

POST INSTALLATION CRACKING OF REINFORCED CONCRETE PIPES – THE BURIED FACTS

Husham Issa Al-Saleem – Humes Pipeline Systems
Wayne Langdon - Humes Pipeline Systems

ABSTRACT

To best understand and evaluate cracking of Steel Reinforced Concrete Pipes (SRCP), engineers should review how SRCP is designed as a structural element, how serviceability and ultimate capacities are measured, and the interaction of pipe and bedding necessary to accommodate external loads. This paper will review the basis of pipe structural and installation design, installation methods and practices, and the type and sources of load on SRCP. Crack orientation is another important factor that evaluators need to understand; the paper will detail types and possible causes of each crack type

The paper will review the basic principles of pipe design, the requirements of current AS/NZS standards, and the recommendations of the pipe industry body, CPAA, and will present an evaluation tables and discussions that could be used as a guideline to evaluate the possible effect of cracks on structural integrity and durability of the pipeline and to advise when possible repairs or replacement are required.

The paper will also review the most common SRCP cracking types in NZ and the possible causes and will highlight necessary actions for both designers and installers to avoid pipe cracking in future installations. An overview of some remedial actions used, their applicability, and possible outcomes will conclude the paper presentation.

KEYWORDS

Reinforced Concrete Pipes, Cracking, CCTV Assessment, Cracking Repairs.

PRESENTERS PROFILE

Husham holds, a BSc, and MSc (Civil Eng.) from University of Baghdad – Iraq, and he is currently CPEng, IntPE, MIPENZ.

He has worked as a senior civil engineer with Humes Pipeline Systems since 2009, where he is involved in various product R & D projects, technical projects management, and sales training and technical support.

Wayne has worked for Humes Pipeline Systems in a variety of engineering roles for over 37 years. As a result he has vast experience in the concrete pipe industry in the Australasian area which includes input into the relevant concrete pipe standards.

Wayne has maintained a close interest in reinforced concrete design and in particular the design and end use of reinforced concrete pipes, and has been involved in numerous significant pipeline projects.

1 INTRODUCTION

Most Territorial Authorities in New Zealand place great emphasis on the durability of their storm water drainage infrastructure. This results in many using various post-installation inspection techniques for new pipe installations to evaluate condition. As more post installation inspection data is generated and presented to owners and engineers, their ability to evaluate the inspection documents and advise any required actions becomes critical. It is necessary to differentiate between minor acceptable defects and defects that require remediation to maintain the design service life of the pipeline. Cracking, both circumferential and longitudinal, is often identified as an area of concern.

Cracking observed in a number of installations throughout the country has highlighted areas for improvement. In particular, the existing post-installation techniques for crack evaluation in New Zealand need to be upgraded to a more precise evaluation technology. Assessors then can use the basic pipe design, construction, and operation principles to better evaluate any possible future consequences of pipe cracking, and recommend the most feasible corrective actions.

2 STEEL REINFORCED CONCRETE PIPES – STRUCTURAL CONSIDERATIONS

Steel reinforced concrete pipes (SRCP) are designed as traditional concrete elements with the following important considerations and/or variations that some players in the industry may not be fully aware of. The following sections will overview these points.

2.1 STRUCTURAL DESIGN OF SRCP

2.1.1 AS/NZS 4058:2007 PRECAST CONCRETE PIPES (PRESSURE AND NON-PRESSURE)

The above standard (Standards Australia/Standards New Zealand AS/NZS 2007a) governs the structural design requirements of SRCP in New Zealand. Unlike the “traditional” design approach where a set of prescribed loads are applied using a material standard to determine the design by calculation, the AS/NZS 4058:2007 approach is to leave the design approach open but the manufacturer must verify the design by type and routine testing (Photograph 1). The manufacturer establishes verified designs for all standard SRCP by diameter (DN) and pipe load class as per AS/NZS 4058:2007 (Table 1). Hence SRCP are supplied to a “performance” based specification rather than the more traditional “prescriptive” based specification approach.

Photograph 1: Design Verification by External Load Testing



Table 1: Test Loads for Load Classes 2 to 10 (AS/NZS 4058:2007 Table 4.2)

Pipe dia.	Proof or ultimate test load (see Note 1) kN/m											
	Load Class (see Note 2)											
	Class 2 (X)		Class 3 (Y)		Class 4 (Z)		Class 6		Class 8		Class 10	
DN	Proof	Ult.	Proof	Ult.	Proof	Ult.	Proof	Ult.	Proof	Ult.	Proof	Ult.
100	13	20	20	30	26	39	—	—	—	—	—	—
150	13	20	20	30	26	39	—	—	—	—	—	—
225	14	21	21	32	28	42	—	—	—	—	—	—
300	15	23	23	34	30	45	45	56	60	75	75	94
375	17	26	26	39	34	51	51	64	68	85	85	106
450	20	30	30	45	40	60	60	75	80	100	100	125
525	23	35	35	52	46	69	69	86	92	115	115	144
600	26	39	39	59	52	78	78	98	104	130	130	163
675	29	44	44	65	58	87	87	109	116	145	145	181
750	32	48	48	72	64	96	96	120	128	160	160	200
825	35	52	52	78	69	104	104	129	138	173	173	216
900	37	56	56	84	74	111	111	139	148	185	185	231
1050	42	63	63	95	84	126	126	158	168	210	210	263
1200	46	69	69	104	92	138	138	173	184	230	230	288
1350	50	75	75	113	100	150	150	188	200	250	250	313
1500	54	81	81	122	108	162	162	203	216	270	270	338
1650	58	87	87	131	116	174	174	218	232	290	290	363
1800	62	93	93	139	124	186	186	233	248	310	310	388
1950	66	99	99	149	132	198	198	248	264	330	330	413
2100	70	105	105	158	140	210	210	263	280	350	350	438
2400	78	117	117	176	156	234	234	293	312	390	390	488
2700	86	129	129	194	172	258	258	323	344	430	430	538
3000	94	141	141	212	188	282	282	353	376	470	470	588
3300	102	153	153	230	204	306	—	—	—	—	—	—
3600	110	165	165	248	220	330	—	—	—	—	—	—
3900	118	177	177	266	236	354	—	—	—	—	—	—
4200	126	189	189	284	252	378	—	—	—	—	—	—

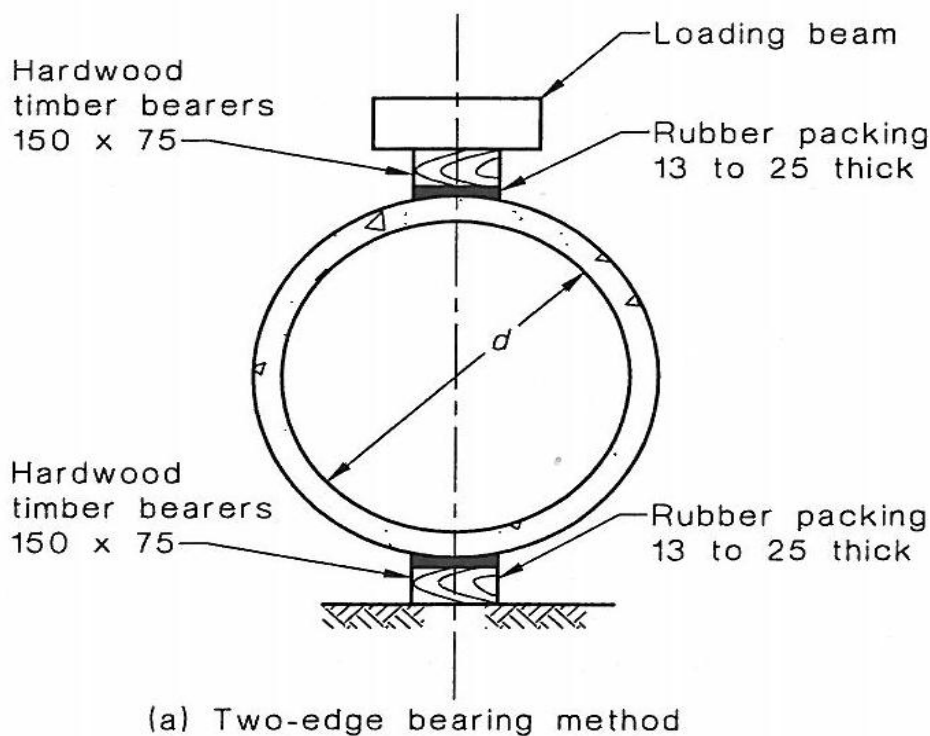
NOTES:

- 1 The test load for a particular application should be determined in accordance with AS/NZS 3725.
- 2 The corresponding traditional alphabetical classes are shown in brackets (e.g., Class 4 = Class Z).
- 3 The proof load magnitude is proportional to the class number (e.g., Class 8 = Class 2 × 4).
- 4 Proof loads for intermediate classes may be obtained by linear interpolation between the closest tabulated values rounded upward to the nearest whole number, e.g., for a DN 300 size class pipe, the proof load for Class 7 is $(45 + 60)/2 = 53$ kN/m.
- 5 For pipe below Class 6, the ultimate load value is calculated to be 1.5 times the proof load and for Class 6 and above the ultimate load value is calculated to be 1.25 times the proof load.

2.1.2 RING ACTION

SRCP pipes are designed, tested (design verification) and installed to carry imposed loads by ring action only. Figure 1 below shows the test set up for pipes made to AS/NZS 4058. Loads are applied along the entire length of barrel at the top and are supported along the entire length of the barrel at the bottom. Hence the forces developed in the pipe (bending, shear and thrust) are those associated with ring action and are carried by the structural capacity of the wall as per Figure 2a (American Concrete Pipe Association, ACPA 1980). As with all reinforced concrete elements the design assumes that the section of the wall will crack at the areas of maximum bending moment; top and bottom inside and haunches outside. The cracked section progresses from a first visible crack to the neutral axis depth at the defined proof load (when the crack width is measured), Figure 2b, to an ultimate limit state where the crack propagates further into the wall thickness, Figure 2c. At both the proof and ultimate loads the capacity of the pipe is determined by a compressive force in the area of the wall above the neutral axis, a tensile force in the steel in the cracked section of the wall and the lever arm between these two forces, Figures 2b and 2c.

Figure 1: Load Test Arrangement Generating Ring Actions around Pipe Wall



The pipe is not designed as a beam where the cross section of the pipe would be engaged to carry loads. Longitudinal steel in SRCP is nominal only and serves only to support the spiral steel which carries the ring forces.

Figure 2a: Forces Carried by "Cracked" Section of Pipe Wall

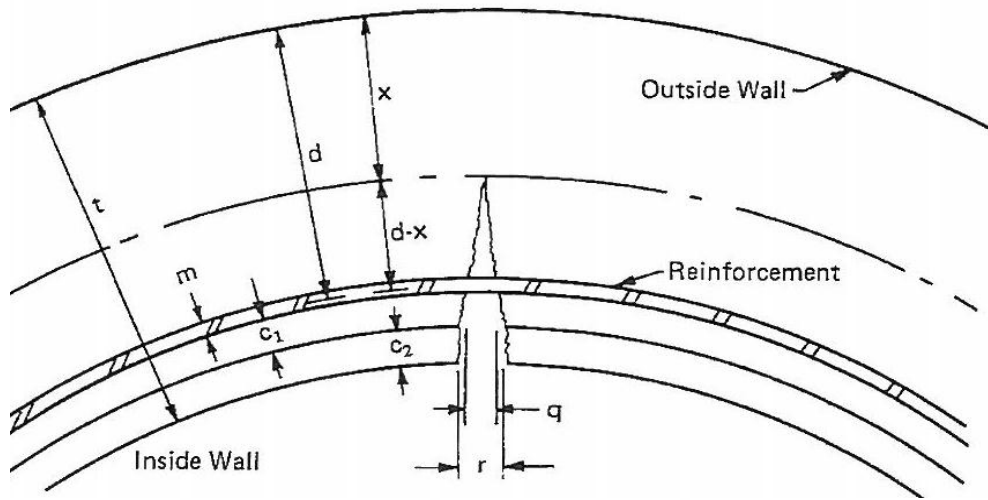


Figure 2b: Stress Block for Service Load Case (Proof Load)

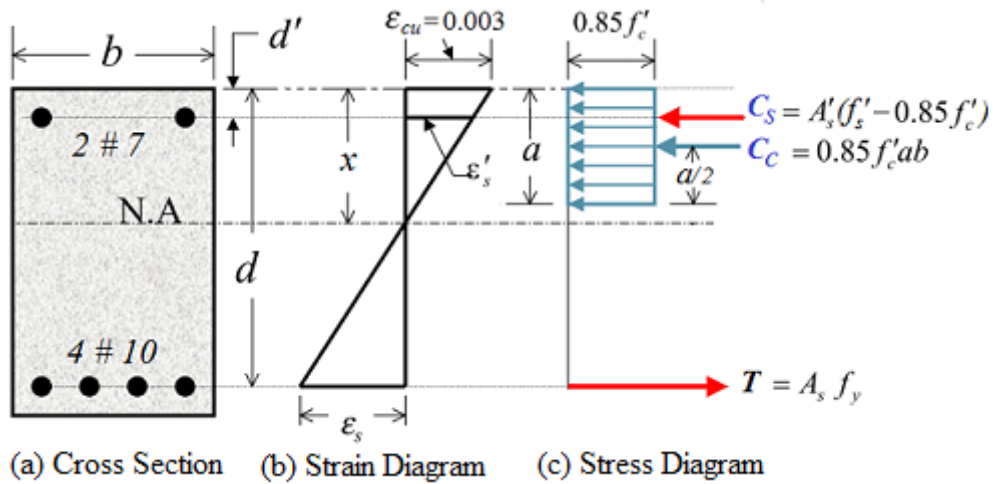
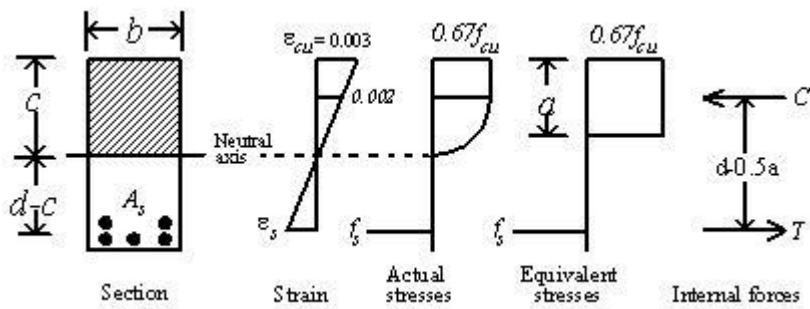


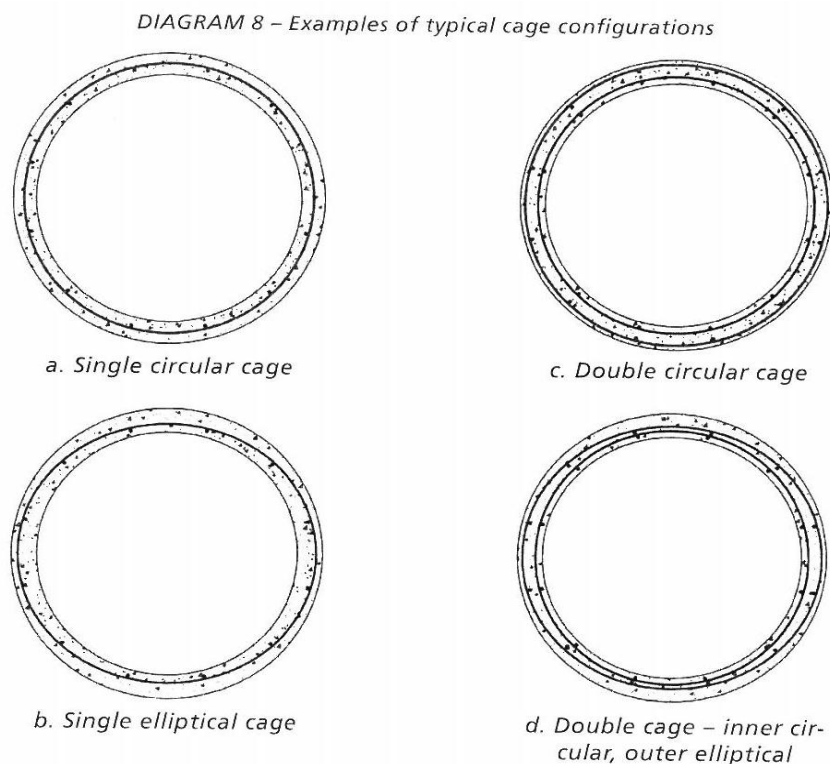
Figure 2c: Stress Block for Ultimate Load Case (Ultimate Load)



2.1.3 TYPICAL REINFORCING CONFIGURATIONS

Design for ring action in accordance with AS/NZS 4058:2007 results in typical cage patterns shown in Figure 3 (Concrete Pipe Association of Australasia, CPAA 2013b).

Figure 3: Typical Cage Configurations to Carry Ring Forces



Note the following;

- a) Single circular cages tend to be used in all pipes with DN < 600mm
- b) Oval cages are very efficient and are used in the mid DN ranges for spun pipes. Steel is placed where it is required, close to the inside top and bottom and close to the outside at the haunches
- c) Double circular cages are generally used in larger diameter pipes, for pipes designed for jacking installation, and for pipes made by vertical processes
- d) Inner circular and outer elliptical cages are typically used in larger DN pipes where there is no requirement for equal strength in all directions

2.2 IN SERVICE STRUCTURAL DESIGN OF SRCP

2.2.1 AS/NZS 3725:2007 DESIGN FOR INSTALLATION OF BURIED CONCRETE PIPES

The above standard (AS/NZS 2007b) determines the loads that are to be applied to the installed SRCP pipeline and provides a specification for various installation options. In combination with AS/NZS 4058 the pipeline designer is able to carry out an indirect design for the in service loads and the selected installation, using the bedding factors shown in Table 2.

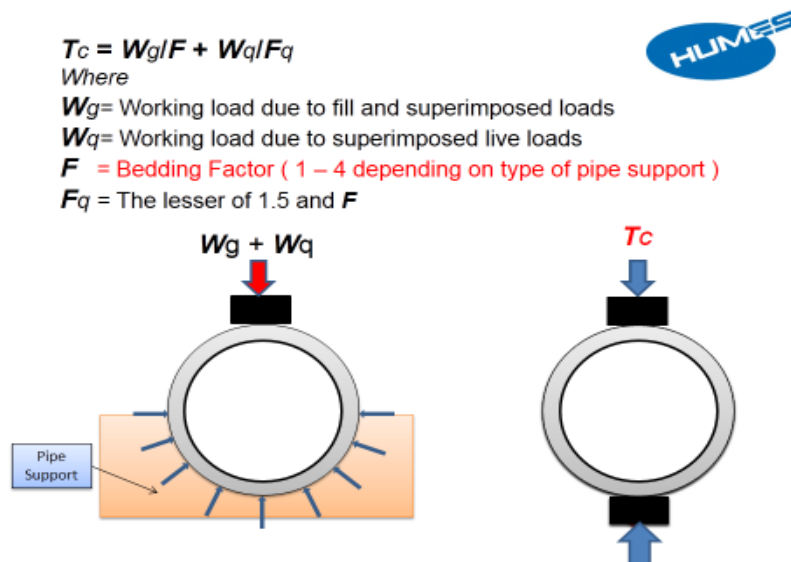
All bedding factors are based on providing full support to the barrel of the pipe thus avoiding beam actions and allowing the in service loads to be carried by ring action.

Table 2: Bedding Factors (AS/NZS 3725:2007- Table 5)

Support Type	Minimum depth, mm		Minimum zone compaction, %			Bedding factor (F)	
	Bed zone x	Haunch zone y	Bed and haunch zones ID	Side zones			
				ID	RD		
U	75					1.0	
H	H1	100 if D < 1500; or 150 if D > 1500	0.1D	50			1.5
	H2		0.3D	60			2.0
HS	HS1	100 if D < 1500; or 150 if D > 1500	0.1D	50	50	85	2.0
	HS2		0.3D	60	60	90	2.5
	HS3		0.3D	70	70	95	4.0

The bedding factors have been semi-empirically determined over the years and provide a method of turning the test loads from AS/NZS 4058 into permissible field loads that are higher than the test loads, which recognizes the degree of soil structure interaction that the selection of the bedding factor provides. This is illustrated by Figure 4;

Figure 4: Applied Field Loads and Soil Structure Interaction



A typical bedding factor used is "H2" with a numerical value of 2 (Table 2). The relationship between test loads and field loads can be expressed as follows;

$$\text{Test load (T)} > \text{Working load (W)/Bedding Factor (F)}$$

To clarify, a DN 1200 Class 2 pipe with a test load of 46 kN/m (proof) may be used for a field working load 92 kN/m with an H2 bedding factor. If the manufacturer has provided a SRCP with a test load close to the Class 2 definition and the H2 installation is designed and installed correctly there will be a reasonable correlation between cracks observed in the verification test and those observed in the field if the full service load is applied.

2.2.2 VERTICAL LOADS ON SRCP

Vertical loads can be broadly split into two categories, dead loads (long term) from earth loads and live loads (short term) from construction or end use vehicles. The extracts below (CPAA 2011a) represent examples of the typical load types.

Vertical Loads on Pipe

Dead load – backfill material

- AS/NZS 3725 recognises 3 main soil types – sand & gravel, sandy clay, and wet clay
- The heavier and more dense the material, the greater the load.



Wet clay



Sandy clay

Vertical Loads on Pipe

Live load - end use and construction load

- Typical vehicle loads
- Construction traffic and equipment

Long term and short term loads determine class of pipe!



Construction load



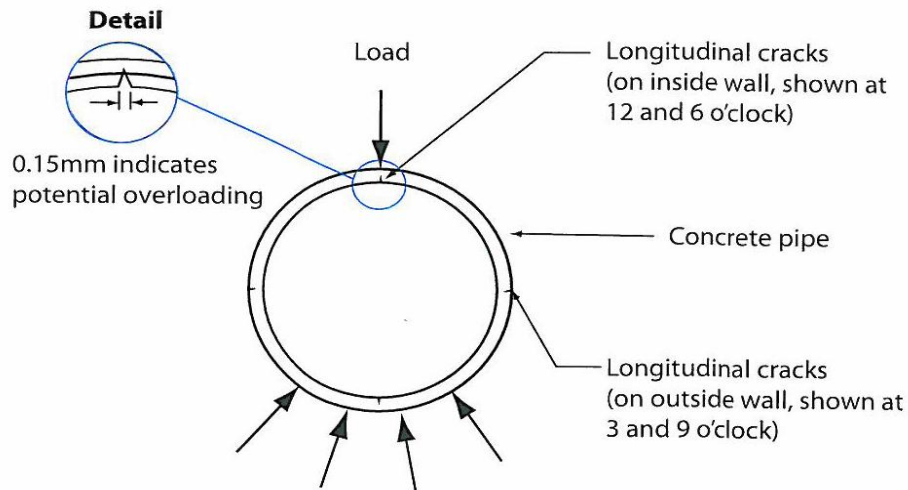
End use load

2.3 IN-SERVICE CRACKING OF SRCP

2.3.1 VERTICAL LOADS

When the pipe is subjected to a vertical load equal to, or more than the design proof load, longitudinal cracks similar to that shown in Figure 5 may occur. This type of cracking is usually evident at the top or bottom of the pipe, does not penetrate the pipe wall, and is likely to be found in concrete pipes from DN 600mm and upward.

Figure 5: Effect of overloading on SRCP



The type of load applied to the completed pipeline has an impact on what may be observed in the field with regard to pipe cracking. The following examples illustrate this point.

- If the predominant load is long term dead load, say from 5 m of earth, then it could be anticipated that a pipe with a "tight" class rating for the above load and the bedding factor provided will exhibit cracking in the field similar to that observed under load test.
- If the pipe class and bedding in example a) is maintained but the long term loads are from 1 m of earth load with the total load being made up of 20% long term and 80% short term loads, then the expectation for field crack widths will change significantly. When the total load is applied crack widths should be similar to example a). However on removal of the short term live load the expectation will be for a crack substantially less than a).

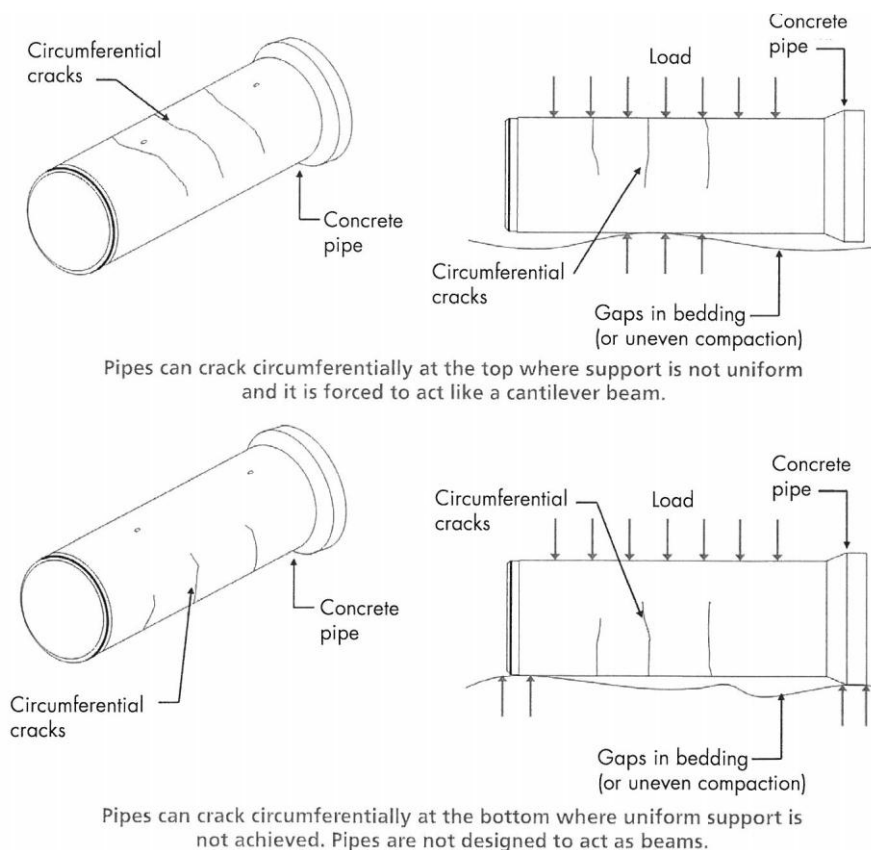
2.3.2 IMPACT OF PIPE DIAMETER

Theoretically there is no difference in the design process for a DN 300 pipe and a DN 1800 pipe. In practice there are a number of observations that need to be clarified.

- Small diameter pipes, say DN 375 and below, are often able to carry the design service load with a Class rating of 2. The manufacturer is often governed by process considerations, hence a typical pipe in this category may not crack under the proof test load. As a result a well installed small diameter pipeline may not show any longitudinal cracking and may lead to the perception that all pipes should look the same in the field. THIS IS NOT THE CASE.

- b) Small diameter pipes are also vulnerable to “broken back” beam action failures resulting from poor initial longitudinal support or loss of that support as a result of ground movements. Figure 6 illustrates how circumferential cracking can occur and it is unfortunately observed at regular intervals (CPAA 2010).

Figure 6: Circumferential Cracking of SRCP



- i. Pipes are not designed as beams
 - ii. The bedding design must provide long term support along the entire length of the barrel
- c) Construction loads are short term loads that must be designed for. Again small DN pipes are vulnerable for two reasons;
- i. Any imperfection in the bedding support will allow beam action to take place and the result is often the typical circumferential cracking that we observe
 - ii. Construction load are often applied with very low fill covers. For a DN 375 pipe this may push the Class rating demand to Class 6, say, compared to the end use load case which may be Class 3. Even with a well-supported pipe barrel the line is grossly overloaded Class 6 proof loads are 30% higher than Class 3 ultimate loads, hence excessive pipe cracking with permanent deformations (cracks remain after construction) are likely. The solution is to provide a pipe with the correct class for the construction load or specify restrictions in the construction loading until sufficient fill cover is achieved so that the class rating demand is not exceeded.

3 STEEL REINFORCED CONCRETE PIPES (SRCP) – PRE INSTALLATION INSPECTION

AS/NZS 4058:2007 clarifies allowable defects under the Workmanship and Finish clauses of the standard. Defects are classified by defect type and severity. Acceptability varies by defect type, area of pipe (barrel or joint) and pipe type (drainage or sewerage/pressure).

3.1 CRACK DEFECTS

3.1.1 TYPE 1 CRACKS

Clearly visible cracks not extending through the pipe wall, and whose width as determined by Appendix C of AS/NZS 4058:2007, at a depth of 3mm, is not greater than the values given in Table 3, except for sewage pipes and pipes intended for use in marine environments, the maximum crack width for a Type 1 defect is 0.10mm regardless of cover.

Table 3: Maximum Width of Type 1 Cracks

Cover (mm)	Maximum acceptable crack width (mm)
10	0.1
>10 - 20	0.15
>20	0.2

3.1.2 TYPE 2 CRACKS

Cracks not extending through the pipe wall, and whose width as determined by Appendix C of AS/NZS 4058:2007, at a depth of 3mm, is not greater than the appropriate test crack width values given in Table 4.

Table 4: Maximum Width of Type 2 Cracks

Cover (mm)	Maximum acceptable crack width (mm)
10	0.15
>10 - 20	0.20
>20	0.25

3.1.3 TYPE 3 CRACKS

Cracks extending through the pipe wall, or cracks whose width, as determined by Appendix C of AS/NZS 4058:2007, at a depth of 3mm is greater than the appropriate test crack width values given in Table 4 but is less than or equal to 0.5mm.

3.1.4 SURFACE CRAZE CRACKS AND HAIRLINE CRACKS

Surface craze cracks and hairline cracks (just visible to the naked eye) that do not extend through the pipe wall are not classified to be defects.

3.2 ACCEPTABILITY OF CRACK DEFECTS

Table 3.6 from AS/NZS 4058:2007 defines acceptability of crack defects.

3.2.1 DRAINAGE PIPES

- a) Type 1 crack acceptable
- b) Type 2 crack acceptable after repair
- c) Type 3 crack acceptable after repair if load test passed

3.2.2 SEWERAGE AND PRESSURE PIPES

- a) Type 1 acceptable if pressure/load test passed
- b) Type 2 crack acceptable after repair if pressure/load test passed
- c) Type 3 crack not acceptable

3.3 FINISHING AND REPAIRS

3.3.1 FINISHING

- a) The pipe barrel shall not be finished by coating with cement wash or any other material before testing
- b) Cement washing of joint surfaces to enhance cosmetic appearance is permitted providing it is carried out before any hydro testing
- c) The finishing of green concrete in the pipe during manufacturing is permitted

3.3.2 REPAIRS

- a) Repairs to pipes shall be carried out using cement mortar, epoxy mortar, or other equivalent material
- b) The tensile and bond strength of the repair material shall not be less than the concrete in the pipe

4 POST-INSTALLATION INSPECTION

Most TA's in New Zealand require contractors to allow for post-installation inspection of newly constructed pipe culverts and stormwater pipelines before final acceptance of the work. Visual inspection may be carried for large diameter, short culverts; the inspector can thoroughly check all defects, take measurements of crack width and length, and hence a full evaluation can be made.

For small diameter culverts and pipelines (and for some larger diameter lines where there is a potential man entry safety risk) robotic CCTV cameras and associated equipment are the only available means to conduct the post-installation inspection.

4.1 CURRENT CCTV INSPECTION METHODS IN NEW ZEALAND

CCTV pipe inspection is usually carried out by specialist operators across the country. A robot handled video camera is inserted from a manhole or other access point inside the

pipe and images are sent to the operator’s monitor. When the operator recognizes a defect, the camera is stopped and rotated toward the defect. If necessary the image is enlarged to record all possible information about the defect.

The records of inspection are handed to the TA on a DVD with an inspection log sheet which usually highlights the location, type, and severity of the defect, with operator’s remarks and in some cases photos of the defect.

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 view 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 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 correlation 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 5) for classification of defects in installed pipelines, and appropriate action to be taken in each instance (McGuire & Harrison 2012)

Table 5: Classification of Defects in Installed Pipelines

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

4.2 DEVELOPMENT IN CCTV MEASUREMENT OF CRACK WIDTHS

Latest developments in electronics and laser technology allow TA’s in the US to specify CCTV records of pipe inspection which include a specific value for crack widths. This allows the assessor to better evaluate the design and installation and decide future measures on a sound basis. The recommended CCTV technology used to meet these specifications includes the following:

- The use of low barrel distortion video equipment with laser profile technology
- The use of non-contact video micrometer, or
- The use of laser light beams of various width as a scale to measure crack width

5 ASSESSMENT OF PIPELINE DURABILITY

Assessors of cracking in SRCP, as measured or predicted during visual and CCTV inspection, should consider the following facts about cracks, when doing their durability assessment:

- Possible minor cracks due to an effective transfer of the stress from the concrete in the tension zone to the steel. Cracks of this type are generally observed as multiple longitudinal cracks and happen mostly when pipes are subjected to loads within their maximum design load.
- Pre-installation cracks of previously load tested pipes may widen marginally after installation and loading, however they should be within acceptable limit of width if the pipe has not been overloaded during installation.
- Minor pre-installation cracks (not from load testing) within the acceptable limits of AS/NZS 4058:2007 may slightly widen after loading
- All crack width limitations of AS/NZS 4058:2007 and the CPAA recommendations are based on nominated steel cover. When steel cover is more than the nominated value, wider cracks than these limits may have some long term effect on the stability and durability of the pipe.
- Circumferential cracks can occur from loads imposed during installation, uneven bedding, or connection of the pipe to another structure followed by differential 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.
- The combined effect of all the previously mentioned pipe and pipeline structural design considerations, installation conditions, and final service conditions, impacts on initiating the crack and the possible future development and effects.

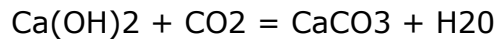
Various transportation agencies, local councils, and pipe producer agencies in Australasia and overseas have maximum allowable crack width guidelines for acceptance of installed pipes for both normal and aggressive environments. AASHTO specifies a maximum width of 2.5 mm for non-corrosive conditions and 0.25 in corrosive conditions for pipes with 25 mm cover (Busba et al 2011), while CPAA specifies 0.5 mm for circumferential cracks, and 0.15 mm for longitudinal cracks in all conditions for pipes with 10 mm cover (McGuire & Harrison 2012). CPAA suggests assessment of the design and future implications when crack widths exceed the specified limits.

Long term observation of cracks of various widths in SRCP indicate that they may, with time, heal themselves, remain stable, or (in relatively rare cases) have a negative effect on the durability of the pipeline. Assessors should understand the mechanism of each possible case to predict the effect of the crack on the durability of the pipe.

5.1 AUTOGENOUS HEALING

Water passing through concrete dissolves small amounts of calcium from the cement. While the cement paste in dense, high strength concrete as used in pipes, is to all intents and purposes impermeable to water, thin-walled concrete structures will often contain discontinuities which allow water to pass through. These may be cracks which have arisen in either the plastic or hardened state, internal separation at surfaces of reinforcing wire or coarse aggregate, or local porous areas. It has been found that given favourable conditions, calcium originating from the cement will be deposited in insoluble form in the void spaces and will eventually seal them. The process is particularly relevant for concrete pipe because the service conditions often provide an ideal environment for autogenous healing to take place.

The chemistry involved in the process that allows the sealing of concrete pipes involves the formation of calcium carbonate crystals; 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 tri-calcium silicate of the cement. The formula for this reaction is:



Technical literature cited by a report published by the University of South Florida (Busba et al 2011) indicated a reasonable expectation of autogenous healing to eventually occur for cracks narrower than about 0.5 mm, while it is not likely to happen for crack widths exceeding 2.5 mm. However laboratory results presented in the same report indicates that experiments did not produce significant autogenous healing of 2.5 mm or 0.5 mm cracks over a period of 2 months.

5.2 STRUCTURAL INTEGRITY

In Feb-1976 the Technical Committee of The California Precast Concrete Pipe Association published the results of a comprehensive investigation on a culvert which was known to have been overloaded to "failure" since its construction in 1962, based on monitoring by the local authorities during the intervening 14 year period (ACPA 1976).

The 1950 mm culvert reducing to 1550 mm was constructed under about 25 m of fill and had been subjected during service to greater than anticipated loads. This caused all pipes except the first 10 and last 18 to exhibit hairline or larger cracks, continuous from the spigot end to the bell. The cracks were located at the pipe crown, invert or both.

The excessive loading resulted in deflection of the pipes causing a vertical to horizontal diameter difference of over 75 mm which produced "slabbing" and flexural cracks. "Slabbing" can be defined as radial tension failure of concrete and can be visualized as the tendency of the curved reinforcing to straighten out under load. Cracks up to 5 mm wide were recorded 18 months after installation; some of the cracks were repaired during the 1962-63 period with epoxy pressure grouting.

In the 1974 investigation, 10 pipes were selected for detailed investigation, and cores were taken in different locations. Analysis of the cores indicated that cracks ranging in width from 0.3 mm to 5.0 mm were still present in the invert and crown of the pipes.

Vertical and horizontal measurements of pipe diameters as compared with the measurements completed 11 years earlier, indicated that there had been very little further movement in the pipe in both directions. It was concluded that the maximum distress had already taken place and no future major movement could be anticipated.

As a result of this investigation, the report concluded the following:

- Structural integrity of this culvert is not affected by cracks to 2.5 mm where slabbing failure has not occurred. Even where cracks of 5 mm width occurred, the structural integrity of the culvert has been maintained.
- Concrete encasement has not been necessary to maintain structural integrity.
- Observation of existing corrosion of reinforcement and calculation of the predicted future corrosion in the "Slabbing Failure Areas" indicates that in the non-corrosive environment of the culvert, a life expectancy of several hundred years is still expected.

The results of this investigation was used as a basis for AASHTO acceptance criteria of crack width up to 2.5 mm in non-aggressive environment.

5.3 CORROSION OF REINFORCEMENT

The CPAA cited the work of Darvall from Monash University and Beeby in its review of the effect of crack width on corrosion of reinforcement. The CPAA stated that 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 can be diffused through sound concrete – Figures 7 & 8 (reproduced from Darvall, 1987). 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 Figure 8, (Beeby 1978), confirm that, within the range shown, the crack width has very little effect. Where the sound concrete is highly impermeable as it is 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.

Figure 7: Simplified Model of Corrosion Process

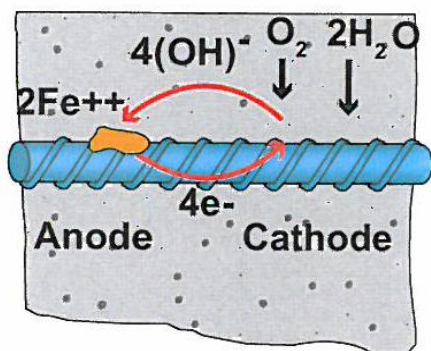


Figure 7: Factors Affecting the Rate of Corrosion

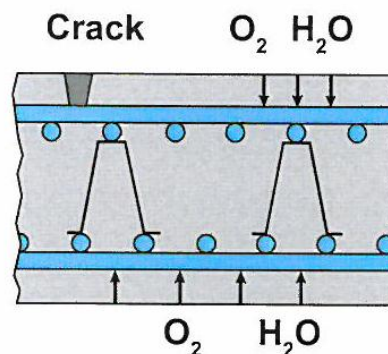
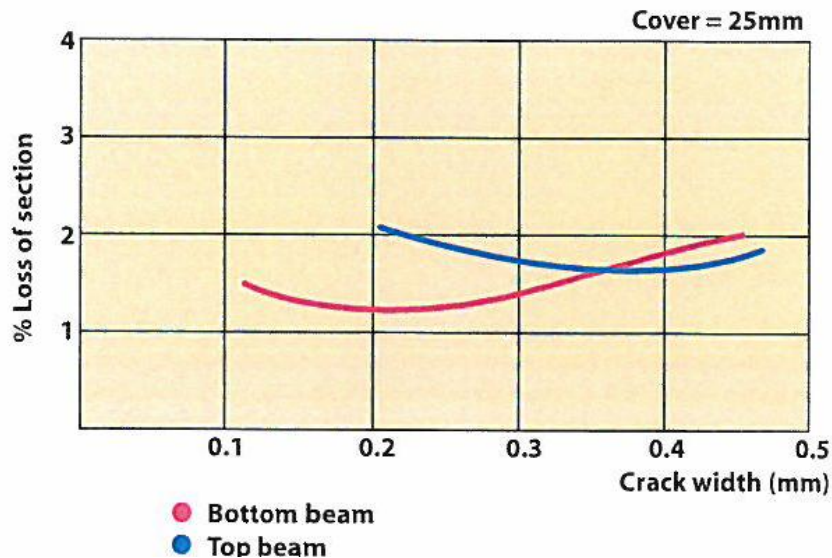


Figure 8: Reinforced Concrete in a Marine Environment – Loss of Section of Reinforcement Bar

The results of the later study of University of South Florida (Busba et al, 2011) indicates that a corrosion related durability of near and above 100 years is expected without limitation when the crack widths do not exceed 0.5 mm for 500 ppm chloride exposure. When the exposure condition exceeds the 500 ppm Chloride limit, the study indicates that 0.25 mm crack limit will be acceptable for the 100 years durability.



5.4 MIGRATION OF FINES AND BACKFILL FAILURE

While some of the wide circumferential cracks have no effect on the structural integrity of the SRCP, it was found that failure of the pipeline may happen in some cases, due to the migration of fines from the back fill through the cracks. This potential mechanism should be considered during any assessment of cracking in SRCP as follows:

- Migration of fines is not likely to happen if the crack is less than 0.5 mm wide and/or if it is not passing through the thickness of the pipe wall.
- Migration of fines will have no adverse effect if the backfill around the pipe is comprised entirely of coarse granular materials.
- Migration of fines will not happen if there is no water movement from outside to the inside of the pipe. In pipeline installations in well drained areas and/or areas well above water table level, migration of fines is not likely to cause any future problems.

5.5 WATER INFILTRATION

Water infiltration to Stormwater pipe networks is not generally considered as a performance issue of concern. However in some special design cases, where the expectation and/or the design requirements specify a completely sealed system, assessment of the cracks in pipes should consider the possible consequences of water

infiltration through wide cracks when the acceptability of the various levels of cracking is evaluated.

Water infiltration is not acceptable for wastewater and pressure pipes, assessment should take any possible leaks or water infiltration into account during the evaluation of the effect of cracks on pipeline performance.

6 CONCLUSIONS – RECOMMENDED ACTIONS

The assessment of post installation cracking of SRCP requires the assessor to examine all the available information about the defect, pipeline design, and installation, to predict the possible effect of the cracks on the structural integrity and durability of the pipe. The required information includes, but is not limited to the following;

- Width and type of cracks, narrow cracks and circumferential cracks do not usually have a negative effect on durability of pipes.
- Location of the cracks
- Period between installation and inspection
- Any signs of healing of the cracks
- Any signs of infiltration, rusting, and fine soil movement
- Cover and wall thickness of the pipe
- Present and future dead and live loads on the pipe as compared to its design class
- Investigation of any possible overloading during construction.
- Installation conditions and actual bedding factor achieved
- Any records of pre-installation cracks.
- Backfill materials and possible migration of fines
- Water table movements and acceptance of infiltration.
- Presence of aggressive materials such as chlorides and sulphates.
- Importance and location of the pipeline.

Assessors of post installation inspections should then clearly advise asset owners to take one or more of the following actions to maintain the design durability of the pipeline:

1. No action required when cracks are narrow, stable, healing, and/or have no negative structural and durability effect.
2. Monitor cracks if they are of critical width, not stable, showing signs of healing or infiltration, and when further loading is expected in future. Cracks in aggressive environments may also need monitoring.
3. Non-structural lining of the pipe or local crack repairs with epoxy; to stop infiltration and exfiltration, protect reinforcement from aggressive environment inside the pipe, and to stop migration of fines.
4. Structural lining or pipe replacement in the case of severe cracking that may affect the structural integrity of the installation.

REFERENCES

- ACPA (1976) "Effect of Cracks in Reinforced Concrete Culvert Pipe – CP Info", American Concrete Pipe Association Website 1976
- ACPA (1980) "Significance of Cracks in Concrete Pipes – CP Info", American Concrete Pipe Association Website 1980
- Australian Standards/New Zealand Standards (2007a) "AS/NZS 4058:2007 Precast Concrete Pipes (Pressure and Non Pressure)"
- Australian Standards/New Zealand Standards (2007b) "AS/NZS 3725:2007 Design for Installation of Buried Concrete Pipes"
- Beeby, A. W. (1978) "Corrosion of Reinforcing Steel in Concrete and its Relation to Cracking", *The Structural engineer*, 56A, No. 3, March 1978, pp 77-81.
- Busba, E. R., Sagues A. A., Mullins, G. (2011) "Reinforced Concrete Pipe Cracking – Acceptance Criteria", University of South Florida – College of engineering, Tampa, FL 33620 July 2011.
- CPAA (2011a) "Manufacture And Design of Concrete Pipes to Australian Standards – Updates in Design & Selection of Concrete Pipe & Box Culverts", Homesglen Tafe, Melbourne August 2011"
- CPAA (2013b) "Guide to Understanding AS/NZS 4058:2007 – Concrete Pipe Association of Australasia, First Edition December 2013"
- CPAA (2010c) "Circumferential Cracking – Engineering Guideline", Concrete Pipe Association of Australasia Website 2010"
- Darvall, P. L., (1987) "Cracking in Concrete", Monash University, 1987.
- McGuire, P., Harrison, N., (2012) "Concrete Stormwater Drainage Pipelines – Acceptance Using CCTV Inspection", Concrete Pipe Association of Australasia Website 2012.