Research on the durability and application of RC in marine environments

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The author began research on the durability of RC in 1975 as a researcher at the Port & Harbor Research Institute of the former Ministry of Transportation. Although more than 40 years were spent on research, there are many problems. Sometimes the considerations differ from the authorized recommendations. I would like to summarize some fundamental considerations and applications that may not be authorized at present.

1. Fundamental considerations regarding the corrosion of steel bars in concrete
   - In almost all of the recommendations, the corrosion of steel bars in concrete is related to the chloride content or Cl-/OH- in the concrete/mortar/paste around the steel bars. In my opinion, the corrosion of steel bars is directly related to the solution surrounding it. In the case of the steel itself, the corrosion is related to the surrounding solution. The reason why the Cl- content in concrete/mortar/paste is used as an indicator for corrosion is because it is very difficult to measure the Cl- content of the solution around the steel bar. The author has proposed a 4-step method to remove the solution and measure the chloride content around the steel bar. These 4 steps are: 1) remove the steel bars from the RC; 2) measure the weight of the steel bars before and after drying (to determine the weight of the water); 3) wash the steel bar with distilled water (the weight should be measured) and measure the ions in the solution; and 4) calculate the concentrations of ions. Up to now the accuracy of this method has not been very effective, but the author proposes a threshold value of 10,000 ppm (Cl- concentration) as initiating the start of corrosion.
   - There is no mention about the spaces around the steel bars. For example, in the case of epoxy coated steel bars, the pH of the solution inside the epoxy may be less than 9, however, because there is no space between the epoxy coating and the steel bar, no corrosion can be observed. In the author’s view, if there is no space between the paste and the steel bar, then there is no corrosion, even though the paste has a high Cl content. Unfortunately, no good data is available to support this view.

2. How to determine the service life: prediction method and the influence of BFS (ground granulated blast-furnace slag) and the mixing water

Based on the research, the author proposes a method for predicting the service life of RC members that have steel bars with corrosion. There are many definitions of the end of service life, but these can be placed into four categories: 1) when corrosion starts (also said as initiation period); 2) when cracking starts; 3) when the cover concrete starts peeling off; and 4) when the load carrying capacity is below specification. The author chooses to define service life as 2) when cracking starts, for calculating and comparing service lives. Also, FIP's criterion (0.2 μA/cm2) is used for calculating the start of corrosion and Yokozeki's equation for determining when cracking starts. These calculations have many assumptions, such as submerged zones and cover depths of 70mm. Figs. 1 and 2 show the results of the calculations. The factors are the replacement ratio of BFS (0, 40, 55, and 70%), Water/Cement ratio (0.5, 0.7) and mixing water (tap and seawater). As shown in Fig. 1, it is clear that the initiation period with seawater is shorter than that with tap water. However, when the replacement ratio is 55% and the W/C 0.5 (◆), the periods even with seawater are longer than when the replacement ratio is 0 (○,●). As shown in Fig. 2, in the case of a replacement ratio of 55% and a W/C of 0.5(◆), the service lives with tap water and seawater do not differ and are much longer than the others, despite the type of mixing water.

Therefore, the service life can be predicted from the initiation of corrosion and the propagation period. These results also show that, when only considering the initial period, concrete mixed with seawater may not be suitable. However, considering the summation of initiation and propagation periods as the service life, concrete mixed with seawater had almost the same service life as concrete mixed with tap water. Particularly in the case of BFS 55% and W/C 50%, the lifetime is about 40 years, which is almost same as that of tap water.

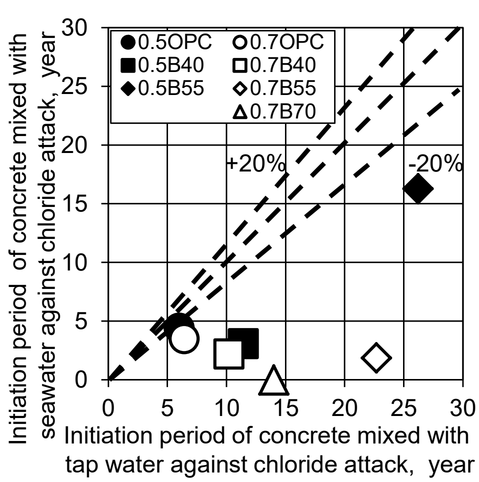

Fig. 1 Initiation periods

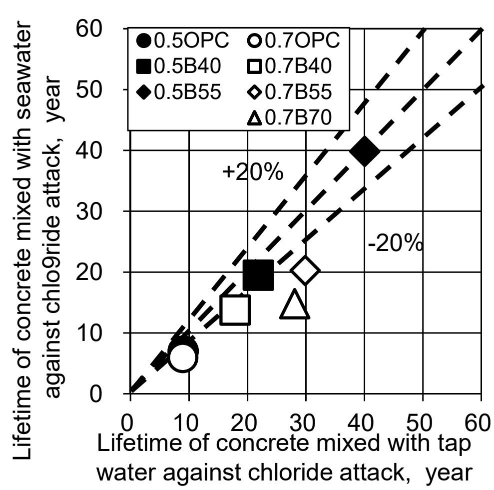

Fig. 2 Service life

3. Recent research on seawater concrete

Although the author's research indicates good results can be achieved from using seawater as the mixing water in both RC non-RC concrete, almost all of the recommendations in the world suggest not using seawater as the mixing water and curing water.

1) Use under very cold seas, such as in the Arctic Ocean

A feasibility study on the use of seawater concrete for constructing underwater structures is in progress. The conditions are as follows;

- In the Arctic region, rainfall is very rare and fresh water is very precious.
- In very cold conditions, the hydration speed is slow. With seawater, the speed may be faster and more beneficial for construction work.
- In very cold seawater (less than 0 degrees, steel corrodes at a slow rate.
- For RC constructed in seawater, the steel bars are arranged in the seawater before the concrete is placed.

With these considerations, the following investigation are in progress.

- With $CaCl_2$ as an accelerator, anti-washout underwater concrete with seawater are mixed and placed to underwater concrete member in laboratory tests and also the corrosion currents are measured.

Optimistically, the feasibility of this type of concrete is very high.

2) Use in deserts

Some researchers in desert regions (such as Kuwait) are very interested in seawater concrete, partly because of the lack of fresh water in these regions and the very low possibility of corrosion due to very little rainfall.

The author may or may not be successful in this research, but hopes that the younger generation will conduct research that looks at alternatives to conventional practices.