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GEOTECHNICAL NEWS

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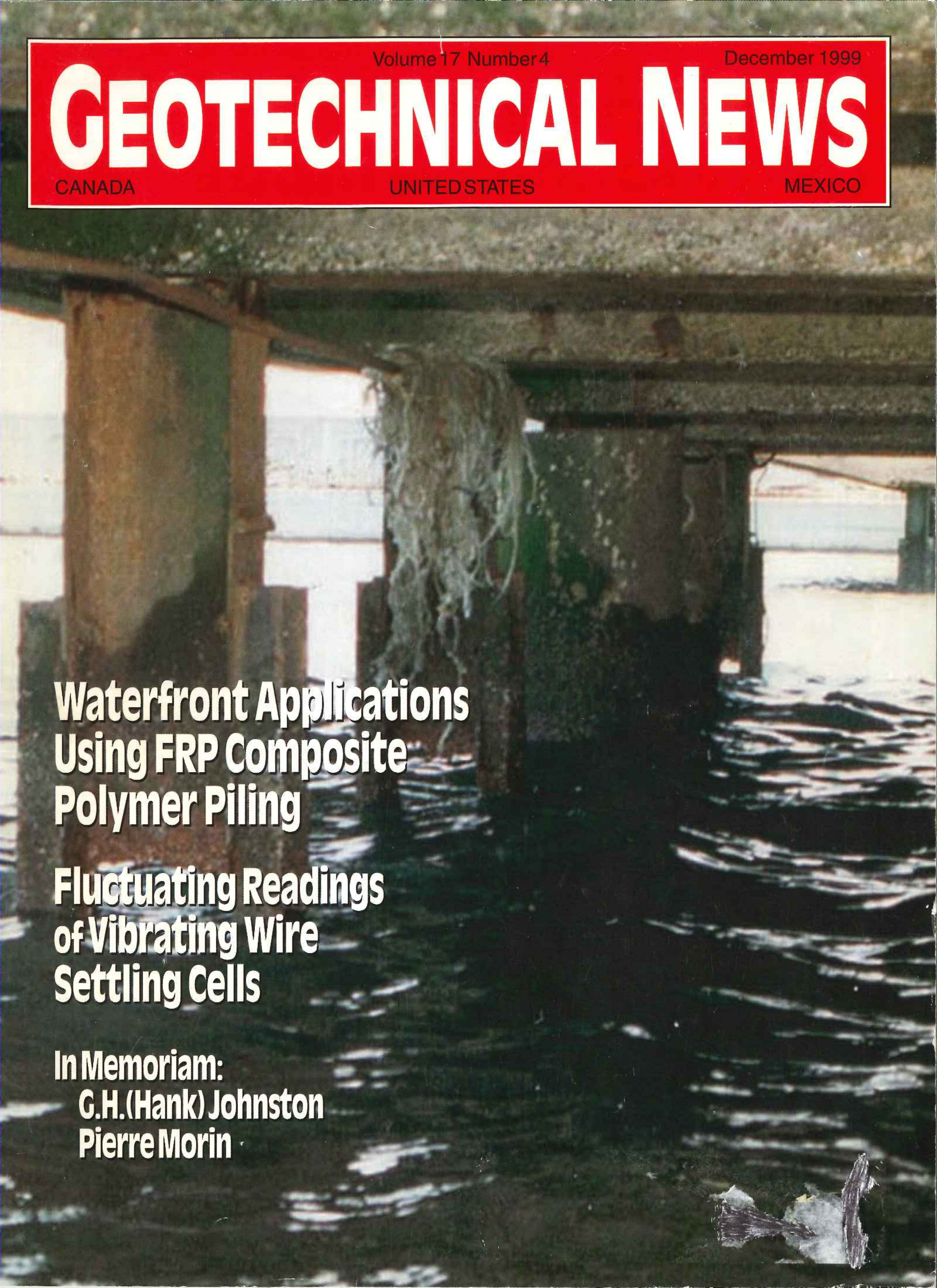

Waterfront Applications Using FRP Composite Polymer Piling

Fluctuating Readings of Vibrating Wire Settling Cells

In Memoriam:
G.H. (Hank) Johnston
Pierre Morin

FRP Composite Polymer Piling:
An Alternative to Timber Piling for Water-Front Applications

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The deterioration of timber, concrete, and steel piling systems costs the United States nearly $1 billion per year for repair and replacement (Lampo et al. 1998). The durability of concrete and corrosion of steel are serious hindrances to water-front construction. In the case of timber piling, the Federal Water Pollution Control Act of 1972 gradually rejuvenated many of the nations water ways and harbors. With the return of the marine life, tiny marine borers started attacking the untreated timber piles which support many of the nations harbor piers (Fig. 1).

Figure 1. Marine borers (Limnoria) attacking untreated timber piles which support many of New York's pile supported highways and harbor piers.

At the same time, over 8.4 billion pounds of rigid plastic containers are produced annually in the United States (Lampo 1995). Most of these containers are made of high density polyethylene (HDPE) milk jugs, and polyethylene-terephalate (PET) soda bottles. As much as 7.2 billion pounds of these materials is landfilled, and the rest is recycled. Fiber reinforced polymer (FRP) composites represent an alternative construction material without many of the performance disadvantages of traditional materials. The use of composites in aggressive environments appears to be more economical when life-cycle costs are considered.

In April, 1987 the first proto-type recycled plastic pile was driven at The Port of Los Angeles (Horeczko 1995). Over the next few years, several vendors produced a variety of piling products made of virgin, recycled, and hybrid composites (Iskander and Hassan, 1998). Composite piles were installed in a number of ports and water front facilities in New York, California, Louisiana, Florida, Delaware, New Jersey, and Mexico. Most FRP piling is used for fendering applications, however it has also been used for support of a few piers. For example, Tiffany Street Pier in New York City was constructed entirely from recycled plastics.

The plastic composite industry and the rapidly emerging industry of recycled plastics have made substantial research & development investment to develop composite construction materials. However, the developed materials suffer from several disadvantages. First, at this time, composite materials, depending on location, cost approximately two to three times the cost of creosote treated timber. However, manufacturers claim that composite piling costs less to maintain, lasts much longer than treated timber piling, and does not present an environmental disposal problem. Second, composite piling is less efficient to drive than conventional piling materials. Third, the long term performance of composite materials under increasingly larger structural loads is not well defined. Fourth, because of their low modulus of elasticity, composite piling materials may exhibit large deformations in excess of the settlement permitted by building codes. The existing composite piling materials are the first generation of composites in foundation engineering. Composite materials faced similar difficulties in other fields of engineering, however these difficulties were overcome in later generation products.

Deterioration of Conventional Piling Materials

Timber: Prior to the clean water act of 1972, marine borers could not exist due to pollution. One trade-off to this environmental benefit is a significant increase in the amount of marine borer activity in coastal waters, resulting in widespread damage to marine timber infrastructures (Fig. 2). Teredo, bankia, and limnoria are the three most common and destructive borers. Teredo and bankia (ship-worms) enter the wood as a larva and follow the grain, tunneling deeper as the worm grows. Numerous tunneling in a timber pile make the wood's interior as holed as Swiss cheese (Fig. 3). Limnoria nibble at the outside edges of the timber piles causing timber piling to lose up to 1 inch in diameter yearly. The most effective method of reducing marine borer attack is the pressure treatment with creosote and arsenate. However treatment doesn't stop borers from attacking the wood completely.

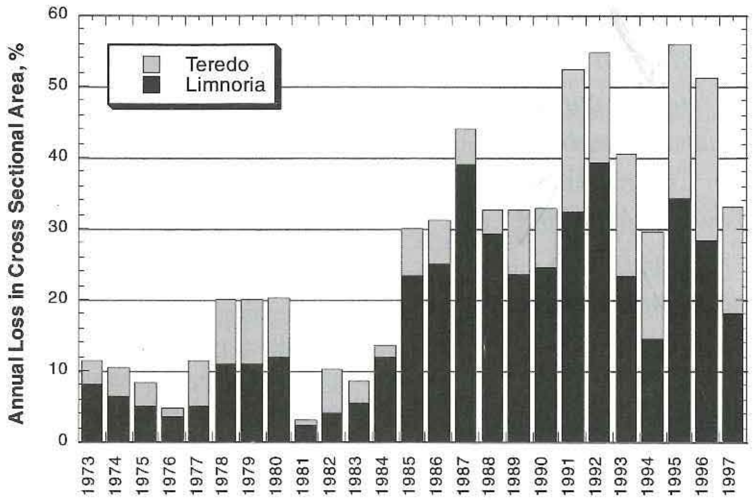

Figure 2. Average intensity of marine borers attack on untreated timber in 32 sites monitored by The Port Authority of New York & New Jersey (After Bognacki & Gill, 1997).

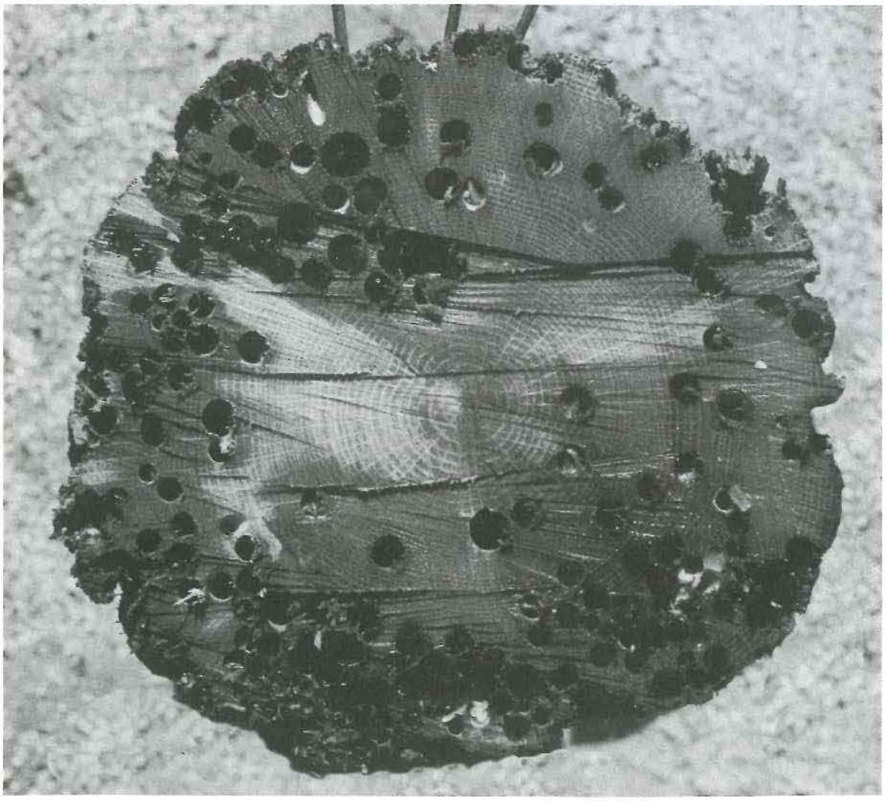

Figure 3. Numerous ship-worms (Teredo and Bankia) tunneling in a timber pile make the wood's interior as holed as Swiss cheese.

Steel: The major cause of deterioration of steel piles is corrosion, especially in industrial and marine environments (Fig. 4). The rate of corrosion in regular soils is approximately 0.03 mm per year; it increases to 1.2 mm per year in the splash zone (Fleming *et al.*, 1992). Corrosion of the steel piles can be prevented by coatings containing heavy metals, but these treatments are harmful to the environment.

Concrete: The most destructive agents for reinforced concrete piles are sodium and calcium chlorides. These salts penetrate through the concrete cracks to the reinforcing steel and form an electrical current which causes the reinforcement to corrode. This corrosion process is accompanied by expansion, which tends to induce high tensile stresses in the surrounding concrete causing cracking and spalling (Fig. 5). In marine environments, in addition to salts, the variation of temperature, freezing and thawing, further degrades the concrete.

Available Products

The majority of the piles produced have properties comparable to timber piles. Most composite piling products are made of fiberglass or high density polyethylene (HDPE) with fiberglass or steel reinforcement. The produced piling products are often non-homogenous and exhibit anisotropic viscoelastic behavior.

Steel Pipe Core Piling: Steel core piling was the first plastic piling product in the American market. These piles are made of a steel pipe encased by a recycled plastic shell (Fig. 6). The steel pipe core provides structural strength while the plastic shell protects the pile from the destructive influence of the environment. Early versions of this product suffered from delamination of the steel core from the plastic shell during driving and due to the difference in thermal coefficients of expansion. However, the manufacturer is currently producing newer products which are guaranteed against shrinkage and expansion cracking for a period of five years. Plastic Piling Inc. is currently the only manufacturer of steel pipe core piling.

Structurally Reinforced Plastic Piling: These piles typically consist of an extruded recycled High Density Polyethylene (HDPE) plastic matrix reinforced with fiberglass rebars (Fig. 6). Additives are used to improve mechanical properties, durability, and ultraviolet (uv) protection. Polymer based resins are heavier than wood and foaming of the resin is used to make the product lighter. The matrix may also contain a small percentage of fiberglass to enhance its physical properties. Seaward International and Plastic Piling. Inc. are currently the producers of this pile type. Seapile™ which is a product of Seaward International, uses approximately 800 recycled one-gallon milk jugs per linear meter.

Concrete-Filled Fiberglass Pipe Piles: These piles consist of an acrylic-coated fiberglass tubular section filled with concrete (Fig. 6). The fiberglass shell provides tensile strength, and the acrylic coating protects the pile against abrasion, ultraviolet, and chemical attacks. Hardcore DuPont and Lancaster Composite produce piles of this type under the commercial names FTP™ and CP40, respectively. FTP™ is driven empty then filled with concrete. CP40 piles are filled with concrete and cured prior to driving thus driving somewhat like pre-stressed concrete piles.

Fiberglass Pultruded Piling: Creative Pultrusions produced a piling product comprised of a pultruded fiberglass cross section (glass/vinyl ester) which resembles a tic-tac-toe pattern. The pattern consists of two sets of orthogonal fiberglass plates joined at four intersecting points (Fig.6). When the pile is used as a fender, its top portion is encased by a HDPE shell, and the tic-tac-toe pattern is filled with HDPE inserts. The shell and inserts are used to protect the fiberglass, help absorb ship impact, and to connect fendering fittings.

Fiber Reinforced Plastic Piling: Fiber reinforced plastic piling consists of a recycled plastic matrix with randomly distributed fiberglass reinforcement in

Fig. 4. Complete corrosion of steel H piles supporting a harbor pier. Note that recently installed retrofit channels are already corroding.

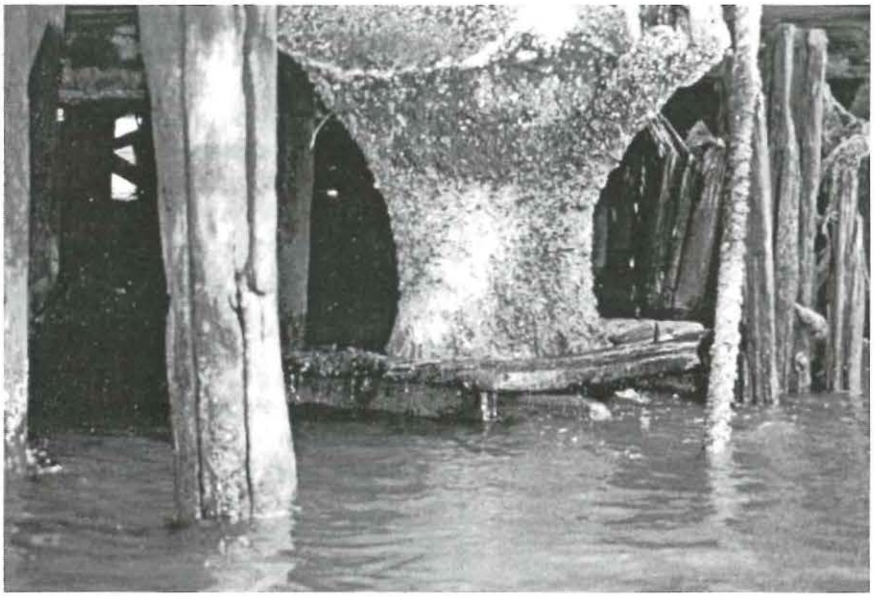

Figure 5. Deterioration of reinforced concrete piling supporting a harbor pier, causing it to lose 65% of its cross sectional area.

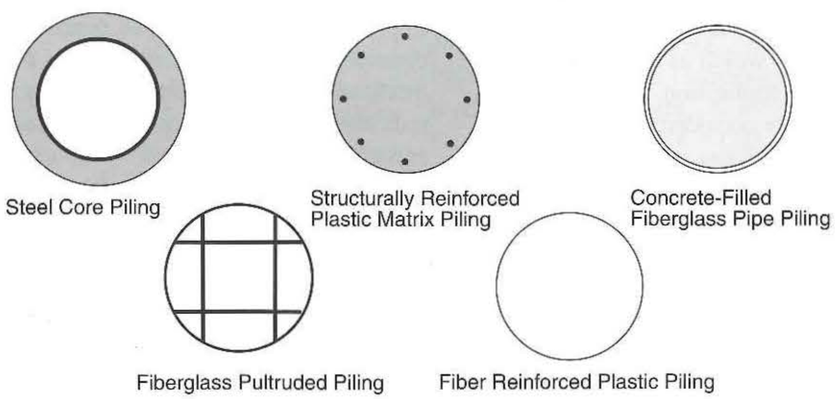

Figure 6. Commercially available FRP composite piling products.

the matrix. Trimax is currently the only manufacturer of this product. Trimax™ Lumber consists of 20% glass-fiber-reinforced high density extruded recycled polyethylene. The product consists of an outer solid section with a foamed center (Fig. 6).

Driveability

Theoretical driveability studies show that composite piling could be driven to reasonable capacities for load bearing (Fig. 7). These studies indicate that the drive-ability of conventional piling is mostly influenced by the soil parameters, while the drive-ability of softer polymeric sections depends mostly on the specific weight and elastic modulus of the pile material (Stachula, 1999).

Composite action between the matrix and reinforcing elements plays an important role in reducing the driving stresses in steel pile core piling and concrete filled fiberglass pipe piling. Bond strength is critical to the development of composite action in all FRP composite piling. Delamination of some composite pile types has been reported in the past. However, manufacturer claims that this problem has been solved.

An important issue related to driving polymeric materials is their anisotropy and non-homogeneity which may result in localized areas of lower strength, particularly when recycled plastics are used. The driveability of polymeric piling is also sensitive to the specific weight of the pile material which can vary by ± 10% of its specified value, thus highlighting the importance of quality control during manufacturing.

Structural Behavior

FRP composites usually have low stiffnesses which is advantageous in fendering application, where steel and concrete are considered too stiff. However, low stiffness may cause differential settlement and may adversely affect the performance of the structure. Additionally, the composite modulus of FRPs is both time and load dependent which may result in creep, and the possibility of time dependent load shedding.

The strength and modulus of some polymeric products can have high coefficients of variations, particularly when recycled plastics are used (Fig. 8). Better definition of performance can be achieved if appropriate quality control measures are implemented.

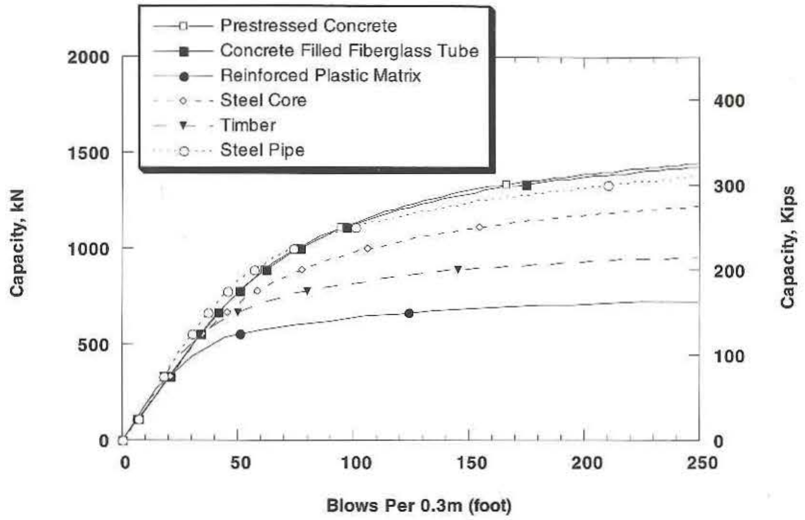

Figure 7. Bearing graphs of 12 m (40 ft.) long piles driven 10.7 m (35 ft.) in sand.

Durability

In the last twenty years polymeric geosynthetic materials have been used extensively in civil engineering construction with apparent success. Even so, degradation of buried plastics in extreme acidic or alkaline soils has been reported. Virtually no information related to the durability of plastics in water front piling is available. Most plastic piles used in construction contain additives and stabilizers which improve the resistance of the polymers to degradation. However these additives are susceptible to leaching or biological attack thereby leaving the plastic pile material unprotected. The principal result of these degradive mechanics is the loss of mechanical strength which may lead to unfavorable engineering performance and a shorter life cycle.

Hydrolysis of polyesters and thermo-oxidation of polyolefins are the two main degradation mechanisms of polymeric piling. Hydrolysis may affect fiberglass piling and reinforcement which is typically made of glass/vinyl ester. Hydrolysis occurs when positively charged hydrogen ions attack the ester linkage thus breaking the polyester chain as well as causing surface erosion of polyesters. The rate of hydrolysis is slow in ambient temperatures, but is not negligible considering the typical lifetime of a civil engineering structure.

Thermo-oxidation affects polyolefin plastics such as HDPE which is the main constituent of structurally reinforced plastic matrix, glass reinforced plastic, and steel pipe core piling. Chain breakage and the associated reduction of strength of polyolefin-based materials depends on the presence of oxygen as well as temperature. The rate of thermal oxidation is slow in ambient temperatures. Salman *et al* (1997) estimated that approximately 50 years are required before a statistically significant change in the strength of polyolefin geosynthetics is observed at 20°C. An additional 35 years is required for a 50% loss in strength. Geosynthetics have significantly smaller thicknesses than piling materials, and accordingly thermo-oxidation of composite piling is expected to occur over a significantly longer time duration.

Hydolysis can also affect polyolofin plastics in low pH environments. Piling made of recycled HDPE has an estimated half life of 32 years in severe acidic environments, which is considerably longer than conventional pile types (Hassan, 1999).

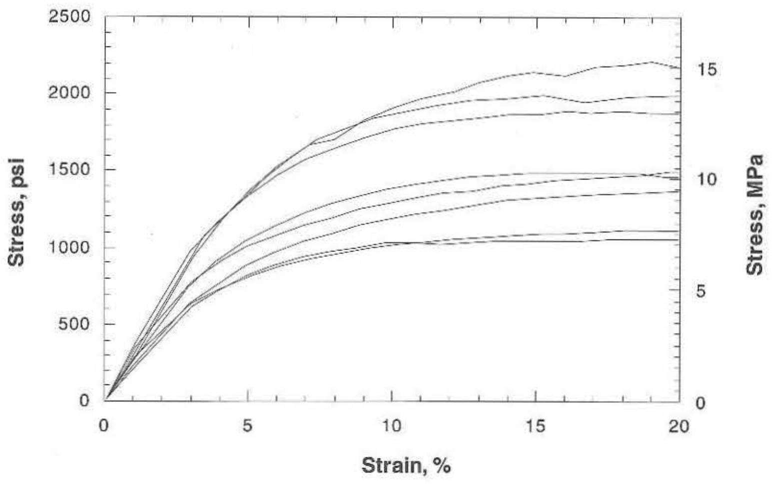

Figure 8. Variation in stress strain properties of piling made of recycled plastics. (all tests were conducted using specimens taken from the same pile)

Environmental Impact

Composite piling offers a number of environmental advantages over conventional creosote treated timber piling, as follows:

- Treatment of timber using Creosote and CCA may pose a threat to marine life, particularly when a large number of piles is involved. Workers who handle creosote and CCA treated timber are also exposed to hazardous materials during manufacturing and installations. Additionally, treated timber present a growing environmental disposal problem since creosote is listed as toxin by The Environmental Protection Agency.
- Wood products are becoming increasingly more expensive and difficult to obtain, particularly as regulations to protect old growth forests and the habitat of the spotted owl were enacted .
- Use of recycle plastics in FRP composite piling offers a solution to the mountains of solid plastic waste which are growing all over the United States and consuming valuable landfill space.

Conclusions

Piling material made of fiber reinforced polymers (FRP) and/or fiberglass has been developed in the last decade. These materials offer performance advantages for use in aggressive and marine environments. So far, composite piling has been used primarily in marine fendering applications and light bearing applications. Several barriers must be overcome for FRP composite piling to be accepted on a widespread basis. First, economic necessity requires FRP piling to be cost-competitive on a life cycle basis. Second, mechanical and physical properties should be defined and long-term performance should be verified under field conditions. Third, design methods for predicting driveability and capacity should be developed. Fourth, design and testing standards should be developed, and fifth, several piles should be instrumented, installed, load tested, and monitored.

Acknowledgments

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