PORT AND OCEAN ENGINEERING UNDER ARCTIC CONDITIONS
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AN EXPERIMENTAL STUDY OF CORROSION OF REINFORCEMENT IN CONCRETE IN SEAWATER ENVIRONMENT

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A study of the corrosion of reinforcement in concrete exposed to seawater has been under work for several years at the Cement and Concrete Research Institute, Technical University of Norway. The test specimens used were concrete columns 15x15x100 cm, each reinforced with 4 main bars of diameter 16 mm and 5 stirrups of diameter 6 mm.

The concrete quality was varied systematically with a water-cement ratio between 0.5 and 1.0, the concrete cover ranged between 1.5cm and 4.5cm. The limits of the concrete cover as well as for the concrete quality were chosen well below limits used in practice, in order to secure a marked corrosion attack on the reinforcement within a reasonable length of time. Parallel series of test specimens of concrete with and without Air-Entraining-Agents were made, and the series were built up with sets of 3 similar specimens.

24 hours after casting the specimens were removed from the moulds and placed in tide-water tanks, where the sea-water level changed periodically in a natural tide-water rythm over the middle 60 cm's of the columns.

After about 3 months exposure to tide-water, the specimens with the lowest quality and the lesser concrete cover gave sign of corrosion attack in form of dark red colour spots on the concrete surface.

After about 36 months cracks were observed on some of the columns. The cracks were mostly found parallel to and just in front of the main reinforcing bars in the high-tide level zone. The development of the cracks was clearly influenced by the thickness of the concrete cover. At the same time it was found very few cracks on the specimens with low concrete quality which indicates a connection between the permeability of the concrete and the cracking phenomena.

During the time of exposure systematical measurements were carried out on all specimens, giving informations on the development of electrical potentials between the reinforcement and the concrete. These potential were measured by means of a mV-meter with high internal resistance using a standard kalomel electrode for transition to the nonmetallic phase.

The development between 12 months and 36 months indicates a progressive process of a shift in the potential level from about 50-100 mV to about 500 mV. The rate of this process is obviously dependant on the quality of the concrete and the thickness of the concrete cover. During the progress of this phenomena rather great gradients may occur in the potential along the surface. These gradients can only be maintained for that part of the concrete surface which at a given moment is above the actual water level. The submersed part of the concrete surface will obtain potentials with only small gradients corresponding to the high conductivity of the seawater compared with the conductivity of the concrete. Figure 1 gives the results from measurement at four different stages during the 12-hour tide-water period. The potential curves along the height of the specimen are given to the left in the figure with the water level marked in each case. The almost constant value of the potential below the water surface gives a form of mean value of the surface potential over the same areas.

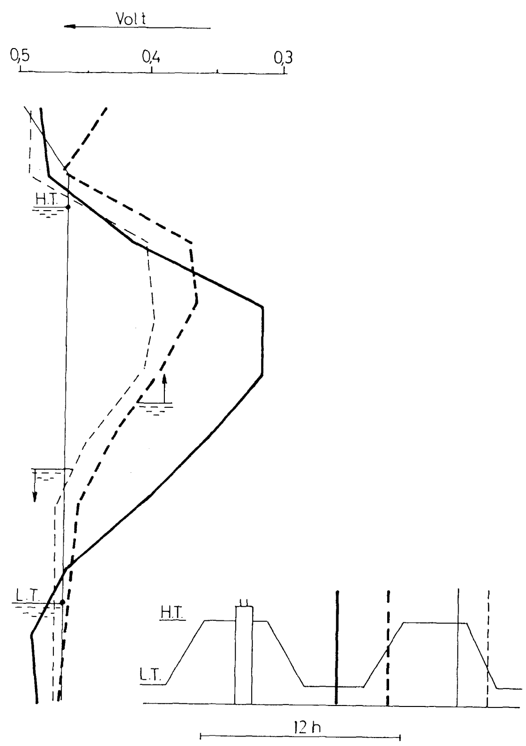

Fig. 1.

The actual resistance to transport of electicity between the different surface areas will change periodically with the tide-water rythm and is believed that this in general will tend to accelerate the attack of corrosion.

After 30 months of exposure a part of the specimens were split for inspection of the reinforcement. The concrete in different parts were analyzed for chlorine.

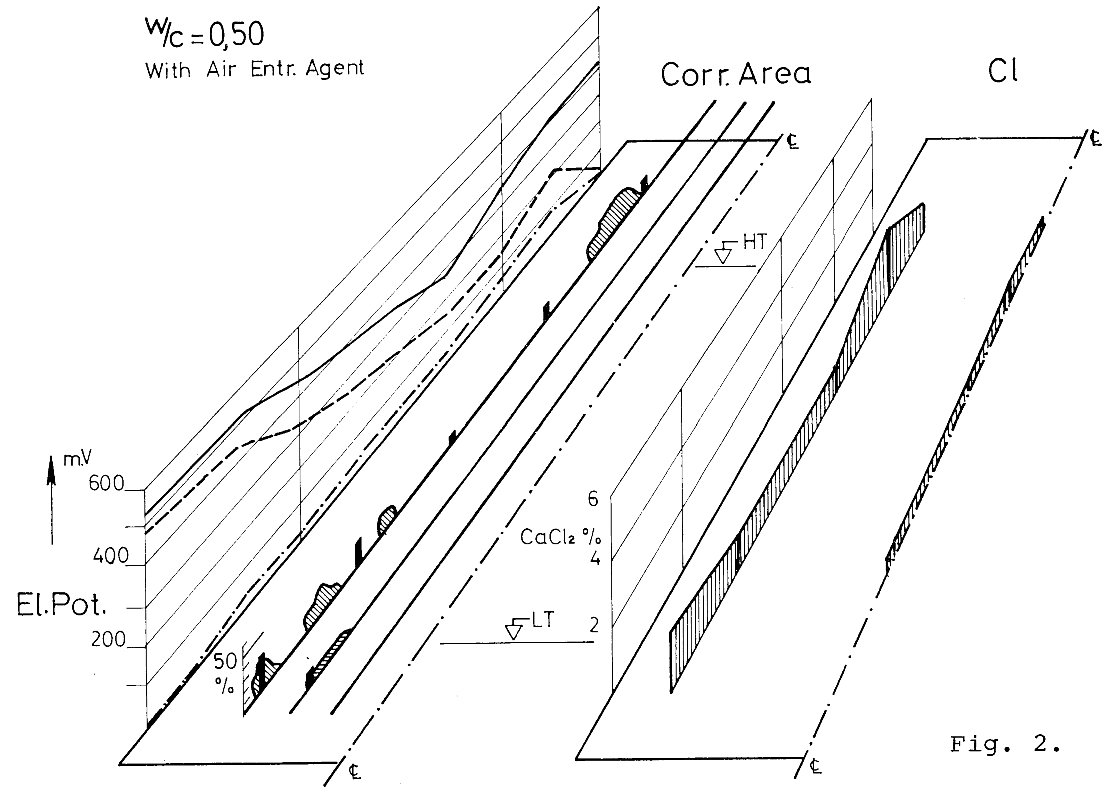

Fig. 2.

Fig. 2 shows the results for the specimens with w/c = 0,50 and with Air-Entraining-Agents. The state of corrosion of the steel is described as corroded area in percent on the total steel surface and is presented in a birds-eye-view diagram in the middle of the figure. The results from three specimens which differ only in the thickness of the concrete cover, are compared. The individual corrosion diagrams are located along the centre lines of the main reinforcing bars in the three different cases. To the left in the figure are given diagrams for the distribution of the electrical potentials measured on the same specimens just before splitting. To the right is shown the amount of chlorine as percent $CaCl_2$ of the cement weight, found in different heights in the center part and in the outher part of the concrete sections.

The specimen with concrete cover 4.5 cm showed no corrosion at this age, and the surface potential was found to be nearly constant with values about 50 mV. The amount of chlorine in the centre part of the concrete section is also small. The specimen with concrete cover 3.0 cm shows som e corrosion at the low-tide level. In correspondance to this the potential has reached 500 mV in the lower part of the column surface, but maintains the low values in the top section.

For concrete cover 1.5 cm corrosion appears in two areas more or less separated. The corresponding potential curve tends to follow this distribution. In the outher part of the concrete section the amount of chlorine is found to be about 2-3 percent $CaCl_2$ of the cement weight.

A general comparison of the amount of chlorine and the corroded areas found at this age indicates that under similar conditions corrosion will occur at least when the chlorine-content reaches a value about 1,0 percent.

The transport of chlorine and the more general transport of ions take place in the waterfilled part of the void-system of the concrete. The amounts of evaporable water (by 105^{o}C) found in the different concrete sections are compared with the total volumes of the different types of voids, based on calculations from the mix proportions. This will give a demonstration of what part of the total waterfilled volume that may be expexted to give room for chlorine transport in the concrete.

In the series described here the temperature in the water and in the air was close to 18^{o}C. The relative humidity in the air measured at some distance from the tanks varied with the season from about 40^{o} to about 60^{o} R.h.

In several additional series are under work studies of the influence of low temperatures and of high relative humidities in the surrounding air, as it is believed that these are decisive factors for the rate of the corrosion attack.