Concrete pressure pipe performance in acid soils

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Investigations were conducted concerning the effects on cement-mortar-coated pipe under long-term exposure in naturally occurring acid soils. Two existing pipelines were excavated and measurements were made of soil pH, total acidity, and resistivity; pipe potentials with respect to a copper sulfate electrode; and the extent of soil acid attack on the mortar coating. At each test station sections of the mortar coating were removed and the circumferential reinforcement and steel cylinder were examined. Long-term degradation of mortar coatings and their corrosion inhibitive properties were inconsequential in the pipelines investigated.

Concrete pressure pipe has a long history of performance in naturally occurring acid soils. Continued corrosion-free performance in aggressive soils depends on the long-term passivating effect of the cement-mortar coating, which, in turn, depends on the high alkalinity of the coating. Destruction of this high alkalinity by acid attack could be detrimental to the long-term performance of the pipe. Although the American Concrete Pressure Pipe Association (ACPPA) has received no reports of problems resulting from acid attack in naturally acidic soils, it has maintained a conservative posture on the subject in view of a lack of verified, quantitative data.

Measures of soil acidity

The term soil acidity relates to the presence in soil of ionized hydrogen (H_+) plus the ionizable hydrogen that has not dissociated from its parent species. The hydrogen ion concentration in soil is usually so low that it is difficult to express it simply as a ratio or fraction. For this reason the term pH was developed. pH is defined as the negative logarithm of the hydrogen ion concentration. A pH greater than 7 is alkaline and a pH lower than 7 is acid, with 7 representing neutrality. For practical purposes, a soil is normally considered neutral if the pH is in the range of 6.5 to 7.5. A pH less than 6.5 indicates an acid soil; a pH greater than 7.5, an alkaline soil. Since pH is a logarithmic function, a pH of 5 is 10 times as acid as a pH of 6. pH is a measure of intensity only, and, unless buffered, the loss of a relatively small amount of hydrogen ions can have a pronounced effect on pH. The other measure of acidity, which includes both the ionized hydrogen and the ionizable but nondissociated hydrogen ions, is referred to as total acidity and is generally reported as a specific number of milliequivalents of acid per 100 g of solution or soil. This is an extensive, rather than intensive, characteristic and is a measure of the total potential for acid reaction. Total acidity buffers the pH intensity by providing a reservoir of nonionized hydrogen ions that are readily ionized and tend to maintain a constant pH to counter any acid-neutralizing influence.

Both pH and total acidity must be included in any realistic definition of the acidity of a given soil. For all practical purposes they are independent of each other, and there is no predictable correlation between their numerical values for any soil or solution. Statistical analyses of 46 National Bureau of Standards soils, from which marshes, peat bogs, and the like were excluded, indicated the correlation coefficient generally ranges from −1 through 0 to +1 where the digits represent perfect correlation and zero represents no correlation.

Determination of soil pH is a simple procedure for which numerous measuring instruments are available for field or laboratory use. Generally, no significant difference should be expected between tests of slurries or supernatant liquid. If sufficient soil moisture is present, tests can be made directly on soil samples. Laboratory tests are best made as soon as possible after the specimens are collected. If the specimens are to be analyzed later, they should be frozen to prevent oxidation or biochemically induced changes in pH during storage.

Measurement of total acidity is much more complex and must be performed in a laboratory. Several methods, including electrometric titration and those of Dennison and Ewing,[1] are reported in the literature. Ewing's short method and titration are the most practical.

The ACPPA research program

In order to develop quantitative data on the performance of concrete pressure pipe in acid soils, the ACPPA initiated a long-term research project under the direction of G.N. Scott.

Scott proposed a series of field investigations at a selected number of sites. The criteria established to determine the suitability of prospective sites were:

- Natural soils, i.e., soils without man-made contamination such as industrial waste or acid mine water runoff,
- Soil pH measurements as low as 5.0,
- At least a 10 percent probability of total acidity as high as 25 meq/100 g of dry soil, and
- The presence of a concrete pressure pipeline, the older the better, for which permission from the owner could be obtained for the investigation.

These criteria were difficult to meet. Data published by the US Bureau of Standards on distribution of acid soils were used to assist in locating potential sites for field investigations. Known "hot spots" and generally regarded acid soil areas were correlated with concrete pressure pipeline locations. Preliminary measurements of both pH and total acidity were made at a number of these spots over a period of several years. Only two sites were found to meet all of the established criteria. These were at Jefferson Parish, La., and at Longview, Tex.

Methodologies for the subsequent field investigations were established by Scott.

- Establish a minimum of 17 test stations on 61-m (200-ft) centers along the pipeline;
- Take soil resistivity measurements with a ground resistance tester* at each test station according to the method of Wenner[2];
- Make excavations at each test station to uncover the top and springline of the pipe, including any undisturbed soil at the same depth beyond the limits of the original trench;
- Collect soil samples at springline depth at each test station, both from immediately adjacent to the pipe and from the undisturbed zone, testing one adjacent and one remote sample for pH on site, sealing a second set of samples in plastic bags, and sending them to a commercial laboratory for testing;
- Conduct commercial laboratory tests for moisture content, resistivity, pH, total acidity, and for certain anions and cations, including bicarbonate, sulfate, and chloride;
- Visually inspect the cleaned, exposed area of each pipe for signs of corrosion or obvious flaws, sounding the exposed areas of pipe with a hammer to locate any unbonded mortar coating;

*Megger ground resistance tester, James G. Biddle Co., Blue Bell, Pa.

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- Expose no less than 20 cm × 20 cm (8 in. × 8 in.) of the reinforcing or prestressed wires at each test excavation;
- Determine the depth of carbonation penetration into the mortar coating by noting the effervescence of the mortar coating cross section when exposed to drops of a strong acid solution;
- Inspect the exposed wires or reinforcement and the steel cylinder to determine if corrosion has occurred, and, if so, the extent of corrosion to be measured, then photograph the exposed wires; and
- Measure the potential of the wires or reinforcement with respect to a copper sulfate electrode positioned directly over the pipe on the soil surface and on the mortar coating.

Jefferson Parish, La.

The pipeline selected for investigation from the Jefferson Parish Waterworks System is a 900-mm (36-in.) prestressed concrete cylinder pipe main, conforming to AWWA Standard C301. Field investigations were performed under the direction of Scott. At the time of testing, the line had been in service for seven years in the area between the New Orleans airport and Lake Pontchartrain. The soil along the right-of-way is highly organic, water-saturated, blue to black in color, with occasional lenses of yellow clay and scattered seashells brought in from the lake. The average earth cover over the line is approximately 1.2 m (4 ft). The geometric mean soil resistivity, measured in the field, was 184.6 Ωcm with values ranging from 100 to 286. The average pH was 6.14 with individual values ranging from 3.70 to 6.82. Total acidity, which was determined by the Ewing method,[1] ranged from 6.4 to 114 meq/100g of dry soil, with the geometric mean value being 32. The electric potential of the pipe, measured with respect to a copper sulfate electrode positioned at the surface over the pipe averaged −542.4 mV for the 17 test stations, thus indicating a net ionic flow of current to the pipe. Carbonation of the mortar coating was observed at each test station and was found to range from a trace to a maximum penetration of 3 mm (1/8 in.) in one instance. Chemical analyses of soil samples indicated: moisture content—79.6 percent; total dissolved solids—7112 mg/kg; calcium—13.2 meq/100 g; magnesium—14.2 meq/100 g; sodium—3.8 meq/100 g; potassium—none detected; carbonate—none detected; bicarbonate—0.2 meq/100 g; sulfate—33.1 meq/100 g; and chloride—153 meq/100 g. Both the prestressing wire and the cylinder were in excellent condition at all test holes, with no signs of corrosion. The steel was a deep, blue-black color.

Longview, Tex.

As in the Jefferson Parish tests, all field work was done under the direct supervision of Scott and all laboratory tests were performed under his direction. The test site was located on a 600-mm (24 in.) pretensioned concrete cylinder pipe (AWWA type 303) in the Longview, Tex., municipal water system. This was a raw water supply line, which runs south from Cherokee Lake to the Sabine River. The pipeline had been in service for 30 years at the time of the field investigation. The soils along the right-of-way are generally coarse in texture and reddish-brown in color, tending toward a more uniform red to the west; gray streaks and lenses appear in the profile to the east. The average depth of cover is 1m (3 ft). Mean soil resistivity, measured* 2450 Ωcm, with values ranging from 680 to 7600 Ωcm. The mean pH, measured in undisturbed soil several feet from the pipe, was 5.24, with values ranging from 4.1 to 6.7. Statistical analysis indicated a minimum pH of approximately 3.5 in the undisturbed soil at the 96-percent probability level. The higher alkalinity adjacent to the pipe shows the ionizable hydrogen in the soil is inadequate to neutralize the slight diffusion of calcium hydroxide from the coating to the soil. Total acidity, determined by the Ewing short method,[1] ranged from 1.6 to 31.4 meq/100 g of dry soil, with the mean value being 12.38. (Samples were collected from the undisturbed soil zone.)

The average pipe potentials measured −388 and −385 mV with respect to the copper sulfate electrode at the adjacent and remote electrode sites, respectively. This close agreement indicates little galvanic action on the pipe except for that resulting from a "long line" current determined to be caused by differential aeration of the line. Pipe potentials ranged from −240 to −494 mV and indicated distinct anodic and cathodic areas and a substantial length of totally inactive pipe. The practical significance of this discovery is that the corrosion of iron is not involved in the reaction, which includes only the rectification of oxygen gas and hydrogen ion imbalances. Advocation of cathodic protection by corrosion engineers on the basis of "long line currents" is thus unjustified for cement-mortar-coated pipelines.

The coating was very hard and dense at all locations. The thickness measured at 13 locations averaged 13.5 mm (0.53 in.) over the rod. Carbonation of the coating could be described only by the words none, trace, and thin. In no instance was it as great as 1.6 mm (1/16 in.) in thickness. Chemical analysis of soil samples performed in a commercial laboratory with 1:5 mixtures of dry soil and distilled water indicated the following average cations and anions: calcium—1.05 mg/L; magnesium—0.49 mg/L; sodium—14.8 mg/L; potassium—1.55 mg/L; bicarbonate—13.8 mg/L; chloride—13.8 mg/L; sulfate—9.8 mg/L; and nitrate—0.24 mg/L.

No rust stains were observed on the exposed pipe coating, and no corrosion of the steel cylinder or reinforcing rods was observed at any of the 17 test holes. The 8-mm (1/4-in.) rod was smooth, shiny, and deep blue to blue-black in color.

*Megger ground resistance tester.

Summary

ACPPA continues to make a determined effort to locate concrete pressure pipe installations in highly acidic natural soils. High acidity, for the purpose of these investigations, was defined as pH values at least as low as 5.0 and having at least a 10 percent probability of total acidity as high as 25 meq/100g of dry soil. Only two suitable pipeline sites have been located to date—one at Jefferson Parish, La., and one at Longview, Tex. Intensive investigations of both these pipelines were conducted.

The only measurable deterioration of mortar coating observed was caused by carbonation, resulting from attack by solutions of carbon dioxide. This attack in only one instance was as great as 3.2 mm (1/8 in.) and was considered inconsequential.

The mortar coatings observed were dense and extremely hard and were continuing to protect the steel components against corrosion. No corrosion of prestressing wire, reinforcing rod, or steel cylinders was observed, even though soil conditions at both of the sites investigated would normally be considered aggressive and corrosive.

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