Innovative Technology and Procedures for Capacity Testing of Open End Cylinder Piles

II. Research Problem Statement

Open-end cylinder piles (concrete and steel) are widely used for bridge foundations and offshore construction, as they provide superior moment resistance (f (diameter^4) and high axial capacity. In California, open-end piles account for over 1/3 of the piles driven by CALTRANS. Similarly large usage can be found in other States such as Oregon and Washington. In addition, large diameter open-end piles (2-3 meters) are becoming very common in areas of high seismic hazard or on projects with potential vessel collision. In California, new or retrofitted toll bridge foundations are almost exclusively large diameter cylinder piles.

This transition to larger open-end piles has brought to focus some of the gaps or inadequacies in current pile design procedures (e.g. AASHTO and API). Small diameter (14" or less) open-end piles are generally observed to plug early in the driving process and are thought to behave similar to close end piles. At larger diameters, however, open-end piles usually "cut" through the soil instead of plugging, resulting in a column of soil within the pile whose height approaches the pile embedment depth. As the large diameter pile is loaded statically to failure, it may behave in one of several ways. It may continue to "cut" through the soil. It may behave as a close-end pile as the soil contained in the pile acts as a plug. Finally, it may behave as a "partially" plugged pile allowing limited plug movement. The differences in these mechanisms can lead to significant differences in both axial capacity and stiffness. Current pile design procedures do not predict the formation of soil plugs or how to account for their presence or absence. Moreover, dynamic methods of estimating pile capacity reflect only the pile's behavior during driving. If the pile behaves plugged, or partially plugged, under static loading, its capacity may be much different than that predicted by dynamic methods.

An additional inadequacy of current pile design procedures (as reflected in AASHTO and API) relates to the treatment of the displacement effect in estimating capacity. When a pile is either solid (i.e. a concrete pile), driven with a closed end, or if it plugs early during driving, the pile displaces a volume of soil approximately equal to its own volume, resulting in increased radial and tip stresses which significantly influence axial capacity. For large diameter open end piles the displacement effect is governed by the thickness of the pile wall. A thicker pile wall should result in an increased axial capacity. AASHTO and API procedures do not take wall thickness into account.

III. Research Objective

Improving our ability to predict the static capacity and axial stiffness of open-end cylinder piles is a difficult and complex problem. It is unlikely that real progress can be achieved without empirical load testing data that includes accurate measurements of residual stress, skin resistance, end bearing, and load settlement. The objective of this proposed project is twofold. First, standards will be developed for the load testing of open-end cylinder piles that go beyond the immediate needs of capacity verification and provide the type and quality of data required to advance the understanding of pile behavior. Second, static and dynamic load testing technologies will be identified, developed, and applied that will not only provide needed high quality data, but will also reduce the expense and difficulty of performing high quality load tests, with the hope this will result in an increased number of tests performed nationwide. The focus will be on the advantageous application of numerous advancements in instrumentation technology that have occurred over the last several years. The goal will be methods and technologies which:

1. Provide accurate residual stress, skin resistance, end bearing, and load settlement data.
2. Facilitate simpler installation, data acquisition, and interpretation.
3. Will be less obtrusive and have minimal impact on contractors operation.
4. Will expedite evaluation and decision process, and reduce delay time for contractor and project while awaiting results/direction.
5. Will be less expensive and reduce overall testing costs via more economical components, methods, and contractor involvement.

Related Work

1. Acoustic methods for driven pile evaluation are being used in the offshore oil industry.
2. Non-Destructive Bridge Testing
3. Advancements in Geophysical Testing Methods
4. The automotive industry has developed robust and economical sensor instruments for application in stability control and safety.
5. The medical industry has also developed numerous robust and economical sensor instruments.
6. Wireless Communications.

IV. Estimate of Problem Funding and Research Period

The cost of this project is estimated to be approximately $500,000 spread over a 3-4 year period. It is envisioned that he project will be coordinated with pile load testing on Highway Bridge Projects such that the load testing cost will be covered by the Highway Bridge Project Budget. Analysis, interpretation, research, etc. will be covered by the NCHRP Project funds. This approach was successfully employed in the recently completed NCHRP project....

V. Urgency, Payoff Potential and Implementation

Open-end cylinder piles provide superior moment resistance (f (diameter^4) and high axial capacity at a moderate cost relative to other foundation alternatives. Large diameter open-end cylinder piles are becoming the foundation of choice in new large bridge construction. Caltrans spends $10 to $20 million annually on open-end driven piles, not counting large toll bridge projects. Foundation costs on toll bridge projects often run in the tens of millions of dollars. The difficulty, expense, and delay associated with existing load testing methods often result in missed opportunities for refinements to the foundation design that can lead to substantial savings. An example of missed opportunities is the Woodrow Wilson Bridge Project. Static load testing of open-end pipe piles for the Project exceeded $1.5-million. The tests did prove capacities, but did not provide pile tip refinement data. In addition, uncertainty over dynamic capacity predictions resulted in the use of a higher FS than would have otherwise been used if the current methods for static and dynamic testing methods were more reliable for open ended cylinder piles. A possible 20% in savings ($18-22 million) were not realized.

User Community
All transportation agencies: highway, mass transit, railroad, airport and marine facilities.

Implementation
The results of this project can be implemented through the following vehicles:

NCHRP reports
National Highway Institute training courses (existing and new),
FHWA pile load test database.
Computer programs (public and private sector).
Changes to the AASHTO design code.

Effectiveness
Benefits to the transportation community would include:

- Significant reduction in foundation costs. Tremendous cost saving in the design and construction of bridge foundations could be realized for both routine load combinations and extreme events. This is conservatively estimated at over a hundred million of dollars a year.
- Improved safety through improved knowledge of open end cylinder pile foundation behavior.
- Reduce wasteful redundancy and repetition of research. Test data can be used for the **timely** development, validation, and evolution of more sophisticated open end cylinder pile static capacity prediction models.
- AASHTO Standard testing and instrumentation procedure
- Assist the bridge community in charting a course for future design methods and research efforts.