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CP Info

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SIGNIFICANCE OF CRACKS IN CONCRETE PIPE

Precast reinforced concrete pipe is manufactured to specified strengths in accordance with American Society for Testing and Materials, ASTM, standards. Since numerous pipe sizes are available, specified strengths are classified as *D*-loads. The *D*-load concept provides strength classification of pipe independent of pipe diameter or horizontal span. For circular, elliptical and arch pipe, the *D*-load equals the three-edge bearing test strength divided by the inside horizontal span.

ASTM standards on reinforced concrete pipe are manufacturing and purchase specifications and include requirements for testing and inspection prior to delivery, but do not cover construction or acceptance of installations. Installation requirements are included in the project specifications and can vary widely in scope and criteria. Some project specifications include crack criteria as a performance limit for buried concrete pipe. This CP Info discusses cracks in precast reinforced concrete pipe, the significance of cracks with respect to durability and structural integrity, and the phenomena of autogeneous healing.

DEVELOPMENT OF 0.01-INCH CRACK CRITERION

Precast reinforced concrete pipe, unlike cast-in-place concrete structures, is accepted by the purchaser before delivery and instal-

lation. The acceptance test most widely used is the external load crushing strength test using the three-edge bearing method of load application.

The initial quality control criteria was the first visible crack in the pipe wall. Professor W. J. Schlick of Iowa State University observed that the visual acuity of the observer was an important factor in determining when the first crack occurred.¹ He conceived the idea of a more definite and measurable criteria and proposed using a 0.01-inch leaf feeler gauge. This 0.01-inch crack criteria was submitted to ASTM and adopted in the early 1930's.

As initially developed, the criteria of the 0.01-inch crack was intended only as a quality control measure and was never intended to be used as a criteria of field performance. Over the years, however, some engineers have mistakenly applied it as a performance limit for buried concrete pipe. Professor M. G. Spangler of Iowa State University has stated for many years that this is an incorrect application,² and, in 1977, proposed a cautionary note to ASTM which was approved and published in ASTM standards for concrete pipe as follows:

NOTE: As used in this specification, the 0.01-inch crack is a test criterion for pipe tested in three-edge bearing test and is not intended as an indication of distress or failed pipe under installed conditions.

Current research is directed to development of soil-structure systems for the analysis and design of buried concrete pipe. Proposed design methods follow the same procedures employed in designing any reinforced concrete structure. These procedures include a check for crack control after the structure is designed to resist anticipated loads. Such methods will eliminate the 0.01-inch crack as a design criterion for buried concrete pipe; however, its use as a quality control measure would still be appropriate.

RELATIONSHIP OF 0.01-INCH CRACK TO CONCRETE COVER

Cracks normally do not completely penetrate the wall of a reinforced concrete pipe. Ordinarily, when cracks do occur, penetration is to the depth of the reinforcement, and maximum penetration is to the neutral axis of the pipe wall. The geometric shape of cracks is triangular, with the maximum width at the surface and tapering to zero. Thus, the depth of penetration of any given width of surface crack is controlled by and related to the thickness of the concrete cover over the reinforcement. The 0.01-inch crack criterion has been historically related to the standard one-inch cover provided over the reinforcement in concrete pipe.

A minimum concrete cover over the reinforcement is specified in

ASTM standards. These minimum covers represent a balance between structural efficiency and durability. Assuming both structural adequacy and proper crack control, greater durability is provided against a variety of aggressive conditions by a thicker concrete cover. A modification of cover to increase durability, however, requires re-evaluation of the structural design of the pipe, and possible use of non-standard forms which could lead to significant increases in pipe costs.

ASTM standards for concrete pipe do not include the relationship between the 0.01-inch crack and the designated one-inch concrete cover over the reinforcement. When additional concrete cover over the reinforcement is proposed, the designer is faced with the question as to what crack width is acceptable at the required test loads.

If the cover over the reinforcement is other than one-inch, it is logical that formation of a 0.01-inch crack would not occur at the required supporting strength of the pipe in the test condition. In this case, the *D*-load supporting strength of the pipe in the test condition should be indicated by a crack width other than 0.01-inch. Width of crack for any concrete cover can be determined by a mathematical analysis based on the straight line theory of flexural design of reinforced concrete. Geometric relationships for this analysis are presented in *Figure 1* and result in the following equation:

$$\frac{q}{(d-x) + m/2 + c_1} = \frac{r}{(d-x) + m/2 + c_1 + c_2} \quad (1)$$

Where:

- q = crack width at standard specification cover, inches
- r = allowable crack width for additional cover, inches

d = distance from outside surface of pipe to reinforcement, inches

x = distance from outside surface of pipe to neutral axis, inches

m = reinforcement diameter, inches

c₁ = standard specification cover over inner cage reinforcement, inches

c₂ = additional cover inner cage reinforcement, inches

The distance from the outside surface of the pipe to the reinforcement can also be stated as:

$$d = t - m/2 - c_1 - c_2 \quad (2)$$

Where:

t = wall thickness, inches

Combining *Equations 1* and *2* results in the allowable crack width for additional cover:

$$r = q \left[\frac{t-x}{t-x-c_2} \right] \quad (3)$$

Solution of *Equation 3* is not very complex. Certain assumptions can be made regarding some of the parameters, however, which can further simplify solutions. For steel yield strengths between 40,000 psi and 65,000 psi, x can be calculated accurately and will usually vary between 0.3d and 0.5d. The difference in range of the x value affects the calculation of r by 0.001 inch. Therefore, x can be assumed to be the average,

0.4d, without appreciable error in calculation of the crack width. Because of the relative magnitudes between the wall thickness and reinforcement diameter, the term m/2 can be considered negligible.

There are several methods of obtaining additional cover over the inner reinforcement cage. One solution for ASTM C76 specified pipe would be to use B wall forms with the cage spacing and reinforcement requirements for an A wall pipe. A 36-inch diameter concrete pipe with a B wall would be 4 inches thick and with an A wall would be 3 inches thick, which, in effect, allows one-inch additional cover over the inner reinforcement cage.

Another solution would be to move the inner reinforcement cage inward the required distance to obtain the additional cover desired. The designer is cautioned that obtaining additional concrete cover by simply reducing the moment arm, d, will require an increase in reinforcement area to maintain the respective *D*-load strength. There are also several design methods currently in use for determining the three-edge bearing strength of concrete pipe. When concrete pipe with additional cover is to be specified, local concrete pipe manufacturers should be consulted to determine manufacturing and design feasibility.

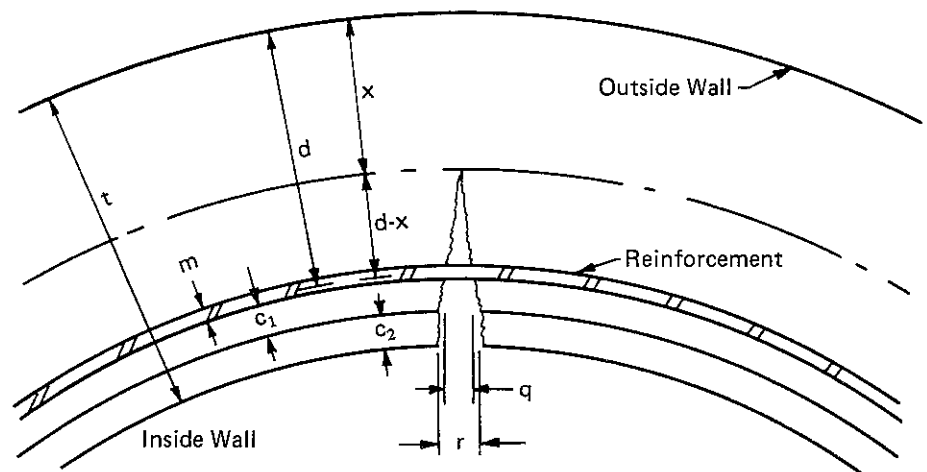


Figure 1. Geometric relationships of cracks.

Application and significance of relationships affecting crack width are best illustrated by an example:

Given:

One-inch additional cover over the inner reinforcement cage is required for a project involving 48-inch diameter ASTM C76 pipe. The pipe has a specified 0.01-inch crack strength of $1000D$.

Find:

The crack width to be specified with the additional cover.

Solution:

B wall forms will be used with A wall reinforcement to provide the one-inch additional cover over the inner reinforcement cage. The B wall is 5 inches thick and the A wall is 4 inches thick. Welded wire fabric style $2 \times 8 - W3.5 \times W1.5$ will be used to provide the required A wall inner cage reinforcement area of 0.21 square inches per linear foot of pipe. The W3.5 wire is the circumferential reinforcement and has a nominal diameter of 0.21 inches. Therefore, solving Equation 2:

$$d = t - m/2 - c_1 - c_2 = 5 - (0.21/2) - 1 - 1 = 2.90 \text{ inches}$$

The distance, x , from the outside surface of the pipe to the neutral axis will be assumed as $0.4d$. Therefore:

$$x = 0.4d = 0.4 \times 2.90 = 1.16 \text{ inches}$$

Substituting the values in Equation 3 and solving for the allowable crack width:

$$r = q \left[\frac{t-x}{t-x-c_2} \right] = 0.01 \left[\frac{5-1.16}{5-1.16-1} \right] = 0.014 \text{ inches}$$

Answer:

A crack width of 0.014 inches would be specified in lieu of 0.01-inch when testing the pipe in three-edge bearing to the 0.01-inch crack D -load.

STRUCTURAL CONSIDERATIONS

The principles of concrete pipe design are basically the same as for reinforced concrete structural building members. Reinforced concrete is a composite structure and specifically designed to utilize the best features of both the concrete and the reinforcement. The concrete is designed for the compressive force and the reinforcement for the tensile force. Unless the concrete cracks, the reinforcement is not being utilized to its design capacity. If the concrete on the tension side of a member is uncracked, the concrete is carrying most of the tensile force and the reinforcement is stressed to only about 2000 pounds per square inch. After the occurrence of micro-cracks, tensile forces are transferred to the reinforcement. As more tensile forces are carried by the reinforcement, hairline cracks become visible, but these occur at loads well below the design loading of the reinforced concrete member. Hairline cracks are not an indication of danger, dis-

stress or loss of structural integrity. If ultimate strength is exceeded, the concrete pipe will deflect, mobilizing passive soil pressures and therefore continue to perform structurally as a four-hinged arch.

As discussed by J. G. Hendrickson, Jr.,⁸ some engineers object to cracking in reinforced concrete pipe based on the erroneous belief that a crack is an indication of loss of structural integrity. Generally, reinforced concrete pipe is designed to withstand a specified load at 0.01-inch crack in the three-edge bearing test.

Reinforced concrete pipe specifications require that ultimate strength in the three-edge bearing test be 1.25 to 1.50 times the design 0.01-inch crack strength, depending on pipe strength. If a reinforced concrete pipe develops a 0.01-inch crack after installation, it has not failed nor is it in danger of imminent collapse. The crack is an indication that the pipe and reinforcement are performing as intended.

The structural considerations of cracks in reinforced concrete pipe

were studied in Texas⁴ and California.⁵ Some conclusions of the Texas study were:

- The load-strain and load-deflection curves indicate that the reinforcing steel becomes structurally effective **only after the concrete cracks** and thus enables the pipe to sustain greater loads than those which produce hairline cracks.
- A reinforced concrete pipe will continue to have structural integrity when loaded beyond the loading required to produce a 0.01-inch crack.

The California report concluded:

- The presence of a 0.01-inch crack in reinforced concrete pipe in the installed condition does not constitute failure of the pipe. In fact, cracks substantially larger than 0.01-inch did not significantly affect the structural integrity of the pipe.
- Even in those areas where cracks as wide as 0.20-inch have occurred, structural integrity has been maintained.

DURABILITY CONSIDERATIONS

Another concern relative to cracking is based on the belief that the crack may provide a path for moisture to reach the reinforcement and induce corrosion. Such durability concerns were also investigated in the Texas and California studies. Both studies indicated corrosion was not a problem. A main conclusion of the Texas report was:

- There is little or no probability of deterioration of either the reinforcing steel or of the concrete surfaces exposed by a hairline crack, even when sulfuric acid is present. (Editor's note: *As a part of the investigation specimens were immersed in laboratory solutions of sulfuric acid.*)

In the California report, similar conclusions were:

- Corrosion of the steel reinforcing was not observed at crack widths up to 0.10-inch where slabbing of the pipe wall had not occurred.
- Based on the observed absence of corrosion in those areas where slabbing did not occur, the life expectancy of the pipe with cracks to 0.10-inch was not affected.
- In those areas where slabbing has occurred and epoxy grouting was not performed, observed corrosion rate of reinforcing steel would lead to a life expectancy of several hundred years.

Spangler expressed his opinion on the subject of crack width relative to durability, . . . "cracks up to approximately 1/16-inch in width will not permit corrosion except under the most adverse conditions."⁶ Investigations by the California Department of Transportation (Caltrans) have resulted in the following being accepted in 1979

as revisions to the State's Construction Manual, Sections 6-65:

Sections of pipe which have been tested and have met requirements of the three-edge bearing test may be used in the work. (Note: The 0.01-inch crack referred to in the three-edge bearing test is not a requirement for acceptability of a pipe.) Small numbers of hairline cracks and minor chips are not so serious as to require rejecting pipe. Pipe with cracks through the wall, exposed reinforcing steel, or damaged bells, spigots or joint grooves should not be accepted.

For culverts that have been installed and the backfill completed, cracks should not exceed 0.01-inch in width in severely corrosive environments (pH of 6.0 or less, water containing vegetal or animal wastes, sea water, or other water with high concentration of chlorides). Conversely for culverts installed in a noncorrosive environment (pH greater than 6, low concentrations of salt, animal or vegetal wastes), cracks of up to 0.10-inch in width in the installed pipe are acceptable if they are not excessive in number. Such cracks are not acceptable if they result from careless handling or improper installation.

Specifying a limitation of surface crack width of 0.01 inches in concrete pipe, even in aggressive exposure conditions, is conservative. From a durability standpoint, surface cracks up to 0.02 inches in width which do not completely penetrate the pipe wall, and with a minimum of one-inch cover over the reinforcement, should be acceptable in an aggressive environment. Pipe with such cracks will have the same durability performance characteristics as an uncracked pipe.

AUTOGENOUS HEALING

Autogenous healing is the ability of concrete to repair itself or heal cracks in the presence of moisture. Reinforced concrete pipe, unlike reinforced concrete beams and slabs, are buried in the ground where moisture conditions are such that cracks may be sealed by autogenous healing.

In 1956 Lauer and Slate⁷ presented an hypothesis for the autogenous healing phenomenon. The hypothesis states that in the presence of moisture, concrete exudes calcium hydroxide which upon exposure to the atmosphere is converted to calcium carbonate which seals cracks. In the actual chemical process, insoluble calcium carbonate crystals are formed when the carbon dioxide in the surrounding soil, air and water carbonates the free calcium oxide in the cement and the calcium hydroxide liberated by the hydration of the tricalcium silicate of the cement. These calcium carbonate crystals precipitate out on the crack surface and eventually fill and seal the crack.

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