ENGINEERING GUIDELINE

Designing Durable Concrete Pipelines

Concrete Pipe Association of Australasia

1. Introduction

Pipelines are vital to the health and functioning of our communities. A pipeline which is out of service even for a short period of time causes extreme inconvenience and can have expensive consequences. Repairs and service difficulties can be minimised by directing more attention at the design stage to the durability of pipe materials.

The durability of a pipe is as important as its ability to perform its structural and hydraulic functions. However, durability cannot always be predicted with the same degree of precision as can structural and hydraulic performance Although much progress has been made in relating durability potential to such concrete properties as pore structure, permeability and diffusion coefficients, durability design still relies heavily on the years of proven performance of concrete pipe manufactured to Australian and New Zealand Standards.

The current Australian and New Zealand Standard, AS/NZS 4058 "Precast concrete pipe (pressure and non-pressure)", is a performance based standard, allowing steel reinforced concrete pipe to be designed and manufactured as an engineered product, ensuring efficiency, innovation and quality. Tight restrictions are set out where minimum standards must be achieved, including - strength under external load, hydrostatic pressure performance, water absorption, and minimum cover to reinforcement. Testing is generally carried out on statistically based samples which ensure that the required levels of performance are achieved. There are also clear guidelines on design for durability, particularly with respect to conditions of exposure.

As a result, AS/NZS 4058 states that when designed, manufactured and installed appropriately the service life of steel reinforced concrete pipe in Australia and New Zealand can expect to exceed 100 years.

2. Concrete Pipe Peformance

For normal everyday installations, the service life of concrete pipe is virtually unlimited. Some of the Roman aqueducts constructed some 2000 years ago are still in service today. The first known concrete pipe in America was laid in 1842 and samples exhumed after 140 years showed it to be in excellent condition[1].

In Australia and New Zealand it is estimated that since the early 20th century approximately 500,000,000 metres of steel reinforced concrete pipe have been installed in drainage, road culvert, sewer and pressure pipe applications. Of that total the number of lines which have suffered from durability problems is extremely small and confined mainly to standard pipe being used in abnormally aggressive conditions.

Concrete pipes being transported to site in the 1920's in Loveday, South Australia.

Exhumed Loveday concrete pipes from 1920 being re-used in the construction of a culvert between Berri and Lyrup (South Australia) in the year 2000.

Steel reinforced concrete pipe exhumed in Toowoomba, Queensland, in 2010. The pipes were originally made and installed in 1943. Note the excellent condition of the inverts after nearly 70 years of service.

Since the very early stages of concrete pipe manufacture in the region, the machinery and equipment used has been characterised by an ability to mould a product with very low water/cement ratio, together with full and reliable compaction. Current methods range from centrifugal roller compaction, heavy vibratory methods using dry mixes, vertical dry cast, and centrifugal spinning with slightly wetter mixes in which the water/cement ratio of concrete is reduced by centrifugal action. The water/cement ratio of concrete in pipes made by these processes is less than 0.4 and commonly will be lower than 0.35. The combination of such low water/cement ratios with full compaction achieves very low permeable concrete with compressive strengths that can be in the range of 60 to 70 MPa.

Concrete produced under these conditions is practically impermeable to water and has the highest level of durability which can be achieved by any commercial concrete casting process.

3. Durability Properties of Concrete Pipe

The essential elements in the manufacture of durable concrete are:

- Sound and durable aggregates which are properly selected and tested and quality controlled.
- Proper application of mix design principles.
- Low water/cement ratio concrete.
- Suitable cementitious binder content.
- Large and efficient compactive forces capable of compacting the low workability mixes.
- Appropriate concrete cover, consistent with the size of the reinforcing wire diameters.
- Effective curing, for some processes achieved by the use of low pressure steam on a controlled cycle.
- Accredited quality assurance systems.

All of the above are inherent in the manufacture of steel reinforced concrete pipe. It is noted in AS/NZS 4058 that typically the water/cement ratio for concrete pipe should be less than 0.4, and binder content not less than 330 kg/m^3 to allow the specified limits for water absorption to be met. These ensure that the two most important properties that lead to the durability performance of concrete pipes are taken care of – permeability of the concrete and the presence of the right amount of alkaline material that is necessary to protect the reinforcement from corrosion.

3.1 Permeability

Low permeability is important in maintaining both the integrity of the concrete and also its ability to prevent corrosion of the reinforcement. Some aggressive agents weaken or disintegrate the concrete progressively from the surface; others penetrate into the concrete without necessarily reducing its strength but eventually neutralise the ability of the concrete to protect the reinforcement. Impermeable concrete also tends to retain moisture which assists in continuing hydration, and is not as affected by wetting and drying cycles. High strength, well cured concrete is several thousand times more impermeable than poorer grades.

Water absorption is a property indirectly related to permeability. Permeability is particularly difficult to measure in dense concrete that is produced with a low water/cement ratio, and so water absorption is used for the purpose of quality control. The joint Australian and New Zealand Standard for concrete pipe specifies a "boiling" method for determination of absorption. A maximum absorption value of only 6% is allowed for all types of steel reinforced concrete pipe produced in these countries. This limit ensures that high quality, durable concrete is produced.

A concrete pipe core sample being tested for water absorption.

NOTE:
For further information refer to the CPAA Technical Guideline "Water Absorption Testing".

3.2 Alkalinity & Autogenous Healing

Water in the pores of hydrated cement is highly alkaline, with a pH in the range 12.5 to 13[2]. In most situations this high pH keeps steel "passive", preventing corrosion even if water and oxygen are present. The alkalinity of the pore water in concrete provides the source of an additional benefit known as "autogeneous healing". In this process, water permeating through the concrete section becomes saturated with calcium hydroxide, a normally crystalline by-product of the cement hydration reaction. When exposed to carbon dioxide from the air, on the surface of cracks or voids, the calcium hydroxide is converted to the less soluble calcium carbonate. This substance precipitates out on the crack surface by much the same process as the formation of stalactites in limestone caves. This slow deposition process eventually fills cracks or voids in the concrete, healing them from within.

The process takes place even if the water is under pressure. Pressure pipes cracked by a surge of excess pressure will autogenously heal when the pressure returns to its working level.

NOTE:
For further information refer to the CPAA Technical Guideline "Autogenous Healing".

Concrete pipe placed in a normal environment


Example of a marine environment due to tidal flow

4. Durability Properties of Steel Reinforcement

4.1 Provisions in AS/NZS 4058

The minimum cover to reinforcement nominated in AS/NZS 4058 is specified to provide for a pipe design life in excess of 100 years for typical buried structure environments defined in the Standard. These environments are defined in AS/NZS 4058 as:

Normal – an underground environment having negligible influence on the in-service life expectancy of pipe.

Marine – an underground environment for a pipe where the interior surface of the pipeline is also subject to tidal flow (i.e. not openly exposed to direct wave action or wind driven salt-borne spray).

Table 4.1 outlines the minimum cover requirements given in the Standard for normal and marine environments.

For areas not covered by the "normal" or "marine" criteria, the Standard refers to "Other" environments. The standard outlines what conditions are suitable for concrete pipe to be specified with minimum cover (as per a "normal" environment) in "other" environments. Appendix E of AS/NZS 4058 provides a guide to this with respect to the more common types of aggressive agent found in the water, soil or air, along with a benchmark for the concentration limits (see Table 4.2). Section 8 of this document provides a guide for specifiers where concrete pipe is found in more aggressive conditions.

TABLE 4.1
Minimum cover for concrete pipe in normal and marine environments (from Table 3.1 of AS/NZS 4058:2007)

Method of Manufacture	Minimum cover – barrel & socket (mm)			Minimum cover – mating surface of spigot (mm)		
	Environment					
	Normal	Marine	Other	Normal	Marine	Other
Machine made pipe (Wall thickness)						
⩽ 25	6	N/A	See Note 1	4	N/A	See Note 1
> 25, ⩽ 35	8	N/A		5	N/A	
> 35	10	20		6	10	
Wet cast pipe (50 MPa)	25	35		25	35	

NOTE:

1. Refers to environments that do not comply with the definitions for either normal or marine environments. These include environments in which one or more of the limits in Table 4.2 below are exceeded.
2. Where pipes are loaded to less than 50% of the proof load, for a marine environment barrel cover may be reduced to 15 mm for machine made pipe and 20 mm for wet cast.

TABLE 4.2

Concentration limits in aggressive conditions - minimum 10 mm cover (From Table E1 of AS/NZS 4058:2007)

Constituent	Soil classification		
	Clay/stagnant	Medium	Sandy/flowing
Chloride (p.p.m Cl–) max.			
Unreinforced concrete	No limit	No limit	No limit
Reinforced concrete	20,000	20,000	20,000
Sulfate (p.p.m SO_4–) max.			
Type GP – general purpose type Portland cement	1 000	1 000	1 000
Type SR – sulfate resisting type Portland cement	10,000	10,000	10,000
Acidity			
Acid (pH) (min.)	4.5	5.0	5.5
Exchangeable soil acid (mL of 0.1 M NaOH consumed by 100 g air-dried soil, max.)	70	50	30
Aggressive CO_2 (p.p.m) max.	150	50	15

Concrete pipe designed for use in sea water in accordance to AS/NZS 4058 (Perth, W.A.)

4.2 Reinforcement spacers

In the manufacture of concrete pipes, cover to reinforcement is usually controlled by spacers, attached to the reinforcement cage, which extend to the outer surface of the pipe. These are either made from the same material as the cage itself, i.e. mild steel or plastic.

Mild steel spacers will often have some corrosion at the exposed ends, but long experience has shown that this does not lead to any diminished durability of the pipe. Similarly, pipes which are cut or broken in two to make junctions, bends or short lengths will have exposed steel, particularly longitudinal reinforcement. It is very rare for corrosion of the exposed steel to penetrate into sound concrete more than a few millimetres and no further corrosion should eventuate.

Plastic spacers sometimes develop very fine shrinkage between the plastic and the concrete as a result of differential expansion of plastic and concrete during heat curing of the concrete pipe. Experience has shown that, where it has occurred, this is quickly sealed through autogenous healing, and does not lead to any diminished durability of the pipe.

Capping the spacers with a non-corroding material such as plastic or brass is of no value and in severe conditions can be harmful. The use of brass would set up a catalytic couple with the mild steel accelerating corrosion.

AS/NZS 4058 recognises this by stating that the concrete cover requirements do not apply to radial nibs, end spacers and longitudinal reinforcement ends.

Mild steel reinforcement spacer exposed for inspection on 32 year old pipe on beach at Altona (Victoria) in 1980's. No corrosion except at normal concrete surface.

5. Cracking and Concrete Pipe Durability

Reinforced concrete which is properly designed will usually crack if the reinforcement is to carry out its function. It is generally accepted in pipe standards throughout the world that the acceptance test criterion at the working or service load allows for a crack of some maximum width, depending on the amount of cover over the steel. In Australia and New Zealand, for the standard 10 mm cover, the allowable crack width under load is 0.15 mm at the surface. Such cracks are tapered and much narrower at reinforcement depth. AS/NZS4058 generally allows greater crack widths (measured at the surface) for greater specified concrete covers.

Except in extreme conditions, such cracks do not make the structure susceptible to corrosion damage because any steel corrosion at the tip of the crack seals the crack, thus stifling further corrosion. While a maximum crack width is used as one of the acceptance criteria in load tests, durability of the product once it is cracked is in fact insensitive to crack width over a range well beyond the test limit. If moisture is present, there is a high probability of autogeneous healing.

NOTE:
For more information refer to the CPAA Engineering Guidelines "Circumferential Cracking" and "The Facts about Cracking in Steel Reinforced Concrete Pipes".

6. Physical Effects on Concrete Pipe Durability

Steel reinforced concrete pipe is strong and robust. It is designed to withstand the various physical forces to which it may be subjected. A few of the more common of these forces are set out in the following sections.

6.1 Loads

The principal load that concrete pipes will be subjected to is derived from the earth fill above it. The impact of the soil dead load is influenced by the type of installation the pipeline requires (i.e. trench or embankment condition). Details on the choice of concrete pipe and calculation of such loads are set out in Australian and New Zealand Standards AS/NZS 4058 and AS/NZS 3725, and in the Concrete Pipe Association of Australasia design software program for the selection of concrete pipe, PipeClass.

Steel reinforced concrete pipe has shown from many years of field experience and factory testing that it is able to sustain loads without failure, loss of the factor of safety, or loss of shape. This is most clearly exemplified by the many cases where reinforced concrete pressure pipes have, after many years in service (ie under sustained tensile loads) not only given excellent performance but have been able to withstand an increase in operating pressure.

In laboratory sustained load tests[3], steel reinforced concrete pipes loaded to 85% of average ultimate strength withstood the applied load for the duration of the test, 20 000 hours. The average crushing strength at this age exceeded the initial average strength.

6.2 Abrasion and erosion

Water velocity by itself does not create abrasion problems for concrete pipe within the ranges normally encountered. Very high velocities (say about 10 m/s) could cause serious cavitation effects unless the surface is smooth and internal offsets at joints are eliminated. It is not so much the water velocity that could cause abrasion but the surcharge or "bed load" of material carried with it, whose abrasive effect depends on the size of the particles being carried and is also strongly affected by the water velocity. In most situations, problems with abrasion will be avoided by limiting water flow velocities to 8 m/s.

When comparing abrasion resistance of concrete pipe with other types of pipe, account should be taken of the thickness of material which can be removed before structural load capacity of the pipe is adversely affected[4].

Abrasion testing of pipe materials.

6.3 Flammability

Until recent years, fire has not been considered as a factor relevant to the serviceability of a pipeline. However, other types of pipe made of possible flammable materials, and the increasing instances of fires in stormwater drains make fire resistance an essential consideration in pipe specification.

Concrete pipe remains serviceable even after severe exposure to fire[5].

6.4 Freeze thaw protection

When water freezes there is an expansion in volume, and if this occurs in a confined space, as with water contained in pores in concrete, there is a disruptive effect on the surrounding medium. Freezing also has the effect of concentrating water in the region where this has occurred – for example, if water in the concrete near an exposed surface freezes, more will diffuse towards the surface from elsewhere and add its volume to that of the ice already present there. Severe disruptive effects in concrete from freezing and thawing are well known in cold climates.

In most parts of Australia and New Zealand, designers need not consider freeze thaw effects on concrete pipe, because of the very low water absorption and water/cement ratio of the concrete. However, in regions with more severe climates, manufacturers should be consulted.

6.5 Wetting – drying cycles and thermal effects

Typical pre-mix or precast concrete may exhibit shrinkage effects as it dries. With dense concrete mixes such as those used for pipes, drying is protracted and shrinkage cracking is not usually a concern.

Concrete expands and contracts with changing temperature, having a coefficient of expansion of 8-13 x 10-6/°C, depending on the type of aggregate used. This means that over a 10°C range of variation a standard length concrete pipe will vary approximately 0.25 mm in length. In practice ambient temperature differences of 30°C could arise, in which case a concrete pipe might show a change in length of 0.75 mm.

Concrete pipes are dimensionally very stable in a buried environment. If pipes are only partly buried with the top exposed to the elements, the combination of thermal gradients due to direct sunshine, together with moisture gradients due to drying above, and being wet below, will often cause minor cracking. Pipes should preferably be installed entirely below ground but if some part has to be left exposed, condition should be maintained as uniform as possible.

Pipes should be stored on a level, hard standing area which is easily accessible to the available lifting equipment. Pipes made with elliptical reinforcing should be stored with the "Top" up.

Steps which can be taken to prevent cracking whilst on site waiting to be installed include locating pipes in a shady area and at 90 degrees to the prevailing wind to minimise the effects of drying and shrinkage.

7. Chemical Effects on Concrete Pipe Durability

Steel in a highly alkaline environment (pH 12-13) such as concrete is protected against corrosion because a microscopically thin layer of a special form of iron oxide forms on its surface. The formation of this oxide layer "passivates" the steel.

However, if the pH of the concrete around the steel is lowered, or if chloride ions are present in sufficient concentration, the steel nonetheless becomes susceptible to corrosion provided other conditions (e.g. access of oxygen to the surface of the steel) are favourable.

Corrosion products occupy a larger volume than the steel from which they were formed, and are capable of generating large expansive forces which may crack and possibly spall the concrete. With high quality concrete this stage may never be reached, particularly if the diameter of the reinforcing wires or bars is small compared with the cover.

Underneath the ground, surfaces may be subject to chemical attack which directly affects the concrete. The effect on steel reinforcement is a secondary concern.

7.1 Potentially aggressive agents and processes

Aggressive agents which may be encountered in Australia and New Zealand are:

- Chloride ions from a marine environment or from saline groundwater.
- Sulfate ions contained in the soil and dissolved in groundwater.
- Organic acids occurring naturally in the ground possibly derived from decaying vegetable matter.
- Sulfuric acid resulting from oxidation of sulfide in the soil, or acid from sewage or industrial operations.
- Carbon dioxide dissolved at high concentration in groundwater, which can have a leaching effect on the concrete, similar in effect to mild acid attack.
- Distilled or very pure water and other less common agents

NOTE:
The effect of sulfates, sulfides and sulphuric acid on concrete is different. Sulfates must penetrate the concrete and be concentrated by evaporation to cause disturbance. Sulfides do not attack concrete, however under favourable conditions hydrogen sulfide gas that is formed can be converted to sulfuric acid. This reacts with the cement matrix and forms a soluble calcium product thus affecting the surface of concrete.

Concrete pipe after prolonged acid exposure (pH 3.5 for 12 years). Note the adhering layer of affected concrete.

7.1.1 Chloride

Chloride is a component of the salt in sea water or salty ground. Chloride ions do not attack the concrete itself but can diffuse through the cement matrix, and at a sufficiently high concentration will depassivate the steel, even at the high pH provided by the cement, allowing rusting to commence provided moisture and oxygen are also present. A wide range has been observed for the threshold level of chloride to depassivate the steel, from 0.25% to 2.5% of the cement[6]. With concrete pipe, minimal corrosion has been observed with the chloride level even above 2.5% of the cement, attributable to the very dense matrix which is able to promote a stable passive film, and also to restrict ingress of oxygen by holding moisture in the pores of the hydrated cement.

For the condition of marine exposure relevant to buried concrete pipe, defined in AS/NZS 4058 as "an environment in which the interior of the pipe surface is subject to tidal flow", chloride levels at reinforcement depth in equilibrium with those at the surface are not sufficient to depassivate the steel.

NOTE:
For more information on this issue refer to the CPAA Technical Paper "Concrete Pipe in Tidal Flow and Saline Ground Conditions".

7.1.2 Sulfates

Sulfate ions dissolved in water react with the tricalcium aluminate in hydrated cement and free lime, if any is present, to form compounds having a larger volume than those originally present. The reactions can have a disruptive effect, especially on weak concrete.

The high strength and low permeability of concrete in pipes confers a high level of sulfate resistance. Moderately high levels of sulfate can be catered for by the use of any Type SR cement, but the highest resistance is obtained with blended cement, which greatly reduces the amount of free lime. While sea water contains a moderately high level of sulfate, the presence of chloride diminishes its effect and Type SR properties for the cement are not required.

NOTE:
For further information refer to the CPAA Technical Guideline "Concrete Pipe in Acid Sulfate Soils".

7.1.3 Acids

Acid attacks the surface of a concrete element. The measure of the strength of an acid is "pH". The lower the pH, the stronger the acid. The pH gives a measure of the initial rate of attack on the concrete surface.

The acid is generally neutralised by the alkalinity of the concrete, and without acid replenishment the reaction stops. This type of attack can occur on the exterior or the interior surface of a concrete pipe.

Exterior surface – When an acidic soil or groundwater is encountered the effect on the concrete is governed by the pH, total acidity, groundwater conditions and backfill material. Aggressive acidic conditions occur very rarely naturally, and groundwater of quite low pH is not necessarily a concern. Some naturally occurring acids such as humic acid, when they react with the surface layer of concrete form a more impermeable barrier, thus protecting the underlying concrete.

Interior surface – Acid attack can occur from two sources. Firstly, hydrogen sulfides in sewage can generate hydrogen sulfate gas, which may then be converted to sulfuric acid on the obvert of the pipe. Secondly, acids can be formed by effluents which contain acids from industrial sites and mines.

It is a matter of observation that, except in unusual, highly acidic conditions, the concrete which has been affected by the acid remains in place over the unaffected concrete. This has a very marked effect on slowing down the rate of attack, after this has penetrated for just a few millimetres.

7.1.4 Carbon dioxide

7.1.4.1 Carbonation

Carbonation is the natural process of conversion of the alkaline hydroxides in concrete to carbonates by their reaction with carbon dioxide, usually from the air. This reaction reduces the pH of pore water in the concrete from above 12 down to 8-9, greatly diminishing the protection normally afforded to reinforcing steel.

The conversion begins at the concrete surface and progresses inwards at a rate determined by environmental factors and the quality of the concrete, including the composition of the cement. The rate diminishes with depth in accordance with a square root function.

For steel reinforced concrete pipe the highly impermeable concrete makes the progression rates of carbonation fronts extremely slow. Examples of pipes up to sixty years old show carbonation depths no greater than a few millimetres.

7.1.4.2 Carbonic acid

Carbon dioxide is soluble in water, forming a weakly acid solution. The amount which dissolves from the atmosphere is not enough to cause any harm to concrete, but at high concentration the solution will dissolve cement at a rate much greater than would be indicated by the pH. Decaying vegetable matter releases carbon dioxide which can lead to such high concentrations in groundwater. If the water is "hard" (i.e. contains dissolved salts of calcium or magnesium), more carbon dioxide is required to have any effect. Attack by carbon dioxide dissolved in water should not be confused with carbonation.

7.1.5 Other aggressive agents

Hydrated cement is partly soluble in water, but in most circumstances a film of calcium carbonate (produced by the action of CO_2 on lime) forms at the surface of the concrete and protects the material underneath. Concrete is therefore susceptible to attack by water which is lower than normal in carbon dioxide and also free of any other material able to form an insoluble film on the concrete surface. Distilled water and water from melting snow are aggressive in this way.

Ammonium and magnesium salts, chlorine and strong alkalis are sometimes aggressive to concrete, but trouble resulting from these is rare except as a result of industrial activities.

8. Designing Pipelines for Aggressive Conditions

Steel reinforced concrete pipe made to AS/NZS 4058 is an engineered product made to a performance based standard. In other words, the product can be adapted to meet the durability and load requirements that are necessary whilst still meeting a standard performance benchmark. To do this however, the Designer, Specifier, Manufacturer and Contractor, need to understand the conditions.

8.1 Site investigation

In an area where the performance of concrete underground has not been previously assessed, a site examination may be desirable. Such examination and assessment will often require assistance from consultants or others with experience in the field of concrete aggressives. The risk of deterioration and the rate at which it might occur will derive not only from the presence of aggressive agents but also from their concentration, and the rate at which they are replenished at the surface of the concrete.

Information is needed on the soil type and the soil/terrain classification (see Table 4.2 as an example) with respect to its permeability, as well as data on the seasonal variation of the natural water table. Pipes laid in conditions where the water table is always below the pipes are more favourably placed.

When examining a site, it is always preferable to obtain a sample of groundwater for analysis. If this cannot be collected then soil samples can be obtained and soluble aggressives extracted with water. However, the composition of groundwater may be governed by its past history just as much as by the local soil, so soil tests alone may not be reliable. Usually the concentration of an agent when evaluated by extraction from soil will be higher than that obtained from naturally occurring groundwater. Special care must be taken with samples for CO_2 determination, as some of the dissolved gas may be lost between the times of sampling and analysis.

Generally the environment underground is particularly favourable to concrete. There are no extremes of temperature, or wetting and drying to induce cracks, and in the moist environment carbonation is slower than above ground.

As can be seen, most of the aggressive agents are conveyed to the concrete by water and mostly need continuing damp conditions to develop their corrosive action. Concrete which remains completely dry would only be affected by gaseous carbon dioxide, which is not a problem for concrete pipe.

Site investigation should also include the inspection of existing concrete structures - pipes, concrete stumps, fence posts and others. This examination can be a good indicator of whether or not the site is aggressive.

8.2 Groundwater

8.2.1 Limits and protective measures for standard pipe

Table 4.2 sets the limits of aggressive agents in groundwater for pipes, to the minimum requirements of AS/NZS 4058, to give a life expectancy of 100 years.

Where the levels of acid or carbon dioxide exceed those in the table, the life of a pipe can be extended to some extent by providing extra ("sacrificial") cover to reinforcement. However if the scope for such increase cannot provide the necessary degree of protection, this will usually be achievable

Analysis of the site conditions, soil type, and classification is vital to understanding the durability requirements for concrete pipe.

by an adhered coating on the outside, or wrapping in a sleeve to slow the rate of replenishment of the aggressive material at the pipe surface.

Whereas acid and aggressive carbon dioxide cause deterioration of the concrete progressing from the surface, the effect of sulfate takes place in the bulk of the concrete, causing distortion or disruption. Sacrificial cover is of doubtful value and protective measures should concentrate on making the concrete itself resistant to attack, or isolating it from the aggressive medium. It is recommended that, where sulfate exceeds 3000 p.p.m. blended cement should be used to provide the necessary resistance. Fortunately, examples of sulfate at a concentration above that which can be effectively neutralised by the use of impermeable concrete and blended cement are practically unknown in natural environments.

Epoxy paint coating is effective in protecting the outside of concrete pipes against highly aggressive groundwater containing sulfates, acids and free carbon dioxide. Two coats of low solvent or solvent less epoxy can be used for the external protection of the concrete pipe. Coating materials are not all equally effective, epoxy paint with a high solvent level having been found to be less effective than solventless material. Very thin protective coatings can be expected to have only a cosmetic effect.

Table 8.1 below provides a guideline to the measures that could be considered when groundwater contains acid or aggressive carbon dioxide, having a concentration limit above those outlined in Appendix E of AS/NZS 4058.

8.2 Salt water exposure

Marine exposure is a well-recognised exposure condition potentially destructive to steel reinforced concrete. Most engineers will have seen examples of concrete pipe in beach front locations showing signs of rust, and wish to avoid installing pipes in circumstances which will lead to early failure.

Types of exposure which need to be considered for durability design include:

- Buried pipelines, below low tide level.
- Pipelines exposed to salt spray or prolonged wetting and drying.
- Underground pipelines subject to tidal flow and stormwater flushing.
- Periodic or continuous immersion in groundwater having chloride content above that found in sea water.

8.2.1 Pipelines below the tidal zone

When a concrete pipeline is placed in a marine environment where it is one metre or more below low tide, a standard concrete pipe may be specified. Oxygen starvation will inhibit corrosion and the service life will not be compromised.

8.2.2 Pipelines exposed to salt spray or wetting and drying

This situation requires extra cover to reinforcement under the marine environment classification (see Table 4.1). The most severe condition occurs when some or the entire pipe is above ground. Thermal effects and differential wetting and drying will almost certainly cause cracking in pipes installed in this way. Installation of steel reinforced concrete pipe in these circumstances will not be ideal if it can be economically avoided. However since loading in these circumstances is minimal, the only significant problem is cosmetic due to inevitable staining. It may be possible to avoid these circumstances by screening with gabions.

8.2.3 Tidal flow with stormwater flushing

In this situation salt does not become concentrated by evaporation. Surveys[7] have shown negligible effects even after long periods of service. AS/NZS 4058 requires minimum 15 mm cover inside for lightly loaded pipes and 20 mm where the load exceeds 50% of the test crack load (see Table 4.1).

Concrete pipe retrieved from Brett Wharf in Brisbane after 50 years being immersed in saline river water. No associated cracking or spalling, cover to steel varied between 15mm and 20mm.

TABLE 8.1
Protection of pipe exterior from the effect of groundwater containing acid or aggressive carbon dioxide

Exposure condition	Evaluation of exposure	Durability provision
Pipe exterior	• pH lower and/or aggressive CO_2 greater than the limits in the Standard or • more free movement of groundwater past the pipe	• Increase cover from 10 mm to 20 mm • Specify a protective coating (epoxy or equivalent), or sleeve • Slow the movement of groundwater by placing impermeable barriers (trench plugs) at intervals in the trench • Specify blended cement

TABLE 8.2
Durability provisions to consider for protection against chloride

Exposure condition	Type of exposure	Durability provision
Pipe exterior	• Complete immersion in water containing > 20 000 p.p.m. Cl^-	• Increase cover from 10 mm to 20 mm • Specify blended cement • Specify higher cement content or lower water absorption • Use a protective coating such as an epoxy chemical resistant coating or protective sleeve
	• Buried in salt-rich soil containing > 20 000 p.p.m. Cl^-	

8.3 Acid Conditions Inside the Pipe

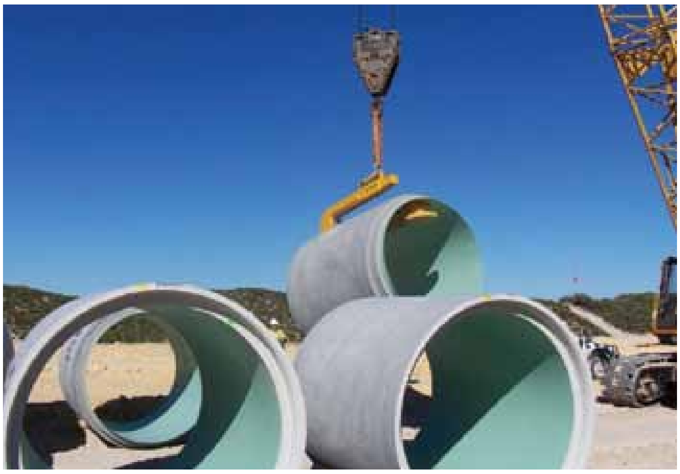
Acids may be contained in waste and stormwater, resulting from mining, industrial chemical plants, or manufacturing facilities. In these instances the attack is limited to the submerged areas or the invert of the conduit. The limit for normal cover may be taken to be the same as that for the pipe exterior subject to flowing groundwater; ie pH 5.5.

In pipes carrying aged sewage, in warm climates, the interior surface above the effluent level is subject to attack by sulfuric acid generated by bacterial action at the pipe wall, making use of hydrogen sulfide gas in the sewer atmosphere. This process is known as "H_2S attack" and can lead to very rapid deterioration.

Table 8.3 below provides a guideline to the preventive measures required to provide durable concrete pipes when acidic conditions are expected.

TABLE 8.3
Protection of pipe interior from attack by acid

Exposure condition	Evaluation of exposure	Durability provision
Pipe interior	• Acidic effluent	• Specify blended cement • Increase cover from 10mm • Specify a protective coating (epoxy or equivalent) • Specify a protective lining
	• H_2S attack	• Increase the total alkalinity of the concrete • Increase cover from 10 mm • Protect the interior surface of the pipe with a keyed-in plastic lining



Example of lined steel reinforced concrete pipe

9. Performance Based Standards

Following the development of concrete pipes in this region more than one hundred years ago, Standards Australia and Standards New Zealand have compiled standards which have been instrumental in setting and maintaining uniform high standards of manufacture.

The first Australian Standard issued in 1937 embraced culvert, sewer, drainage and pressure pipes and included methods for calculating loads on pipes from earth fill and live load. This Standard was reviewed in 1957 and the detail on load calculation, laying and bedding of pipes was issued

separately as a new code (CA33) in 1962. In 1972, the concrete pipe code was again reviewed, metricated, and reissued in two parts - AS 1342 covered drainage, culvert and sewer pipes and AS 1392 covered pressure pipes. These were superseded in 1992 by AS 4058, which covers drainage, sewer and pressure applications. CA33 was replaced by AS 3725 in 1989.

A similar history of Standards development has occurred in New Zealand. The 1961 Standard uplifted the 1957 Australian document and in 1965 CA33 was adopted. Further reviews resulted in a 1968 issue and the release in 1976 of the metricated version, NZS 3107, which maintained an Australian link with the referencing of AS 1392. Following this, in 1992 AS 3725 was adopted as a harmonised standard.

In 2007 both AS/NZS 4058 "Precast concrete pipe (pressure and non-pressure)" and AS/NZS 3725 "Design for installation of buried concrete pipes" were revised and released as Australian and New Zealand standards. The latest versions of the Standards have been updated to increase the production requirements to ensure that durability conditions are consistently met to enable steel reinforced concrete pipe to last 100 years.

In each of the reviews undertaken by Standards Committees they have been able to assess changes due to many years of satisfactory performance of unique, thin walled, high quality Australian and New Zealand concrete pipe. These Standards have over the years laid down clear requirements on matters such as dimensional tolerances, appearance and workmanship, external load test strengths, sampling and testing criteria for acceptance. They are performance standards which give a measure of freedom to the manufacturer to design and manufacture the most economical pipe. Acceptance tests are based on external load tests for strength, hydrostatic pressure, absorption testing and cover to reinforcement. These tests are generally carried out on statistically based samples which provide the assurance for strength, impermeability and ultimately durability.

Steel reinforced concrete pipe – setting the standard for a 100 years.

Concrete pipe being manufactured using horizontal cast methods to AS/NZS 4058.

Concrete pipe manufactured using dry vertical cast methods to AS/NZS 4058.

Concrete pipe being load tested in accordance to AS/NZS 4058.

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