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A Study on Behavior of Headed Bars Made of Fiber-Reinforced Polymers in RCC Exterior Beam Column Joints

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Abstract: Seismic pressures on a reinforced concrete moment-resisting structure are known to create critical and essential regions at the reinforced beam-column joints. Beam-column junctions are a microcosm of the whole structure, therefore brittle behavior at these points predicts brittle action. Ductile behavior at beam-column joints predicts ductile action. Under the influence of seismic forces, the joints between RC beams and columns are exposed to high shear stresses. Learn more about the performance of fiber-reinforced polymer headed bars in rcc external beam column joints in this publication.

Keywords: Fiber-Reinforced Polymers, Beam Column Joints, Reinforced Concrete, Ductility.

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1. Introduction

Due to their primary design for gravity loads, reinforced concrete frame buildings built before the adoption of seismic design rules were found to be unfit to sustain the loads created during seismic occurrences. Most reinforced concrete frame structures built before the 1970s suffer from issues such inadequate anchoring design, low concrete strength, insufficient transverse beam column joint reinforcing, and the use of plain bar for longitudinal reinforcement. Throughout their useful lives, reinforced concrete frame buildings in seismically active areas will need to be upgraded so that they can withstand the expected seismic pressures. [1-2]

Existing structure evaluation calls for in-depth familiarity with structural behavior under severe loading conditions. Recently developed computer resources and improved understanding of solid mechanics have made it feasible to model and analyze key components of seismically deficient buildings to determine their capability before retrofitting. The present work focuses on three-dimensional finite element analysis of external beam-column (EBC) connections, which are common in reinforced concrete buildings built before the 1970s.[3-4]

Transmission of loads between beams and columns in a reinforced concrete instant frame relies heavily on the quality of the beam-column joints. The majority of conventional reinforced concrete frame buildings in the Middle East are shear deficient since they were constructed before the implementation of seismic construction guidelines.[5-7]

Improved seismic performance of newly constructed buildings and reduced risk of damage or collapse are the results of research conducted over the last few years that informed the creation of design standards that give seismic requirements for reinforcement details.

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Avoiding the brittle failure of joints in RC frames systems, keeping them intact, and minimizing their stiffness deterioration are all ways to do this. [8-9]

Recent seismic activity on an existing RC structure demonstrates the need for a variety of reinforcing approaches; nonetheless, many structures throughout the globe have been planned, specified, and constructed without explicit seismic criteria and may be susceptible to seismic occurrences. Conventional methods include jacketing the frame parts in concrete or steel, which is a difficult, invasive, and labor-intensive process. While more advanced methods like base isolation and supplementary damping devices exist, there are still obstacles to be overcome in areas like cost, invasiveness, and practical deployment.[10]

2. Material and Methods

Fiber Reinforced Applications Polymers are more versatile than traditional reinforcing materials. Physically, FRP varies in value according on the direction of calculation. The fibre orientation of FRP increases its strength. The shear strength, the dowel action, and the bond performance are all disrupted by this phenomenon. Fiberglass reinforced plastic (FRP) is linear elastic up to the point of failure; it does not give. Lack of ductility in design is something to be aware of. Advantages of FRP include quality assurance throughout factory production and a reduced need for on-site installation. Live load capacity of weight-restricted bridges using FRP deck replacements is increased, and installation time is decreased due to the lightweight FRP and the lighter equipment required to lift and put panels.

- **Materials**

1. Cement

In this experiment, we'll use regular Portland cement, often known as cement of grade 53. The various qualities of a cement usage have been tested in accordance with IS: 4031-1988, and the cement has been determined to meet the requirements of many IS: 12269-1987 standards.

2. Fine Aggregate

We'll be using natural river gravel that has been carefully sorted to pass a 4.75mm screen. The requirements for fine aggregate in India were met IS 383-1970.

3. Coarse Aggregate

Coarse aggregate refers to aggregate that is larger than 4.75 mm in size. Normal continuous grading is utilised with crushed aggregate in the 10mm and 20mm size range. Coarse aggregate sieve analysis conforms to Indian Standard 10262.

4. Glass Fibre

Glass fibre is a material made up of thousands of microscopic strands of glass. Its mechanical characteristics are similar to those of other fibres like carbon fibres and polymers. When used with composites, glass fibre is both more cost-effective and less brittle. As a result, glass fibre is utilised as a reinforcing element for numerous polymers to create a composite material known as GRP, commonly known as "fibreglass." This substance is denser since it does not contain any air or gas.

5. Steel

Carbon, iron, and sometimes other elements come together to form steel. Steel's primary raw material is iron. For ordinary iron-carbon, the range of carbon concentration ranges from 0.002% to 2.14% by weight. Steel's inexpensive price and great tensile strength make it ideal for a wide variety of construction, infrastructure, shipping, tool, vehicle, machine, and even weapon applications. Deformed steel bar in the following strength categories is required for use as reinforcement in concrete per IS 1786: 2008. There's Fe 250, Fe 415, Fe 500, & Fe 550. Fe 600.

- **Mix design**

Nominal mix:

The ratio of cement to fine and coarse aggregates, among other factors, used to be specified in concrete's technical requirements. Nominal mixes are those with a predetermined ratio of cement to aggregate that will provide satisfactory results in terms of strength.

Standard mix:

Nominal mixes with a constant cement-aggregate ratio might be either too weak or too powerful. Because of this, many requirements now call for a minimum compressive strength to be met. Standard mixes refer to these combinations.

To produce concrete with a specified minimum durability and strength as cheaply as feasible, mix design involves choosing appropriate materials and establishing their relative amounts. Finding the optimal cement-to-sand-to-aggregates ratio in order to get the desired concrete strength is the goal of concrete mix design. The formula for concrete may be expressed as follows: Concrete Mix = Cement x Sand x Aggregates. Steps, calculations, and laboratory testing are all part of the concrete mix design process. More expensive concrete grades (M40+) and large-scale building projects with substantial concrete usage tend to choose this method.

Table1: Mix Design for M-20

Grade of concrete	**M20**		
Compressive strength of concrete	20		
Maximum size of aggregate	20		
Workability	100 mm slump		
The specific gravity of cement	3.15		
The specific gravity of C.A.	2.51		
The specific gravity of F.A.	2.47		
Water absorption of C.A.	0.50%		
Water absorption of F.A.	1.00%		

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Standard deviation	4		
Zone of F.A.	Zone3		
Target mean strength			
fck=	20	N/mm^2	
f'ck=	26.6	N/mm^2	
W/Cratio	0.57		
Selection of water content	186	litre	
Corrected water content for 100mmslump	197.16	litre	
Cement content	345.8947368	kg	
Content of C.A and F.A.			
Final Volume of C.A.	0.64		
The volume of F.A.	0.36		
Calculation of Mix Proportions			
Volume of concrete	1	m^3	
Volume of cement	0.109807853	m^3	
Volume of water	0.19716	m^3	
Volume of aggregate	0.693032147	m^3	
Mass of C.A.	1113.286841	kg	
Mass of F.A.	616.2441851	kg	
Mix Proportion			
Cement	345.8947368	kg/m^3	
Water	197	litre	
F.A.	616.2441851	kg/m^3	
C.A.	1113.286841	kg/m^3	
The wet density of concrete	2272.425763	kg/m^3	
W/Cratio	0.569537432		
Corrections for water absorption			
Absorption for F.A.	6.162441851	litre	
Absorption for C.A.	5.566434205	litre	
Total absorption	11.72887606	litre	
Therefore, the actual amount of water to be used	208.7288761	litre	
The actual mass of C.A.	1107.720407	kg	
The actual mass ofF.A.	610.0817433	kg	
Final mix proportions			
Water(litre)	Cement(kg)	F.A.(kg)	C.A.(kg)
208.7288761	345.8947368	610.08174	1107.7204
0.603446233	1	1.7637786	3.2024784

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Table2: M-30 Mixing Scheme

Gradeofconcrete	M30		
Compressivestrengthof concrete	30		
Maximumsizeofaggregate	20		
Workability	100 mm slump		
A measurement of the density of cement	3.15		
A measurement of the density of C.A.	2.51		
A measurement of the density of F.A.	2.47		
WaterabsorptionofC.A.	0.50%		
WaterabsorptionofF.A.	1.00%		
Standarddeviation	5		
Zoneof F.A.	Zone3		
Targetmeanstrength			
fck=	30	N/mm^2	
f'ck=	38.25	N/mm^2	
W/Cratio	0.46		
Selectionofwatercontent	186	litre	
Correctedwatercontentfor 100mmslump	197.16	litre	
Cementcontent	428.6086957	kg	
ContentofC.AandF.A.			
FinalIntensity of C.A.	0.64		
Intensity of F.A.	0.36		
CalculationofMixProportions			
Intensity of concrete	1	m^3	
Intensity of cement	0.136066253	m^3	
Intensity of water	0.19716	m^3	
Intensity of aggregate	0.666773747	m^3	
Massof C.A.	1071.105348	kg	
MassofF.A.	592.8952162	kg	
MixProportion			
Cement	428.6086957	kg/m^3	

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Water	197	litre	
F.A.	592.8952162	kg/m^3	
C.A.	1071.105348	kg/m^3	
Thewetdensityofconcrete	2289.60926	kg/m^3	
W/Cratio	0.459626699		
Correctionsforwaterabsorption			
AbsorptionforF.A.	5.928952162	litre	
AbsorptionforC.A.	5.355526739	litre	
Totalabsorption	11.2844789	litre	
therefore,theactualamountofwatertobeused	208.2844789	litre	
Theactual mass of C.A.	1065.749821	kg	
Theactualmass ofF.A.	586.966264	kg	
Finalmixproportions			
Water(litre)	Cement(kg)	F.A.(kg)	C.A.(kg)
208.2844789	428.6086957	586.96626	1065.7498
0.48595486	1	1.3694689	2.4865334

Table3: Mix Design for M-40

Gradeofconcrete	M40		
Compressivestrengthof concrete	40		
Maximumsizeofaggregate	20		
Workability	100 mm slump		
A measurement of the density of cement	3.15		
A measurement of the density of C.A.	2.51		
A measurement of the density of F.A.	2.47		
Water absorption by C.A.	0.50%		
Water absorption by F.A.	1.00%		
Standarddeviation	5		
Zoneof F.A.	Zone3		
Targetmeanstrength			
fck=	40	N/mm^2	
f'ck=	48.25	N/mm^2	
W/Cratio	0.38		

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Selectionofwatercontent	186	litre	
Correctedwatercontentfor 100mmslump	197.16	litre	
Cementcontent	518.8421053	kg	
ContentofC.AandF.A.			
FinalIntensity of C.A.	0.64		
Intensity of F.A.	0.36		
CalculationofMixProportions			
Intensity of concrete	1	m^3	
Intensity of cement	0.164711779	m^3	
Intensity of water	0.19716	m^3	
Intensity of aggregate	0.638128221	m^3	
Massof C.A.	1025.089173	kg	
MassofF.A.	567.4236137	kg	
MixProportion			
Cement	518.8421053	kg/m^3	
Water	197	litre	
F.A.	567.4236137	kg/m^3	
C.A.	1025.089173	kg/m^3	
Thewetdensityofconcrete	2308.354892	kg/m^3	
W/Cratio	0.379691621		
Correctionsforwaterabsorption			
AbsorptionforF.A.	5.674236137	litre	
AbsorptionforC.A.	5.125445867	litre	
Totalabsorption	10.799682	litre	
therefore,theactualamountofwatertobeused	207.799682	litre	
Theactual mass of C.A.	1019.963728	kg	
Theactualmass ofF.A.	561.7493776	kg	
Finalmixproportions			
Water(litre)	Cement(kg)	F.A.(kg)	C.A.(kg)
207.799682	518.8421053	561.74938	1019.9637
0.400506589	1	1.0826981	1.9658461

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Beam-Column joints breakdown under seismic stress occurs not only in regular structures but also in high-rise buildings, necessitating the use of high-grade concrete, justifying the selection of M20, M30, and M40. Beam-column joints' shear strength is particularly crucial during earthquakes; hence earthquake-proofing is essential overall.

- **Beam-Column Joint Analysis Using ANSYS**

In a reinforced concrete structure, the weakest link is the connection between the beam and the column. During severe ground shaking, it is exposed to enormous pressures, and its actions greatly impact the structure's reactions. High shear forces produced inside a joint are neglected when the joint is assumed to be rigid. Especially under seismic conditions, shear failure is brittle and indicative of poor structural performance. Understanding joint behaviour is crucial for making appropriate design decisions.

Beam bars must meet specifications for FRP head and diameter. Shear transfer at the joint and the availability of transverse reinforcement are the primary issues. Research on the usage of "additional" FRP-headed bars at the joint core reveals that the rectangular head provides a novel additional mechanism of shear transmission and prevents diagonal cleavage fracture at the junction. Yet, there is a lack of experimental and analytical studies that examine the use of nonstandard external joint features. Despite a mountain of test data, headed bars' effect on joints' shear strength is not addressed in the relevant international regulations. This research aimed to find a way to improve core concrete confinement without adding excess reinforcement to the joints.

Specimens with headed bars put at the junction serve as confining reinforcements and are compared to the performance of exterior joint assemblages constructed for seismic stresses in compliance with IS 1893:2002. The analytical model built using the finite element software programme ANSYS11.0 is used to verify the experimental data obtained with a loading frame. While we mostly worked on analytically addressing static issues in undergrad, most engineering problems are considered to be dynamic. Dynamic may be a phrase that many looking at FE software solutions find puzzling. Non-static circumstances where loading conditions vary with time rather than place are referred to as "dynamic" in engineering curricula. But, Ansys's Transient Analysis allows us to experiment with different loading circumstances, both in terms of where they are applied and how much force they exert.

Living loads, also known as imposed loads, are loads that are either in motion or only there temporarily. Impact, momentum, vibration, sloshing fluid dynamics, and fatigue are all examples of dynamic loads that must be taken into account. Loads that vary over time are essential to a transient analysis. An ANSYS Civil structural problem solver-based transient structural analysis is available in the Civil application.

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3. Results

- **Result of Mix Design**

Amount needed to make one cubic foot of M20 concrete:

Quantity of C.A. = 3.7385 kg

Quantity of F.A. = 2.0590 kg

Quantity of cement = 1.2971 kg

Water=0.7044 litre

Table4: Concrete M20 Compressive Strength

M20 grade concrete(MPa)				
Days	**1 Sample**	**2 Sample**	**3 Sample**	**Average**
7days	20.85	20.75	20.80	20.81
28days	27.05	27.10	26.95	27.03

Amount needed to fill one cube with concrete of grade M30:

Quantity of C.A, = 3.5969 kg

Quantity of F.A. = 1.9810 kg

Quantity of cement = 1.4465 kg

Quantity of water=0.7029 litre

Table5: Tensile Strength of Concrete of Grade M30

M30 grade concrete(MPa)				
Days	**1 Sample**	**2 Sample**	**3 Sample**	**Average**
7days	29.87	29.93	29.90	29.90
28days	39.00	38.85	38.45	38.76

Formula for 1 m3 of M40 concrete:

Quantity of C.A. = 3.4423 kg

Quantity of F.A. = 1.8959 kg

Quantity of cement = 1.7510 kg

Quantity of water=0.7013 litre

Table6: M40 Concrete Compressive Strength

M40 grade concrete (MPa)				
Days	**1 Sample**	**2 Sample**	**3 Sample**	**Average**
7days	38.45	38.40	38.40	38.41
28days	49.50	49.75	50.05	49.76

- **ANSYS Results**

In reinforced concrete framed constructions, the beam-column connection, where the components contact in all three dimensions, is a particularly crucial zone. Based on our findings, we can safely assume that the outside junction is the most significant or vital of all beam-column joints during earthquakes and seismic loads.The external beam-column joints are investigated using a variety of metrics, such as the maximum principle stress, the maximum shear stress, the displacement, and the rotations. Casts were made and studied in the lab so that results from the analysis and the experiment could be compared. The tabulated marginal variations are found to be in close agreement with the results of the ANSYS analysis and the experimental observations.

Casts were made and studied in the lab so that results from the analysis and the experiment could be compared. It is found that the marginal variations calculated in the ANSYS analysis are quite similar to the experimental results. Additional Joint or lateral reinforcement using headed bars of varying rebar diameters helped minimise cracking at the column-beam junction. The orientation of header bars provided additional reinforcement to the members to which they were attached. Beam ends are fortified by headed bars inserted at regular intervals along the beam, and the column itself is bolstered by bars inserted at regular intervals along the column. The efficiency of headed reinforced external beam-column joints was evaluated and compared to that of standard joints. Shear resistance, displacement ductility, or energy absorption are all significantly improved when FRP-headed reinforced concrete is used in beam-column joints. The results of the research also showed that using FRP-headed reinforcement at the beam-column joint is an effective method for reducing the amount of bending reinforcement there. The shear strength of the joint and the shear stress at the site of the first fracture may both benefit considerably from this.

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Table7: Analytical vs Experimental Comparison of Deflection

Time (sec.)	Deflection (mm)		Marginal Variation In %	Deflection (mm)	Marginal Variation In %
	Experimental Result	Analytical Result		Analytical Result	
1	4.51	4.1887	7.12	4.2213	6.40
2	9.23	8.3983	9.01	8.4537	8.41
3	14.68	11.9723	18.44	13.3382	9.14
4	20.24	18.5560	8.32	18.4163	9.01
5	25.70	29.4022	14.40	23.4486	8.76

Table8: Stress Analysis: An Experimental and Theoretical Comparison

Time(sec.)	Stress(MPa)		MarginalVariationIn%	Stress(MPa)	MarginalVariationIn%
	Experimental Result	AnalyticalResult		AnalyticalResult	
1	0.956	0.8866	7.25	0.8876	7.15
2	1.357	1.2363	8.89	1.2426	8.43
3	1.723	1.2698	26.30	1.6042	6.89
4	2.06	1.8962	7.95	1.9092	7.32
5	2.39	2.2003	7.93	2.2093	7.56

4. Conclusion

As a result of applying transient loading to the free end of the scale model in ANSYS, the maximum deflection or stress in the beam were determined to be 29.4 mm and 2.2 N/mm2, respectively. Concrete mix designs for M30 and M40 may be based on the findings from M20, but with square and rectangular headed bars instead of FRP. Bond strength of a bar with a circular head is lowest because its gross area is the smallest compared to that of a bar with a square or rectangular head.

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