ABSTRACT
Marine environment is the most severe exposure condition for reinforced concrete structures due to the presence of moisture, chlorides and sulphates. Coastal and offshore structures are subjected to time-dependent deterioration due to chemical attack and steel corrosion. The components of the concrete jetties show rapid deterioration due to the combined effects of abrasion, corrosion and changes in both temperature and moisture content. Maintenance of concrete jetties is a major concern to Port and Harbour Authorities in both developing and developed countries. This paper reviews the possible deterioration mechanisms, inspection techniques and restoration methods used for concrete jetties. Restoration methods can be grouped into four categories, namely, conventional repair, cathodic protection, chloride extraction and protective coatings. Advantages and disadvantages of these methods are discussed. Restoration strategy needs to cover issues such as (a) whether a short-term or long-term strategy is needed; (b) merits and limitations of restoration methods; (c) procedures of the restoration techniques; (d) criteria for successful protection of jetties; and (e) comparison of initial and on-going cost.

1. INTRODUCTION
Coastline of Australia has many reinforced concrete jetties in service and some of them were constructed over 20 years ago with the materials, specification and technology existed at that time. Due to the severity of the exposed environment, it is not surprising to see some jetties with signs of deterioration. They require restoration for their continuous service. The maintenance of the jetties is a major concern to the Port and Harbour Authorities in Australia.

A concrete jetty consists of several components including, piles, headstocks, edge and centre beams, deck planks and top deck. They are subjected to different exposure conditions depending upon their locations in the structure. The pile sections may be in one of the following four zones namely, mud zone, submerged zone, tidal and splash zone and atmospheric zone. Other components may be subjected to tidal, splash or atmospheric zones. The main cause for the deterioration of the jetties is the diffusion of chlorides, carbon dioxide and sulphates into the cover concrete. To minimise the maintenance cost and to enhance the service life, it is necessary to develop maintenance programs based on the proper understanding of the deterioration mechanisms. In addition, a sound knowledge on the repair techniques is needed to make informed decisions on the possible repair options. This paper reviews the deterioration mechanisms, inspection techniques and restoration methods for reinforced concrete jetties.
2. DETERIORATION MECHANISM REINFORCED CONCRETE JETTIES

Marine environment is the most severe exposure condition for reinforced concrete structures due to the attacks by sulphates, acidic water, freeze-thaw action, chlorides and carbon dioxide. Damage patterns in marine concrete structures vary from loss of concrete sections through chemical attack to cracking and spalling due to corrosion of steel in concrete. Permeability of concrete, which influence the rate of deterioration in concrete jetties, is affected by factors such as water to binder ratio, curing condition, compaction of concrete and degree of cracking. The use of fly ash or ground granulated blast furnace slag is found to increase the corrosion resistance of concrete due to the reduction in the permeability of concrete [1 - 3].

Concrete is an excellent material to provide protection to steel against corrosion due to its high alkalinity (pH of 12.5 or more). However, the ingress of carbon dioxide into concrete reduces the alkalinity (pH of below 10) and depassivates the steel thus increasing the risk of steel corrosion in the presence of oxygen and moisture. In a concrete jetty, the chloride ions migrate through the concrete to reach the reinforcing steel level. The rate at which this occurs is dependent on several factors, including the concrete cover and permeability, drainage, wetting and drying cycles, temperature, degree of cracking, and effectiveness of other protective methods. The chloride ions reduce the electrical resistivity and alkalinity of concrete. The levels of chloride required to initiate corrosion are extremely low and suggested between 0.2 and 0.4% of the cement weight, depending upon the tricalcium aluminate content in cement used. [4]. Even at high pH in concrete, chloride ions have the ability to destroy the passivity of steel reinforcement.

2.1 Electrochemical corrosion of steel

It is well known that the corrosion of steel in concrete is an electrochemical process. The following chemical reactions indicate the corrosion processes. The corrosion products are two to eight times of the volume of the iron.

\[
\begin{align*}
Fe &\rightarrow Fe^{++} + 2e^- & \text{Anodic reaction} & \text{Eq. (1)} \\
4e^- + O_2 + 2H_2O &\rightarrow 4(OH)^- & \text{Cathodic reaction} & \text{Eq. (2)} \\
Fe^{++} + 2(OH)^- &\rightarrow Fe(OH)_2 & \text{Ferrous hydroxide} & \text{Eq. (3)} \\
2Fe^{++} + 6(OH)^- &\rightarrow 2Fe(OH)_3 & \text{Ferric hydroxide} & \text{Eq. (4)} \\
2Fe(OH)_3 &\rightarrow Fe_2O_3 + 3H_2O & \text{Ferric oxide} & \text{Eq. (5)} 
\end{align*}
\]

It can be seen that during the corrosion process oxygen is consumed and water is regenerated. Hence, the corrosion process is continued once it is started. There is no steel corrosion in a completely dry atmosphere, probably below 40% R.H. and also in water submerged condition. The optimum relative humidity for the corrosion of steel to occur is between 70 and 80%. At higher humidities, the diffusion of oxygen is considerably reduced and the environmental conditions become more uniform along the steel.

2.2 Corrosion of steel in the presence of chloride ions

In concrete jetties, the migrated chlorides react with water to form hydrochloric acid, which destroys the microscopic passive ferric oxide layer on steel surface. The activated locations in the steel surface become the anode areas whereas; the passive areas in steel act as the cathode areas. The ensuring corrosion is in the form of localised pitting. In the presence of chlorides, the schematic reactions are as follows:
Fe$^{++}$ + Cl$^-$ + H$_2$O $\Rightarrow$ Fe(OH)$_2$ + HCl (acid)  
\[ \text{Eq. (6)} \]

HCl $\Rightarrow$ Cl$^-$ + H$^+$  
\[ \text{Eq. (7)} \]

Eqn. (7) indicates that the generation of chloride ions. The other reactions, and especially the cathodic reaction, are as in the absence of chlorides as shown in Eqns. (1) to (5).

Because of the acidic environment in the pit, once it has formed the pit remains active and increases in depth. Pitting corrosion takes place at a certain potential, called 'pitting potential' which is higher in dry concrete than that for wet concrete. As soon as a pit is formed, the potential of steel in the neighbourhood drops, so that no new pit will be formed for some time. Eventually, there may be a large-scale spread of corrosion. It must be emphasised that electrochemical corrosion can only occur in the presence of water and oxygen. Even if there are large quantities of chloride, there will be no corrosion, if the concrete is dry.

3. INSPECTION OF CONCRETE JETTIES

A proper maintenance program for concrete jetties should include periodical inspections by qualified personals to assess the conditions of the jetties. Early detection of the deterioration is essential to minimise the cost of repair and to increase the service life of the jetties at minimum cost. Deterioration of the concrete jetties can be evaluated by using a combination of visual inspection and detailed examination of the structural components. This can lead to identification of the deterioration mechanisms and proper selection of the restoration methods.

3.1 Visual inspection

A visual inspection should be carried out on concrete jetties, before any detailed investigation is conducted. In general, any concrete jetty should be inspected regularly once in six months by a qualified technician or an engineer. The records of the previous inspections can be used to indicate the changing conditions of the concrete jetty. Types of deterioration such as, rusting, staining, size and shape of cracking, major and minor spalling and delamination of existing coating should be investigated. The locations of the deterioration should be noted and classified into areas such as, piles, headstocks, edge beams, centre beams, deck planks and top deck. Assessment can be made to identify the deterioration in relation to the exposure conditions of the members, such as seaward side or landward side members. Patterns of deterioration should also be noted. The length and width of the cracks should be measured and locations such as, parallel to and co-linear with bottom steel should be identified.

3.2 Chloride sampling

It is necessary to perform drilling at several locations in the concrete jetties to determine the chloride profiles. For the purpose of consistency that samples should be taken at regular distances from the main steel bars and some centrally between the bars. The drilling locations should be about 50 mm from the reinforcement in non-repaired concrete sections. At each sampling point, a 10mm diameter hole should be drilled into the concrete using a hand-held electric drill to a depth of 75mm. The drillings should be collected carefully from the depths up to 25 mm, from 25 to 50 mm and 50 to 75 mm. The depth intervals for the collection of the drillings can be reduced to increase the accuracy. However, this involves additional testing of the samples and increases the cost of investigation.

The drillings should be tested for acid soluble chlorides according to the relevant method. The acid soluble chlorides are bound chlorides, which are not likely to cause corrosion whereas the water-soluble free chlorides are likely to cause steel corrosion. However, it is possible that...
the bound chlorides could become free with time to increase the corrosion risk for steel. Therefore, testing for acid chlorides is a conservative approach.

3.3 Half-cell potential measurements

Electrical potential of the embedded steel in concrete can be measured using a half-cell (either Cu/CuSO$_4$ or Ag/AgCl) and the readings taken at various locations can be used to produce potential mapping. This method is applicable to all members of the concrete jetty, regardless of their size or the concrete cover. The potential mapping is useful to locate the corrosion activity in visually sound areas of the concrete structures. There is no minimum spacing requirement between the half-cell potential measurement locations. The readings taken with a wide spacing may neither detect corrosion activity nor provide sufficient data for proper evaluation. Engineering judgment is needed on the spacing, which should be consistent with the concrete members and the intended use of the results. Spacing can be reduced where adjacent readings exhibit voltage differences over 150mV, since this indicates a high degree of corrosion. Minimum spacing generally should provide at least 100mV difference between the readings.

Using ASTM C875-80 classification, the concrete jetty can be categorised into three zones: (i) zone where the potential is more than -200mV indicating 95% probability of the absence corrosion (passive state); (ii) zone with the potential between -200mV and -350mV representing an uncertain area (unknown state); and (iii) zone with the potential less than -350mV indicating 95% chance of corrosion (active state). If positive potential is obtained, then it generally means that there is insufficient moisture in concrete and the reading is considered invalid. In order to locate the probable locations of the corrosion activity in jetties, it is necessary to know both potential of steel and electrical resistivity of concrete.

4. RESTORATION METHODS

Restoration methods can be grouped into four categories namely, conventional repair, cathodic protection, chloride extraction, and protective coating. This section reviews these methods in relation to the procedures, advantages and limitations.

4.1 Conventional repairs

Convention repair method involves in filling up the cracked and spalled areas with suitable patching or filling material such as, mortar, concrete, epoxy resin or epoxy based mortar. However, the corrosion of the steel will continue within the unrepaired section and new cracks and spalls will appear soon or later. Even if protective coatings were applied to the total concrete surface, chloride induced steel corrosion would continue to progress in some members, resulting in staining, cracking and spalling.

4.1.1 Restoration technique for spalled members

At the spalled and cracked locations, concrete should be removed up to about 25 mm above the bottom steel level using a power hammer or by high pressure water blasting. Saw-cuts can be made on the inner and outer sides of the beams to controlled depths without damaging the stirrups or main bars. The exposed sections of the steel bars should be cleaned and immediately coated with cement slurry, which can be prior to the setting of concrete forms. If more than 10% of the bar section is lost then additional steel should be added to replace stirrups for the beams. For both deck and edge beams conventional repairs can be used. In the case of deck beams, low permeable concrete can be placed via feed holes drilled through the deck. These holes are used to access the concrete by poker vibrators, which supplement form
vibrators fixed to the underside of the beams. Once the concrete sets the forms can be removed and the newly formed concrete surface should be prevented from drying so that curing can be promoted.

4.1.2 Restoration technique for cracked members

Wide cracks in the headstock, edge beams and deck beams can be repaired by filling up the cracks with repair materials such as, cement paste and epoxy mortar. Prior to the repair, it is necessary to remove any loose materials along the cracks and the corroded bars should be wire-brushed. The cracks wider than 0.5 mm should be cut out and the voids should be filled with either cement mortar or epoxy mortar. Narrow cracks should be surface sealed and holes should be drilled along the crack line. They can be filled with a low viscosity epoxy forced through a series of nipples fixed in the drilled holes.

4.1.3 Advantages and limitations of the conventional repairs

In the short-term, the conventional repairs are least expensive to restore the condition of concrete jetties. It is the "quick-fix" solution and provides a new and clean wearing surface. The workmanship for conventional repair must be of high standard for its effectiveness since the jetties are in marine environment. Compared to other restoration methods such as, chloride extraction and cathodic protection, the long-term cost is more, since the conventional repair has to be carried out at least once in five years. The chlorides in the older sections of the concrete remain and they may induce further steel corrosion due to their diffusion. In addition, the ingress of new chlorides into the repaired areas is possible. When the conventional repairs are being carried out it may be necessary to limit the use of concrete jetty, causing inconvenience to the users of the jetty.

4.2 Cathodic protection (CP) system

In an electro-chemical process, the cathode is the area where the harmless chemical reaction occurs, whereas the corrosion occurs at the anode. Cathodic protection (CP) method works by providing electrons from an external direct current power supply via an external anode installed on or in the system. When the electrons flow between the anode and the reinforcement it makes the reinforcement into a cathode, thus preventing it from corrosion. Grapiglia and Green [5] explained that the application of the driving current provides protection as a consequence of the following effects:

- The net positive current flow towards the steel stifles the flow of positive iron ions away from the surface.
- Potential of the steel surface is polarised to values more negative than the pitting potential, which restricts the dissolution of iron ions.
- Chloride ions are transported away from the steel surface by the ionic current flow.
- Hydroxyl ions, formed at the steel surface by the reduction of oxygen, increase the pH around the steel.
- Oxygen is consumed at the steel surface, which reduces the capacity of the steel to support the cathodic and anodic reactions.
- The production of adsorbed free radical and metal oxide intermediates on the steel surface, which favour passive film formation.
4.2.1 Types of cathodic protection systems

An important factor when designing a cathodic protection system is the type of anode used. The Society of Cathodic Protection of Reinforced Concrete classifies the cathodic protection system into three types. In the first type, anodes embedded in cementitious overlays on concrete increase the dead load on the structure and change the profile such as, raising the deck level. In the second type, anodes are conductive coatings, usually paints or thermal sprayed metals, which are less hard wearing but do not change the load or profile. Finally, anodes embedded in slots or holes cut in concrete, which can be harder wearing than coating without changing the load or the profile of the structure.

Design of a CP system requires the knowledge on the physical condition of the structural components as well as their electrochemical state. The design process involves the development of the most efficient, cost effective and durable system of distributing the appropriate current levels to the members being protected. Following design aspects should be considered, prior to the installation of a CP system:

- If the reinforcement is electrically discontinuous, then stray current corrosion can occur under the influence of impressed current.
- Cathodic polarisation yields hydroxyl ions, thereby increasing the pH of the pore water at the cathode. Susceptibility of the alkali-aggregate reaction in concrete should be assessed.
- Hydrogen gas can be produced as a cathodic product on the steel if it is over-protected. This could lead to a reduction of the bond strength of steel to concrete.
- Electrical resistivity of concrete can vary depending on moisture content, chloride content and temperature of concrete. Thus, a concrete jetty needs to be divided into various zones, enabling different levels of treatment to be set.
- The density of reinforcement and the quality of concrete can influence the levels of required cathodic protection.
- To avoid short circuits, the surface mounted anode must not come into contact with the metallic embedment.
- Since an electrical current cannot be transmitted across an air gap all fractured and delaminated areas need to be removed and replaced prior to treatment.

For a CP system designed for a minimal maintenance for a period not less than 30 years, the design current density on steel reinforcement embedded in concrete of 20mA/m² should be used. Where tidal effects may influence the circuit resistance, the CP system should be designed to operate in discrete zones. Zoning shall optimise uniformity of protection and allows adjustments to be made to achieve uniformity of protection.

4.2.2 Cathodic protection criteria

For reinforced concrete structures, the recommended criterion set by the National Association of Corrosion Engineers which stipulates that the reinforcing steel must be polarised with a minimum 100mV at anodic locations for effective CP and the polarisation decay method can be used to verify the required polarisation. Under the decay method, the decay is determined by switching off the protective current and measuring the reinforcement's potential shift from the 'instant-off' potential.

The recommended depolarisation shift criterion stipulates a minimum of 100mV potential decay over sufficient representative points within the structure being protected, subject to a most negative limit of approximately -1100mV, with respect to Ag/AgCl 'instant-off' potential. The potential decay is the difference between the 'instant off' potential and the potential measured after 4 hours of switching off. In addition, potential shift criterion and absolute potential criterion can be used for CP systems. The potential shift criterion stipulates...
that a minimum 150mV negative shift from the base potential (prior to commissioning of CP) to the 'instant off' potential. The absolute potential criterion indicates that the instant off potential should be -800mV (Ag/AgCl) or more negative. This criterion is more suitable for sections immersed in seawater or frequently wetted by seawater.

4.2.3 Advantages and limitations of cathodic protection method

In the last decade, cathodic protection has emerged as a strong corrosion control and prevention technique for reinforced concrete structures where deterioration was caused by chloride induced corrosion of reinforcing steel [6 - 7]. In this method, structural benefits are also achieved since chloride ridden concrete behind the steel need not be removed. Expensive and complex propping of structures may not be required if the chloride-affected concrete is not removed. Other advantages of cathodic protection are minimum disruption to the functioning of the jetty as well as the absence of noise, dust, debris and vibration during the restoration period.

Since the acid substance produced effects the life of the anode, it is necessary to monitor the current to maximise the life of the CP system. The capital cost of a CP system is high compared to the conventional repair. In addition, on-going anode maintenance and monitoring of the performance of the installed CP system leads to additional expenses. One of the main disadvantage of the CP system is that the performance criteria is not comprehensively defined for reinforced concrete structure and some reinforcement may be over-protected.

4.3 Chloride extraction method

The objective of chloride extraction is to remove chloride ions from the otherwise sound concrete. The method is basically a simple process, in which chloride ions are transported out of the concrete by ion migration under the influence of an electrical field. Simultaneously, the pH level of the concrete surrounding the reinforcement is increased sufficiently to passivate the reinforcement and prevent corrosion from taking place.

Chloride extraction is performed by applying an electrical field between the steel in the concrete, as the cathode, and an externally mounted electrode mesh, as the anode. The electrode mesh is embedded in a sprayed-on mixture of water and cellulose fibre. During treatment, negatively charged chloride ions are transported out of the concrete towards the positively charged external electrode mesh by means of migration, where they are trapped in a fibrous electrolyte mixture. Once the chloride content has been reduced to within the acceptable levels, and the pH of the concrete has been raised, the temporary electrolyte media, contains the chloride, is removed from the structure after necessary duration. This method is often used with the conventional repairs and protective coating.

4.3.1 Chloride extraction procedure

Corrosion potential survey and visual inspection are used for the selection of members for chloride removal. It is necessary to establish the chloride profiles at the selected locations by analysing the drillings taken from various depths and to confirm the areas for chloride removal. A round steel bar of at least 7mm in diameter placed through a drilled hole in the concrete cover is welded to the main steel. The opening in the cover concrete is then sealed with epoxy. Prior to mounting of the anodes, the concrete surface is thoroughly wetted with fresh water and kept wet until the impressed current is switched on.

Anode embedded in a conductive medium (electrolyte) is then separately prepared. A typical anode may consist of four layers of chicken wire mesh. A paper mache, produced by mixing of shredded paper, water and wallpaper paste with sufficient consistency, is used as the
electrolyte. To this mix, 10g of powdered graphite and 10g of builder's lime are added for 1kg of dry paper used. Mounting of anodes to the concrete surface should be done in such a way that no metallic fixing comes in contact with the live wires or paper mache. In the case of the soffit sections of the decks of the jetty, the anodes are mounted off the scaffolding or other rigid support using a series of jacks. In the case of headstocks, mountings are made using the jacks or ropes using tightening toggles. The concrete surface is thoroughly wetted in advance and gently sprayed with fresh water prior to pressing the anode into contact with the concrete surface. There should be a minimum delay between placing the anode and 'switching on' of the current. The current of 10A is applied when the corresponding voltage is below 100V. As drying and heating occur the resistance increase and when a reading of 100V is attained the system is 'switched off'. The effectiveness of the chloride removal can be determined by analysing the drillings for chloride content and comparing with the original chloride content, at various locations.

Once resistance rises too much, or sufficient time passed based on experience, the system is 'switched off" and the anode is removed as soon as possible. As the removal of chloride ions results in an increase in the permeability of concrete and the hydroxyl ions may have moved out with the chloride ions, it is important that pore blocking should be carried out and realkalization of concrete should be achieved. These two processes can be achieved at the same time by the treatment of the concrete surfaces with sodium silicate. In the presence of calcium ions sodium silicate undergoes base exchange, forming insoluble calcium silicate hydrate and sodium hydroxide, a strong base. The insoluble silicate blocks the pores, whereas the soluble hydroxide ions protect the steel from further corrosion. Once this treatment is over, the residual sodium silicate is removed by brushing without rewetting. Then, a solution of 40% by weight alkyl trialkoxy silicane in an anhydrous alcohol solvent should be applied to coat the concrete surface and to reduce the chloride ingress into concrete.

### 4.3.2 Advantages and limitations of chloride extraction method

The chloride extraction method allows large areas to be treated at a time and requires only a basic surface preparation. It re-establishes the corrosion protection of the concrete without affecting its quality or appearance. Since on-going treatment is not required, in the long-term it is cost effective compared to both cathodic protection method and the conventional repairs. The removal of chloride ions means the main cause of corrosion is removed. The chloride extraction performance criterion is simple, based on chloride measurements taken before and after extraction.

Electrochemical reactions occurring at the steel surface can cause a bond loss between the steel and the concrete if excessive polarisation of the steel occurs. The efficiency of chloride removal diminishes with depth beyond the steel level and the chloride ions from these areas are capable of diffusing into the treated cover concrete. High current densities can cause resistive heating during treatment, which in turn may lead to cracking.

### 4.4 Protective coatings

The main objective of using the protective coatings in the restoration of concrete jetties is to prevent the ingress of moisture, chlorides, carbon dioxide and other aggressive substances into the concrete. They can be applied after remedial works or on newly built structures. The preparation of the concrete surface is necessary to improve the adhesion of the coating material. Loose materials, dirts and contaminant should be removed by suitable cleaning methods. To ensure a maximum penetration, the silane is applied by saturation flooding using a low-pressure spray. At least two applications are necessary and the interval between each application should not be less than 6 hours. For better results, impregnation of silane should
not be carried out when the shade temperature is below 5°C or the concrete temperature is greater than 25°C. The depth of silane penetration can be tested by taking 50mm diameter by 50mm long cores. By spraying each core with a temporary volatile dye, the depth of silane penetration can be established.

4.4.1 Advantages and limitations of using silane coating
Since the silane coating allows the concrete to lose moisture and prevents moisture from entering into concrete, the moisture content of the concrete is gradually reduced with time. This in turn increases the resistivity of concrete and decreases the risk of steel corrosion. The silane treatment can make the concrete to resist the ingress of chloride ions and is equal to 120mm of extra good quality concrete cover. Since silane is capable of reacting with concrete to form a bond and therefore the protective coating is more durable.

5. CASE STUDIES

5.1 Greenwell Point fisherman's jetty
Greenwell Point fisherman's jetty in NSW was built in 1979 and consists of H-section steel piles, precast reinforced concrete deck and edge beams. The deck and headstocks were constructed with in-situ concrete. The concrete specification indicated that 20MPa concrete was used with the concrete cover of 65 mm. There was not much cracking or spalling evident on the jetty. Chloride analysis indicated the chloride content was less than 0.1% by mass of concrete at the steel level. Hence, chloride extraction method was not considered for restoration.

To prevent the chloride-induced corrosion of steel, cathodic protection method was chosen. Two anode systems were tried out, namely panel CP system in one of the jetty beams and a combination of discrete internal anodes and strip anode systems to two jetty beams. The results showed that without reaching an 'instant off' potential of more negative than 1100mV a polarisation shift of greater than -150mV was reached in both systems used. The potential decay criterion for the second system was tested and found to meet the minimum 100mV decay.

5.2 Eden Mooring jetty
Mooring jetty in Eden Harbour in NSW was constructed in 1980 and consists of steel tubular piles, cast in-situ reinforced concrete headstocks, precast edge and deck beams and a cast in-situ reinforced concrete deck. Sulphate resisting Portland cement, which had a poor corrosion resistance due to low tricalcium aluminate content, was used in the concrete mix. The undersides of the deck were coated with Vandex sealant and the concrete cover was 40mm. Failure of the coating also contributed to the deterioration of the deck.

Since late 1980's, the jetty showed signs of chloride-induced corrosion damages. An inspection in 1988 indicated the existence of cracks in 19 of the 28 headstocks and numerous fine cracks on the deck beams. The corrosion cell was formed with the steel in the in-situ deck as the cathode and the steel in the beams and headstocks as the anode. Due to high concentration of chlorides in the concrete, chloride extraction method was chosen as the restoration method. The extraction was first carried out for 72 hours using a 110V/10A DC machine. At any time, the maximum voltage and current were not reached due to constant monitoring and adjusting. Post treatment testing was done to determine the need for further chloride removal. A 24 hr cool down period was required before further treatment was carried out. Following the treatment, sodium silicate product was applied followed by the application
of silane coating. Chloride sampling showed that the effectiveness of the chloride extraction method depended on factors including, initial chloride content, moisture content, previous repair history, size and condition of the member and sampling location factor.

6. CONCLUDING REMARKS

The major cause for the deterioration of reinforced concrete jetties is the ingress of chloride ions. Visual inspection and detailed investigation can be used to identify the deterioration mechanism and appropriate the restoration program must be chosen. Restoration strategy needs to cover issues such as (a) whether a short-term or long-term strategy is needed; (b) merits and limitations of restoration methods; (c) procedures of the restoration techniques; (d) criteria for successful protection of jetties; and (e) comparison of initial and on-going cost.

7. REFERENCES


