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LOAD CAPACITY OF AUGER DISPLACEMENT PILES

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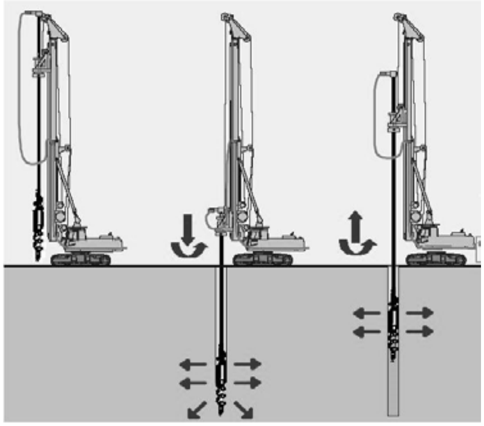
Auger displacement piles (ADP) have been used throughout the construction industry in Australia and worldwide for decades as foundation elements for structures and embankments. Over the last two decades, several different auger types have been developed, all classified as full displacement pile augers, each with small geometrical variations. Static load test results carried out in Belgium from 1998 to 2002 were used by the authors to demonstrate that ADPs installed by slightly different augers will show dissimilar load-settlement behaviour in similar soil conditions. This can result in unanticipated risks for the design and installation of ADPs.

Keywords: auger displacement piles, auger mechanics, rigid inclusions, static load tests

1. BACKGROUND

Auger displacement piling is a rotary drilling technique in which a hollow stem, fitted with a purpose built displacement tool at the tip, is drilled into the ground. Unlike non-displacement piles, like Continuous Flight Auger (CFA) piles or conventional bored piles, the soil is not excavated during the penetration process, but is displaced laterally and to a lesser extent vertically. The cavity created by the drilling tool is filled with concrete during the extraction as described in Figure 1. The spoil created by ADP augers is minimal.



Installation of Auger displacement piles:

1. Set up auger at pile position and install
2. cap to close concrete outlet at auger tip.
3. Install auger by rotating clockwise and
4. applying vertical pull-down force.
5. Drill auger to design depth; the displacement
6. body of the auger pushes the soil cut by the auger tip into the surrounding ground.
7. Pump concrete through hollow auger stem and extract auger while rotating clockwise, always maintaining positive concrete pressure with the auger embedded in fresh concrete.
8. Install reinforcement into fresh concrete, if required.

Figure 1. Typical installation process of auger displacement piles using rotary drilling technique

2. BASIC AUGER MECHANICS FOR PILING AUGERS

In order to understand the general working principle of ADPs, it is important to understand the basic principles of screw auger mechanics. Detailed discussion of screw auger models and the most accepted theories can be found in the literature (Viggiani 1993, Fleming 1995, Slatter 2000) and are beyond the scope of this paper. However, it is important to understand the influence of the auger geometry on the stresses and displacements created in the soil, as well as the installation parameters and pile load capacities. All screw auger theories and models are essentially based on three basic auger actions: (i) soil cutting, (ii) soil transport, and (iii) soil displacement. Depending on the auger shape, geometry and the main installation parameters (penetration rate, torque, pull down force, auger rotations), the influence of the three auger actions is different. For an Atlas or Fundex auger (Figure 2), soil displacement is the governing auger action, whereas soil cutting and transport are the major auger actions in the lower auger sections of Omega and de Waal pile augers.

3. AUGER DISPLACEMENT PILES (ADP)

Auger displacement piles were developed in the 1960's in Europe (Bustamante and Gianeselli 1998). The Atlas Pile was a pioneer of a bored, full-displacement pile, followed by the Omega pile as the flagship of the next generation of ADPs (Figure 2). With the development of hydraulic piling rigs and the increasing torque and thrust capacities of these machines, ADPs became more economical and over the past few decades several different auger shapes have been developed by different manufacturers. The augers shown in Figure 2 are all referred to as full-displacement pile augers, but generally fall in two different groups: (i) short augers (Atlas / Fundex), and (ii) long auger systems (Omega, de Waal, others).

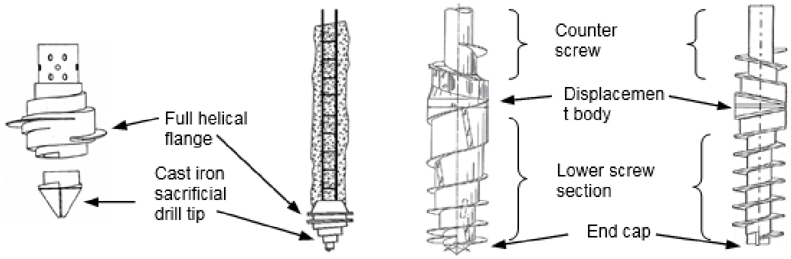


Figure 2. Selection of different full displacement piling augers (Atlas, Fundex & Omega, de Waal)

Omega and de Waal displacement augers are designed with longer flighted sections and the lower auger sections are used for cutting and transporting the soil to the displacement body of the auger. The counter screw sections, located above the displacement body, re-displace soil that has collapsed into the cavity behind the auger during the extraction process. The auger geometry of Omega and de Waal augers seems similar, and visually both augers seem comparable. However, the Omega auger is a progressive displacement auger. The stem diameter of the lower auger section progressively increases towards the displacement body. During penetration, soil is displaced progressively along the lower auger section and finds it peak at the location of the displacement body. Omega augers require high installation torque. The de Waal auger can be defined as a rapid displacement auger, since the displacement body has a larger diameter than the auger stem. Soil displacement occurs rapidly at the displacement body and no displacement is expected below and above it. Installation torque and pile capacities should be lower for rapid displacement augers compared to progressive augers (Slatter 2000).

The Atlas and Fundex systems rely on a short, single, full-helical flange to cut the soil and pull it in the displacement body, with little or no soil transport. The compact displacement bodies displace the soil. Usually, high torque capacities are required for these pile types, since a large amount of soil displacement occurs and the iron-cast, auger-shaped drill head of the Fundex system is sacrificial. In contrast, the Atlas drill head is extracted and only the drill tip is left in the ground. The installation of reinforcement is carried out prior to concrete placement for both systems via the hollow casing or auger stem, unlike that described in Figure 1.

Well-accepted piling codes and standards (e.g. AS2159-2008, BS EN 12699:2001) do not allow for shaft friction adjustments for different ADP auger types like Atlas, Fundex, Omega or de Waal. Some authors (Van Impe 1988, Bustamante and Gianeselli 1998) developed general design methods for ADP mainly relying on in situ soil test results (i.e. CPT, SPT, PMT), but none of the authors incorporates adjustment factors for different ADP geometries into the design.

3.1. LOAD-SETTLEMENT BEHAVIOUR OF DIFFERENT ADP TYPES

Between 1998 and 2002, a research project on ADPs was carried out in Belgium (Holeyman 2001, Maertens and Huybrechts 2003) to investigate ADP behaviour in granular soil (at Limelette) and cohesive soil (at Sint-Katelijne-

Waver). The authors analysed the test results and compared the load-settlement behaviour of de Waal and Omega piles, which use similar "long" displacement augers, with similar diameters in both granular and cohesive ground. The test results of two Fundex piles are displayed in Figure 3 as an example of a "short" displacement auger pile type.

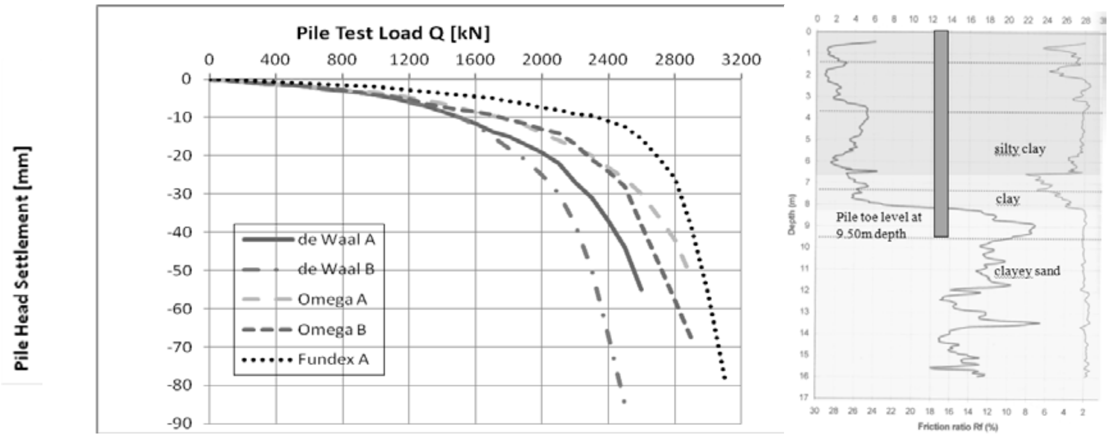


Figure 3. Static load tests results of Omega, Fundex and de Waal piles from the Limelette campaign

3.1.1. LOAD-SETTLEMENT BEHAVIOUR OF ADP IN GRANULAR SOIL

For the test campaign in Limelette, several different ADP types were installed in the heterogeneous soil consisting of three distinctive soil layers: (i) silty clay, (ii) clay, and (iii) clayey sand. Figure 3 compares the static load test results for Omega, de Waal and Fundex piles with similar diameters and pile lengths (9.50 m). No information about installation parameters was made available in the literature and it is assumed that those parameters, which reflect the installation energy, were different for both the Omega and de Waal, as well as the Fundex piles.

Figure 3 shows the load-settlement behaviour, the soil profile, a typical CPT, and the pile toe level, for the Limelette test campaign for Omega piles, de Waal piles (both 410 mm in diameter) and Fundex piles (base diameter 450 mm, shaft diameter 380 mm). Figure 3 shows a very stiff response for the Fundex pile, with the highest shaft capacity. The predominant auger action of this pile type is soil displacement at the auger tip, and during the installation process the clayey sand around the lower pile shaft was compacted well, increasing the skin friction in this location. The load-settlement responses of the other pile types show a generally lower stiffness, indicating an increased shaft capacity for the Omega pile compared to the de Waal pile, in the range from 10 to 25%. The base responses of de Waal and Omega piles, indicated by the steeply-angled end part of the load-settlement curve, are comparable and the gradients are in the same range. The short Fundex pile shows a slightly softer response for base capacity.

3.1.2. LOAD-SETTLEMENT BEHAVIOUR OF ADP IN COHESIVE SOIL

For the test campaign in Sint-Katelijne-Waver, a similar set-up was used. Omega, de Waal and Fundex piles of identical lengths and similar diameters (see 3.1.1) were installed into stiff clay, as shown in Figure 4. Two different pile toe levels (7.60 m and 11.70 m) were used.

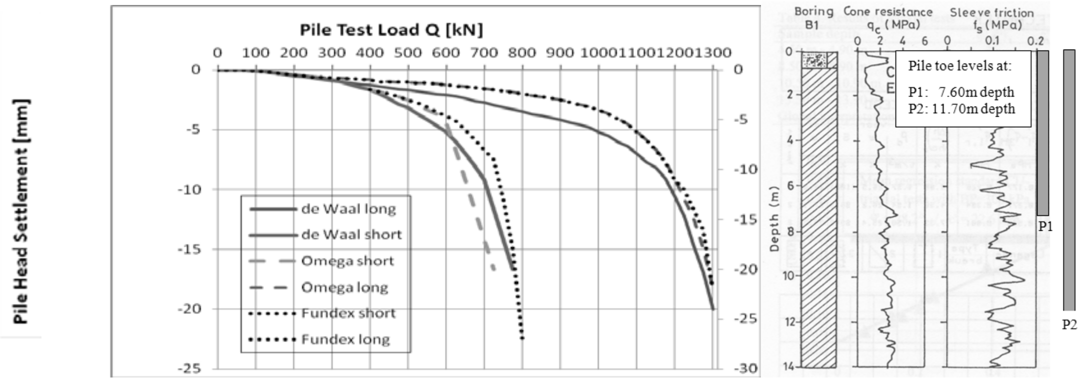


Figure 4. Static load tests results of Omega, Fundex and de Waal piles (Sint-Katelijne-Waver campaign)

Figure 4 shows almost identical behaviour for the long Fundex and Omega piles. The short Fundex pile shows a weaker toe response, but shaft capacity of similar stiffness. In general, both de Waal piles have a weaker stiffness than the other piles and reduced shaft capacities of 5 to 10%. The base resistance of all piles is in the same range for the long piles. De Waal and Omega piles show slightly stiffer toe responses compared to that of the Fundex reference pile.

4. RIGID INCLUSIONS

Rigid inclusions are cast-in-place concrete or grout columns, constructed by vibrating or rotary drilling techniques. This paper focuses on the installation of rigid inclusions using ADP, which have become increasingly popular in Australia and all over the world during the last decade.

Rigid inclusions aim to improve a soil formation with semi-rigid or rigid columns which are installed in a certain grid. These columns act as soil reinforcement elements and, unlike piles which transfer structural loads directly to stiffer soil layers, rigid inclusions will improve the entire soil block. Rigid inclusions are separated from the structure or embankment by a load-transfer layer, usually made of granular material, which distributes the loads applied by the structure into the column heads and into the soil between the columns.

Rigid inclusions have been used as foundation elements for road embankments (Wong and Muttuval 2011) and other structures, as well as for anti-liquefaction treatment (Plomteux 2007).

Plomteux and Lacazidieu (2007) define the condition of equilibrium by equation (1):

$$Q + Fn = Fp + Qp \tag{1}$$

where:

Q = vertical load at the head of the rigid inclusion;

Fn = negative skin friction, applied above the equal-settlement lower plane;

Fp = positive skin friction, mobilised below the equal-settlement lower plane; and

Qp = tip resistance in the anchorage layer.

Wong and Muttuvel (2011) define equilibrium as load-sharing between the soil and the rigid inclusion, combining: (i) compressibility of the columns, (ii) yielding of the column toe, and (iii) load-sharing via a load-transfer platform. Simon and Schlosser (2006) describe the shear mechanism and settlement mechanism of an embankment founded on a soil block, reinforced by rigid inclusions with a load-distribution layer as shown in Figure 5.

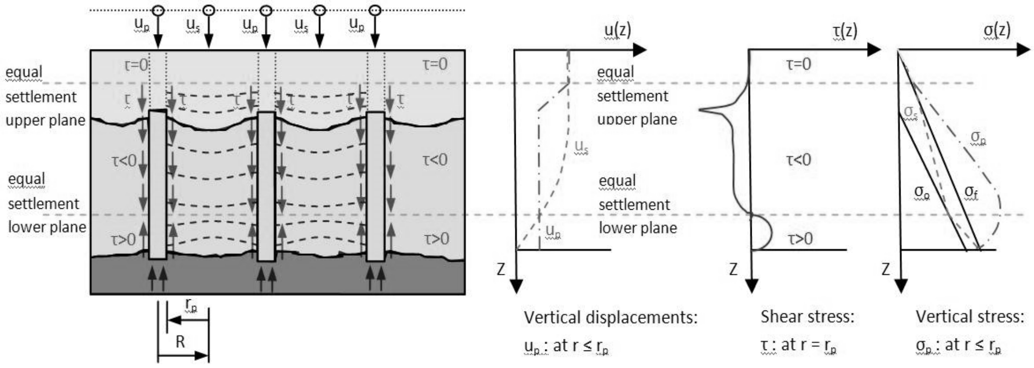


Figure 5. Shear mechanism of an embankment founded on rigid inclusions (Simon and Schlosser 2006)

The load applied by the embankment causes settlement of the load-transfer layer above the column heads up and of the soil surrounding the columns us. The settlement of the soil and column at the “equal-settlement upper plane” is similar. However, below this level the settlement us of the soil is greater than the column settlement up, which causes the stiffer rigid inclusion to punch into the load-distribution layer.

The soil surrounding the upper part of the column applies negative skin friction to the shaft of the column until the settlement of the soil us and that of the column up reach equilibrium at the neutral point corresponding to the “equal-settlement lower plane”. Below the neutral point, the column settlement up is larger than the soil settlement us, which causes the rigid inclusion to develop positive shaft resistance and base resistance below the toe of the column. Eventually, stress equilibrium occurs over the full length of the inclusion.

The design of rigid inclusions relies mainly on shaft friction values for the determination of the load-settlement behaviour of the rigid inclusion. It is critical for the design of the system to understand the two main contributing aspects that determine the skin friction capacity of the rigid inclusion: (i) the in situ shear strengths of the soil, and (ii) the capability of the installation method to increase or decrease this shear strength.

5. CONCLUSION

Auger displacement piles are used to install rigid inclusions as well as foundation piles. Different manufactures have developed different augers and auger types. It has been demonstrated by static load tests during test campaigns in Limelette (granular soil) and Sint-Katelijne-Waver (cohesive soil) that the load-displacement behaviour of seemingly similar auger types (Omega, de Waal) varies, with shaft capacities differing by 10 to 25% at a particular test site. Unfortunately, data about installation details were not published and could not be correlated with the test results. It is concluded that progressive piling augers seem to produce higher shaft capacities than rapid displacement augers. However, design specifications usually do not differentiate between progressive, rapid or any other displacement auger types.

The design concept of rigid inclusions relies on the choice of accurate soil parameters to correctly estimate the shaft friction and base capacity of the columns. Rigid inclusions installed with an auger type that potentially causes more or less shaft friction than a comparable full-displacement auger, may result in the system failing, or being over-designed and uneconomical.

The paper highlights the need for further research to better understand ADP behaviour in both granular and cohesive soils. Load tests prior to the commencement of projects are strongly recommended to obtain reliable values for specific auger types in specific soil conditions, and to ensure safe and also economical designs.

6. ACKNOWLEDGMENTS

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