

## Static and Dynamic Load Tests on Driven Polymeric Piles

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**ABSTRACT:** Repair and replacement of deteriorating piling systems cost the United States up to \$1 billion per year. In the case of marine piling, actions required by the Clean Water Act rejuvenated many of the nation's waterways, but also allowed the return of marine borers, which attack timber piles. At the same time, less than 10% of the 13.7 million tons (122 GN) of plastic containers and packaging produced annually in the U.S. are recovered by recycling. Using recycled plastics to manufacture piles utilizes material which (1) would have been otherwise landfilled and (2) can be more economical in aggressive environments when life-cycle costs are considered.

A series of polymer piles were driven in Elizabeth, New Jersey. Three concrete filled fiberglass shell piles, three polyethylene piles reinforced with steel bars, three polyethylene piles reinforced with fiberglass bars, and two solid polyethylene piles were installed. One closed end steel pipe pile was also driven for reference purposes. Three static load tests were performed on one of the concrete filled fiberglass shell piles, and one of each of the reinforced polyethylene piles. High strain dynamic pile tests were performed on all piles during initial driving and restrike after load testing. This study describes the adjustments to assumed material properties required during installation testing and the correlation between static and dynamic load tests.

### INTRODUCTION

A decade ago, Lampo et al. (1998) noted that repair and replacement of deteriorating piling systems cost the United States up to \$1 billion per year. In the case of marine piling, actions required by the Clean Water Act rejuvenated many of the nation's waterways, but also allowed the return of marine borers, which attack timber piles. In Boston, New Orleans and other areas of the country prone to fluctuations in ground water levels timber piles and other foundation systems are subject to attack by rot and termites. Infrastructure and private facility owners must consider these end-of-life costs when approving a design or repair.

According to EPA (2006), less than 10% of the 13.7 million tons (122 GN) of plastic containers and packaging produced annually in the U.S. are recovered by recycling. As demand for petroleum products skyrocket with increasing global economic growth, recycled plastic resins will become more cost competitive over time. Using recycled plastics to manufacture piles utilizes material which (1) may have been otherwise landfilled and (2) can be more economical in aggressive environments when life-cycle costs are considered.

The past decade has shown some advancement in our understanding of recycled plastic piles. A range of products have come on the market: Fiber Reinforced Polymer (FRP) wraps for existing piles, concrete filled polymer shells, recycled polymers reinforced with stiffer bar elements, or piles manufactured purely from recycled plastics. Han et al. (2003) summarize these various categories and propose a design framework for computing the buckling, lateral and axial load capacities for a subset of these pile types.

Iskander et al. (2001), through a parametric wave equation study using polymeric material properties, investigated the impacts of pile and hammer type on pile driveability. That study concluded that the hydraulic hammers may be more effective at installing plastic piles and that the plastic piles' lower density and elastic modulus compared to conventional steel, concrete and timber piles appeared to have a more significant impact on the pile's driveability. Iskander and Stachula (2002) further investigated driveability of FRP piles using measured data from three field sites.

Since 2002, full scale installation projects have occurred in practice as well as research efforts. Pando et al. (2006) provided a well documented study that included laboratory and field components. This paper describes the installation and testing efforts of another full-scale field test performed between November 2001 and May 2002.

**Table 1. Approximate soil profile at Elizabeth, NJ site.**

| <b>Depth (m)</b> | <b>Soil Description</b>   | <b>Average SPT N-Value (blows/0.3 m)</b> |
|------------------|---------------------------|--|
| 0 – 4.5          | Fill—Sand with gravel     | 56, reducing to 15 with depth            |
| 4.5 – 7.3        | Organic Clay with Peat    | 6  |
| 7.3 – 10.7       | Fine Sand, some silt      | 29                                       |
| 10.7 – 23.2      | Silt and Clay             | 14                                       |
| 23.2 – 27.4      | Sand with some silt, clay | 47                                       |
| 27.4 – 28.2      | Weathered Shale           | 141                                      |
| 28.2 – 29.7      | Red Shale                 | Fractured                                |

## **SITE DESCRIPTION**

At the Port Authority of New York and New Jersey's facility in Elizabeth, New Jersey, construction efforts for an express railway bridge over McLester Ave were underway in November of 2001. A site below the western approach ramp of the bridge near the corner of West Bay Avenue and Polaris Street was available for a full scale installation of a series of plastic piles. Table 1 summarizes the soil profile encountered at one soil boring near the site of the load test program. Prior to pile installation the upper five feet of fill was excavated to remove existing construction debris that may have impeded pile driving.

## PILES

Pile driving on the site consisted of one steel pipe pile, three fiberglass cased concrete piles manufactured by Lancaster Composites, Inc., three fiberglass bar reinforced plastic piles manufactured by Seaward, three steel bar reinforced plastic piles manufactured by Plastic Pilings, Inc., one recycled plastic pile manufactured by American Ecoboard and one recycled plastic pile manufactured by Trimax. A static load test was performed on a representative pile from the concrete filled fiberglass shell piles, from the steel reinforced plastic pile and from the fiberglass bar reinforced plastic pile. The static load test piles and the steel indicator pile will be the focus of this study.

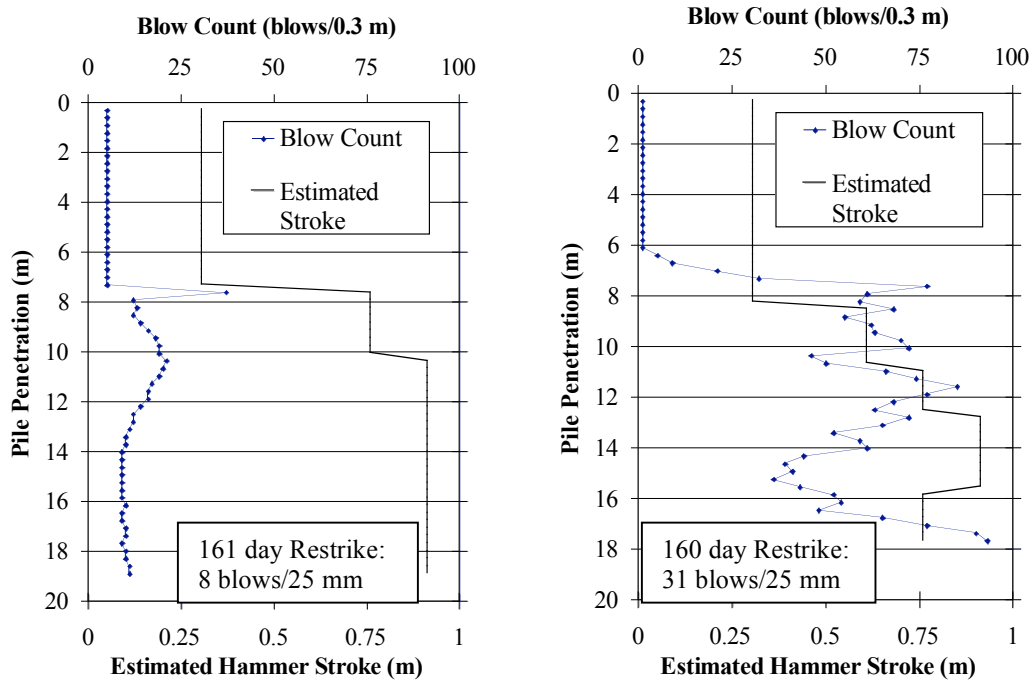
All piles had outer diameters of 406 mm. The steel pipe pile was driven closed-ended with a 0.5 inch thick wall and a 45 degree rock point on one end. The pipe was manufactured from A252, Grade 2 steel. The concrete filled fiberglass shells were constructed with concrete that had a design 28 day compression strength of 6 ksi. The steel reinforced plastic piles were reinforced with a full length cage of 16 one-inch diameter steel bars, similar to those reported in Pando et al. (2006). The fiberglass reinforced plastic pile included sixteen 1.75-inch diameter fiberglass bars.



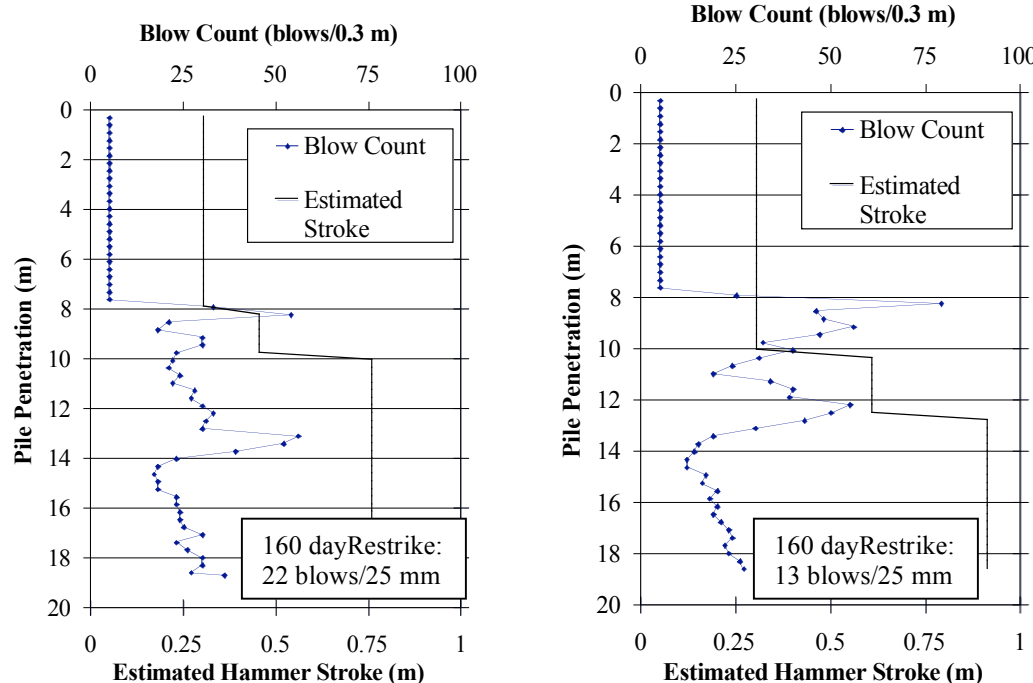
**Fig. 1. Photographs of Installation and Load Testing at**

## HAMMER

Pile handling was easy with two pickup points, and the pile installation was uneventful (Fig. 1). The test piles were driven with an ICE 70 single acting hydraulic hammer, which had a 31.1 kN ram with a rated maximum stroke of 0.9 m. This hammer has a pump controlled stroke that was varied from 1 to 3 feet during initial driving and restrike. Plywood cushions were used to protect the pile top. In most cases, the cushion was nominally 243 mm thick. The concrete filled fiberglass shell pile, however, used a reduced 150 mm thick cushion during initial driving given the experience with two other piles of this type.



**Fig. 2. Steel pipe (left) and concrete filled fiberglass (right) pile driving records**

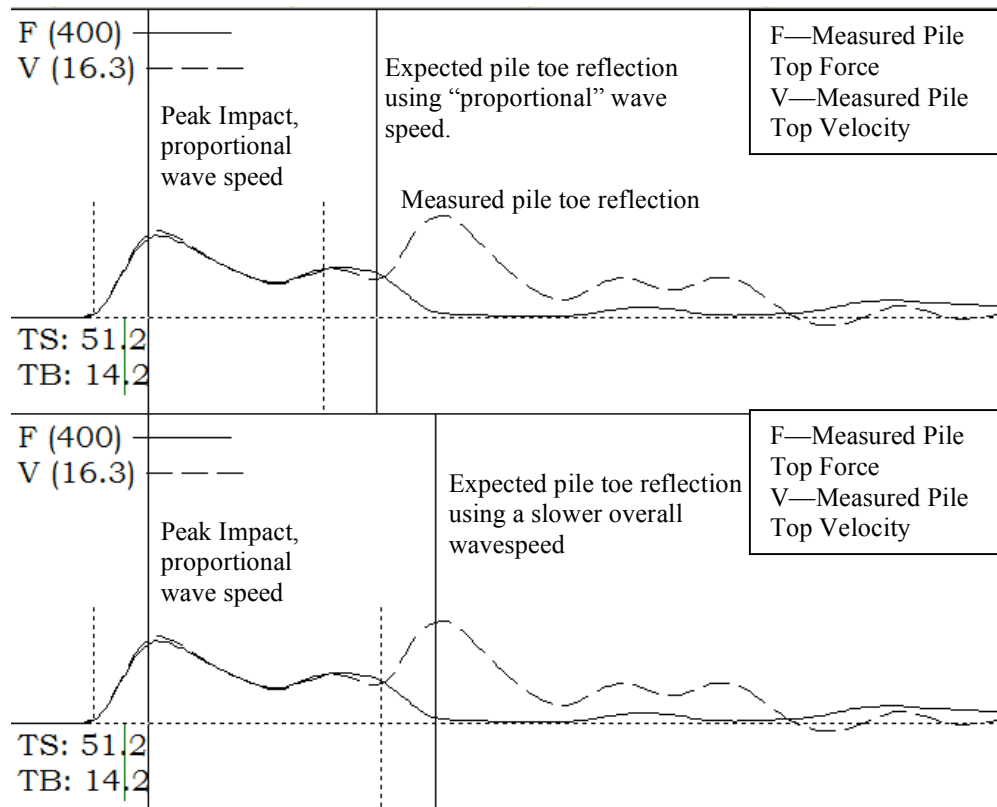


**Figure 3. – Fiberglass reinforced (left) and steel reinforced (right) plastic pile driving records.**

The driving record for each static load test pile is shown in Fig. 2 and 3. Note that the upper six to eight meters of driving were generally intermittent blows, and thus represent an average blow count over the upper portions of the pile. Similarly, the estimated strokes were those requested to the contractor during driving. Restrike blow counts over the first 25 mm of driving and the time after installation is also included on these figures.

## STATIC AND DYNAMIC LOAD TESTS

High strain dynamic testing was performed per ASTM D4945-00 using a Pile Driving Analyzer (PDA) (GRL, 2002). Four strain transducers and four accelerometers were placed three to five feet from the pile top. The reinforced polymer piles were drilled and tapped for gage attachment in a manner similar to the steel pipe pile, while the concrete filled shell had one pair of strain and acceleration sensors attached directly to the surface of the shell (although bolted with concrete anchors) and one pair placed directly on the interior concrete exposed by cutting windows in the fiberglass. For this latter pile type, the collected data were quite similar whether windows were cut or not.



**Fig. 4. Comparison of proportional and overall compressive wave speed on fiberglass bar reinforced plastic pile.**

The polymeric piles in particular showed some unusual behavior in the dynamic testing records. Typically, data quality is assessed by comparing the velocity data at the impact peak to the strain data at the peak impact. The two quantities are proportional by the pile material's 1-D compression wave speed. Because the composite material's properties were largely unknown, the compression wave speed was determined by forcing proportionality. When proportionality was forced on the reinforced plastic piles, a second measure of the overall compression wave speed in the pile based on the time required for the wave to travel to the pile toe and back did not match (Fig. 4). To maintain the underlying theoretical assumptions of the PDA's calculations, two different wave speeds were used so that both measured compressive stresses and forces at the gage location and estimated tensile stresses and ultimate resistance values would be correctly calculated.

Table 2 summarizes the differences in proportional and overall compressive wave speeds observed in each pile type. Note the concrete filled fiberglass shell pile (and, of course, the steel pipe pile) showed very little difference between the two values. However, as the stiffness of the pile's reinforcing material decreased, the overall percent decline of the observed overall wave speed compared to the proportional wavespeed increased. These differences are believed to be a by-product of the manufacturing process of the recycled plastic piles, which are foamed from the outside to the inside. Often, the interior plastics are considerably less dense than the exterior plastics, which could lead to slower wave propagation through the composite section than at the surface.

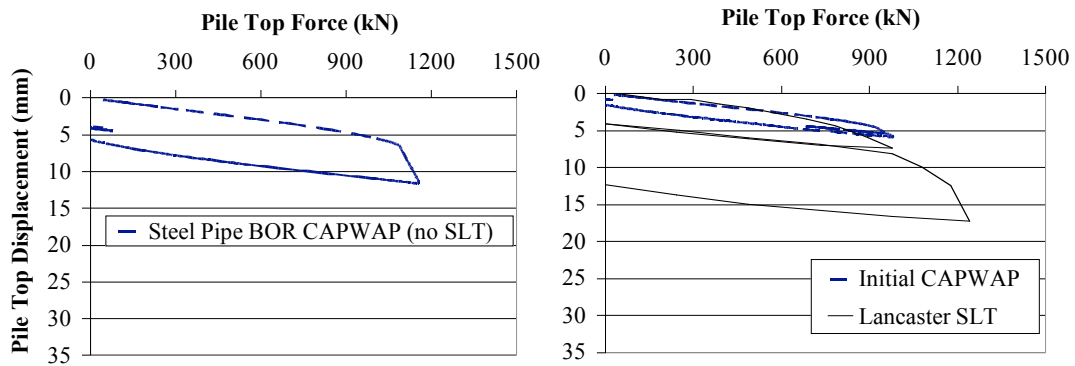
**Table 2. Compression wave velocity measurements from dynamic tests.**

| Pile Type        | Reported Specific Weight<br>(kN/m <sup>3</sup> ) | High Strain Dynamic Testing            |                                       |  |                                       |
|------------------|--|--|---------------------------------------|--|---------------------------------------|
|                  |  | Proportional Wave speed<br>$c_p$ (m/s) | Estimated Elastic Mod.<br>$E_p$ (GPa) | Overall Wave speed<br>$c_{2L/t}$ (m/s) | Estimated Elastic Mod.<br>$E_h$ (GPa) |
| Polymer only     | 7.9  | 1829                                   | 2.68                                  | 1372                                   | 1.51                                  |
| Concrete filled  | 22.0   | 4176                                   | 39.07                                 | 4023                                   | 36.27                                 |
| Steel bar reinf. | 8.0  | 3810                                   | 11.85                                 | 3322                                   | 9.01                                  |
| Fiberglass bar   | 8.5  | 3048                                   | 8.03                                  | 2530                                   | 5.53                                  |

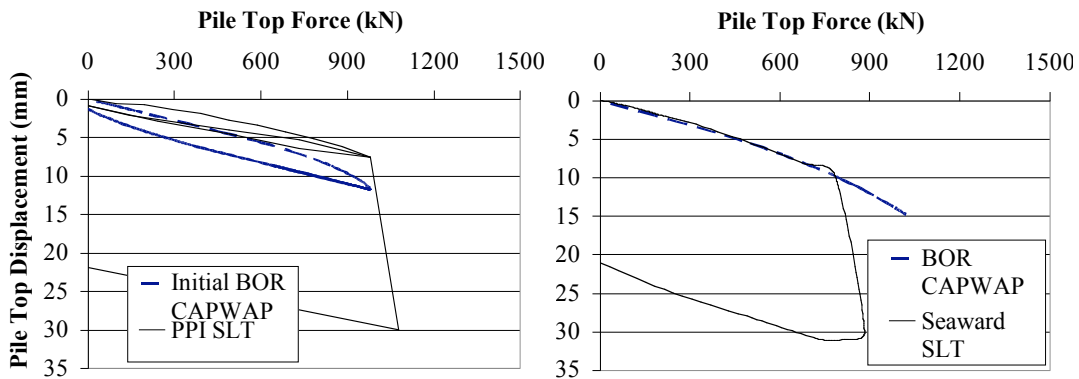
Selected blows were analyzed using the CAPWAP computer program during end of drive and restrrike. This program more rigorously evaluates the distribution of the ultimate shaft and toe static resistance under a blow.

Figure 5 and 6 present the static and dynamic load test results. Despite the overall uncertainty in the material properties, the static load test and CAPWAP results are similar. The concrete filled pipe pile was underpredicted slightly, although the very high blow counts observed during the restrrike implies the available static resistance was not fully activated. The fiberglass reinforced pile was slightly overpredicted, for reasons that will be investigated in future studies. In general, these piles were designed such that they could be driven, and as such the static capacity of the concrete filled shell and the steel pipe pile were likely much lower than their structural

capacity.



**Fig. 5. CAPWAP simulated load test curve for steel pipe (left) and Static and CAPWAP load curves for concrete filled fiberglass shell pile (right).**



**Fig. 6. Static and dynamic load test results for FRP pile reinforced with steel bars (left) and fiberglass bars (right).**

## CONCLUSIONS

This study summarized the installation and load testing behavior of four piles driven on the grounds of Port Elizabeth, New Jersey. Installation and dynamic testing of 12 piles and static testing of three piles were performed. Representative piles were summarized as a starting point for future work. While further work is needed on the long term creep performance and durability of these pile materials under typical load conditions, this project has shown the possible applicability of plastic piles to traditional axial loading applications. Dynamic testing of the polymeric piles showed an unusual reduction in the compression wave speed from the value measured at the gage location and as measured from 1-D wave travel. This variation merits further exploration. Static testing showed similar geotechnical capacities across all four piles tested, and reasonable comparisons to the CAPWAP simulated static load test curves.

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## REFERENCES

- Environmental Protection Agency, EPA. (2005). "Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2005." <http://www.epa.gov/epaoswer/osw/consERVE/resources/msw-2005.pdf>
- GRL Engineers, Inc. (2002). *Polymer Pile Driving Research Project*. Report No. 011121 to Polytechnic University. Cleveland, Ohio.
- Han, J., Frost, J.D., and Brown, V.L. (2003). "Design of Fiber-Reinforced Polymer Composite Piles Under Vertical and Lateral Loads." *Transportation Research Record*, no. 1849, 71-80.
- Iskander, M.G. and Stachula, A. (2002). "Wave equation analyses of fiber-reinforced polymer composite piling." *Journal of Composites for Construction*, v 6, n 2, 88-96.
- Iskander, M.G. and Stachula, A. (2001). "Driveability for FRP composite piling" *Journal of Geotechnical and Geoenvironmental Engineering*, v 127, n 2, 169-176.
- Lampo, R., et al. (1998). "Development and demonstration of FRP composite fender, load-bearing and sheet piling systems." Report. Construction Engineering Research Lab., U.S. Army Corps of Engineers.
- Pando, M., Ealy, C., Filz, G., Lesko, J. and Hoppe, E. (2006). "A Laboratory and Field Study of Composite Piles for Bridge Substructures." Report FHWA-HRT-04-043. FHWA, <http://www.tfhrc.gov/structur/pubs/04043/index.htm>