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Seismic Behavior of Carbon Fibre Reinforced Polymer upgraded RC beam column joint

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***Abstract*— This paper shows a comprehensive behavior of Carbon Fibre Reinforced Polymer (CFRP) beam-column joint under cyclic loading. The study examines the structural response of CFRP beam-column joint subjected to cyclic loading using finite element analysis on ABAQUS. It mainly consists of study on strain behavior of the cracks at joint. The analysis considers how CFRP beam-column joint affect the performance of normal beam-column joint. The curve typically shows the dissipated energy as a function of load v/s displacement. Performance of CFRP upgraded beam column joint under cyclic loading with CFRP is majorly affected. The crack formation within area has been distributed over larger area and the total crack strain is decreased up to 38%.**

***Index Terms*— CFRP, Retrofitting, Beam-column joint, crack formation, Cyclic load.**

I. INTRODUCTION

Research into beam-column joint composed of CFRP is essential for structural engineering. The advantages of using CFRP over steel and concrete is due to its light weight. It is having exceptional mechanical properties like high strength to weight ratio, corrosion resistance and durability. The buildup of damage over structure cause fatigue failure in structures and materials under cyclic loading[1]. Steel jackets are the most frequent form of reinforcing material used in the construction industry, however other materials like as steel plates, ferrocement, and fibre reinforced polymers are also available.

It can be eliminated by understanding the load carrying capacity of the structure against cyclic loading. It can be investigated on various structures like bridges, aircraft, automotive elements. Structures may encounter displacement, stress distribution due to the loading, knowing how these parameters affect the structural performance. Some materials will perform flawlessly under static loading but under cyclic loading they are susceptible to breaking soon. Engineers need to find some materials that will cater to these drawbacks. Because of its low weight, high strength and stiffness, corrosion resistance, ease of application, outstanding fatigue resistance, and other benefits, FRP-based strengthening has become an appealing choice to restoring joints to their intended capacity. Gergely et al[2].

While integrating CFRP structures particularly in load bearing applications, most of the research is on bolted connections. These types of jackets increase the weight and dimensions of the structural elements. A few attempts have been made for the use of corrugated or plain steel plates as jacketing material in concrete frames[3]. It is having high risk of joint fracture or deformation. Another research is on hybrid joints. The CFRP composite improved the ductility and shear resistance of the beam-column joints[4]. It consists of mechanical fastening and bonding that would enhance performance of the construction. It was discovered that CFRP rehabilitation approaches were successful in preventing brittle joint shear and bond slip failure[5]. The behavior of CFRP joint on the spread of crack and fatigue were studied in earlier investigations. For assessing the durability of CFRP joint without causing damage, various Non-Destructive methods were used. It mainly consists of ultrasound, thermography and X ray imaging. When compared to control beams, CFRP retrofitted beams increased maximum load by up to 170%[5]. To increase strength, stiffness and resilience of CFRP joints researchers focused on the optimized functioning. Environmental elements like moisture, temperature and chemical exposure can cause CFRP joints to deteriorate. In this study we are going to analyze beam column joint upgraded with CFRP under cyclic loading. This study mainly focuses on the stress initiation pattern of the beam column joint after cyclic loading was applied.

II. OBJECTIVES OF PROPOSED WORK

1. Formulation of the problem statement, development of methodology, and possible validation with high-quality research articles
2. Performing cyclic loading analysis for seismic beam column joints by using CFRP as a retrofitting method.
3. To evaluate the displacement acting on the beam-column joint of normal and CFRP upgraded specimen.

III. METHODOLOGY

From the above literature studies, it's observed that several researchers have studied the static, dynamic behaviour, and seismic performance of reinforced concrete beam column joint. However, many researchers have theoretically given the concept of this which will benefit in many ways. Additionally, more studies are needed to account for the other effects of beam column joint failures due to various loadings.

In this research, cyclic load acting on beam column joint is analyzed. Magnitude of the stress acting on the specimen was observed. Analysis is done based on load vs deformation acting on the beam column joint.

IV. ANALYTICAL PROGRAM

Concrete damaged plasticity:

The model is continuum, plasticity based, damage model for concrete. It categorized two failure mechanisms as tensile cracking and compressive crushing of concrete material.

Eo=(undamaged)elastic stiffness of the material

The damage plasticity constitutive model was based on the following stress-strain relationship.

$$\sigma = (1 - d_t)\,\bar{\sigma}_t + (1 - d_c)\,\bar{\sigma}_c$$

The total strain tensor e was comprised of the elastic part and plastic part.

$$\varepsilon = \varepsilon^{el} + \varepsilon^{pl}$$

For the specimen, uniaxial loading stress reaches at ultimate point, and it follows linear elastic relationship. Compression curve is greater than tension as value of compression is large. Elastic part is undamaged part which is taken up to elastic limit. After elastic part it shows softening point (1-dt)Eo. Softening part forms micro cracks on the surface in plastic region response is characterized by stress hardening.

Flow rules:

The plastic damage model assumes non-essential potential flow, which means that the yield functionality and plastic potential does not occur at the same time. [6]The flow potential G chosen for this model is the Druken-Prager hyperbolic function.

Dilation angle:

Dilation angle in the p-q plane where p indicates mean stress and q indicates deviatoric stress.

Eccentricity:

Flow potential eccentricity ε. The eccentricity is a small positive number that defines the rate at which the hyperbolic potential approaches its asymptote. The default value is ε =0.1

$$\frac{f_{bo}}{f_{co}}$$

[7]The ratio of initial equibiaxial compressive yield stress to initial uniaxial compressive yield stress. The default value is 1.16.

K:

Kc, the ratio of second stress invariant on tensile meridian q_{TM} to that on the compressive meridian q_{CM}, at initial yield for any given value of the pressure invariant p such that the maximum principal stress is negative σ_{max}. It must satisfy the condition 0.5<kc<1. The default value is 2/3.

Viscosity parameter:

Viscosity parameter μ used for the visco plastic regularization of the concrete constitutive equations in analysis. This parameter is ignored in Abaqus/Explicit. The default value is 0.

Hashin Damage model

Materials specially metals are isotropic as their property remains same but in case of composite materials like Carbon Fibre reinforced polymer property changes in different directions. While defining type in case of elastic material we are having two options like lamina and engineering constants. Lamina is for 2D materials like shell. It consists of different directions for representing fibre and matrix. We can define modulus of elasticity and modulus of rigidity at different directions. In case of Engineering constants, we can use 3D materials. It takes three directions into consideration. In case of damage criteria, we can define hashin damage criteria.

Damage initiation refers to the onset of degradation at a material point. In Abaqus the damage initiation criteria for fiber-reinforced composites are based on Hashin's theory. These criteria consider four different damage initiation mechanisms.

Fiber tension $\hat{\sigma}_{11} \geq 0$

$$F_{ft} = \left(\frac{\hat{\sigma}_{11}}{X^T}\right)^2 + \alpha\left(\frac{\hat{\sigma}_{12}}{S^L}\right)^2$$

Fiber compression $\hat{\sigma}_{11} \geq 0$

$$F_{fc} = \left(\frac{\hat{\sigma}_{11}}{X^C}\right)^2$$

Matrix tension $\hat{\sigma}_{22} \geq 0$

$$F_{ft} = \left(\frac{\hat{\sigma}_{22}}{Y^T}\right)^2 + \left(\frac{\hat{\sigma}_{12}}{S^L}\right)^2$$

Matrix compression $\hat{\sigma}_{22} \geq 0$

$$F_{ft} = \left(\frac{\hat{\sigma}_{22}}{2S^T}\right)^2 + \left[\left(\frac{Y^C}{2S^T}\right)^2 - 1\right]\frac{\hat{\sigma}_{22}}{Y^C} + \left(\frac{\hat{\sigma}_{22}}{S^T}\right)^2$$

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XT denotes the longitudinal tensile strength.
XC denotes the longitudinal compressive strength.
YT denotes the transverse tensile strength.
YC denotes the transverse compressive strength.
SL denotes the longitudinal shear strength.
ST denotes the transverse shear strength.

α is a coefficient that determines the contribution of the shear stress to the fibre tensile initiation criterion.

$\hat{\sigma}_{11}$, $\hat{\sigma}_{22}$, $\hat{\sigma}_{12}$ are components of the effective stress tensor, that is used to evaluate the initiation criteria.

α value is taken as 0 and for hashin damage model it is 1. All above values required for the model were given in Fig. 1.

Dilation angle	Eccentricity	$\frac{f_{bo}}{f_{co}}$	K	Viscosity parameters
31	0.1	1.16	0.67	0

Fig. 1. Details of the input properties

Table: Properties of Fibre used

Sr No.	Physical properties	Value
1	Modulus of Elasticity	240 GPa
2	Density	1.7 g/cm^3
3	Thickness	0.117mm

Types of cyclic loading:
1. Fluctuating loading
2. Repeated loading
3. Reversed loading

Fluctuating loading

It varies in a manner of sinusoidal wave. It varies with some amplitude value and mean value. Variation of the fluctuation is between maximum and minimum value of the stress function.

Repeated loading

It shows a variation in sinusoidal manner with respect to time. Minimum load is zero. It starts from the ordinate of y-axis till the value of the stress levels. Total cycle of the load varies above x- axis.

Reversed loading.

Reversed loading also possess sinusoidal curve with respect to time. It has a mean value of zero. Cycle completes in two halves one is tensile and other is compressive.

Finite Modelling:

Creation of part:

Select suitable geometry of the model. Create model by using shapes of geometry considering extrusion command. Create part of the beam column joint by using the constraint line command. Fix the model by using the fixed constraint command.

Assembly:

In this step we are adding whole individual part of the model into single one. Assembly looks like a structure after attaching all the parts into single piece.

Interaction:

Total structure is assembled into single piece and the interaction on it is created that is the point of application of the load on the structure. Various loadings are applied on this points to get the required results.

Load:

Load is considered as application of boundary condition to the structure. Before application of the load, we need to apply the step in the structure. Step considers the total increments required for running the analysis. We need to assign the minimum as well as maximum steps required for the analysis.

Mesh:

Mesh is required in the analysis of finite element modelling. Total mesh count will give the accuracy of the answer. As we increase the no. of mesh sizes, accuracy of the solution will increase. Mesh can be taken as per the requirement of the problem. Various shapes taken are triangular, hexagonal, rectangular, etc. If the mesh formed in the structure is not showing proper geometry given above, then we may face some issues in running the software. Mesh should be taken as individual as it will not give proper results if it is improper.

V. RESULTS AND DISCUSSIONS

Van mises:

Von Mises stress is a measure of the effective stress at a point in the model after application of load. It represents combined measure of normal and shear stress. It is used to assess the potential for yielding or failure in a material. For getting the results from the analysis we need to do post processing.

Cyclic loading:

Define the cyclic loading pattern for the joint. It can be series of load steps or predefined cyclic loading function. You can specify the amplitude, frequency and number of cycles for the loading.

Node or element output requests: Define output requests to obtain stress values at specific locations within joint over time. You can specify the type of stress component and extract corresponding values.

History output request: Define history output requests to obtain stress values at specific locations within the joint over time. This can be useful for tracking stress distribution during

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cyclic loading.

The specimen of normal beam-column joint is assessed for the maximum level of stress at the point of cyclic loading. The value of stress at the point of cyclic loading application is 15.45 N/mm2. The stress level of CFRP upgraded beam-column joint was observed as 9.24 N/mm2. The magnitude of plastic strain shown a decrease of 38% as compared to normal specimen. The curve of load v/s displacement shown in Fig. 3.

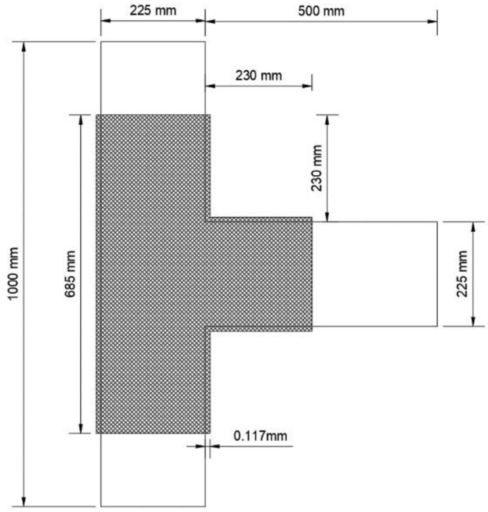

Fig. 1. Side view of beam column joint specimen

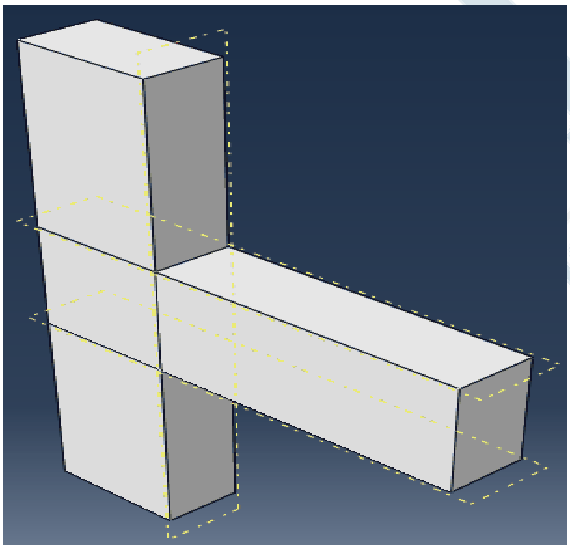

Fig. 2. Beam-column joint specimen.

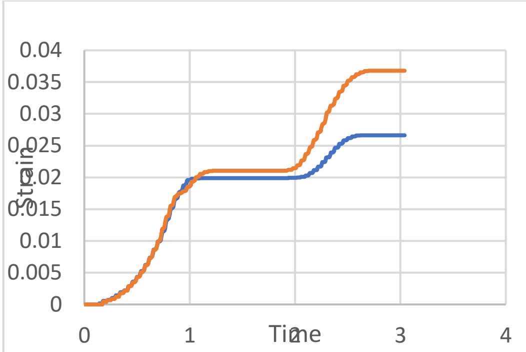

Fig. 3. Strain v/s time

VI. CONCLUSION

The following conclusions might be taken from the analytical investigation. Observations concerning the control and CFRP-retrofitted beam-column intersection specimens were:

1. There is a decrease in the value of the strain due to the provision of CFRP which is up to 38%.
2. Deflection in normal beam-column joint is drastically decreased in the CFRP region. There is 28% decrease in deflection of CFRP section.

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