XIII ICSMFE, 1994. New Delhi. India / XIII CIMSTF. 1994. New Delhi. Inde

TOE RESISTANCE EVALUATION IN OPEN TOE PILES

EVALUATION DE LA RESISTANCE A LA POINTRE DES PIEUX A POINTRE OUVERTE

S. Niyama[1] *A. Oshima*[2] *N. Takada*[2]

[1]Institute for Technological Research, Sao Paulo, Brazil
[2]Osaka City University, Osaka, Japan

SYNOPSIS: Instrumentation used to determine toe resistance in open toe driving piles presents some difficulties with reference to its data interpretation, because it depends on the plug behaviour. With the purpose of studying this aspect, an experimental program was developed, including centrifuge testing, field load test and small scale model test. The main conclusions are that, almost always, the open toe piles work as unplugged or partially plugged piles and the toe resistance could be computed as sum of internal skin friction and toe bearing acting on the pile net area. A simple method to estimate the internal shaft resistance is proposed.

INTRODUCTION

Open toe pipe piles are widely used to be driven into sand layers. During driving, soil column which enters the pile is able to become of the pile plugged or unplugged. As reported by Paikowsky and Whitman (1990), in spite of frequent occurrence of plugging and the importance of its effects, limited attention has been given to the subject.

It is essential to know the plug behaviour for the piling design and the interpret properly the instrumentation used to obtain the toe resistance. In fact, there are different hypotesis to establish the share ratio between toe resistance and total bearing during driving, depending on the plugging condition, i.e., the toe resistance can be considered as a force acting on the net area or the sum of this force and the skin friction acting on pile inside wall.

Usual instrumentation, based on pile wall axial strain measurement cannot separate the internal and external skin friction. So it is impossible to compute the realistic total toe bearing. In general, the toe resistance is assumed as the axial force acting close to pile toe (Figure 1), indicated by the lowest positioned strain-gage, in the case of static instrumentation. The same problem discussed for the static case is observed for the dynamic condition.

This paper discusses the plug behaviour and its influence on the pile instrumentation analysis, particularly to evaluate the toe resistance.

PLUGGING MECHANISM

Some existing experimental studies of soil plug behavior during driving have consisted only on continuous monitoring of inner soil top movement (Niyama et al, 1989; Raines et al, 1992), due to the difficulties to measure the dynamic phenomena. This simple procedure presents some limitations, considering that important plugging mechanisms, such as sand densification, develop near the pile toe.

There is a certain consensus that during driving the piles, almost always, are not plugged, mainly for the steel pipe type. In case of concrete piles, different behaviour is observed. The experimental relationship presented in Figure 2, obtained from several field data for piles driven in sand, shows a clear different trend depending on the pile type.

In the other hand, many authors agree that during static loading the piles work as closed-toe piles and it is common to assume that toe capacity is given only by the axial force $Q = \varepsilon . E . A$, obtained from the strain-gage installed close to the pile toe (Q_1, in the example of Fig.1), where ε is the measured specific strain, E is the Young modulus and A is the cross sectional area of the pile. This computed toe resistance probably will be an under-estimated value, less than considering the gross toe bearing, which would represent the plugged condition.

To study some of the aspects discussed herein, an experimental program was developed.

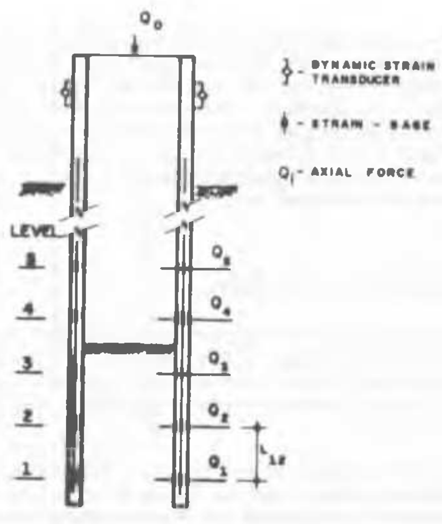

Fig. 1 - Schematic of Usual Dynamic and Static Instrumentation.

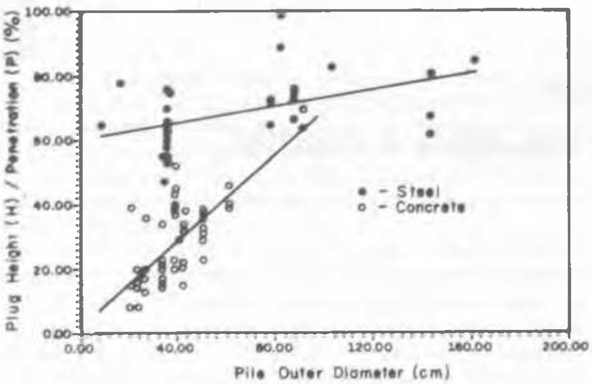

Fig. 2 - Relationship Between Plug Height / Pile Penetration and Pile Diameter.

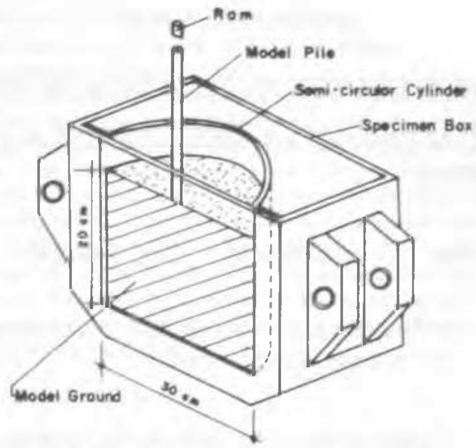

Fig. 3 - Model Pile and Model Ground.

CENTRIFUGE TESTING

Due to the difficulties involved in an observation of pile inside plug behaviour during driving, as already mentioned, the pile driving was simulated in a centrifuge. The centrifuge utilized was Mark 5 in Osaka City University having a 2.56m nominal radius rotor driven by a 22kW induction motor, with the maximum centrifugal acceleration of 200G.

The prototype ground is assumed as an axi-symmetrical cylindrical column, half of which is simulated in a semi-cylindrical column, 30cm in diameter and 20cm in height. The vertical cross-section of the model ground is supported by a glass plate, through which the plug and the ground deformation can be observed. The detailed description of this test apparatus can be encountered in Mikasa et al(1989).

The pile model was made using, also, a semi-cylindrical steel tube (16mm outside diameter, 0.5mm thickness and 30cm total length). The pile was driven at the center axis, as can be seen in Figure 3; the ram, weighing 20g, was wound up by an electric motor by means of string to a constant 1.0cm height, and then automatically released to drop along a guide perpendicular to the model ground.

The soil is a clean sand finer than 2mm, mixed with a weathered granite, 75 % finer than 0.075mm, by 5.8 % at dry mass. Its uniformity coefficient is 3.4, maximum dry density 1.71 t/m³ and minimum dry density 1.36t/m³. The model set up in the centrifuge was put in 100G centrifugal acceleration for about 1 hour allowing the settlement under its selfweight, before the pile driving.

Figure 4 shows the diagram of pile penetration (P) against plug height (H) in this prototype scale, observed during static penetration (due to 100G selfweight of the ram and ram hammer device) and during dynamic driving. It is interesting to observe that during the static penetration occurred slight plugging; during driving was not verified this phenomenon. In Figure 5 it is presented the family of ground displacement curves obtained from photo interpretation analysis, which to confirms that,during driving, the pile was not plugged.

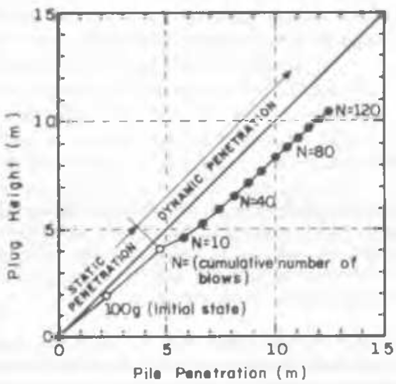

Fig. 4 - Pile Penetration x Plug Height.

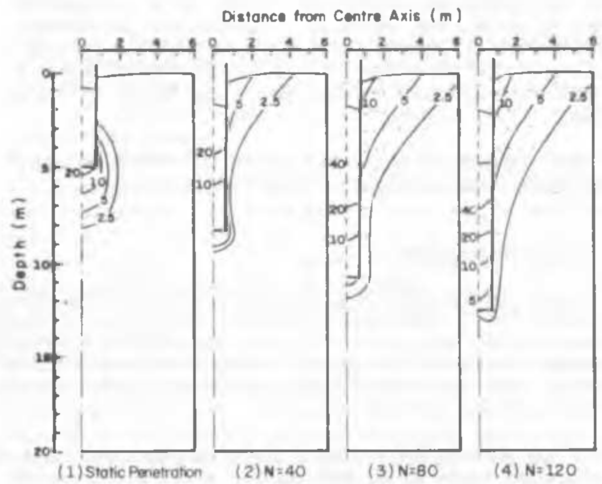

Fig. 5 - Displacement Curves Along the Pile Penetration

FIELD STATIC LOAD TEST

In order to verify the hypotesis that during static loading the pile, in general, behaves plugged, a simple apparatus (a type of tell-tale) was used to measure any plug toe movement which could occur during the static load test (Figure 6). Details of this test is presented in ABEF (1989).

During the driving, the soil plug top rose continuously into the pile, denoting un plugged condition. During the static load test, the maximum displacement at the pile top was 4.64mm, leading to permanent settlement of 0.70mm, and the plug toe rised 1.93mm into the pile.
This result demonstrated that, even during static condition, it is possible to occur some plug displacement, sufficient to mobilize the internal skin friction, characteristic of unplugged condition.

SMALL SCALE MODEL PILE TEST

Subsequently, a complementar study was conducted on a steel model pile. The pile with 139.3 mm outside-diameter and 5 mm thickness, instrumented along its length, was driven dynamically into a sand column compacted in a chamber. The sand was clean, fine and uniform, with grain size varying from 0.08 to 0.4 mm. Two mini tell-tales were previously installed in the sand, during its compaction process, at two levels, the lowest one at previous estimated position of pile toe. During the pile driving, its toe depth was controlled to coincide with lowest tell-tale.

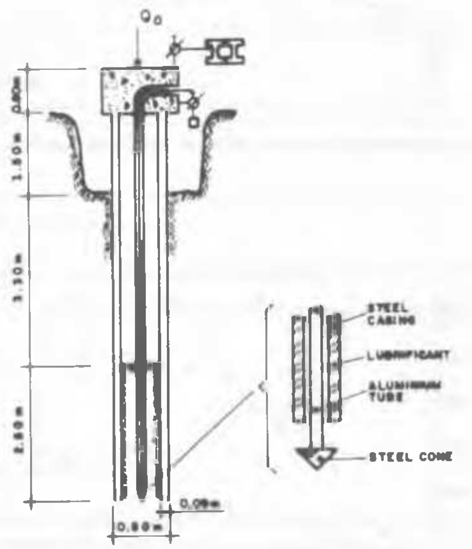

Fig. 6 - Measurement of Plug Toe Movement during Static Load Test.

Figure 7 shows the view of three static loading tests carried out in this chamber. The first test was performed according to SML method (Fig.7a). The displacements indicated by those two tell-tales allowed to deduce that major part of the deformation of sand occurred within two pile diameters from the plug toe. Similar result was obtained by Kishida and Isemoto (1977) in their full scale model pile tests.

In the second test, the pile internal soil was replaced by a steel tube connected to a rigid disc at its end, like a "piston", simulating the closed-toe pile (Fig.7b). This "piston" was instrumented, so it could be measured the load applied on it (Q_{PT}), and then the correspondent base unit pressure which was compared with the unit pressure computed from force Q_1 acting close to pile toe (as in Fig.1), usually assumed as the toe resistance, divided by net area or gross area of the pile.

In the third test, this "piston" was removed and a "counter-weigth" simulating the removed soil mass was rested on the bottom of the pile interior, aiming to minimize the effects of soil unconfinement surrounding the pile toe (Fig. 7c). In this condition, was considered that pile bearing capacity would be basically due to outside skin friction.

Finally, from some simplified hypotesis, this series of model tests allowed to separate the total shaft resistance (Q_S) in internal (Q_{SI}) and external (Q_{SE}) shaft friction, as follows:

$$Q_S = Q_O - Q_l \qquad (1)$$

where,

Q_O=load at pile head
Q_l=load close to pile toe (Fig.1)

then,

$$Q_{SI} = Q_S - Q_{SE} \qquad (2)$$

and from second test, it would be obtained:

$$Q_{SE} = Q_O - Q_{PT} - Q_l \qquad (3)$$

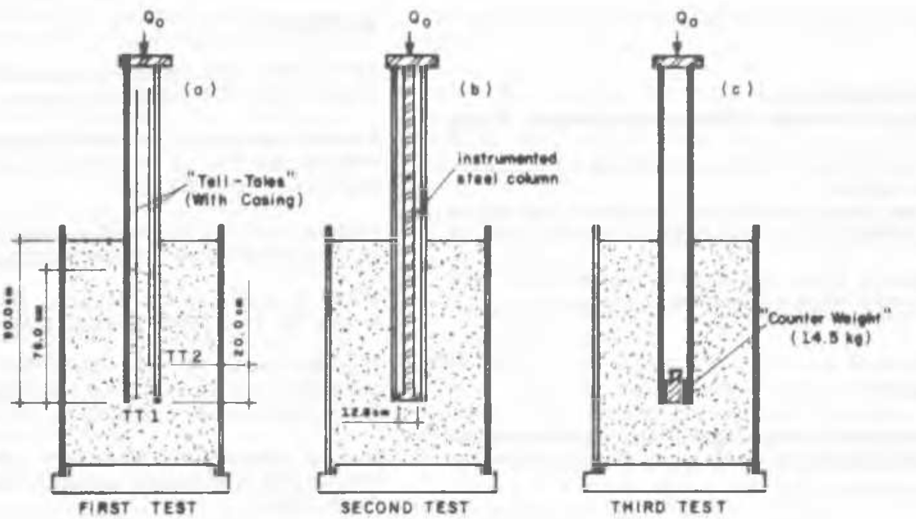

Fig. 7 - Static Load Test Arrangements : (a) after driving ; (b) simulating closed end pile (toe bearing + external friction); e (c) simulating open end pile (Without internal friction).

Figure 8 shows the curves of shaft resistances in function of the settlements at pile head. It is observed that Q_{SE} curve computed from the second test is very close to the Q_{SE} curve obtained from the third test. Figure 9 shows the average unit skin frictions $q_{SI} = Q_{SI}/A_{SE}$ and $q_{SE} = Q_{SE}/A_{SI}$, where A_{SE} is the outside shaft area of the pile in contact with the soil and A_{SI} is the inside shaft area corresponding to two diameter heigth.

TOE RESISTANCE DETERMINATION

One of the main objective of this study was to investigate the method to obtain a suitable toe bearing resistance (Q_P) of open toe piles, considering the plug effect. The results of the present preliminary tests allowed to conclude that, in general, it is verified a partially plugged condition, given by:

$$Q_P = Q_1 + Q_{SI} \qquad (4)$$

The value Q_1 is obtained directly from instrumentation, but QSI is not possible to obtain from ordinary instrumentation. Expressions (3) and (2), also, cannot be used because, normally, Q_{PT} is not available. Then, a way to compute Q_{SI} is proposed. From the force equilibrium in the interval L_{12} indicated in Fig.1, corresponding to a positions of gages 1 and 2, follows:

$$q_{SI} \cdot A_{LI} + q_{SE} \cdot A_{LE} = Q_2 - Q_1, \qquad (5)$$

Thus, the assumption of the average q_{SI}/q_{SE} ratio = 6.5 deduced from Fig.9, in conjugation with equation (5) leads to the relation:

$$Q_{SI} = (Q_2 - Q_1)/(1 + L_{12}/13\, B_I) \qquad (6)$$

where B_I is the inside pile diameter.

This relation is valid for steel pipe pile driven in dense sand. Similar investigation carried out on concrete open toe pile conducted to the relation:

$$Q_{SI} = (Q_2 - Q_1)/(1 + L_{12}/15\, B_I) \qquad (7)$$

Both relations (6) and (7) were applied to several cases of full instrumented load tests, specially in cases where was available some complementary data, such as uplift load tests in the same pile. The new toe resistance determined according to proposed method resulted satisfactory and, in general, more suitable and in better agreement with usual static prediction formulas.

CONCLUSIONS

The main conclusions of this study are:
- the use of centrifuge test is feasible to observe directly aspects of plug behaviour;
- even during static loading the pile plug presents some displacement, denoting unplugged cobdition;
- the internal unit shaft friction obtained was very higher than average external unit shaft friction and it occurred within two diameters from the pile toe;
- the proposed method to assess internal shaft resistance from usual instrumentation allowed to obtain a more suitable toe resistance.

ACKNOWLEDGMENT

The authors wish to thank the colleagues from Osaka City University and Instituto de Pesquisas Tecnológicas de São Paulo for their support and cooperation.

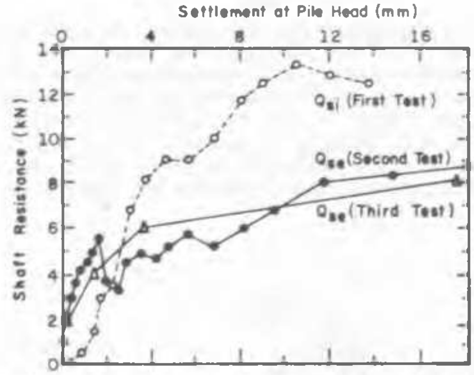

Fig. 8 - Internal and external shaft resistances evolution.

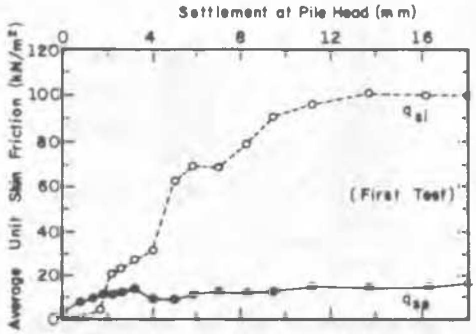

Fig. 9 - Internal and external unit skin friction evolution.

REFERENCES

ABEF. (1989) ABEF research on foundation engineering. Published on the occasion of the XII ICSMFE, Rio de Janeiro.

Kishida,H. and Isemoto, M. (1977) Behavior of sand plugs in open- end steel pipe piles. Proc. of IX Intl. Conf. on Soil Mechanics and Foundation Engineering, Tokyo, 601- 604.

Paikowsky,S.G. and Whitman,R.V. 1990. The effects of plugging on pile performance and design. Canadian Geotech. Journal 27, 429-440.

Mikasa, M.,Takada,N. and Ohshima,A. (1989) Dynamic consolidation test in centrifuge. Proc. ICSMFE, Rio de Janeiro, 947-950.

Niyama,S.,Azevedo,N. and Polla,C.M. (1989) Drivability and performance assessment of driven piles subjected to negative skin friction. Proc. Drivability of piles, Tech.Comm. on Pile Driving, 75-78.

Raines,R.,Ugaz,O.G. and O'Neil,M.W. (1992) Driving characteristics of open toe piles in dense sand. Journal of Geotechnical Engineering, v.118, No.01, 72-88.