FEM Performance of Beam-Column Joint under Cyclic Loading with Column Inclination at Joint Portion

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Abstract: Outside non-ductile reinforced concrete (RC) beam-column connections are the primary subject of this article's analysis of their cyclic behaviour. This study utilizes experimental data and complex finite element simulations to probe the effect of angle inclination on the link. During the course of the experiment, both standard RC beam-column junction specimens and specimens with an angled column at the joint were tested. The samples were detailed for seismic activity. Physical test findings were contrasted with those obtained from computer-generated FEM simulations of similar specimens. In this research, we use the ANSYS software to perform in-depth 3D non-linear finite element (FE) simulations of beam-column junctions made of reinforced concrete (RC) at a range of inclinations. Beam-column specimens are subjected to cyclic loading in reverse with carefully calibrated amplitudes so that we can study how these parameters respond to repeated loading cycles. Finite element analysis results for energy dissipation and stiffness versus displacement are quite similar to experimental data. With its excellent ductile behaviour, ferrocement can be used as a hybrid reinforcing solution to improve the seismic performance of RC beam-column junctions. Analytical analyses supported the experimental research using finite element models developed with ANSYS software. The results show that the hysteresis simulation works well for both un-strengthened and ferrocement-strengthened specimens, proving its worth in practice.

Keywords: Beam-column joints, Cyclic load, ferrocement, Ductility, Hysteresis curve, ANSYS.

1. Introduction

In seismically active regions, the performance of beam-column joints is crucial to the structural integrity of reinforced concrete (RC) moment resistant frames. Beam and column cross-section profiles near joints in reinforced concrete (RC) buildings are important. During intense seismic activity, these elements experience significant bending moments and shear forces [23], The transfer of force to the structure is regulated by the moment resistance frame that exists within the beam-column joint. The design check for joints in RC frames intended for gravity loads deviates from the standard procedure. During recent seismic events such as urkey earthquake on August seventeen 1999, Sichuan Province of China on 12 May 2008 and also Bhuj, Gujarat on 26 January, 2001[13]the structural joints experienced a collapse as a result of shear failure. Moment resistant frames must have sufficient overall dimensions included into their initial designs. It's also crucial to make sure the connection has the proper support. The effects of earthquakes must be properly accounted for, even in the case of buildings in moderate and low seismic zones. Exposure to substantial lateral loads, such as those caused by high winds, seismic activity, or explosive forces, reduces the structural efficiency of a beam-column junction. It is essential to incorporate a large number of traverse hoops within the joint core for constructions located in these areas to achieve higher strength, stiffness, and ductility under cyclic stress [4]. Several ANSYS-based experimental and analytical studies concluded that the seismic performance might be improved by adding cross-bracing reinforcement [5], using continuous SIMCON jackets improved column lap splice confinement at the joint. Nonlinear dynamic analysis was used to investigate the hysteretic response of the external beam-column joint[11]. The degradation of the joint's rigidity was the primary focus of the analysis, which took into account both the presence and absence of a punch effect. The investigation also looked at how low and high punch effects influenced the behavior of the joint. [12]states that two different joint designs were tried out, one with conventional steel rebar reinforcement and the other with a prefabricated cage system (PCS). The IS456-2000 and IS13920-1993 standards were used to evaluate the specimen's exterior beam-column joint design. Afterwards, a GFRP-AFRP/AFRP-GFRP hybrid fibre sheet was used to retrofit the specimen, which had been designed in accordance with the requirements described in IS456-2000. After the modifications were made, the specimen's performance was compared to that of the standard. According to the results of the research, the load-bearing capability of the specimen made according to the IS13920-1993 design was 10% to 11% higher than that of the IS456-2000 specimen. [18]explains that ferrocement, often known as ferro-cement or thin-shell concrete, is a method of building that uses reinforced mortar or plaster. Lime or cement, sand, and water make up the bulk of this compound. Thin steel rods like rebar are used for reinforcement coupled with a layer of metal mesh, woven expanded-metal, or metal fibers[3] that are placed closely together. The effectiveness of three composites in increasing the strength of outside beam-column joints made of reinforced concrete under reversed cyclic loading was compared. When compared to the use of FRPs for reinforcing beam-column joints, the adoption of ferrocement has been found to be a viable and cost-effective alternative. This research, as reported in a [14], attempted to determine how various strengthening methods affected the external joint terminations under differing axial stresses. Existing reinforced concrete (RC) columns could have structural faults due to a number of factors, such as insufficient transverse reinforcement or design flaws that lead to inadequate load carrying capacity. The purpose of this research was to examine the effectiveness of using oblique columns to strengthen the vertical framework of a tall building. According to the research results, oblique column constructions are stronger and more capable of withstanding horizontal force than vertical column structures [20]An in-depth seismic analysis of a reinforced concrete (RCC) building with angled support columns is what this research is all about. The purpose of this analysis is to assess the response and functionality of the RCC structure under seismic loads. The research aims to determine how well adding inclined extra columns improves the building's seismic protection and overall stability. The analysis will make use of cutting-edge computer techniques. ETABS is used for both static and dynamic analysis of corner columns in 11-story L-shaped buildings. The analysis's primary goal is to ascertain how much the structure's drift and storey displacement have been reduced.Research published in [2]concludes that the seismic behavior of a multi-story building with oblique columns at different angles of inclination was studied in depth. The research found that an inclination angle of 80^0 performed better than the other angles tested[6],[16].The ultimate strength, energy dissipation capacity, ductility, and joint stiffness of the control concrete specimens were the main focus of the analysis. Column inclination angles of 85^0, 87.5^0, and 90^0 (Normal) were used to compare specimens with and without ferrocement laminates for these properties. Following the guidelines laid out in IS13920-1993 and IS456-2000, FEA software was used to analyze the functionality of exterior joint assemblages. The analysis' findings were then contrasted with those of the modified specimen.Beam-column couplings that meet the requirements of IS456-2000 [10]and IS13920-1993[9]are the focus of the current study. The ferrocement laminates used in this retrofitting process are then put through rigorous testing using a reverse cyclic load.

2. Experimentalmethodology

2.1 Specification information and specimen descriptions

This study examines three variations of RC BCJs, focusing on the control of three joints with different angle inclinations: 85^0, 87.5^0, and 90^0 (normal). Additionally, three other joints are reinforced with ferrocement in the RC BCJs. The design and detailing of all RC BCJs adhere to the provisions outlined in the Indian standard codes, namely IS13920-1993 and IS456-2000, both revised in 2002. Additionally, the dimensions of the RC BCJs are scaled down to one-third of their actual size. Figure 1 provides a comprehensive depiction of the dimensions and specifications pertaining to the BCJs. The M20 concrete mixes are formulated in accordance with the specifications outlined in IS 10262 [8]Table 1 provides a comprehensive breakdown of the concrete mix, presenting the average outcomes for both compressive and split tensile strength of the concrete cube and cylindrical specimens, respectively. The concrete used in the tests has a cement-to-sand-to-aggregate ratio of 1:1.916:3.304. Additionally, all reinforced concrete samples have cured for 28 days in the same conditions.

The column portion and beam section employ a combined quantity of 20 longitudinal bars, with each bar having a diameter of 20 mm. Furthermore, a total of 16 cylindrical bars with a diameter measuring 12 millimetres are utilized. The longitudinal bars, which possess a cover thickness of 20 mm, are utilized in both the compression and tension regions. Furthermore, for the purpose of restricting reinforcement, transverse reinforcement bars with a diameter of 8 mm are employed, with a spacing of 100 mm centre-to-centre. The transverse reinforcement bars are positioned at a distance of 800 mm on both sides of the joint. The transverse reinforcing bars for both the column and beam sections are arranged with a centretocentre spacing of 150 mm. However, when the distance from the joint reaches 1200 mm, the spacing is adjusted to 200 mm centre-to-centre. The gap between the centre of the remaining column and beam is 150 mm.Table 2 presents the mechanical characteristics of steel bars, encompassing the yield strength, ultimate tensile strength measured in N/mm^2, and elongation percentage.

Table 1: Concrete mixture details

Avg. 28daycompressive strength (Mpa)	Avg. tensile strength (MPa)	w/c (%)	Cement (kg/m3)	Water (kg/m3)	Fine aggregate (kg/m3)	Coarse aggregate (kg/m3)	
						12.5 (mm)	20 (mm)
26.88	3.15	0.55	359	197	688	484	702

Table 2: Mechanical properties of steel bars

	Bar types Fe 415		
	8 mm	**16 mm**	**20 mm**
Mass per meter (Kg/m)	0.41	1.634	2.493
Yield stress (N/mm^2)	449.7	426.2	431.8
Ultimate tensile strength (N/mm^2)	517.1	490.1	496.5
Elongation (%)	16.4	19.7	17.7

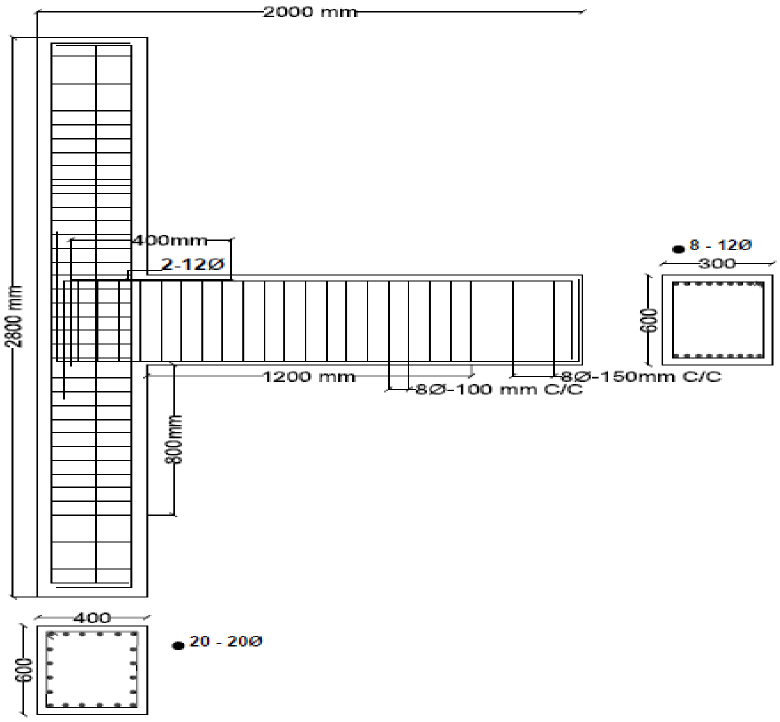


Fig 1: Details of dimensions of BCJs specifications

As per the guidelines outlined in ACI549, ferrocement refers to a structural element characterized by its thin-walled composition, measuring less than 25 mm in thickness. This composition primarily consists of a compact arrangement of small diameter wire mesh, closely interwoven within a matrix of cement mortar. This study involved the casting of ferrocement laminates measuring 125 x 25 x 500 mm. Two different volume fractions, namely 1.72 and 3.44, were used for the ferrocement laminates. The laminates were reinforced with welded and woven mesh, with a cross section ratio of 2:3 CM. The current study employed a single layer composed of both weld mesh and woven mesh. The strength parameters are provided in Table 3. The layer is composed of both weld mesh and woven mesh, with a volume fraction of 1.72 percent. The fiber mats that were stored within the mold were subjected to the grouting process. The cement and sand were combined in a mortar mixer, incorporating a super plasticizer to enhance the workability of the mixture. Table 3 presents the mixing ratio of cement and sand, as well as the modulus of elasticity for two distinct volume fractions.

Table 3: The mechanical properties of the ferrocement

Weldmesh			
Wire diameter (mm)	**Size of mesh openings (mm)**	**Cross sectional area of each wire (mm^2)**	**Ultimate tensile strength of reinforcement (N/mm^2)**
1.42	16	1.58	482.24
Mortar composition			
Sand/ cement	**Water/ cement ratio**	**Super-plastiziers/ cement**	
0.66	**0.30**	**0.025**	
Composite properties			
Modulus of elasticity (N/mm^2)		**Modulus of elasticity (N/mm^2)**	
0.71×10^5		1.36×10^5	

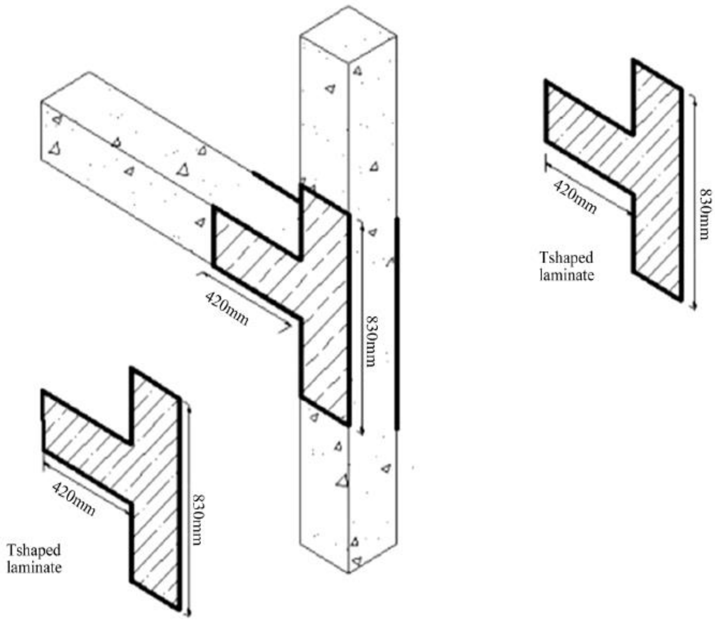


Fig 2: Wrapping details of ferrocement laminate [19]

Figure 2 displays the diagram illustrating the specific components and configuration ofthe ferrocement laminate T-shaped wrapping. Table 3 presents comprehensiveinformation pertaining to the mechanical properties of the ferrocement.

3. Experimental approach

All specimens will be loaded vertically with displacement-controlled reversed cycles as part of the experiment. A distance of 100 mm is used to apply the load from the beam's end. For this, we employ a 100 kN servo-controlled dynamic actuator. Figure 3 displays the schematic diagram illustrating the comprehensive details of the laboratory test set-up. The hydraulic actuator utilizes a linear variable differential transformer (LVDT) for precise displacement measurement. Moreover, the system functions in a mode characterized by displacement control[15], it has been observed that the amplitude of the loading exhibits a linear growth, with a rate of 5 mm. The loading frequency for this particular scenario was determined to be 0.1 Hz. The cyclic loading history is depicted in Figure 4.

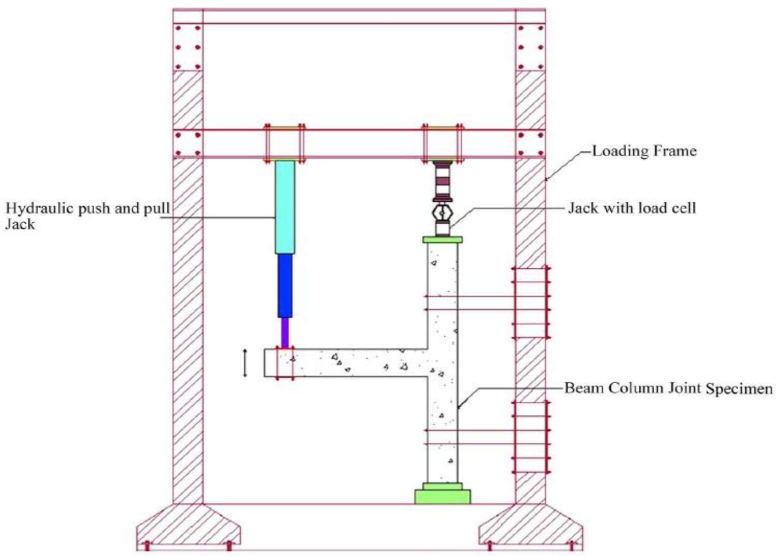


Fig 3: Laboratory test set up for BCJ [23]

A schematic picture illustrating the laboratory test setup for subjecting the BCJ (Bonded concrete joint) to cyclic loads is presented.

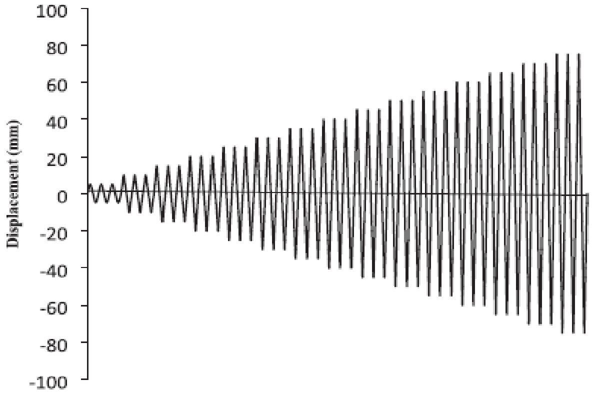


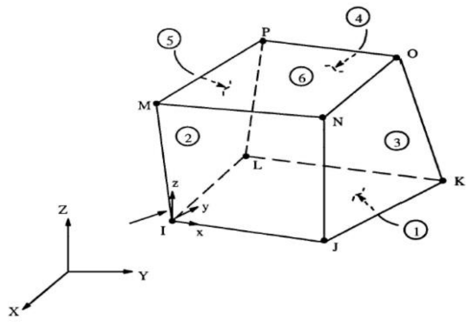
Fig 4: Cyclic loading history[17]

3.1 Finite element modelling

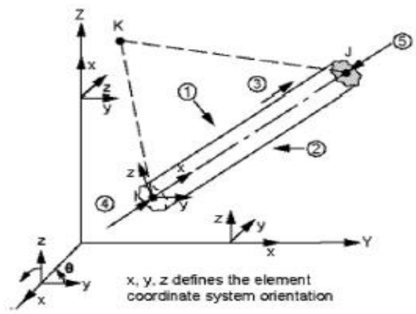
To examine the seismic behavior of the reinforced concrete beam-column Joint (RC BCJ) under reverse cyclic loading, a set of numerical 3D micro models was generated for each specimen utilizing ANSYS software.[1]In the current analysis, we will examine the comprehensive configuration of BCJ. The reinforcement bars will be represented as link elements, while the internally confined ferrocement will be modelled in a separate and detailed manner. The boundary condition of the BCJ is maintained in accordance with the test setup depicted in Figure 3. In this analysis, the concrete body is represented by a SOLID 45 model, as shown in Figure 5(a). The reinforcement bars are shown using a LINK 180 bar element, as illustrated in Figure 5(b).The ferrocement materials are represented using SHELL 181 and SOLID 65 for the mortar layers, as shown in Figures 5(c) and 5(d) respectively. The interface between concrete, steel, and the ferrocement lament is modeled using CONTA174, as illustrated in Figure 5(e). The modeling approach employed in this study assumes a behavior characterized by bonding. The interaction between concrete and reinforcement bar is commonly known as beam formulation. The selection of an unsymmetrical newton-raphson iteration approach has been made for the aim of conducting finite element analysis.

The determination of the compressive uniaxial stress-strain relationship for concrete is achieved through the utilization of the modified hognestad elastic model (Bangash, 1989). The model is visually shown in Figure 6, showcasing the elastic linear portion of the stress-strain graph. This particular region is constrained to a maximum of 30% of the ultimate compressive strength. Following this, the stress-strain curve transitions into the non-linear or plastic area.

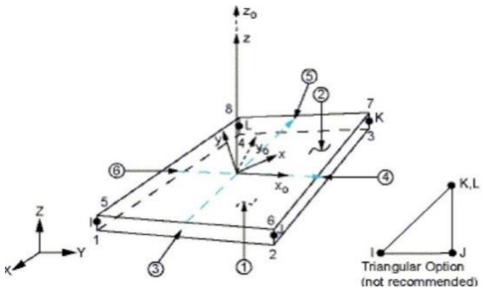
The characteristics of steel reinforcement and ferrocement have been summarized previously. Displacement-control mode testing was performed on the samples. In order to provide an overall picture, the finite element studies were broken down into a number of time increments. As shown in Figure 4, the displacement was delivered to the beam's tip at each time step to mimic the cyclic monotonic loading approach. The first step of the experiment was applying a 5 mm displacement for three cycles. After then, the displacement amplitudes were gradually increased until either the system failed to converge or the displacement changed drastically at a predetermined reference step number, also known as the failure step. This point marks the end of the analysis.



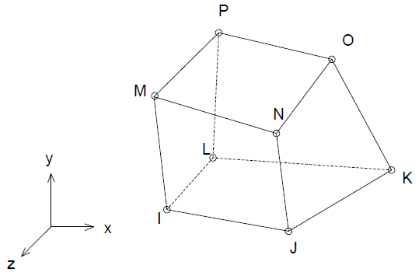
(a)SOLID45 element



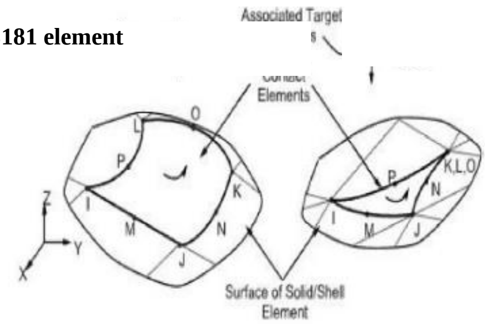
(b) LINK80 element



(c) SHELL181 element

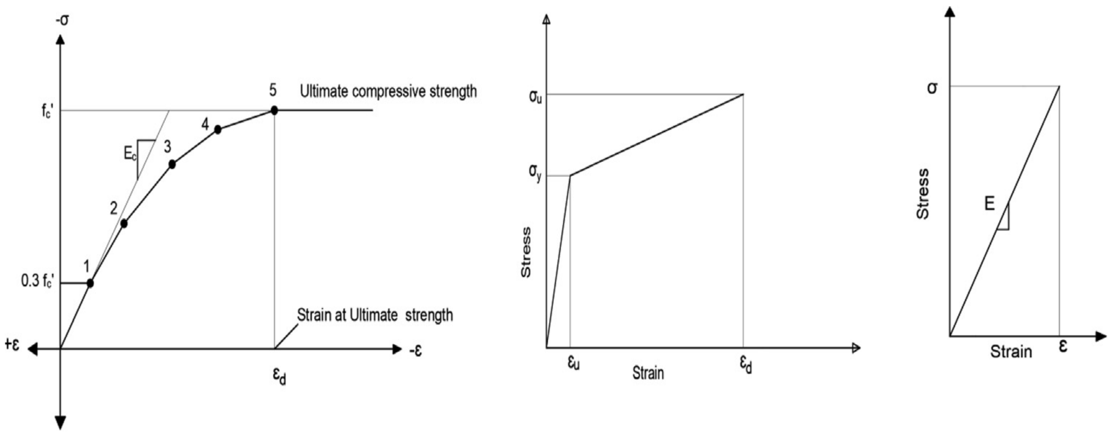


(d) SOLID65 element



(e) CONTA174 element

Fig 5: ANSYS model represent element[7]



(a) Concrete in compression (b) steel (c) Geogrid

Fig 6: Stress strain curve of material[21]

4. Result and discussion

4.1 Energy dissipation versusdisplacement for the specimens

Figures 7, 8, and 9 depict the relationship between energy dissipation and displacement for three scenarios: experimental without retrofitting, analytical, and experimental with retrofitting. These scenarios correspond to column-beam inclinations of 85^0, 87.5^0, and 90^0 (Normal), respectively. In the provided figure, it can be observed that there is a direct relationship between displacement and energy dissipation. As displacement increases, the amount of energy dissipated also increases. The energy dissipation values for displacements ranging from 0 to 40 mm, with intervals of 5 mm, are observed to increase up to 602.15, 815.63, and 895.25 kN mm, respectively. These values correspond to inclinations of 85^0, 87.5^0, and 90^0 (Normal) for the column. Based on the graphical representation, it can be observed that the experimental values and analytical values exhibit the presence of 5.23, 7.20, and 7.18, respectively. The comparison between connection without retrofitting and connection with retrofitting reveals that the energy dissipation is increases by up to 23.75%, 28.74%, and 18.22% at the maximum displacement of the connection, respectively.

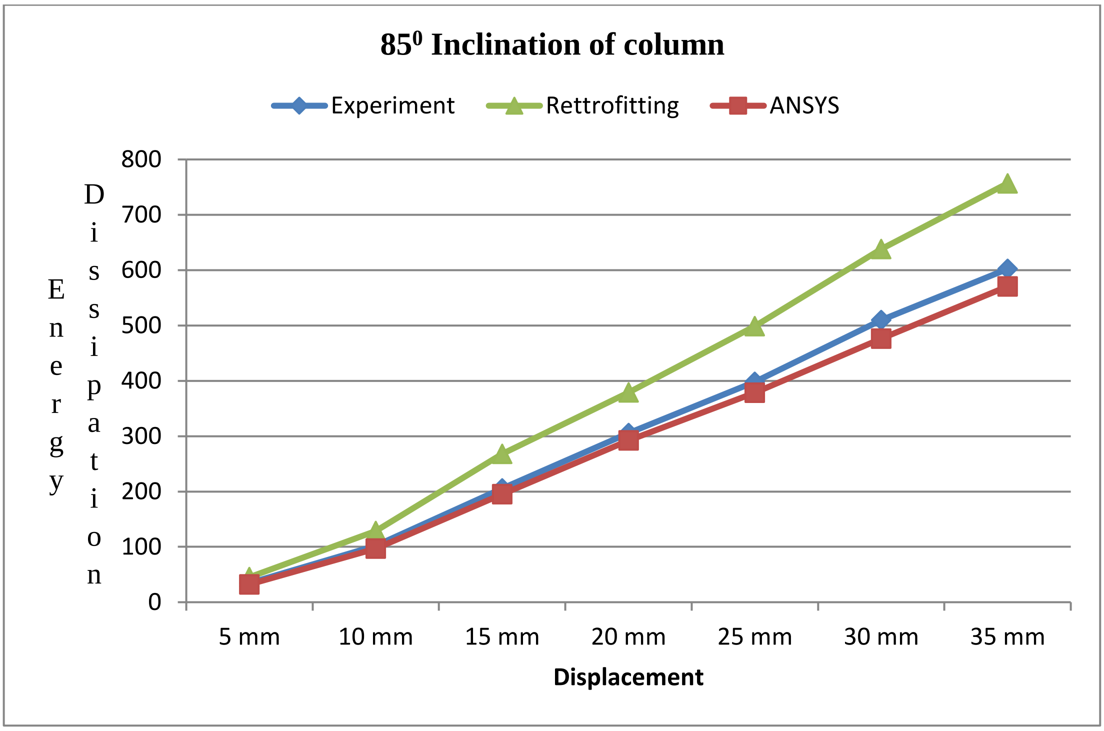


Fig 7: Energy dissipation versusdisplacement for 85^0inclination of column

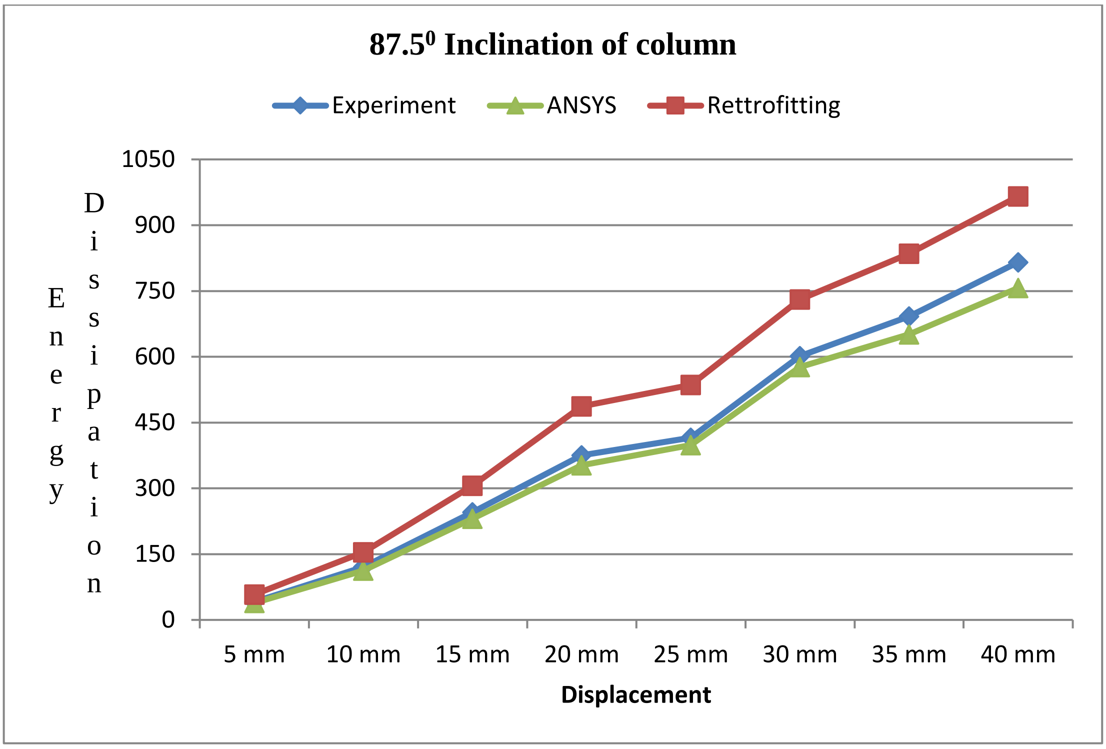


Fig 8: Energy dissipation versusdisplacement for 87.5^{0} inclination of column

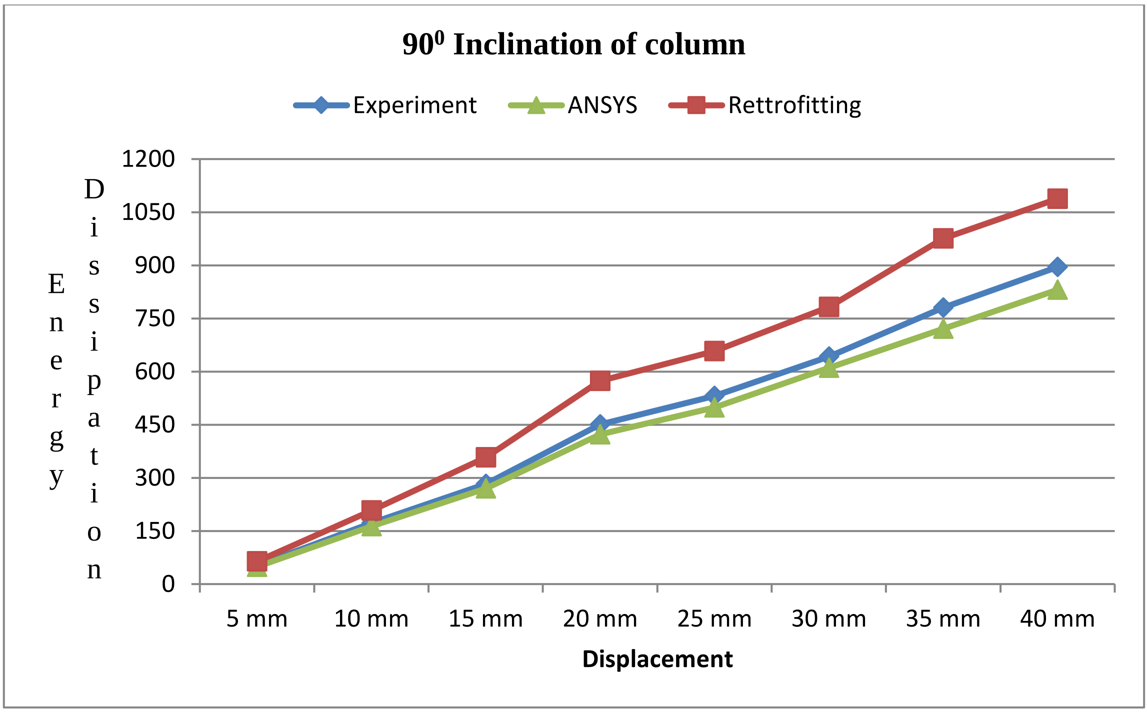


Fig 9: Energy dissipation versusdisplacement for 90^{0}inclination of column

4.2 Stiffness versus displacement for the Specimens

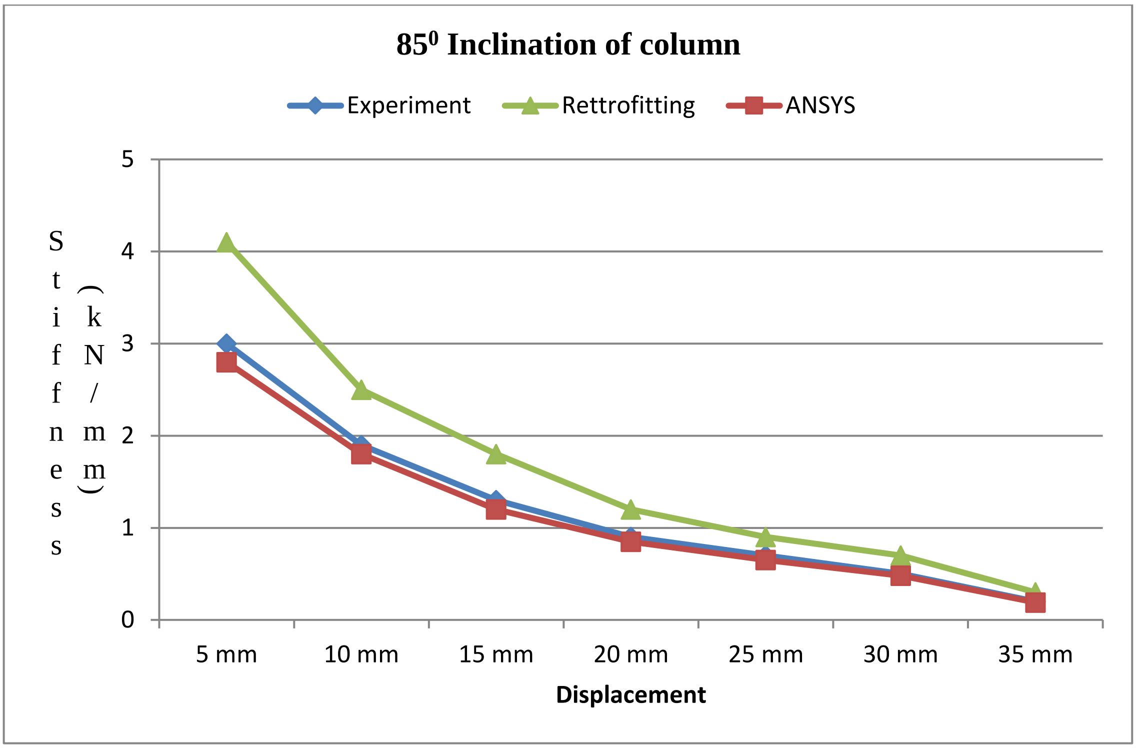


Fig 10: Stiffness versusdisplacement for 85^0inclination of column

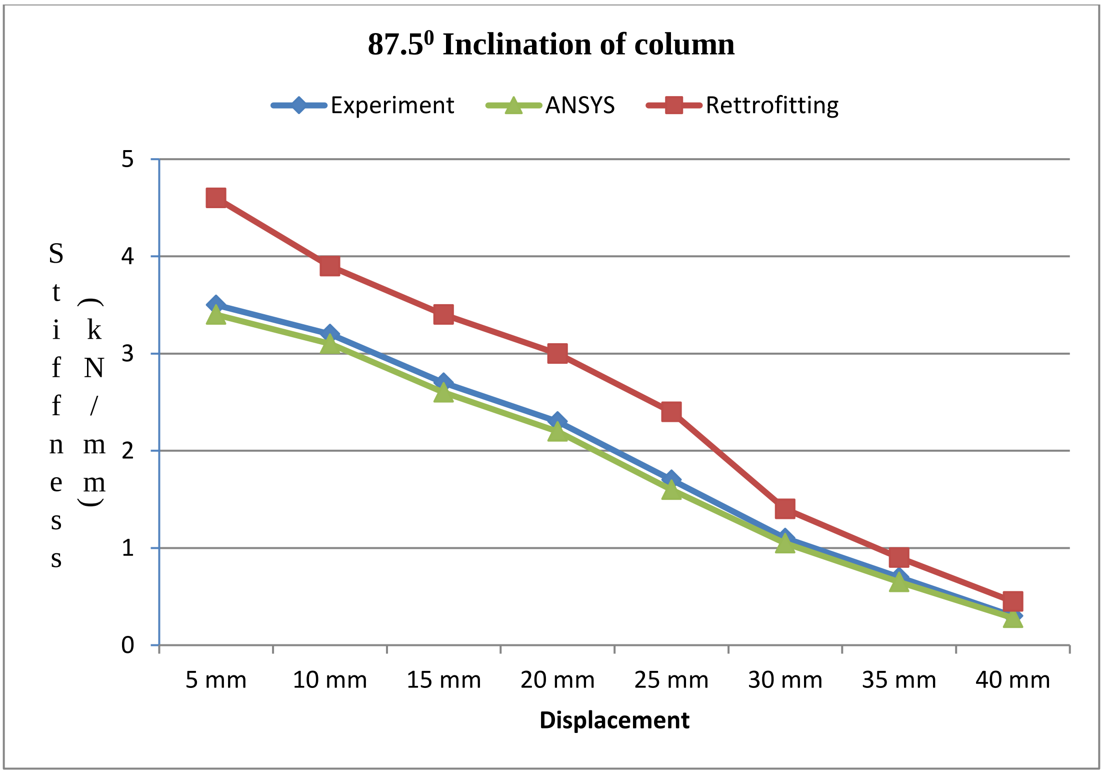


Fig 11: Stiffness versusdisplacement for 87.5^0 inclination of column

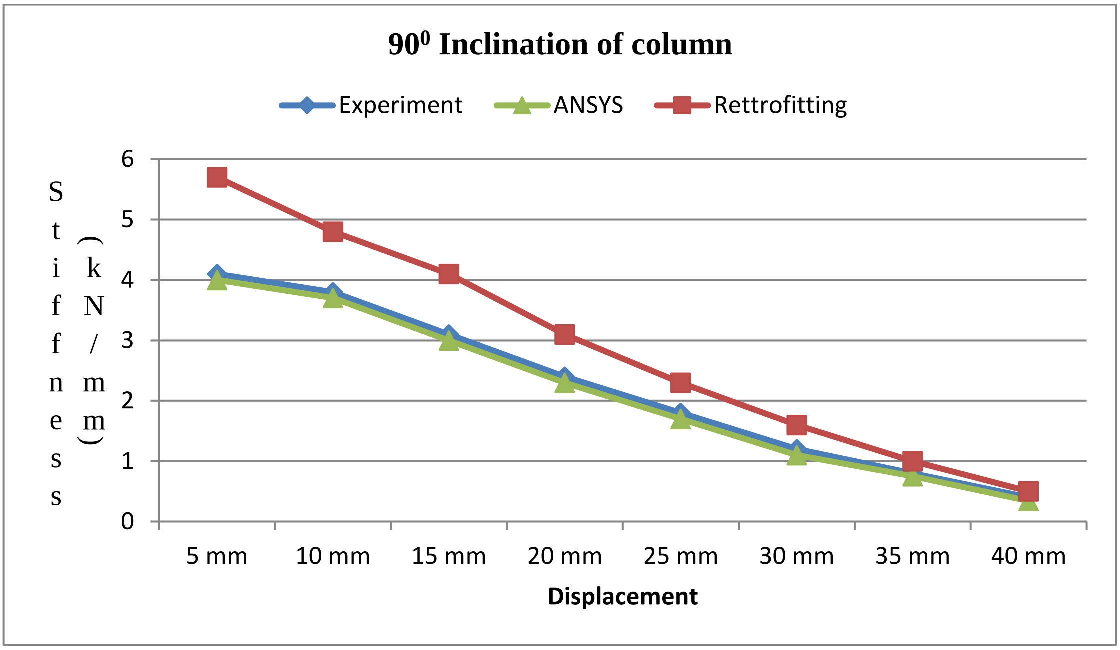


Fig 12: Stiffness versusdisplacement for 90^0inclination of column

Figures 10, 11, and 12 show the stiffness versus displacement envelop curve for all BCJs, including analytical and experimental with or without retrofitting data. The experimental results show that specimen stiffness decreases with displacement. Visual study shows that column tilt increases column-beam stiffness. The finite element analyses match the experimental results.

5. Conclusions

This work analyzes reinforced concrete beam-column junctions (BCJs) reinforced using ferrocement material through experiments and finite element calculations. BCJ finite element (FE) analyses use ANSYS. BCJ specimens undergo reverse cyclic loading with controlled amplitudes to determine their cyclic performance in relation to load-displacement envelope and stiffness factor.

- The specimen BCJ with seismic detailing and ferrocement retrofitting has a much higher energy dissipation capability than the specimen without retrofitting.
- The stiffness of a specimen is inversely related to its displacement. The ferrocement retrofitting specimen has more stiffness than the baseline specimen.
- Finite element (FE) calculations of boundary condition joints (BCJs) accord well with experimental data for energy dissipation capacity and stiffness factor. This consistency proves the finite element model and analyses can effectively anticipate BCJ responses.
- The graph shows that increasing the column-beam angle decreases energy dissipation capacity and stiffness. agreement shows that the finite element model and studies may effectively anticipate BCJ responses.

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