ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 5, Issue 4, April 2016

Experimental and Analytical Study of Steel Fiber Reinforced Concrete Exterior Beam Column Joints Under Cyclic Loading.

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ABSTRACT

The main aim of the investigation is to study the behavior of beam column joint with and without steel fiber reinforcement under cyclic loading both experimentally and analytically. Concrete mix of M30 grade has designed as per is10262-2009 with a water cement ratio of 0.45. A total of two specimens, one is conventional and other is crimped type steel fiber reinforced beam column joint were casted and tested. The parameters like deflection characteristics, crack pattern, stress degradation, load vs deflection curve, energy dissipation and ductility are observed. After the experimental investigation, the beam column joint is analysed in ANSYS software and the results are compared, the results of experimental and analytical found similar.

Key words: Beam Column joint, Steel fibers, Cyclic Loading, deflection.

I. INTRODUCTION

Beam column joint is the most important component in the reinforced concrete moment resisting frame. Beam column joint should be designed and detailed properly because the lateral forces effect is very high. Beam column joint will be highly affected during the earthquake or earthquake loading and to overcome from the severe damage of the beam column joint, it should be designed according the required strength with added fibers or with adding any other constituent materials. During the earthquake, the beams adjoining the joints will be subjected to moments either clockwise or anti clockwise direction. Because of these moments, the top bars in the beam column joint is pulled in one direction and bottom ones in the opposite direction. These forces are developed by the bond stress which is developed between the concrete and steel in the joint region. The column should be wide enough and also the strength of the concrete in the joint should high or unless it provides the insufficient grip of the concrete on the steel bars. When such circumstances are not provided, the bar slips inside the joint region and the beam loose their capacity to carry load. Under the action of the above pull and push forces, the joint goes under geometric distortion. Due to the application of the load in both the directions, one diagonal length of the beam column joint under goes compression and other elongates. The cross sectional area of the beam column joint should sufficient or else the concrete in the joint develops diagonal cracks and the attempt has been made to study the behaviour of the steel fiber reinforced exterior beam column joint under cyclic loading.

II. EXPERIMENTAL PROGRAM

A.Materials

Materials used in the experimental work are tested for their properties and the details are furnished. Raw materials listed below are used for preparing of the specimens; ordinary portland cement (OPC) 53 grade, coarse aggregate with 20mm maximum size, Fine aggregate passing through 4.75mm sieve is selected and mechanical properties shown in table1.

Table1. Mechanical Properties of materials

S.No.	Mechanical properties	Experimental Results
1	Fineness of cement	10%
2	Specific gravity of fine aggregate	2.65
3	Specific gravity of coarse aggregate	2.70
4	Specific gravity of cement	3.15

5	Initial setting time	35min
6	Standard consistency	32%

B. Mix Proportion

Mix design is adopted from IS 10262:2009 to design for M30 grade of concrete. The quantity of the material required for the beam column joint is given in the table2.

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Table2: Mix proportion for beam column joint

Type of Beam column joint	Cement in kg	F.A in Kg	C.A in Kg	Water in liters	Steel fibers in kg
Conventional	26.01	38.66	67.06	11.70	----
Steel fiber reinforced	25.75	38.27	66.39	11.58	1.32

C. Preliminary Studies

In the Preliminary Studies, the cube of the standard size (150x150x150mm) were tested, three cubes are to be casted for each mix proportion and they are to be cured for the required number of days and after the curing, the cubes are to be tested in the compression testing machine and the compressive strength observed for the conventional cube (without added fibers) for 28 days is 33.94 N/mm^2, for concrete (0.75% added fibers) is 39.45 N/mm^2 (13.92 % increase in strength), for concrete (1% added fibers) is 42.23 N/mm^2 (19.63% increase in strength) and for concrete (1.25% added fibers) is 45.56 N/mm^2 (25.5% increase in strength) and 1% added fibers strength is adopted for beam column joint.

D. Exterior beam column joint specimen details

Both conventional and steel fiber reinforced beam column joints will be identical in beam and column sizes. The column has a cross section of 200 mm x 150 mm with the overall length of 1000 mm and the beam having the cross section of 150 mm x 200 mm with the cantilever portion of length 1000 mm. Figure1 shows the cross section and reinforcement configuration for exterior beam column joint specimen.

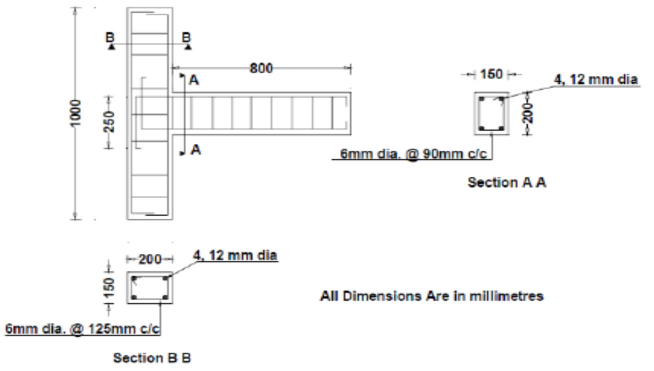

Figure1: Reinforcement detailing of exterior B.C Joint

E. Casting and testing of specimen

Wooden moulds are used for the casting of the specimens. Reinforcement cages are prepared and then required quantity of cement, coarse aggregate, fine aggregate and suitable amount of water are mixed thoroughly in drum type mixing machine for the conventional beam column joint and for the steel fiber reinforced beam column joint additionally suitable amount of steel fibers are to be added. The mixes were poured in the mould in the form of different layers and they are vibrated with the vibrating machine to avoid voids in the concrete. The moulds are kept for 24 hours after casting and then they are to be demoulded and curing is to be done with the wet bags for 28 days.

The testing of the specimen is to be done in the loading frame of 100tonne or 1000kN capacity. A constant load of 150kN, from which the 15% - 20% of the axial load capacity is applied for the column which is used for holding the specimen .A hydraulic jack of 50tonne or 500kN capacity is applied the load at the beam. Cyclic load of 2kN with the increment is to be applied in the beam. Digital dialguage is used for measuring the deflections in the beam. Strain gauges are also used for finding the strain at beam column joint during the increment of load. From figure2, test setup for the application of load for beam column joint, where the load is applied to suitable percentage from top, to make the column and specimen stiff and for the beam, where the load is applied from the bottom or cantilever end to the beam.

Figure2: Test Setup for beam column Joint

III. EXPERIMENTAL PROCEDURE

After completion of the setup for test, the load is to be applied about 2kN incrementally. In this experimental investigation from 0-10kN is taken as the first cycle for the conventional beam column joint. Similarly, the load increment of 2kN procedure is applied for steel fiber reinforced beam column joint and during the application of the load, the cracking load and ultimate load of beam column joints are to be noted.

IV. ANALYTICAL PROGRAM

Analytical program is carried out in ANSYS software. At first before analyzing the beam column joint directly, the model and the other required parameters should be worked out. Young's modulus, poisons ratio, density of concrete, yield strength of concrete should be studied.

Before the modeling of beam column joint, the reinforcement of the beam column joint is to be prepared in ANSYS and the reinforcement consisting of 12mm diameter longitudinal bars and 6mm diameter rings are to be provided with suitable spacing and the reinforcement detailing of beam column joint is shown in figure3.

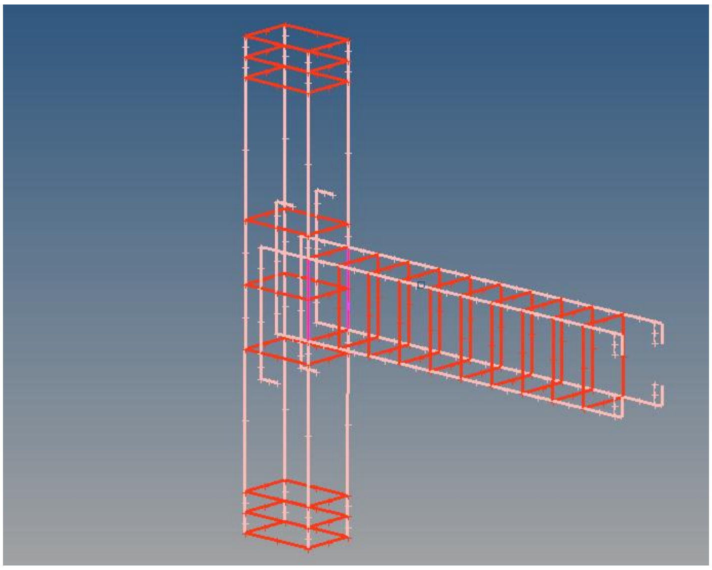

Figure3: Reinforcement of beam column joint

After preparing the reinforcement of the beam column joint, the modelling of the beam column joint is to be prepared by giving the dimensions of the beam column joint and the model of the beam column joint with provided reinforcement shown in figure4 and after the completion of the model, the load is to be applied according to the requirement, then the different parameters of the beam column joint is observed.

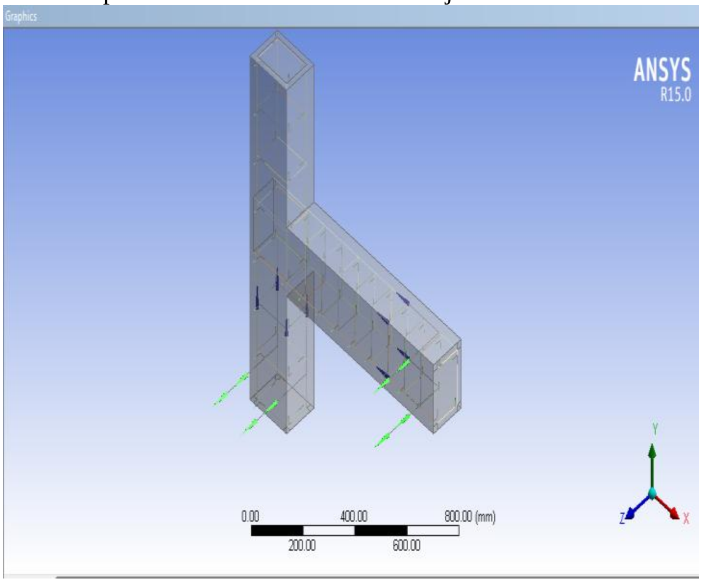

Figure4: Model of Beam Column Joint

Also we can go for the finite element model for beam column joint, in which the clear cover and the dimensions of the beam column joint is taken into the consideration and in the finite element model, it gives one element to the other element dimensions clearly with provided horizontal and vertical lines.

When the finite element model is to be compared with the normal modelling of the beam column joint, we can observe the clear difference from normal model to the finite element model and the finite element of the beam column joint is shown in figure5.

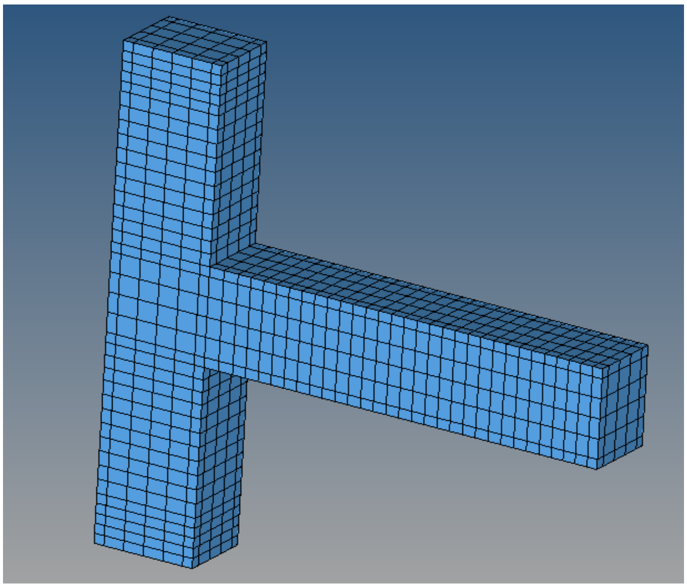

Figure5: Finite Element Model of Beam Column Joint

V. EXPERIMENTAL RESULTS

(a) ULTIMATE LOAD

Type of Beam column joint	Cracking load in kN	Ultimate load in kN
Conventional beam column joint	10	42
Steel fiber reinforced beam column joint	16	64

Figure6: Bar chart showing comparison of strength for conventional and SFRC beam column joint

The comparison of the conventional beam column joint with steel fiber reinforced beam column joint with the increase in ultimate load is shown in figure6.

(b) FAILURE PATTERN

All the beam column joints exhibit a reasonably ductile performance and the failure results from the yielding of high performance concrete followed by the crushing of concrete.

The cracking load of conventional beam column joint is found at 10kN and the further increase in the load leads to the increase in the cracks and the cracks at different loading for conventional beam column joint is shown in figure7.

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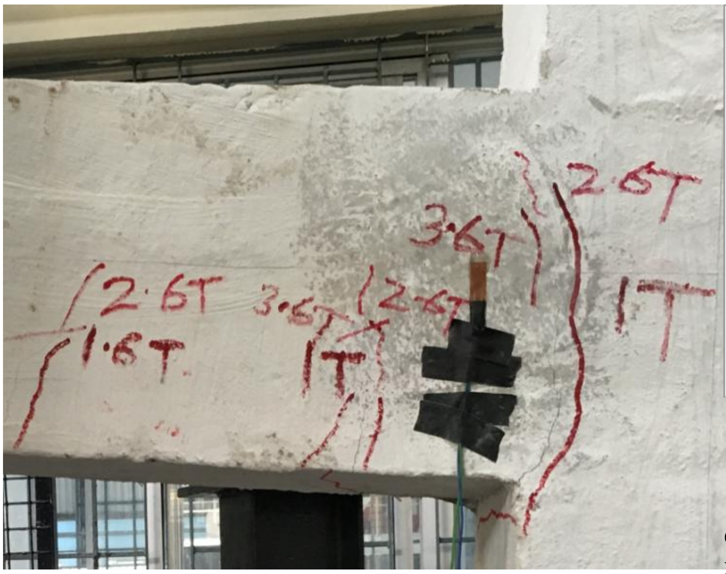

Figure7: Crack pattern of Conventional B.C Joint

In SFRC beam column joint, the cracking load is observed at 16kN and the cracks are propagated with the increase in the load and the crack found at the joint of the beam column, then load is considered as ultimate load, it is shown in figure8.

Figure8: Crack pattern of SFRC Beam column joint

(c) **LOAD vs DEFLECTION**

In conventional concrete beam column joint, the testing of an specimen undergo 4 cycles with the combination of forward and reverse cycling and it is shown in figure9.

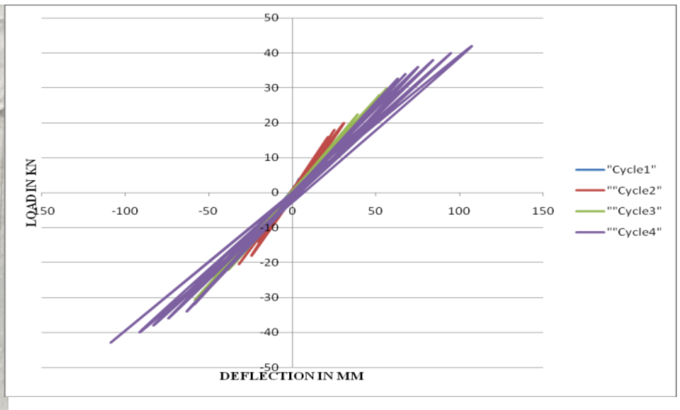

Figure9: Load vs Deflection for Conventional B.C Joint

In SFRC beam column joint, the testing of an specimen undergo six number of cycles, combination of forward and reverse cycle which include both compression and tension, then the load vs deflection for 6 cycles is shown in figure10.

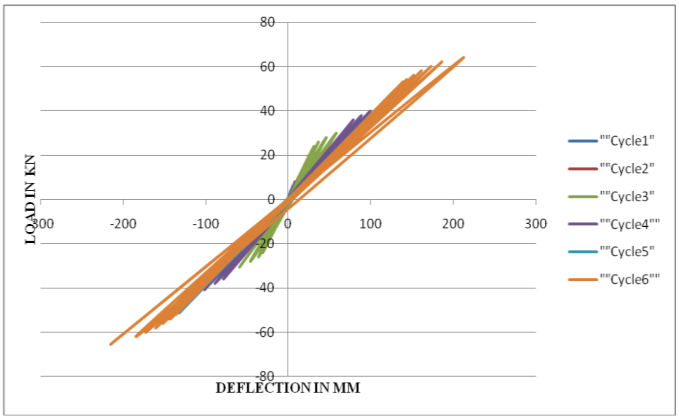

Figure10: Load vs Deflection for SFRC B.C Joint

(d) STIFFNESS DEGRADATION

During the testing of the specimen, the degradation of the stiffness is observed for both conventional and steel fiber reinforced beam column joint and the stiffness degradation of the conventional beam column joint is less when compared with SFRC beam column joint because the load application is about 22kN lesser for conventional beam column joint when compared with SFRC beam column joint.

The stiffness degradation of the conventional beam column joint, the degradation percentage is 73% and the degradation goes on increasing with the increase in the number of cycles or incremental load application to the specimen, stiffness degradation of the conventional beam column joint is shown in figure11.

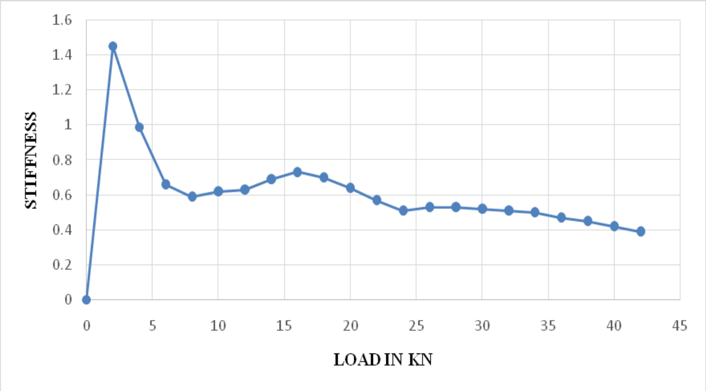

Figure11: Stiffness Degradation for Conventional B.C. Joint

In SFRC beam column joint, the stiffness degradation percentage is 84% and it will get increased with the incremental loads. But, when it is compared with the conventional with SFRC beam column joint, the stiffness degradation is relatively less for SFRC beam column joint and it is shown in figure12.

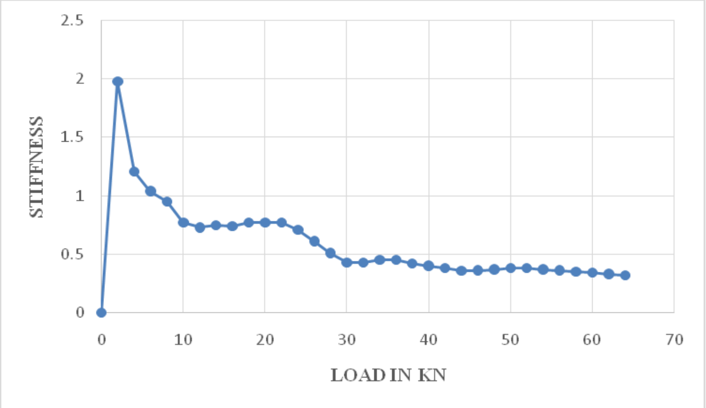

Figure12: Stiffness Degradation for SFRC Beam column joint

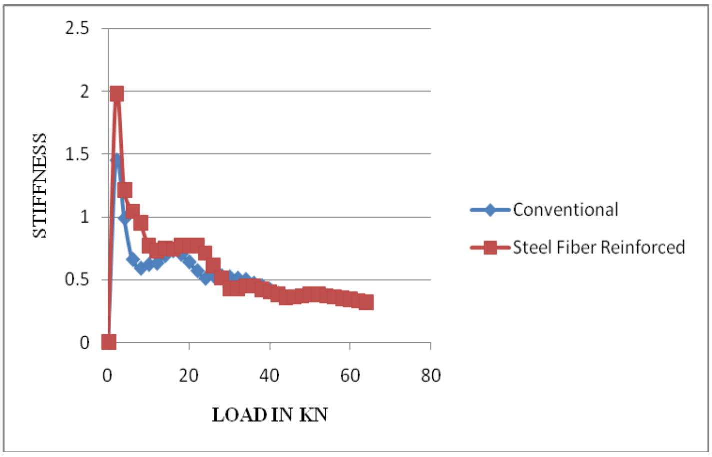

Figure13: Stiffness Degradation (Combination)

In conventional beam column joint, the load applied is 42kN and for SFRC beam column joint the load applied is 64kN, the difference in stiffness degradation for SFRC beam column joint is 17% only for the difference of 22kN load and the combination shown in the figure13.

(d) ENERGY DISSIPATION

With the increase in the load, the energy of the specimen will be decreased and the energy dissipation leads to the cracking of the specimen with the incremental load.

(e) DUCTILITY

The ductile behavior of conventional beam column joint is less when compared with the steel fiber reinforced beam column joint because the cyclic stresses can be withstand more for SFRC beam column joint.

VI. ANALYSIS OF EXPERIMENTAL RESULTS

From ultimate load, increase in percentage of strength for steel fiber reinforced exterior beam column joint, when compared with conventional beam column joint is 34%.

Crack pattern vary from Steel fiber reinforced beam column joint with conventional beam column joint, in conventional beam column joint the cracking load is at 10kN and for SFRC beam column joint, it is at 16kN, increase in cracking load percentage for SFRC beam column joint is 37.5%.

Stiffness degradation will be increased with the increase in the load and for conventional beam column joint, the stiffness is degraded to 73% and for steel fiber reinforced exterior beam column joint, the stiffness is degraded to 84%.

Energy dissipation will be increased with the increase in the load and ductile behavior of beam column joint is decreased with the increase in the energy dissipation and also with the increase in the cracks.

VII. ANALYTICAL RESULTS

When the load is applied for the beam, then the beam gets deflected and when the load is compared in X-direction for the beam column joint, the deflection is high in its surface of the beam, shown in figure14.

Similarly, when the load is applied for the beam, the load application in Y-direction is to be stressed more in column, when compared with the deflection in X-direction of the beam column joint and it is shown in figure15.

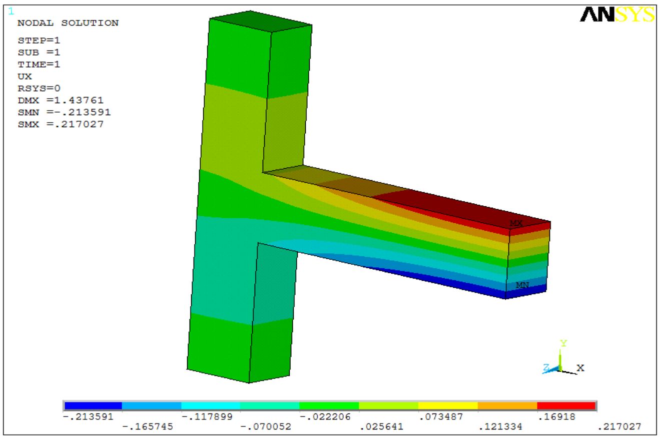

Figure14: Displacement in X-Direction

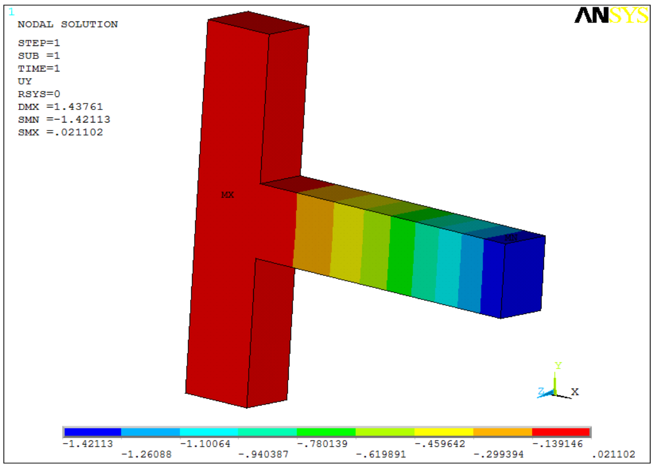

Figure15: Displacement in Y-Direction

When the load applied, the Z-direction shows highly influenced at the intersection of the beam column joint it is highly stressed and the crack at the joint shown in figure 16.

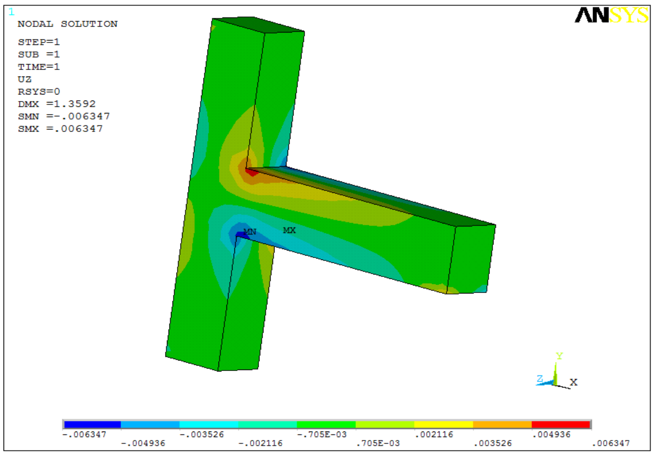

Figure16: Displacement in Z-Direction

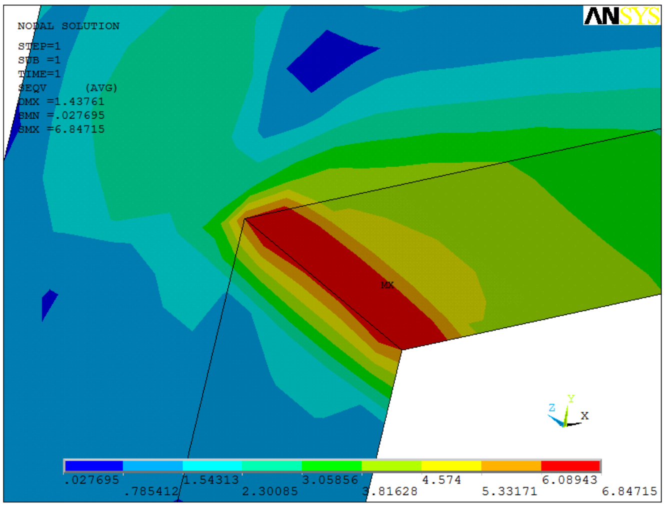

Figure17: Crack at ultimate load in conventional B.C Joint

The ultimate load of conventional beam column joint is observed at the load of 38kNand the macro crack is to be observed in the joint of the specimen shown in figure17.

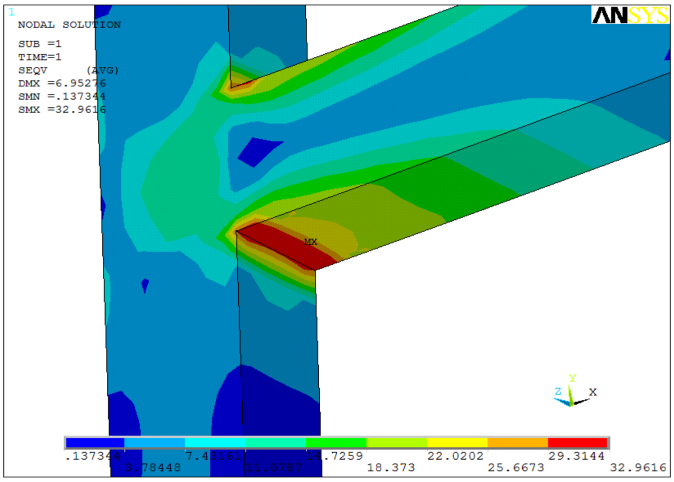

Figure18: Major crack at the joint in SFRC B.C Joint

Similarly, the ultimate load of SFRC beam column joint is observed at the load of 58kN and the major crack is observed at the joint of the beam column shown in the figure18.

VIII. ANALYSIS OF ANALYTICAL RESULTS

The ultimate load for conventional beam column joint under cyclic loading in analytical work is observed to be 38kN and for steel fiber reinforced exterior beam column joint, the ultimate load is 58kN.

We can see the crack pattern of both conventional beam column joint and steel fiber reinforced beam column joints from figure 17, 18 and the failure is exactly at the joint.

Deflection of the beam column joint is also to be analyzed and the deflection will be increased with the increase in the load or incremental load also in analytical work.

Ductility of the beam column joint is reduced with the increase in the load.

IX. COMPARISON OF BOTH EXPERIMENTAL AND ANALYTICAL RESULTS

The ultimate load for SFRC beam column joint is 34% increase in percentage is similar, when compared with the conventional beam column joint for both experimentally and analytically.

The crack pattern is similar when compared with the experimental and analytical results.

The deflection of the beam column joint is increasing with the increase in the load analytically and the progressive increase in deflection is observed, it is similar to the experimental results.

The load application, which gives the increase in the deflection and it leads to the degradation of the stiffness which is similar to the experimental results.

X. CONCLUSION

The ultimate load for Steel fiber reinforced concrete is to be increased for 34%, when we compare with the conventional concrete. So, the use of the steel fibers in the concrete increases the strength.

Crack arresting property is very high in steel fiber reinforced concrete when compared with the conventional concrete. The air cracks are also to be arrested with the use of crimped steel fibers in concrete.

The stiffness degradation of Conventional beam column joint is 73% and for SFRC beam column joint is 84% and only 17% increase in the stiffness degradation is observed for difference of 22kN.

Energy dissipation will be increased and the ductile behavior of the beam column is decreased with the incremental cyclic loading for conventional beam column joint when compared with SFRC beam column joint.

ACKNOWLEDGEMENT

I would like to express my profound sense of gratitude to my guide Ms.S.Karthiga, for his valuable guidance, continuous encouragement and help in carrying out the work presented in this report. I would like to extend my special thanks to Dr.K.Satyanarayanan, Head, Department of civil engineering, SRM University, Chennai.

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