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Study of Cyclic behaviour of Corroded HPC beams strengthened with GFRP laminates by Nonlinear finite element modelling and experimental investigations

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Abstract: Corrosion is a very big threat to the civil Engineering Structures especially on the coastal areas. Apart from the corrosion, the tidal forces on the structures act as the cyclic loading which in turn damage the structures by way of cyclic loading. There are two types of cyclic loading, which are constant amplitude and varying amplitude. In this experiment, cyclic loading was taken with Constant amplitude. Strengthening the corroded beams on tension face ie below the beams with GFRP laminates improve the cyclic life of the beams. In this paper, the non linear finite element analysis (ANSYS) for the corroded high performance concrete beams under cyclic loading to predict the cyclic life of the beams. The results were compared with the experimental results with regard to cyclic life and Maximum deflection. It is found that it is reasonably agreeable. This indicates that the proposed FEMs can capture the cyclic behavior of the corroded HPC beams strengthened with GFRC laminates of 2 different thicknesses of high accuracy.

1. Introduction:

Wang and Chen (2003) studied on the RC T-beam with applied CFRP at tension face or bottom face of the beam and applied GFRP at side/shear face of beam.. Authors accurately predicted the discrete model of load displacement behaviour and found excellent agreement between measured plate strain and the strain predicted by model.

Hsuan-Teh Hu, et.al (2004) carried out numerical study by ABAQUS based on finite element method to predict the ultimate loading capacity of rectangular reinforced concrete beams strengthened by fibre reinforced plastics applied at the bottom or on side face of those beam. It was also observed fibre orientation, beam length and reinforcement ratio on the ultimate strength of the beam. Investigators concluded from the numerical result FRP strengthening is not effective for high reinforcement ratio as compared with low reinforcement ratio. Authors observed more crack at the central region of the beam with high reinforcement ratio which was strengthened with FRP at the bottom, and found comparatively more crack at support area of the beam with low reinforcement ratio which was strengthened with FRP at the bottom. Authors conclude increased ultimate strength and deceased crack when FRP applied on bottom face of the beam.

Sergio F. et.,al (2004) experimentally carried out tests on eighteen small scale reinforced concrete beam strengthened by CFRP composites. Authors used three different type of configuration, laminates were attached only tension face of the beam, secondly laminate were attached only shear/side face of the beam and for third case laminates were attached entire specimen or U-shape. strain gauges were used in a region where crack in concrete were performed to monitor the variation of strains throughout testing. From the experiment they concluded composite pattern/configuration directly affects behaviour of load versus deflection of the beam was affected by composite configuration. Authors observed local strain didn't provide a realistic representation of the global beam behaviour.

Lundqvist, .,et.al (2005) carried out study on anchorage length of FRP to effective strengthening of RC beam. Authors did experimental work and analytical investigation by ABAQUS based on finite element analysis. Author used strengthening technique such as bonded plates, sheets and the Near Surface Mounted Reinforcement (NSMR).. Author also observed that increased in anchorage length added structural safety but does not increase in load carrying capacity.

Fathelbab, Ramadan and Al-Tantawy (2011) conducted analytical investigation on strengthened RC simple beam with externally bonded FRP sheets technique, that beam was loaded in flexure, shear and a combination of flexure and shear. Authors used ANSYS software to perform structure linear and non-linear analysis. Authors studied main parameter control beam of different schemes of FRP sheets in flexural, shear and combination of flexure and shear. Investigator compared that results and conclude that beam capacity and ductility directly proportional to CFRP sheets applied on the beam but at the same time author observed that the beam capacity didn't increased with increased in CFRP sheets but ductility did.

Kaushal Parikh and C.D.Modhera (2012) carried out experimental and analytical investigation on preloaded retrofitted beam with GFRP for enhancement in flexural strength. Seventeen beams for experimental study, out of that two were control beams and fifteen were preloaded at 0%, 40% and 90% of control beam. Author used new arrangement of FRP for strengthening the beam in which they were applying full length of single layer, length and width were reduced in second and third layer. It was also carried out analytical investigation using ATENA 3D software which was based on finite element method. It was concluded from the analytical and experimental results, that new arrangement so effective that was shift the flexural crack away from the flexural region and also come out from the debonding failure. They observed load vs. deflectionnot more than 5% varied in experimental and analytical results, failure mode were also remarkable compared.

Vijayakumar, Venkatesh babu and Jayaprakash (2012) investigated behaviour of FRP beams. Bending moment was calculated, the model considers an exponential function in the stress-strain diagram of RC in both tension and compression parallel to the fibre.Authors conducted four point loading test to determine load versus displacement relationship of RC beam with GFRP and CFRP sheets adhered to the tension face/bottom face. Authors used finite element techniques to understand best warping style for retrofitting the deficient beams and they also study of effectiveness of CFRP/GFRP sheets in flexure strength of RC beams. From the results, authors concluded that general behaviors of the finite models show good agreement with experimental results of beam test. Also form the result obtained by authors that demonstrated that CFRP was more efficient than GFRP in strengthening the reinforced concrete beams for shear.

Jayajothi, Kumutha and Vijai (2013), conducted ANSYS based analytical investigation on simulate behaviour of failure mode of RC beams strengthened in flexure and shear byFibre reinforced polymer (FRP) laminate. Authors carried out study on four beams model, from those two were control beams and remained was strengthened with CFRP.It was obtained the load deflection relationship until failure and crack pattern by ANSYS and that result compared with experimental results available in literature. It was observed numerical result seen good agreement with experimental results. Based on analytical results authors concluded that ultimate load carrying capacity was increased comparatively, flexural strength increased substantially while CFRP applied on tension face and load carrying capacity of beam strengthened by U-warp CFRP was found to be higher compared with CFRP applied on tension face only.

Dhanu M.N , Revathy D, Lijina Rasheed and Shanavas S (2014) carried out studied on experimental and numerical investigation of retrofitted reinforced concrete beams using Fibre Reinforced Polymer (FRP). They were used GFRP and Coir FRP for retrofitting of beam and compared performance between them. Experimental study involves the determination of flexural load by three point loading. They calculated permissible load by using proper factor of safety on ultimate load. They took that permissible load for numerical study. For numerical study of RC beams retrofitted with GFRP were considered and they used ANSYSv13 software to analysis of beams structure. They applied uniformly distributed load supported by fixed support at its ends. It was concluded from experimental and numerical analysis that the flexural strength and ultimate load capacity with same deflection of the beam can be improved by retrofitting.

Parandaman P. and Jayaraman (2014) presented on finite element analysis of beam retrofitted with different fibre reinforced polymer composite sheets carried out using ANSYS software. They applied GFRP, CFRP and KFRP on same size of beam and then modeling and analysis was done by using ANSYS software.It was concluded from the ANSYS results, when compared to control beam, deflection of the retrofitted beam with CFRP is minimized about 73%, GFRP is minimized about 65% KFRP is minimized about 60% and load carrying capacity of retrofitted beam is higher than the controlled RC beam..

Rameshkumar et.al., (2014) investigated on flexural behaviour of aramid fiber (Kevlar fiber) reinforced polymer (AFRP) used for strengthening reinforced concrete (RC) beams of M25 grade of concrete. Investigator took the beam size was 100 x 150 x 1200 mm and that was strengthened by Aramid fiber polymer sheets. Authors studied on effect of strengthening on load carrying capacity and effect of damage degree. Authors used ANSYS software for validation of Experimental work and they found good agreement between analytical result and experimental result. They only work on flexural behaviour so beams were wrapped with AFRP sheets in single layer and double layers along the full length of beam at the bottom face. Authors concluded from results that the ultimate load carrying capacity for 0% damage degree beams were increased after strengthened with single layer and double layer of 100 mm width AFRP strip was 27.59% and 49.27% respectively compared with controlled beam, ultimate load carrying capacity were increased with increased in layer of AFRP strip, with increased in degree of damage, deflection at ultimate load was found to be decreasing by applying AFRP strip and 0%, 70%, and 80% damaged degree beams showed higher performance in terms of load carrying capacity, while 90% and 100% damage degree beams did not show appreciable increased in load carrying capacity.

Spyrakos, Raftoyiannis, Credali and Ussia (2015) carried out experimental and analytical investigation of the effectiveness of FRP strengthening sheets on RC beams to increase their flexural strength and stiffness. Authors conducted four point bending tests on four full scale reinforced concrete beams strengthened with externally bonded FRP. Author investigated the strength, deflection and failure mode strengthened beams in both experimentally and analytically. Form the results by the application of CFRP increased beam strength and stiffness. They were observed that different resin and anchorage system significantly influenced the resulting strength and stiffness of the specimen.

Yang Xiao Ming, Li Fu-Zhai and SUN Guo-Jun (2016) conducted the numerical simulation analysis of a corroded reinforced concrete (RC) beam after being subjected several times to fatigue load. Parameters, such as section area, yield strength, and ultimate strength of the steel bars, were modified to simulate the influence of reinforcement corrosion and cyclic loading. The nonlinear static analysis of the RC beam at different corrosion rates and cycle numbers after cyclic loading was also performed.The yield load of the corroded RC beam after cyclic loading decreases almost linearly with an increase in the corrosion rate and number of cyclic loading, and the influence of the two factors on the yield load were similar. The ultimate deflections of the RC beam increases nonlinearly with an increase in the corrosion rate and increases almost linearly with an increase in the number of cyclic loading. The authors concluded that the influence of corrosion rate was larger than that of the number of cyclic loading and was particularly more obvious when the number of cyclic loading is higher.

2. Experimental Procedure

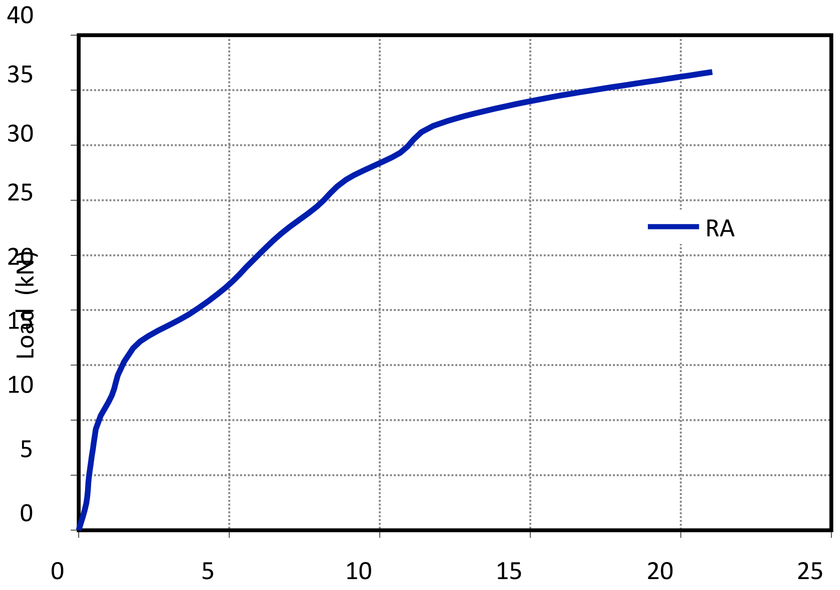
High Performance Concrete beams were laid with 150X250X3000mm with the Asc of 401.92mm^2 and Ast of 401.92mm^2. The beams were tested with tested with 3 point loading for Static loading as shown in fig.1 A total of twenty two rectangular beams were cast for the present research work.. 2-legged 8 mm diameter stirrups were provided at 125mm c/c, in order to avoid any shear failure and ensure flexural action of beams up to failure. Out of twenty two specimens one beam served as control specimen, seven beam specimens were strengthened with CSMGFRP, WRGFRP, UDCGFRP laminates and tested without any corrosion damage (R-Series), seven beams were strengthened with CSMGFRP, WRGFRP and UDCGFRP laminates having 3mm/5mm thickness and tested after inducing 10% corrosion damage (A-Series). Seven beams were strengthened with CSMGFRP, WRGFRP and UDCGFRP laminates having 3mm/ 5mm thickness and tested after inducing 20% corrosion damage (B-Series). The variables considered for thestudy included % of corrosion, type of GFRP laminate and thickness of GFRP laminates.The control specimen is tested under static loading to get the ultimate load.

Static loading: Fig.1 shows the experimental set up for static loading of beam. Load was applied on the Control beam in increment of 25 kN. For each load increment, the deflections readings were noted. To measure the slope of the beam at different loadings one dial gauge was set up above the support which gives the decremented readings. 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. The first crack load, first crack width, crack length were measured. At the ultimate load deflections were noted. Load - deflection curve was drawn. In the case of control beam the trend of the load-deflection relation showed an initial linear increase of up to 0.3 kN. Afterwards, there was a non-linear variation of load-deflection up to 0.4 kN. Subsequently, the increase in load was small while the increase in deflection was phenomenal till a failure load of 0.6 kN was reached and the maximum deflection reached was 40 mm. The trend of load-deflection relation was in conformity with regular RC beam.The stress- deflection curve was drawn in Graph1

Fig.1: Static Test Results of Reference Specimen

Table 1: The load- deflection curve is as given below

First Crack Load in kN	17.167
Deflection at First Crack load in mm	1.32
Yield Load in kN	49.05
Deflection at Yield Load in mm	20.34
Crack Width at Yield Load in mm	1.2
Ultimate Load in kN	56.40
Deflection at Ultimate Load in mm	39.97
Deflection Ductility	1.965
Energy Ductility	2.336

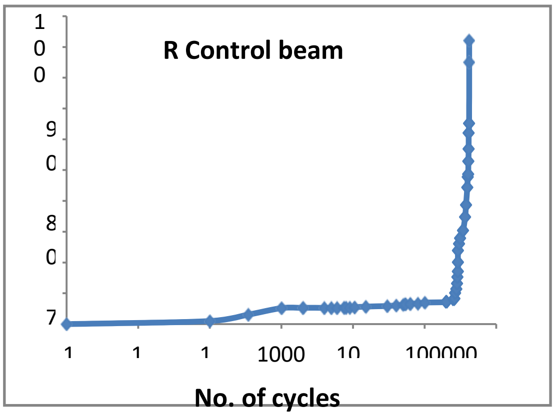


Deflection (mm) Graph1

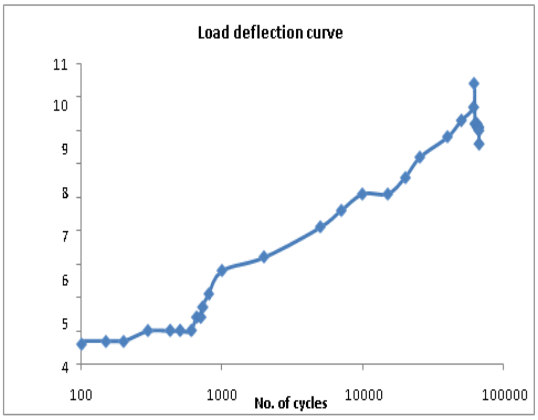
Cyclic loading: Experimental set up is as shown in Fig.2.In this investigation 21 HPC beams were tested cyclic load of frequency0.9 Hz were applied on the beams in order to have basic understanding of their behaviour. They were corroded to the extent of 10% and 20% by electrochemical process. Corroded beams were also subjected to the same cyclic loading and their fatigue lives were evaluated. Corroded beams were then repaired with 3 mm and 5 mm sheets of different category of GFRP sheets. The repaired beams were also tested under fatigue loading in stress range varying from 10% - 50% to 10% - 90%. The fatigue lives of these beams were also determined. Stress range vs fatigue life plot depicting that S-N curve was prepared and the necessary equation was established.

Graph2: shows the cycle- deflection curves for 21 beams

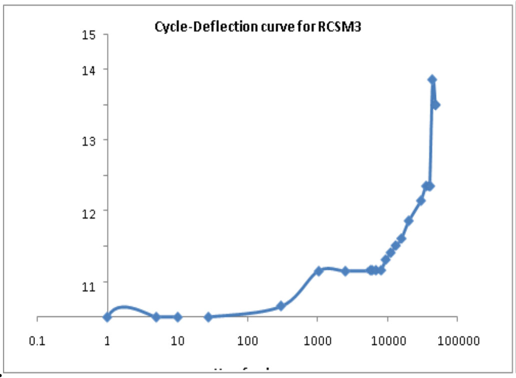
1.Regression analysis: The different graphs were drawn with No. of cycles v/s deflection for all the 21 beams.In this paper the behaviour of 7 beams of un -corroded and 7 beams of 10% corroded In Graph2. The beams were given and the table containing the numerical values of deflection and the cycle life of different beams of Un-corroded(R), 10% corroded (A) and 20%corroded beams



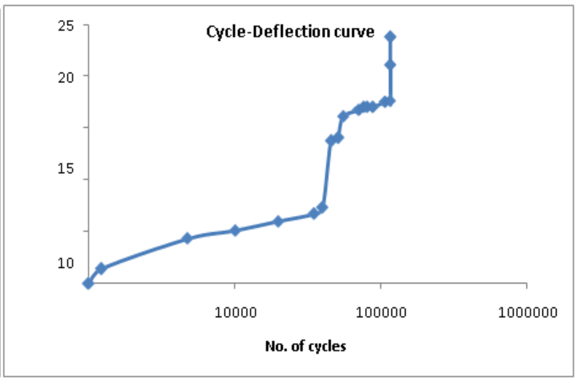
R- Control beam



RCSM3



RCSM5 Beam



RWR3 Beam

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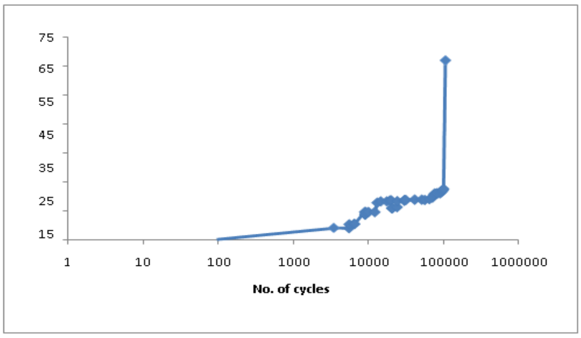
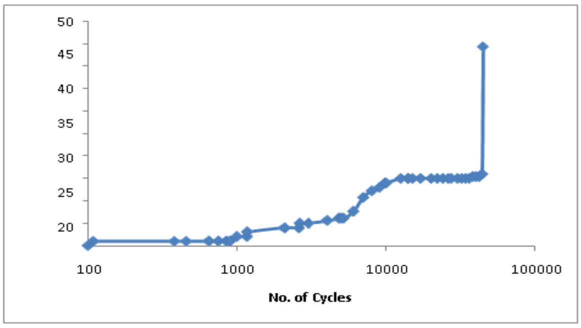
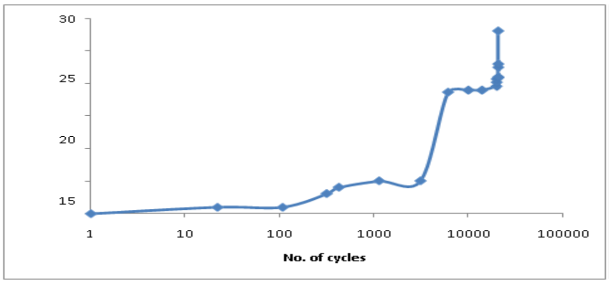


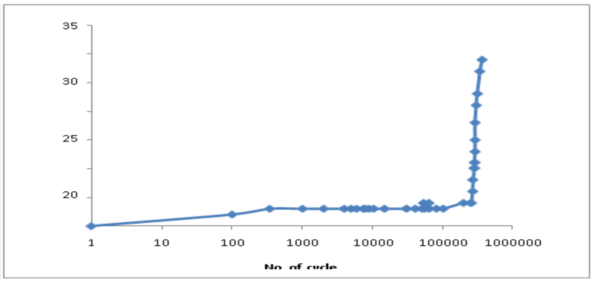
RWR5 Beam



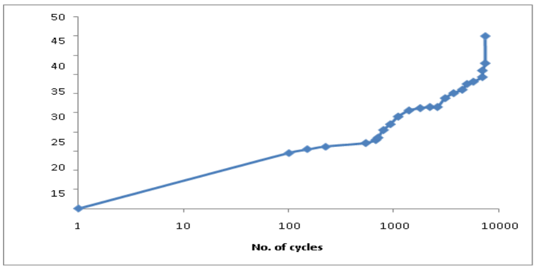
RUDC3 Beam



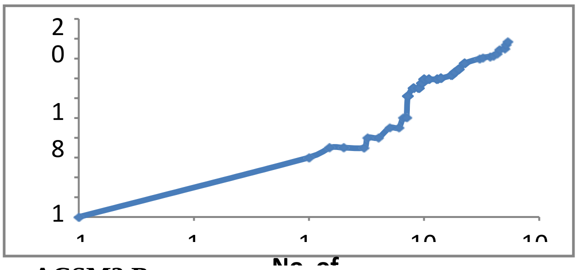
RUDC5 Beam



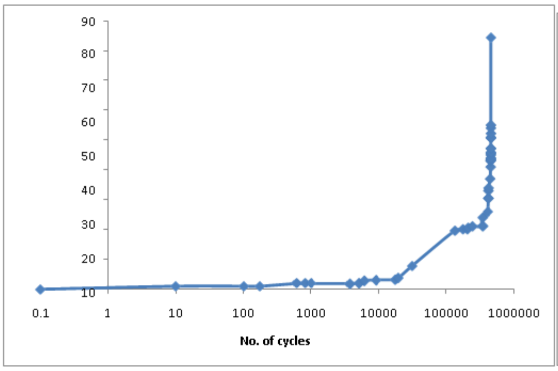
A- Beam



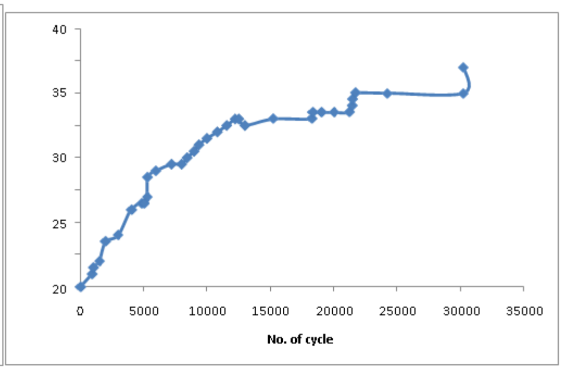
ACSM5 Beam



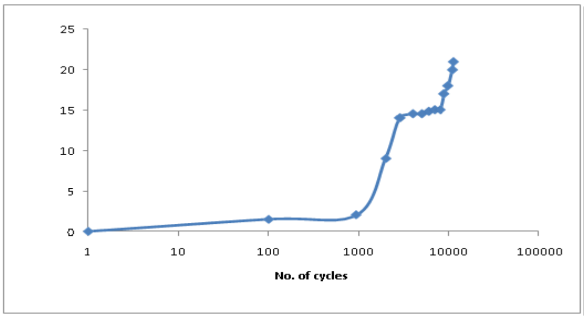
ACSM3 Beam



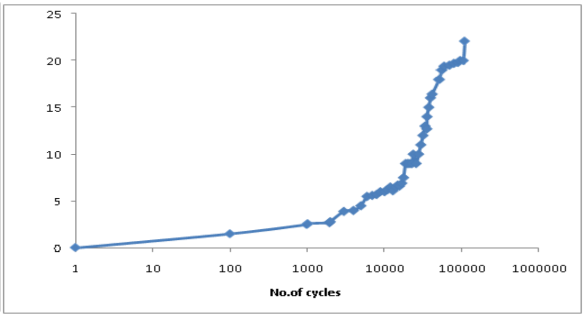
AWR3 Beam



AWR5 Beam



AUDC3 Beam



AUDC5 Beam

A mini tab software was used for finding the stress vs Number of cycles. In this software screen plot was analysed and Regression equation to predict the number of cycles for the corroded high strength concrete beams with and without FRP laminates for the given stress and vice versa
Scatterplot of Stress in N/mm^2 vs No. cycles in Graph.3

Regression Analysis: No. cycles versus Stress in /mm2
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	1.94086E+11	1.94086E+11	27.96	0.000
Stress in N/mm2	1	1.94086E+11	1.94086E+11	27.96	0.000
Error	19	1.31897E+11	6941931748		
Lack-of-Fit	16	1.31280E+11	8204971835	39.88	0.006
Pure Error	3	617153869	205717956		
Total	20	3.25983E+11			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
83318.3	59.54%	57.41%	39.61%

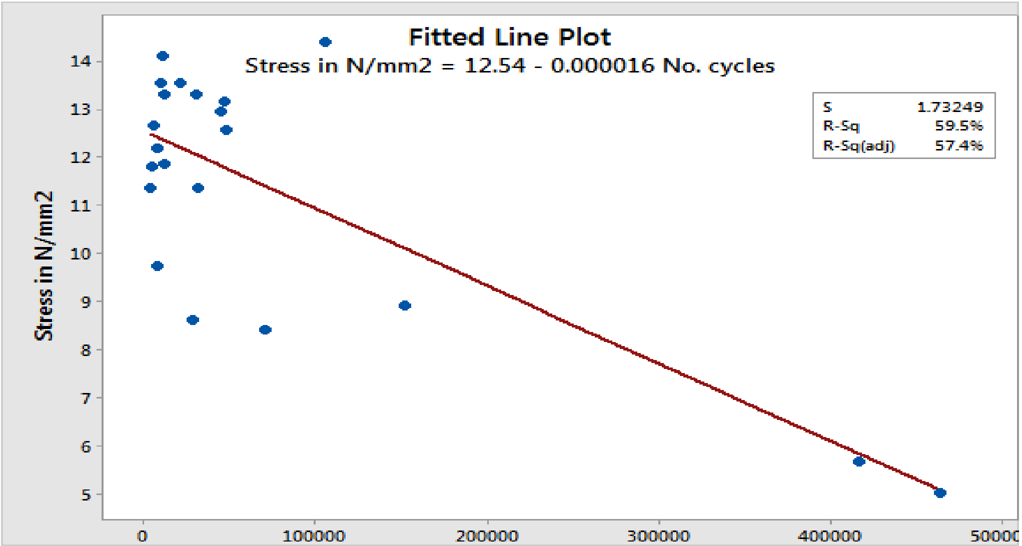
Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	494754	81793	6.05	0.000	
Stress in N/mm2	-37108	7018	-5.29	0.000	1.00

The regression equation is
Stress in N/mm2 = 12.54 - 0.000016 No.cycles
S = 1.73249 R-Sq = 59.5% R-Sq(adj) = 7.4%
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	83.918	83.9179	27.96	0 .000
Error	19	57.029	3.0015		
Total	20	140.947			

Fitted Line: Stress in N/mm^2 versus No. cycles in **Graph.3**



Graph 3:

The behaviour of beams under cyclic load with respect to stress was shown in Fig. 4.17. In the case of control beam up to 0.01 million cycles there was no variation in stress. At this stage there was a sudden surge in stress of up to 1%, At this point there was retardation because of the spreading of stress across the width of the beam till about 0.02 million cycles at which there was a sudden shoot up in stress of up to 2%. Here also there was retardation for a few hundred cycles. Subsequently, the stress gradually increased to 3%. With a small retardation at 3% stress, there was a steep increase in stress up to 4%.at 0.8 million cycles.In the case of 10% corroded beam similar trend was observed. However, the variation in stress values was irregular.

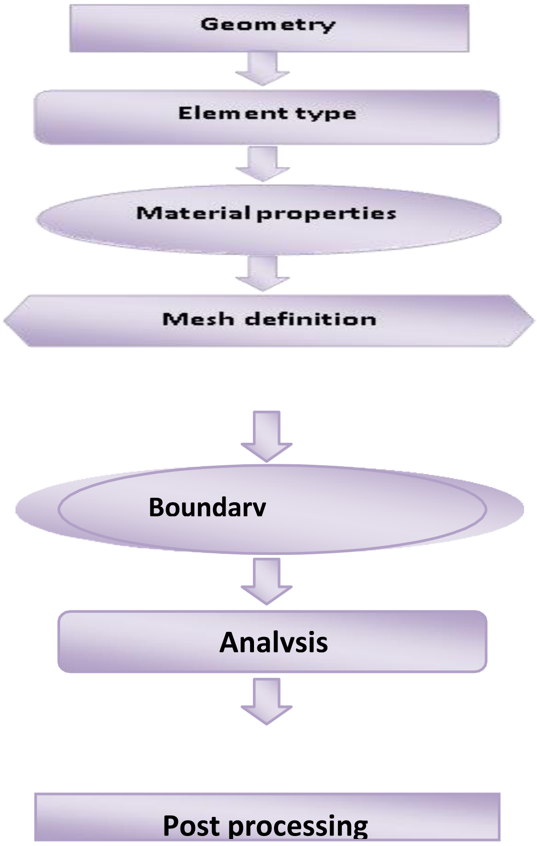
The control beams show the normal behaviour with more number of cycles. In the case of 10% corroded beams the numbers of cycles are lesser than the control beam and still minimum in the case of 20% corroded beams.

In the case of control beams the deflection of beam increased very slowly with the numberof cycles till about 0.5 million cycles. Afterwards the rate of increase was faster. At about 0.8 million cycles there was an exponential growth in deflection. The slope was very steep.

The deflection reached a peak of 30 mm. In the case of 10% corroded beam there was almost no variation in deflection till 0.001 million cycles. Afterwards deflection increased rapidly with the number of cycles till about 0.01 million cycles at which there was an exponential growth till the ultimate deflection of 60 mm was reached. Compared to the control beam, the 10% corroded beam lost considerable stiffness and hence has undergone more deflection. The trend of variation of deflection with the number of cycles was the same for all beams. Almost similar trend was observed by Balaguru and Shah (2001). However, the control beam exhibited a larger deflection with the cycles and had registered a maximum deflection of 85.1 mm 0.8 million cycles. In the case of corroded beams the deflections were drastically reduced to below 30 mm and the number of cycles also was phenomenally reduced to 0.001 million cycles.

3. Finite Element Modeling

The ANSYS finite element program (ANSYS 2014) was used in this study to simulate the behavior of the experimental beams. To create the finite element model in ANSYS, there are multiple tasks that have to be completed for the model to run properly. Models can be created using command prompt line input or the Graphical User Interface (GUI). For this model, the GUI was utilized to create the model.Fig.3



3.1 Finite Element Discretization

The finite element analysis requires meshing of the model for which, the model is divided into a number of small elements, and after loading, stress and strain are calculated at integration points of these small elements. An important step in finite element modeling is the selection of the mesh density. A convergence of results is obtained when an adequate number of elements are used in a model. This is practically achieved when an increase in the mesh density has a negligible effect on the results.

3.2 Non-Linear Solution

In non-linear analysis, the total load applied to a finite element model is divided into a series of load increments called load steps. At the completion of each incrementalsolution, the stiffness matrix of the model is adjusted to reflect non-linear changes in structural stiffness before proceeding to the next load increment. The ANSYS program **(ANSYS 2014)** uses Newton-Raphson equilibrium iterations for updating the model stiffness. Newton-Raphson equilibrium iterations provide convergence at the end of each load increment within tolerance limits.

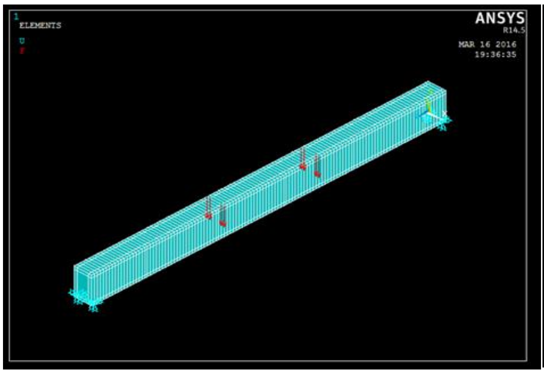
In this study, for the reinforced concrete solid elements, convergence criteria were based on force and displacement, and the convergence tolerance limits were initially selectedby the ANSYS program. It was found that convergence of solutions for the models was difficult to achieve due to the non-linear behaviour of reinforced concrete. Therefore, the convergence tolerance limits were increased to a maximum of 5 times the default tolerance limits in order to obtain convergence of the solutions.

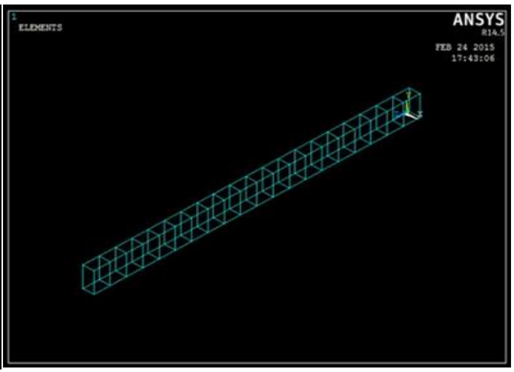
3.2.1 Meshing

To obtain good results from the Solid 65 element, the use of a rectangular mesh is recommended. Therefore, the mesh was set up such that square or rectangular elements were created. The volume sweep command was used to mesh the steel plate and support. This properly sets the width and length of elements in the plates to be consistent with the elements and nodes in the concrete portions of the model.

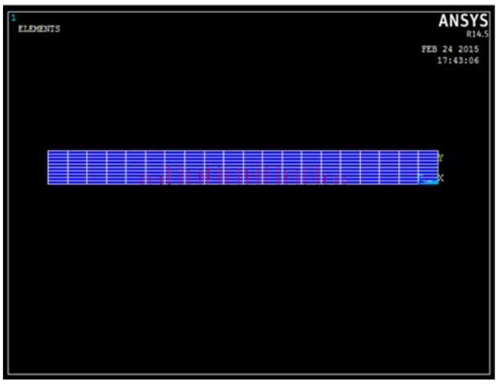
3.2.2 Loads And Boundary Conditions

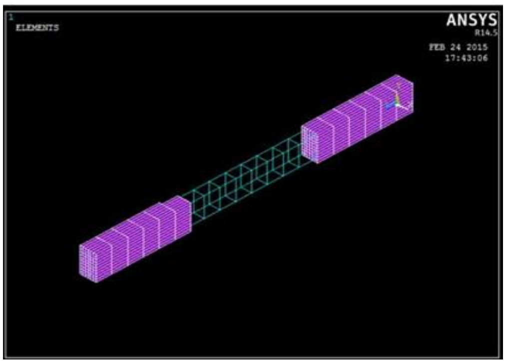
Displacement boundary conditions are needed to constrain the model to get a unique solution. To ensure that, the model acts the same way as the experimental beam, boundary conditions need to be applied at points of symmetry, and where the supports and loadings exist. Loading and boundary conditions are shown in Fig.4



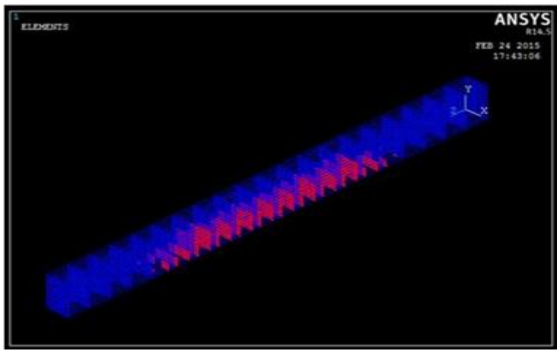


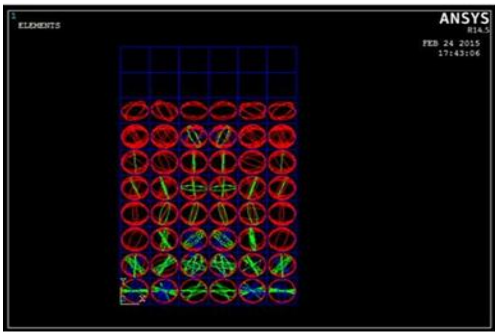
Loading and Boundary conditions **Modeled Steel Reinforcement**



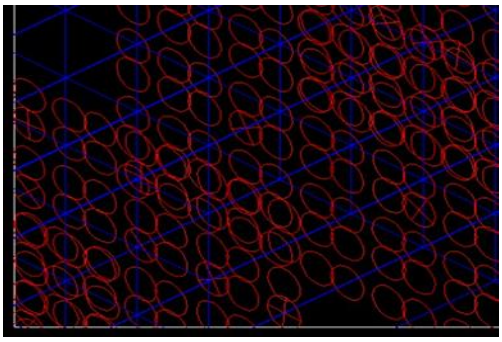


Flexural Crack Pattern **Modeled Steel Reinforcement**





Flexural Crack Pattern **Flexural Crack Signs**



Concrete Crack Signs

3.3 Results Of Finite Element Analysis And Discussion

The 21 beam specimens that were tested under four-point bending were analyzed using the ANSYS finite element code. The results pertaining to the objectives of the study are presented and discussed in this section. The finite element analysis results of the reference specimens and reinforced concrete beams with GFRP laminates

Table 2. gives the Maximum Deflection at Maximum load with No. of cycles at failure.

at different load levels are presented .The images showing predicted crack pattern and deflections of 21 beams by Ansys.The percentage reduction in deflection at maximum ultimate load level of the reference beam of A, B and C series are presented in Table 5.6. A series beams exhibit a decrease in deflection of 6.66 to 13.20% while using CSM, WR and UDC GFRP laminates with varying thickness corresponding to the number of cycles of reference beam. B series beams exhibit a decrease in deflection of 4.54 to 13.20% while using CSM, WR andUDC GFRP laminates with varying thickness corresponding to the number of cycles of reference beam. C series beams exhibit a decrease in deflection of 5.43 to 9.26% while using CSM, WR and UDC GFRP laminates with varying thickness corresponding with the number of cycles of reference beam.

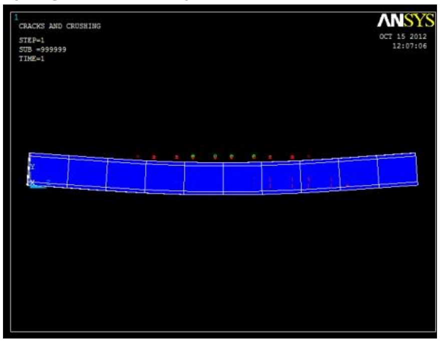
The percentage increase in number of cycles with the reference beam of A, B and C series are presented in Table 5.5. A series beams exhibit a increase in number of cycles 4.30 to 13.23% while using CSM, WR and UDC GFRP laminates with varying thickness. B series beams exhibit an increase in number of cycles 5.42 to 12.30% while using CSM, WR and UDC GFRP laminates with varying thickness. C series beams exhibit an increase in number of cycles 4.50 to 12.22% while using CSM, WR and UDC GFRP laminates with varying thickness.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.

In the case of control beams the deflection of beam increased very slowly with the number of cycles till about 0.5 million cycles. Afterwards the rate of increase was faster. At about 0.8 million cycles here was an exponential growth in deflection. The slope was very steep. The deflection reached a eak of 30 mm. In the case of 10% corroded beam there was almost no variation in deflection till 0.001 million cycles. Afterwards deflection increasedrapidly with the number of cycles till about 0.01 million cycles at which there was an exponential growth till the ultimate deflection of 60 mm was reached. Compared to the control beam, the 10% corroded beam lost considerable stiffness and hence has undergone more deflection. The trend of variation of deflection with the number of cycles was the same for all beams. Almost similar trend was observed by Balaguru and Shah (2001). However, the control beam exhibited a larger deflection with the cycles and had registered a maximum deflection of 85.1 mm 0.8 million cycles. In the case of corroded beams the deflections were drastically reduced to below 30 mm and the number of cycles also was phenomenally reduced to 0.001 million cycles.

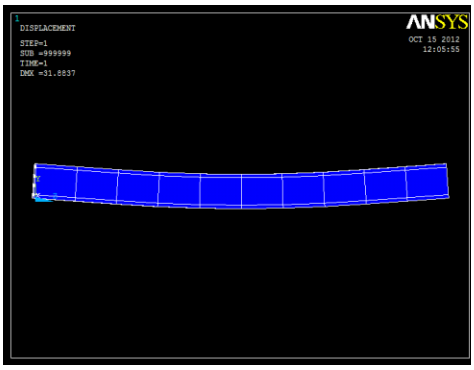
The percentage increase in number of cycles with the reference beam of R, A and B series are presented in the above Table. A series beams exhibit a increase in number of cycles 4.30 to 13.23% while using CSM, WR and UDC GFRP laminates with varying thickness. B series beams exhibit an increase in number of cycles 5.42 to 12.30% while using CSM, WR and UDC GFRP laminates with varying thickness. C series beams exhibit an increase in number of cycles 4.50 to 12.22% while using CSM, WR and UDC GFRP laminates with varying thickness. From the results that the experimental and numerical solutions are in reasonably good agreement for both the categories of beams signifying the validity of the numerical model adopted for the purpose.

The percentage increase in number of cycles with the reference beam of R, A and B series are presented in the above Table. A series beams exhibit a increase in number of cycles 4.30 to 13.23% while using CSM, WR and UDC GFRP laminates with varying thickness. B series beams exhibit an increase in number of cycles 5.42 to 12.30% while using CSM, WR and UDC GFRP laminates with varying thickness. C series beams exhibit an increase in number of cycles 4.50 to 12.22% while using CSM, WR and UDC GFRP laminates with varying thickness.

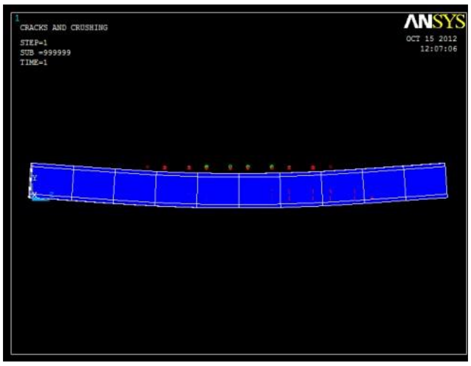
From the results that the experimental and numerical solutions are in reasonably good agreement for both the categories of beams signifying the validity of the numerical model adopted for the purpose.



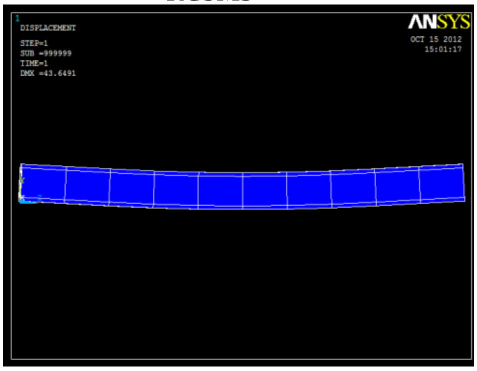
R



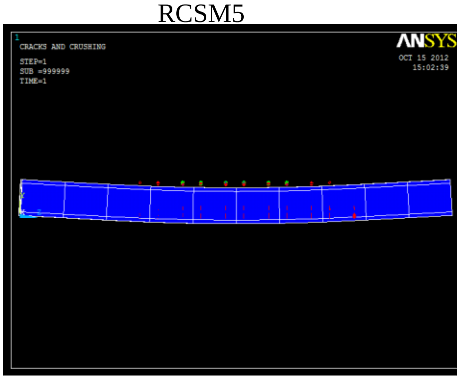
RCSM3



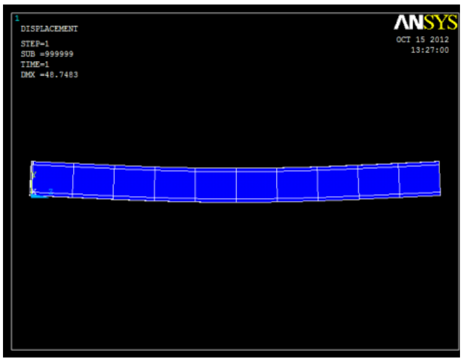
RCSM5

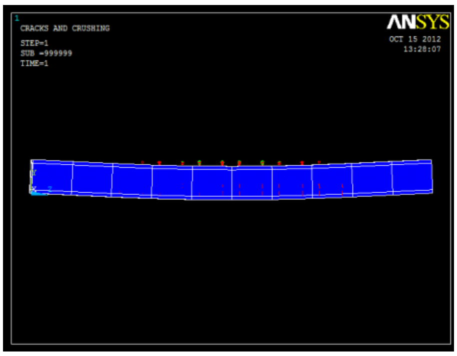


RWR3



RWR5





RUDC3 **RUDC5**

Fig.4.1: Failure Modes and Crack Patterns of R-Series Beams

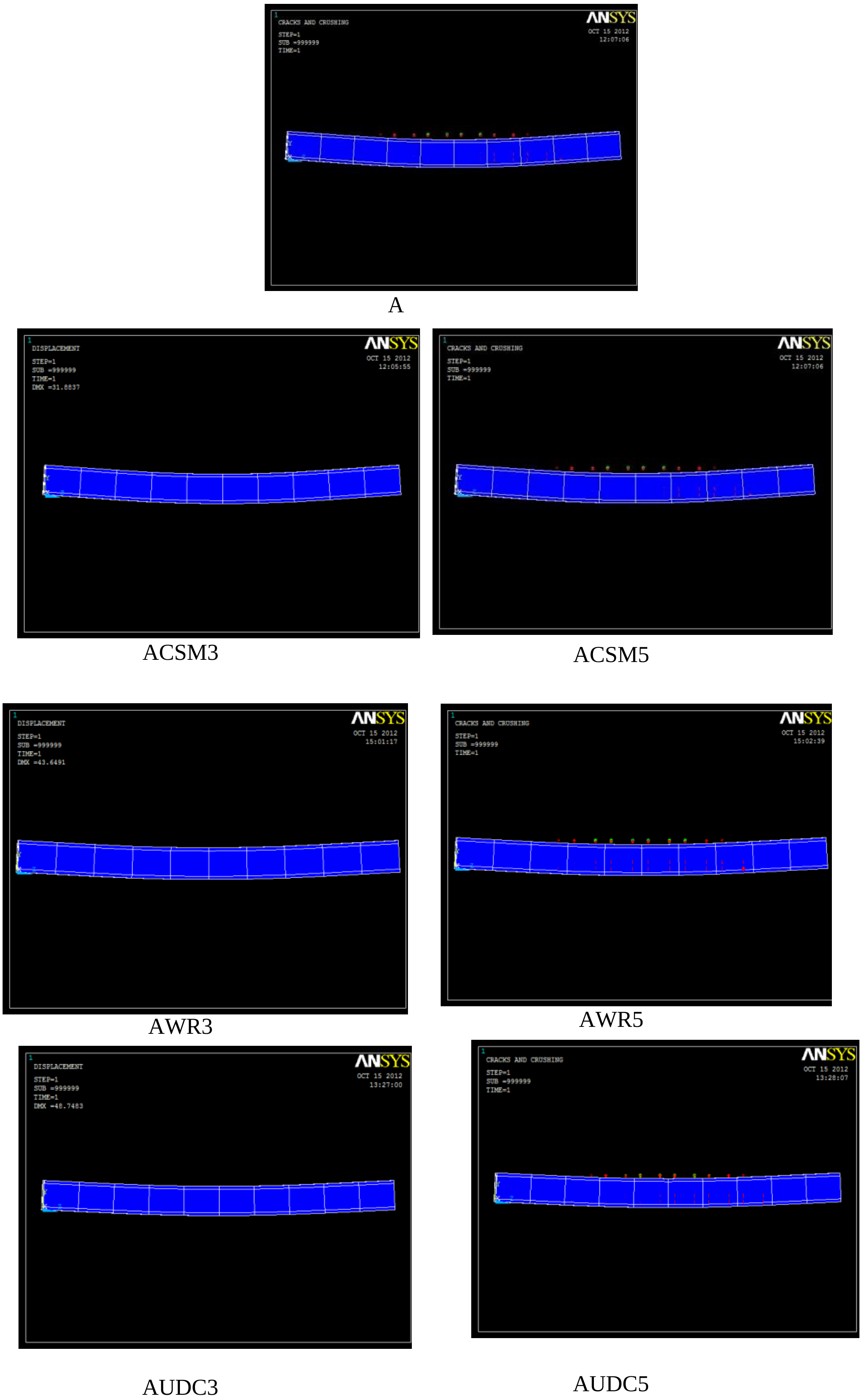


Fig.4.2: Failure Modes and Crack Patterns of A-Series Beams

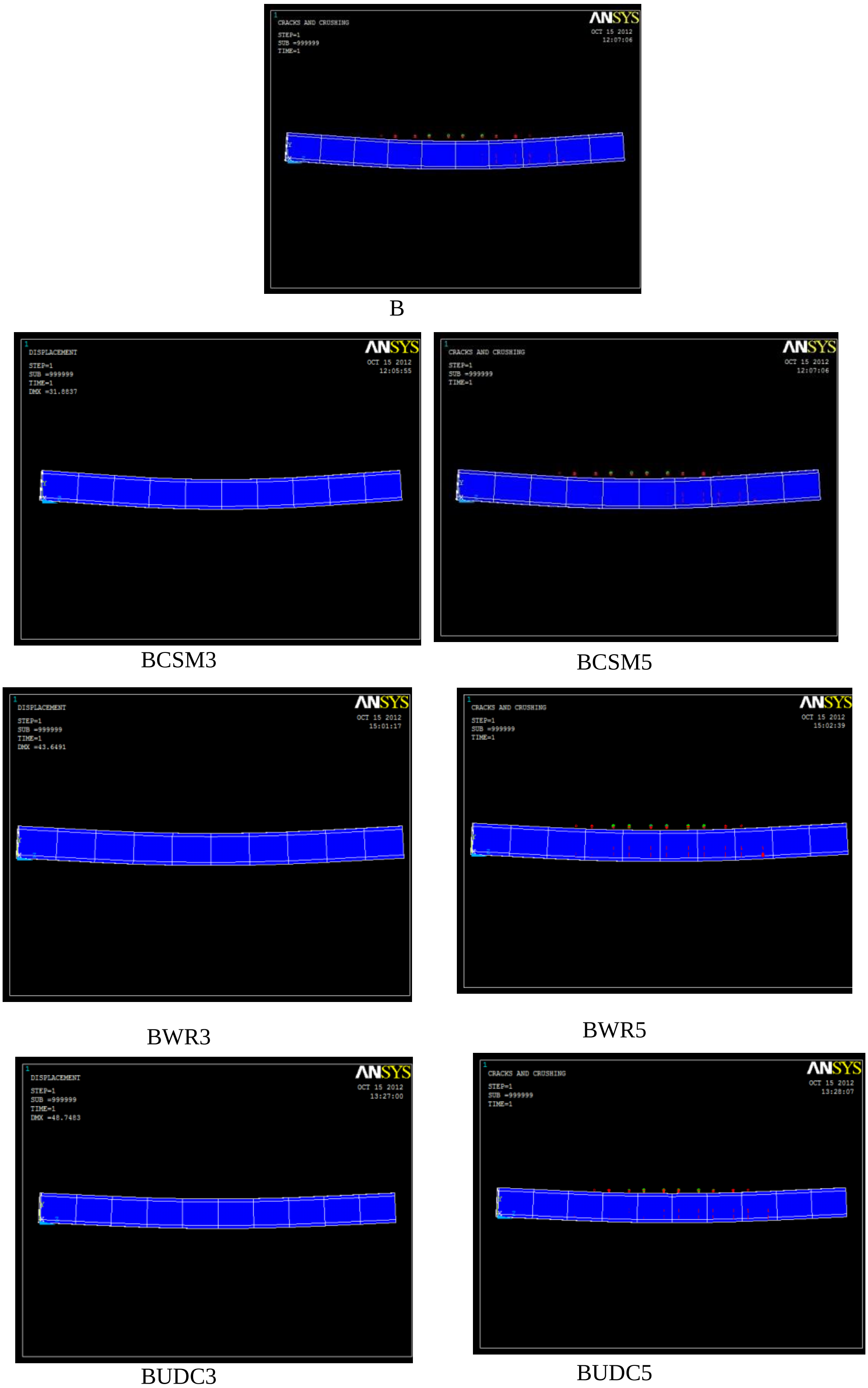


Fig.4.3: Failure Modes and Crack Patterns of B-Series Beams

Comparision of Predicted life cycle with Experimental results

Series	Beam Designation	Type of Loading	No. of Cycles			Deflection in mm		
			Exp	Ansys	% Error	Exp	Ansys	% Error
R	R	Cyclic	416741	471876	13.23	85	90.7	6.70
	RCSM 3	Cyclic	48229	49789	3.23	13	14.7	13.20
	RCSM 5	Cyclic	70554	75740	7.35	28	31.1	11.23
	RUDC 3	Cyclic	44774	50250	12.23	30	32.9	9.80
	RUDC 5	Cyclic	20882	22031	5.50	44	47.8	8.56
	RWR3	Cyclic	152101	160162	5.30	29	31.8	9.80
	RWR5	Cyclic	105570	110110	4.30	22	23.6	7.43
A	A	Cyclic	8340	9274	11.20	28	29.9	6.66
	ACSM 3	Cyclic	7433	8080	8.70	37	40.2	8.73
	ACSM 5	Cyclic	6300	6712	6.54	19	20.9	9.80
	AUDC 3	Cyclic	11279	11890	5.42	21	23.1	9.83
	AUDC 5	Cyclic	11763	12731	8.23	22	24.9	13.20
	AWR3	Cyclic	463502	515572	11.23	55	57.5	4.54
	AWR5	Cyclic	30262	33984	12.30	19	21.5	13.20
B	B	Cyclic	31221	33563	7.50	32	34.4	7.65
	BCSM 3	Cyclic	27997	29257	4.50	18	19.6	8.84
	BCSM 5	Cyclic	5250	5892	12.22	49	53.5	9.26
	BUDC 3	Cyclic	47278	50895	7.65	11.5	12.5	8.82
	BUDC 5	Cyclic	9553	10284	7.65	19	20.6	8.54
	BWR3	Cyclic	3585	3936	9.80	4.7	5.1	9.24
	BWR5	Cyclic	12157	13209	8.65	20	21.1	5.43

4. Conclusions

In this investigation, the behaviour of normal and corroded beams was studied under static loading and the ultimate capacity was evaluated. The failure patterns of beams were established. The control beams showed the normal behaviour and the energy absorption was normal. In the case of 10% corroded beams, the load-deflection curve showed the less percentage of ultimate loading and lesser percentage of energy absorption percentage and whereas in the case of 20% corroded beams show very brittle and took minimum load percentage and minimum energy absorption percentage. Beams were also tested under cyclic loading. The corroded beams were repaired with GFRP sheets and tested under cyclic load. Numerical analysis using ANSYS software package was performed on experimental beams to validate the results. Multivariate regression analysis was also carried to validate experimental results.

Based on the results presented, the following conclusions are drawn:

- The reduction in cyclic age was attributed to the loss of cross-sectional area of steel reinforcement due to corrosion
- The deflection at failure was decreased with increasing level of corrosion damage, leading to a reduction in the ductility of the beams.
- The increase in corrosion intensity decreased the absorbed energy and hence the ductility of the beams.
- The corrosion damaged concrete beams failed in brittle manner at higher levels ofcorrosion.
- The variation in deflection of control beam under static loading exhibited the same trend as for a normal reinforced concrete beams with initial linear relation up to certain load and subsequent non-linear relation afterwards,
- The corroded beam revealed a loss in stiffness due to which the deflectionincreased even at lower load.
- The deflection of beam under cyclic load initially varied almost slowly with thenumber of cycles and then near failure increase exponentially.
- Corroded beams exhibited the same trend, however, the deflection values were drastically reduced.
- The numerical and regression analyses corroborated the results obtained in experiment thus validating the same.

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