Seismic Analysis of Reinforced Concrete Exterior Wide Beam-Column Joints using Fiber Reinforced Polymer

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Abstract— In reinforced concrete structures, beam column joints are considered as most damageable structural element subjected to lateral loads. This research aims to the finite element study of exterior wide beam column joints by using fiber reinforced polymers by considering horizontal cyclic loads. This topic of work was decided as the present scenario of the beam column joints are the most venerable failures due to poor work man ship and lack of detailing of reinforcement. These failures can be rehabilitated by using glass and carbon fiber reinforced polymers at the exterior wide beam column joints. Use of fiber reinforced polymer (FRP) composites for strengthening of beams and columns in RC structures has attracted great attention in recent decades. The free end of the column is subjected to cyclic loading. Three specimen is considered and one is unstrengthened, second one is strengthened with CFRP and third one is strengthened with GFRP were modelled and analysed. An effective re-habitation strategy is in order to increase the ductility of the wide beam column joint and transfer the failure mode to beam or delay the shear failure mode. The stress and deformation results were evaluated and compared their results with strengthened and unstrengthened specimen. The numerical result shows that the beam column joint strengthened with CFRP and GFRP can increase their structural stiffness, strength, ductility and energy dissipation capacity.

Key words: Wide Beam Column Joint, FRP, Finite Element, ANSYS, Strengthening

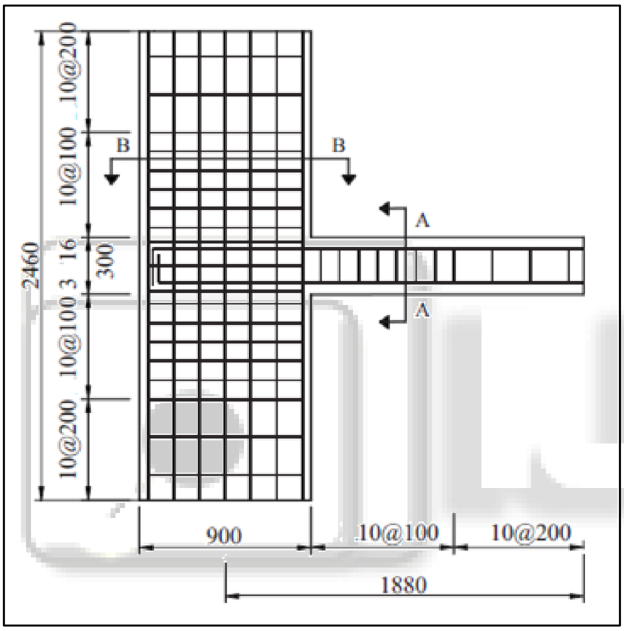
I. Introduction

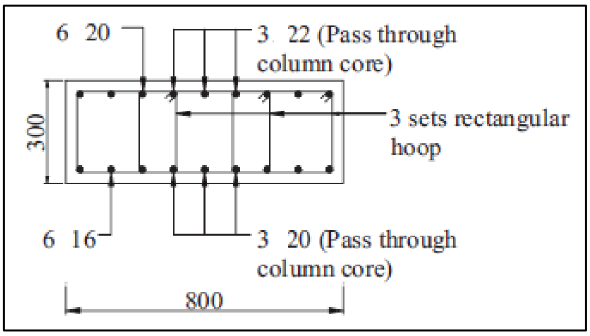
In the analysis of reinforced concrete moment resisting frames the joints are generally assumed as rigid. In various parts of the world, the behaviour of reinforced concrete (RC) moment resisting frames during recent earthquakes has highlighted the consequences of poor performance of reinforced concrete (RC) beam - column joints. The RC structures, constructed in the developed world, are often found to exhibit distress and suffer damage even before service life is over due to several causes, such as improper design, faulty construction, over loading, earthquakes, explosions, corrosion, wear and tear, flood, fire, etc. Adopting a wide beam system for the design scheme provides many advantages. They include reducing the amount of formwork required, providing simplicity for repetition and thus decreases the storey height. All of these would eventually result in a faster construction at a reduced cost. Gravity load-resisting frames in non-seismic regions commonly utilize RC wide beam frame buildings and composite structural systems of wide beam framing with other members due to these advantages. Currently, these advantages have brought about increased of wide beam systems even in seismically active regions.

II. Previous Studies

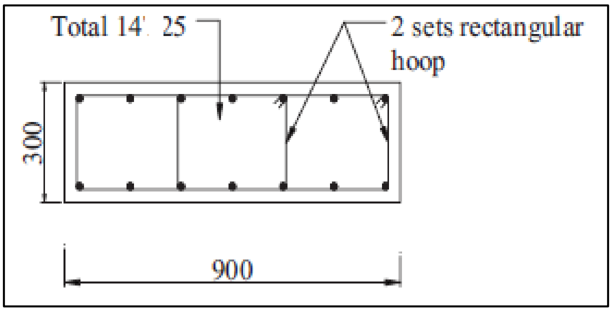
The potential advantages and applications of the wide beam system as a lateral load-resisting structure is often ignored due to the lack of understanding in the performance of these structures under seismic demand. The current design code BS 8110, British Standards strictly restricts the use of wide beam-column connections to resist earthquake loads. Such geometric restrictions are often based on historical design practices. In the United States, for example, beam width is restricted of bc+1.5hb, where hb is the beam depth and bc is the column width. In New Zealand, the beam width restriction is the lesser of bc+0.5hc and 2bc, where hc is the column depth. However, some researchers (Bing Li et. al. 2010) conducted an experimental and numerical investigation carried out on RC wide beam-column joints when subjected to seismic loads. Simulations of earthquake loadings were applied on to the specimens via quasi-static load reversals. They concluded that wide-beam column joints perform well in carrying the horizontal lateral loads as they can generally attain their strength and deformation capacity and clearly suggest an improvement in joint shear stress by increasing the longitudinal bar anchorage ratio. (Maria Teresa De Risi et. al. 2016) conducted the study on seismic response of non-ductile reinforced concrete buildings can be affected by the behavior of beam-column joints involved in the failure mechanism and the attention is focused on exterior joints without transverse reinforcement. (Bing Li et. al. 2009) conducted experimental and finite element numerical investigations on interior wide-beam column joints to study the seismic behavior. The finite element analysis results showed an improvement in the joint shear stress when the longitudinal reinforcement anchorage ratio is enhanced. (Behnam et. al. 2015) evaluated the applicability of the nominal joint shear strength specified in codes of practice including ACI 318-08, NZS 3101: 2006 and EN 1998-1: 2004 for the wide beam-column joints. (J.S. Kuang et. al. 2013) simulated five wide beam-column joint specimens with the same column sizes but different beam widths and beam depths. It is shown that lesser crack opening occurs in wide beam-column connections; hence less pinched hysteresis loops are observed. The beam width has significant effect on the load transfer paths in wide beams and the corresponding joint cores. (V. B. Dawari et. al. (=2014) they analyzed the nonlinear Concrete design for FE examination of RC Beams. They investigate on non-linear flexural parameter of RC beams. Comparison is analyzed between the experimental outcomes and FE analyses concerning primary crack formation and the ultimate load competency of beams. (A. S. Harihar et. al. 2016) they studied about the nonlinear FE Analysis that has been found to simulate the performances of RC beams strengthened using CFRP sheets. The reinforcement provided increases the strength also increases by the increase in many layers of CFRP sheet the strength and hardness also increases. (M. S. Safna et. al. 2014) conducted numerical analysis CFRP coated RC columns. The work focused the appropriateness of CFRP coating for strengthening column. (I. Elyasian et. al. 2006) they investigated the FRP shear strengthening of RC beams numerically using ANSYS. The results show that FRP shear strengthening is quite viable and by choosing the parameters carefully adequate ductility can be obtained in addition to reasonable strength gains. The model is used to examine the influence of fiber orientation, compressive strength of concrete, area of tensile and compressive reinforcements.

III. REINFORCEMENT DETAILS





SECTION A-A



Section B-B

IV. MATERIAL PROPERTIES

A. *CONCRETE*

- Density – 2300 kg/m^3
- Young's Modulus -33166 MPa
- Poisson's ratio – 0.2

B. *REINFORCEMENT*

- Density - 7850 kg/m^3
- Young's Modulus – 200000 MPa
- Poisson's ratio – 0.3

C. *CFRP*

- Density – 1700 kg/m^3
- Young's modulus - 240000 MPa
- Poisson's ratio – 0.3

D. *GFRP*

- Density – 2600 kg/m^3
- Young's Modulus – 73000 MPa
- Poisson's ratio -0.28

V. FINITE ELEMENT ANALYSIS

The finite element method (FEM) has become a staple for predicting and simulating the physical behaviour of complex engineering systems. The commercial finite element analysis (FEA) programs have gained common acceptance among engineers in industry and researchers. The Finite Element Analysis is a numerical technique in which all complexities of the problems varying shape, boundary conditions and loads are maintained as they are but the solutions obtained are approximate. Solutions can be obtained for all problems by Finite Element Analysis.

VI. FINITE ELEMENT MODELLING

ANSYS is general-purpose finite element software for numerically solving a wide variety of structural engineering problems. The ANSYS element library consists of more than 100 different types of elements. For the numerical simulation of any RC structure, three dimensional solid element SOLID186 has been used for modelling the nonlinear behaviour of concrete and FRP, three dimensional spar elements LINK180 has been used for modelling the reinforcement.

VII. ELEMENT TYPE AND CHARACTERISTICS FOR FE MODEL

A. *Concrete*

Concrete generally exhibits large number of micro cracks, especially, at the interface between coarse aggregates and mortar, even before it is subjected to any load. The presence of these micro cracks has a great effect on the mechanical behaviour of concrete, since their propagation during loading contributes to the nonlinear behaviour at low stress levels and causes volume expansion near failure.

Solid 186 is used modelling of concrete, CFRP and GFRP. It is a higher order 3-D 20-node solid element that exhibits quadratic displacement behaviour. The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. The element supports plasticity, hyper elasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elasto plastic materials, and fully incompressible hyper plastic materials.

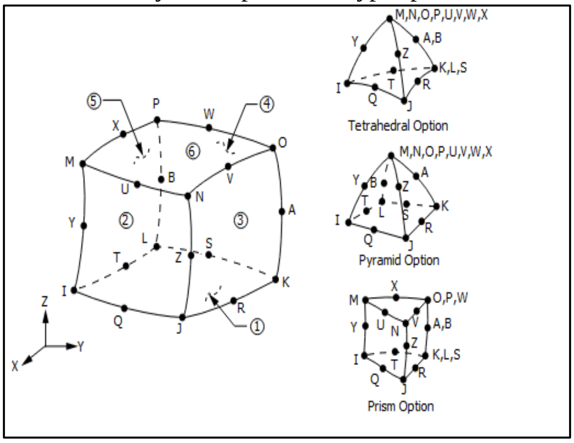


Fig. 1: SOLID 186 Element

VIII. STEEL REINFORCEMENT

The reinforcement can be provided in two different ways either discrete or smeared. The discrete model uses bar or beam elements that are connected to concrete mesh nodes. So the concrete and reinforcement share the same nodes.

LINK180 is a spar that can be used in a variety of engineering applications. This element can be used to model trusses, sagging cables, links, springs, etc. 3-D spar element is a uni-axial tension-compression element with three degrees of freedom at each node: translations in the nodal x, y, and z directions.

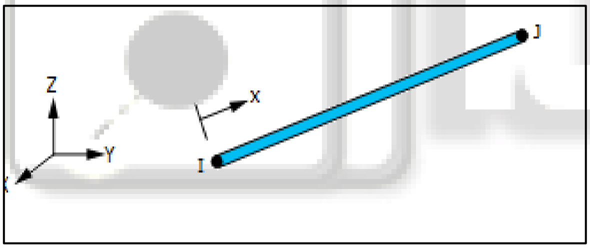


Fig. 2: LINK180 Element

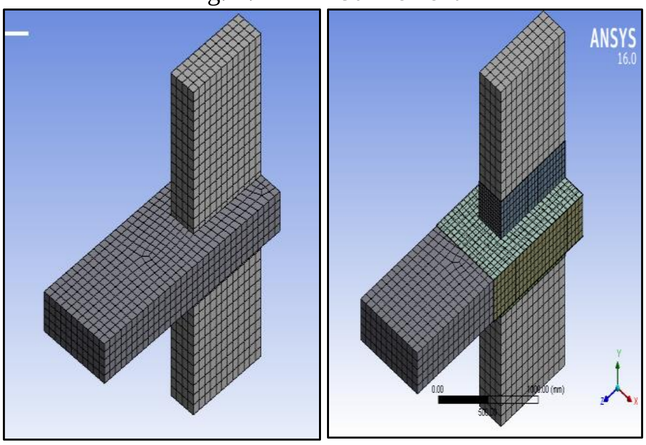


Fig. 3: meshing of exterior wide beam column joint without FRP and with FRP using ANSYS

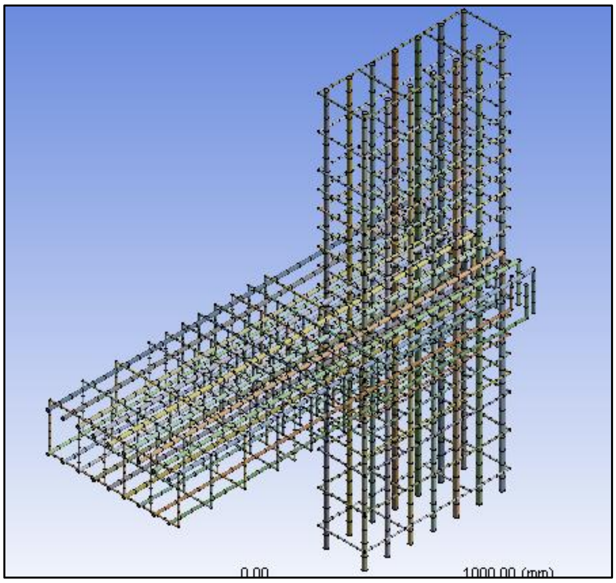


Fig. 4: Detailing of specimen as per IS 13920:1993

The meshing is the important step .This is the process of discretization of the structure to obtain accurate results. Finer the mesh size accuracy also increases. To obtain good results from the Solid186 element, a rectangular mesh is used. Therefore, the mesh is setup such that square or rectangular elements are created. This properly sets the width and length of elements in the concrete support and makes it consistent with the elements and nodes in the concrete portions of the model

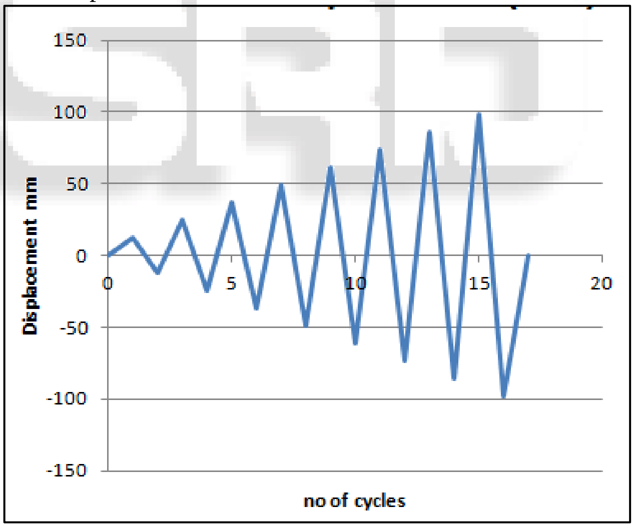


Fig. 5: cyclic horizontal loading history

IX. RESULTS AND ANALYSIS

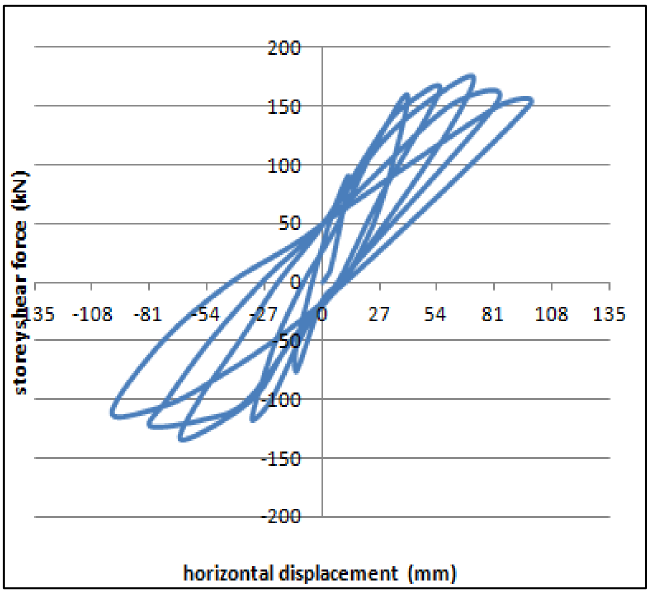


Fig. 6: shear force – displacement graph without FRP

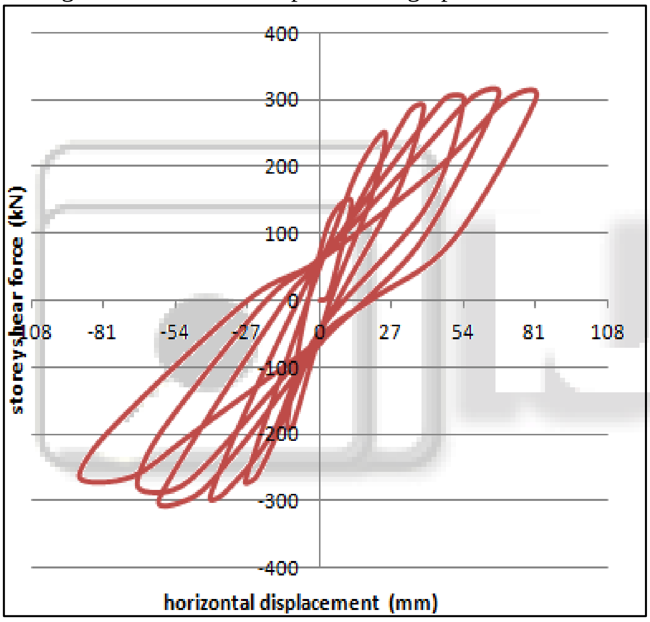


Fig. 7: shear force – displacement graph with CFRP

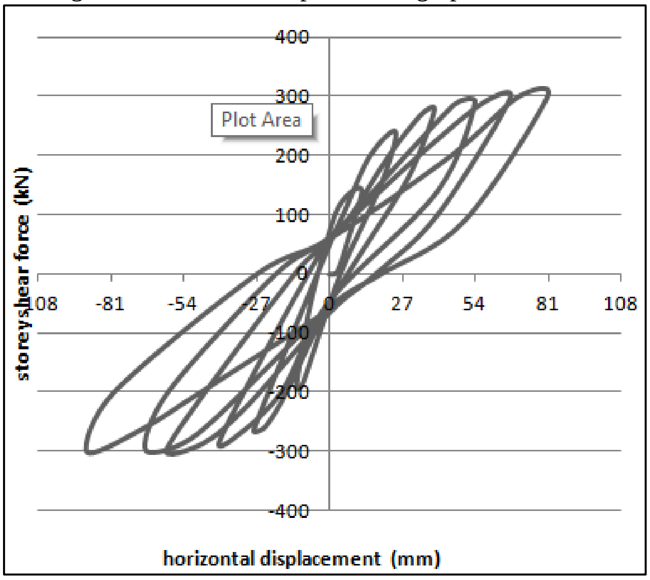


Fig. 8: shear force displacement graph with GFRP

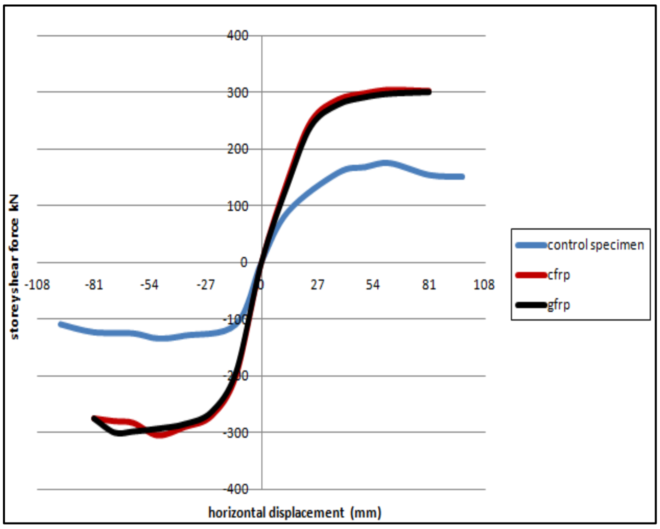


Fig. 9: shear force – displacement graph (without FRP, with CFRP and GFRP)

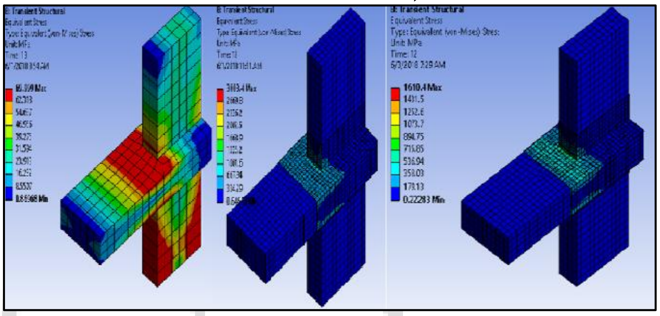


Fig. 10: equivalent stress without FRP, with CFRP and GFRP

Fig 6,7 and 8 shows the storey shear force verses displacement curves (hysteresis loops) of wide beam column joint without FRP, with CFRP and with GFRP subjected to horizontal cyclic loading in nonlinear analysis using ANSYS workbench16 software. Maximum storey shear force of wide beam column joint without FRP coating is 170 kN, with CFRP is 303 kN and with GFRP is 300 kN respectively.

Fig 9 shows envelop of the storey shear force verses displacement curves between wide beam column joints without FRP, with CFRP and coated with GFRP. By comparing this envelop we can see that retrofitted specimen by FRP sheets shows more load carrying capacity than the first one and more energy dissipation capacity too.

Fig 10 shows the equivalent stresses of wide beam column joints without and with FRP laminates. The colour indicates various stress concentrations from maximum to minimum.

X. CONCLUSIONS

Based on the FE numerical results of the exterior wide beam-column joint specimens, the following conclusions can be drawn:

1) The FE investigation was effective in successfully predicting the local behavior of wide beam-column joints. The numerical study clearly suggests an improvement in joint shear stress by retrofitting of FRP sheets. The maximum joint shear force experienced an enhancement of approximately 43.89% as retrofitted by CFRP and increased from 43.3% by using GFRP.

2) Wide beam-column joints, when designed with suitable parameters, perform quite well in carrying the horizontal lateral loads as they can generally attain their strength and deformation capacity.
3) Concrete grades did not provide much influence the performance of the specimens.
4) Strengthening FRP sheets in the connection zone moves the plastic hinge forward from the joint to a reasonable distance and decreases maximum concrete strain in the joint region.
5) The modeling performed in this study on three specimens before and after being retrofitted, shows that FE modeling can be evaluate the cyclic performance of RC joints by adequate approximation. Therefore, the most effective retrofitting schemes under earthquake loads can be easily recognized using the low cost finite element models.

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