

EFFECTS OF STRESS CORROSION CRACK ON STEEL IN EMBEDDED CONCRETE UNDER MARINE CONDITIONS

B.T. Patil, G. Ranganna, Shrikanth Channel

Karnataka Regional Engineering College, Srinivasnagar 574 157.

A.B. Wagh, S.S. Sawant

National Institute of Oceanography, Goa 403 004.

and

M.R. Gajendragad

Mangalore University, Mangalagangotri, 574 199.

ABSTRACT

Corrosion of steel embedded in concrete is a complex electrochemical phenomenon. Out of many factors, stresses and cracks in the concrete structures play an important role in the corrosion of structures when the structures are exposed to marine conditions. An attempt is made to understand the behaviour of concrete structures under bending stresses. Evaluation of the corrosion of embedded stressed steel is done by monitoring the corrosion potentials by polarization technique. Appropriate concrete beams were prepared by bending the reinforcement rods with the help of bolts and nuts. The stress level in the steel is varied from zero to 23 N/mm². These specimens were exposed to marine conditions near Goan waters. Specimens were removed periodically at monthly intervals and the study continued for 5 months. They were subjected to polarization studies. The values of corrosion potentials obtained show that stress level points are vulnerable for severe corrosion.

INTRODUCTION

Under the combined effects of exposure to ocean environment and heavy structural loading, there are a number of other deteriorating processes taking place. It is observed that electrochemical corrosion of the reinforcement represents a severe threat to the durability of concrete. This is mainly due to the corrosive environment at the steel-concrete interface caused by permeation of chloride and hydroxide ions which reduce the alkalinity around the reinforcement thus lowering corrosion resistance of the concrete (Verbeck, 1978 and ACI-222, 1985). These factors are mainly responsible for the formation of micro-corrosion cells leading to the formation of anodic and cathodic zones. Further, these processes may be accelerated by cracks in the concrete because these cracks provide easy access to the corrosive medium (Tutti, 1978). The cracks may be widened by excessive corrosion of the embedded steel. The volume of the corrosion product being more than the volume of steel and so more space would be needed. In order to provide for the extra space cracks would develop. However, it may take a long time to reach this stage.

In addition to these factors, there exists another important factor namely stress in the structural element arising out of loading of the structure. Stress corrosion cracking will be more severe than the effect produced when stress and crack act separately.

In stressed steel, a small damage caused by corrosion can lead to a serious loss in tensile strength as corrosion

continues at the anodic area. The other possible factor may be stress corrosion cracking at its intergranular interface where hydrogen gas may be absorbed causing loss of ductility and cracking. The result of this may lead to reduction in the cohesive strength of steel.

EXPERIMENTAL SET UP

The performance of stressed and cracked concrete beams was studied in the marine environment of Dona Paula, Goa. Specimens of RCC beams (size of 50 x 80 x 1000 mm) of 1:1:2 grade with water cement ratio of 0.45, cast using ordinary Portland cement, crushed granite and river sand were used. Each beam was provided with two 10 mm diameter reinforcement rods with a cover of 20 mm. Provision was made for using the ends as anode terminals. The specimens were also provided with a hole of diameter 20 mm at each end for the steel bolt to effect stresses in the beam (Plate 1). The specimens were cured in potable water for 28 days. Then they were grouped into four categories.

First set: Beams without stress and without crack.

Second set: Beams with stress and without crack. For this, stress level at the centre of the beam was 27 N/mm² with no visible cracks observed on the specimens.

Third set: Beams under stress and with cracks. The stress level at the centre of the beam was 59 N/mm². At this level of stress a crack width of 1mm was observed very near the centre of the beam. Cracks were also observed on either side of the

centre. The crack width reduced from 1 mm at the centre to 0.3 mm at a distance of 100 mm on either side of centre.

Fourth set: Beams with crack but without stress. These beams were subjected to stress on account of which they developed cracks. After releasing the stress, the crack depths closed to some extent. The crack at the centre was about 0.3 mm while other cracks were not visible to the naked eye.

These specimens were kept in the splash zone in sea for a period of 5 months.

RESULTS AND DISCUSSION

The half cell potential values taken along the length of the beam using silver/silver chloride electrode in saturated KCl in respect of all the four sets of beams at various stages of exposure are shown in Figs. 1-6.

From these values one can readily see that there is a particular trend in the variation of potential along the bar. Half cell potentials are on the increase in all types of beams. But this increase is again influenced by the presence of either stress or crack or both.

Cracks have played an important role in the corrosion of steel bars. In the absence of stress and crack, half cell potential readings have increase from about -550 mV to about -568 mV over an exposure period of 4-5 months. But this trend is higher (-550 mV to -615 mV) when the bars were subjected to bending stress of 23 N/mm² at the centre of the beam with no visible cracks on the beam. Further, these values of potentials have increased when the stress level in the rod is also increased to 59.3 N/mm². The change in values at this stage is from -555 mV to -630 mV. It is also observed that the potential towards the end where bending stress is negligible remained more or less at a constant level around -570 mV. From these values it is observed that the bending stress induced in the steel bar contributed to increase in the potential. These stress levels might have resulted in almost invisible hairline cracks. These cracks will have an easy access to corrosive agencies like chlorine, oxygen etc. They also cause lowering of pH around the embedded steel.

The variation is found to be marginal at the initial stage of 3 day exposure. This may be due to ingress of ions into the concrete through the natural voids present in the concrete. This variation has shown some difference for an exposure time of 60 days or more. Stress levels and cracks have played an important role in increasing the corrosion potentials. But this trend has been arrested to some extent between 30 and 60 days. The main reason for this sudden variation could be the passivation of the steel surface. A similar trend has been observed when corrosion was monitored by the change in resistance when the exposure is continued beyond 60 days and the trend continues on account of the aggressiveness of

both the stress and cracks (Patil, 1985 and Patil et al, 1988). At this stage steel exhibits transpassive zone. The difference of potentials observed after 150 days is quite large.

CONCLUSIONS

Based on the observations and results of the present investigation conducted in marine environment, the following conclusions have been drawn:

1. Stressed and cracked concrete beams are more vulnerable to corrosion than mere cracked concrete beams.
2. Hairline cracks in the concrete structure coupled with applied stress in the reinforcement enhances corrosion of the embedded steel.
3. Reinforcement rods show active-passive and transpassive behaviour over the period of exposure.
4. Corrosion potentials vary as a function of the bending stress distribution, being the maximum at maximum bending moment point and least at the support point where the bending moment is zero.

ACKNOWLEDGEMENTS

The authors are grateful to the Director, NIO, Goa for permission to carry out this investigations in NIO Laboratories. They would like to thank the authorities of Karnataka Regional Engineering College for their encouragement throughout this work.

REFERENCES

1. ACI Committee 222 (1985), *Corrosion of Metals in Concrete*, ACI Journal, Vol.82, No.1, pp.3-32.
2. Patil, B.T. (1985), *Investigations on Corrosion of Steel and Deterioration and Protection of RCC Structures in Marine Environment*, Ph.D. Thesis, Mysore University.
3. Patil, B.T., Ranganna, G., Ramachandran, T. and Gajendragad, M.R. (1988), *Mathematical Model for Prediction of Diffusion of Chlorides into Concrete Structures*, Proceedings of All India Seminar on Durability of Concrete in Coastal Areas, The Institution of Engineers (India), Calcutta, July 7-8, pp.PBT 1-8.
4. Tutti, K. (1978), *Cracks and Corrosion*, CBI Forskning FO Research 6:78, Swedish Cement and Concrete Research Institute, Stockholm.
5. Verbeck, G.J. (1975), *Mechanism of Corrosion of Steel in Concrete*, ACI Publication SP-49, pp.21-38.

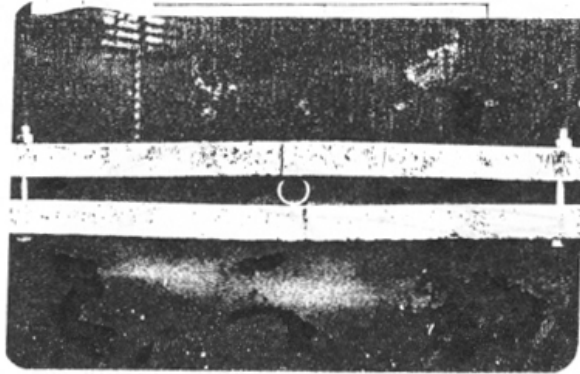


Plate 1: Beam Specimen for Exposure

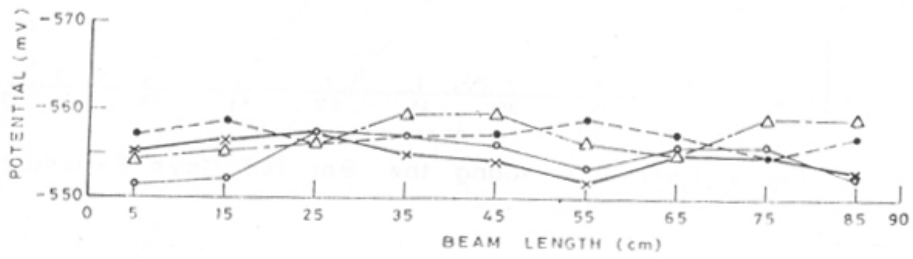


Fig. 1. Potentials Along the Bar (3 Days Exposure)

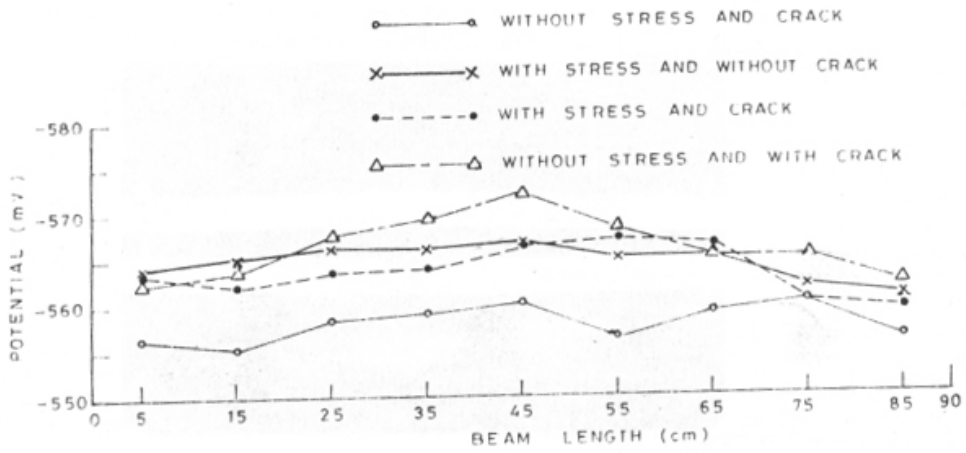


Fig. 2. Potentials Along the Bar (30 Days Exposure)

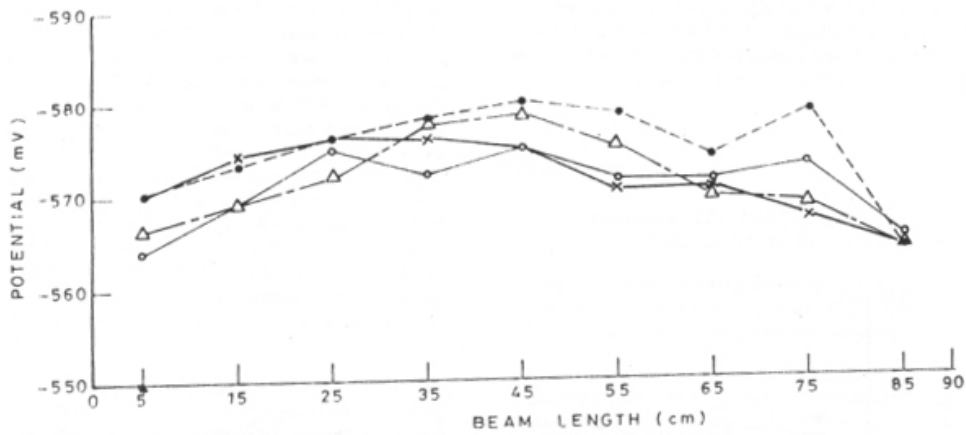


Fig. 3. Potentials Along the Bar (60 Days Exposure)

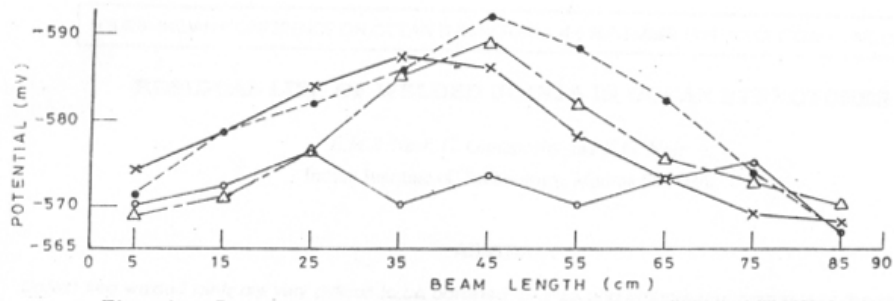


Fig. 4. Potentials Along the Bar (90 Days Exposure)

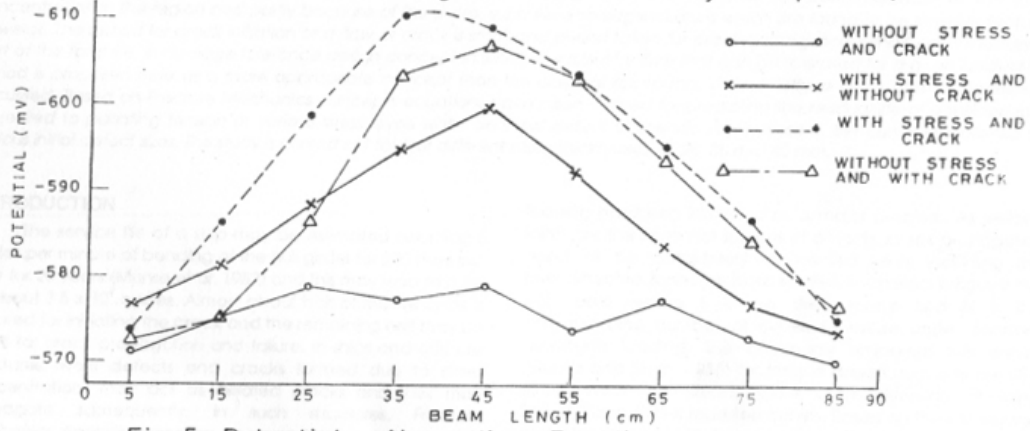


Fig. 5. Potentials Along the Bar (120 Days Exposure)

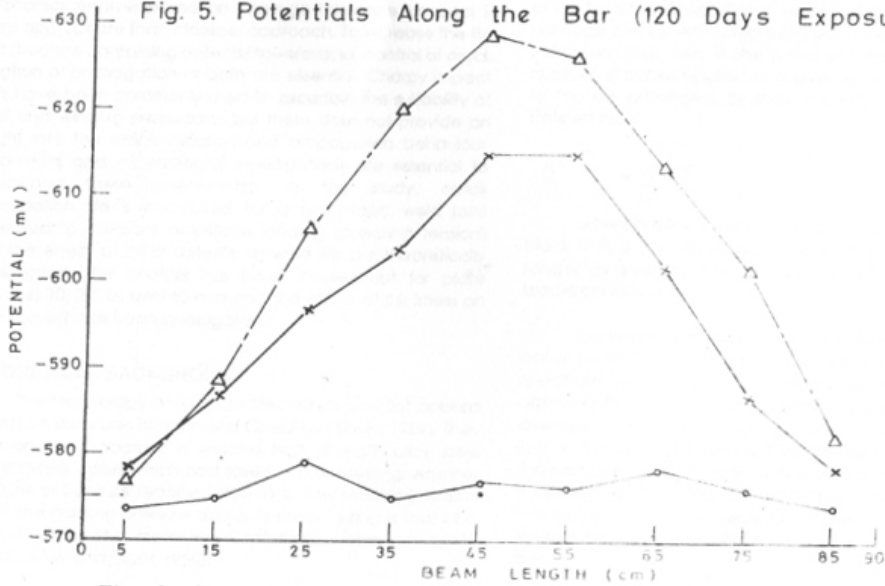


Fig. 6. Potentials Along the Bar (150 Days Exposure)