Significance of Cracking in Reinforced Concrete Pipe

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• MANY engineers still regard with concern the formation of cracks in reinforced concrete pipe. Therefore, it may be worthwhile to review past experience with the acceptable limits of cracking in such structures. Objections to cracking are generally based on two points:

1. The crack may provide a point at which moisture can induce corrosion of the reinforcing steel; and
2. The crack is an indication of overstressed reinforcement with possible danger to the stability of the structure.

Cracking of reinforced concrete structures has always been accepted as a design assumption except possibly for certain hydraulic structures. Stresses have been restricted to a low level so that generally cracking is nearly invisible to the normal viewer. In reinforced concrete pipe, however, instead of designing to a specified stress level in the reinforcing steel, the general practice is to design to meet a specified cracking load. In the early days of the concrete pipe industry, the first visible crack was an accepted criterion for pipe performance. However, the occurrence of such a crack often varied with the zeal, eyesight, and certain other qualities of the observer. In the interests of consistency, a crack of a specified width was considered more suitable. Eventually the 0.01-in. crack as measured by a feeler gage of a specified shape became the accepted criterion for pipe performance both in a test and in the field.

There has been considerable use of the 0.01-in. crack as an acceptable crack width for reinforced concrete in service. The Washington State Highway Department exposed a series of cracked reinforced concrete blocks for 10 years. Even for crack widths as high as 0.02 in., dangerous corrosion of the reinforcing steel did not occur.

In 1950 Amerikian advocated 0.01 in. as the maximum width that should not be considered deleterious in exposed structures.

Practice abroad, particularly — Denmark and Sweden, is to use higher steel stresses but to control crack widths to about 0.01 in. except in structures exposed to chemical attack.

In the United States, the occurrence of the 0.01 in. crack in concrete pipe structures has been accepted for 30 years or more. As far as is known to the author, there has never been a case of deleterious corrosion of the reinforcement due to the existence of cracks of the order of 0.01 in. in width. Generally such cracks, in a moist atmosphere, heal autogenously. This has also been observed in countless sanitary and storm sewers, as well as culverts.

In consideration of these factors, the American Concrete Pipe Association has recommended that the 0.01-in. crack be an accepted width in concrete pipe storm sewers, sanitary sewers and culverts which do not normally flow under pressure. Wider cracks probably should be sealed although many reinforced concrete pipe lines have served perfectly for years despite the presence of cracks greater than 0.01 in.

The relationship between crack widths and stress in the reinforcing steel in reinforced concrete pipe is extremely complicated. It probably is not possible to spell out a relationship that will hold for all possible sizes of pipe and types of pipe loading. Factors which affect the crack width in reinforced concrete structures are (a) stress in the reinforcing steel; (b) tensile and bond strength of the concrete; (c) cover over the reinforcing steel relative to the effective depth of the beam or slab; (d) amount and size of steel reinforcement used; and (e) ratio of the modulus of elasticity of the steel to the modulus of elasticity of the concrete.

Considerable study has been given to the effect of these variables on cracking in flexural members. Formulas have been developed which give computed values of crack widths in good agreement with observed values. These studies have been concerned almost entirely with deformed bars meeting the requirements of ASTM Specification A305. Deformed reinforcing bars are sometimes used in the manufacture of concrete pipe, but welded wire fabric or plain hot-rolled bars are much more widely used. Where smooth bars are used, either in the form of mesh or as a built-up cage, the bond between the steel and the concrete is developed at the welded cross wires. As a result, the crack spacing often is very close to the cross-wire spacing. Consequently, the crack width is proportional to the stress in the steel over a length equal to the cross-wire spacing. Cross-wire spacing in welded wire fabric is commonly 8 or 12 in., but may occasionally be 6 in. In built-up reinforcing cages, the spacing of the cross wires may be much greater.

In concrete pipe requiring heavy reinforcing, multiple cages or doubled-up cages are often used. Two or more layers of mesh may be placed so as to stagger the cross wires. This considerably reduces the crack spacing and proportionally reduces the crack width from that occurring in a single cage under the same stress.

Requirements for high-strength pipe in recent years have resulted in the development of special reinforcement systems. These have been built with shear reinforcement that has tended to decrease the spacing of cracks, with a consequent decrease in crack width. In some cases, the ultimate strength of the pipe has been reached without the formation of a crack as wide as 0.01 in.

The theoretical steel stresses which develop in concrete pipe at acceptable cracking loads (0.01-in. crack) vary widely with pipe diameter. Generally, these stresses are much higher than conventional steel stresses permitted in reinforced concrete beams and slabs. Theoretical steel stresses are higher in small pipe. In part this is due to the variation in the steel stress around the circumference of the pipe, particularly under the three-edge bearing test loading. An additional factor is also the redistribution of moments that must take place around the circumference of the pipe as cracks develop in the pipe wall.

A careful study of test data on a large number of 48-, 60-, 72-, and 84-in. pipe has indicated that theoretical steel stresses are apparently in the range of 40,000 psi at the formation of the 0.01-in. crack. All of these pipes had conventional reinforcement. Tests by a number of companies have shown, however, that by careful attention to crack control, the 0.01 in. crack test load can be increased 50 percent without increasing the steel area and would therefore occur at an apparent theoretical stress of 60,000 psi. Crack control can be achieved by the use of shear reinforcement, closer spacing of longitudinals or cross wires, deformed bars, or combinations of these.

SUMMARY

The formation of the 0.01-in. crack in the field is acceptable in reinforced concrete pipe. It is not a point at which corrosion of the reinforcing steel begins. It often closes through autogenous healing.

Cracks wider than 0.01 in. should probably be sealed to insure protection of the reinforcing steel.

Cracks wider than 0.01 in. and not accompanied by spalling of the concrete cover over the steel are not necessarily an indication of an overloaded pipe. These cracks should be considered in the light of the following factors:

1. A single wide crack at the top and bottom of one or two sections of pipe may indicate nothing more than poor bond. This may be due to the accidental presence of grease, loose scale or other undesirable material on the steel when the pipe was made.
2. Pipe reinforced with large diameter bars may develop cracks at lower loads than pipe reinforced with an equal area of steel made up with smaller bars. Stresses in the two pipes are the same.
3. Pipe reinforced with cages having a few widely spaced longitudinal cross wires may develop cracks at lower loads than pipe reinforced with cages having numerous closely spaced longitudinal cross wires. The stresses in the two pipe are the same.
4. Occasionally pipe is manufactured with an extra inch of concrete cover over the reinforcing steel. Slightly wider surface cracks may develop at lower loads than in standard pipe.
5. A large number of closely-spaced cracks exceeding the 0.01-in. width, particularly in pipe reinforced for crack control, usually indicates an excessive load. However, if no spalling of the concrete over the steel has occurred, the load should not be cause for concern. Probably the pipe should be checked to make sure that no further widening of the cracks is occurring and the cracks eventually should be sealed.

It is neither practical nor economical to design reinforced concrete pipe to specified theoretical stresses. Using a specified crack width at a specified test load as a basis of acceptance is economical and practical; if properly carried out a check on the actual strength and quality of the pipe is provided.

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