CRACKING IN STEEL REINFORCED CONCRETE PIPE

FACT SHEET

Concrete Pipe Association of Australasia

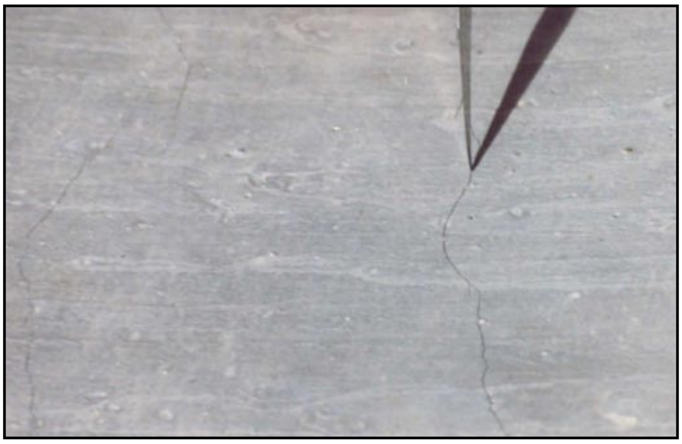
THE FACTS ABOUT CRACKING IN STEEL REINFORCED CONCRETE PIPES

BACKGROUND

Steel reinforced concrete flexural members are typically designed on the basis of cracking in the concrete tensile zone, enabling the reinforcing steel to carry the tensile stress. With steel reinforced concrete pipe, flexural stresses are developed at the top and bottom inside surfaces and on the outside surface at the sides as a result of external vertical earth loads. In the load test described in the concrete pipe Standard AS 4058, the cracking characteristic is used as a criterion for non-destructive quality control testing. Pipes are designed to withstand a specified proof load without developing a crack wider than a specified figure (most commonly 0.15 mm crack width for 10 mm minimum concrete cover to steel).

The AS 4058 test at proof load adopts procedures from previous Australian Standards for concrete pipe, which in turn follow American (ASTM) practice developed in the 1930s for a limiting crack width of 0.01 inch (0.25 mm) with 1 inch (25 mm) of concrete cover. This particular crack width was arbitrarily proposed by Professor W J Schlick of Iowa State University "because a leaf gauge of that dimension was readily available" (Ref. 1).

The design crack width of 0.15 mm in AS 4058 is set for the purpose of industry standardisation, and while experience has shown that cracks up to this width have no significant effect on performance, the design width does not necessarily represent a limit from the aspect of either structural adequacy or protection of the steel reinforcement. However where cracking occurs to an extent which has not been envisaged in the design, it becomes necessary to consider whether repairs to cracks are required and, if so, what form they should take. Such considerations can often be complex, depending on the type of pipeline application (whether drainage, sewerage or pressure) and the consequence on serviceability of the pipeline as opposed to the mere visible presence of the cracks which in themselves may be not harmful. For example, any crack passing through the pipe wall will be a concern with pressure or sewer pipe, on account of leakage, but not necessarily with a drainage line. In a moist environment fine



Cracks in concrete pipe under external load. Feeler gauge is used to test crack width

cracks will heal (Ref. 2), and where the pipeline must eventually be watertight it may be desirable to allow a period for this to take place, rather than embark immediately on replacement or repairs.

Apart from hydraulic considerations the basis for concern can generally be divided into two categories — structural overload due to excessive loads acting on the pipe from the surrounding soil, and the possibility of gradual strength loss due to corrosion of the reinforcement.

STRUCTURAL ASSESSMENT

In a cracked pipe, the steel reinforcement confers flexibility on the pipe and allows a redistribution of stress both inside the pipe wall and to the surrounding earth.

The following points serve as a guide for structural assessment.

1. Multiple longitudinal cracks, particularly in the top quarter of the pipe, indicate effective transfer of stress from the concrete to the steel and so are of less concern than a single, wide longitudinal crack.

2. Visible longitudinal cracking will be more severe at the top and invert inside the pipe than on the outside at the haunches. The appearance inside gives the worst indication of the condition of pipe cracking.
3. The most serious condition likely to be

encountered is indicated by wide longitudinal cracks at the invert, perhaps with a step at the cracked concrete surface of the pipe resulting from mid-wall delamination or shear failure. This condition is due to hard and/or irregular bedding underneath the pipe.

4. Circumferential cracks can occur from loads imposed during installation, uneven bedding, or connection of the pipe to another structure followed by relative movement due to settlement. Unless closely spaced, circumferential cracks will have little if any effect on the ability of the pipe to carry external loads.

In a typical installation, soil loads will continue to consolidate and stabilise over about three months. If unexpected cracking is discovered during this time, the correct decision will often be to wait until the installation has stabilised before making a final assessment. In some areas the ground/soil condition is altered by seasonal changes affecting the water table level and a longer period of stabilisation (e.g. a year) may have to be anticipated. Obviously commissioning of the pipeline could not be deferred for this length of time, and a prediction of performance may need to be made at an early stage when the unexpected cracking has been recorded.

Load testing of Steel Reinforced Concrete Pipe

CORROSION

Effect of crack width

A steel reinforcing bar or wire surrounded by concrete is normally protected from corrosion by the alkalinity of the concrete. In an alkaline environment, a very thin, coherent layer of oxide which prevents corrosion is formed on the surface of the steel. In this state the steel is described as being passivated. Only if this passivity is broken down will corrosion commence. Two states by which the passivity can be destroyed are (1) by carbonation of the concrete surrounding the bar, which reduces the alkalinity, or (2) by ingress of chloride ions, which appear to break down the passive layer at the steel surface. Carbonation is the result of the reaction between the hardened cement paste and carbon dioxide in the atmosphere or pipeline environment. Chloride ions are present in sea water and in saline ground water.

The existence of a surface crack in the concrete pipe permits easier access of either chloride or carbon dioxide into the concrete, which may lead to depassivation of a small area of bar in the region of the crack. In the electrolytic process necessary for corrosion, the depassivated area becomes the anode, while portions of the bar still protected by sound alkaline concrete become the cathode. At the anode, metal ions are released. At the cathode, oxygen combines with water to form hydroxyl ions which flow through the electrolyte to the anode, where they combine with the metal ions to form iron hydroxide. As a secondary reaction, this hydroxide combines with further oxygen to form rust.

The rate at which corrosion can progress depends on the electrical resistance of the path external to the bar between anode and cathode. This path passes through boundary layers at the steel surface, and the surrounding concrete. The rate also depends on availability of oxygen at the cathode, which is situated in sound concrete — see Figs 1 and 2 (below), reproduced from Ref. 3. Thus the role of the crack is to allow the process to be initiated by local loss of passivity but the rate of corrosion depends on the properties of the sound concrete. Results of corrosion tests shown in Fig. 3 (from Ref. 4) confirm that, within the range shown, the crack width has very little effect.

Where the sound concrete is highly impermeable as it is in spun concrete pipes, diffusion of oxygen to the cathode is so slow that the corrosion rate is negligible.

On this basis, flexural cracks up to 0.5 mm wide in pipes having correctly specified cover are not considered to be a threat to the long term load bearing capability of the pipe.

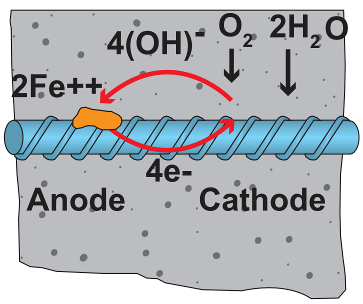
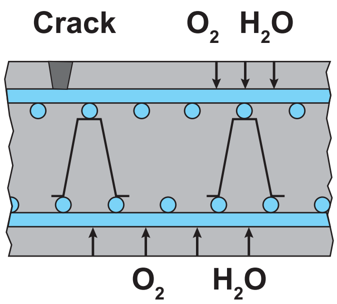


Figure 1
Simplified model of corrosion process



Rate of corrosion = f(O_2,H_2O at Cathode)
(Resistivity of Concrete)(Size of Cathode)

Figure 2
Factors affecting the rate of corrosion

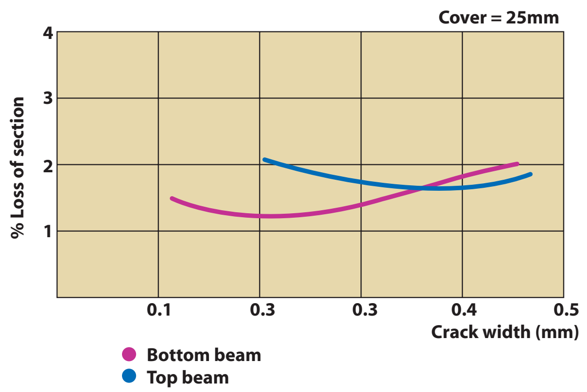


Figure 3
Reinforced concrete in a marine environment - Loss of section of reinforcing bar

Corrosion effects

The rust formed from corrosion of reinforcement occupies a larger volume than the original steel from which it is formed. In some circumstances this increase in material volume can lead to the progressive damage of the surrounding concrete through spalling. The circumstances favourable to this process are:

Large bar diameter relative to cover thickness (e.g. the cover is less than the bar diameter).

Weak, permeable cover concrete, which allows corrosion to occur in places even where the reinforcement is beneath a substantial layer of concrete, and which can exert little pressure on the corrosion products to stifle the corrosion process.

In spun concrete pipe, the conditions are unfavourable to this process. Reinforcement consists of small diameter wire and the concrete is very strong and highly impermeable.

Concrete pipe may be found in service with steel exposed due to:

Cover removed by chemical attack (e.g. H2S).

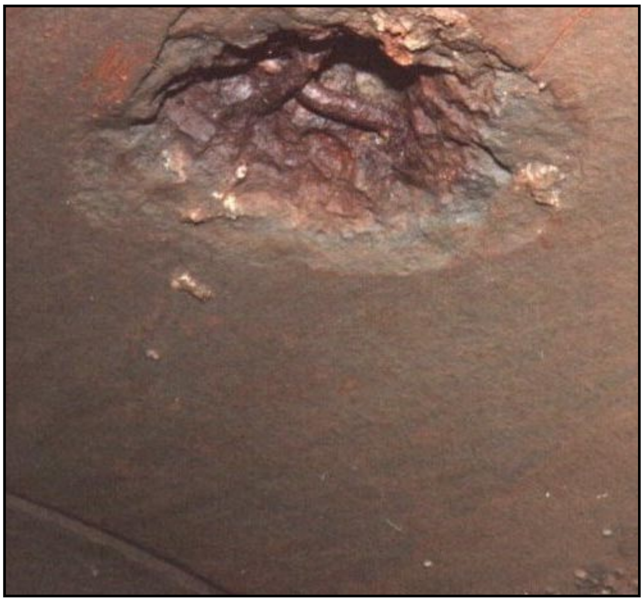
A hole broken through the pipe wall, e.g. for field connection of a branch pipe or site-made lifting hole.

Use of mild steel wire for reinforcement spacers (Ref. 5).

Where these situations have been observed (e.g. Fig. 4), surrounding concrete has not been damaged as a result of steel corrosion. This is in contrast to common observations of above-ground structures.

Thus with concrete pipe in typical conditions of service for drainage, sewerage or water reticulation, there will not be any accelerated deterioration due to disruption of cover by corroding steel, even if there are localised areas where a steel surface is exposed.

Figure 4 - Concrete pipe with exposed steel



Hen and Chicken Bay, Drummoyne, NSW. 1500 mm pipeline - age about 30 years.

Inspected as an example of concrete pipelines subject to tidal flow. Reinforcing steel is exposed at a subsidiary lifting hole knocked through the pipe wall. This situation is assessed as not-deleterious.

Altona Beach, Victoria - age 32 years.

Example from a survey of mild steel reinforcement spacers. Concrete was chipped away from the spacer, showing negligible corrosion.

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5. "Designing Permanent Pipelines", Concrete Pipe Association of Australasia, 1995.

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