFE Conference held in Hamburg, Germany in September 1997.

Among the auger and screw piles, one distinguishes piles allowing for full excavation of soil on the one hand and piles with soil displacement during penetration on the other hand. In between these two extreme cases of full de-compaction (pile to be considered as a bored pile with reduced decompression of soil) and complete displacement of soil, a number of screwed pile types exist, allowing for partial excavation and / or displacement.

The de-compaction / displacement behaviour of a screw pile is directly related to the shape of the auger head used to penetrate the soil. In other words, the auger chosen to penetrate the soil has a great influence on the stress field around the pile and consequently on its final bearing capacity. It should be emphasised that the capacity of the screwing equipment in terms of thrust and torque influences in a drastic way the behaviour of auger piles and their final capacity. Finally, the character of the installation procedure (i.e. the degree of de-compaction or displacement) is obtained not solely during the phase bringing the auger at the required installation depth, but also during the concreting phase. This clearly emphasises the importance of the details of the overall installation process and their adequate control.

The most severe limitation of all augercast techniques is the high sensitivity of the pile quality to the overall execution procedure. Therefore, attention and preferably (electronic) control of each phase of the installation of the auger pile are important. For example, an insufficient auger penetration rate will cause an over-excavation (with severe de-compression) of the soil surrounding the pile and possibly induce unwanted effects of settlement to adjacent, existing structures. Insufficient skill and care of the crew operators thus quickly result in inconsistent quality and bearing capacity of the pile.

Mainly in order to clarify the above mentioned problems, Professor Viggiani from Naples(Italy) made an interesting mathematical analysis of the mechanics of augering of CFA piles(1989). Going out from the volume of soil displaced by the auger penetration and the volume of soil removed by the screw, the auger installation conditions with respect to penetration are formulised (varying between net compression and complete removal of the soil). Viggiani further examines the augering mechanism in terms of the capacity of the used piling equipment and concludes that axial thrust is needed at the beginning of penetration but after reaching a certain depth, only a torque will be sufficient to continue the penetration of the auger. Also, the required equipment capacity increases with increasing diameter of inner stem (and identical outer diameter). This is also stated in Chapter 2.2 about PCS - piles.

The displacement or de-compaction aspect due to the installation of the pile can be checked by controlling, out of soil investigation tests, the resistances of the soil surrounding the screw pile tip.

An overview regarding the currently used screw piles now follows. In Europe and in Belgium particularly, different types of soil-displacement screw piles co-exist. The purpose of the paper is obviously not to describe all existing vibration-free screw piles. The aim is to illustrate the unavoidable evolution from systems with high rates of penetration (also into resistant layers of soil) but with reduced bearing capacity - such as the conventional CFA-piles - to more complex screw pile systems, at the same time well-performing regarding penetration and allowing for capacities comparable to those of driven piles (i.e. the Omega pile). For all of the described systems, the relative importance of the screwing tool, the rig equipment and the installation procedure will be highlighted.

2. Cast in situ piles installed with a continuous auger: transport of soil to the surface

Piles installed with a continuous auger allow for penetration into resistant layers of soil, whether these layers are intermediate or bearing layers. They are especially suitable when pile embodiment or anchoring into the hard layer is required. The diameters of the augers range from 0.3 to 1.2 metres and the lengths of the piles can reach 35 metres. The piles have smooth shafts. Extraction of soil during the installation of piles installed with a continuous auger obviously affects the bearing capacities of these foundations.

2.1. CFA piles or Continuous Flight Auger piles: full extraction of soil

The conventional CFA procedure permits the rapid and vibration-free installation piles with diameters commonly ranging from 0.3 m to 1.2 m by means of a continuous auger consisting of a hollow stem with an inner diameter of 10:12.5 cm (4 to 5 inches).

The torque needed for the introduction of the auger into the soil currently varies between magnitudes ranging from 40 kN.m to 150 kN.m, restricting the application of CFA piles to penetration in rather soft upper layers or thin and medium resistant intermediate soil strata before reaching the bearing strata. The penetration rate of the auger nearly always being smaller than the rate of revolution ('n') times the pitch of the screw flange ('l'), soil is often transported upwards along the flights resulting in decompression of the soil along the auger but facilitating the boring operation, especially in granular soils.

At installation depth, concrete is casted under pressure while progressive extraction of the CFA is maintained ('closed' concreting system through concrete pump). The installation of CFA piles should always be monitored. Absence of automatic recording can result in improper installation of the pile, e.g. insufficient penetration rate and / or uncontrolled concreting phase. Concerning the concreting phase, the release of the seal at the base of the hollow tube always involves lift-up together with rotation of the tool, causing a mixture of soil and concrete at the base of the pile. Too rapid withdrawal of the CFA auger might cause necking of the pile. In each of these cases, the foundation itself will not be reliable with respect to, among others, the criteria of bearing capacity. In the same case, the amount of spoil generated can even exceed the volume of the pile.

Load tests on instrumented CFA piles generally confirm that their behaviour is intermediate between the behaviour of driven piles and the behaviour of bored piles.

2.2 Second generation of continuous flight auger piles: partial extraction of soil

An improvement to the previously mentioned weaknesses of the classic CFA pile is given by the CFA-Starsol (Enbesol) pile. This system combines a continuous flight auger, a tremie pipe, a cleaning system (and a quality control system). Pile diameters reach up to 1 metre and the especially designed Starsol machine is equipped with a 90 kN.m rotary head. Inside the hollow (external) stem of the CFA tool itself, an inner co-axial tube is mounted, allowing to be extended into the concrete over a distance of up to 1.20 metres. The tube thus acts as a concreting tube, with two holes for concreting at its base. The base is also fitted with a so-called pilot tool for cutting the soil during screwing-in. At installation depth, the external stem is slightly raised (approximately 5 cm) while the pilot tool remains in place. The concreting holes are exposed and concreting under pressure can start, exactly as if done with a tremie pipe and under permanent control of pressure and volume of concrete. The main advantage of the technique consists of ensuring good contact between the borehole and the casted concrete during the whole duration of the installation procedure.

Another interesting evolution of the conventional CFA pile is the so-called pressurised concrete screw pile or PCS pile. It is characterised mainly by an important increase of the penetration rate and casting of the concrete under high but controlled pressure. This amendment is beneficial to lateral displacement of the soil surrounding the pile, optimal contact between soil and pile and to the shaft resistance of the pile especially. The control of the concrete pressure in the 'closed' system is achieved by means of continuous electronic monitoring. Equally, the monitoring system permits to control the penetration rate that should be sufficiently high in order to reduce the decompression of the soil. Higher capacities of rigs, preferably equipped with a 200 kN crowd, are needed. The higher torque (> 100 kN.m) of the rotary table thus enables the formation of such piles (with outer diameters up to 1.20 m) without removing an excess of soil upwards.

Out of dilatometer and pile load test results, it is clear that - more particularly in the case of PCS piles - the degree of soil displacement highly depends on the precautions taken during execution of the pile and clearly influences its shaft resistance (positively in case of efficient quality control of auger penetration rate and high concrete pressure).

The large stem diameter flight auger pile such as the Socofonda PCS-Lambda pile (or Pressurised Concrete Screw Lambda piles) is an interesting evolution in the installation technique of the CFA pile by reducing the decompression of the soil surrounding the pile. In some layers of soil a beneficial soil displacement can even be noticed.

The main improvements are the following:

- a larger diameter of the hollow stem (150 to 330 mm) and a range of pile diameters from 0.25 to 1.20 metres;
- the injection of concrete under high pressure;
- the high capacity of the rotary torque (i.e. 80 kN.m to 220 kN.m);
- the possibility to use a pull-down
- and the continuous electronic monitoring of the execution of the pile.

The final result is less excavation of soil (and de-compression) than what is achieved with the CFA technique and a better bearing capacity of the pile.

The Bauer VS-Pfahl is a combination of a very large diameter flight auger on which a small continuous screwflange is mounted, with a lower and small CFA part. The maximal diameter of the pile reaches up to 0.63 m. The pile can be anchored into the bearing layer while allowing for reduced excavation of soil due to partial displacement of soil during screwing-in. Also here the load-settlement behaviour is by far better that what is obtained with the classic CFA piles.

Recently the so-called Llamada pile has been developed representing an innovative approach to auger design in that it uses contra-rotating CFA augers at a certain stage of the penetration process. Starting the installation of the pile through the conventional CFA technique, the upper and lower sections of the CFA are separated and the rotation of the upper auger is reversed. This action results in downward transport of soil that will meet the upwardly moved soil transported by the lower 'lead' flight. Displacement is supposed to occur at this meeting point. The installation requires an especially designed rig equipped with twin rotary heads. Compared to displacement screw piles, the system certainly seems to allow for proper penetration into resistant layers of soil, what is mainly due to the use of a continuous flight. Questions remain regarding the real improvement of soil around the pile shaft.

3. Cast in situ piles without transport of soil to the surface and with lateral displacement of soil: use of the screwing technique.

3.1. Some general statements and attempted classification

Since more than twenty years, Belgium has a leading position in the development ofthe new generation of displacement screw piles. Closely linked with this screw pile evolution, a scientific-technical terminology has generated and is gradually being accepted world-wide.

Vibration-free displacement of soil is obtained by using a screwing system. The various screw heads differ from each other with respect to the amount of soil that is extracted in the lowest part of the auger and the efficiency of the screwing-in phase.

One can summarise the main differences as follows:

- amount of soil that is loosened at the bottom of the auger;
- concreting phase: open or closed circuit;
- required energy and penetration rates;
- so-called single or double displacement.

The volume of soil transported to the surface is virtually non-existing. According to the granular, respectively cohesive nature of the soil, the lateral displacement will be translated in compaction, respectively displacement (but without real densification) of the soil. Some of the advantages related to the execution of these piles are the absence of spoil and consequently the ease of manoeuvrability on site, the fact that no cost is involved with the transportation of spoil and their applicability on contaminated sites. As already emphasised, the installation without vibrations allowing for executing these piles in constructed areas.

The difference between single and double displacement is based on the technique of execution during the screwing procedure and during the formation of the pile. For a screw pile with single displacement of soil, the displacement is recorded during the downward movement of the auger head solely. During the formation of the pile properly spoken, the screw head is simply withdrawn while the pile is being concreted at the same time. For a screw pile with double displacement, displacement of soil is also required to occur during the extraction phase of the auger head.

With soil displacement augers, the net force causing compaction should be directed mainly horizontally because, if no special precautionary measures were taken, the only available vertical reaction force will originate from the own-weight of the screwing equipment. As a consequence, the presence of very resistant layers of soil ($q_c > 20$ MPa) sometimes causes slip (i.e. non-penetration) of the auger head on top of such layers, thus slowing down the auger penetration rate. The installation of a pull-down system (additional axial thrust force) on the piling equipment can compensate for this shortcoming. In an additional attempt to lower this effect, even the intrinsic design of some screw auger heads has been adapted, see for example Chapter 3.3.2.

3.2 Screw piles with excavation of soil at the base of the pile

Augers allowing for the installation of such screw piles clearly consist, at their lower part, of a combination of CFA-like parts and a displacement body placed above the partial flanges. During screwing-in and pushing down, the lower CFA-like part excavates soil below the auger tip, thus loosening soil all along during the penetration phase. Only at the location of the actual displacement body, the soil is displaced laterally. According to the type of auger considered, the displacement body is either very simple or more elaborate. Also the CFA-like part is more or less important resulting in more or less penetration. Two examples are given below.

3.2.1 The Strabag pile (Strabag SVV - Pfahl)

The displacement body is very simple i.e. a single step tapered-wise increasing massive cylinder. The CFA-like part located below this massive body is equally simple and consists of a screw flange with two revolutions only, leading to slow penetration rates. The amount of spoil generated is low, certainly resulting from the fact that soil is being displaced adequately. However, due to the simple design of the auger, the displacement occurs quite abruptly and therefore a high energy-input is needed so as to enable the compaction of the soil: the required rotary head capacity of the piling rig amounts up to 400 kN.m. During screwing-out, also the second displacement is achieved in a simple way by a one-step change of diameter (from inner stem to maximal diameter of displacement body).

3.2.2 The De Waal pile

Contrary to the Strabag pile, here the displacement body is more elaborate i.e. with a multiple step increase of diameter, a constant pitch of screw flange and change of direction of the screw flange for displacement during screwing-out (double displacement screw pile). The lower CFA-like part for loosening the soil during penetration is important with five revolutions of screw flange and constant pitch, resulting in higher penetration rates (than the Strabag pile). Above the small displacement body, a small CFA-like part (1 revolution of screw flange) with reversed direction of screw flange allows for preventing transport of soil to the surface during withdrawal of the auger. During concreting under gravity ('open' circuit), the rotational direction of the auger is reversed in order to release the tip.

3.3. Screw piles without extraction of soil

In this group one again distinguishes piles with single soil displacement and piles with double soil displacement. Three examples are given below.

3.3.1. Screw piles without extraction of soil and single soil displacement

In this group one for example knows the Fundex-auger pile. The steel casing (up to 450 mm of diameter) has a large, special auger tip at its base, attached by means of a bayonet joint. The tip has a slightly greater diameter than the casing (up to 560 mm outer diameter) and is lost. Because of this, only a single displacement of soil is ensured during the vibration-free installation procedure. The pile tip / soil interaction is intense and functions as a slightly enlarged base for the pile.

During the concreting phase (under gravity, so-called 'open' system), the casing is vertically pulled up (in gradual and small upward & downward oscillating movements) ensuring a continuous smooth concrete pile shaft. Both screwing and translation energies, required to introduce the big Fundex tip, are very important. The piling rig should indeed be able to develop a maximal torque of 500 kN.m on the casing, together with a crowd (downward pushing force) of 200 kN. In order to properly transmit such forces, a especially built rotary drive located near the centre of gravity of the piling rig is needed and so, the installation of the pile becomes time-consuming.

3.3.2 Screw piles without extraction of soil and double soil displacement

A. The Atlas-Franki screw pile

The Atlas pile with its characteristic very rough pile shaft is the first pile of this group ever developed. The Atlas auger is a small helical tool with an increasing diameter from bottom to top, tapering from the casing diameter to the (desired) maximal diameter of the pile shaft. At this latter location, a flange is welded over 360° . The casing behind this auger has a constant diameter and consists of steel tube segments. In a continuous helical penetrating movement, the Atlas auger is moved by rotation and translation down into the soil by means of a complex combination of drilling / pressure tables located near the bottom of the rig. The especially designed Atlas drilling rig develops a maximal torque of 450 kN.m, together with a crowd varying from 100 to 200 kN. During screwing-in, the soil is displaced or compacted mainly laterally. The casing is filled with plastic concrete and casted under gravity. During extraction of the auger, the tip, sealing the bottom of the auger, is lost and guarantees a permanent contact with the soil. The reversed drill head is filled with concrete and displaces soil again.

The Atlas auger - not involving extraction of soil at its base - being very small, the displacement is again induced very brutally, thus requiring high input-energies and a bottom-located drill table and resulting in lower installation rates of the pile. The high bearing capacity achieved is due to the soil compaction at base and all along the shaft. Along the shaft, the shape of the local concrete flanges can be enlarged over a pre-set height (during screwing-out) enhancing the shaft resistance even more. Naturally, this effect of increased lateral resistance is especially beneficial in clayey soils.

B. The Omega pile

Six years ago, the Omega pile has been developed in an attempt to optimise the penetration rate together with maximal soil displacement. The whole principle of the Omega screw system is therefore based on particular design characteristics that are beneficial to a number of closely linked factors: efficient transport of soil during screwing, double soil displacement, high penetration rate, energy-input and closed concreting circuit. The idea is to mount the screw flanges (of constant outer diameter) directly on the displacement body, and to induce the lateral displacement gradually.

The geometry of the Omega auger head is further characterised by a discontinuously diameter-increasing casing. The displacement is achieved by means of downwardly oriented slots (discontinuous diameter increase) reducing - at the same time - the upward directed vertical soil resistance along the auger. The slopes, inducing a cinematic impact onto the soil, cause a better and more dynamic displacement than when the diameter increase is gradual. It is important to point out that the displacement takes place in a progressive way, what results in less important energy-input (compared to the above mentioned displacement systems).

The pitch of the screw flange increases away from the tip. This increase is very important for ensuring the efficient upward transport of the soil in the screw and again for achieving high penetration rates. At the tip of the auger there is maximal transport of soil upwards and minimal soil displacement. While moving towards the maximal displacement body, the importance of the effect of displacement gradually increases and the importance of transport decreases, so as to finally stop.

The link between installation parameters and final capacity of CFA-piles (Viggiani - analysis) has been used to theoretically define the augering mechanics of the Omega pile and geotechnically optimise the ratio of the increasing diameters as well as the pitch of the screw flanges.

The installation of the Omega pile is based on a screwing-in / screwing-out procedure with the direction of rotation remaining the same throughout the whole installation of the pile. This avoids soil to be remoulded at the base of the pile and results in a very good pile tip - soil contact. The Omega auger is screwed-in by a rotary head with minimal value of 160 kN.m and a maximal value of 300 kN.m, while a vertical pull-down force eventually facilitates this action. During the screwing-out phase, the distinct counter-screw transports soil downwards, up till the maximal displacement body and displaces it laterally at this location. At the same time, concrete is conducted under pressure resulting in a third displacement (of soil). The influence of concreting under pressure on the overall behaviour of the Omega pile should not be underestimated and its positive effect has been proven by the results of a scientific research programme analysing the results of Omega pile load tests in clayey soils. The several displacement effects achieved during the Omega pile installation undoubtedly lead to an improved bearing capacity of the pile.

Further details about the geometry of the Omega auger, the installation of the Omega pile and the load-transfer mechanisms between Omega piles and sandy as well as clayey soils have been extensively described in the past. The pile load test results illustrate the behaviour of a soil displacement pile with load-settlement curves revealing a considerable stiffness at the beginning of the curve. They further confirm an excellent soil-pile interaction resulting in high installation parameter values (e.g. in the considered sandy profile, the pile worked for approximately 60% on pile shaft and approximately 40% on pile base capacity).

Control of the correct pile installation can be obtained by means of sophisticated monitoring devices, checking the execution parameters in real time. Full control is obtained these execution parameters are combined with results of soil investigation before, during and after the execution of the pile.

During the execution of a screw pile such as the Omega pile, important installation parameters to consider are depth, penetration speed, torque and pressure of the concrete (important because concreting occurs under pressure). It is very important to bear in mind that some of these parameters should be interpreted in combination with each other, such as for example penetration speed together with the torque. High values of penetration speed and torque for example indicate that a resistant (eventually) bearing layer have been reached. A high value of penetration speed and a low value of torque on the other hand indicate that the auger does not develop its self-gripping effect in the resistant layer and that the use of crowd is required. This proves that an immediate and correct analyse of the recorded information will enable the operator to adequately handle during the installation of the pile and execute it perfectly.

4. The Omega experience world-wide and in Korea

4.1 Introduction

Because the Omega system allows for a combination of simplicity and efficiency together with the realisation of a high quality pile, the Omega technology rapidly grew world-wide. Presently, deep foundation specialists of countries such as U.K., Sweden, Australia, France, Korea, Brazil, U.S.A., Hungary and Egypt are experiencing the Omega pile application. By introducing the Omega pile in different countries indeed, knowledge was gained about its installation in various soil conditions, about designing the pile using several methods of soil investigation, about different approaches of design.

Through the Omega co-operation in foreign countries, the paramount importance of reliable soil investigation test results for designing the Omega pile has, once more, been highlighted. Correct and sufficient soil information is even more necessary in areas with geological (and geotechnically different) soil conditions that change within very short distances (i.e. hundreds of metres). Unlike driven piles, where the measurement of the refusal during driving can be interpreted as a dynamic sounding providing direct information about the resistance of the soil, the installation of displacement screw piles is more dependent on prior and reliable soil resistance information. This fact is directly related to the already mentioned difficulty of correctly analysing a number of installation parameters in combination with each other. As far as the installation of conventional CFA like systems is concerned, it is clear that prior soil information is less primordial because the piles are usually embedded deeper into the bearing layer.

The large number of tests, respectively comparative tests performed on the Omega pile (mainly pile load test results) further permits to confirm its technical performances, respectively its behaviour with respect to other currently used screw technologies. Finally, the experience from 'outside' permits to refine some aspects of the use of the Omega technology and its further evolution.

4.2. The Omega experience in Korea

4.2.1 Chronology

In January 1997, the Omega pile was introduced in Korea.

In November 1997, the official demonstration of the Omega pile was organised in Inchon City, 30 km west of Seoul. During this event, more than two hundred engineers, contractors and academic people from Korea were invited to attend the demonstration of the installation of the Omega pile in situ. On the test site, Omega piles with a length of 11 m were installed using an electrical 130 kN.m-Hitachi KH-180 piling rig. The profile, as determined out of SPT results, was as follows: 1 m fill, 6 m silty clay, 3 m sand and gravel overlying weathered rock. Two fully instrumented static pile load tests were performed. At design load (800 kN), both Omega pile settled less than 3 mm, while at 1600 kN of test load the settlements reached 11 mm for the first test pile and 20 mm for the second test pile.

In May 1998, 83 Omega piles were successfully installed for the Shindo-Rico factory. Length of the piles varied between 8 and 8.5 m and the safe working load was 800 kN. The soil strata are as follows: 1.7 to 2.8 m fill, fine sand with silt down to 6.7 to 8.3 m depth, very dense sand and gravel (bearing layer), followed by weathered rock and soft rock. The concrete strength is 300 kg/cm^2 and the slump value of the concrete 150 to 180 mm. The characteristics of the reinforcement cage are 6 bars with ø 16 mm and 10 mm ø spiral (pitch of 300 mm). Two fully instrumented static pile load tests were performed on 8 m - length piles. At design load, one Omega pile settled nearly 3 mm, while at 182 tonnes of test load it had a settlement of nearly 12 mm. At design load, the other Omega pile showed a settlement of nearly 2 mm, while at 207 tonnes of test load it had a settlement of nearly 9 mm.

In February 1999, the Korean Industrial Property Office published the 'notice of allowance of patent', hereby notifying that the application of the Omega patent had been granted.

4.2.2. The Hongcheon Apartment construction site

The Hongcheon Apartment Omega jobsite was awarded in February 1999. The Omega job site, located at Hongcheon-kun, Kangwon-do, Korea lasted from March to June 1999, involving the installation of 1,532 Omega piles for the deep foundations of 10 apartments (each fifteen floors). Out of the results of SPT -tests, the soil profile consists successively of:

- 0.5 m of very loose fine silty sand;
- 4 to 5 m loose to medium dense medium sand;
- 3 to 4 m very dense sandy soil with gravel, diameter 5 to 10 cm (bearing layer);
- very dense silty sand and finally very weathered rock: 1 to 3 m.

The piles were installed with an Omega auger of diameter 410 mm. The totally installed length being 9,548 metres, the length of the piles varied from 4 to 8 m / pile (average length of pile = 6.25 m). The design load of the piles is 100 tonnes / pile. The average interdistance between adjacent piles was of 1.8 metres.

The concrete strength is 300 kg/cm^2 and the slump value of the concrete 150 mm. The dimension of the aggregate of the concrete is maximum 25 mm. The characteristics of the reinforcement H-beam are H - 100 x 100 x 6 x 8 and the reinforcement cage has 6 bars with ø 16 mm and 10 mm ø spiral. The reinforcement was introduced after the concreting phase.

Two electrical piling equipment of the crawler crane type were used, each with a total power capacity of 462 kW and rotary heads developing 100, respectively 140 kN.m. (Hitachi KH-180).

Prior to the installation of Omega piles for the foundations of the apartment buildings, twenty trial Omega piles were installed. Fifteen piles were installed for the purpose of providing a basis of quality control scheme for the installation procedure itself and five piles were installed for the purpose of extraction by excavation in order to confirm the shape and integrity of the Omega piles. From the picture it can be seen that the diameter of the Omega piles is constant over the total length and that the closing nut auger tips remain in the centre of the pile base.

In the Korean Omega application, the Omega shaft was modified by overlapping a 400mm ø steel pipe onto the original auger shaft in order to avoid possible collapse when screwing-in through the sandy and gravel layers of sand. It should be pointed out that this type of precaution can be taken but is not applied as a rule nor in Belgium where layers of sand and gravel under high water tables are very commonly encountered, nor in other countries (in similar conditions of soil profile).

During the screwing-in phase of the Omega piles, some augering problems arose due to the unexpected but frequent presence of cobble stones. As can be seen from photographs, some stones showed dimensions up to 400 mm. in a densely packed matrix of sandy soil, therefore not allowing the displacement of these large elements of gravel.

Twenty non-instrumented static pile load tests were performed (or 2 piles per building). The tests were stopped at a maximal load Q_{max}(test) of two times the safe working load of 1,000 kN and three loading-unloading steps. The summary of the load test results, analysed according to the Hanssen 90% method. Out of these pile load test results, the installation depth was determined on reaching at least a certain reference electrical value (calibration). At this stage, it is interesting to point out a different approach in the use of pile load tests. In many countries around the world (i.e. U.K., U.S.A.) and also in Korea, a preliminary pile is tested in order to check the adequacy of an existing design of a production pile.

The limitation of this type of procedure lies in the fact that - if combined with non-adequate or discontinuous determination of the soil profile - the tested production pile possibly will not be installed at the correct depth in the bearing layer.

Consequently, the pile load test result will not be as representative as should be. This again proves the prior and primordial need of reliable, sufficient and continuous information about the considered soil profile. In Belgium, because of the proven reliability of in-situ tests based design methods, static load testing of piles is generally confined to the control the conformity and intrinsic quality of the piles on site.

The Hongcheon pile load test results are satisfactory and the settlements certainly acceptable. Indeed, at design load, the values of settlement roughly vary between 5 and 9 mm (calculated average of 6.5 mm) and at loads of two times the design load, the settlements roughly vary between 12 and 25 mm (calculated average of 18.8 mm).

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