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Studies on Behaviour of Rcc Beam-Column Joint Retrofitted with Basalt Fiber Reinforced Polymer Sheet

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Abstract - Reinforced Concrete (RC) buildings designed for IS 456-2000 have been found to be weak in adequate seismic design provisions, capacity design considerations and detailing for ductile behaviour. Experimental tests RC frames have shown that the excessive damage or failure of beam-column joints, in particular exterior (or corner) joints which can lead to the global collapse of a building. The poor joint behaviour of older construction can be attributed to the inadequate shear reinforcement in joint region and the deficient anchorage details into the joint region. Recent evaluation of Civil Engineering structures has demonstrated that most of them will need major repairs in the near future. Up gradation to higher seismic zones of several cities and towns in the country has also necessitated in evolving new retrofitting strategies.

One of the techniques of strengthening the RC structural members is through confinement with a composite enclosure. This external confinement of concrete by high strength fibre reinforced polymer (FRP) composites can significantly enhance the strength and ductility as well as result in large energy absorption capacity of structural members .FRP materials such as basalt, glass and hybrid fibre, available today in the form of sheets, are being used to strengthen a variety of RC elements to enhance the flexural, shear and axial load bearing capacity of elements.

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GJRE-E Classification : FOR Code: 290801

STUDIES ON BEHAVIOUR OF RCC BEAM-COLUMN JOINT RETROFITTED WITH BASALT FIBER REINFORCED POLYMER SHEET

Strictly as per the compliance and regulations of :

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Keywords : basalt fiber, epoxy resin, cement, aggregate and water.

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I. Introduction

In the last few decades, moderate and severe earthquakes have struck different places in the world, causing severe damage to reinforced concrete (RC) structures.

Retrofitting of existing structures are the major challenges that modern civil engineering field is facing these days. Recent evaluation of civil engineering structures has demonstrated that most of them will need major repairs in the near future. Up gradation to higher seismic zones of several cities and towns in the country has also necessitated in evolving new retrofitting strategies.

In RC buildings, portions of columns that are common to beams at their intersections are called beam-column joints. Since their constituent materials have limited strengths, the joints have limited force carrying capacity. When forces larger than these are applied during earthquakes, joints are severely damaged.

Beam column joints in a reinforced concrete moment resisting frames are crucial zones for transfer of loads effectively between the connecting elements (i.e. beams and columns) in the structure. In normal design practice for gravity loads, the design check for joints is not critical and hence is not usually done. But, the failure of reinforced concrete frames during many earthquakes has demonstrated heavy distress due to shear in the joints that culminated in the collapse of the structure.

a) Objectives

In general this investigation was carried out to study the behaviour of the beam-column joint under static and reverse loading. In more specific terms this research was conducted to achieve the following objectives

- Studies and behaviour of reinforced concrete beam-column joint retrofitted with Basalt fibre reinforced polymer sheets (BFRP).

b) Literature Review

Dylmar Penteado Dias (2005)[1] et al The purpose of this work was to investigate the influence of the volumetric fraction of the fibers on the fracture

Global Journal of Researches in Engineering (E) Volume XIII Issue V Version I Year 2013

toughness of geopolymeric cement concretes reinforced with basalt fibers.

- T. Cziga´ny(2006)[2] The strength properties of hybrid composites improved owing to surface treatment and this was proven by mechanical tests and microscopic analysis, as well.
- Jongsung Sim,(2006)[3] et al This study investigates the applicability of the basalt fiber as a strengthening material for structural concrete members through various experimental works for durability, mechanical properties, and flexural strengthening.
- M.M. Smadi et al(2008)[4] Ten slab–column connections were tested under combinations of gravity and lateral loads to investigate the effect of adding steel fibers to concrete mix on the structural behavior of normal- and high-strength slab–column connections.
- Bu¨ lent O¨ ztu¨ rk (2006)[5] et al In the present study, hybrid friction materials were manufactured using ceramic and basalt fibers. Ceramic fiber content was kept constant at 10 vol% and basalt fiber content was changed between Experiments show that fiber content has a significant influence on the mechanical and tribological properties of the composites.
- Xin Wang et al (2010)[6] To overcome the limitations of conventional steel stay cables in a thousand-meter scale cable-stayed bridge, hybrid basalt and carbon (B/C) FRP cables were investigated to achieve integrated high performances in the bridge of this scale as a replacement for steel cables.
- Mohamed F.M. et al (2010)[7] Commonly used fiber-reinforced polymer (FRP) includes Carbon, Glass, and Aramid FRP composites. The aim of the study is twofold. In case of different types of FRP composites, providing equivalent confinement modulus (lateral stiffness), five models are employed to find the FRP-confined concrete stress–strain relationship of three scale-model circular columns.
- Catherine Papanicolaou , et al (2010)[8] Externally bonded grids are used in this study as a means of increasing the load-carrying and deformation capacity of unreinforced masonry (URM) walls subjected to cyclic loading.

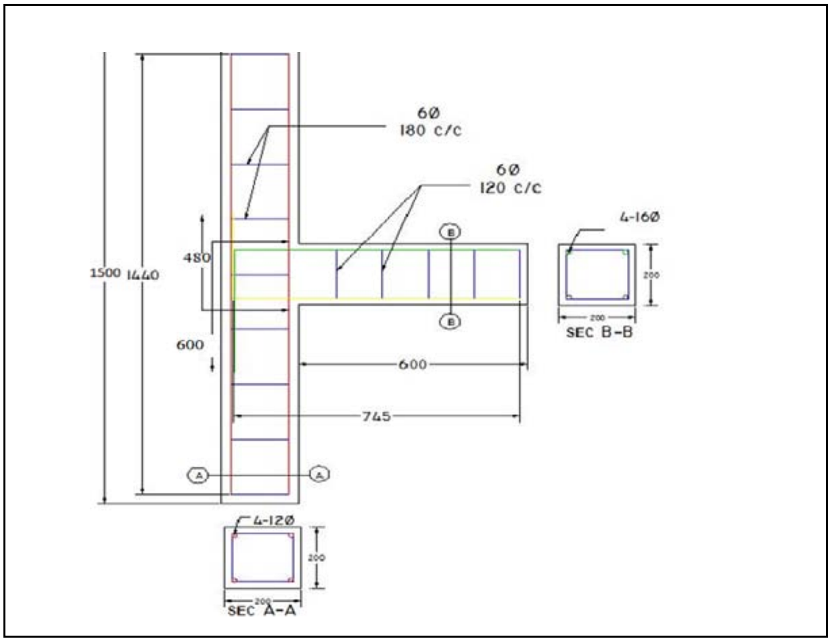
c) Experimental Investigation

The experimental program consisted of testing of nine reinforced concrete beam-column joint specimens. The columns had a cross section of 200 mm x 200 mm with an overall length of 1500 mm and the beams had a cross section of 200 mm x 200 mm with a cantilevered portion of length 600 mm. In three specimens, the lateral ties in the column are provided with spacing 180 mm c/c as per IS 456:2000. In remaining three specimens, the lateral ties in the column are provided with spacing 80 mm c/c and 100 mm c/c as per IS 13920:1993. The concrete mix was designed for a target strength of 30 MPa at the age of 28 days. The load carrying capacity of the column was evaluated as 525 kN as per the code IS 456-2000.

d) Parameters Investigated

- M30 grade concrete was made with a mix ratio of 1:1.502:2.558. Companion cubes were made to find the value of characteristic strength of concrete. The longitudinal reinforcement in the column portion in all the specimens consisted of 4 no. 12mm Ø (HYSD) bars. The tension reinforcement in the beam portion consisted of 2 no 16mm Ø bars and the beam compression reinforcement consisted of 2 no 16mm Ø bars. The anchorage length of the tension and the compression reinforcement of the beam is extended into the column as per codal provision. The details of the specimens are given below.

SlNo	Name of Specimen	Code Reference	Criteria Axial Loads	Retrofitting
1	BCJ 1	IS 456	15%	Nil
2	BCJ 2	IS 456	30%	Nil
3	BCJ 3	IS 456	45%	Nil
4	BCJ 4	IS 13920	15%	Nil
5	BCJ 5	IS 13920	30%	Nil
6	BCJ 6	IS 13920	45%	Nil
7	BCJ R1	IS 456	15%	Basalt Fiber
8	BCJ R2	IS 456	30%	Basalt Fiber
9	BCJ R3	IS 456	45%	Basalt Fiber



e) Reinforcement Details of Beam Column Joint Specimen

i. *Preparation of Mould*

Moulds made of steel sheet had been welded and prepared for casting the beam column joint specimen. It consists of a long steel plate and two L-shaped welded plates and this assembly was bolted together by using square plates at the ends. The inner dimensions of the mould are 1500 x 200x 200 mm in the column portion and 600 x 200 x 200 mm in the beam portion.

ii. *Casting of Test Specimen*

The Reinforced concrete beam column joint specimens were cast using specially fabricated steel moulds. Two moulds were prepared for this purpose. The fabricated reinforcement steel was placed inside the mould and it is kept in position using cover blocks.

Concrete was mixed manually and poured into the moulds. Care was taken to see that the concrete was properly placed and compacted beneath and also on the sides of the mould using a needle vibrator.

The sides of the mould were removed after 24 hours from time of casting and the test specimens were cured for water using gunny bag coverings. 3 cubes of sizes 150 x 150 x 150 mm were cast along with each test specimen for evaluating the 28day compressive strength of concrete. Figure describes the above mentioned casting and curing operations.

iii. *Preparation of the Retrofitted Specimens*

The failed specimens BCJ 1, BCJ 2, and BCJ 3, were retrofitted and new specimens BCJR1, BCJR2 and BCJR3. The concrete near the area of failure was removed completely. After applying cement paste in this area, the portion was filled and compacted with the same grade of concrete. The specimens were cured for 28 days. Before wrapping the Basalt fiber sheet the faces of the specimens were ground mechanically to remove any laitance. All the voids were filled with putty. Then a two component primer system was applied on the concrete surface and allowed to cure for 24 hours. A two component epoxy coating was then applied on the primer coated surface and the Basalt fiber sheet was immediately wrapped over the entire surface of the reinforced concrete beam-column joint.

A roller was then applied gently over the wrap so that good adhesion was achieved between the concrete surface and the Basalt fiber wrap, as suggested by the manufacturers and allowed to cure for seven days. Another coat of the two component epoxy was applied over the fiber sheet. Then the second wrap was applied by following the same procedure and allowed to cure for a further period of seven days. Both the wrapped layers were orthogonal to each other.

iv. *Description of the Test Program*

The RC beam-column joint specimens were tested using loading frame in the structural laboratory of Karunya University. A push-pull jack was set up in the structural laboratory. Both the column ends were provided with hinged boundary conditions. At one of the column ends the axial load was applied by using hydraulic jack of 500 kN capacity which has a load measuring arrangement fitted to it.

A transverse load was applied at the free end of the beam by using a push pull jack. A deflectometer was placed on the other side of the beam which shows the deflection that occurs at the point of application of load on the beam. The testing involves pushing of the beam using the push pull jack by applying the load in the pushing direction up to control deflection of 75mm.

Then the pulling load was applied until the beam comes back to its original position. So, one cycle of load reversal was applied to the test specimens. i.e. the beam was pushed from the normal position, then pulled to the normal position, then it was pulled back from the normal position and again pushed back towards the normal position.

The deflectometer readings were noted down at particular load intervals and the deflection of the beam was determined. Typical view of test setup is shown in figure.

II. Discusson of Test Results

a) *Results of the Experimental Investigation on Controlled Specimens*

BCJ 1 : This specimen has been designed and detailed as per code IS 456:2000. An axial load of 15 % of the safe load on column was applied. The value of the axial load applied was 90KN. The lateral load applied on the beam was at an interval of 5KN. First crack appeared on the tension side of the beam at a load of 19KN. Further three to four cracks developed on the tension side were observed. At a load of 23.5KN first crack developed on the compression side of the beam and further cracks were widen on both compression and tension side of beam. At a load of 38.1KN crack on the tension side started propagating into the column. Spalling of concrete was also started on the compression side of the beam. The application of load was stopped when the controlled deflection of 70.5mm. the load corresponding to that deflection was 47.8KN.

While pulling more cracks occurred at compression side of beam and it propagated into column. Cracks widened and spalling of concrete also observed.

BCJ 2 : This specimen has been designed and detailed as per code IS 456:2000. An axial load of 30 % of the safe load on column was applied. The value of the axial load applied was 180 kN. The lateral load applied on the beam was at an interval of 5KN. First crack appeared on the tension side of the beam at a load of 20.9KN. Further three to four cracks developed on the tension side were observed. At a load 25.9KN first crack developed on the compression side of the beam and further cracks were widen on both compression and tension side of beam. At a load of 41.7KN crack on the tension side started propagating into the column. Spalling of concrete were also started on the compression side of the beam. The application of load was stopped when the controlled deflection of 70.5mm. the load corresponding to that deflection was 52.6KN. While pulling more cracks occurred at compression side of beam and it propagated into column. Cracks widened and spalling of concrete also observed.

BCJ 3 : This specimen has been designed and detailed as per code IS 456:2000. An axial load of 45% of the safe load on column was applied. The value of the axial load applied was 270KN. The lateral load applied on the beam was at an interval of 5KN. First crack appeared on the tension side of the beam at a load of 17.6KN. Further three to four cracks developed on the tension side were observed. At a load of 21.7KN first crack developed on the compression side of the beam and further cracks were widen on both compression and tension side of beam. At a load of 35.2KN crack on the tension side started propagating into the column. Spalling of concrete were also started on the compression side of the beam. The application of load was stopped when the controlled deflection of 70.50 mm. the load corresponding to that deflection was 44.6KN While pulling more cracks occurred at compression side of beam and it propagated into column. Cracks widened and spalling of concrete also observed.

BCJ 4 : This specimen has been designed and detailed as per code IS 13920:1993. An axial load of 15% of the safe load on column was applied. The value of the axial load applied was 90 kN. The lateral load applied on the beam was at an interval of 5KN. First crack appeared on the tension side of the beam at a load of 21.9KN. Further three to four cracks developed on the tension side were observed. At a load of 27KN first crack developed on the compression side of the beam and further cracks were widen on both compression and tension side of beam. At a load of 43.6KN crack on the tension side started propagating into the column. Spalling of concrete were also started on the compression side of the beam. The application of load was stopped when the controlled deflection of 70.5mm. the load corresponding to that deflection was 55KN. While pulling more cracks occurred at compression side of beam and it propagated into column. Cracks widened and spalling of concrete also observed.

BCJ 5 : This specimen has been designed and detailed as per code IS 13920:1993. An axial load of 30% of the safe load on column was applied. The value of the axial load applied was 180KN. The lateral load applied on the beam was at an interval of 5KN. First crack appeared on the tension side of the beam at a load of 24KN. Further three to four cracks developed on the tension side were observed. At a load of 29.8KN first crack developed on the compression side of the beam and further cracks were widen on both compression and tension side of beam. At a load of 48.2KN crack on the tension side started propagating into the column. Spalling of concrete were also started on the compression side of the beam. The application of load was stopped when the controlled deflection of 70.5mm the load corresponding to that deflection was 61KN. While pulling more cracks occurred at compression side of beam and it propagated into column. Cracks widened and spalling of concrete also observed.

BCJ 6 : This specimen has been designed and detailed as per code IS 13920:1993. An axial load of 45% of the safe load on column was applied. The value of the axial load applied was 270KN. The lateral load applied on the beam was at an interval of 5KN. First crack appeared on the tension side of the beam at a load of 20.2KN. Further three to four cracks developed on the tension side were observed. At a load of 25KN first crack developed on the compression side of the beam and further cracks were widen on both compression and tension side of beam. At a load of 40.5KN crack on the tension side started propagating into the column. Spalling of concrete were also started on the compression side of the beam. The application of load was stopped when the controlled deflection of 70.5mm. the load corresponding to that deflection was 51.3KN. While pulling more cracks occurred at compression side of beam and it propagated into column. Cracks widened and spalling of concrete also observed.

b) Results of the Experimental Investigation on Retrofitted Specimens

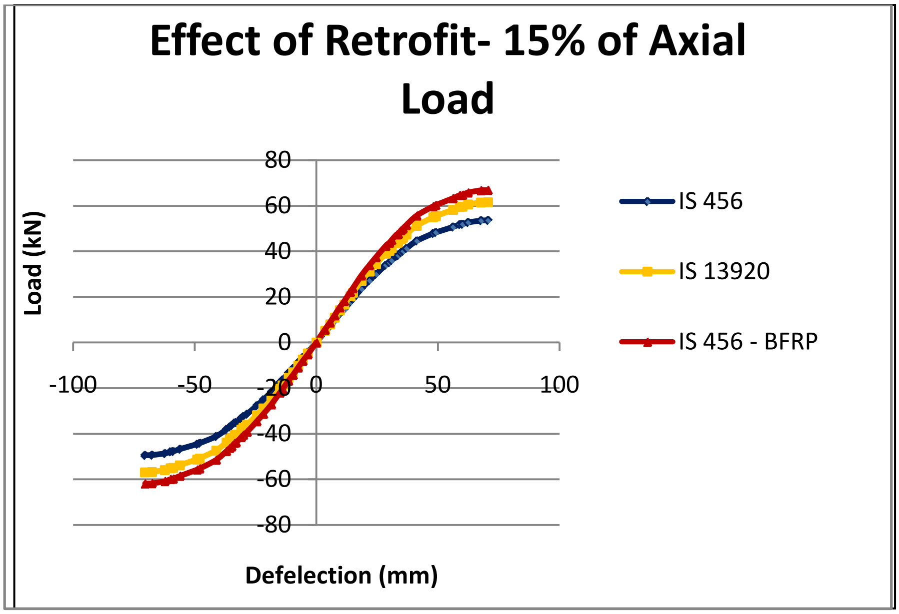
BCJ R1 : This specimen has been retrofitted with Basalt FRP sheets. An axial load of 15% of the safe load on column was applied. The value of the axial load applied was 90KN. The lateral load applied on the beam was at an interval of 5KN. First crack appeared on the tension side of the beam at a load of 23.8KN. Further three to four cracks developed on the tension side were observed. At a load of 29.4KN first crack developed on the compression side of the beam and further cracks were widen on both compression and tension side of

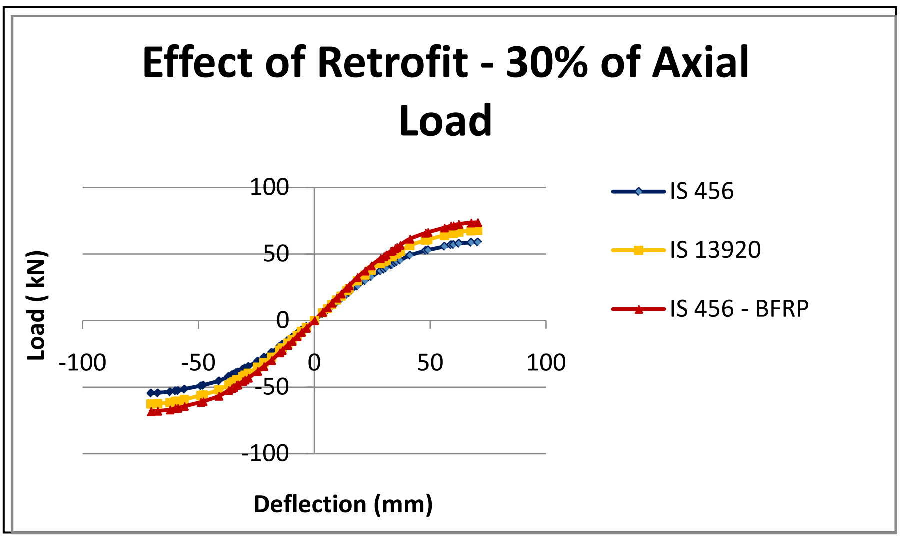
Global Journal of Researches in Engineering (E) Volume XIII Issue V Version I Year 2013

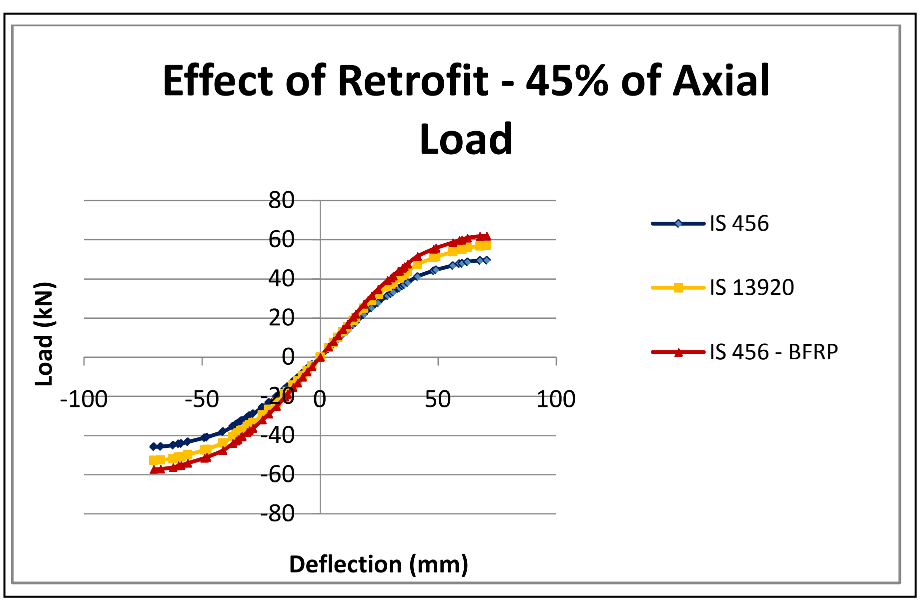
beam. At a load of 47.6KN crack on the tension side started propagating into the column. Spalling of concrete were also started on the compression side of the beam. The application of load was stopped when the controlled deflection of 70.5mm. the load corresponding to that deflection was 59.8KN. While pulling more cracks occurred at compression side of beam and it propagated into column. Cracks widened and spalling of concrete also observed.

BCJ R2 : This specimen has been retrofitted with Basalt FRP sheets. An axial load of 30% of the safe load on column was applied. The value of the axial load applied was 180KN. The lateral load applied on the beam was at an interval of 5KN. First crack appeared on the tension side of the beam at a load of 26.1KN. Further three to four cracks developed on the tension side were observed. At a load of 32.4KN first crack developed on the compression side of the beam and further cracks were widen on both compression and tension side of beam. At a load of 52.4KN crack on the tension side started propagating into the column. Spalling of concrete were also started on the compression side of the beam. The application of load was stopped when the controlled deflection of 70.5mm. the load corresponding to that deflection was 66.3KN. While pulling more cracks occurred at compression side of beam and it propagated into column. Cracks widened and spalling of concrete also observed.

BCJ R3 : This specimen has been retrofitted with Basalt sheets. An axial load of 45% of the safe load on column was applied. The value of the axial load applied was 270KN. The lateral load applied on the beam was at an interval of 5KN. First crack appeared on the tension side of the beam at a load of 22KN. Further three to four cracks developed on the tension side were observed. At a load of 27.1KN first crack developed on the compression side of the beam and further cracks were widen on both compression and tension side of beam. At a load of 44KN crack on the tension side started propagating into the column. Spalling of concrete were also started on the compression side of the beam. The application of load was stopped when the controlled deflection of 70.5mm. the load corresponding to that deflection was 55.3KN. While pulling more cracks occurred at compression side of beam and it propagated into column. Cracks widened and spalling of concrete also observed.







Axial Load on Column (Controlled and Retrofitted Specimens)

III. Finite element Analysis using Ansys

a) Solid 65 (3D Reinforced Concrete Solid) and 45 (3D Structural Solid)

SOLID 65 elements were used to model reinforced concrete problems or reinforced composite materials (FRP). This element has eight nodes each node having three translational degrees of freedom in the nodal X, Y & Z directions as shown in Figure 5.5. The Solid 65 may be used to analyse cracking in tension and crushing in compression and solid 45 element has stress stiffening, large deflection, placticity, large strain capabilities, creep etc. The element may be used to analyse cracking in tension and crushing in compressionUp to three rebar specifications may be defined. The typical solid 65 element was shown in fig.

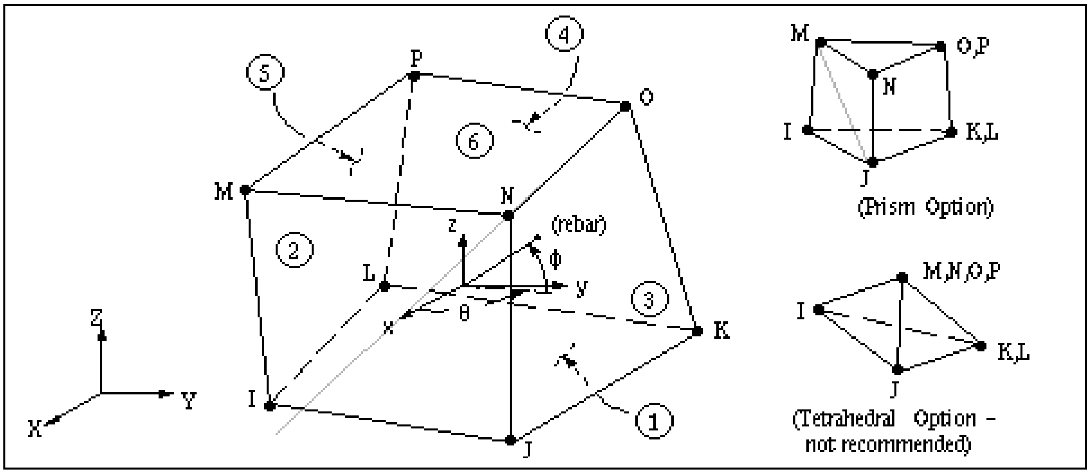
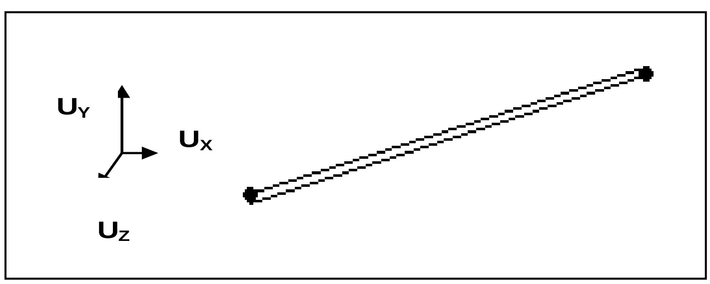


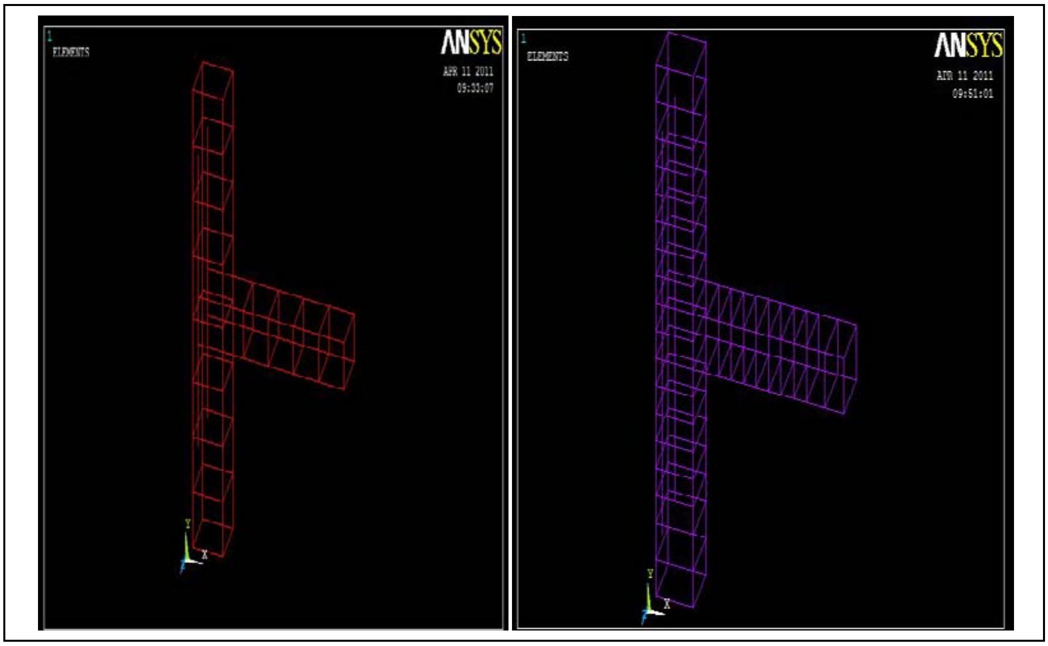
Figure : Solad 65 Element

Link 8

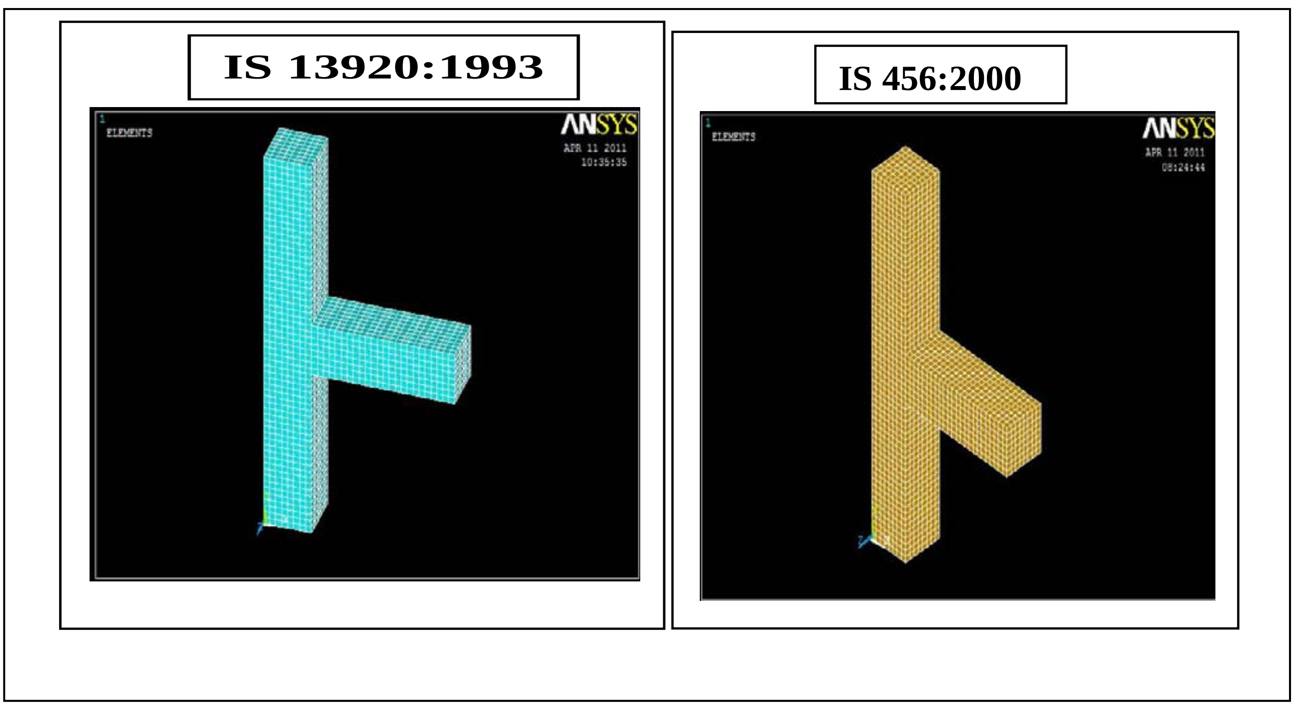
Link 8 Is A Spar Element, Which May Be Used In Variety Of Engineering Applications. Depending Upon The Applications, The Element May Be Thought As A Truss Element, Cable Element, Reinforcing Bar And Bolt. The Three-Dimensional Spar Element Is Having Two Nodes And Each Node Having Three Translational Degrees Of Freedom. This Element Is Capable Of Plasticity, Creep, Swelling And Stress Stiffening Effects.



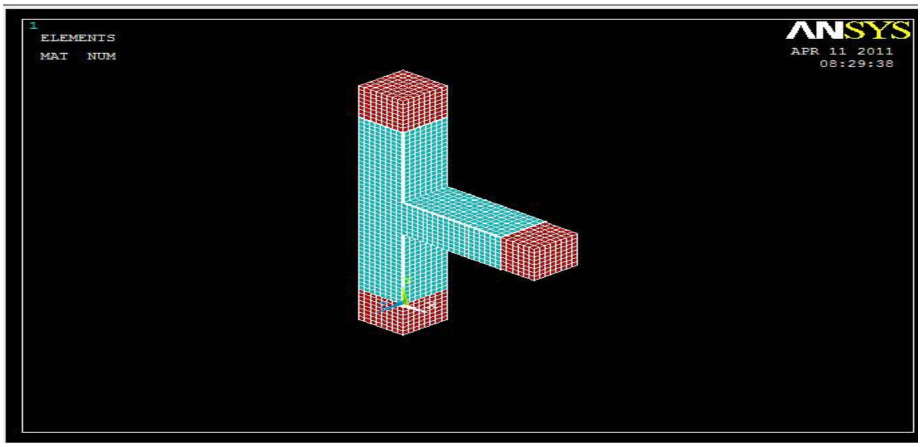
LINK 8 Elements



Reinforcing Detailing on Beam-Column Joints



Fully Modelled Beam-Column Joints

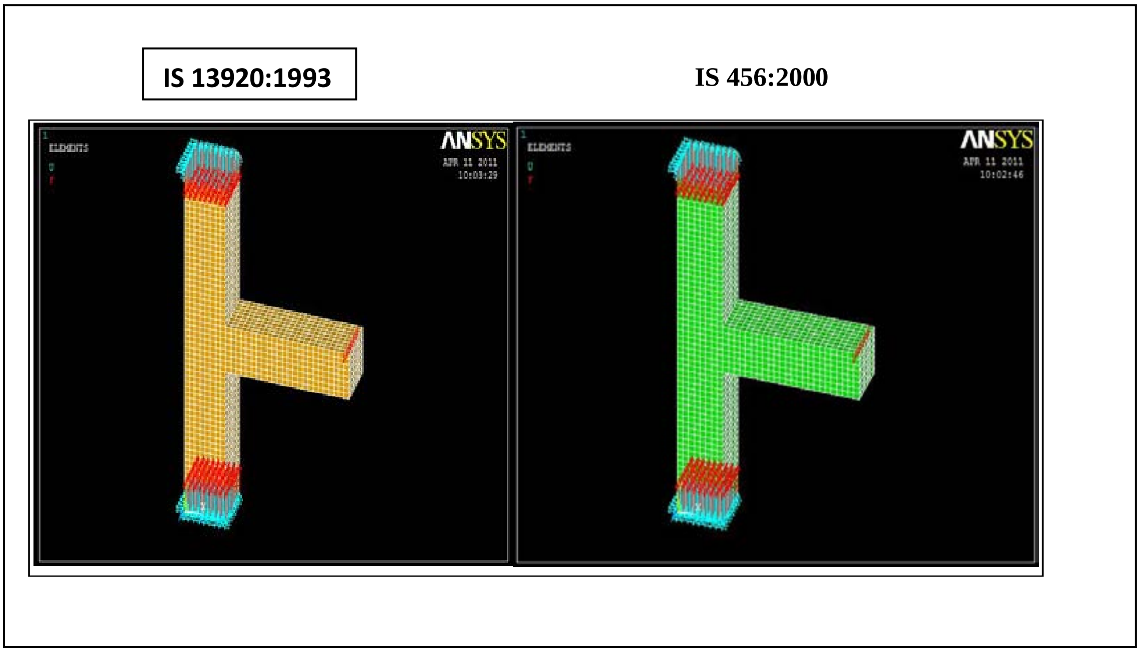


b) Application of Loads and Boundary Condition

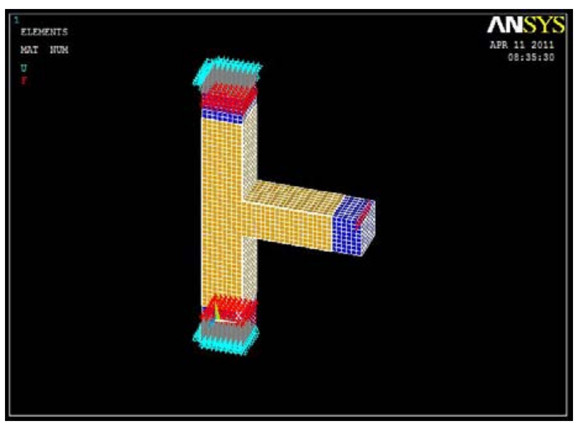
Displacement boundary conditions are needed to constrain the model to get a unique solution. To ensure that the model acts the same way as the experimental beam, boundary conditions need to be applied at points of symmetry, and where the supports and loadings exist. Both ends of the column were provided hinged boundary condition. A lateral load was applied at the free end of the beam. The load applied in model which had detail as per code IS 456:2000 was 23 kN. Similarly in model which had details as per code 13920:1993 ,the load applied was 26 kN. The comparative result were given in table.

AXIAL LOAD	**DETAILED AS PER CODE IS 456:2000**			**DETAILED AS PER CODE IS 13920:1993**			**IS 456:2000(Retrofitted Specimen)**		
	LOAD IN kN	DEFLECTION BY EXPERIMENTAL INVESTIVESTIGATION IN mm	DEFLECTION BY ANSYS RESULT IN mm	LOAD IN kN	DEFLECTION BY EXPERIMENTAL INVESTIVESTIGATION IN mm	DEFLECTION BY ANSYS RESULT IN mm	LOAD IN kN	DEFLECTION BY EXPERIMENTAL INVESTIVESTIGATION IN mm	DEFLECTION BY ANSYS RESULT IN mm
15%	53.5	70.5	52.27	61.5	70.5	59.87	66.9	70.5	51.5
30%	58.9	70.5	52.27	67.7	70.5	56.6	73.6	70.5	48.9
45%	49.5	70.5	56.9	43.8	70.5	47.6	61.9	70.5	49.47

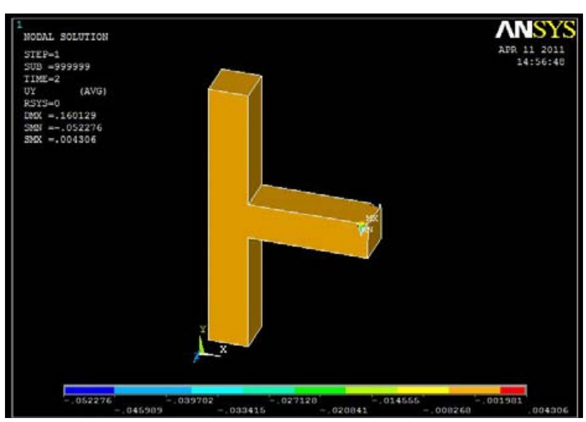
Comparison of Results Between Ansys and Experimental Result



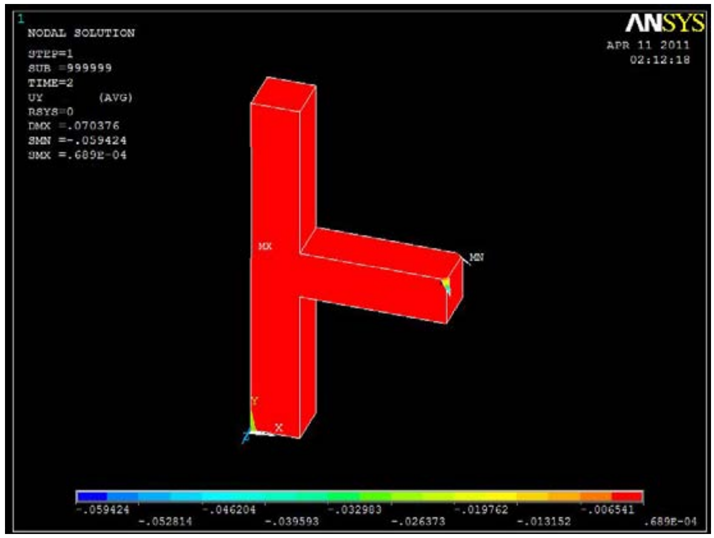
Loading arrangements and boundary condition of Beam-Column Joints



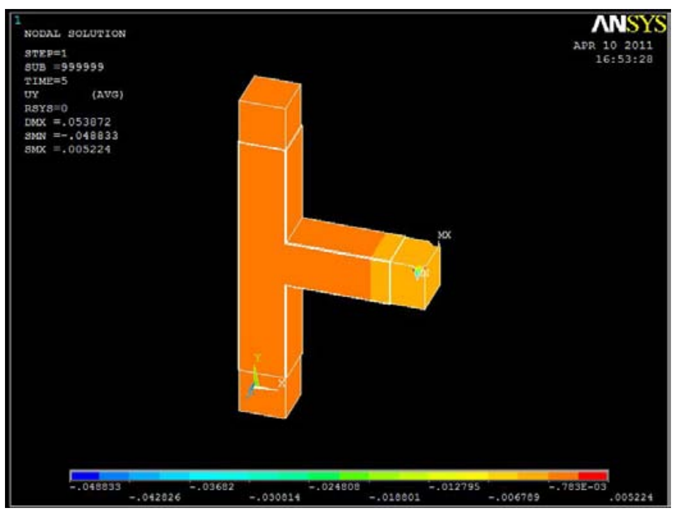
Loading arrangement and boundary condition of Beam-Column Joints retrofitted specimen



Displacement Solution For Beam-Column Joints As Per Code Is 456: 2000 For The Load of 49.5 kN



Displacement Solution For Beam-Column Joints As Per Code IS 13920: 1993 For The Load of 61.5 kN



Displacement Solution For Beam-Column Joints As Per Code IS 456 Retrofitted Specimen 66.9 kN

IV. Conclusions

- In the case of specimens having reinforcement details as per code IS 456:2000, there is an increase of 14.4% in load carrying capacity and 18.87% in energy absorption capacity, when the axial load on column was increased from 15% to 30%.
- In the case of specimens having reinforcement details as per code IS 456:2000, there is an increase of 12.90% in load carrying capacity and 16.61% in energy absorption capacity, when the axial load on column was increased from 15% to 45%.
- In the case of specimens having reinforcement details as per code IS 13920:1993, there is an increase of 16.71% in load carrying capacity and 21.06% in energy absorption capacity, when the axial load on column was increased from 15% to 30%.
- In the case of specimens having reinforcement details as per code IS 13920:1993, there is an increase of 12.25% in load carrying capacity and 14.10% in energy absorption capacity, when the axial load on column was increased from 15% to 45%.
- In the case of specimens retrofitted by Basalt FRP wrapping, there is an increase of 31.89% in load carrying capacity and 33.07% in energy absorption capacity, when the axial load on column was increased from 15% to 30%.

- In the case of specimens retrofitted by Basalt FRP wrapping, there is an increase of 14.58% in load carrying capacity and 16.31% in energy absorption capacity, when the axial load was increased by 15% to 45%.
- In the case of specimens having reinforcement details as per code IS 13920:1993 with 15% of axial loading on the column, there was an increase of 18.5% in load carrying capacity and 19.5% increase in energy absorption capacity than the specimens with reinforcement details as per code IS 456:2000 with same axial load on column.
- In the case of specimens having reinforcement details as per code IS 13920:1993 with 30% of axial loading on the column, there was an increase of 17.4% in load carrying capacity and 18.4% increase in energy absorption capacity than the specimens with reinforcement details as per code IS 456:2000 with same axial load on column..
- In the case of specimens having reinforcement details as per code IS 13920:1993 with 45% of axial loading on the column, there was an increase of 16.3% in load carrying capacity and 17.3% increase in energy absorption capacity than the specimens with reinforcement details as per code IS 456:2000 with same axial load on column.
- In the case of specimens having reinforcement detailing as per code IS 456:2000 with 15% of axial load on column, retrofitted with–Basalt FRP wrapping, there was an increase of 32.6% in load carrying capacity and 29.5% increase in energy absorption capacity than the specimens with reinforcement detailing as per code IS 456:2000 with same axial loading on column.
- In the case of specimens having reinforcement detailing as per code IS 456:2000 with 30% of axial load on column, retrofitted with Basalt FRP wrapping, there was an increase of 35.3% in load carrying capacity and 31.5% increase in energy absorption capacity than the specimens with reinforcement detailing as per code IS 456:2000 with same axial loading on column.
- In the case of specimens having reinforcement detailing as per code IS 456:2000 with 45% of axial load on column, retrofitted with Basalt FRP wrapping, there was an increase of 33.91% in load carrying capacity and 34.84% increase in energy absorption capacity than the specimens with reinforcement detailing as per code IS 456:2000 with same axial loading on column.
- Experimental test result of IS 456-2000 specimen when compared with ANSYS result was found to be less with error of 34.87%.
- Experimental test result of IS13920-1993 specimen when compared with ANSYS result was found to be with less of 34.87%.
- Experimental test result of IS 456-2000 retrofitted specimen when compared with ANSYS result was found to be less with error of 36.89%.

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