Analysis of Pipe Pile In Sandy Soils

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Abstract*- Design guidelines for predicting the axial capacity of piles in sand have long been the source of considerable debate due to the geotechnical profession's inadequate understanding of pile behavior. Analytical studies, alone, cannot resolve the uncertainties in axial capacity predictions due to the complex nature of pile behavior in sand. This will present some of the factors which occur during installation and loading of pipe piles in sand, along with their potential impact on axial capacity.*

Keywords*-* Plugging of piles, pore water pressure, API method.

I. INTRODUCTION

Analytical studies, alone, cannot resolve the uncertainties in axial capacity predictions due to the complex nature of pile behavior. Experimental research on the physical processes that control the behavior of piles during installation and loading is required in order to resolve the issues involved. Considering the large number of variables involved in axial pile capacity development, as well as the high cost of load tests on full scale instrumented piles, it is unlikely that a sufficient number of full scale load tests can be performed to resolve the problem. Furthermore, the test conditions of full-scale load tests, generally, cannot be controlled satisfactorily to isolate independent variables. Experimental research on model piles can, however, be used to resolve some of the important design uncertainties.

Analytical methods based on simplified limit equilibrium or cavity expansion models have also been used to predict pile capacity. Analytical methods typically use design parameters which describe soil conditions and stresses prior to pile installation, and do not account explicitly for the substantial change in soil conditions and state of stress due to pile driving. Additionally, analytical methods do not account for soil compressibility and soil structure interaction. At this stage, analytical methods are most useful in preliminary computations, as well as in extrapolating load test results to other pile dimensions at the same site.

1.2 Installation Effects That Influence the Capacity of Pipe Piles in Sand

1.2.1 Plugging of Piles

During installation of open-ended pipe piles, the soil enters the pile at a rate that is equal to, or larger than, the rate of pile penetration. This mode of penetration is referred to as *coring* or *cookie cutter*. As penetration progresses, the soil core inside the pile may develop sufficient frictional resistance along the inner pile wall to prevent further soil intrusion, causing the pile to become *plugged*. Plugging is important, not only because it directly contributes to the tip bearing capacity, but also because it indirectly contributes to the developed shaft capacity (Gavin and Lehane 2002, Paik and Salgado 2003), since a plugged pile displaces more soil than a coring one, which increases the effective stresses surrounding the pile. Plugging also influences the dynamic behavior of piles, which complicates the dynamic analyses of piles (Paikowsky and Whitman, 1990; Raines *et al*. 1992).

On some occasions, piles may plug and impede driving. If the available pile hammer cannot drive the pile to the design depth a problem may arise, particularly for piles with thickened walls near the surface or mud-line, such as piles used to resist lateral loading (Murff*et al*., 1990). If the pile "refuses" prematurely, the required thick section may end up above the mud-line. In these circumstances, the plug is typically removed by drilling or jetting. The effects of the removal of the soil plug on the final pile capacity are controversial.

1.2.2 Buildup of Pore Water Pressure

Arching of soils inside the pile to form a plug depends on the ability of the soil to drain pore pressures and develop high frictional stresses along the soil/pile interface. Under cyclic or earthquake loading, the soil core may become partially drained, which may prevent pile plugging (Randolph *et al*. 1991), or reduce pile capacity (Choi and O'Neill 1997). There has been increasing recognition of gain in pile capacities in sand with time. York *et al*. (1994) attributed the gain over a period of a few weeks to dissipation of pore water pressure. Chow *et al*. (1998) attributed the gain over a period of 5 years to creep that leads to break down of circumferential arching stresses allowing increase in radial stress as well as increased dilatation due to aging.

II. API DESIGN GUIDELINES FOR PILES IN SAND

The axial load capacity (QC) of a driven pipe pile in cohesion less soils is estimated using API (2000) as follows:

$QC = Qs + QP \pm WP$

Where:
Qs= capacity in side shear
QP= tip capacity, taken as zero for piles in tension

WP weight of the pile submerged in soil, positive for tensile loading and negative for compressive loading. *WP* is often neglected due to its small contribution.

The side shear, Qs, is given by:

$Qs = \sum f_s \, C\Delta L$

Where:
fs= local side shear between the pile and the surrounding soil, limited to *film*
C =pile circumference
Δ□*L*= increment of pile length in the *i' th*layer

The tip capacity, *QP*, is given by:
$QP = qp\ Ap$

Where:
qp net pressure between the pile tip and soil limited to *qlim*
Ap tip area of the pile

For open-ended steel pipe piles, the tip capacity is the smaller of: (1) the tip bearing capacity of an equivalent closed-ended pile, or (2) the end bearing on the steel rim plus the side shear capacity of the soil core inside the pile.

2.1Assessment of the API Method for Piles in Sand

The wide use of API RP-2A has brought about numerous criticism as well as support for the method (Iskander and Olson 1992). Many of the criticisms are valid, but resolution of the criticisms is hindered by the profession's lack of a good understanding of pile behavior, as well as a lack of relevant high quality data.

Hossain and Briaud (1992) pointed out the large user variability in the capacities predicted using the API method. This variability results for two reasons; lack of an accurate definition of relative density, and the need for a clarification onwhether the limiting skin friction is intended as a limit on the local or average skinfriction. Relative density of sands is difficult to measure and is usually estimated from blow count correlations. Measurement of SPT blow counts is rare in the offshore environment; more commonly, penetration resistance is measured using a down-hole wire-line hammer and a Shelby tube sampler.

2.3 Axial Capacity Mechanism

2.3.1 Pile Movements

Typical load-settlement curves for pipe piles in sand indicate that there is no plunging failure load, and that loads continue to increase with increasing settlement. The magnitude of the design load should be tied to the load-settlement characteristics of the pile/soil system, and the tolerance of the structure to foundation movements.

2.3.2 State of Stress in the Vicinity of the Pile

The API recommended practice implies that the vertical effective stress close to the pile is the free field vertical effective stress. It is clear that loads transferred between the pile and the surrounding soil must perturb the previous free field stresses, but by indeterminate amounts, especially for pile groups.

Experimental evidence (Vesic 1970) indicates that the rate of increase of unit skin friction and end bearing reduces with depth, probably due to the stress dependency of *K* and Δ□

Load transfer between a pile and the surrounding soil is usually determined by measuring the axial load in the pile as a function of depth. Such measurements typically indicate zones of reduced side shear near both the top and bottom of piles (Vesic 1970). Reduction in load transfer near the tip is attributed to the loss of support of the soil adjacent to the pile near the tip, which results from compression of the underlying soil layers, due to mobilizing the tip's bearing capacity. Reduction in the load transfer near the top may be due to pile shaking during driving. Go (1990) suggests that neglecting the load transfer for one diameter at the tip of the pile increases the accuracy of the predicted axial capacity.

2.3.3 Friction between Pile and Soil

Some engineers believe that pile-soil shearing displacement occurs at the interface between the pile and the soil, thus making the soil-pile friction angle Δ the relevant parameter, rather than the soil friction angle. Evidence of this view comes from pull-out tests in which the pile surface is clean. The counter view that failure occurs within the soil is supported by occasional pull out tests in which the pile is coated with sand. Studies by Uesugi*et al* (1988) suggest that failure occurs between the soil and the pile unless the pile is very rough. There is also limited evidence that pile driving crushes the adjacent sand so the material surrounding the pile may differ significantly from the natural sand. In such a case, sand/pile shearing tests that have been used by some investigators (*e.g.* Furlow 1968) become less relevant.

2.3.4 Tension versus Compression

Some believe that the side shear in tension should be less than the side shear in compression by perhaps 30% as reflected in the 1982 API RP-2A. Skin friction can be reduced in tension over compression due to (1) strain compatibility of the soil-pile system, and (2) reduction in the pile's diameter due to Poisson's effect. Both factors would reduce the normal stress acting at the soil-pile interface. A finite element study, (Nystrom 1984) employing the Modified Cam Clay model in drained conditions (frictional resistance) suggested that the difference in the axial capacity of piles in tension and compression due to axial straining of the soil is less than 1%.

2.3.5 Type and Rate of Loading

Unlike lateral loading, API RP-2A does not provide guidelines for the effects of cyclic loading and rate of loading on the axial capacity of piles. There is evidence that cyclic tensile loading, in particular, may significantly reduce pile capacity (Kraft 1990).

III. CONCLUSION

The API Method has become the accepted industry standard for pile design as demonstrated by its widespread use. The criticisms cited herein are, to a great extent, a product of inadequate understanding of pile behavior. The criticisms apply not only to the API method but also to many other experience based deign approaches. The number of useful load tests in predominantly cohesion less soils is small, especially for steel pipe piles. The number of load tests is less than the number of degrees of freedom in the system; accordingly there are various combinationsof properties that yield equivalent results. Additionally, the suspect quality of many of the available case histories contributes to the scatter between measured and predicted capacities. Thus, many of the important issues cannot beresolved on the basis of the available data alone.

Experimental research on the physical processes that control the behavior of piles during installation and loading is required in order to resolve the important in axial capacity predictions. Considering the large number of variablesinvolved in axial pile capacity development, as well as the high cost of load tests on full scale instrumented piles, it is unlikely that a sufficient number of full scale load tests can be performed to resolve the problem. Experimental research on model piles can however be used to resolve some of the important design uncertainties. One of the objectives of this monograph is to provide a blueprint for developing the necessary facilities required to perform such research.

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