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A REVIEW ON STRENGTHENING OF BEAM-COLUMN JOINT WITH FRP SHEETS

Jay R. Bhimani[1], Dr. Tarak P. Vora[2]

[1]*Marwadi Education Foundation, Civil Engineering,*
[2] *Marwadi Education Foundation, Civil Engineering,*

Abstract— Many reinforced concrete structures in our country are in a deteriorated or distressed state. Beam–column joint is the very important zone in a reinforced concrete moment resisting frame. Failure of beam-column joints is main reason of collapse of many moment-resisting frames. Hence strengthening such structures or increasing the load limit on structural component is becoming necessary to extend their service life. Covering research has been carried out in recent years on the use of fibre-reinforced polymer (FRP) composites in the strengthening of reinforced concrete (RC) structures. Different applications of fibre reinforced polymer composites (FRPCs) for external strengthening in civil construction are reviewed in this paper. Experimental as well as analytical and mathematical research contributions have been focussed in the review. The main structural component such as beam-column joints, have been reviewed and structural behaviour of component is discussed briefly. The efficiency and effectiveness of carbon fibre-reinforced polymer (CFRP) sheets which increasing the shear strength and ductility of deficient beam-column joints have been studied. This paper provides a concise review of existing research on the behaviour and strength of FRP strengthened RC structures elements, with a strong focus on those studies which effected directly to the development of strength models. Finally, all concluding remarks are given along with possible future scope of research.
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Keywords— moment resisting frame, Beam-column joint, strengthening, frp, CFRP-sheets,FEM ANSYS 16

I. INTRODUCTION

Concrete is one of the commonly used building materials all over the world in various structures like bridge, chimney, flyover, residential building, marine structural industrial building etc. [6, 7, 14]. The first concrete structure appeared, it is well known that concrete is a building material with high compressive strength and low in tension strength [6]. The failure of the concrete structure may occur suddenly in most cases and in a brittle manner [6]. The deterioration of these structures is mainly due to ageing, poor maintenance, corrosion, aggressive, environmental, conditions, poor initial design or construction errors and accidental situations like earthquakes [9,13,18,20,21,25]. As structural engineer mainly we focused on structural components in RC buildings. Structural components like slab, beams, column, and foundation. We know that load was transfer with slab to beams, beams to column, column to foundation. In RC buildings, when load is transfer through beam to column, due to load transfer the beam–column joint is act as very important zone in a reinforced concrete moment resisting frame [28, 29]. The life of such structures depend up on the continue performance of building which is performed by conducting structural health monitoring techniques [9].The absence of transverse reinforcement in the joint, insufficient development length for the beam reinforcement and the inadequately spliced reinforcement for the column just above the joint can be considered as the most important causes for the failure of the beam–column joint under any unexpected transverse loading on the building [29]. Beam–column joints are subjected to large forces during severe ground shaking and its behaviour has a significant influence on the response of the structure [24, 26, 28].The RCC beam-column joints may require upgradation due to deficient detailing of reinforcing bars, insufficient column sections or due to increased loading on the structure [25,27].As replacing the damaged structure with new structure will lead to the heavy investment of money and time which does not prove to be a good option [1, 7,13,22]. Many construction Methodologies that are being practised are of importance now but they were ignored previously, resulting in distress and hence require strengthening [14]. In such cases strengthening the damaged structure with various techniques become best option in terms of saving the time and money [7, 13,18,21,28]. It has been a challenging task to repair, maintain, and enhance the capacity of existing civil structures [11,27].now a days FRP is being widely used all over the world but still lots of research is required to be carried out regarding optimized and economic way of strengthening the damaged structure[7,12,15,24,25]. The use of fibre reinforced polymer (FRP) composites for the rehabilitation of concrete structures has become a popular choice due to its advantageous properties – high strength to weight ratio, high resistance to corrosion and ease in application [7,8,9,10,11,14]. Various types of FRP composite material are available in the markets such as Carbon fibre reinforced polymer, Glass fibre reinforced polymer, aramid etc. [7, 9, 10]. Limited research studies have been conducted on the strengthening of damaged reinforced concrete structure using CFRP. The Strengthening of concrete, with CFRP results in an increase in load capacity as well as an increase in stiffness [4, 11, 18, 22, 26]. Different arrangements with respect to the Direction of fibres, thickness of sheets, and number of layers are proposed by researchers [11]. The technique involves the use of Fibre reinforced polymers~ FRP as externally bonded reinforcement EBR in critical regions of RC elements [27]. A significant improvement in the moment carrying capacity, rotational ductility, energy absorption, etc. was observed for all the strengthened specimens. Also, the moment carrying capacity was found to increase with increase in number of layers of strengthening material [28].

II. MATERIAL DESCRIPTION

Concrete: -

The concrete mean compressive strength was fc=36.4MPa (cylinder strength) for all specimens and the steel bars were S500 [24]. The concrete used is of M30 grade (30N/mm2) [25.] The concrete used in constructing the specimens was of 25 MPa compressive strength, with maximum aggregate size of 20 mm and slump between 75 and 80 mm [26]. Crushed aggregates with a maximum size of 15 mm in a water: cement: aggregate ratio of approximately 0.65:1:6.4 by weight [27]. IS method of mix proportioning was adopted to arrive a design mix for M20 grade concrete as 1:1.72:3.64 with water–cement ratio 0.50[28]. The used concrete was normal strength concrete of 25 MPa target strength, which was the average of three standard cubes of 150 mm side [29]. Concrete having characteristic compressive strength of 25 MPa was used for casting the beam-column joints [31]. Normal Strength Concrete (NSC) of grades M20, M25 and M30 are used to cast the concrete beam-column joints. Ordinary Portland cement is used to prepare the concrete. The maximum size of aggregate used is 20 mm and the size of fine aggregate ranges between 0 and 4.75 mm. After casting, the specimens are allowed to cure in real environmental conditions for about 28 days so as to attain strength [37]. The strength of concrete under uniaxial compression is determined by loading 'standard test cubes' (150 mm size) to failure in a compression testing machine, as per IS 516 [15] (IS-Indian Standards) [37].The specimens were cast by using the 53 grade ordinary Portland cement conforming to IS 12269[39]. The concrete mix was designed for a targeted concrete strength was 32 MPa at 28 days [40]. Minimum concrete compressive strength is 20 MPa and it was selected as a target compressive strength [43].

Steel: -

Steel is used as per standard code of different country. It Manson different grad of steel with its strength. As per Indian standard code the steel was used is grade of Fe415 & Fe500.

FRP (fibre reinforced polymer): -

In 90's steel plating was considered as a most effective way to strengthen an RC structure, however steel plating demand high cost and difficult in application, exhibits less fatigue resistance, may easily corrode, and increases dead weight of the structure. On the other hand, FRP has Many advantages in terms of ease in application, high strength to weight ratio, non-corrosiveness, non- magnetic characteristic. These characteristics make FRP a most effective material for repair and rehabilitation of a deficient RC structure. Trend of research potential on FRP has been arisen since last many years, but its applications are still unexplored. Strengthening and retrofitting of existing structures using externally bonded FRP is one of the first applications of FRP introduced in civil engineering. In 1980s, several researchers initiated using FRP in civil engineering applications as a separate research domain to explore properties of FRP and highlighted typically three main fibrous materials as glass, aramid, and carbon to strengthen structural members. Carbon fibre is usually manufactured in two categories i.e. high modulus and high strength. Glass fibre is produced in two forms i.e. E-glass and S-glass. However, E-glass fibres are comparatively not much stronger and stiffer than S-fibres. Aramid fibre is much higher than carbon and glass fibres. General behaviour of FRP in comparison steel under tensile stresses, stress-strain relations has been shown in Fig. Which shows that stiffness of CFRP is higher than GFRP and AFRP.

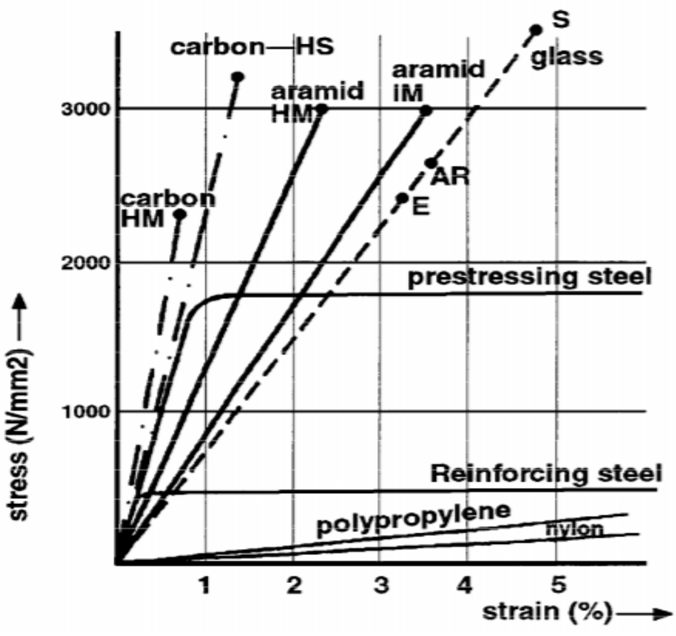

Figure-1[48]

Whereas, CFRP and GFRP are used in high level of reinforced concrete strengthening applications. Some of typical material properties of FRP carbon, glass, and aramid have been shown in Table.

TABLE-1[47]

Type of fibre	Thickness(mm)	Ultimate Tensile Strength (MPa)	Elastic Modulus (Gpa)	Ultimate Tensile Elongation (%)
Carbon	0.10-0.25	2100-6000	215-700	0.2-2.3
Glass	0.06-0.30	1900-4800	70-90	3.0-5.5
Aramid	0.10-0.30	2900-4100	70-130	2.5-5.0

TABLE-2[47]
Typical densities of FRP materials, lb/ft3 (g/cm3)

STEEL	GFRP	CFRP	AFRP
490(7.9)	75 to 130(1.2 to 2.1)	90 to 100(1.5 to 1.6)	75 to 90(1.2 to 1.5)

Density—FRP materials have densities ranging from 75 to 130 lb/ft3 (1.2 to 2.1 g/cm3), which is four to six times lower than that of steel. The reduced density leads to lower transportation costs, reduces added dead load on the structure, and can ease handling of the materials on the project site.

TABLE-3[47]
Typical coefficients of thermal expansion for FRP materials

Direction	GFRP	CFRP	AFRP
Longitudinal, αL	3.3 to 5.6 (6 to 10)	–0.6 to 0 (–1 to 0)	–3.3 to –1.1 (–6 to –2)
Longitudinal, αT	10.4 to 12.6 (19 to 23)	12 to 27 (22 to 50)	33 to 44 (60 to 80)

Coefficient of thermal expansion—the coefficients of thermal expansion of unidirectional FRP materials differ in the longitudinal and transverse directions, depending on the types of fibre, resin, and volume fraction of fibre. Lists the longitudinal and transverse coefficients of thermal Expansion for typical unidirectional FRP materials. Note that a negative coefficient of thermal expansion indicates that the material contracts with increased temperature and expands With decreased temperature.

TABLE-4[47]
Environmental reduction factor for
Various FRP systems and exposure conditions

Exposure conditions	Fibre type	Environmental reduction factor CE
Interior exposure	Carbon	0.95
	Glass	0.75
	Aramid	0.85
Exterior exposure (bridges, piers, and unenclosed parking garages)	Carbon	0.85
	Glass	0.65
	Aramid	0.75
Aggressive environment (chemical plants and wastewater treatment plants)	Carbon	0.85
	Glass	0.50
	Aramid	0.70

As Table illustrates, if the FRP system is located in a relatively benign environment, such as indoors, the reduction factor is closer to unity. If the FRP system is located in an aggressive environment where prolonged exposure to high humidity, freezing-and-thawing cycles, salt water, or alkalinity is expected, a lower reduction factor should be used. The reduction factor can reflect the use of a protective coating if the coating has been shown through testing to lessen the effects of environmental exposure and the coating is maintained for the life of the FRP system. Till date, FRP has been used extensively in construction industry mainly for repair and rehabilitation. All types of FRP are supportive in strengthening of RC structure. In this study carbon fibre is used for re-strengthening of RC beam because CFRP of overhauled on other FRPs comparative of other FRP. Glass fibre reinforced polymer (GFRP) increased strength of concrete up to certain level depends on strips Configuration. GFRP beams are less effective as compare to CFRP strength. Similarly, Aramid fibre reinforced polymer (AFRP) is flexible and high resistance against abrasion, but less strength then CFRP. The well-known properties of CFRP composite material are relatively easy to apply, high strength to weight ratio, non-corrosive, non-magnetic character, make them most effective material for repair and rehabilitation for deficient RC structure [20].

Epoxy Adhesive: -

Epoxy Resin Sikadur 52 [24]. Epoxy putty was used to fill the voids and concave areas [25].

III. STRENGTHENING SYSTEM

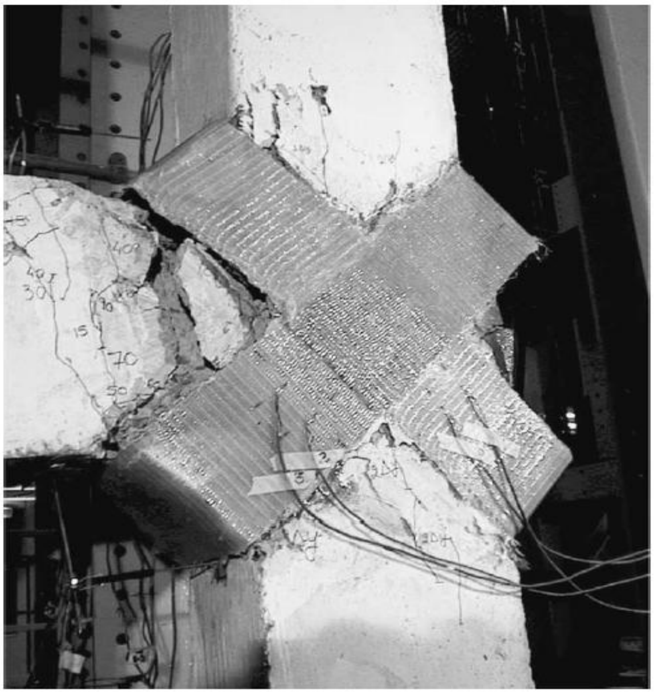

Figure-2[26]

Three layers of unidirectional GFRP were wrapped in the direction of diagonal tension forces in the joint at ± 45°, with the vertical [26]. In specimen initial cracking was observed in the beam at the face of the column, pointing to flexural hinge formation [26]. Due to the poor confinement of the rectangular column section and the bulging of the concrete, the fibre wrap delaminated as shear failure started in the joint region [26]. The three GFRP layers used were successful in delaying the joint shear failure while a ductile flexural plastic hinge was forming in the beam. Due to the coincidence of the beam flexural strength and joint shear capacity, ultimately the joint failed in shear [26].

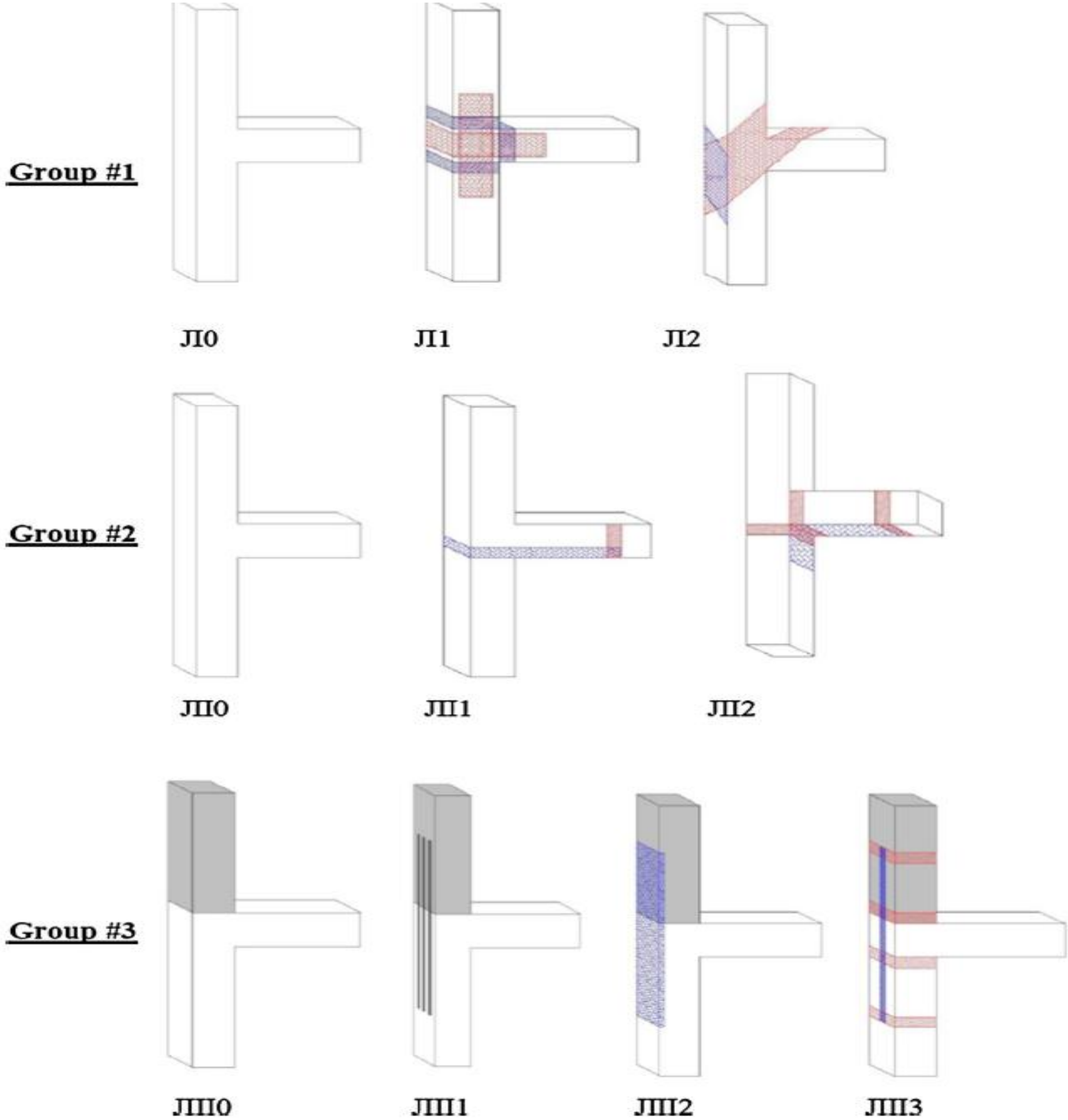

Figure-3[29]

Strengthening the joint using CFRP sheets yielded the increased ultimate capacities of the joint by about 55% and 61% as for specimen JI1 and JI2, respectively, compared to that of the reference specimen, JI0 [29]. Specimen JI1 began to crack at the same load as that of the reference specimen but cracks began to appear at higher load for specimen JI2 which was about 58 kN. The proposed configurations for strengthening this defect showed their efficiency in increasing the ultimate capacity of the joint. In addition, the failure of both configurations occurred on the CFRP sheets by rupture of the sheets at the joint[29].

The ultimate capacities of the two proposed configurations were higher than that the reference specimen JII0 by about 21% and 28%, respectively for specimen JII1 and specimen JII2[29]. The ultimate capacities of the two proposed configurations were higher than that the reference specimen JII0 by about 21% and 28%, respectively for specimen JII1 and specimen JII2. On the other hand, these increases were 6.4% and 12.5%, respectively, compared to that of the base control specimen J0[29]. This means the proposed configurations were not strong enough for significant gain in strength and additional layers of CFRP are recommended[29]. The failure of the first strengthening configuration was characterized by the peeling off the CFRP layers while the rupture of the CFRP sheets characterized the failure of the second configuration. The failure of the reference specimen, JIII0, was characterized by splitting of the upper implanted column at about a vertical load of about 65 kN which is lower than that of the base control specimen by about 19%[29]. The most appearing phenomenon for all specimens of this group was that all of them began to crack at the same vertical load, and then different behaviour was noticed till the complete failure had occurred. The failure of both specimens JIII1 and JIII2 was due to the peeling off of either the CFRP NSM or CFRP sheet. On the other hand, rupture of the anchorage U-shaped characterized the failure of specimen JIII3[29].

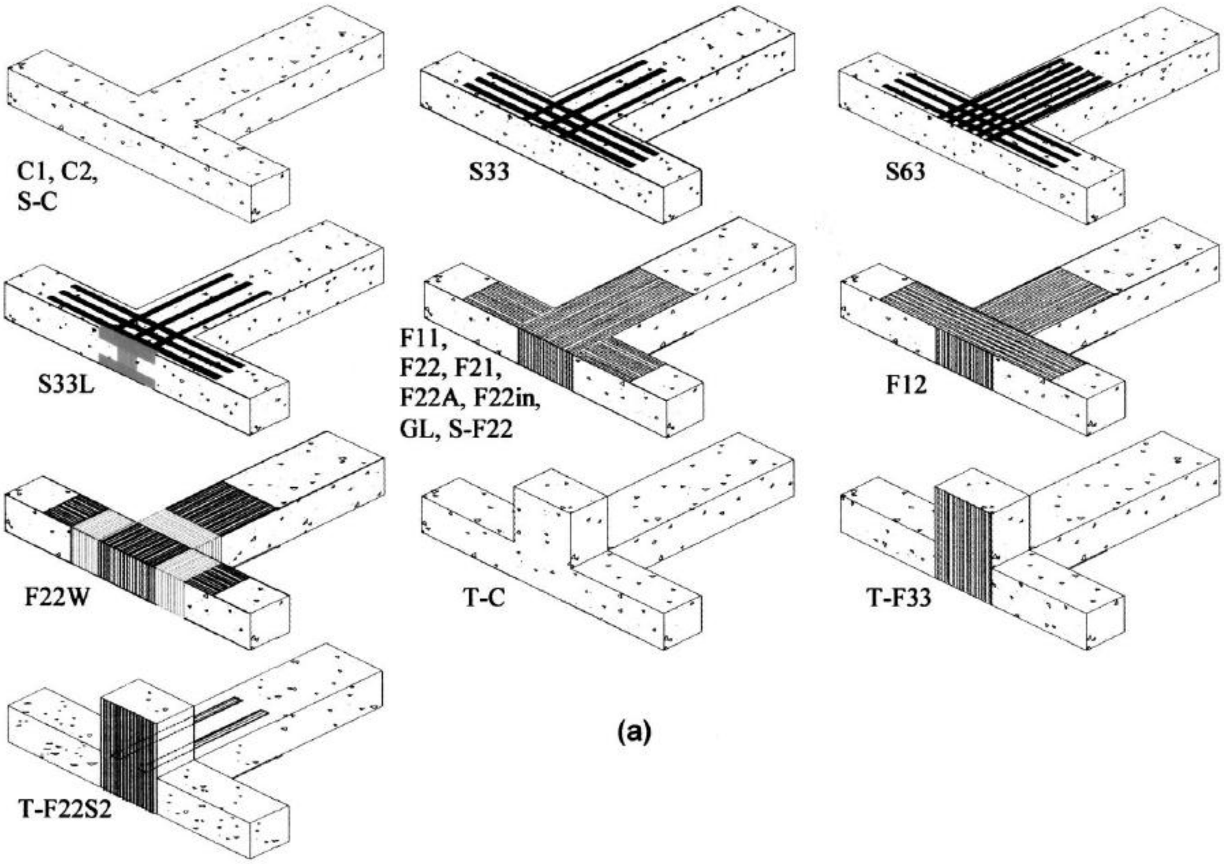

Figure-4[27]

S33 had three carbon strips on each side of the beam and three on each side of the column [27]. S63 had six carbon strips on each side of the beam and three on each side of the column [27]. In specimens S33 and S63, gradual debonding of the beam strips from the face of the beam was observed, initiating at the ends of the strips in the joint region, when the displacement was about 15–20 mm ~near 20 mm for S33 and near 15 mm for S63. Debonding of the beam strips in the joint caused debonding initiation of the column strips, too, especially of the outermost one, in the region around their mid length, due to uplift forces[27]. As the displacement increased and the deboned areas of beam and column strips increased in a stable manner ~in the joint region, the innermost column strips deboned suddenly at their ends due to the high tensile forces transferred. Specimen S33L~with the steel angle providing improved anchorage to the beam strips! behaved in a different manner[27]. Debonding initiated in the non-anchored end of a beam strip due to tension ~at a displacement of 15 mm, but it also developed in column strips first in compression due to local buckling at a displacement of 25 mm and then in tension at a displacement of about 30mm bottom left[27].

<u>Specimens with Sheets, No Stirrup in the Joint, No Transverse Beam</u>

Specimen F11 was reinforced with one layer of carbon sheet on each side of the beam and the column. Debonding of the sheet started near the corners of the joint at a displacement of 20 mm[27].On one side of the beam, debonding propagated gradually towards the end of the sheet[27]. Full debonding was observed at a displacement of about 40 mm; whereas on the other sided bonding was followed by tensile fracture of the beam FRP[27]. This fracture occurred through a horizontal crack, which propagated gradually until the entire beam FRP fractured perpendicular to the fibres ~at a displacement of 35 mm! causing partial fracture of the column FRP due to tension perpendicular to the fibres[27]. In specimen F22 ~with two layers of carbon sheets on each side of the column! fracture of the sheet did not occur but debonding developed similarly to F11; deboned areas developed near the corners until a fraction of the beam FRP was detached and deboned all the way to the free end[27]. Specimen F21 ~with two layers of sheets on each side of the beam and one on each side of the column! was characterized by full debonding of both the beam and the column FRP on one side, and by limited debonding near the corners, combined with limited tensile fracture of the column FRP ~near the corners! on the other side. The main characteristic of the response of specimen F12~with one layer of FRP on each side of the beam and two on each side of the column! was full tensile fracture of the beam FRP on one side ~this followed debonding in the region underneath the fracture line! and full debonding ~which developed gradually though! of the sheets on the other. Specimen F22A ~identical to F22 but with higher axial load in the column! developed similar failure characteristics to specimen F11 ~fracture of the beam FRP on one side and partial debonding of the beam FRP on the other! In specimen F22W, which had special FRP wrappings at the beam and column ends, debonding was extremely limited. The beam FRP started fracturing on both sides at a displacement of about 20 mm. Cracks in the sheets propagated in a stable manner as the displacement increased until full fracture of the beam layers on one side occurred at a displacement of 35 mm. Full fracture of the layers on the opposite side was completed when the displacement reached 40 mm[27]. Specimen F22in was loaded before strengthening up to a displacement of 10 mm ~two series of three cycles each at a 5 mm increment!, unloaded, strengthened, and then reloaded. At the end of preloading, diagonal cracking in the joint was already visible ~although barely[27]. Upon reloading the strengthened specimen and during the loading history, pinching became more intense as a result of precaching. Failure of the FRP sheet progressed through debonding, similarly to specimen F22, with the following two differences: ~1! on one side of the joint, debonding of the FRP was full; and ~2! on the other, it was mainly observed in the inner part of the column. Specimen GL was the only one strengthened with glass fibre sheets. Debonding of the glass fibre reinforced polymer ~GFRP! jacket started near the corners ~at a displacement of about 20 mm! and propagated until the jacket was fully detached from the joint on one side[27]. On the other side of the specimen, where debonding was less severe and rather localized in the vicinity of the joint ~near the end of the beam, minor tensile fracture of the beam sheet initiated when the displacement reached 30 mm and propagated slowly until the crack tip reached the part of the sheet which consisted of three layers[27].

IV. **FINITE ELEMENT IMPLEMENTATION**: -

ANSYS 16 SOFTWARE IS USED FOR MODELLING THE SPECIMEN [41].

ELEMENT TYPES USED FOR MODELLING: -

SOLID 65: -

THIS ELEMENT IS USED TO MODEL CONCRETE. THIS ELEMENT HAS 8 NODES WITH THREE DEGREES OF FREEDOM AT EACH NODE-TRANSLATIONS IN THE NODAL X, Y, Z DIRECTIONS. THIS ELEMENT IS CAPABLE OF PLASTIC DEFORMATION, CRACKING IN THREE ORTHOGONAL DIRECTIONS AND CRUSHING [35, 36, 41].

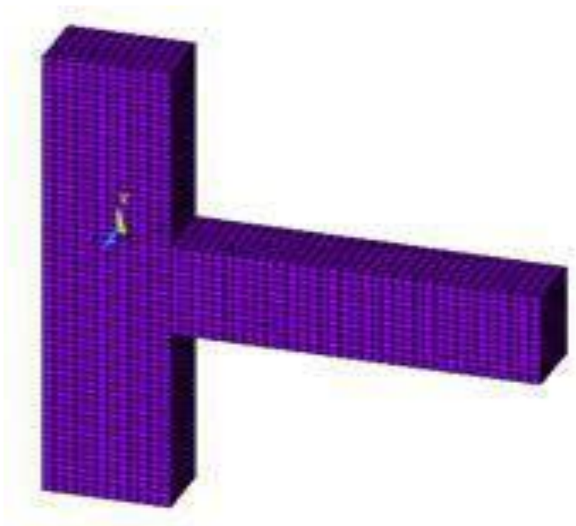

Figure-5[36]

Link 180: -

this element is used to model the steel reinforcement. This element is a 3D spar element and it has two nodes with three degrees of freedom at each node – translations in the nodal x, y, z directions. This element is also capable of plastic deformation [35, 36, 41].

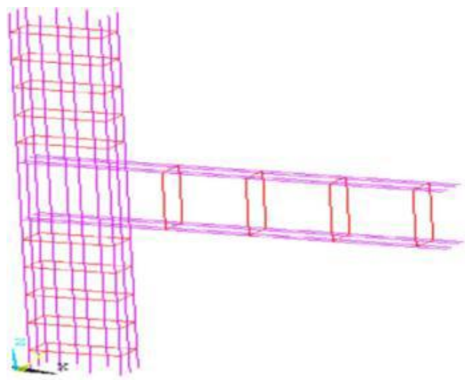

Figure-6[36]

MESHING: -

To obtain good results from the SOLID65 element, the use of a rectangular mesh is recommended. Therefore, the mesh is set up such that the square or rectangular elements is created. The meshing of the reinforcement is a special case compared to the concrete volumes. Meshing of reinforcement is not needed because the individual elements are created by the mesh of concrete through the nodes [35, 36, 41].

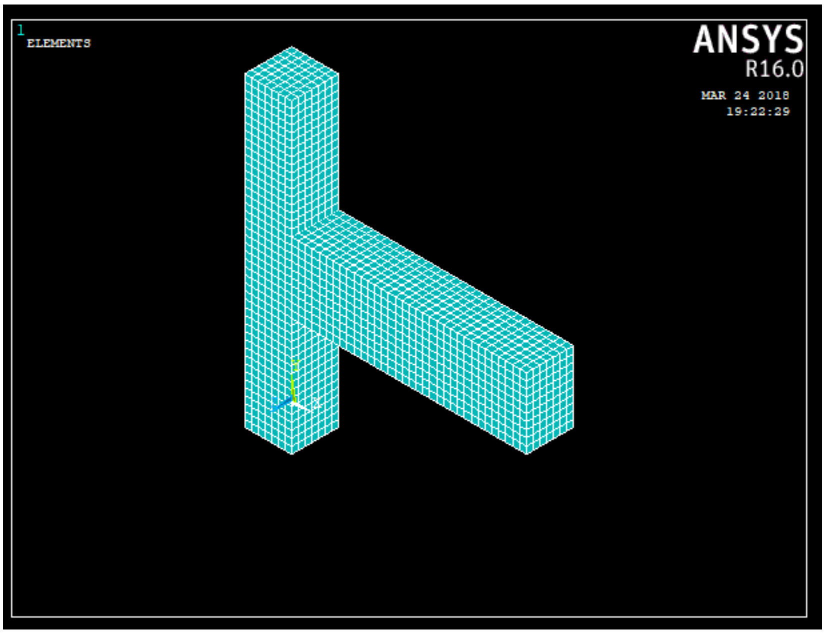

Figure-7[41]

LOADS AND BOUNDARY CONDITIONS: -

To get a unique solution, displacement boundary conditions are needed to constrain at the nodes (UX, UY, UZ) with the constant values as 0. The static force of5kN was applied at the end of the free cantilevered beam for both the specimens. Force was increased in steps till a control load of 20kN [35, 36, 41].

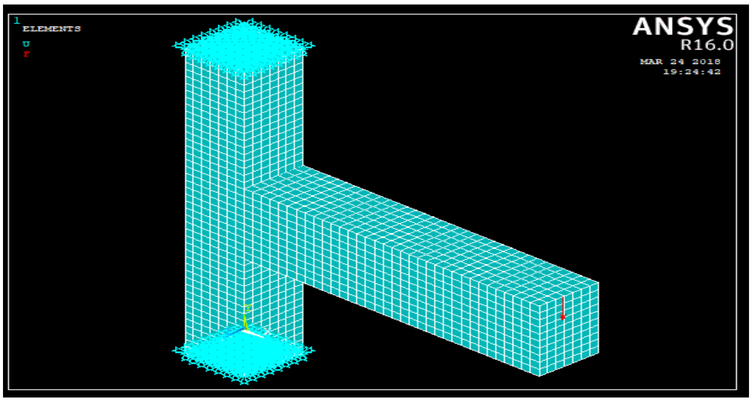

Figure-8[41]

V. Conclusions: -

From the observed responses of the tested specimens it can be deduced that the use of epoxy Resin even in the cases of large-scale damage can restore the response of the specimens [24]. The load-carrying capacity and the energy absorption of the repaired specimens were observed to be better than those of the control specimens [24]. The damages in all repaired specimens concentrated outside the joint area [24]. The use of C-FRP sheets substantially improved the load-carrying capacity and the energy absorption of the examined beam–Colum connections [24, 25, 27, 36, 38, 41, 46]. For the same reinforcement area fraction, flexible sheets are more effective than strips [27]. The failure of control and strengthened beam–column joints except those strengthened using CFRP were characterised by the formation of vertical cracks at the joint whereas the specimens strengthened using CFRP failed due to the formation of vertical cracks at a distance of effective depth from the face of the column [28]. CFRP strengthened specimens showed good ductility and better cracking characteristics and prevented the failure at the joint [28]. The orientation of the CFRP plates has a great effect on the performance of the strengthened joint [29, 34]. The shear strength of one-way exterior joints has been improved with ±45-degree fibres in the joint region [33, 34]. The joint region was free from cracks except for some hairline cracks, and therefore the joints had adequate shear-resisting capacity [39]. The deflection of the confined CFRP beam column joints reduces the deflection about 38.84% when compared with the deflection of the control specimen [41]. The flexural and shear capacities of the damaged beam were recovered by wrapping the member with longitudinal CFRP sheets at the top and bottom surfaces by anchoring them with transverse CFRP sheets as to improve the shear capacity of the damaged member [43]. Due to the lack of joint transverse reinforcement, deficient beam-column joint can be exposed to brittle type of shear failure, which adversely affect the overall seismic behaviour of the RC structures [43].

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