Concrete pipe in tidal flow or saline ground conditions

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Introduction

For severe salt water environments, reinforced concrete will usually be specified with a high strength grade, high cover and an additional property aimed at ensuring that the concrete will delay as far as possible the penetration of chloride to reinforcement depth. The ASTM rapid chloride test C1202, resistivity (1) or a prescribed minimum amount of SCM 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. Estimating service life of a structure is made more difficult by uncertainty about conditions which will prevail at the concrete surface. While the concrete structures code AS 3600 has a classification C defined as “sea water, in tidal or splash zones”, the splash zone above the high water mark is in fact 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 concrete pipes. Surveys carried out by the industry in Australia, first in 1988 and extended in 2000 (2), found little or no deterioration in pipes subject to tidal flow, including several instances where the cover to reinforcement was less than 15 mm. According to American experience (3)

> *There are no reports nor evidence of any chloride induced corrosion problems with buried precast concrete pipe*.

Compared with other types of marine structures this raises the question, is the difference in the concrete, or in the type of exposure? Since different manufacturing techniques are used in Australia and America the similar performance cannot be attributed to the *same* aspects of the manufacturing process, 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 examples, 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 0.7% of the concrete (corresponding to about 4% of the cement) – significantly higher, by a factor of 10, than the commonly accepted threshold for initiation of corrosion. Consultants 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/NZS 4058 recognises “an environment in which the interior pipe surface is subject to tidal flow”, which 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 to “tidal” is quite different from AS 3600’s exposure classification C.

Protection of steel in concrete and the effect of chloride

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, are 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.*

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.

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,

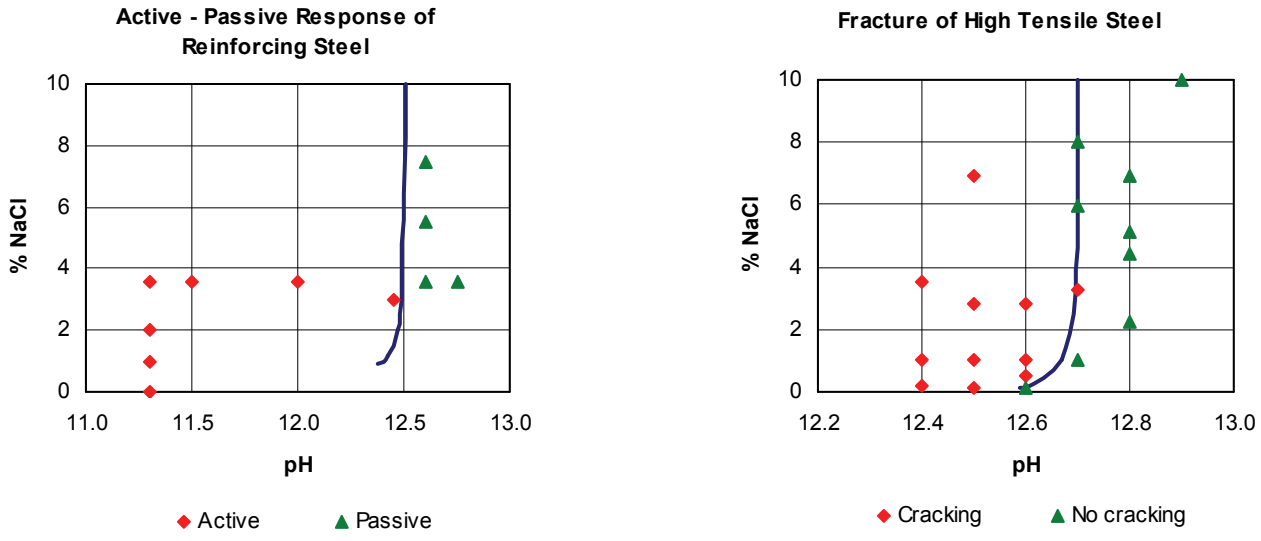

Fig. 1. Effect on steel of alkaline solutions containing sodium chloride

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.

Minimum cover to reinforcement

In view of these data it is no surprise that concrete pipes underground 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 – ie the concrete at this depth is not 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.

Fig. 2. Samples of reinforcing steel in salt solution

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