NUMERICAL ANALYSIS OF HYBRID FIBRE REINFORCED CONCRETE BEAM COLUMN JOINT

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by

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I **RISHIKUMAR SORAISHAM** (2K22/STE/12) hereby certify that the work which is being presented in the thesis entitled "**Numerical analysis of hybrid fibre reinforced concrete beam column joint**" in partial fulfillment of the requirements for the award of the Degree of **Master of Technology**, submitted in the Department of Civil Engineering, Delhi Technological University is an authentic record of my own work carried out during the period from August 2023 to May 2024 under supervision of **Dr. Nirendra Dev, Professor, DTU**

The matter presented in the thesis has not been submitted by me for the award of any other degree of this or any other institute.

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CERTIFICATE BY THE SUPERVISOR

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ABSTRACT

This thesis investigates the hybrid effect of incorporating both metallic and nonmetallic fibers into concrete at a full-scale beam-column joint section subjected to seismic loading. The research aims to evaluate the improvements in mechanical properties and overall performance of the beam-column joints achieved through the addition of hybrid fibers.

The experimental study employed one normal grade concrete mix (M25) and four different hybrid fiber combinations: hooked end steel fiber with basalt fiber, and crimped steel fiber with polypropylene fiber. These mixtures were designed and tested in the laboratory to determine their compressive, tensile, and flexural strengths following relevant Indian Standard code provisions.

The full-scale beam-column joint section was designed according to the Bureau of Indian Standards (BIS), incorporating ductile detailing as per seismic design requirements. The same geometric configuration was modeled using the finite element software ANSYS v21. Numerical models of concrete and steel were developed, incorporating non-linear stress-strain relationships in uniaxial compression and tension based on the experimental data.

The finite element models were subjected to two loading conditions: steady static loading and non-linear reverse cyclic displacement-controlled loading, simulating seismic effects. The study evaluated key performance parameters, including initial crack load, initial crack deflection, ultimate load capacity, and ultimate deflection. The results showed that the hybrid combination of 0.40% basalt fiber with 0.80% hooked end steel fiber outperformed the other mixtures in terms of compressive strength, flexural strength, energy dissipation capacity, and stiffness degradation. Notably, the hybrid effect of 0.80% crimped steel and 0.20% polypropylene fiber exhibited the highest tensile strength and best resistance to initial cracking, likely due to the micro-filament nature of the polypropylene fibers. However, increasing the polypropylene content to 0.40% led to a gradual decrease in both tensile and flexural strengths.

The findings of this research contribute to the understanding of the synergistic effects of hybrid fiber reinforcement in concrete, particularly for critical structural elements such as beam-column joints subjected to seismic loading. The enhanced mechanical properties and improved crack control achieved through hybrid fiber reinforcement can potentially lead to more resilient and durable structures, mitigating the risk of catastrophic failures during seismic events.

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Before I commence with the presentation of this study, it is imperative that I express my gratitude to all the individuals whose contributions were indispensable in bringing this work to fruition. Foremost, I would like to express my heartfelt gratitude to God for the wisdom, strength, and inspiration provided throughout the course of this research.

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RISHIKUMAR SORAISHAM

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CHAPTER 1
INTRODUCTION

1.1 GENERAL

Beam-column connections is the only structural component experiencing larger shear stresses due to earthquake and it can cause critical damage and reduction in stiffness. When there is seismic loading on the structure, at the beam-column joint section, beams on either side are under moments in same direction which may be both hogging or sagging. This is very different from the case of normal gravity loading. Past earthquake predicts that severe damage or collapse of structure due to brittle failure mechanism. This study aims to assess the hybrid effect of steel fibre (SF), basalt fibre (BF), and polypropylene fibre (PF) on concrete with a volume of 1% and 1.4% (M25) through compressive, flexural, and uniaxial split tensile tests, using the hybrid effect index. The compressive, tensile, and flexural properties of different hybrid mixes are determined. Total of five numbers of beam-column joint models are simulated in ANSYS finite element software.

1.2 BEAM COLUMN JOINT

The joint of Beam Column, also known as a moment-resisting joint or moment connection, is a structural component used in building construction to connect a beam to a column. These joints are designed to resist moments (rotational forces) and transfer loads between the beam and column efficiently. The connection where one beam interacts with the column's vertical face and other two beam also attach perpendicularly into the joint is termed as exterior joint. Generally, as the name suggests exterior joints are located at the exterior wall of a structure. The interaction of bond stress and shear transfer mechanism play a crucial role in resisting the exterior load experienced by the structure. For any type of load which may be of higher or lower degree, the maximum stress always occurs at the junction of beam-column which is due to the load transfer mechanism shift from the column to the beam and vice versa. When lateral loading occurs, the external joint is always in the prone of either fully tensile or fully compression zone which is very critical. So, a good ductile detailing of the joint is definitely necessary to sustain seismic load or any kind of lateral load.

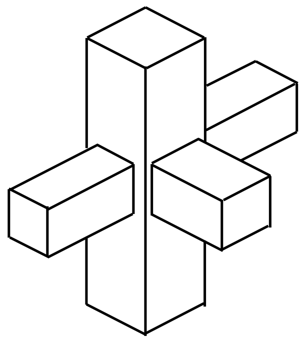


Figure 1.1 A typical exterior beam column joint

1.3 FORCES IN BEAM COLUMN JOINT

1.3.1 Gravity load

Compressive stress, tensile stress and shear stress are generated at the joint section when the structure is subjected to any type of load. The resisting moment in beams on either side of the joint are always either both in hogging or sagging. Under gravity loading condition, at the beam's mid span section compressive stress is developed while at the zone just next to the joint or at the joint region tensile stress is generated at the upper section of beam cross section. While at the lower cross section of the beam it is vice-versa. These compressive and tensile stress from beam and the axial load from column are transferred directly to the joint.

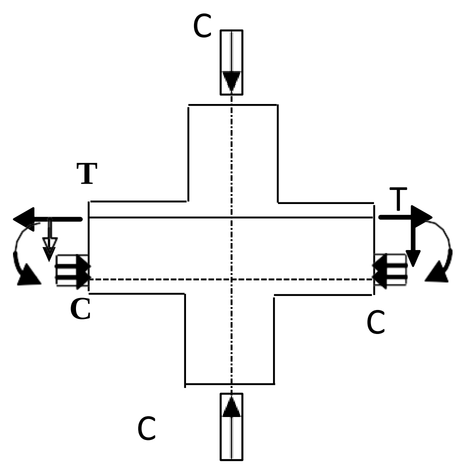


Figure 1.2 Beam Column joint under gravity

1.3.2 SEISMIC LOAD

Under lateral loading, stresses from beam and column form an equilibrium stress generating diagonal tensile and diagonal compressive shear stresses inside the joint. In this case, resisting moments on either side of the joint are alternate in direction which is hogging on one side and sagging on another side of the joint. In the Fig.1.3, which is a joint section sway to right direction, dotted lines indicate compressive strut while the solid lines indicate tensile ties. As a result of the tensile shear stress along line AB, crack is developed perpendicular to AB.

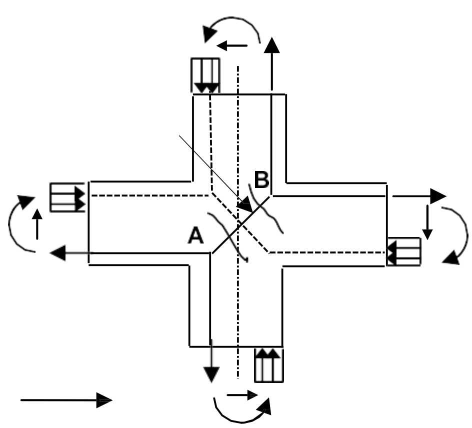


Figure 1.3 Beam column joint under lateral load

1.3.3 Shear forces

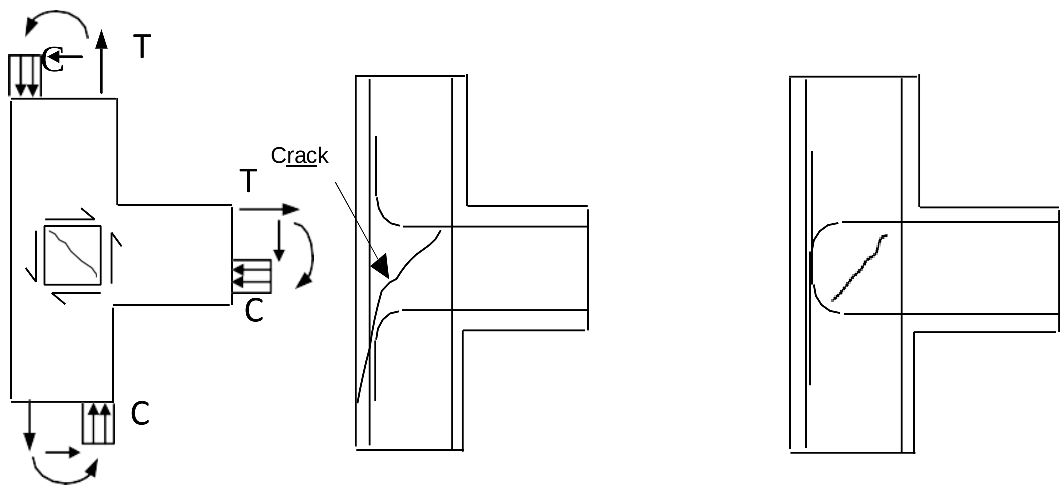


Figure 1.4 (a) Forces in exterior joint (b) poor anchorages (c) Satisfactory anchorage

In exterior joint, the longitudinal reinforcements from the beam do not pass through the joint, they terminate inside the joint only. The beam's upper and lower reinforcement, unlike the internal joint, must be sufficiently secured to the column to prevent reinforcement pull out failure. Before the occurrence of the first crack, shear transfer in reinforced concrete is termed as closed shear transfer. In this phase, the concrete resists shear forces effectively, with the fibers enhancing connection between the reinforcement and the concrete matrix. After cracking, the system shifts to open shear transfer. The presence of fibers, especially in hybrid fiber-reinforced concrete (HFRC), helps in maintaining shear transfer even after cracks have developed. Hybrid fibers improve the beam-column joints' shear capacity by bridging cracks and distributing shear forces more evenly. This reduces the likelihood of shear failure and enhances the overall load-carrying capacity.

1.4 SHEAR RESISTING CAPACITY

The steel and concrete combined contribute to the shear junction’s strength. Contribution from the concrete is generally in the form of compressive stress and that of steel is in the form of bond stress between longitudinal reinforcement and concrete. This results in a more ductile failure mode, which is essential for absorbing and dissipating energy during seismic events, thereby reducing the risk of catastrophic collapse. Consequently, the use of HFRC in beam-column joints not only improves their load-bearing capacity but also enhances their resilience and longevity, making it a superior choice for critical structural applications.

Adequate shear reinforcement within the joint region plays a crucial role in enhancing the shear resistance through the truss mechanism. Building codes, such as IS:13920-2016 and ACI 352R-02, emphasize the importance of confining the horizontal reinforcement to ensure the axial load-carrying capacity of the column, while ACI 318M-11 recommends the provision of adequate transverse reinforcement to prevent shear failure within the beam-column joints.

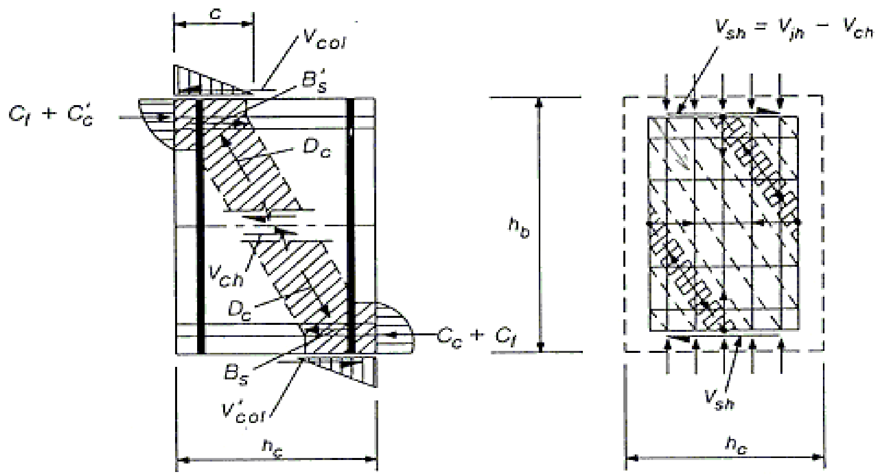
It is essential to design and detail the shear reinforcement in beam-column joints carefully, considering the anticipated shear demands under seismic loading conditions. Proper confinement and anchorage of the reinforcement within the joint region are critical to ensuring the effective transfer of forces and preventing premature failure modes, such as shear cracking or joint degradation.

By optimizing the shear resisting capacity through a combination of diagonal strut action and truss mechanisms, reinforced concrete beam-column joints can achieve the desired level of ductility and energy dissipation capacity, thereby enhancing the overall seismic performance of moment-resisting frames.

1.4.1 Joint section shear capacity

The joint section shear capacity is given by the following equation as:

$$V_{jh} = V_{ch} + V_{sh}$$



(a) Mechanism of Strut (b) Mechanism of Truss

Figure 1.5 Mechanism resisting shear at joint

The mechanism that resists shear of the joint section is developed by two factors namely diagonal concrete strut action and truss action.

1.5 SHEAR REINFORCEMENT

Shear resistance is developed due to presence of horizontal and vertical shear reinforcement within beam-column joint resulting into truss mechanism. The maximum permissible area determined by the diagonal compression's maximum stress and the minimum reinforcement area needed to support the truss mechanism govern the design of shear reinforcement. Codes such as IS:13920-2016 and ACI 352R-02 emphasize the significance of confinement of horizontal reinforcement ensuring the column's capacity to support an axial load, while ACI 318M-11 (2011) recommends the provision of adequate transverse reinforcements to prevent shear failure at beam-column joints. However, the increase in the number of transverse reinforcements can lead to challenges during construction, such as steel congestion, which may affect concrete pouring and compaction, ultimately impacting concrete quality and deformation capacity, especially during seismic events.

1.5.1 Lateral Reinforcement

In the event of beam flexural yielding, the bond between the beam reinforcement and concrete gradually deteriorates. Consequently, as bond degradation progresses, the truss mechanism fails, and the diagonal strut mechanism becomes the primary means of resisting shear forces in the joint. The concrete on the joint's compression face counteracts the tensile forces in the beam section that are not effectively transferred through bond to the concrete at the joint interface. This results in an increase in compressive stress within the primary strut.

1.6 DUCTILITY OF REINFORCED CONCRETE STRUCTURES

Ductility refers to a structure's capacity to deform beyond its elastic limit. Structural ductility, stemming from the ductility of its individual members, plays a crucial role in dissipating energy during seismic events. Member ductility typically manifests through inelastic rotations, commonly termed plastic hinges. The only places where structural damage can occur are plastic hinges, due to inelastic deformation, exceeding the material's elastic limit. It is more tolerable for beam parts to have damage, such as plastic hinges, than columns. Plastic hinges forming in columns can lead to a soft story mechanism, which poses significant danger and can result in catastrophic structural failure. Thus, the strong-column weak-beam behavior principle is crucial.

1.7 FIBRE REINFORCED CONCRETE

The idea of addition of fibrous material into clay or mud for has been done since the past few centuries. Fibrous materials like hay, animal hairs, jute, thin organic strips, etc into clay reduced the formation of cracks under extreme temperature fluctuation reducing expansion in hot summer or reducing shrinkage in cold winter. This idea of fibre has been adopted in concrete in modern engineering. Fibrous material in concrete under controlled quantity improves the compressive strength capacity, reduces the early growth of crack, increase tensile as well as flexural strength, and also increase the energy dissipation capacity to a great extent. Excess quantity of fibres into concrete always makes lower workability to the concrete which is not appreciated for construction purposes so, application of a good plasticizer improves workability.

1.7.1 Crimpled Steel Fibers

Figure 1.6 Crimpled steel fibres

A form of reinforcement called crimpled steel fibers is added to concrete and other building materials to improve its mechanical qualities, including tensile strength, durability, and impact resistance. These fibers are characterized by their wavy or crimped shape, which helps them bond better with the concrete matrix compared to straight fibers. Aspect ratio, or the fiber's length divided by the smallest lateral dimension determines the basic dimensional properties of that fibre. The crimpled steel fiber that is employed has an aspect ratio of 69.

1.7.2 Hooked end Steel fibres

Figure 1.7 Hooked end steel fibres

Another kind of reinforcement used in concrete to enhance its strength is called hooked-end steel fibers. mechanical properties, particularly tensile strength, impact resistance, and durability. These fibers are distinguished by their hooked ends, which provide additional anchorage within the concrete matrix. The basic function of the fibre is influence by the shape and material properties. The steel fibre with hooked end that is employed has an aspect ratio of 47.

1.7.3 Basalt Fibres

Figure1.8 Basalt fibres

Basalt fibre is clean, healthy and eco-friendly fibre with no environmental pollution. Basalt fibre is drawn from extremely fine fibres of basalt which is obtained under melting and crushing of basalt rock. It is fibre glass type structure with higher elastic modulus and higher conductivity. It has acid alkali resistant property, good insulation and good mechanical property. Aspect ratio of basalt fibre used is 80.

1.7.4 Polypropylene Fibres

It is a low elastic modulus fibre having very high tensile strength. The high tensile property of the polypropylene fibre is the special quality for the application in concrete. It is a soft polymer having light weight, high strength and corrosion resistant. Aspect ratio of the fibre used is 133.33.

Figure 1.9 Polypropylene fibres

1.8 HYBRID FIBRE REINFORCED SECTION

For a structure to resist seismic load, Fibers can be added to concrete to improve key properties such as the ductility and energy absorption capacity of beam-column junctions. When tensile stress is transferred to fibre, it can stop macrocracks from propagating and significantly improve concrete strength. One hybridization is achieved by two or more types of fibre such as steel-carbon fibre, steel-polypropylene fibre, etc. Hybridisation enhances the concrete performance based on the constituent such that one fibre may be of higher elastic modulus and one may be lower elastic modulus. One fibre with flexible nature helps in bridging micro cracks and other fibre with stiffer and stronger will help in resisting macro cracks and further propagation of cracks. Thus, different fibres play definite roles in the different period of the concrete failure.

CHAPTER 2
LITERATURE REVIEW

2.1 GENERAL

Over the past few decades, researchers have concentrated a great deal of effort on improving the seismic resistance of beam-column junctions.. Recent earthquakes have underscored the necessity of designing reinforced concrete structures with higher ductility. The strength and ductility of these structures largely hinge on the ductile detailing of the reinforced beam-column joints. If the shear strength of the joint is insufficient, it can disrupt the force transmission within the joint, leading to failure. During seismic events, Unlike the nearby beams and columns, the beam-column junction zones experience considerable horizontal and vertical shear stresses.Ordinary concrete loses its tensile resistance after developing numerous cracks under these conditions. However, fibre reinforced concrete (FRC) can endure more cycles of loading and resist additional cracking. The hybridization of two or more types of fibres can enhance the crack-bridging mechanism; fibres with higher elastic modulus, when combined with those of lower elastic modulus, can yield better results at different stages of cracking. Given that When building a moment-resisting reinforced concrete structure, the beam-column connection is essential, it must be sufficiently stiff and robust to handle the stresses transferred from the beams.

2.2 LITERATURE REVIEW

Various literatures related to the investigation of fibre effects in beam column joint are presented as follow:

(i) Literature review on Reinforced Concrete Beam column joint

(ii) Literature review on Fibre Reinforced Concrete

(iii) Literature review on Hybrid Reinforced Concrete

(iv) Literature review on Numerical Studies

2.2.1 Literature review on Reinforced Concrete Beam Column Joint

Hanson and Connor (1967) Experimental studies on beam-column joints were first conducted in the United States. In these studies, Tests were conducted on seven beam-column joints with earthquake-like loading. Various parameters were evaluated, including the maximum deflection of the beam, ultimate moment, moment capacities at first yield, ductility, and bond stress of the beam reinforcement anchorage. The studies concluded that a properly designed RC frame can resist severe earthquakes without losing strength and withstand moderate earthquakes without damage.

Hegger Josef et al. (2004) utilized ATENA software for the nonlinear analysis of reinforced concrete structures, focusing on both exterior and interior beam-column junctions. The study employed nonlinear finite element analysis to evaluate these connections, noting significant differences in their behavior. Various parameters were examined during the analysis, including the material qualities, reinforcing, joint slenderness, connection geometry, and compressive strength of the concrete.

S.R. Uma (2006) With an emphasis on the different shear stresses from adjacent beams and columns, the seismic behavior of beam-column junctions in moment-resistant reinforced concrete frame structures was investigated. and the shear resistance mechanisms of a moment-resisting frame during an earthquake. The study explored how different types of joints are affected by seismic forces and identified key design factors for withstanding such forces. Additionally, the article described the fundamental differences in joint section behavior under gravity loads versus lateral loads.

Sharbatdara M.Kazem et al. (2012) An experimental study was conducted to examine the damaged external reinforced concrete beam-column joint specimens' cyclic behavior. The damaged models were retrofitted using curb and steel prop pieces. Out of four half-scale RC joints, two control specimens with varying beam depths were loaded to their ultimate strength before being retrofitted. These retrofitted specimens were then reloaded under the same conditions as new specimens.

2.2.2 Literature reviews on Fibred Reinforced Concrete

Ganesan N.etal. (2007) Ten exterior beam-column joints made of steel fiber reinforced high performance concrete (SFRHPC) that were subjected to cyclic pressures were the focus of the inquiry. Fibre volume fraction ranged from 0 to 1 percent, increasing in 0.25 percent increments. The study evaluated the strength, ductility, and stiffness of the joints under positive cyclic loading. The results demonstrated that incorporating SFRHPC in beam-column joints significantly enhances overall performance and is an effective solution for reducing steel congestion in the joint region. Additionally, An increase in load-carrying capability was correlated with an increase in fiber content.

Realfonzo et al. (2014) In order to assess the seismic performance of reinforced concrete (RC) beam-column junctions improved using fiber-reinforced polymer (FRP) systems, the author carried out a study.The research involved testing eight full-scale RC beam-column joint specimens under constant reversed axial cyclic stress. Among these specimens, one served as a control specimen. Following damage to the remaining specimens, they underwent reinforcement with FRP systems, repair, and retrofitting before being retested under conditions of cyclic loading with a constant 300KN axial load at the column.

Ahmad M. Ishtewi et al (2015) A study with varying volume fractions was carried out to examine the shear capacity of beams cast with crimpled and hooked steel fibers. In order to validate the testing methodology, fiber-reinforced concrete (FRC) samples were subjected to in-plane pure shear loading using the digital image correlation (DIC) technique. The results led to the conclusion that the shear relationship proposed by Ashour et al. (1992) provided the closest fit to the experimental data. Additionally, it was found that when compared to crimpled steel fiber with equivalent aspect ratios, the hooked end steel fiber's anchoring shape proved more effective.

Sudha C. et al. (2016) Using basalt fiber, researchers examined the cyclic loading behavior of fiber-reinforced concrete in the beam-column joint. They examined different volume fractions of basalt content, namely 0.75%, 1%, and 1.25%. Experimental setups for the beam-column joint were established for all three volume fractions. The column was anchored on both ends, with loading applied to the beam. The findings showed a notable enhancement in flexural strength by 4.2%, 10.1%, and 17.2%, respectively, for the varying volume fractions.

2.2.3 Literature Reviews on Hybrid Reinforced Concrete

Oinam et al. (2003) The performance of a hybrid mix of steel and polypropylene fibers was studied at the joint region of a beam and column, scaled at 1/3rd according to IS-13920:2016 standards. Steel fibers, sourced from high tensile steel wire, and polypropylene fibers, derived from a blend of plastic polymers, were utilized. Through cyclic loading tests, various parameters including ductility, strength, stiffness, and energy dissipation were evaluated. The inclusion of steel fibers regulated cracking and mitigated the propensity for concrete to fail in a brittle manner.

Perumal P. et al. (2011) The study investigated the characteristics of exterior beam-column joints under cyclic loading, utilizing high-performance concrete (HPC) and a combination of steel and polypropylene fibers. Five models of beam-column joints, scaled at 1/4th of a building's size as per BIS standards, were examined. All specimens were cast with M60 grade concrete, each with varying volumes of fiber content. The first model was reinforced without considering seismic code provisions, designed according to IS456:2000. The second specimen adhered to IS-1893(part-1):2002, incorporating ductile detailing in the beam-column junction to meet IS-13920:1993 seismic standards. Both of these initial specimens were cast using M60 grade high-performance concrete

Le Huang et al. (2015) The research explored the combined impact of steel and polypropylene fibers on column sections under simultaneous axial and cyclic lateral loads through experimental analysis. The findings indicated that the hybrid fibers substantially enhanced seismic performance, particularly in terms of ductility and energy dissipation capacity.Contrary to expectations, the study revealed that the hybrid system of steel and polypropylene fibers did not outperform steel fibers alone, specifically at a 1.5% dosage. However, it was noted that the hybrid fiber reinforced concrete (RC) exhibited superior characteristics in terms of ductility, energy dissipation, as well as stiffness and strength retention, compared to solely steel fiber reinforced concrete.

V. Anandababu (2018) In an experimental study, a hybrid fiber reinforced concrete beam was subjected to testing, incorporating polypropylene fibers and hooked end steel fibers. Polypropylene fiber volume fractions ranged from 0.5 to 1.25 percent, while steel volume fractions varied from 0.005 to 0.125 percent. The concrete used was of ordinary grade M25, possessing a 28-day compressive strength of 32.1 N/mm^2. Through experimentation, the authors determined the optimal dosage of the hybrid mix, resulting in a maximum compressive strength of 38.16 N/mm^2. The researchers concluded that the addition of fibers to the concrete primarily enhanced flexural toughness rather than strength. Moreover, as the fiber content increased gradually, there was observed improvement in the concrete's response under post-crack conditions, enhancing energy absorption and ductility. These enhancements collectively resist further propagation of cracks within the concrete.

2.2.4 Literature reviews on Numerical studies

Syed Sohailuddin S.S. et al. (2013) Finite element modeling of a reinforced concrete beam-column junction was conducted using ANSYS. The study encompassed four distinct models. This model adhered to the seismic design guidelines outlined in IS 13920:1993. Cross bracing bars were strategically placed diagonally at the joints and beam reinforcement. This model featured 6mm cross bars in the beam region instead of cross braces at the joint. Similar to the third model, but with 8mm cross bars instead of 6mm in the beam region. The analysis was performed utilizing ANSYS 11.0 (1995) with SOLID 65 for concrete elements, SOLID 45 for hinge support at the base, and LINK 8 for reinforcement. To simulate earthquake loading, a reverse cyclic loading pattern was applied to each model. The 28-day cylinder compressive strength of concrete was utilized, replacing cube strength, However, laboratory testing was used to determine the reinforcing bars' yield stress and tangent modulus. A monotonic upward and downward load was provided at a distance of 50 mm from the free end of the beam in the experimental setup, while an axial load was applied at the top of the column.

M.A. Najafgholipour et al. (2017) Finite element analysis was conducted to assess the behavior of beam-column connections, with a focus on shear failure modes at the joint. Parameters such as joint shear capacity, crack pattern, and deformation were evaluated. ABAQUS FEA software was employed, utilizing a model of the plasticity of concrete damage to represent the non-linear behavior of concrete. The experimental findings from two non-ductile beam-column connections one exterior and the other interior—were used to validate the finite element model.

Alaa Adnan Hafedh et al. (2019) Finite element analysis was conducted to examine how the reinforcement of steel fiber affects the performance of reinforced concrete beam sections. Five models were created using ANSYS, each with varying volume fractions of steel fiber (0%, 0.5%, 1%, 1.5%, and 2%), all without web reinforcements. The analytical results were then compared with available experimental data. The study also involved a comparative analysis with the ACI Building equation proposed by Ashour et al. This equation is commonly used to predict the shear capacity of reinforced concrete elements. The numerical analysis revealed that as the quantity of steel fiber increased, the shear capacity of the beam section improved.

Lou Yafei et al. (2021) A numerical study was conducted to develop a simplified approach for representing the uniaxial stress-strain curve of concrete and its application in numerical simulations using ABAQUS. The study involved plotting four stages of the stress-strain relationship under uniaxial compression, where the first three stages represented linear elastic behavior ascending to non-linear behavior, and the final stage depicted the descending curve indicating concrete damage. Similarly, under uniaxial tension, two stages of stress-strain relationship were determined. The simplified stress-strain curve developed for uniaxial compression closely resembled the values prescribed by the relevant building codes. The study concluded that the simplified stress-strain curve for uniaxial compression was in excellent agreement with the prescribed code values, affirming its validity for numerical simulations in ABAQUS.

2.4 GAP OF THE STUDY

From the literature study, it was concluded that:

(i) Hybrid effect of hooked end steel fibre with polypropylene fibre does not show better result so another hybrid effect of holed end steel fibre with basalt fibre can be carried out.

(ii) Crimples steel is not effective as compared with hooked end steel under similar aspect ratio so, hybrid effect of crimpled steel with polypropylene can also be carried out as well.

CHAPTER 3

METHODOLOGY

3.1 GENERAL

Numerical Analysis of Hybrid Fibre reinforced beam column joint involves several key steps, which can be categorized into the following main stages: problem definition, model development, material modelling boundary conditions and loading, numerical solutions and validation and analysis of results.

3.2 METHODOLOGY

The methodology employed in this study encompasses a systematic and well- structured approach to investigate and analyze the subject matter. This section outlines the steps undertaken to achieve the objectives of the research, ensuring the reliability, validity, and accuracy of the findings.By examining existing scholarly works, research articles, and relevant sources, asolid understanding of the current state of knowledge is established. This process not only allows for the identification of existing research gaps but also provides valuable insights and establishes a contextual framework for the subsequent stages. Upon recognizing these research gaps, the next phase involves procuring the necessary materials and resources for experimentation. Rigorous attention is paid to selecting suitable materials that align with theobjectives of the study, ensuring their availability and compatibility with the research design.

To explore the impact of Fibre reinforcement on the optimized concrete mixture, additional samples are cast and subjected to controlled loading conditions. These loading experiments simulate real-world scenarios and provide insights into the behavior and performance of the concrete under varying loading conditions. The final phase entails acomprehensive analysis of the collected data, where statistical techniques and analytical toolsare employed to derive meaningful conclusions. The results obtained from the tests and software analysing are scrutinized, compared, and interpreted to shed light on the performance and behavior of the fibre reinforcement on the concrete mixture.

The methodology employed in this study ensures a rigorous and scientific approach to obtain reliable and valid results. It serves as a roadmap for the research process, guiding through the necessary steps to uncover new knowledge, bridge existing gaps, and contribute to the advancement of the field.

3.3 MATERIAL

The cement used for the mix is OPC grade 43 which is Ultratech collected from the local vendor. Locally available river sand of size passing through 4.75 mm sieve is used. The aggregate size varied from 12.5mm to 20mm.

3.3.1 CEMENT

All of the specimens were cast using ordinary Portland Cement according to IS: 8112-2013.

3.3.2 COARSE AGGREGATE

The experiment employed coarse material that had passed through a 20mm sieve but remained on a 12.5mm sieve.

3.3.3 FINE AGGREGATE

Sand has a specific gravity of 2.59, according to IS: 2386 (I)-2016. Sand sieve analysis was performed in accordance with IS: 2386(I)-2016. Below are the details of the sieve analysis.

Table 3.1 Result of sieve analysis of fine aggregate

Sieve size	Weight retained (gm)	Weight retained (%)	Cum% weight Retained	Cum % Retained
	A	B	C	D=100-C
4.75mm	-	-	-	-
2.36mm	4	0.4	0.4	99.6
1.18mm	4	0.4	0.8	99.2
600 micro metre	6	0.6	1.4	98.6
300 micro metre	252	25.2	26.6	73.4
150 micro metre	712	71.2	97.8	2.2
75 micro metre	16	1.6	99.4	0.6
Pan	6	0.6	100	-
Total	1000		226.4	

$$\textbf{Fineness Modulus} = \frac{\textbf{Cum.\% wt.retained}}{\textbf{100}}$$

$$= \frac{226.4}{100}$$

$$=2.264$$

As per IS: 383-2016 the fine aggregate is fine sand and falls under Zone-IV.

3.3.4 PROPERTIES OF FIBRES

The specific details data such as size, density, elastic moduli, tensile strength, aspect ratio, etc were also provided along with the fibres by the supplier. Table 3.2 shows all the properties of the fibre to be used for the study.

Table 3.2 Properties of fibres

Properties	Hook end steel fibre (HSF)	Crimpled steel fibre (CSF)	Basalt fibre (BF)	Polypropylene fibre (PF)
Density (g/cm cube)	7.9	7.9	2.7	0.91
Elastic Modulus (GPa)	200	200	86-90	4.70-6.90
Tensile strength (MPa)	1150	1150	415-480	570-660
Length(mm)	27.6	28.2	8	12
Diameter/min. dimension(mm)	0.4	0.6	0.1	0.09
Aspect ratio(L/D)	69	47	80	133.33

3.4 CONCRETE MIX DESIGN

Design of the mix was carried out based on IS:10262-2009 to achieve M25 grade. For a normal concrete mix and four different mixes with varied proportions of hooked end steel fibres, crimpled steel fibre, basalt fibre and polypropylene fibre was carried out. Water cement content was maintained at 0.45

Table 3.3 Mixed design for variouis specimen with mixed fibre

Details	N.C.	H.B.1	H.B.2	C.P.1	C.P.2
Grade designation	M25 without fibre	M25 with 1% hybrid fibre	M25 with 1.4% hybrid fibre	M25 with 1% hybrid fibre	M25 with 1.4% hybrid Fibre
Type of Cement	OPC 43 Grade based on IS:8112-2003	OPC 43 Grade based on IS:8112-2003	OPC 43 Grade based on IS:8112-2003	OPC 43 Grade based on IS:8112-2003	OPC 43 Grade based on IS:8112-2003
Max nominal Aggregate Size	20mm	20mm	20mm	20mm	20mm
Type of Aggregate	Crushed angular	Crushed angular	Crushed angular	Crushed angular	Crushed angular
Workability (Slump)	100 mm	90 mm	83 mm	85 mm	78 mm
Mass of Hybrid fibre(kg/m3)	-	22.82	31.82	22.82	31.82
Mass of Cement (kg/m3)	585.3	585.3	585.3	585.3	585.3
Mass of Water (kg/m3)	263.33	263.33	263.33	263.33	263.33
Mass of Fine aggregate(kg/m3)	585.3	585.3	585.3	585.3	585.3
Mass of Coarse aggregate(kg/m3)	1170.61	1170.61	1170.61	1170.61	1170.61

3.5 CONCRETE CUBE, CYLINDER AND PRISM

Cube (150 x 150 x150mm) as per IS: 516-2021, cylinder (150 x 300mm) as per IS: 5816- 1999 and prism (100 x 100 x 500mm) as per IS: 516-2021 were casted with different fibres mixes. After 24 hours the moulds were removed and shocked into tank with average temperature 25±2 ℃ .

Table 3.4 Nomenclature of samples

Specimen Designation	Vol of concrete replaced (%)	Crimpled steel fibres (%)	Hooked steel fibres (%)	Polypropylene fibres (%)	Basalt fibres (%)
NC	0 %	-	-	-	-
HB1	1.00 %	-	0.8	-	0.2
HB2	1.40 %	-	0.8	-	0.6
CP1	1.00 %	0.8	-	0.2	-
CP2	1.40 %	0.8	-	0.6	-

3.5.1 STRENGTH OF SAMPLES

The samples were taken out from the tank on the 28th day and kept instantly into the machine. Universal testing machine of 100KN capacity has been used for the compressive strength test. For the split tensile strength test and flexural strength test, digital servo UTM was used. The rate of loading was calibrated following code provision IS: 516-2021 and IS: 5816- 1999.

Table 3.5 Characteristics strength on 28 days

Sample	Tensile strength of Cylinder (N/mm^2)	Compressive Strength of cube (N/mm^2)	Flexural Strength of beam (N/mm^2)
N.C.	1.67	26	5.0
H.B.1	1.9	28.34	6.87
H.B.2	1.8	31.11	6.90
C.P.1	2.9	26.85	6.197
C.P.2	2.3	27.45	6.098

The recorded data were used to evaluate the respective strength of the samples using the respective codes. Table 3.5 shows the calculated strengths of the samples.

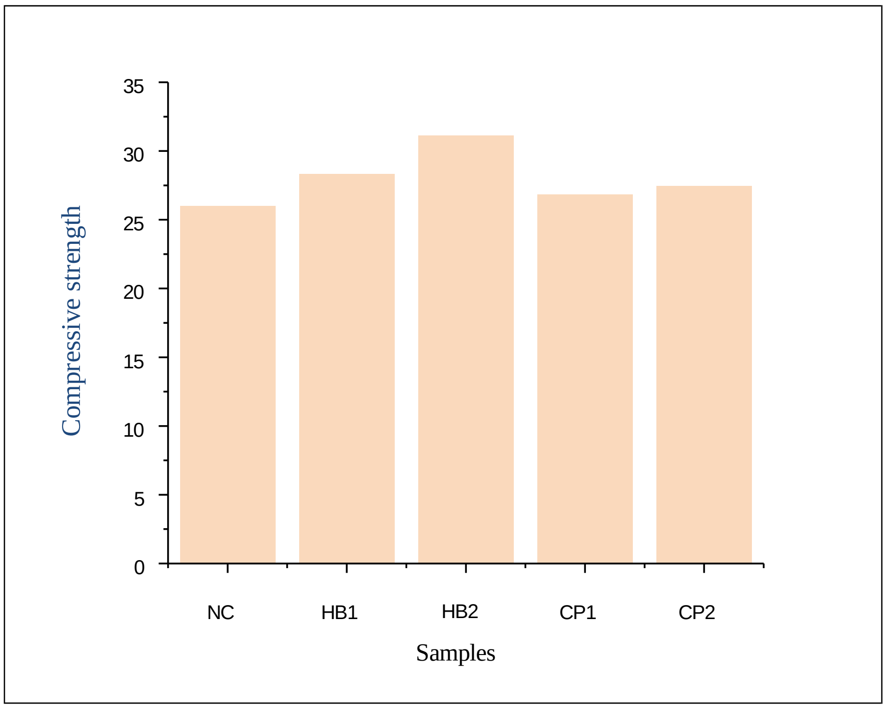


Fig: 3.1 Compressive strength of cube samples

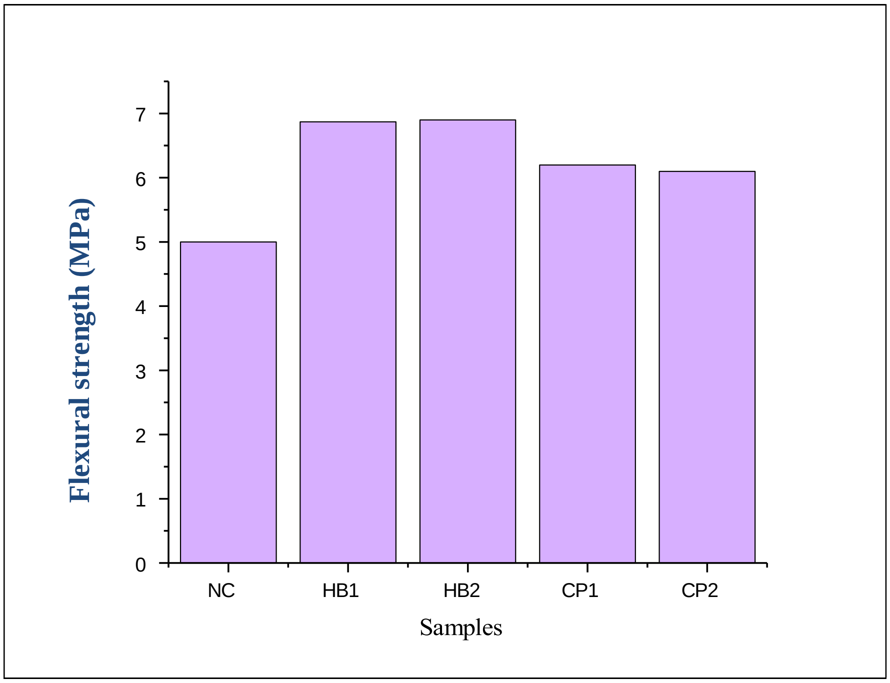


Fig. 3.2 Flexural strength of Prism sample

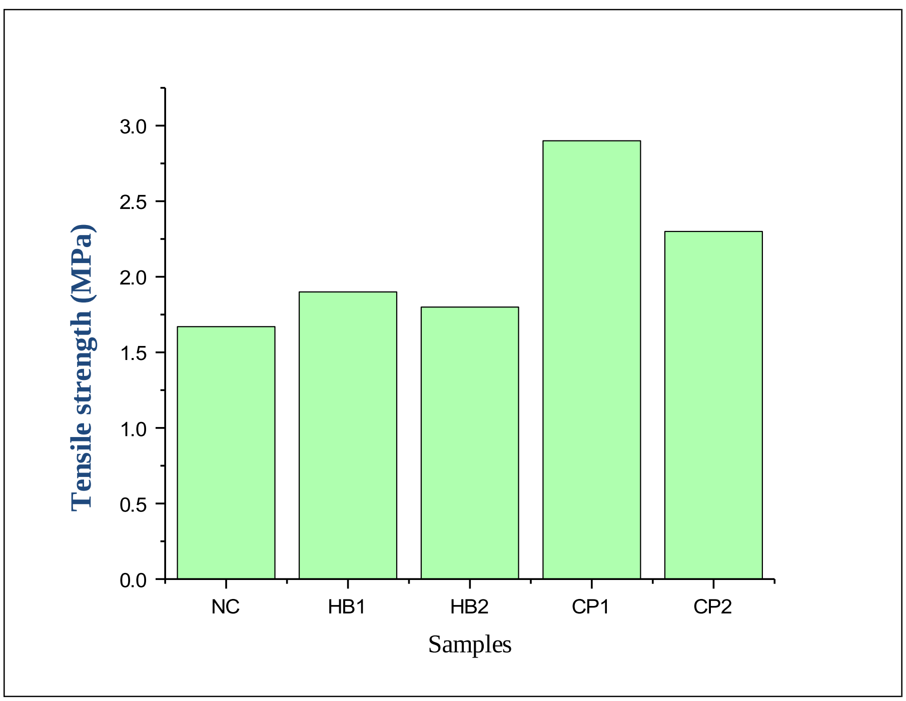


Fig. 3.3 Split tensile strength of cylindrical sample

3.6 NUMERICAL MATERIAL MODEL

The simulation, ANSYS finite element analysis software is used, where the accuracy of the input data directly influences the accuracy of the output. Concrete is modeled as an isotropic solid element with non-linear uniaxial stress-strain behavior, while steel is considered to have a relatively linear stress-strain response. Specifically, in ANSYS, only certain types of elements can accurately represent the unique characteristics of concrete, which include cracking under tensile stress and crushing under compressive stress, when combining solid elements for concrete with line elements for reinforcement.

3.6.1 CONCRETE MODEL

The compressive strength of a cylinder is used in simulations because it provides a precise measure that closely approximates actual strength, with field strength typically being 80% of cube strength. Concrete material properties, including both elastic and inelastic behaviors, are modeled in ANSYS. This model integrates isotropic tensile and compressive plasticity and uses an isotropic elastic damage model to represent the inelastic behavior of concrete.

Table 3.6 Cylinder compressive strength

Sample ID	Cube f'_{ck} (N/mm^2)	Cylinder f'_c=0.8f'_{ck} (N/mm^2)
NC	26	21.1
HB1	28.35	23.66
HB2	31.12	25.66
CP1	26.86	22.49
CP2	27.46	22.08

3.6.2 SOLID 65 ELEMENT

The SOLID 65 element from ANSYS is a 3D structural element with or without rebar. The capacity to crack in tension and crush in compression is another property of this element. This is an eight-node solid structure with three degrees of freedom with nodal X, Y, and Z translation. Material qualities that are non-linear can be properly characterized. When cracking and crushing are used together, apply the load carefully to avoid false crushing of the concrete before proper load transfer may occur through a closed crack.

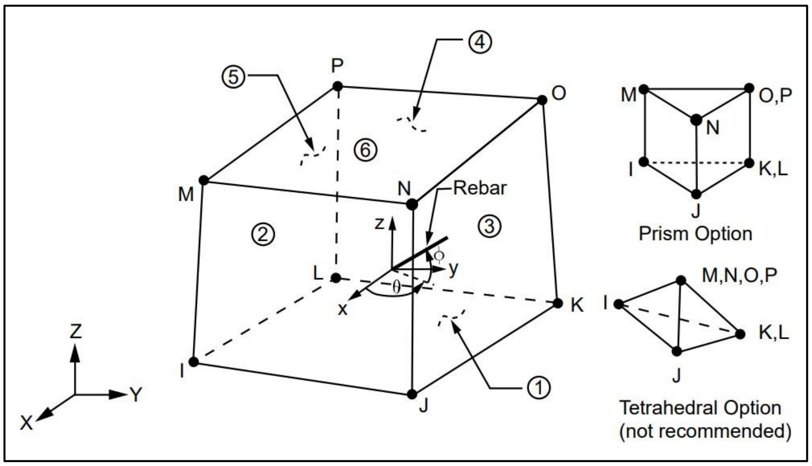


Fig: 3.4 Solid 65 elements

The Poisson's ratio for concrete typically ranges from 0.15 to 0.20, and for all models, a value of 0.18 is used. The elastic modulus is calculated according to IS: 456-2000 using the formula:

$$E = 5000\sqrt{f'ck}$$

In the non-metal plasticity model, concrete is characterize distinctly from steel due to ANSYS's default focus on metallic materials. The shear transfer mechanism in reinforced concrete changes based on the material properties and the action of bond stress. Before the deformation of reinforced concrete or the first crack, the shear transfer mechanism is referred to as closed shear transfer. In ANSYS, this is represented by the coefficient βtβt , which ranges from 0.0 to 1.0. A value of 0.0 indicates shear transfer failure (smooth crack), while a value of 1.0 indicates full shear transfer with no loss (rough crack). In practical field tests, full shear transfer is never achieved; thus, the coefficient is conventionally assumed to be between 0.7 and 0.9. For hybrid models, a closed shear coefficient of 0.8 to 0.9 is used, reflecting their superior strength and energy dissipation capacity compared to regular concrete. Similarly, after the first crack occurs, the open shear transfer mechanism is defined by the open shear coefficient. For ordinary grade concrete, this coefficient is typically 0.2. For hybrid models, the open shear transfer coefficient assumed to be between 0.3 and 0.4, with higher values assigned to samples with greater tensile strength.

Beam-column specimens are designated as BCNC, BCHB1, BCHB2, BCCP1 and BCCP2.

Table 3.7 Input data for solid 65 Elements

S.no		Unit					
1.	Sample ID		BCNC	BCHB2	BCHB1	BCCP2	BCCP1
2.	Density	Kg/m^3	24000	24000	24000	24000	24000
3.	Linear Isotropic property						
	Initial elastic modulus	MPa	22803.7	24939.76	23806.76	23430.9	23173.6
	Poison's ratio	-	0.18	0.18	0.18	0.18	0.18
4.	Non - metal plasticity property						
	Open shear transfer co- efficient	-	0.2	0.3	0.4	0.3	0.4
	Closed shear transfer co-efficient	-	0.7	0.8	0.9	0.8	0.9
	Uni - axial cracking stress	MPa	1.69	1.86	1.95	2.34	2.92
	Uni - axial crushing stress	MPa	20.82	24.85	22.64	22.95	22.46

The Uni-axial cracking stress represents the cylindrical split tensile strength which are obtained from laboratory testing . And the Uni-axial crushing stress represents the compressive strength of the cube samples which are similarly obtained.

3.6.3 NON LINEAR STRESS STRAIN BEHAVIOUR

Using the formula developed by P. Desayi et al. (1964). The compressive strength at any strain point can be predicted using the ultimate compressive strength f'c as follows:

$$f'c = \frac{\varepsilon\, Ec}{1 + (\frac{\varepsilon}{\varepsilon_0})^2}$$

$$\varepsilon_O = \frac{2\, f'c}{E_C}$$

ε_o, strain at ultimate compressive strength f'_c

Ec , Elastic modulus = $\frac{\sigma}{\varepsilon}$

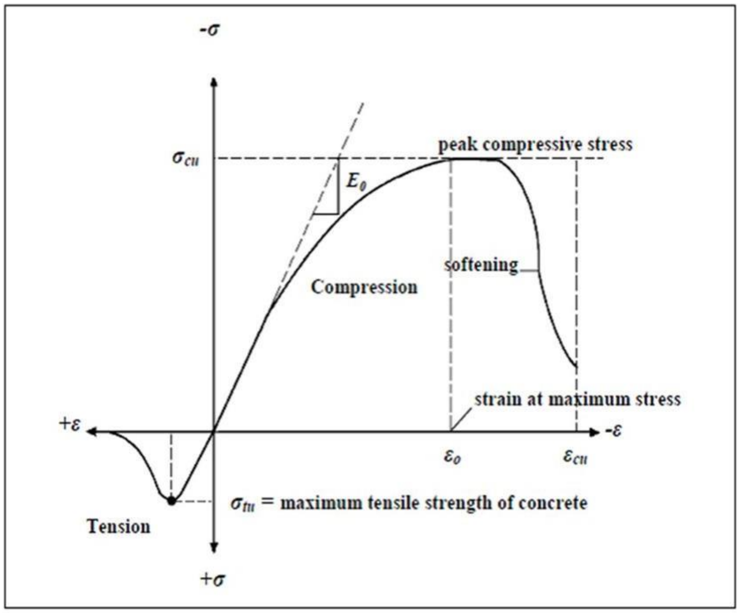


Figure 3.5 Stress strain curve

Figure 3.5 illustrates a typical stress-strain curve under uniaxial tensile and compressive stress. In this region, concrete's ultimate tensile strength is only 2-3% of its maximum compressive strength. The numerical analysis accounted for tensile and compressive strengths only up to their peak values, excluding the softening region of the concrete. The relevant data points are presented in Table 3.8

The initial elastic modulus represents the initial slope of the stress-strain curve, which is typically considered to be a straight line. According to IS: 456-2000, the ultimate compressive strain of concrete under uniaxial compression is 0.0035. The peak compressive strength (f′c) is reached at a strain range of approximately 0.0015 to 0.0020.

Beyond this point, the strength decreases significantly to about 3 to 8% of the ultimate strength, entering the softening region. In this region, the tangential slope becomes negative, which poses convergence issues in ANSYS. Consequently, ANSYS only accommodates values up to the strain at the ultimate ($f'c$). Beyond this strain, the slope is assumed to flatten out until it reaches 0.0035.

Table 3.8 Non linear stress strain data

Points		1	2	3	4	5	6
	Strain	0	0.0004	0.0008	0.0012	0.00182	0.0035
BCNC	Stress	0	8.1214	14.3004	18.0999	19.8	21.8
	Strain	0	0.0004	0.0008	0.0012	0.00175	0.0035
BCHB1	Stress	0	10.5236	17.1878	21.4484	23.6969	23.6969
	Strain	0	0.0004	0.0008	0.0012	0.0020	0.0035
BCHB2	Stress	0	10.9579	18.1875	22.9768	25.88	25.88
	Strain	0	0.0004	0.0008	0.0012	0.00156	0.0035
BCCP1	Stress	0	10.2963	16.6823	20.5969	22.48	22.48
	Strain	0	0.0004	0.0008	0.0012	0.00158	0.0035
BCCP2	Stress	0	10.3273	16.8654	20.9344	22.9699	22.9699

3.6.4 REINFORCEMENT MODEL

Steel is generally very uniform in the stress-strain behaviour compared to that of concrete and the stress-strain relation can be adequately defined numerically. Steel exists the stress- strain behaviour in both tensile and compression zone. The stress-strain relation of steel exists in different stages, the initial stage is the linear elastic, then follows by plastic region in which stress increases again until strain hardening eventually follows by fracture.

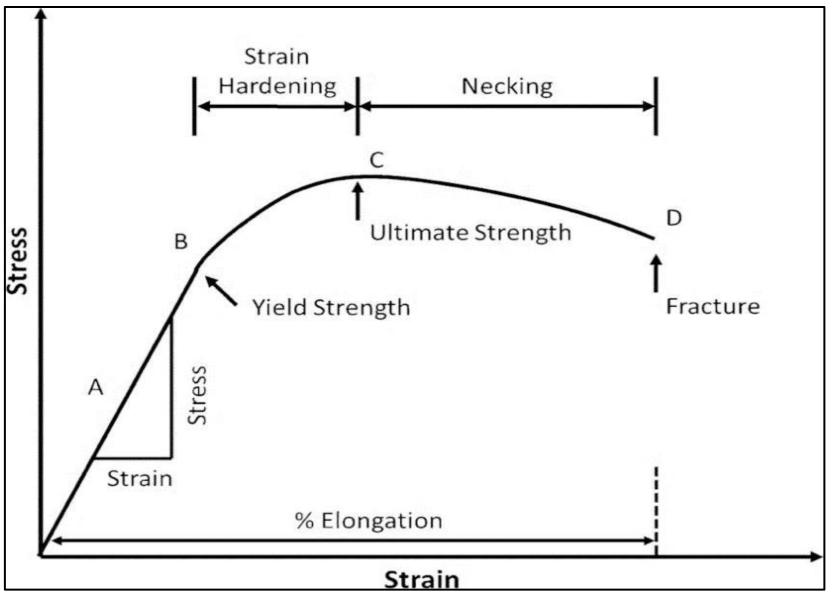


Figure 3.6 Stress strain curve for steel

The region AB represents the linear elastic phase. After point B, yielding occurs, causing a slight change in the material's stress-strain behavior. Additionally, if unloading occurs beyond the yield point, plastic deformation may occur. This behavior is described by a bilinear stress-strain relationship with two distinct slopes. The first slope is the linear elastic modulus $EXEX$, and the second, which is lower, is known as the tangent modulus $ETET$. The Poisson's ratio was assumed to be 0.3.

3.6.4.1 LINK 180 ELEMENTS

In concretes, the LINK180 truss two nodes are used for steel reinforcement. It possesses 3 DOF in x, y, and z direction. There exists 3D truss element that accommodates uniaxial as well tension-compression. No bending is possible with this element as it is pin-jointed. Plasticity, creep, rotation, large strain, and large deflection are other features of the opportunities allowed by this element.

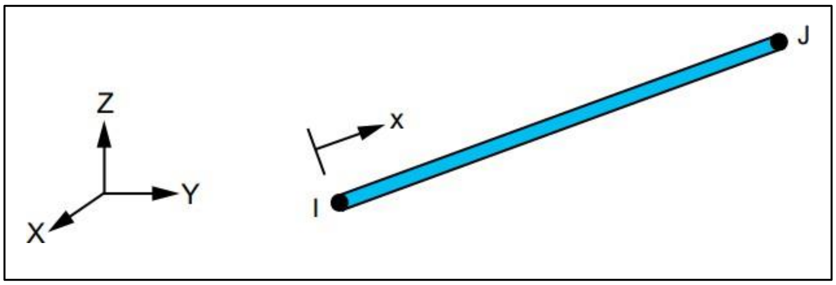


Figure: 3.7 Link 180 Geometry

Table 3.9 Link 180 Input parameters

					Linear Isotropic		Bilinear isotropic	
	Section	Density (kg/mm^3)	Section area (mm^2)	Material ID	Elastic Modulus E_X (MPa)	Poison's ratio PRXY	Yield strength f_y (MPa)	Tangent Modulus E_T (MPa)
1	Rebar(25mm)	7.85E-06	490.62	180	2e+05	0.3	500	1000
2	Rebar(20mm)	7.85E-06	314	180	2e+05	0.3	500	1000
3	Stirrups(10mm)	7.85E-06	78.4	181	2e+05	0.3	500	1000

3.7 Beam column joint details

Five full-scale beam-column joint section are designed as per Bureau of Indian Standard.

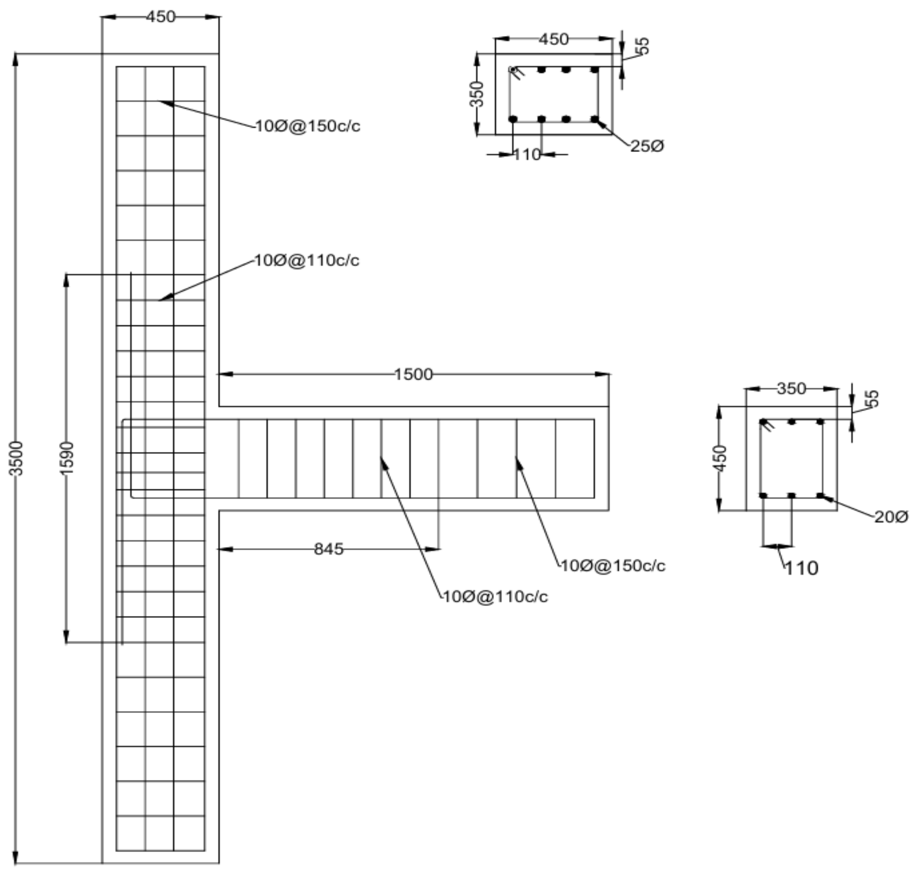


Figure 3.8 Beam Column dimension

We designed an under-reinforced beam with dimensions of 350 mm × 450 mm according to IS: 13920-2016, and a column section of the same dimensions, also following IS: 13920-2016, using ductile detailing at the joint section. The beam has a span of 1500 mm, and the column has a length of 3500 mm. For a distance of 845 mm along the beam from the face of the joint, the stirrup spacing is 110 mm, as specified by IS: 13920-2016. Ductile detailing is provided along the column section near the joint for a total length of 1590 mm on either side, with the stirrup spacing also maintained at 110 mm.

3.8 Geometry and Modelling

Material modelling of concrete and steel are done in the software. a proper mesh size will help to coincide the created nodes as so coincident nodes from different elements merge into one node to form a bonding among the elements. For this simulation, a mesh size of 50 mm is chosen. Total numbers of nodes generated is 5670 and that of elements is 5720.

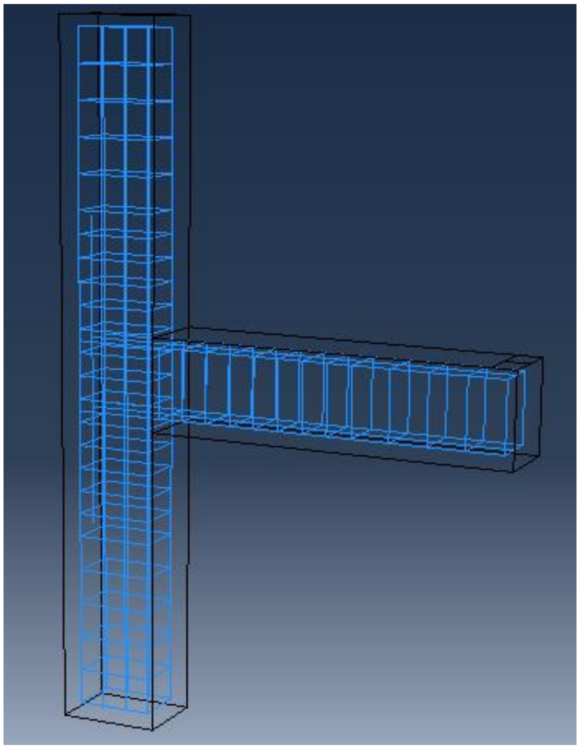


Figure 3.9 Reinforcement model

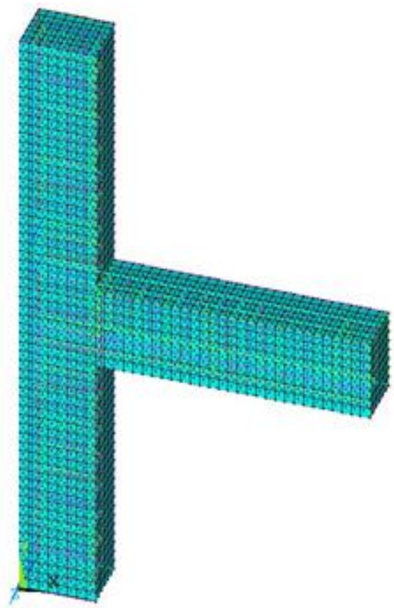


Figure 3.10 Ansys FE Model

3.9 Boundary conditions and loading

The loading and boundary conditions are illustrated in the figure. Nodes at the ends of the members are fixed in the axial x, y, and z directions. For the static and reversed cyclic loading analysis, a monotonically increasing load is applied to the tip nodes of the beam member. The finite element analysis uses two convergence criteria: force iteration convergence and displacement iteration convergence. Both criteria are set at 5% until the first crack occurs. After the initial crack, displacement convergence is considered to account for non-linearity.

3.9.1 Static loading

Static analysis is performed using ANSYS Workbench. The column ends are fixed, and a constant static load is applied to the upper edge of the beam.

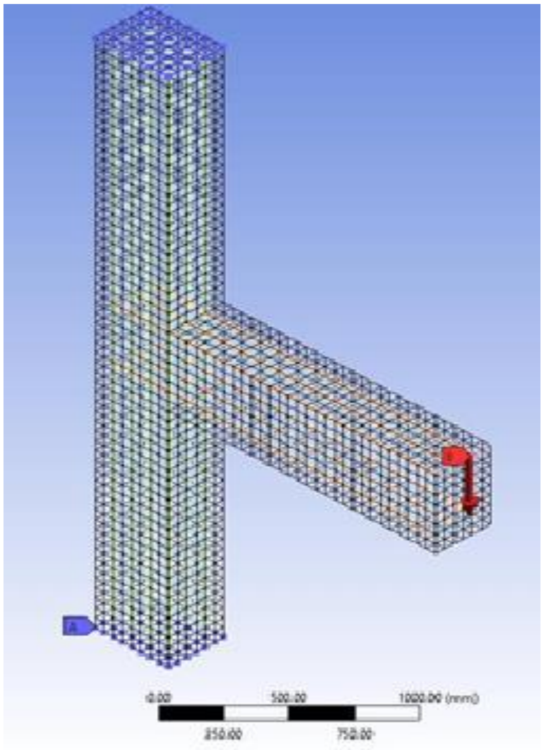


Figure 3.11Boundary conditions and loadings

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 GENERAL

The numerical analysis of hybrid fiber-reinforced concrete (HFRC) beam-column joints was conducted to evaluate their performance under various loading conditions. The study focused on understanding the enhancements brought by the addition of hybrid fibers—such as steel, glass, and synthetic fibers—compared to conventional concrete joints. The key areas of investigation included load-displacement behavior, crack patterns, and the determination of initial and ultimate cracking loads. The incorporation of hybrid fibers in concrete is expected to significantly improve the mechanical properties and overall performance of the beam-column joints. The fibers are known to enhance the tensile strength, ductility, and energy dissipation capacity of the concrete, thereby contributing to greater structural integrity and durability. The enhanced properties of HFRC joints are particularly beneficial for structures subjected to dynamic and seismic loads, where superior load-bearing capacity and improved crack control are crucial for maintaining structural safety and longevity. The following sections present detailed analyses of the load-displacement behavior, crack patterns, and initial and ultimate cracking loads of HFRC beam-column joints. These analyses provide insights into the effectiveness of hybrid fiber reinforcement in improving the performance of concrete joints, highlighting the potential benefits for practical engineering applications. The results are compared with those of conventional concrete joints to underscore the improvements achieved through the use of hybrid fibers.

4.2 Results under static loading

The results under static loadings are shown below in the table:

Table 4.1 Load and displacement data

Specimens	First crack load (KN)	Displacement at first crack (mm)	Ultimate Displacement (mm)	Ultimate load capacity (KN)
BCNC	39.86	0.986	25.12	181.02
BCHB1	40.21	0.821	21.02	199.02
BCHB2	40.07	0.792	19.81	231.12
BCCP1	40.56	0.842	21.42	187.76
BCCP2	40.48	0.834	21.08	194.12

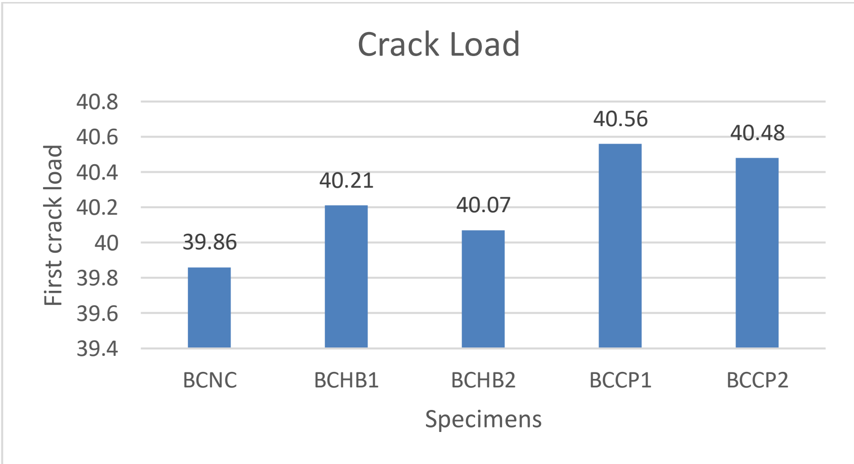


Fig:4.1 First crack load

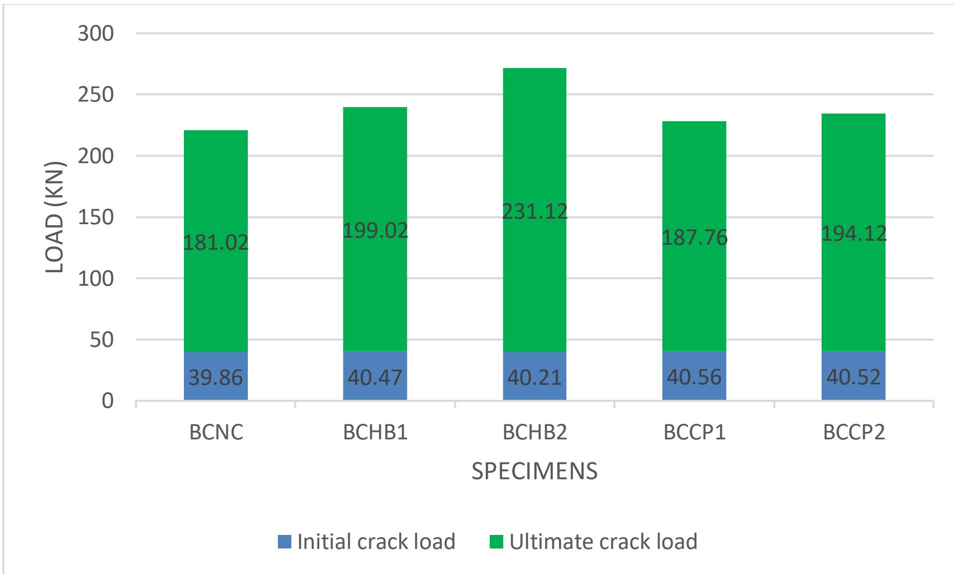


Fig:4.2 First crack load and Ultimate crack load

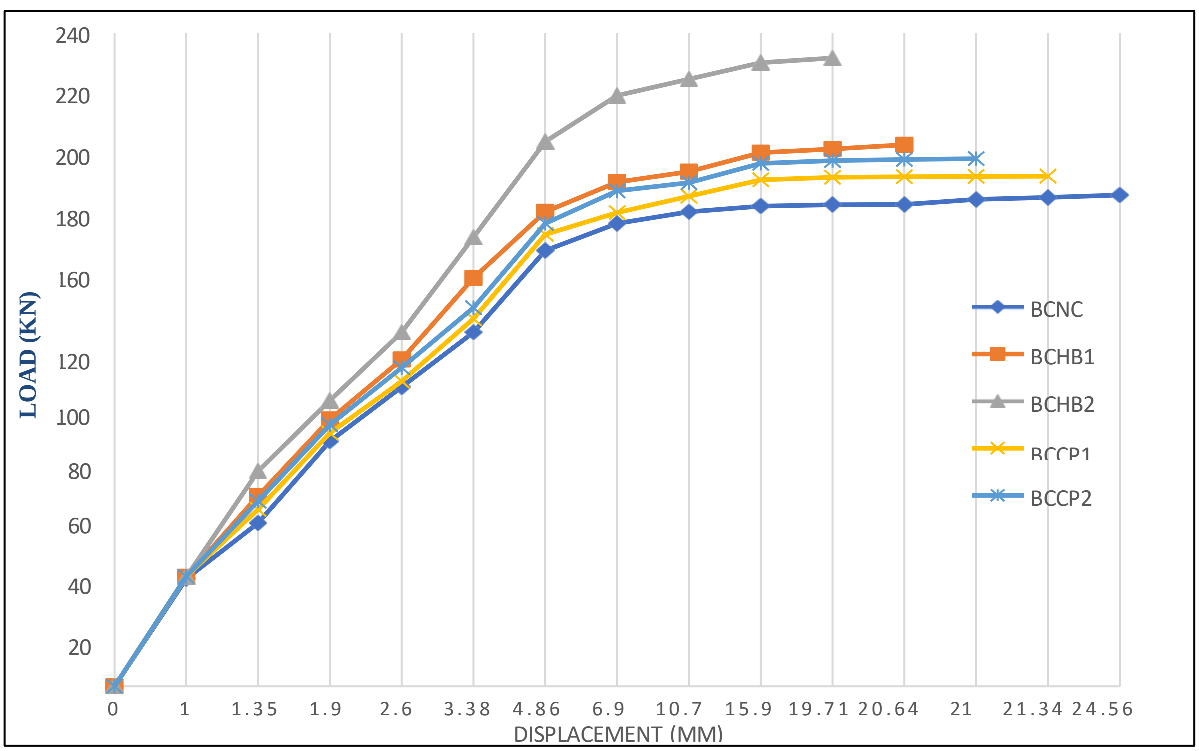


Fig: 4.3 Load Vs displacement curve of all specimens

4.3 CRACK PATTERN

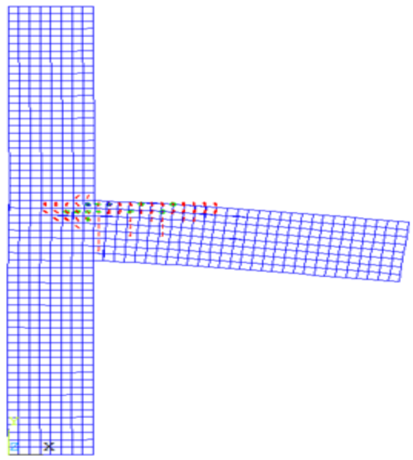


Figure 4.4 BCNC Crack pattern

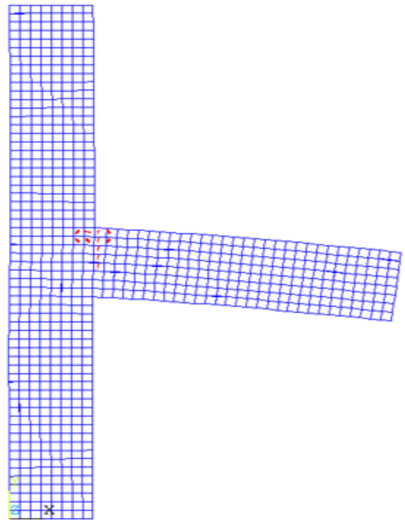


Figure 4.5: BCHB2 Crack pattern

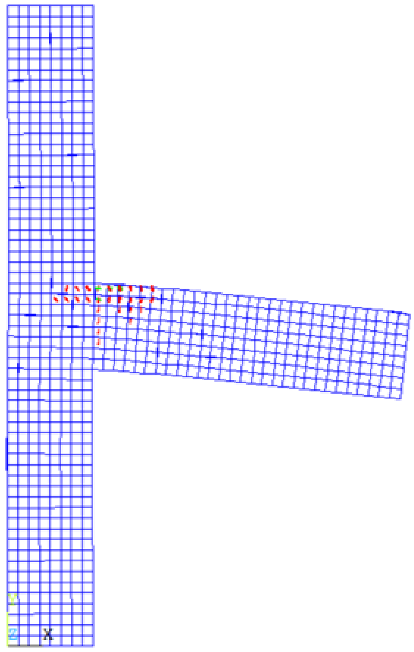


Figure 4.6: BCCP1 Crack pattern

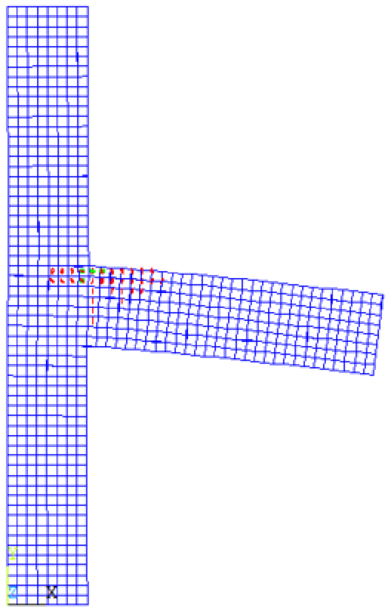


Figure 4.7: BCCP2 Crack pattern

Conclusions on crack pattern:

The conclusions on crack pattern are as follows:

(i) The appearance of flexural cracks of BCNC specimen, the first crack appears at the load of 39.86 KN with a displacement of 0.986 mm. The expected crack location in BCNC specimen is comparatively very large. The expected location of crack is very large in compared with other specimens.

(ii) The first crack load of BCHB1 which is 40.21 KN is slightly higher than BCHB2 which is 40.07 KN at displacement of 0.821 mm and 0.792 mm respectively. BCHB2 has the least expected crack area compare to all other specimens.

(iii) BCCP1 and BCCP2 containing polypropylene have ultimate load carrying capacity of about 4% and 8% higher than that of BCNC with ultimate displacement of 21.42 mm and 21.08 mm respectively.

(iv) The content of crimpled steel with polypropylene has shown significant improvement in resisting initial crack. Moreover, the crack locations in BCCP1 and BCCP2 occurs mostly in the beam section.

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 SUMMARY

The objective of this numerical study was to investigate the hybrid effect of incorporating both metallic and non-metallic fibers into concrete at a full-scale beam-column joint section. The study involved using one normal grade concrete mix (M25) and four different combinations of fibers: hooked end steel fiber with basalt fiber and crimped steel fiber with polypropylene fiber. These mixtures were designed and tested in the laboratory to determine their mechanical strengths according to relevant code provisions. The full-scale beam-column joint section was designed following the Bureau of Indian Standards, incorporating ductile detailing. The same geometry was modeled in the finite element software ANSYS v21. Using data from the laboratory tests, numerical models of concrete and steel were developed, employing non-linear stress-strain relationships in uniaxial compression and tension. Appropriate boundary conditions were applied to the models, which were then subjected to steady static load and non-linear reverse cyclic displacement-controlled loads. The study evaluated initial crack load, initial crack deflection, ultimate load, and ultimate deflection.

5.2 CONCLUSIONS

i. It has been concluded that the hybrid combination of 0.40% basalt fiber and 0.80% hooked end steel fiber yields the best results in terms of compressive strength, flexural strength, stiffness degradation, and energy dissipation, outperforming the hybrid mix of crimped steel and polypropylene fibers.
ii. Increasing the basalt content from 0.20% to 0.40% enhances the overall mechanical strength.
iii. The combination of 0.80% crimped steel and 0.20% polypropylene fiber, the latter being a micro-filament, provides the highest tensile strength and the most

effective resistance against initial cracking.

iv. Increasing the polypropylene content to 0.40% results in a continuous decrease in both tensile and flexural strength.

5.3 SCOPE FOR FUTURE WORK

(i) The experimental test on hybrid Fibre reinforced concrete beam column joint can also be done in the future.

(ii) The variation in the ductile detailing of lateral reinforcement can also be carried out in the future.

(iii) In ABAQUS FEA concrete damage plasticity model can also be made.

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ANNEXURE-IV

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