Concrete stormwater drainage pipelines - acceptance using CCTV inspection

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ABSTRACT

The increasing use of CCTV inspections for acceptance of stormwater as well as sewer pipelines has highlighted a number of installation issues, including that of cracking due to construction overload.

Cracking has been "enshrined" in Australian and New Zealand Standards for concrete pipe, which, following American (ASTM) practice developed in the 1930s, use a limiting crack width for the pipe under a specified proof load as a criterion of performance in a non-destructive, quality control test. In America, and subsequently in Australia and New Zealand, the crack widths were set arbitrarily for the purpose of the test and do not represent limits either from the aspect of structural adequacy or protection of the steel reinforcement.

When design or installation requirements have not been met on a particular project, cracks wider than these empirical limits may appear inside the pipeline. It then becomes necessary to consider:

- is the cracking acceptable?
- will the life of the asset be compromised?
- are repairs required; and
- if so, what form should they take?

Such considerations depend on the pipeline application, the consequences and risk of failure and the effect on pipeline service life, not merely the visible presence of cracks which, of themselves, may not be harmful.

This paper reviews action taken to address serviceability issues with installed pipelines, together with experience and scientific evidence in relation to cracking of steel reinforced concrete. Criteria are proposed for acceptance of pipelines constructed from steel reinforced concrete pipe.

Key Words: CCTV inspection, concrete pipes, installation, cracking, standards, asset life, risk, acceptance criteria, asset management.

INTRODUCTION

The Concrete Pipe Association of Australasia (CPAA) is concerned about service life and durability of stormwater drainage assets constructed from precast concrete and addresses these issues on a broad front:

- Australian and New Zealand Standards
- Other standard specifications, drawings and documentation
- Information bulletins
- Industry training
- Quality systems
- Inspection, testing and certification.

McGuire & Cottman[1] identified the principal stakeholders in the drainage infrastructure industry – designers, developers, consultants, manufacturers & installers, together with asset owners & managers, and highlighted many of the issues which impact on the delivery of durable public infrastructure assets. The Association has

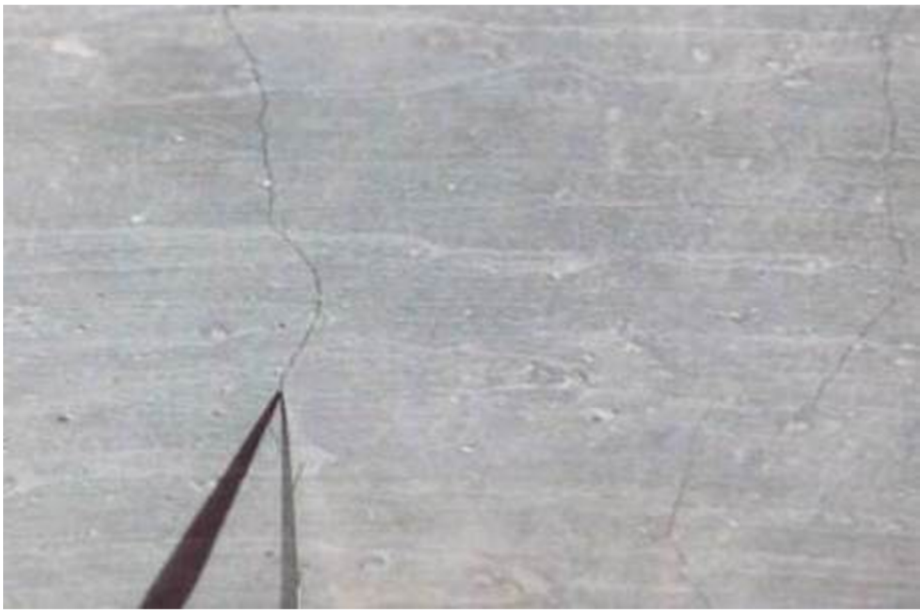
also been working closely with the Brisbane City Council (Lee, Hansen & Demartini[2]), with emphasis on the effects of construction loads. The Association released a package of initiatives in 1999 which included:

- User-friendly design software
- Simple charts to enable contractors to assess the impact of different classes of construction equipment on buried pipelines
- A "Recommended Practice" to assist engineers and technicians in inspection, evaluation and acceptance of "as constructed" stormwater infrastructure
- Industry training at all levels.

This paper reviews issues associated with CCTV inspections of installed concrete pipelines, especially cracks, and proposes acceptance criteria for application in Australia and New Zealand.

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 tests described in the Australian and New Zealand concrete pipe Standards AS 4058 and NZS 3107, the cracking characteristic is used as a criterion for non-destructive quality control testing. Pipes are designed to withstand the specified proof load without developing a crack wider than a specified figure - in New Zealand 0.125 mm, in Australia most commonly 0.15 mm for 10 mm cover to steel.

The proof load test adopts procedures from previous Australian and New Zealand 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"[3].



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

The design crack widths of 0.15 mm and 0.125 mm in Australian and New Zealand Standards are set for the purpose of industry standardisation, and while experience has shown that such cracks have no significant effect on the performance of an installed pipeline, 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 was not 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 will heal[4] , 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 the excessive loads acting on the pipe from the surrounding soil, and the possibility of gradual strength loss due to corrosion of the reinforcement.

Load testing of Steel Reinforced Concrete Pipe

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. 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 significant cracks are 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 (eg 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 unexpected cracking has been recorded.

CORROSION

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.

A crack in the concrete 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. Thus rate of corrosion depends on the properties of the sound concrete. Results of corrosion tests[6] (Fig. 3) confirm that, within the range shown, the crack width has very little effect.

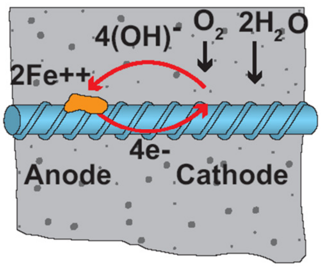


Figure 1. Simplified model of corrosion process

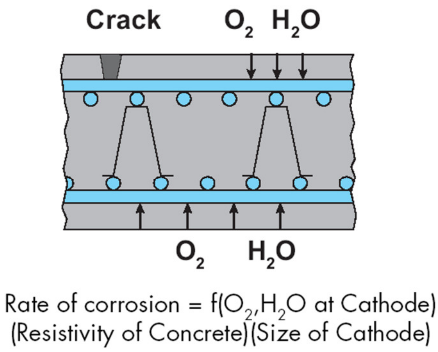


Figure 2. Factors affecting the rate of corrosion

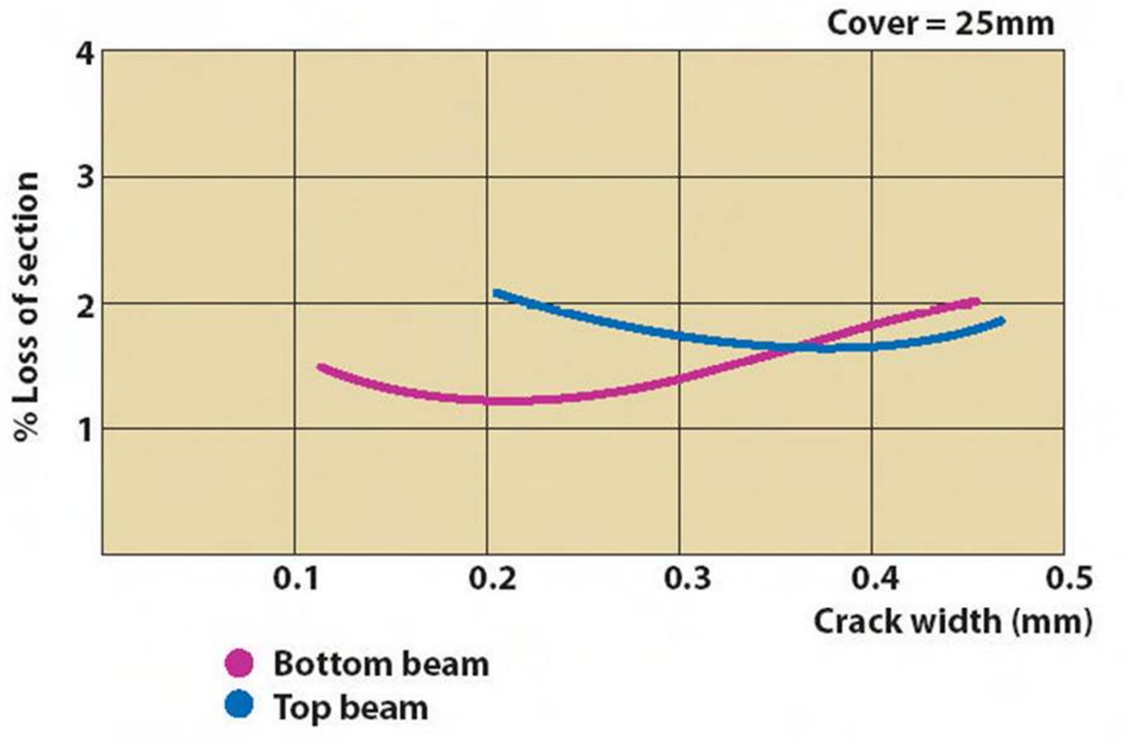


Figure 3. Reinforced concrete in a marine environment - loss of section of reinforcing bar

Where the sound concrete is highly impermeable, as in concrete pipes made to Australian and New Zealand Standards, 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.

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 progressive damage of the surrounding concrete through spalling. The circumstances favourable to this process are:

- Large bar diameter relative to cover thickness (eg 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 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:

- Use of mild steel wire for reinforcement spacers[7].
- Cover removed by chemical attack (eg H_2S).
- A hole broken through the pipe wall, eg for field connection of a branch pipe or site-made lifting hole.

Where these situations have been observed (eg Figs. 4 & 5), surrounding concrete has not been damaged as a result of steel corrosion. This is in contrast to common observations of above-ground structures.

Figure 4. Reinforcement Spacer – outside surface of pipe
Altona Beach, Victoria, age 32 years. Concrete was chipped away from the spacer, showing negligible corrosion.

Figure 5. Exposed steel inside the pipe Hen & 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.

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.

CCTV SURVEYS

The basis for structural design of concrete pipelines is set out in AS 3725, known in New Zealand as NZS/AS 3725, and actual designs are most readily carried out using the CPAA software package PipeClass. However the extent to which the installed pipeline actually conforms with the design depends on influences at work at the time the pipes are being laid – the skill level of the installers, inspection and supervision, and also pressures to have the construction completed on time and on cost. As it is not possible to supervise every detail of construction, inspection after installation is a valuable complement to other controls for ensuring that the outcome is a thoroughly serviceable asset which will serve for as long as it is required. For underground drainage pipelines, most commonly the asset will be expected to provide a service life of at least 100 years.

CCTV surveys provide visual evidence of the quality of installation. At the very least they will identify major faults where there is no numerical measurement involved – localised damage due to impacts, debris remaining in the pipeline, rubber rings so severely displaced that they are visible inside the pipeline, and of course the existence and numbers of cracks. Estimates of dimensions can be made by relating the size of a feature of interest to the known internal diameter of the pipeline (taking due account of the angle of sighting of the camera). This can apply to quite small dimensions – for example the widths of gaps at rubber ring joints.

Cracks can be described in terms of severity – whether hairline, or just having a defined width in the image, or of obviously greater width. While it would be premature to align these without qualification to numerical values of width, there is an approximate correspondence with the two representative sizes of crack width discussed in this paper – cracks narrower than 0.15 mm will appear as hairlines (if they appear at all), and cracks wider than 0.5 mm will show a defined width in the image at close range.

The CPAA proposes the table below (Table 1) for classification of defects in installed pipelines, and appropriate action to be taken in each instance.

TABLE 1. PIPELINE ASSESSMENT

Defect	Description	Magnitude	Solution
Type 1	Circumferential crack	Width <0.15 mm	Accept
	Longitudinal crack	Width <0.15 mm	Accept
Type 2	Circumferential crack	0.15 mm< Width <0.50 mm	Accept
	Longitudinal crack	Width >0.15 mm	Assess Design
Type 3	Circumferential crack	Width >0.50 mm	Assess implication of ingress
	Longitudinal crack	Width >0.50 mm	As per Type 2
Type 4	Chip or spall	Depth <0.25×cover	Accept
Type 5 or 6	Chip or Spall	Depth >0.25×cover	Assess implication Repair

CONCLUSIONS

Like other reinforced concrete structures, steel reinforced concrete pipes made to AS 4058 and NZS 3107 are designed to crack, enabling the circumferential reinforcing steel to carry the imposed tensile stress.

CCTV inspections can distinguish between hairline cracks, corresponding to widths specified for proof load testing of the pipes, and cracks wider than 0.5 mm, which may represent a corrosion risk to the steel reinforcement.

Localised exposure of steel at the concrete surface does not lead to accelerated deterioration of concrete pipes.

Circumferential cracks do not affect the loadbearing capability of the pipe.

Defects detectable by CCTV inspections have been classified and appropriate actions specified.

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