Analytical Examination of Reinforced Concrete with Hybrid Fibres Exterior Beam Column Joint

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Abstract. This research paper pacts with the analytical examination of synthetic fibres (Polypropylene and Recycled polyethylene terephthalate RPET) and steel fibres in reinforced exterior beam column joint by using ANSYS. Based on IS 10262-2009, M40 grade of concrete was prepared along by volume fractions up to 0.5% of synthetic and steel fibre. 9 number of exterior beam column joint with various proportions of hybrid fibre incorporated reinforced concrete specimens were tested by means of monotonic loading. Their experimental results exhibited that reinforced concrete exterior beam column joint specimens with hybrid fibre specimens achieved superior performance along with high ductility, high strength and less crack patterns. The main aim of this research paper was based on the experimental input, analytical examination by ANSYS was carried out and related with the experimental results found. The comparison showed that both the experimental and numerical results similar.

1. Introduction

A later improvement in fibre reinforced composites apprehensions the usage of hybrid fibre system (HyFRC) to maximize numerous material performances. Fibres can be efficient in stopping cracks at together micro and also macro levels in the Fibre Reinforced Concrete (FRC) [1]. For an ideal retort, various type of fibres can be effectively combined to make the Hybrid Fibre Reinforced Concrete (HyFRC). Instead of using individual fibres in the concrete mix, grouping of two or more fibres in the concrete resulting in better engineering properties [2]. Fibres would be combined with various dimensions, shapes, young's modulus, and tensile strength in the concrete mixes. For restraining the plastic cracks, usage of synthetic fibres with higher ductility, dispersion and fineness would be recommended [3]. In addition, steel fibre with higher stiffness and ductility would be suggested for improving the toughness and compressive strength of concrete mixes [4]. Several Industrial rejects are used to improve the strength properties of concrete and it’s an eco-friendly solution to dispose the waste [5][6]. The mechanical properties of reinforced concrete were improved by using the combination of synthetic and steel fibres in
the concrete mix [7][8].

Most of the earthquakes occurred recently revealed that the importance of constructing the structures with higher ductility. In the earthquake resistant structures, beam column joint plays a major role in the analysis and design of moment resisting frames [9].

This investigation deals about the finite element modelling of exterior beam column joints by using ANSYS. Each beam column joint models by ANSYS were checked for deflection appropriate to initial crack load and ultimate load. Already obtained experimental results were compared with the analytical examination by ANSYS[10].

During the modelling of beam column joint specimens, following assumptions were made: Modelling of steel and concrete as homogeneous and isotropic materials, reinforcements used in the modelling was assumed as elastoplastic material and similar while applying tension and compression, plane sections even after loading also remains the section as plane. According to IS 456: 2000, concrete with 0.0035 mm was assumed as maximum compressive strain and also assuming that efficient bonding would be there between the concrete and the reinforcement.

Qian et al. conducted the investigation on strength properties of polypropylene – steel fibre reinforced concrete by optimising the flyash content and also fibres in terms of size and type. Their research studies revealed that larger quantity of steel fibres blended with low quantity of polypropylene fibres would be getting better results. Their findings showed that 1.2% of steel fibres blended with 0.3% of polypropylene fibres possessed better compressive strength, split tensile strength, modulus of rupture and yielded good result in compaction also [11]. The strength properties of high strength concrete were compared with high strength steel fibre reinforced concrete in terms of toughness index, compressive strength, split tensile strength and modulus of rupture. The optimized steel fibres were added in the concrete mixes with proportions such as 0, 0.5, 1.0, 1.5 and 2%. The fibre content of 1.5% concrete showed better compressive strength values by about 15.3% over the high strength concrete. Similarly, fibre content of 2% showed better splitting tensile strength and modulus of rupture values by about 98.3% and 126.6% respectively over the high strength concrete [12].

Ochi et al. examined the hand mixing process of PET fibre along with the concrete. Results showed that efficient concrete mix was obtained by mixing the PET fibre content upto 3%. Test results revealed that strength values would be similar to the normal concrete, until the crack development in the specimen’s load deflection values also showed the similar curve. They recommended that utilization of alkali resistant PET fibre should be used in the concrete mixes [13]. Machine Hsie et al. conducted the investigations for determining the strength properties of hybrid fibre reinforced concrete with polypropylene fibres. The physical form of polypropylene fibre used would be coarse monofilament of 3kg/m$^3$, 6kg/m$^3$, 9kg/m$^3$ and staple type of fibres at 0.6kg/m$^3$. The efficient bonding in-between the two forms of polypropylene fibres showed that better strength properties compared to individual fibre reinforced concrete. Hybrid fibres used in the concrete dispersed throughout the concrete and effectively reducing the drying shrinkage. Staple form of polypropylene fibres with fines materials restraining the cracks in the initial stage of concreting [14].

P. Perumal et al. conducted the experimental studies on the behaviour of reinforced concrete with hybrid fibre exterior beam column joints. The hybrid fibres used in the concrete were steel and polypropylene fibres. In their experimental work, 5 set of samples of beam column joints were casted and experimenterd by means of displacement-controlled loading by applying the reversed cyclic loading pattern. Upon identifying the ductility, energy dissipation, strength properties in the specimens showed that 0.2% of polypropylene fibre with 1.5% steel fibre reinforced concrete beam column joints achieved better performances. Higher displacements without development of wider cracks were achieved by hybrid fibres and also resisting the deformations effectively [15]. Ganesan et al. investigated exterior beam column joint with steel fibre reinforced concrete under cyclic loading. The steel fibres with an increment of 0.25% from 0-1% were mixed in the concrete mix. The test results revealed that congestion of reinforcement in beam column joint would be reduced and stiffness, strength, ductility would be obtained
better than the high-performance concrete without any type of fibres [16]. Sivakumar et al. had done the investigation on high strength concrete with grouping of non-metallic and hooked steel fibres with a volume fraction upto 0.5%. The high strength concrete with hybrid fibre combination such as steel-glass, steel-polypropylene, steel-polyester were studied. The final results showed that apart from all other fibres, non-metallic fibres deferred the formation of micro cracks in the concrete and also enhanced the mechanical properties further when compared to the concrete with all other fibre combinations [17].

The review of literature has focused largely on the performance of beam column joint subjected to seismic behaviour and cyclic loading. The pigmentation in the concrete also have impact on compressive strength [18]. The benefits of steel fibres, fly ash [19], FRP [20], banana fibre [21], glass fibre and PET fibres[22] in the concrete are widely explained in many of the literatures. Soft computing techniques were used in literatures for analysis of research work [23].

2. Methodology

2.1 Element Types

The concrete was shown as Solid65 element. This 8 nodes Solid65 element with degrees of freedom to each node – translations in the nodal directions of x, y, and z. The plastic deformations and cracking were observed in all the three orthogonal directions of this solid65 element.

The steel reinforcement was modelled as Link180. This 3D spar element of Link180 has 2 nodes with 3 degrees of freedom to each node – translations in the nodal directions x, y and z. This Link180 element is also capable of plastic deformation. Table 1 shows the specimen element types.

| ANSYS Element | Material type   |
|---------------|----------------|
| Link180       | Concrete       |
| Solid165      | Steel Reinforcement |

2.2 Material Properties

The beam column joint was modelled in ANSYS with the parameters listed in the table 2. The material model of each element is divided into multiple parts. Material model No. 1 denotes to the Solid65 element. The isotropic material property such linear and multilinear is applicated to Solid65 elements for proper model concrete.

PRXY is the Poisson’s ratio (ν) and modulus of elasticity of the concrete (E_c) is represented as EX. The modulus of elasticity is founded on the compressive strength of concrete,

\[ E_c = 5000\sqrt{f_{ck}} \]

Here the value of \( f_{ck} \) equal to 40 MPa and 0.2 is for their Poisson’s ratio.

2.3 Modelling

The exterior beam column joint was modelled in ANSYS as volume. The model dimensions were shown in table 2 and the combined element volume types created in ANSYS were revealed in table 1. Figure 1 displays the exterior beam column joint model volume creation by using ANSYS, figure 2 displays the mesh creation of beam column joint model, figure 3 displays the configuration of reinforcement modelled in beam column joint and figure 4 displays that meshing of created reinforcement in the ANSYS beam column joint model.
Table 2. Column and Beam Specimen Model - Dimensions

| Coordinates of ANSYS model | Column Model (mm) | Beam model (mm) |
|----------------------------|------------------|-----------------|
|                            | Volume Type 1    | Volume Type 2   |
| Z1, Z2 Z - coordinates     | 0                | 0               |
| Y1, Y2 Y - coordinates     | 0                | 1000            |
| X1, X2 X - coordinates     | 0                | 200             |

Figure 1. Beam Column Joint – ANSYS Volume Creation

Figure 2. Beam Column Joint – ANSYS Mesh Creation

Figure 3. BCJ - Reinforcement Configuration model

Figure 4. Meshing of reinforcement model

2.4 Meshing

For obtaining the better result from the Solid65 concrete element in ANSYS, rectangular mesh is recommended. So, the mesh was created that square or rectangular pattern would be created. The meshing of the exterior beam column joint as revealed in figure 2.

2.5 Loads and Boundary Conditions

For obtaining the unique solution, displacement boundary conditions are required. The constant value of zero would be specified for the translation at the nodes (UX, UY and UZ). Figure 5 and 6 displays the support conditions at the bottom and top of the column. At a distance of 50 mm from the face of the beam, force F is applied.
2.6 Analysis Process

In the ANSYS analysis, initial load and ultimate load were found. Regarding the non-linear analysis, Newton-Raphson method is followed to model the specimens. The time at the end to every load step approaches to the loading applied. Regarding the initial load step, 5000 is the timing at the end of load step representing the load of 5000 N applied on the beam. The force and the displacement are the two integrated criteria were used in the analysis. Upto the cracking load, integrated criteria values were left as default. Though the cracking was initiated in the beam column joint, default values in integrated criteria was unbearable. The force does not converge, but the displacement does. Accordingly, the displacement value would be given as 5 as reference value and the criteria for force is released. For the nonlinear analysis, the above obtained value was multiplied by 0.05 of tolerance value for achieving the criteria of 0.25. A minor criterion essential be used to apprehension precise response. For the remaining of the analysis, the above criteria were used. The load increment of 5 kN is applied, if it does not converge means the failure of the model is effectively defined. This ANSYS analysis program displays the information that large deflection was applied on the model exceptional to the displacement limitation. Table 3 displays the deflection values and load increments from initial crack load to ultimate load. The results obtained from the finite element modelling studies of the reinforced concrete with hybrid fibre beam column joint specimen were related with the outcomes from the experimental learning. The above information warrants that the concrete and steel elements, real constants of the materials, properties of materials and criteria such as force and displacement were satisfactory to model the reply of the member.

3. Results and Discussion

The analysis of exterior beam column joint specimens by ANSYS were identify from beam free end. The obtained deflection values are given in the table 3.

| Applied Load (kN) | Deflection Values (mm) |
|------------------|------------------------|
|                  | 0  | 5  | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 |
| BCJ0             | 0  | 0.72 | 1.40 | 2.29 | 3.74 | 5.56 | 7.86 | 11.00 | -  | -  |
| BCJ1             | 0  | 0.98 | 2.03 | 3.44 | 5.19 | 7.02 | 9.20 | 11.88 | 13.08 | 15.02 |
| BCJ2             | 0  | 0.86 | 1.82 | 3.14 | 5.04 | 8.23 | -   | -   | -   | -   |
| BCJ3             | 0  | 0.75 | 1.72 | 3.32 | 5.76 | -   | -   | -   | -   | -   |
| BCJ4             | 0  | 1.33 | 2.70 | 4.20 | 6.00 | 8.01 | 10.10 | 12.09 | 14.08 | -   |
| BCJ5             | 0  | 1.02 | 2.14 | 3.49 | 5.22 | 7.89 | -   | -   | -   | -   |
| BCJ6             | 0  | 0.86 | 1.85 | 3.43 | 6.04 | -   | -   | -   | -   | -   |
| BCJ7             | 0  | 1.24 | 2.54 | 4.56 | 7.09 | 10.04 | -   | -   | -   | -   |
Initially, the finite element model ruins in the linear region as characterized by a straight line. The first crack of beam column joint occurs at the applied load of 12 kN and 16 kN as designated by an alteration in slope of the linear region and is denoted in Fig. 7 and Fig. 8.

The stresses and deflections in the beam column joint will not be identified, if the cracking occurs. Later a load of 10 kN and 14 kN, the non-linear region starts and endures upto a load of 35 kN and 40 kN for BCJ0, BCJ1 of the specimens respectively.

The first crack of beam column joint occurs at the applied load of 7 kN and 5 kN as specified by the alteration in slope of the linear region and is characterized in Fig. 9 and Fig. 10. After the applied load of 7 kN and 5 kN, the non-linear region starts and endures up to a load of 25 kN and 20 kN for BCJ2, BCJ3 specimens respectively.
The first crack of beam column joint happens at a load of 13 kN and 9 kN as designated by the alteration in slope of the linear region and is characterized in Fig. 11 and Fig. 12. After the applied load of 13 kN and 9 kN, the non-linear region starts and endures up to a load of 39 kN and 25 kN for BCJ4, BCJ5 specimens respectively.

The first crack of beam column joint occurs at the applied load of 6 kN and 7 kN as specified by a change in slope of the linear region and is characterized in Fig. 13 and Fig. 14. After the applied load of 6 kN and 7 kN, the non-linear region starts and endures up to a load of 20 kN and 25 kN for BCJ6, BCJ7 specimens respectively.

The first crack of beam column joint happens at the load of 13 kN and 9 kN as designated by the alteration in slope of the linear region and is characterized in Fig. 11 and Fig. 12. After the applied load of 13 kN and 9 kN, the non-linear region starts and endures up to a load of 39 kN and 25 kN for BCJ4, BCJ5 specimens respectively.

The first crack of beam column joint occurs at the applied load of 6 kN and 7 kN as specified by a change in slope of the linear region and is characterized in Fig. 13 and Fig. 14. After the applied load of 6 kN and 7 kN, the non-linear region starts and endures up to a load of 20 kN and 25 kN for BCJ6, BCJ7 specimens respectively.
The first crack of beam column joint occurs at the applied load of 5 kN as designated by the alteration in slope of the linear region and is denoted in Fig. 15. After the applied load of 5 kN, the non-linear region jumps and endures up to a load of 12 kN for BCJ8 specimen. Beam column joint deflection shape is provided in the fig. 16 and maximum stress created by the applied load is shown in fig. 17.

**Figure 16.** Beam column Joint – Deflected shape

**Figure 17.** Beam Column Joint - Maximum Stress Distribution

4. Conclusion

Thus, the performance of reinforced concrete hybrid fibre exterior beam column joint by monotonic loading was analysed by using ANSYS software. The applied load deflection curve of ANSYS specimens is similar to experimental results of exterior beam column joint with hybrid fibre reinforced concrete. The FEM analysis deflection under initial crack load and ultimate load obtained by ANSYS model specimens are generally in realistic concord with the experimental test results.

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