Precast Concrete Pipe Durability: State of the Art

MIKE BEALEY

ABSTRACT

In this paper the performance of precast concrete pipe is reviewed, and state-of-the-art information concerning the durability of buried precast concrete pipe is presented. The properties of precast concrete pipe, and other factors that influence durability, are discussed. The performance of precast concrete pipe in specific aggressive environments is evaluated. The service life of precast concrete pipe in most installation environments is virtually unlimited. Aggressive environments are readily identifiable in the design stage, and precautions are available to eliminate any concerns with the use of precast concrete pipe.

Most aspects of buried pipeline design, from flow determination to loads to structural analysis, are well-established. The aspect of durability, however, is not as well understood by designers, and therefore it is generally not given proper or adequate consideration, especially when bids are requested on alternate materials, unless a least-cost analysis is being performed (1). Any consideration of durability and least-cost analyses must begin with definitions of the required project service life and the durability of pipe materials.

In NCHRP Synthesis of Highway Practice 50 (2), "Durability of Drainage Pipe," service life is defined by the number of years of relatively maintenance-free performance; and it is noted in the synthesis that a high level of maintenance may justify replacement before actual failure occurs. In this report it is stated that for service life guidelines, designers generally are looking for relatively maintenance-free culvert performance for at least 25 years in secondary road facilities; for 40 years or more in primary highway, urban transit, or rail facilities; and longer service life requirements for hard-to-place culverts in key urban locations or under high fills. It is also stated in the synthesis that a durability safety factor of at least two should be used to assure that the structure will definitely serve its required life span. Sewers are key facilities and are constructed in urban areas where any installation is costly in terms of both dollars and public inconvenience; therefore they should be designed for a service life at least the same as required for pipe under high-type road facilities.

The Bureau of Reclamation has developed the most comprehensive definition of a durable concrete pipe, but it can be applied to any pipe: "A durable concrete pipe is one that will withstand, to a satisfactory degree, the effects of service conditions to which it will be subjected" (3). This definition contains three variables that must be evaluated: the concrete pipe, the satisfactory degree of performance, and the service conditions.

DURABILITY

For all normal, everyday installations, the service life of concrete pipe is virtually unlimited. For example, the Roman aqueducts are still usable after more than 2,000 years, and there is a buried concrete pipeline in Israel that was tentatively dated as 3,000 years old (4). More recently, the first known concrete pipe sewer in North America was located; five sections were removed in September 1982 for inspection and historical purposes (5). Installed in Mohawk, New York, in 1842, this 6-in. precast concrete pipe is in excellent condition after 140 years, and the sections remaining in service are expected to perform for several more centuries.

A search for precast concrete pipe durability problems indicates that few problems exist, and consequently few investigations have been conducted and published (2,6). In 1982, however, the Ohio Department of Transportation published a report on the results of a 10-year study of more than 1,600 culverts in all areas of the state, which included 545 precast concrete pipe installations (7). The environmental conditions in Ohio are relatively neutral, as are most areas of North America, and the soils and water do not possess any characteristics that would contribute to premature deterioration of pipe, except for a few areas with mine acid drainage problems. An equation for predicting service life was developed for precast concrete pipe, which relates pH and pipe slope to the number of years for the pipe to reach a poor condition. With the equation plotted graphically (Figure 1), it is readily apparent that a concrete pipe placed on an average slope of 1.5 percent, and installed in an environment with a pH of 7, will take about 1,000 years to reach a poor condition; and, in an aggressive environment with a pH of 4, the concrete pipe will last 100 years, which is adequate for any sewer or high-type road facility.

MATERIAL PROPERTIES

Three properties of concrete--compressive strength, absorption, and water/cement ratio--are generally considered indicators of durability and are included

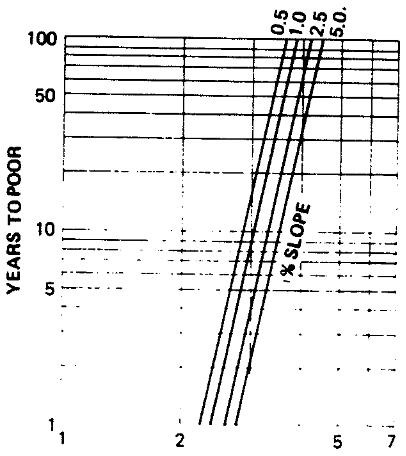

FIGURE 1 Concrete pipe culvert life.

in all concrete product and project specifications. A comparison of these three properties as commonly found in precast concrete pipe with those found in cast-in-place concrete clearly reveals why precast concrete pipe is durable.

Compressive Strength

Cast-in-place concrete for pavements and structures is generally specified as 3,000 to 4,000 psi compressive strength at the end of 28 days. Precast concrete pipe specifications require 4,000 to 6,000 psi compressive strength when delivered, which is anywhere from 3 to 7 days after manufacture, and which normally results in 28-day strengths of 8,000 to 12,000 psi.

Absorption

Absorption is a static measure that simply determines the volume of voids in concrete. Initially used as a quality control test for thin-wall concrete drain tile to assure adequate resistance to leaching action, absorption testing has been gradually applied without any substantiating research to larger pipe with thicker walls as an indicator of durability. Cast-in-place concrete is considered high quality with 10 to 12 percent absorption, whereas precast concrete pipe specifications require absorption not to exceed a maximum of 8.5 to 9 percent, and pipe is normally produced with absorption significantly less.

Water/Cement Ratio

Precast concrete pipe is produced with a low water/cement ratio concrete. The water/cement ratio is so low for machine-made pipe that the concrete is said to have a negative slump, which means that water would have to be added before any slump would occur. Cast-in-place concrete mixes are designed with much higher water/cement ratios and are placed with slumps ranging from 2 to 12 in., which results in relatively low strength concrete with excessive voids.

SERVICE CONDITIONS

Concrete pipe has been proven to be a durable, long-serving product that has gained the respect and confidence of engineers throughout the world, but there are several specific environments, which are readily identifiable, that usually concern engineers. Except for acid environments, however, the concerns are perpetuated by experiences with exposed cast-in-place concrete and statements from the competition, even though there are no records of any problems with buried precast concrete pipe in these environments. The performance of concrete pipe in each environment is discussed, along with any physical characteristics and environmental conditions of a specific installation that could influence durability.

Abrasion and Erosion

The velocity of an effluent, by itself, does not create problems for precast concrete pipe. The city of Los Angeles specifies a maximum velocity of 40 ft/sec for concrete pipe (8). Most road drainage criteria require concrete linings for ditches where velocities exceed 12 to 15 ft/sec. Abrasion or erosion depends on the size, hardness, and quantity of solids being moved through the pipe.

An investigation by the American Concrete Pipe Association in the 1950s to locate and quantify abrasion failed to find any problems, but did find precast concrete pipe set on a 45-degree slope serving as a flume for mine tailings, with no evidence of abrasion (9). In the past 14 years only one instance of an abrasion problem was reported, and this was a culvert on a steep mountain slope in West Virginia, which had a high volume of water carrying boulders 1 to 2 ft in diameter through the pipe. The final solution was welding railroad rails to the reinforcement cage in the invert to allow the boulders to skid through the pipe.

Freeze-Thaw

Freeze-thaw damage of pavements and bridge decks is all too familiar, but this problem is experienced by exposed cast-in-place concrete and is related to the frequency of freeze-thaw cycles. Precast concrete pipe does not freeze when buried, except, possibly, for the ends of large diameter culverts. The high strength, low water/cement ratio concrete of precast concrete pipe inherently has excellent resistance to freeze-thaw forces (10).

Sulfate Soils

Sulfate problems have been almost exclusively limited to exposed cast-in-place concrete structures located in arid areas of North America with alkali soils. The Bureau of Reclamation has wide experience in these areas and has developed general criteria for evaluating sulfate environments. The bureau states, however, that is has not found any sulfate problems in buried precast concrete pipe (3). The resistance of precast concrete pipe to sulfate attack is easily understood in view of the bureau's guidelines for preventing sulfate attack in exposed cast-in-place concrete, and the mechanism of sulfate attack. Besides use of Type II or Type V cement and fly ash, the bureau indicates that sulfate resistance is increased by steam curing, high cement content, and low absorption--exactly the characteristics of precast concrete pipe.

Sulfates attack the interior of the concrete through a chemical reaction with tricalcium aluminate to form expansive compounds that disrupt the concrete. For sulfate to permeate concrete, it must be in solution, and the lack of rain and groundwater in alkali soil areas greatly reduces this possibility. To obtain a sufficient amount of sulfate to cause disruption of the concrete requires an evaporative surface to concentrate the sulfates within the concrete.

Figure 2 shows four possible cases of hydrostatic and hydrokinetic relationships. In Case 1 water pressure is equal on both sides of the pipe wall, the concrete becomes saturated, stability is reached, no further water movement takes place, and no sulfate attack can occur. In Case 2 there is a pressure differential that causes water movement through the wall, but there is no evaporative surface to concentrate sulfates. The direction of movement is also critical, and normally it will be from the inside to the outside of the pipe, which would prevent soil sulfates from permeating the pipe. In Cases 3 and 4 water movement is by differential pressure or capillary action to an evaporative surface exposed to the atmosphere. In practice these cases are represented by canal linings and pave-

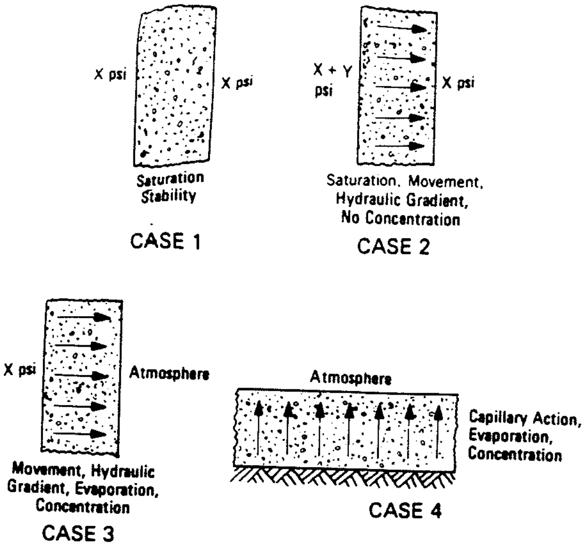

FIGURE 2 Hydraulic and hydrokinetic relationships.

ments, which have experienced most of the problems from sulfate attack. With respect to buried precast concrete pipe, sulfate problems are inhibited by a lack of the proper mechanism to concentrate sulfates in the concrete, and are further inhibited by the high strength, low absorption properties of precast concrete.

Chlorides

The most significant aggressive action of chlorides is corrosion of steel, and problems have been experienced with the reinforcement of bridge decks and seawater structures exposed to tidal action, such as pilings and piers. As with sulfates, to cause corrosion chlorides must be in solution, permeate the concrete, be concentrated, and also have a ready supply of oxygen. There are no reports or evidence of any chloride-induced corrosion problems with buried precast concrete pipe. Again, this absence of problems is attributed to a lack of the proper mechanism to concentrate chlorides in concrete, a lack of oxygen, and the high strength, low absorption properties of precast concrete. This conclusion was recently confirmed by Naval Civil Engineering Laboratory research on concrete spheres with less than 1 in. cover over the reinforcement in which the spheres were submerged up to 5,000 ft deep in the Pacific Ocean (11).

Acids

The last environment of concern, and the only one readily aggressive to buried precast concrete pipe, is an acidic environment. Acid attack is a surface attack, and is divided into two categories: interior and exterior.

Interior Acids

In the pipe interior acid attack can occur from two sources. The first source is the hydrogen sulfide cycle, which may occur in sanitary sewers (12). Under proper circumstances sewage can generate hydrogen sulfide gas that may be converted to sulfuric acid on the crown of the pipe. Since 1974 several scientific breakthroughs now enable generation of hydrogen sulfide to be controlled existing sewers (12) and predicted in new sew (13); in new sewers, if the problem cannot be leviated by proper system design, then the concre pipe can be designed to be sufficiently resistant acid attack so as to meet the required project se vice life (3).

It appears that some confusion prevails regardi sulfates, sulfides, and sulfuric acid. As previous stated, potentially aggressive sulfates are the so alkalies found in the dry western areas. Sulfat must penetrate the concrete and be concentrated evaporation to cause disruption. The use of Type cement is recommended to make cast-in-place concre more sulfate resistant. Sulfides in sewage do no attack concrete. Hydrogen sulfide gas does not at tack concrete, but it does attack iron, steel, an other metals; also, it is toxic and flammable. Und favorable conditions hydrogen sulfide gas is co verted to sulfuric acid on the crown of the sew pipe. Sulfuric acid attacks the surface of concrete, iron, steel, and other materials. Type II cemen does not make concrete more resistant to acid attack, although it is erroneously specified as such by some agencies and engineers.

The second source of interior acids is the effluent. Occasionally, an effluent can contain some acid: in culverts mine acid drainage could be a problem, and in sewers acids can be dumped in from a variety of sources. An acidic effluent will attack most pipe materials, and the area of attack is limited to the pipe invert, or the submerged portion. In any case, in the states it is illegal to dump acid in a sewer or stream. Pretreatment is required and has successfully alleviated corrosion problems.

Exterior Acids

Exterior acid attack, although chemically the same as an interior attack, involves a completely different environment. When an acidic soil or groundwater is encountered, its effect on concrete is governed by pH, total acidity, groundwater conditions, and backfill material. Total acidity is the amount of acid available to attack the pipe. As an example, a total acidity of 25 mg per gram of soil equivalent with a pH of 5 would indicate a potentially aggressive situation, and a comprehensive analysis of the site and countermeasures should be required. Such aggressive situations occur rarely naturally, and are generally manmade, such as sanitary landfills and industrial waste disposal areas.

In an installation with no movement or slow movement of groundwater, the acid in contact with the concrete pipe will be neutralized and form a neutral zone that stops further corrosion. For installations with significant groundwater flow, limestone backfill has been successfully used as a neutralizing barrier to prevent corrosion of the concrete pipe; also, an impermeable backfill material, such as clay, has proved to be an economical and successful barrier that prevents flow from reaching the concrete pipe.

If acids are encountered and cannot be alleviated by other countermeasures for either interior or exterior acids, a precast concrete pipe can be produced with a higher total alkalinity, increased concrete cover, a protective coating or lining, or any combination of these. In addition, for exterior exposure only, the backfill material can be either of low permeability so as to inhibit acid replenishment, or calcareous aggregate so as to neutralize the acid.

SUMMARY

Precast concrete pipe has served in an impressive fashion for more than 100 years, is being installed at the rate of more than 1,000 miles a month in North America, and has experienced few problems. These problems have been identified and related to specific environments. Adequate countermeasures have been developed to alleviate the problems. With the knowledge available, the concrete pipe installed today will last for centuries.

Discussion

Carl M. Hirsch*

Bealey speaks of service life of concrete pipe as virtually unlimited in most environments. A few selected examples of old concrete conduit showing outstanding durability were presented, which is possible to do for any pipe material. He noted that little was actually done to investigate concrete pipe durability until the Ohio Department of Transportation conducted a visual evaluation of 545 culvert pipes and published the results in 1982. He relies mainly on the results of this study to substantiate his claim of virtually unlimited durability. Emphasis is placed on a life-prediction graph produced for the Ohio report (7), which predicts life in acidic water on the basis of water pH and pipe slope. In this report nearly two identical graphs, which indicate that acid resistance increases as pipe slope decreases, were produced. The graphs illustrate a slope range of 0.5 to 5.0 percent, which encompasses a limited illustrated pH range of about 2.2 to 4.5. They predict 100 years life at pH 4.5 if the slope is 5.0 percent and 100 years life at pH 3.7 if the slope is only 0.5 percent. Bealey concludes that the graph(s) predicts about 1,000 years life at a pH of 7.0 and a slope of 1.5 percent.

DATA REVIEW OF OHIO REPORT

An examination of the data used to construct the graphs indicates that they are not useful in predicting life. The data are too sparse and too inconsistent to permit life prediction by the technique used in the Ohio report.

The sparseness of the data is evident in that only 72 of the 545 concrete pipes surveyed were in water with measured pH values less than 7.0, and only 31 of the 72 pipes were exposed under conditions within or near the illustrated graph pH and slope ranges. Furthermore, 10 of the 31 pipes had fully protective acid-resistant invert liners (vitreous clay). Five of the remaining 21 pipes had no reported slope and thus could not have been used in constructing the graphs in their present form. Of the remaining 16 pipes, 7 were exposed at low pH (2.4 to 3.2), where they revealed rapid deterioration, so they are of little value in determining performance trends in the critical upper end of the pH range given in the graph. Of the remaining nine pipes, six had invert sediment that improved performance. Because the authors of the Ohio report constructed their graphs for unsedimented conditions, and because they could not possibly know how the six sedimented pipes would have performed without sediment, there are only three unsedimented pipes with known slopes to determine performance trends in the graph pH range greater than 3.2.

There were only two other pipes exposed below pH 5.9, and one of these at pH 5.0 had a protective vitreous clay liner, and the other at pH 5.5 had sediment. There were also 39 pipes in the 5.9 to 6.9 pH range, and their performance should never be used to support any perceived performance trends within the illustrated graph pH range because the effect of pH can change drastically over such a large pH range (2.4 to 6.9), and even over a much smaller range.

DATA INTERPRETATION

The interpretation of such sparse data is open to extreme error. The authors of the Ohio report followed the common technique for this type of study, which is to look for the best perceived mean or average performance trend in the data as a whole. They tried to improve the technique and predict life by noting the average effect of pH in the data as a whole while accounting for inconsistencies in this effect with slope differences. They also produced correction factors to adjust graph predictions for the effect of sediment.

Actually, the effect of pH in the sparse, scattered data is uncertain, as can be noted by plotting the pipes on the graphs according to pH and time to poor. Fair rated pipes (moderate loss of aggregate) are assigned any of various reasonable estimates of time to poor (2-4X present age). As shown in Figure 3, the four slope-range lines from the Ohio study depict a large beneficial effect of increasing pH at each pipe slope and thus suggest long life at higher graph pH values. However, these four lines do not represent the data significantly because the effect of pH is highly inconsistent, and there is no slope pattern that resolves the inconsistency. The unsedimented pipes do not have a slope pattern that agrees with the theoretical values of the four slope-range lines; there is no credible pattern of any type. Also, there is no slope pattern for sedimented pipes, either as they are plotted in the figure or after applying the sediment correction factors for each pipe. Actually, a line such as CD could be the average effect of pH (see note 3 in figure), and line CD is indicative of a far lesser effect of pH and far poorer pipe performance. The data appear to separate into better- and poorer-than-average groups that more or less parallel line CD.

Under such conditions any attempt to predict life using pH and slope must produce large errors. This is best noted by comparing specific pipes. For example, a pipe at pH 2.6 and 0.5 percent slope was rated fair after 5 years, whereas a pipe at pH 4.6 and 0.7 percent slope was rated fair after 4 years. Thus the pipe at the lower pH performed slightly better, despite exposure to an acid concentration about 100 times greater, and yet the slopes of the two pipes are essentially equal. Likewise, a pipe at pH 2.4 and 2.0 percent slope was rated poor after 11 years whereas another pipe at pH 3.0 and 1.9 percent slope was rated poor after 4 years. Thus the first pipe performed nearly 3 times as well, despite exposure to an acid concentration about 4 times as great, and yet pipe slopes are virtually identical.

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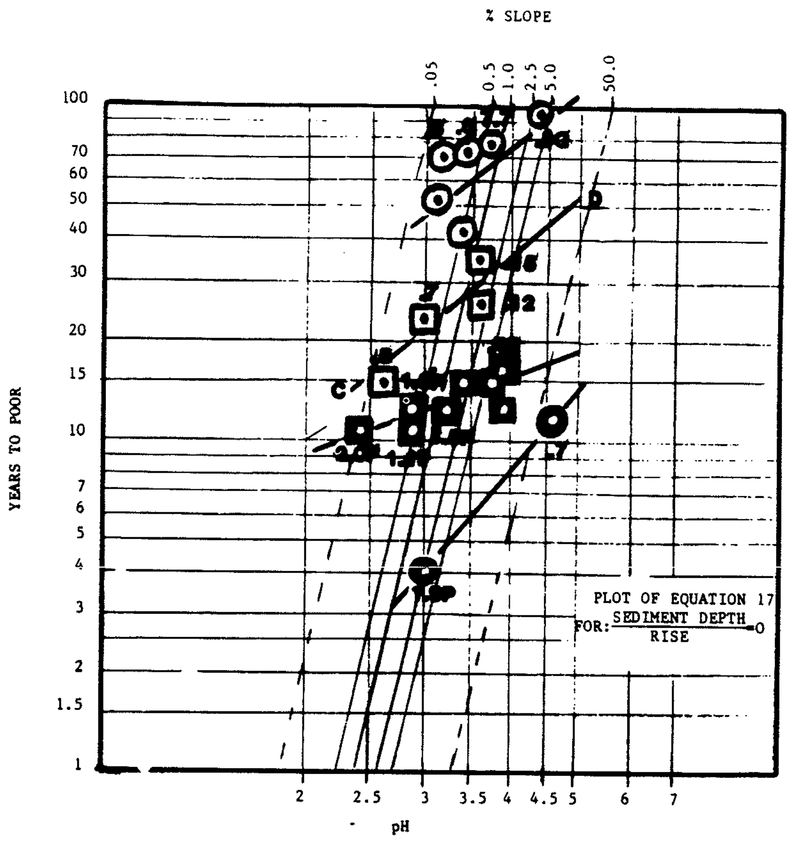

1. NOTE: IF THE ABOVE GRAPH FAIR-RATED PIPES ARE GIVEN AN ESTIMATED TIME TO POOR OF 3X PRESENT AGE. ONE GOOD-RATED ONE IS GIVEN ABOUT 5X AGE. ONE RATED VERY GOOD AFTER 4 YEARS CANNOT BE ESTIMATED REASONABLY WELL.

2. NOTE: ACTUAL SLOPE IS NOTED BESIDE EACH OF 15 DATA POINTS. PIPES RATED POOR OR GOOD AT PRESENT AGE HAVE P OR G AFTER SLOPE (ALL OTHERS ARE FAIR).

3. NOTE: IT IS MORE EVIDENT THAT CD CAN BE THE AVERAGE pH EFFECT BY SEEING THAT THE DATA HORIZONTAL SPREAD IS ARTIFICIALLY COMPRESSED BY THE GRAPHING OF THE LOG OF pH (LOG OF LOG OF ACID CONCENTRATION) VS. THE LOG OF TIME.

FIGURE 3 Graph of slope, pH, and years to poor.

Obviously, the lack of effect of low pH among such data is caused by some unknown acid-mitigating factor(s) other than slope. Two sedimented pipes with nearly identical sediment correction factors included one pipe at pH 3.2 and 0.6 percent slope rated fair after 24 years and one pipe at pH 3.6 and 0.12 percent slope rated fair after 9 years. Thus the pipe at lower pH and higher slope performed considerably better, contrary to graph predictions; also, the slope is misleading.

The degree of error produced by using slope and pH alone can be seen easily in some cases by comparing graph life predictions with actual performance. For example, one unsedimented pipe at pH 3.8 and 0.4 percent slope reached the poor condition in only 16 years, whereas the graphs predict that close to 200 years should have been required (another unsedimented pipe at pH 3.8 with no reported slope reached the poor condition in only 13 years). Another unsedimented pipe at pH 4.6 and 0.7 percent slope reached the fair condition in only 4 years, and this high rate of deterioration contradicts graph predictions of about 450 years to reach the poor condition. A sedimented pipe at pH 3.6 and 0.15 percent slope reached the fair condition in 12 years, which contradicts graph predictions. This pipe, even in the absence of sediment, has a graph prediction of about 250 years to reach the poor condition, if it can be assumed that the beneficial effect of decreasing slope extends down to 0.15 percent. Thi assumption is uncertain; therefore, using a conservative higher slope value of 0.5 percent gives predicted life of about 80 years in the absence sediment. With its thick sediment layer, the pipe supposed to last a good deal longer (about 2,2 years using the 28X sediment factor used in the Ohi report for the pipe), but actually this sediment pipe reached the fair condition in only 12 year The sediment factor is likely in extreme error, b even if the factor were only 1.5X or even less, t graph prediction error would still be extremel large.

The graph predictions tend to overrate the pip exposed at higher pH and to underrate those a lower pH. An example of the latter case is a pipe a 0.5 percent slope and pH 3.0 that is rated fai after 5 years, whereas the graphs predict 4 years t reach the poor condition. These tendencies indicat that the graph angle of the four slope-range lin is steeper than that of the line that represents th real average effect of pH. Thus the real avera effect of pH is less than that suggested by the fou lines, and no pipes last as long as the graphs predict at the upper end of the pH range.

When the effect of pH is misjudged substantially and the assumed performance trend for young pip (most are less than 15 years old, and the four oldest are 18 to 26 years old) is extrapolated to 100 years, extreme error, such as in these cases, can be expected. Bealey's suggestion to use the graphs outside their illustrated pH range and extrapolate to 1,000 years would greatly compound the error that is already extreme.

For further discussion on the life-prediction graphs from the Ohio study, the reader should see my discussion of the report by Hurd in this Record.

Author's Closure

I thank Hirsch for pointing out that the substantiation was not too clear concerning the virtually unlimited service life of concrete pipe in normal, everyday installations.

A literature search in 1983 indicated that 33 states and numerous researchers had performed culvert surveys and investigated the durability of pipeline materials since 1925, resulting in 131 reports. Because the durability of concrete pipe is so evident, and research money is normally spent only on problems, 63 percent of the reports are concerned primarily with the deterioration and short service life of corrugated metal pipe, 28 percent of the reports cover multiple pipe materials, and 5 percent of the reports deal with only concrete. (A list of the 131 bibliographies resulting from the literature search is available from the author.)

It was in the mid-1960s that some states began comprehensive surveys and gathered data on all pipe materials, not just those exhibiting problems. The seven most comprehensive reports and their conclusions regarding concrete pipe are as follows.

1. V.E. Berg. A Culvert Material Performance Evaluation in the State of Washington. Washington State Highway Commission, Olympia, 1965: "Concrete culverts were not inspected on an organized basis as were the metal culverts. . . . Concrete culverts, when constructed on a firm foundation, not overloaded and not subjected to abrasive wear, should last almost indefinitely. Numerous culverts were examined which appeared as new, even though they were installed over 25 years ago. No appreciable signs of material disintegration or chemical attack were found."
2. L.W. Hyde et al. Detrimental Effects of Natural Soil and Water Elements on Drainage Pipe in Alabama. Alabama Highway Department, Montgomery, 1969: "Concrete is resistant to corrosion except under conditions of extreme acidity or alkalinity. . . . However, under conditions other than extreme acidity or alkalinity, concrete pipe can be expected to give many years of satisfactory service. . . . In areas where the pH of surface water is less than 4.5, drainage structures should be concrete or vitrified clay. In areas of highly mineralized acid mine drainage or where the pH is significantly less than 4.5, drainage structures should be vitrified clay or concrete with a proven protective coating."
3. Corrugated Steel Pipe for Storm Drains, A Value Engineering Study. Los Angeles County Flood Control District, Los Angeles, 1973: "Presently, storm drains are constructed using primarily reinforced concrete pipe or box. . . . For the past 8 or 9 years, the Corps has used only reinforced concrete pipe in this area. . . . However, almost all of the jurisdictions within the County are replacing corrugated steel pipe with reinforced concrete pipe when the need arises. The main reasons given are high maintenance costs attributed to the need for frequent, thorough inspection, and limited maintenance personnel."
4. H.N. Swanson et al. Performance of Culvert Materials in Various Colorado Environments. Colorado Division of Highways, Denver, 1977: "Concrete sections made of Type II cement, Type II low alkali, Type II low C_3A and Type V cements were placed at the Fruita and the Olathe sites in 1974 and 1975. Samples made with Type II and Type V cement were placed in Fossil Creek in 1966. All of the above concrete samples are sound and in good condition. Sections of concrete pipe, one made with regular aggregate and one with limestone aggregate, have been exposed to the acidic conditions of the Straight Creek site for five years. . . . The areas exposed to water show definite attack by the acid water. Attack has only removed the cement surface, exposing the aggregate. The attack is not very serious and the pipe under the highway is expected to remain in service for at least another twenty years."
5. Kentucky Culvert Study. Byrd, Tallamy, MacDonald and Lewis, Falls Church, Va., 1979: "Acid environment (greater than 4 pH and less than or equal to 6 pH). . .the reinforced concrete pipe is still appropriate in this pH range." "Extremely acid environment (pH equal to or less than 4). . .concrete pipe requires special protection to provide an acceptable risk level for adequate service life."
6. Evaluation of Highway Culvert Coating Performance. Report FHWA/RD-80-059. FHWA, U.S. Department of Transportation, 1980: "Concrete is usually used in severely corrosive areas. Most concrete is installed uncoated."
7. R.W. Kinchen. Evaluation of Metal Drainage Pipe Durability--Analysis After Six Years. Louisiana Department of Transportation and Development, Baton Rouge, 1980: "The Department's hydraulics engineers can generally choose either reinforced concrete or corrugated metal pipe in their designs. Concrete pipe is very durable and with stable bedding conditions can normally serve effectively for the life of a highway. The LADOTD also recognizes that metal pipe has its place in the field of hydraulics and maintains an interest in innovations in metal pipe. . . . The major drawback with metal pipe is its tendency to corrode in the presence of moisture, oxygen, and salt."

As the foregoing indicate, substantial and comprehensive research was actually done to investigate concrete pipe both before and after the start of the Ohio Department of Transportation study in 1972; however, the data from these investigations indicated that the performance of concrete pipe was so good that the development of predictive service life equations was meaningless, and instead general statements were made to the effect that concrete pipe would last indefinitely in normal environments. Initially, even the Ohio study was afflicted with this problem.

For the Ohio study, both the concrete and corrugated steel pipes were randomly selected for investigation but, to obtain any meaningful service life equation for concrete pipe, only the data from sites with a pH of less than 7 were statistically analyzed. A look at the overall study indicates the excellent performance of concrete pipe: out of the 519 concrete culverts studied, only 9 were rated in poor condition, 33 in fair condition, and 477 in good to excellent condition. Of the nine in poor condition, one has been repaired, and repairs are contemplated for the other eight. Another difficulty in pipe investigations is the establishment of objective and equal rating classification systems. For example, in the Ohio study concrete pipe was rated poor when there was significant loss of mortar and aggregate or when concrete was in a softened condition, whereas the corrugated steel pipe was rated poor when the invert was lost, there was perforation, or when the pipe could be penetrated by a geologist's hammer. These are clearly not comparable ratings, which indicate that the predictive equations for concrete pipe are conservative and that the predictive equations for corrugated steel pipe are liberal. If, as for corrugated steel pipe, concrete pipe was rated poor only when its invert was lost, then the service life of concrete pipe would be unlimited in even adverse environments.

In his discussion Hirsch devotes five sentences to an off-hand review of my paper and several pages to a critique of the Ohio study paper by J.C. Hurd (whose paper is also in this Record). I suggest that Hirsch's comments on the Ohio study should be directed to authors of that report.

REFERENCES

1. Bid Evaluation by Least Cost Analysis. Buried Fact No. 4. American Concrete Pipe Association, Vienna, Va., Feb. 1983.
2. Durability of Drainage Pipe. NCHRP Synthesis of Highway Practice 50. TRB, National Research Council, Washington, D.C., 1978, 37 pp.
3. Concrete Manual, 8th ed. Bureau of Recla tion, U.S. Department of the Interior, 1975.
4. Concrete Pipe Handbook. American Concrete Pi Association, Vienna, Va., 1981.
5. First Concrete Sewer Pipe Found. Concrete Pi News, Feb. 1983.
6. Evaluation of Highway Culvert Coating Perfo mance. Report FHWA/RD-80/059. FHWA, U.S. D partment of Transportation, June 1980.
7. Culvert Durability Study. Ohio Department Transportation, Columbus, 1982.
8. Materials for Storm Drains: Storm Drain De sign--Maximum Velocities. Special Order 500 0172. City Engineering Department, Los Angele Jan. 31, 1972.
9. E.J. Duggan. Climax Milling Practice. Mini Technology, March 1942.
10. Guide to Durable Concrete. American Concret Institute Journal, Vol. 74, No. 12, Dec. 1977.
11. Concrete Wins Victory at Sea. Engineering Ne Record, Oct. 14, 1982.
12. Process Design Manual for Sulfide Control i Sanitary Sewerage Systems. Technology Transfe Office, U.S. Environmental Protection Agency, 1974.
13. R.D. Pomeroy and J.D. Parkhurst. The Forecasting of Sulfide Build-Up Rates in Sewers. Progress in Water Technology, Vol. 9, 1977.

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For Want of Air, a Drainage System Was Nearly Lost

CARL F. CRUMPTON, GLEN M. KOONTZ, and BARBARA J. SMITH

ABSTRACT

The omission of entrained air from a concrete pipe end section in 1972 set up a chain of events that could have been much more destructive. Freezing and thawing, which were aided and abetted by salty meltwater from de-icing salts running over the exposed invert of the end section, caused the pipe to scale. By the end of 10 winters the scaling had worked completely through the pipe invert, allowing runoff water to erode beneath the end section and the adjacent concrete ditch liner. The end section and a large portion of the ditch liner were lost. Minor slides and soil slumping at the toe of the fill began. The damaged end section and portions of the ditch liner were removed and replaced in 1983. Had corrective action not been taken, a much larger portion of the drainage system and the fill could have been lost. To paraphrase Ben Franklin in Poor Richard's Almanac of 1758: For want of air, an invert was lost; for want of an invert, an end section was lost; for want of an end section, a ditch liner was lost, being undercut and destroyed by uncontrolled runoff, all for want of care about entrained air.

Kansas published its pipe culvert study results i 1970, 1971, and 1972 (1-3). Therefore, for thi symposium, the authors chose to follow a sequence o events in one 1972 installation to illustrate wha can happen when one little detail is overlooked o ignored.

This brief account is related to an omission of a extremely cheap substance--entrained air--from co crete. The entrained air was something that coul have been had for almost nothing (4). Yet its omission did not violate any applicable Kansas Department of Transportation (KsDOT), AASHTO, or AS