# Large Diameter Open-end Pipe Piles Challenges & Opportunities

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Many things in deep foundations get bigger and bigger and that is particularly true for open-ended pipe piles. For decades, they have been driven to deep penetrations and GRL has monitored their installation, tested them dynamically, and analyzed them for driveability on offshore, nearshore, and on-land projects. The National Cooperative Highway Research Program Synthesis (NCHRP Synthesis) (i) defines Large Diameter Open-End Driven Pipe Piles (LDOEP) as either concrete or steel pipes with diameters of 36 inches (910 mm) or more. For offshore oil platforms, 48 to 96 inch (1220 to 2440 mm) diameters are common, and have been successfully used following American Petroleum Institute (API) specifications. Lately, windfarm monopiles of more than 200 inch (5000 mm) diameters have been considered. LDOEPs are also used in port construction, and occasionally on bridge foundations, when heavy equipment and material can be economically transported.

In favorable soils, installation may be by vibratory hammer, however in most cases an impact hammer is needed to reach design penetration and to evaluate capacity by dynamic testing. Bearing ca-

pacity evaluated during pile installation, however, may not fully represent the pile response in the static service condition. The high inertia of the soil prevents plugging during driving. The pile 'cookie cuts' its way into the ground, making installation to design penetration relatively easy but reducing end bearing during driving.

In fact, even the internal friction will not exhibit its full static potential during driving because of the up-and-down motion of the pile during installation. Not surprisingly, dynamic methods generally predict lower capacities than anticipated from static considerations. During static loading, however, internal friction may be enough to resist the end bearing acting over the whole pile bottom area. So while the contractor is happy about the installation progress, the pile designer is often concerned about the low apparent soil resistance.

To make things worse, designers occasionally install 'constrictor plates' (with a center hole to allow water and soft soil to escape) inside piles at a location where they would generate 'end bearing' effects without causing too much of an installation problem. The uncertain condition of the soil plug under the constrictor plates and its effect under dynamic conditions, unfortunately, complicate the driveability assessment and evaluation by dynamic load testing.

The NCHRP Synthesis makes clear that designers and construction professionals need dynamic analysis and testing methods both for LDOEP job preparation and for construction control. Static load testing, while the indisputable method for static soil capacity determination, is usually not a feasible alternative due to cost and time constraints. Moreover, driving stresses and pile integrity assessments, not possible by static testing, are often very important due to the limited number of LDOEP's used in a foundation. Dynamic tests during installation are the best means of assuring that installation meets specifications. Fortunately, dynamic methods perform well, particularly when local conditions and experiences are taken into account.

GRL was recently involved in a number of challenging LDOEP projects, most notably the Kentucky Lakes Bridge where the load test program included static, dynamic, and rapid force pulse tests on 48 and 72 inch (1220 and 1830 mm) diameter pipe piles. The challenges of evaluating static bearing capacity of LDOEP by dynamic methods were addressed in part by employing advanced modeling in the CAPWAP® software, in particular using radiation damping in lieu of the standard Smith model. Other considerations for successful dynamic testing of LDOEPs include: (i) Dynamic tests during restrike have high benefit/cost ratio and are highly recommended, since low dynamic testing capacity results during driving are more frequently due to disturbed soil than a moving plug. ( ii ) Excessive energies loosen the soils, resulting in low dynamic resistance. Try to limit energies and, during data analysis, use superposition of early with late restrike resistance distributions. Reduce high energies by cushioning to improve chances of measuring the full end bearing. (iii) The unit resistance at the plugged LDOEP pile toe will be less than that for the small area against the steel only (when performing driveability analysis with GRLWEAP, use only 50 percent of the anticipated unit end bearing). (iv) When investigating potential toe damage, realize that all dynamic methods assume uniform stresses over the pile cross section. However, a large diameter pile encountering obstructions or sloping rock can have very high local stresses at the toe. Thus, for non-uniform resistance conditions, consider lower allowable average driving stresses at the toe.

Research is ongoing in many parts of the world, and we all need to stay informed about progress in this important deep foundation specialty. Fortunately, dynamic testing provides a cost effective option that can be successfully implemented into many LDOEP projects.❖

*Brown, D.A., and Thompson, W.R., Design and Load Testing of Large Diameter Open-Ended Driven Piles; A Synthesis of Highway Practice; NCHRP Synthesis 478, Transportation Research Board, Washington, D.C, 2015*