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Static and Cyclic Behaviour of High Performance Corroded Steel Concrete Beams

Seshadri Sekhar.N. Raghunath.P.N.

Abstract- ***Experimental investigations were carried out on corroded reinforced High Performance Concrete (HPC) beams of size 150 mm X 250 mm X 3000 mm under both static and cyclic loading, separately under four point bending. Some of the beams were provided with 10%corroded steel and some with 25%. Corrosion of reinforcement was induced by immersing the RC beams in NaCl solution and by electrical conductivity and monitored with the corrosion analyser. The trend of the load-deflection relation of the beams was similar to that in the case of normal reinforced concrete beams under static loading. The strain energy absorbed by the both categories of the beams was calculated. It was found that the energy absorbed by corroded beams were lower by 10%, 25%, respectively. Some of the beams were also tested under cyclic load separately. It was observed that the deflection, compressive strain, tensile strain of the beams increase with the number of cycles. The paper presents in detail the experimental investigations conducted on beams and pertinent conclusions drawn there from.***

Keywords: ***High performance Concrete, Corroded steel, Silica Fume, Hyper Plasticizer.***

I. INTRODUCTION

Concrete is a popular construction material. With the addition of reinforcement the load capacity of beam is enhanced as the reinforcement steel is able to resist the tensile stresses in concrete induced by the applied loading. When the placement and compaction of the concrete are not of good quality, the concrete becomes pervious thus allowing the ingress of harmful agencies like oxygen and moisture leading to corrosion of reinforcement. Now-a-days reinforced concrete is used in building structures in coastal areas or offshore platforms or marine structures in the midst of ocean. Any deterioration in such structures will lead to their premature failure resulting in loss of life and revenue. Besides, offshore structures are subjected to wave induced cyclic loading which when applied repeatedly leads to initiation of crack and its propagation with the number of load cycles. Corrosion of reinforcement steel in conjunction with fatigue loading is detrimental to the performance of such structures and consequential catastrophic failure. Extensive research on RC beams with regard to its behaviour under different types of loadings has been carried out and well documented. However, not much progress in research has been made with regard to the behaviour of corroded steel reinforced HPC beams under both static and cyclic loading.

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The HPC is prepared with ordinary Portland cement complying to IS:12269 [1] and using zeolite, fly ash, silica fume as admixtures and as partial replacement cement to the extent of 5%,10%,15% and 30% with w/c ratio 0.27 to 0.45 as the admixture along with coarse aggregate and fine aggregate and super plasticizer, the 28 day characteristic strength being achieved ranging from 103.8 MPa to 114.7 MPa [2]. The chloride diffusion tests were studied by exposing the concrete to 5M NaCl for 30 to 60 days [3]. By using both ultra-fine fly ash and silica fume as replacement of 15% of cement along with use of 0.5% of super plasticizer by weight of cement better characteristic strength than that of ultra-fine fly ash HPC and silica fume HPC. The authors have analysed the pore structure, micro hardness to get compare the compressive strength and flexural strength of all the concretes [4]. The optimum proportions of concrete mixes are achieved by considering the cost of the material with respect to different countries. The authors have discussed as when and where to use high performance concrete by considering the factors such as shrinkage, curing, super plasticizer with cement. It was proposed specific proportions for getting the required cylinder strengths for some countries [5]. HPC was designed by the minimum void ratio method, by replacing the cement with slag and silica fumes partially and 15% of sand by fly ash. Stress curves for compressive, splitting and flexural strengths of HPC specimens were measured and indicated the experimental concretes had better pastes to void ratios than control batches ratio. N = Vp/Vv = 1.3 Where Vp= Paste volume and Vv= Voids volume.. The results indicate that pozzolanic material not only provide chemical strength effect, but also physical packing effect. The compressive stress curves may keep growing as the concrete ages.

Corrosion occurred only at intersection of rebar with cracks in the concrete, high performance concrete is more protective than ordinary RC and the type of loading is less impact on corrosion than type of concrete and exposure conditions [6] The process of inducing of corrosion of steel and time of induction of corrosion was also explained by the authors [7]. The low cycle fatigue test results indicate that the corroded steel bars exhibit a gradual reduction by both the load bearing ability as well as the available energy. Tensile tests confirm the gradually occurring embrittlement due to corrosion of steel bars. A reduction of number of cycles to failure under conditions of low cycle fatigue was observed. As the two significant degradation factors, corrosion and low cycle fatigue are functions of time, it seems that the reliability of steel bars S500 tempcore is time dependent as well [8]. Corrosion increases both deflection and crack width at service loads and reduces the strength at ultimate level.

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Besides, corrosion modifies the type of failure in concrete beams with usual ratios of reinforcement. Tested beams failed by bending, deteriorated/corroded beams failed by shear. Pitting at links and cracking and spalling of top concrete cover, due to corrosion of reinforcement, have been shown the most relevant damages in the tested beams [9]. The process of corrosion is cyclic spraying of NaCl and drying at 40°C. The amount of corrosion and induced damage is observed and measured in image analysis. As the corrosion increases the product accumulates at the interface of steel and concrete thereby diffusion of concrete occurs. Only small amount of corrosion product 100 µm thick covering 20% of rebar covering, is needed to generate first visible cover crack (= 0.05 mm width). It is also estimated that the amount of cement paste to cover corrosion product during the free expansion stage is not more than 100 µm.

A hysteretic model was developed on the concept of accumulated damage [10]. The damage concept was used to predict the response of reinforced concrete structures subjected to fatigue loading. An empirical formula was introduced considering damage parameter, cumulative damage variable β and variable n values [11]. An increase in degree of corrosion of reinforcement decreased the fatigue life of the beams and caused them to collapse in a brittle failure mode. For the same fatigue load, the ratio of maximum elongation at rupture to yield strength of corroded steel decreased with increase in fatigue stress magnitude [12]. The fatigue failure of the normal R.C. beam is actually the consequence of damage of the material components (concrete and steel) and the bond between them. The compressive strength of concrete decreases with an increase in magnitude of repeated loading and the number of cycles [13]. If the cyclic stress of reinforcing steel is higher than its allowable fatigue stress, the failure of RC beam is controlled by the fatigue failure of steel reinforcement.[14] Cyclic behaviour of RCC beam strengthened with CFRP sheets as shear supports by taking some percentage of ultimate static load as the maximum load of the fatigue loading. The deflections and strains were noted above 50000 cycles.

The paper presents the results of experimental investigations carried out on varied percentage corroded steel reinforced concrete beam. The paper also discusses the behaviour of the beam as well as their ultimate capacity under static loading and about fatigue life under cyclic loading. The deflection and strains were studied along with the crack width from the beginning of the cycles. Conclusions drawn on investigations are also present.

II. EXPERIMENTAL PROGRAMME

The mix proportion of concrete was arrived at by trial and error method and also as per the IS code with the following proportions per cubic meter of it. The quantities of materials of the concrete mix used, .i.e., Cement: Fine Aggregate: Coarse Aggregate: Silica Fume = 1:1.73:2.51:0.055 shown in Table-1

Six beams of size 150 mm X 250 mm X 3000 mm were cast. Table 2 shows the description of the beams. Two specimens were considered as control beams, one for static loading and the other for fatigue loading. Out of the four balance beams, 2 beams with 10% corrosion were tested under both static and cyclic loading individually. The remaining 2 beams with 25% corrosion were tested under both static and cyclic loading.

Table 1 Quantities of materials used

Details	Content
Targetted 28 day concrete strength	60 MPa
Cement	450 Kg
Max. size of coarse aggregate	20 mm
Weight of 20 mm aggregate	680 kg
Min. size of aggregate	10 mm
Weight of 10 mm aggregate	450 kg
Fine aggregate	780 kg
Silica Fume(S.F)	25 kg
Hyperplastisizer-Gilinum233 (BASF) = 0.8%(cement+SF)	380 gr
Water/cement ratio	0.35

Table 2 - Beam details

S. No	Beam Designation	No. of Beams	Percentage of Corrosion	Reinforcing Details
1	R0	2 no.	No corrosion	Top: 10 mm dia, 2 no. RTS, Bottom: 12 mm dia, 2 no. RTS. Stirrups: 8 mm dia @ 150mm c/c
2	A0	2no.	10% Corrosion	As above
3.	B0	2 no.	25% Corrosion	As above

Since all the beams were cast on the same day 3 cubes of size 150 mm X 150 mm X 150 mm, 3 cylinders of diameter 150 mm and 3 square prisms of size 100 mm X 100 mm X 500 mm were cast along with the beams to determine the Young's modulus of concrete, cube compressive strength, cylinder compressive strength and flexural strength of the concrete.

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To maintain the uniformity in the concrete mix, the mix prepared for the beams were also used to cast the control specimens. The beams and control specimens were cured for 28 days with wet sack. The experimental results are shown in Table 3**.**

Table 3 Properties of concrete

S.No	Property	Results in MPa
1.	Cube compressive strength	60.58
2.	Cylinder compressive strength	41.27
3.	Flexural strength	4.19
4.	Young's Modulus	$2.25X10^4$

For inducing corrosion, the beams were immersed in NaCl solution and maintain the pH value was maintained as 11, with induced current of 11 amps to be inducted. By using the Faraday's law, time of corrosion is calculated and verified by measuring the loss in mass of steel rods. The corrosion is monitored by the corrosion analyser. For getting the 10 % loss in mass of steel, calculated time is 23.5 hrs and for 25% corrosion the calculated time is 59 hrs. Hourly reading of the corrosion analyser is noted. The corrosion analyser shows the range of corrosion as follows.

If the reading is > (-200 mv), then it is 10% corrosion. Between (-350 mv) to (-200 mv) then it is just 25%. Between (-500) mv to (-350) mv then it is > 90% corrosion. If greater than (500 mv) then it is to be taken as severe corrosion.

III. TESTING

Figure 1 shows the experimental set up of the beam. It is a two point loading or four point bending arrangement. All the control beams and corroded beams were tested under both static and cyclic loading.

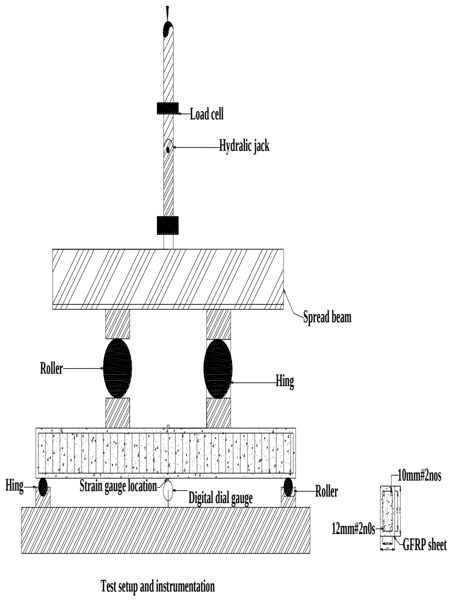
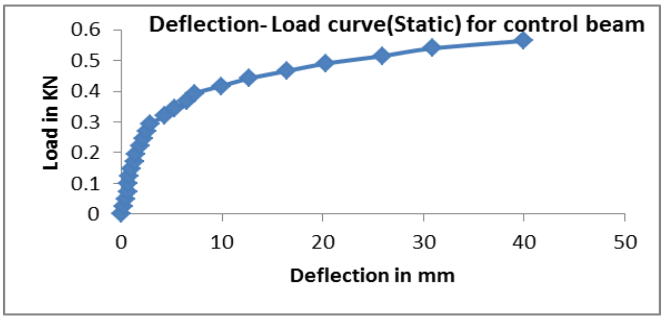
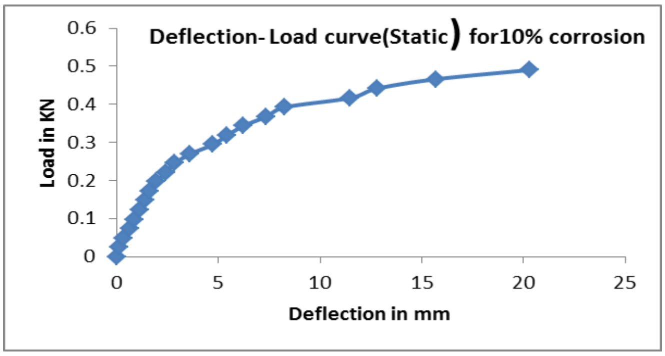


Fig-1 Experimental set up

Static loading: Load was applied on the beam in increment of 25 KN. For each load increment, the deflections readings were noted. The deflections were noted at the mid-span of the beam with the help of mechanical dial gauge. To measure the slope of the beam at different loadings one dial gauge was set up above the support which gives the decremented readings. At ultimate load the deflections were noted. The first crack load, first crack width, crack length were measured. Load - deflection curve was drawn. The area under the curve gives the energy dissipated and it is given in the Table 4. A typical load–deflection curve for control beam and 10% corroded beam are given separately in Fig. 2.





Load in kN	Deflection in mm
0	0
0.024525	0.27
0.04905	0.41
0.073575	0.63
0.0981	0.7
0.122625	0.82
0.14715	1.04
0.171675	1.32
0.1962	1.48
0.220725	1.82
0.24525	2.17
0.269775	2.51
0.2943	2.89
0.318825	4.25
0.34335	5.32
0.367875	6.54
0.3924	7.25
0.416925	9.9
0.44145	12.64
0.465975	16.43
0.4905	20.34
0.515025	25.95
0.53955	30.92
0.564075	39.97

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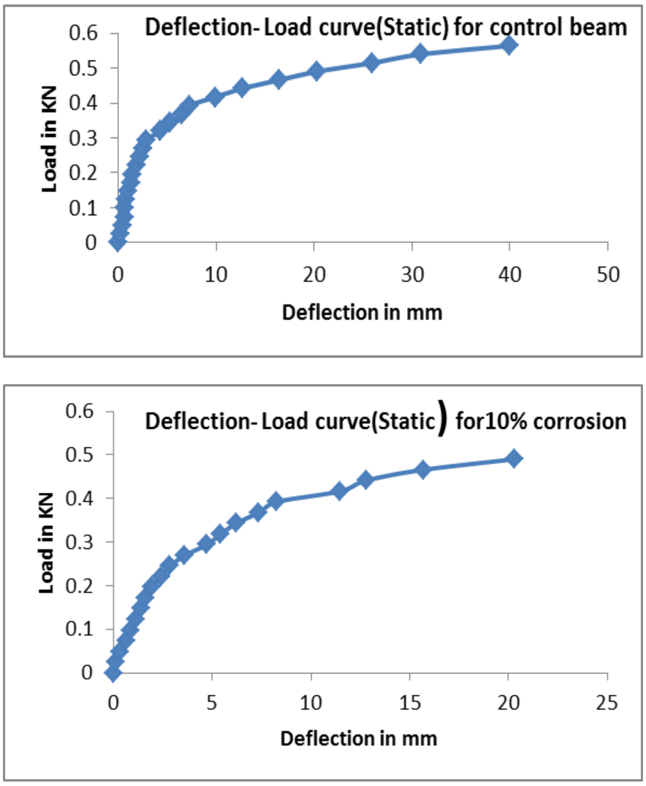


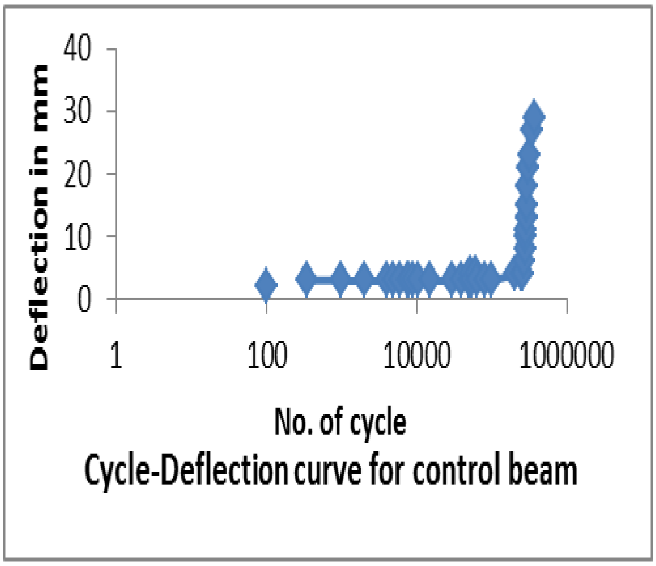
Fig. 2 Load Deflection curve for static loading

Cyclic loading: The experimental set up is same as in static loading. The time history of loading is shown in Table. 5.

Table 5 Time history of load

Time	0.1 sec	0.1 sec	0.5 sec	0.1 sec	0.1 sec
Load	5000N	10000N	40000N	5000N	0 N

Here, the load is constant throughout the experiment. Load was arrived as the percentage of ultimate static load ranging from 25% to 90%. The deflections are noted at the centre of the beam. The strain gauges were fixed to the beam using Araldite to measure compressive strain at the top of the beam. The readings were noted from the chart attached to the measuring instrument. Typical number of cycle v/s deflection curve for control beam and 10%corroded beam are shown in (Fig. 3),.



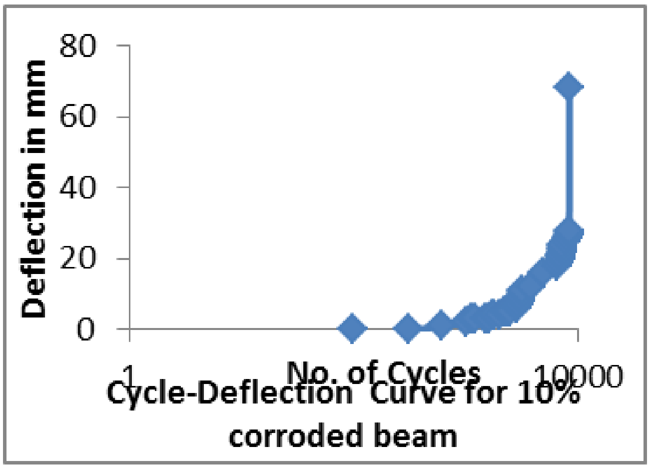


Fig. 3 Typical Cycle- Deflection curves for cyclic loading

IV. RESULTS AND DISCUSSIONS

It is observed that in the case of static loading strain energy absorbed by the control beam is higher than the corroded beams. The area under the load deflection curve is more than the area of corroded beams. It is also observed that, the curve follows steep slope and tends to become horizontal for control beam and the less slope for control beams leaving lesser area under the curve. The energy absorption is inversely proportional to the percentage of corrosion. The load - deflection curve indicates that the deflection varies with the percentage of corrosion.

In the case of cyclic loading, since the loading is constant, cycle v/s deflection curve is prepared and found that the deflection is minimum at the beginning for control beam R0 and the deflection in the beginning varies with the corrosion. The horizontal cracks developed in concrete at the compression steel and tensile steel areas with the percentage of corrosion. It is observed that the strain measured in the compression concrete and the tensile steel varies with number of cycles and the stress. The unique behaviour of strain varies with the stress, number of cycles and percentage of corrosion shows the variations are unpredictable. It is observed that the strain in control beams varies in step type as load is constant and varies with cycles.

V. CONCLUSIONS

In this investigation, the behaviour of normal and corroded beams was studied and the ultimate capacity was evaluated. The failure patterns of beams were established. The control beams show the normal behaviour and the energy absorption is normal. In the case of 10% corroded beams, the load-deflection curve shows the less percentage of ultimate loading and lesser percentage of energy absorption percentage and whereas in the case of 25% corroded beams show very brittle and took minimum load percentage and minimum energy absorption percentage.

The control beams show the normal behaviour with more number of cycles. In the case of 10% corroded beams the numbers of cycles are lesser than the control beam and still minimum in the case of 25% corroded beams. The behaviour of beams under cyclic load with respect to strain were shown in Fig.(4) and is due to retardation and experimental limitations.

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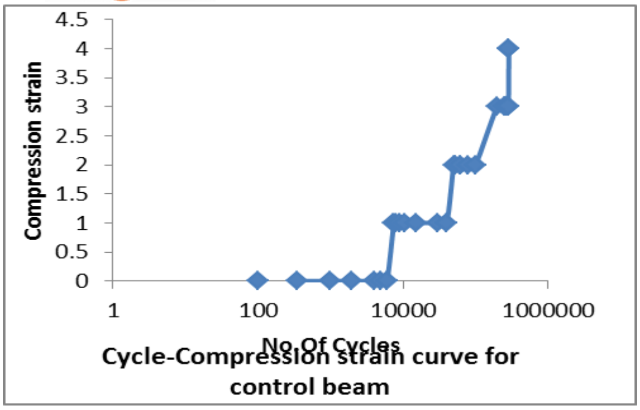

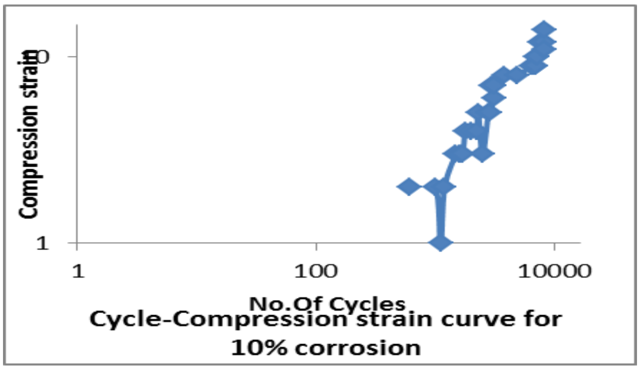

Fig. 4 Cycle- Strain curves for cyclic loading

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