Concrete pipe in tidal flow or saline ground conditions

Dr Norwood Harrison, *Technical Support Manager, Humes*

Urban Salinity Sydney, June 2010

INTRODUCTION

For saline conditions such as highly concentrated chloride induced groundwater or severe salt water environments, steel reinforced concrete will usually be specified with an appropriate grade of compressive strength, a high cover depth to the steel reinforcement, and/or additional properties to improve their durability. This is aimed at ensuring that the concrete will delay, as far as possible, the penetration of chloride to the reinforcement depth.

However, difficulty arises when attempting to check the level of penetration of the chloride, or in fact the ability of the material to delay the process. The ASTM rapid chloride test C1202 for resistivity[1] may be specified for this purpose, but there is in fact no single measurable property suitable for inclusion in a specification which will accurately reflect the rate at which chloride will diffuse into the concrete. As such it is important that the concrete element subjected to aggressive environments is designed and manufactured using appropriate methods to provide long term durability and confidence.

Estimating the service life of such structures is made all the more difficult by the uncertainty of conditions which are likely to prevail at the concrete surface. While the concrete structures standard AS 3600 has an exposure classification C for durability, defined as "sea water, in tidal or splash zones", the splash zone above the high water mark is actually more severe than areas washed by the tide. Given the complexity of processes leading to corrosion of reinforcing steel in concrete by chloride it is not surprising that structures designed and built using an earlier state of knowledge have often failed to live up to expectations.

EXPERIENCE WITH CONCRETE PIPE

This however has not been the case with steel reinforced concrete pipes. Surveys carried out by the Concrete Pipe Association of Australasia and its Australian members, first in 1988, and extended further in 2000[2], found little or no deterioration in concrete pipes that had been subject to tidal flow. This included several instances where the cover to reinforcement was less than 15 mm. According to American experience[3]:

"There are no reports or evidence of any chloride induced corrosion problems with buried precast concrete pipe."

Compared with other types elements such as marine structures this raises the question, is the difference in the concrete or in the type of exposure? Since different manufacturing techniques are used to make concrete pipe in Australia and America the similar performance cannot be attributed to the manufacturing process (even though different processes may in fact give similar outcomes). The American publication attributes the absence of problems "to a lack of the proper mechanism to concentrate chlorides in concrete, a lack of oxygen, and the high strength, low absorption properties of precast concrete pipe."

As part of the Australian survey of 2000 a core was taken from one of the pipe samples which had been in service for 55 years. Examination of the reinforcement showed minimal corrosion. The concrete was analysed for chloride, giving a concentration at reinforcement depth at 0.7% of the concrete (corresponding to about 4% of the cement). This was significantly higher, by a factor of 10, than the commonly accepted threshold for initiation of corrosion. The consultants at that time, Taywood Engineering, who carried out the examination, concluded that:

"The apparently low incidence of corrosion initiation may be due to a combination of bound chlorides raising the corrosion activation level, the very dense cement matrix, which promotes a stable passive film, and saturated concrete, which restricts oxygen ingress required for corrosion processes."

The Australian & New Zealand concrete pipe standard AS/NZS4058 "Precast concrete pipes – pressure and non pressure" recognises the environment in which the interior surface of a concrete pipe may be subjected to tidal flow. The exposure classification known as marine environment is defined as:

"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 4.2 of AS/NZS4058 then outlines the appropriate depths of cover required for the steel reinforcement under these conditions, as well as the standard "normal" environment for both the barrel and socket and at the mating surface of the spigot. However, Appendix E of AS/NZS4058 goes further than Table 4.2 and provides information pertaining to the appropriate cover depths for concrete pipe subjected to environments not covered under normal or marine exposure.

Appendix E recommends the maximum concentration limits of soil and terrain constituents that a concrete pipe can be subjected to, yet maintain the minimum 10mm cover in the barrel (as defined for a normal environment). It also reminds the specifier that the durability performance of a buried pipeline system is dependent on the time of continual exposure to these constituents (at various levels of concentration). Significantly, Table E1 of the Appendix suggests that concrete pipe can be made with the minimum cover of 10mm when exposed to chlorides at the maximum concentration limit of 20,000 p.p.m in the groundwater.

This is undoubtedly less severe than open-air environments where salt is concentrated on the surface of the concrete, and, in spite of the shared reference in the marine environment definition to "tidal", is quite different from exposure classification C as defined in AS 3600.

PROTECTION OF STEEL IN CONCRETE AND THE EFFECT OF CHLORIDE

Despite common opinion, the mitigation of chloride ions through concrete not actually affect the material. However when they reach the steel reinforcement the passivating influence of the alkalinity around the steel is broken down and this is where corrosion may occur. Passivation depends on high pH provided by the cement, and is destroyed by a sufficiently high concentration of chloride. If the chloride level in the water is below the concentration required to destroy the passivity layer, the steel will not corrode.

The mechanism by which steel in concrete is protected from corrosion, even in the presence of moisture and oxygen, and how the presence of chloride can allow corrosion to take place, is explained as follows[4]:

"Steel embedded in hydrating cement rapidly forms a thin passivity layer of oxide which strongly adheres to the underlying steel and gives it complete protection from reaction with oxygen and water. - Maintenance of passivity is conditional on an adequately high pH of the pore water in contact with the passivating layer. - However, chloride ions destroy the film and, in the presence of water and oxygen, corrosion occurs."

Relationships between pH and salt (sodium chloride) levels to allow corrosion of reinforcing steel were investigated by Shalon and Raphael[5], and to induce stress corrosion cracking in high tensile steel by McGuinn and Griffiths[6]. Both test series involved immersing samples in solutions of sodium chloride and either cement extract or calcium hydroxide, the main agent of alkalinity in concrete. The solutions remained in contact with the atmosphere, providing oxygen if the condition was such as to allow any corrosion. For the corrosion series, assessment was by weight loss, allowing each example to be classified as passive or active, and for the cracking series by stability or extension of previously induced cracks.

Results are shown in Fig. 1, and while cracking of high tensile steel is not relevant to concrete pipes used in salt water conditions it is of interest that a similar pattern is shown by both sets of data – for low salt levels a dependence on pH but at higher levels, to the maximum investigated, a threshold pH above which there is no effect. For ordinary reinforcing steel this is below the minimum level of pH 12.6 provided in the concrete by saturated calcium hydroxide. Alkali in cement, in addition to the calcium hydroxide, will usually result in pH above 12.6, giving a further margin, and passivity is maintained at salt levels well above the typical value for sea water, which contributes chloride equivalent to sodium chloride at about 3%. The effect is further illustrated by photographs of samples of reinforcing steel used for pipes, set up for the purpose of demonstration, in Fig. 2.

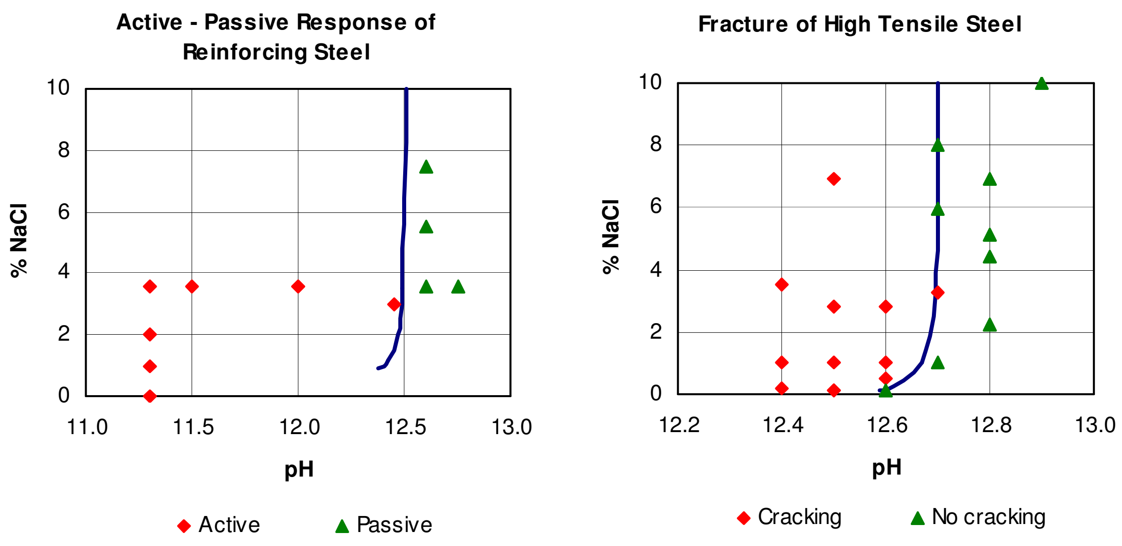

Figure 1. Effect on steel of alkaline solutions containing sodium chloride

Figure 2. Samples of reinforcing steel in salt solution

CONCLUSION

In view of these data it is no surprise that steel reinforced concrete pipes buried underground, that are exposed to levels of chloride as great as the level found in sea water, show no deterioration even after very long periods of service. The rate of chloride penetration, given so much emphasis in investigation of above ground structures, is just about irrelevant. The reinforcing steel in concrete *in equilibrium* with environments containing moderate levels of chloride, whether from sea water or groundwater, is not subject to corrosion provided only that alkalinity is maintained at reinforcement depth. Salty water is no more able than fresh water to corrode the reinforcement.

This puts the onus squarely on maintaining alkalinity at reinforcement depth (i.e. the concrete at this depth must not be carbonated) but in terms of required cover this is no greater than would be necessary in a normal environment. Some extra cover for marine exposure may be justified on the basis that the greater the specified cover, the less the risk of reinforcement accidentally being placed at too shallow a depth. However there is no correspondence with high levels of cover required for the most severe open-air environments.

REFERENCES

1. D Baweja, H Roper, V Sirivivatnanon, "Specification of Concrete for Marine Environments", ACI Materials Journal 96, No. 4, July-August 1999, pp 462-470.
2. "Durability of Concrete Pipe in a Marine Environment", Concrete Pipe Association of Australasia, 2000. Available on CPAA website www.concpipe.asn.au.
3. M Bealey, "Durability Considerations – Precast Concrete Pipe", The Katherine & Bryant Mather International Conference on Concrete Durability, Atlanta, 1-7 May 1987, pp 493-508.
4. A M Neville, "Properties of Concrete", 4th edition, Longman, 1995, p 498 & p 563.
5. R Shalon, M Raphael, "Influence of Sea Water on Corrosion of Reinforcement", Journal of the American Concrete Institute, June 1959, pp 1251-1268.
6. K F McGuinn, J R Griffiths, "Stress Corrosion Cracking of Cold Drawn Eutectoid Steel Wire", Third Tewksbury Symposium, 1974, pp 274-285.

admin@cpaa.asn.au
www.cpaa.asn.au