The benefit/cost analysis was performed in 2003

Research Pays Off

JTRP / INDOT RESEARCH PROGRAM

Load Tests on Pipe Piles for the Development of CPT-Based Design Method— SPR 2361

Both open-ended and closed-ended pipe piles are often used in practice, but high-quality information available on the bearing capacity of these piles is very limited and better understanding of the load-carrying capacity of these piles can lead to significant cost savings. This appears to be especially true for open-ended piles. The soil plug that forms inside the pile during pile driving affects both the driving response and static bearing capacity of open-ended piles. The formation of the soil plug and its effect on pile load response are still not completely understood.

The core of this research was the pile load tests done on two pipe piles: one open-ended and the other closed-ended. The information generated by the load tests is particularly useful for engineers interested in the design of open-ended pipe piles in sand, as detailed data was collected on soil plug formation during driving and on static plug resistance.

To investigate the effect of the soil plug on the static and dynamic response of an open-ended pile and the load capacity of pipe piles in general, field pile load tests were performed on instrumented open- and closed-ended piles driven into sand. The experimental data accumulated during pile driving and during the static load tests were then used to enhance understanding of the drivability and load capacity of both closed-ended and open-ended pipe piles.

Research Findings and Implementation

While driving open-ended piles varying degrees of soil plug forms. When open-ended pipe pile is driven in a partially plugged mode, the incremental filling ratio (IFR) increases with the relative density of sand. Also the cumulative blow count lowers to drive the open-ended pile compared to a closed-ended pile to the same depth. But the difference is mostly due to the early stages of driving, when the soil plug is not well developed.

The effect of the soil plug on pile capacity is not well understood. This research through laboratory tests has produced results that explain and describe these effects. In this research, the base resistance and shaft capacity of the open-ended pile, normalized by average cone resistances, resulted in 36% and 52% lower than the corresponding values for the closed-ended pile. For the open-ended pile, the plug resistance was only about 30% of the annulus resistance, and the average shear stress between the soil plug and inner surface of the pile was 45% higher than the outside shaft resistance.

Based on the field and calibration chamber pile load tests, new relationships for determination of the load capacity of open-ended piles are proposed. The relationships are based on soil-state variables (relative density and stress state) and cone penetration test (CPT) results. The proposed methods were established based on results from the full-scale field pile load tests and model pile load tests in the calibration chamber. The predicted pile load capacities from the proposed methods were compared with measured capacities from case histories and results calculated from existing pile design methods. The proposed CPT-based method was added to CONPILE (Salgado et al., 1999), the pile load capacity calculation program

The research results are immediately relevant to pile design practice. The findings suggest significant cost savings as shown below. INDOT and other DOT's can refer to these results when designing piles under similar conditions. It is advisable for INDOT and FHWA to consider efforts so that the findings of this research can be extended and find their way into pile design practice across the country.

Potential Benefits

Table 1 below shows the total pipe pile length driven in Indiana in the period 11/17/1998 - 5/12/2002. The total length of piles driven was 94218 m, corresponding to an amount of $8,246,109. If the same level of under-prediction of pile load capacity is observed in all the pipe pile designs done in the State, the annual savings could reach $2 million by improving the design process. This potential benefit is demonstrated by the analysis shown below.

Cost of Research $28,146

Table 1 Pile length and cost driven in Indiana (11/17/1998 – 5/12/2002)

Pile Description	Number of Projects	Pile Length	Units	Cost (US $)
Concrete, Steel Shell Encased	136	94218	m	8,246,109

Estimated Economic Value Over 20 Years At 5% Discount Rate

Costing Method	Length of Piles driven per Year (m) [1]	Discounted Savings (20 years) [2]	Discounted Annual Savings [3] = [2] / 20	Benefit/Cost Ratio [5] = [4] / $28,146
Current (C)	26,919	$20,548,980	$1,027,449	36.50
Proposed (P)	13,459			

Assumptions

- That INDOT will construct 26,919 meters (94218 / 3.5 years - Table 1 duration) of piles per year .
- That the annual cost of driving piles based on above data is $2,356,031 ($8,246,109/3.5). Provided by Operations Support.
- That the annual potential savings in pile length driven each year is 50% of the total based upon study findings.
- That the cost of driving piles will increase by 3% each year over next 20 years analysis period.

References

- Kwangkyun K., Rodrigo S., Junhwan L., and Kyuho P., “Load Tests on Pipe Piles for Development of CPT-Based Design Method,” Joint Transportation Research Project FHWA/IN/JTRP-2002/4 Final Report, November 2002.
- Salgado, R. and Lee, J., "Pile Design Based On Cone Penetration Test Results" Joint Transportation Research Project FHWA/IN/JTRP-99/98, Final Report, October 1999.