Ductile Iron Piles
Corrosion Resistance

Ductile Iron Piles are often a preferred, cost-effective foundation support solution for a variety of projects particularly in urban settings. Similar to other types of deep foundation systems (i.e. steel, concrete, timber piles, etc.) that are driven or drilled into the ground, the electro-chemical reaction between the soil and the foundation system needs to be considered in the design for long-term performance. These complicated reactions which can lead to corrosion of metals or degradation of concrete are often more pronounced in urban settings with impacted fill soils or in organic soils. This technical brief provides information pertaining to research on the corrosion potential of Ductile Iron Piles, comparisons with steel piles and design approaches to address corrosion of the piles.

Soil Corrosion Potential

Corrosion potential of soil is highly-variable and depends on many different conditions. According to the FHWA (2005), the following is a list of variables which indicate a high corrosion potential and form the basis of the ground aggressivity:

- Low resistivity of ground;
- High concentration of chlorides or sulfides in ground or groundwater;
- Too low or too high hydrogen potential (pH) of ground or groundwater;
- High saturation conditions; and
- Stray currents.

Corrosion potential can be evaluated by performing a number of standardized tests as shown in Table 1. The criteria to classify the corrosion potential of the soil is also included.

Table 1: Criteria for Assessing Ground Corrosion Potential (FHWA, 2005)

Test	Units	Strong Corrosion Potential / Aggressive	AASHTO Test Method
pH	-	< 5, > 10	T 289
Resistivity	Ohm-cm	< 3,000	T 288
Sulfates	ppm	> 200	T 290
Chlorides	Ppm	> 100	T 291

Ground conditions are considered to have a strong corrosion potential if any of these limits are exceeded.

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Testing

A simulated corrosive environment was created in the lab at Vienna University of Technology to perform a comparison of corrosion resistance between Ductile Iron Piles and steel piles (Linhardt and Ball, 2014).

Similar dimensioned samples of Ductile Iron Pile, and European S235 steel (ASTM A284 equivalent) and European S355 (ASTM A633, A656 equivalent) were selected (Figure 1). The samples were placed into a controlled environment consisting of compact sand in the lower portion and gravel in the upper portion as shown in Figures 2 and 3. The container was filled with an electrolyte (deionized water and dissolved salts). The electrolyte was routinely flushed with aerated water, but only in the upper portion to increase oxygen exposure. The compact sand environment models a stagnant, low oxygen environment while the gravel (upper) environment models a high-oxygen condition with routine flushes of the electrolyte. As a result of the test setup, the aerated (upper) section models an oxygen reduction reaction while the non-aerated (lower) section models anodic metal dissolution.

The test setup included instrumentation including shunt resistors, a reference electrode and a data acquisition system to record the corrosion current between the sections and the corrosion potential. Tests were performed continually over the course of 441 days to evaluate the effects on the samples.

Figure 4 shows a picture of the prepared samples prior to introduction to the test device: Ductile Iron Pile, S235 steel, S355 steel (left to right). Figure 5 shows a picture of the samples following removal from the test environment.

The testing found that the high-temperature casting annealing skin created as a part of the Ductile Iron Pile manufacturing process covers and adheres to the pile surface and provides superior protection to the metal beneath. The results show that this casting skin is dense and well-adhering to the piling. The integrity of the skin as well as its protective nature is evidenced by the lack of pebbles adhering to the pile surface in Figure 5. In the upper oxygen-rich portion of the test setup, the number of locations forming corrosion products in crevices between

Figure 1: Picture of Samples prior to Testing

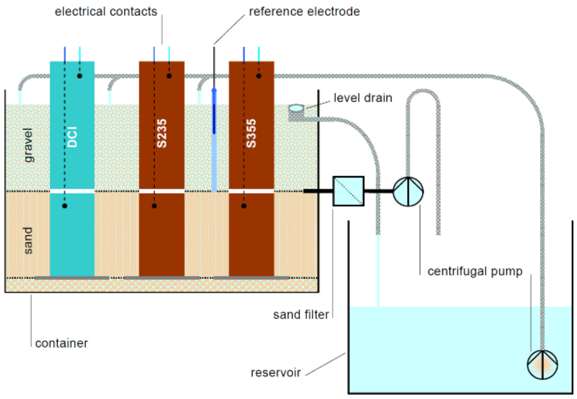

Figure 2: Schematic of Test Setup

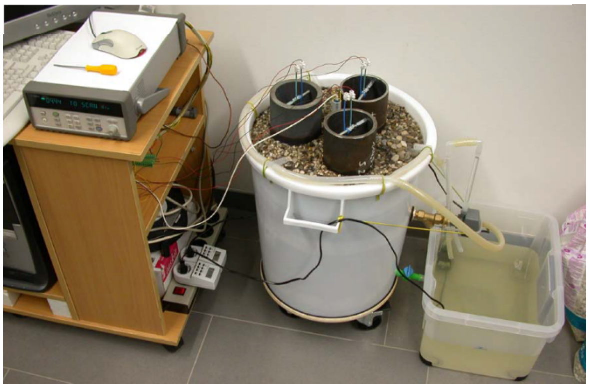

Figure 3: Picture of Lab Test Setup

the pile surface and the pebble were few. The behavior in the lower anerobic portion of the setup was dictated by anodic reaction created by the electrical contact with the cathodic upper portion. This anodic reaction caused metal dissolution at localized areas thereby reducing the effectiveness of the corrosion passivation. However, this behavior resulted in only shallow, localized pitting of the skin.

In contrast, the steel samples behave as an actively corroding metal. The rolling skin from the manufacturing process offered far less protection than the Ductile Iron casting skin, resulting in a more wide-spread pattern of corrosion evidenced by the nearly complete coverage of pebbles to corrosion locations (Figure 5). The development of this corrosion layer does have a benefit by acting to reduce the access to oxygen and reduce continued corrosion with time only after substantial corrosion has occurred. The presence of the electrical current created by coupling with the upper section intensified the corrosion and the dissolution of the rolling skin in the lower portion.

Figure 4: Picture of Samples after Testing (pre-cleaning)

Figure 5: Picture of Samples after Testing (post-cleaning)

In summary, the Ductile Iron Pile exhibits superior corrosion protection. The ductile pile material performed better than steel in the simulated corrosive environment with only localized areas of corrosion product and shallow pitting – a vast difference compared to the overall performance of the steel sections.

Design Approaches

The selection of the corrosion potential for foundation systems depend on many variables including aggressiveness of ground conditions, design service life, structure type, loading conditions, and consequences of failure. These factors are considered in the design of the Ductile Iron Piles. Corrosion implications for Ductile Iron Piles are handled through a few different approaches involving oversizing to capture a sacrificial (corroded) layer and / or encapsulation.

Firstly, the interior of Ductile Iron Piles is filled with grout to minimize exposure of the pile interior to any corrosive environment. Further steps depend on whether the pile develops capacity using either end-bearing or friction. All friction Ductile Iron Piles are installed by pumping sand-cement grout to fill through the interior of the pile. The grout is then pumped out the pile bottom to fill an exterior annular space between the pile and soil created by driving the patented oversized conical grout cap. The combination of the interior and exterior grout filling the annular space completely encapsulates the pile material with multiple inches of concrete. This encapsulation process protects the piling material from exposure to corrosive conditions.

End-bearing piles only use interior grout, leaving the exterior pile face exposed to soil and groundwater. The construction industry employs a variety of tools to protect exposed materials from corrosion. These include epoxy-coating, corrosion-inhibiting compounds, sheathing and other approaches. Another common approach is to incorporate a "sacrificial" layer or reduction of material thickness due to corrosion losses. Despite the improved protection to corrosion offered by the Ductile Iron Piles, this common approach models the pile as a steel element. Corrosion loss rates are published in various standards and literature from different sources. FHWA references values for corrosion loss of 0.02 mm per year (1 mm for 50 year service life) for steel piles buried in a sea bed condition (FHWA, 1996). Further information cites a minimum of 1.6 mm ($^{1}/_{16}$-in) of loss on the outside wall thickness of casing for micropiles installed in aggressive environments (FHWA, 2005). European ÖNORM standards for Ductile Iron Piles reference wall thickness corrosion losses ranging from 0.6 mm up to 1.75 mm for a 50 year service life depending on the corrosion potential of the soil (Austrian Standards Institute, 2012). Finally, another Ductile Iron Pile specific corrosion reference reports a wall thickness loss of 1 mm for a service life of 100 years in normal conditions (0.75 mm in 75 years) with extreme cases approaching 0.4 mm of wall thickness loss every twenty years (1.5 mm in 75 years) (Schutz, et al 1999).

Based on these various references, Ductile Iron Pile wall thickness loss of 0.75 mm per side ($^{1}/_{32}$ -inch) are often incorporated in designs for a mild corrosion rate. A reduction in wall thickness of 1.5 mm ($^{1}/_{16}$ -inch) applies to a moderate corrosion rate. Highly-aggressive environments are often addressed using a grout encapsulation approach.

Summary

Ductile Iron Piles have been used in European foundation construction for more than two decades and are increasingly used in the United States and Canada as a cost-effective foundation system with rapid installation rates. Independent research shows that the Ductile Iron Piles provide superior protection against corrosion and performs better in side-by-side comparisons with various steel products. The favorable corrosion characteristics are largely attributed to the casting skin that develops from the manufacturing process compared with the rolling skin in steel. Despite the high resistance to corrosion, Ductile Iron Pile design considers the effects of corrosion by including a percentage of "sacrificial" material (material loss) in the design capacity and / or by grouting (encapsulating) a portion or all of the pile in grout.

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