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A REVIEW PAPER ON STRENGTHENING OF BEAM COLUMN JOINT UPGRADED WITH CFRP SHEETS

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***ABSTRACT**: Shear failure of beam-column joints is identified as the principal cause of collapse of many moment-resisting frame buildings during recent earthquakes. In this review paper, the efficiency and effectiveness of carbon fiber-reinforced polymer (CFRP) sheets which increasing the shear strength and ductility of seismically deficient beam-column joints have been studied. For this purpose, four as-built specimens corner/knee joints were constructed. Out of these four as-built specimens, two specimens were used as control specimens and the other two were strengthened with CFRP sheets under two different strengthened specimens arrangement. The first arrangement scheme consisted of CFRP sheets epoxy bonded to the joint region in beams, and part to the column regions. In the second arrangement, sheets were epoxy bonded to joint region only with prevention against any possible debonding through mechanical anchorages system. Comparisons of result were done through hysteretic loops, load-displacement envelopes, ductility, and stiffness degradation. The comparisons result shows that CFRP sheets are very effective in improving shear resistance and deformation capacity of the corner beam-column joints and delaying their stiffness degradation.*

***Keywords:** Beam Column Joint, Behavior of Joints during Earthquake, CFRP Material, Strengthening Technique.*

I. INTRODUCTION

1.1 Beam Column joint

In RCC buildings the portion of column that are common to the beam at their intersection are called beam-column joints. The constituent materials of joints have limited force carrying capacity and limited strength. When the forces that applied during earthquake are larger than the resisting capacity of joints, joints are severely damaged. Beam-Column joints are the weakest link in RC moment resisting frame. The prime reason behind it failure is the inadequate shear strength of the joints, and this is occurred due to the insufficient and inadequate detailed reinforcement in the joint region. Damage must be avoided by using different techniques during construction stages because repairing of damaged joints is very difficult after it appears. Generally in earthquake resisting frame the column should be stronger then beam.

1.2 Types of beam-column joint

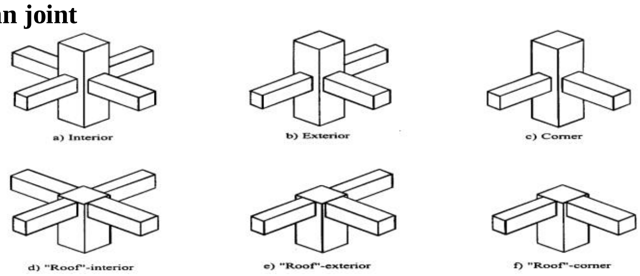


Fig.1 Different Schemes to Strengthen the Beam Column Joint

1.3 Literature Review

Excellent research work is reported on the effect of seismic loads on poorly detailed RC beam-column joints in the past. Also number of substantial works has been reported on experimental studies of composite upgraded joints.

Al-Salloum and Almusallam 2007 and Alsayed et al. 2010 proposed effective rehabilitation schemes by using advanced composite materials for RC beam-column joints. Pampanin et al. 2007 conducted experiments and made analytical investigations on CFRP retrofitted existing beam-column joint. These experimental results provided very satisfactory confirmation of the viability and reliability of the adopted retrofit solution and of the proposed analytical procedure to predict the actual sequence of events.

Ghobarah and El- Amoury 2005 proposed rehabilitation systems to enhance the resistance to bond slip of the bottom steel bars anchored in the joint zone and to upgrade the shear resistance of beam column joints. Antonopoulos and Triantafillou 2002, Gergely et al. 2000, and Almusallam and Al-Salloum 2007 presented analytical models for the prediction of shear capacity of the FRP strengthened beam-column joints. The above review of literature illustrates that despite a substantial work on FRP-upgraded interior and exterior joints, investigations related to FRP-strengthened and/or repaired corner or knee joints are very limited. Also, the behavior of seismically excited FRP repaired/strengthened corner beam-column joints is not well established at various stages of response, e.g., before and after yielding of reinforcements, crushing of concrete, fiber fracture, or debonding.

S. H. Alsayed, Y. A. Al-Salloum, T. H. Almusallam, and N.A. Siddiqui, in 2010, epoxy-bonded CFRP sheets have been used with different scheme such as control, strengthened, repaired specimens at the joints for the upgrading the shear strength and ductility of exterior beam-column joints. The author compared the results of different scheme through hysteretic loops, load-displacement envelopes, joint shear distortion, ductility, and stiffness degradation and found that CFRP sheets are very effective in improving shear resistance and deformation capacity of the exterior beam-column joints and delaying their stiffness degradation.

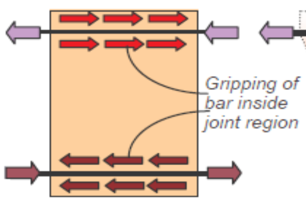
S. H. Alsayed, Y. A. Al-Salloum, T. H. Almusallam, and N.A. Siddiqui, in 2010**,** epoxy-bonded CFRP sheets have been used with different scheme for the upgrading the shear strength and ductility of Knee or corner reinforced concrete beam-column joints. In this paper the thickness and length of CFRP sheets have been increased, and the results of CFRP repaired and strengthened specimens were compared with their corresponding control specimens through hysteretic loops, load-displacement envelopes, joint shear distortion, ductility, and stiffness degradation and it was observed that CFRP sheets improve the shear resistance, ductility, and deformation capacity of the seismically deficient RC corner joints to a great extent.

Suhasini M Kulkarni, Yogesh D Patil, discussed that, the most important factors affecting the shear capacity of exterior RC beam-column joints are the concrete compressive strength, joint aspect ratio of the joints and number of lateral ties inside the joint. Advanced Reinforcement Pattern (ARP crossed inclined bars) is a feasible solution for increasing the shear capacity of the cyclically loaded exterior beam-column joints.

II. BEHAVIOR OF JOINTS DURING EARTHQUAKE

2.1 Pull and Push Forces

During earthquake shaking, the beams adjoining a joint are subjected to moments in the same direction either in clockwise or anti-clockwise. Under these moments, the top bars in the beam-column joints are pulled in one direction and the bottom one in the opposite direction. These forces are balanced by bond stress developed between concrete and steel in the joint region. If the column is not wide enough or if the strength of the concrete in the joint is low, there is insufficient grip of concrete on the steel bars. In such condition the bar slips inside the joint region and beam lose their capacity to carry load. Under these pull and push forces at top and bottom ends joints undergo geometric distortion, one diagonal length of the joint elongate and the other compresses and if the column cross-sectional size is insufficient, the concrete in the joint develops diagonal cracks. These pull-push forces on joint cause two problems i.e. Loss of grip on beam bars in joint region and distortion of joints causing diagonal cracks and crushing of concrete.



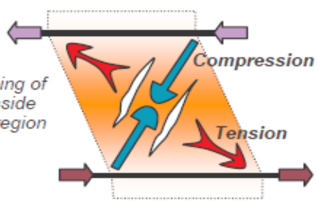


Fig 2. Pull and Push Forces Fig 3. Diagonal Forces

2.2 Joint Mechanism

In the figure 4 and 5, the loading in beam column joint during an earthquake and Internal load distribution in a joint are shown.

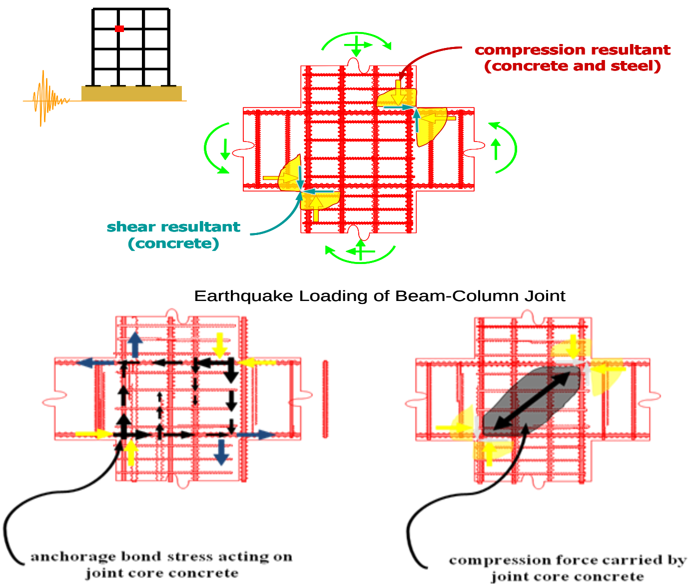


Fig.5 Internal load distribution in a joint

III. CFRP MATERIAL

3.1 Carbon-fiber-reinforced polymer

Carbon-fiber-reinforced polymer or carbon-fiber-reinforced plastic is a very strong and light fiber-reinforced polymer which contains carbon fibers. Carbon fibres are created when polyacrylonitrile fibres (PAN), Pitch resins, or Rayon are carbonized (through oxidation and thermal pyrolysis) at high temperatures. It is expensive but commonly used wherever high strength and rigidity is required.

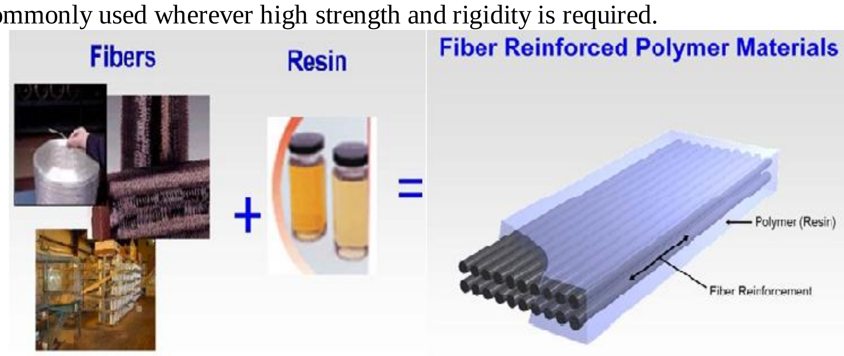


Fig.6 Carbon fiber reinforced polymer materials

3.2 Properties of CFRP material

Table: 1

Fiber material	High strength carbon
Areal Weight	600 gm/m^2
Fabric width	610 mm
Nominal thickness	0.33 mm/ply
Ultimate Tensile Strength	3800 MPa
Tensile Modulus	227 GPa
Ultimate tensile strength per unit weight	1.25 KN/mm/ply
Tensile Modulus per unit width	76 KN/mm/ply
Ultimate Rupture strain	1.25 %

3.3 Advantages

- Low weight: The CFRP is much less dense and therefore lighter than the equivalent volume of steel. The properties of CFRP material are particularly important when installation is done in cramped locations. The use of fiber composites does not increase the weight of the structure and dimensions of the member.
- Mechanical strength: CFRP can provide a maximum material stiffness to density ratio of 3.5to 5 times that of aluminum or steel. CFRP is so strong and stiff for its weight, it can out-perform the other materials.
- Formability: The material can take up irregularities in the shape of the concrete surface. It can be molded to almost any desired shape.
- Chemical resistance: CFRP is less reactive, making it ideal as a protective covering for surfaces where chemical.
- Joints: Laps and joints are not required.
- Corrosion resistance: Unlike metal, CFRP does not rust away and it can be used to make long-lasting structures.
- Low maintenance: Once CFRP is installed, it requires less maintenance. The materials fibers and resins are durable if correctly specified, and require little maintenance. If they are damaged under loading, it is relatively simple to repair them, by adding an additional layer.
- Long life: It has high resistance to fatigue and has shown excellent durability over the last 50 years.
- Easy to apply: The implimentation of CFRP plate or sheet material is very easy like applying wallpaper; once it has been rolled on carefully to remove entrapped air and excess adhesive it may be left unsupported. Fiber composite materials are available in very long lengths while steel plate is generally limited to 6 m. These various factors in combination lead to a significantly simpler and quicker strengthening process than when using steel plate.

3.4 Application

- Aerospace Engineering: - It is used in wings and fuselage component of airplane. The A380 is the first commercial airline to have a central wing box made of CFRP. It has high strength to weight ratio used in micro air vehicles.
- Automotive Engineering: - It is used in high end automobile racing vehicles in body panel due to increase strength and decrease weight.
- Civil Engineering: - It is used in building to strengthening the joint and to increase stiffness and ductility of structure. It increases stiffness up to 10% and the ultimate tensile strength 3000 MPa more than 10 times mild steel.
- Carbon Fiber microelectrodes: - It is used as single carbon fiber with dia 5-7 µm is sealed in a glass capillary and also used in amperometry or fast scan cyclic voltammeter for detection of biochemical signaling.
- Sports goods: - It is used in tennis, badminton racquets sport kite spare, high quality arrow shafts, hockey stick, fishing rod. In 2006 cricket bats with thin carbon fiber layer on the back were introduced and used in competitive match including Ricky ponting and Michal Hussey but it banned from all 1st class matches by ICC in 2007.
- Other: - It also used in laptop cases, audio components, musical instruments etc.

3.5 Limitation

- It is very expensive which limits its use in some fields.
- In case of pre-stressing construction it cannot be used due to difficulties in anchorage of strands.
- It has no endurance limit when exposed to cyclic loading.
- In case of automotive application, its use is limited for creating body panel.

IV. EXPERIMENTAL SETUP AND PROCEDURE

4.1 Experimental Setup:

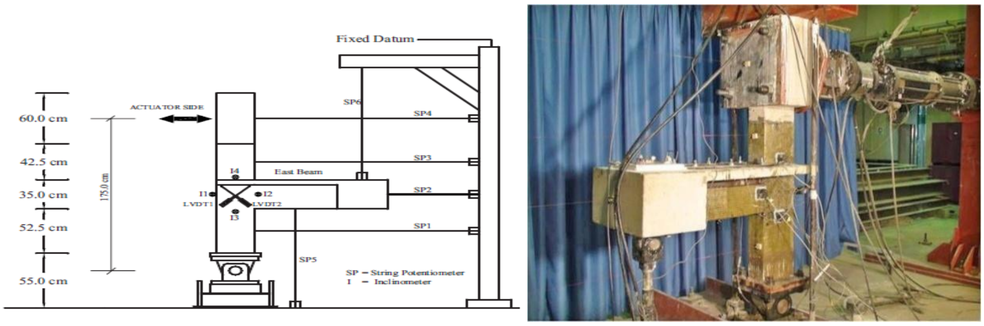


Fig. 7 Schematic diagram of experimental setup

4.2 Strengthening Technique

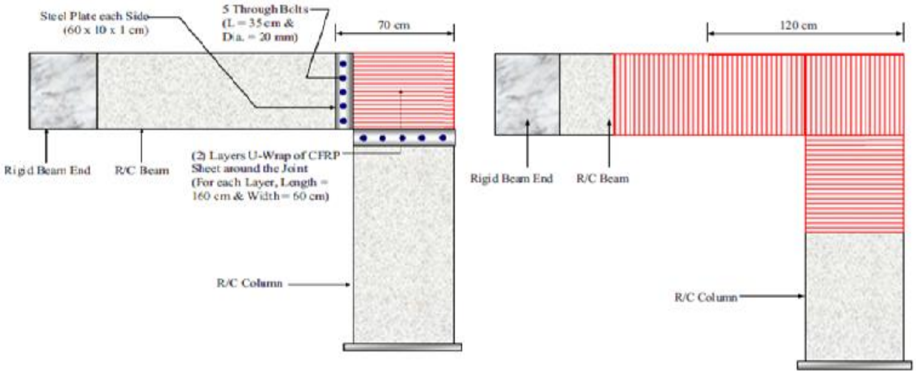


Fig. 8 placement of CFRP material with different schemes

4.3 Experimental Procedure

Four specimens was prepared for testing out of these one specimen was tested as a control specimen and the other three were rested after strengthening with TRM, CFRP, and glass FRP sheets. The specimens are placed as shown in Schematic diagram with the different application of load and results is obtained by using different displacement measuring devices such as string potentiometer used to measure vertical and horizontal displacement and inclinometer used to measure the joint rotation as shown in fig. 7.

The FE result were compared with the test result through load-displacement behavior, ultimate load, and crack pattern and it was observed that the nonlinear FE model can satisfactorily predict the behavior and response of the as built control and CFRP strengthening exterior RC beam column joint. It observed that the ultimate load carrying capacity of the CFRP strengthening specimen is maximum.

V. COMPARISON OF RESULTS

5.1 Load-displacement curve

From the control and strengthen specimens curve, it is clear that the strengthen specimen resist heigher loading and higher stiffness as compare to control specimen.

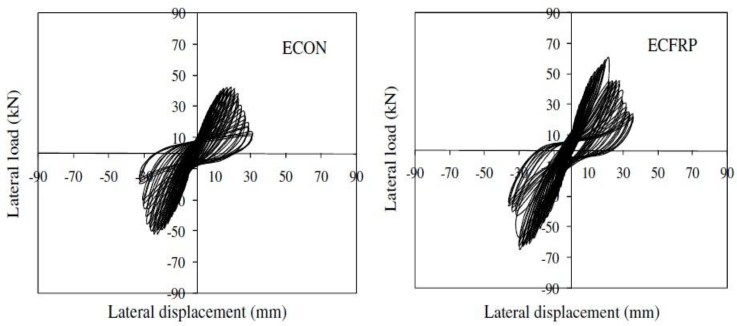


Fig 9 Load-Displacement Curve For Control and strengthen specimens

5.2 Load displacement response for control and CFRP Specimen

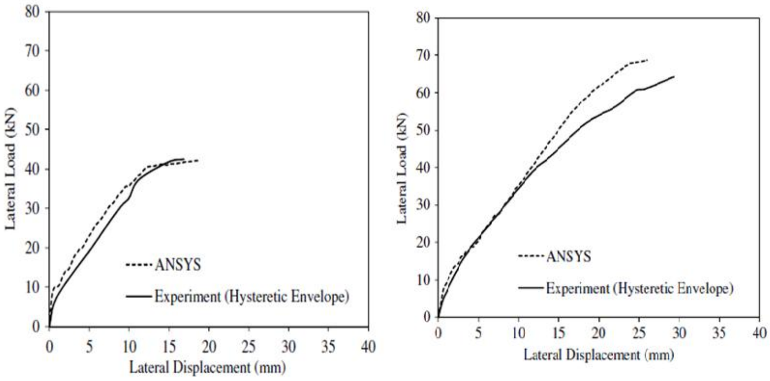


Fig 10 Load displacement response for control and CFRP Specimen

VI. CONCLUSION

From all these paper when compared the results of different scheme through hysteretic loops, load-displacement envelopes, joint shear distortion, ductility, and stiffness degradation it is found that CFRP sheets are very effective in improving shear resistance and deformation capacity of the exterior and interior beam-column joints and delaying their stiffness degradation during earthquake. For strengthening the beam column joint small thickness of CFRP sheet cause of mechanical debonding, so it can be reduced by improving the thickness of CFRP sheet or implementation of additional layer of CFRP sheets . The control specimen experienced diagonal shear failure at the top column that contributed to the soft-storey mechanism phenomenon when tested under lateral cyclic loading at 1% drift.

VII. FUTURE SCOPE

There is a wide scope for research and to learn more about the beam column joint. In all research papers the author has not used steel plates at the joint for the strengthening of beam column joint. So, using steel plates with different scheme at the joint we can also improve the shear resistance and deformation capacity of the exterior and interior beam-column joints and delaying their stiffness degradation. The numerical investigation can be done by using ANSYS and Reinforcement arrangement as per recommendation of IS-13920 and SP-34 can be implemented for the joint.

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