International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 03 Issue: 09 | Sep-2016 www.irjet.net p-ISSN: 2395-0072

A Comparative Study of Retrofitting of Beam Column Joint Using Concrete jacketing, Steel Plate Jacketing, Glass Fiber wrapping

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Abstract - *This study presents an analytical investigation of three retrofitting techniques, using finite element analysis aimed at improving the behavior of reinforced concrete beam-column joints to enhance the performance and load carrying capacity of structures. The three suggested retrofitting techniques presented are concrete jacketing, steel plate jacketing and glass fiber reinforced polymer (GFRP) sheets wrapping to strengthen the joint and reduce deformations. Nonlinear static finite element analysis was carried out to evaluate the performance of the original and strengthened joint models. The performance has been investigated in terms of load carrying capacity, deflection, failure pattern. In this thesis a comparative study of three different methods; using concrete jacketing steel plate jacketing and glass fiber wrapping by ANSYS software are proposed.*

Key Words: **Retrofitting techniques, Nonlinear Static Analysis, Load carrying capacity, Deflection, Failure pattern etc ...**

1. INTRODUCTION

The RCC structures constructed across the world are often found to exhibit distress and suffer damage, even before service life is over, due to several causes such as earthquakes, corrosion, overloading, change of code provisions, improper design, faulty construction, explosions and fire. For all framed structures, the most important component is the beam-column joint, and the structural design of the joint is usually neglected. During the design stage, attention is only restricted to provision of sufficient anchorage for the beam. It is well known that joint region in reinforced concrete framed structures are recognized as very critical as it transfers the forces and bending moments between the beams and columns. Retrofitting of beam column joints is needed to maintain structural safety and reliability. In this study three methods of joint strengthening will be discussed. These methods are: concrete jacketing, glass fiber reinforced polymers (GFRP) confinement, and steel jacketing. Static analysis is carried out and load carrying capacity, load-deflection behavior and failure pattern will be studied.

2 FE MODELING OF BEAM COLUMN JOINT

ANSYS 14.5 software is used for modeling the specimen.

2.1 Control Specimen

The specimens had reinforcement details as per code IS 456:2000 and code IS 13920:1993as shown in Fig-1. The columns had a cross section of 200 mm x 200mm with an overall length of 1600 mm. The beams had a cross section of 200 mm x 200 mm with a cantilevered portion of length 600 mm. The column portion was reinforced with 4 numbers of 12 mm diameters and the beam portion was reinforced with 4 numbers of 16 mm. The main reinforcement had yield strength of 415 MPa. The lateral ties in the columns were 6 mm diameter at 180 mm center to center (c/c) spacing and the beams had vertical stirrups of 6 mm diameter at 120 mm c/c. The lateral ties and the vertical stirrups had yield strength of 250 MPa. The concrete strength of the specimen adopted was 20 MPa.

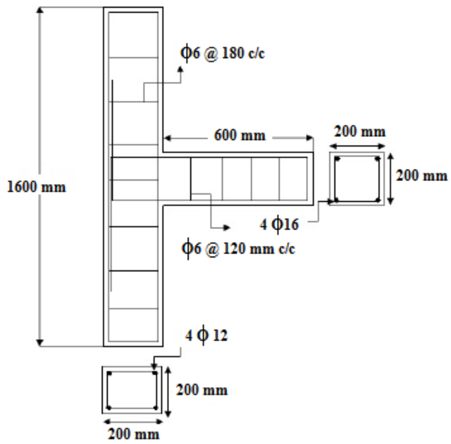

Fig-1.Reinforcement Details of Specimen

2.2 Element Types and Material Properties

The Solid 65 element is used to model concrete. This element has eight nodes with three degrees of freedom at each node – translations in the nodal x, y, and z directions. This element is capable of plastic deformation, cracking in three orthogonal directions, and crushing. A Link 180 element is used to model 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 and z directions. This element is also capable of plastic deformation. The Solid 185 element is used for the modeling of steel plate for application of load. This element is defined by eight nodes having three degrees of freedom at each node translations in the nodal x, y, and z directions. The element is capable of plasticity, hyper elasticity, stress stiffening, creep, large deflection, and large strain capabilities. SOLID185 is available in two forms: Homogeneous Structural Solid (default); and Layered Structural Solid. Homogeneous Structural Solid with simplified enhanced strain formulation is used to model steel plate for application of load Solid 65 element requires linear isotropic and multi-linear isotropic material properties to properly model concrete. The modulus is (as per Cl. 6.2.3.1 of IS 456: 2000), E_c=22361 MPa. Poisson's ratio is taken as 0.2. Shear transfer coefficient for the open crack 0.3 and for closed crack is set to 1. The uniaxial cracking stress is based upon the modulus of rupture. This value is 3.13 (as per Cl. 6.2.2 of IS 456: 2000). The uniaxial crushing stress in this model was based on the uniaxial unconfined compressive strength. The yield stress is defined as 415 MPa for main reinforcement, while it is 250 MPa for stirrups and ties. The tangent modulus (of the plastic region) is defined as 0. Elastic modulus is defined as 2,00,000 MPa and Poisson's ratio as 0.3.

2.3 Modeling and Meshing

The beam column joint is modeled as volume. To obtain good results from the Solid65 element, the use of a rectangular mesh is recommended. The meshing divided it into a number of small brick elements with (20 x 20 x 20) mm dimensions. No mesh of the reinforcement is needed because individual elements are created in the modeling through the nodes created by the mesh of the concrete volumes

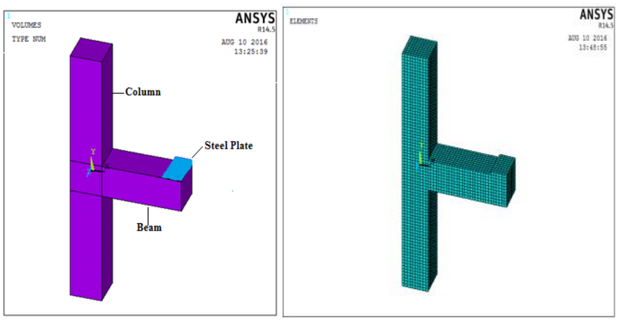

Fig-2. Volume and mesh Created in ANSYS for Control Specimen

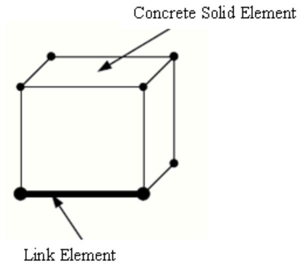

Fig-3.Element connectivity: concrete solid and link elements

2.4 Loads, Boundary Conditions and Analysis

Displacement boundary conditions are needed to constrain the model to get a unique solution. To achieve this, the translations at the nodes (UX, UY and UZ) are given constant values of 0. The force, F, is applied at the loading plate. The applied load was performed as a static load at the free end of the cantilever beam as a small forces divided by the number of nodes at that location. For the purpose of this model, the Static analysis type is utilized.

The FE analysis of the model is set up to examine three different behaviors: initial cracking of the beam, yielding of the steel reinforcement, and the strength limit state of the beam-column joint. The Newton-Raphson method of analysis is used to compute the nonlinear response. The application of the loads up to failure is done incrementally as required by the Newton-Raphson procedure. After each load increment is applied, the restart option is used to go to the next step after convergence. Load increment analysis is done with 5000 N at each step. Failure for the model is defined when the solution for a 1 N load increment still does not converge. The program then gives a message specifying that the model has a significantly large deflection, exceeding the displacement limitation of the ANSYS program.

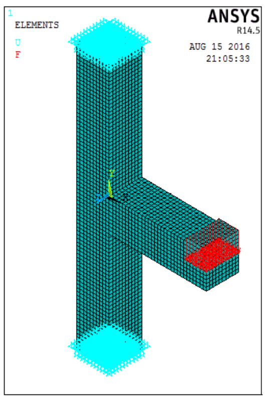

Fig-4. Loads and Boundary Conditions in ANSYS for the Control Specimen

2.5. Retrofitted Specimen

The control specimen is now retrofitted with externally bonded concrete, steel plate, glass fiber reinforced polymer (GFRP) with 20 mm and 40 mm thickness and 200 mm from beam and column joint regions, in a typical retrofitting scheme and analyzed in ANSYS 14.5 software. Solid 185 used for retrofitting. The properties of concrete used for retrofitting is same as control specimen. Material properties, young's modulus and poison's ratio for steel 2 x 10^5MPa and 0.3, glass fiber it is 72x10^5 and 0.3. Ultimate tensile stress and strain are 250 MPa and 15 % for steel 1950 MPa and 3% for glass fiber. Modeling, meshing, loads, boundary conditions and analysis are same as control specimen.

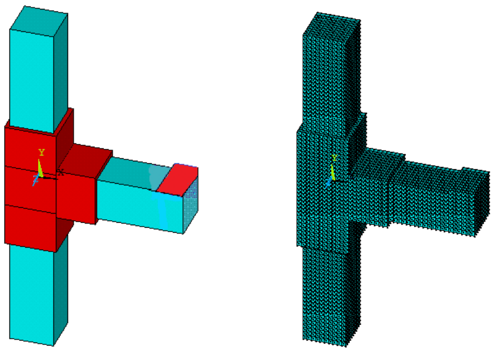

Fig-5. Volume and Mesh Created in ANSYS for the retrofitted Specimen

3. RESULT AND DISCUSSIONS

In this the results from the FEM study of the controlled specimen are compared the results of the retrofitted specimen.

3.1. Control Specimen

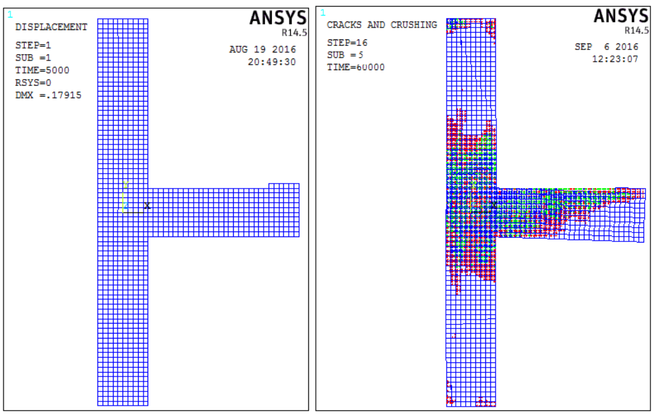

Fig-7. Deflected Shape of Control Specimen at 5000 N & Failure Pattern at 60000 N

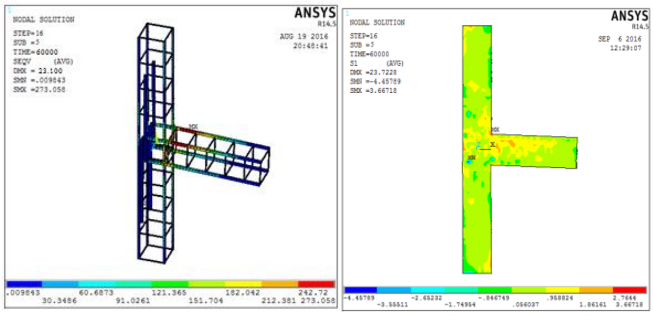

Fig-8. von-Mises Stress in Rebar & Principle Stress in Concrete for control specimen

After a load of 7 kN, the non-linear region starts and continues up to a load of 55 kN. Significant flexural and diagonal tension cracking occurs at the beam-column junction. After a load of 55kN, yielding of steel reinforcement occurs. At the ultimate load of 60kN, the joint can no longer support additional load as indicated by an insurmountable convergence failure. Corresponding deflection is 23 mm. Von - Mises stress in rebar and principle stress in concrete are 273N/mm^{2}and 3.66N/mm^{2}respectively.

3.2. Retrofitted Specimens

Retrofitting was done with 3 different types of materials, concrete, steel and glass fiber. Control specimen was retrofitted in two different thickness, 20 mm and 40 mm. The results from retrofitted specimen are presented below.

20 mm thickness

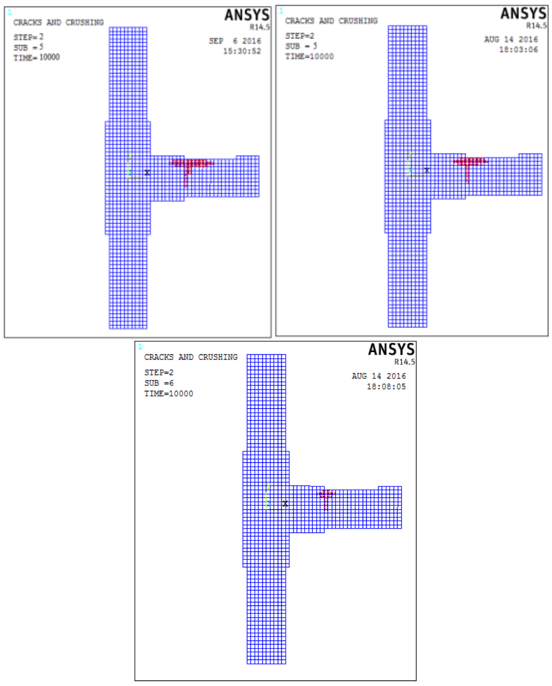

Fig-9. Initial crack formation for Concrete, Steel & Glass Fiber Retrofitting Respectively

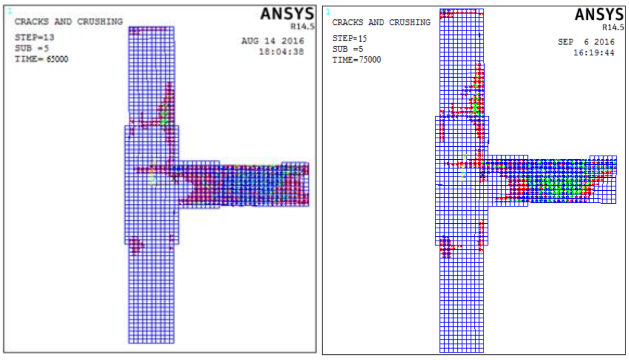

Fig-10. Failure Pattern for Concrete & Steel Retrofitting

The first crack occurs at a load of around 10kN. Once cracking occurs, deflections and stresses become more difficult to predict. After a load of 10kN, the non-linear region starts and continues up to a load of 70kNfor steel and 75kN for glass fiber retrofitting. For concrete jacketing it is 60 kN. At this point in the response, the displacements begin to increase at a higher rate as more loads is applied. For steel retrofitted specimen at the ultimate load of 75 kN, the joint can no longer support additional load as indicated by an insurmountable convergence failure. Corresponding deflection is 10.82 mm. For concrete retrofitted specimen at the ultimate load of 65 kN , corresponding deflection is 16.55 mm. For glass fiber retrofitted specimen at the ultimate load of 80kN, corresponding deflection is 14.05 mm.

40 mm Thickness

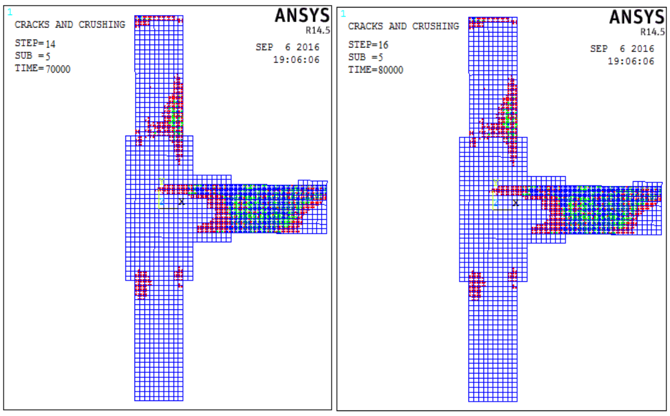

Fig-11. Failure Pattern for Concrete & Steel Retrofitting

The first crack occurs at a load of around 10 kN as indicated by change of slope in the linear region. After a load of 10kN, the non-linear region starts and continues up to a load of 75 kN for steel, 65 kN for concreting and 90kN for glass fiber retrofitting. After this non-linear region, yielding of steel reinforcement occurs. For steel retrofitted specimen at the ultimate load of 80 kN, corresponding deflection is 9.50 mm. For concrete jacketed specimen ultimate load is 70 kN and corresponding deflection 14.77 mm. For glass fiber retrofitted specimen at the ultimate load of 95 kN , the joint can no longer support additional load as indicated by an insurmountable convergence failure. Corresponding deflection is 12.55 mm.

4. COMPARARITIVE STUDY OF RESULTS

For glass fiber initial deflection is larger than steel due to low value of Young's Modulus. Specimen retrofitted shows reduction in deflection values. Concrete jacketed specimen with 20 mm thick shows 31.25 % reduction in deflection values. Steel plate with 20 mm thickness shows 55 % reduction in deflection value, while glass fiber retrofitted specimen results in 42 % reduction in deflection compared to the control specimen. In case of 40 mm thick concrete retrofitted specimen shows 38.3 % reduction in deflection value compared to the control specimen. While for steel and glass fiber retrofitting reduction in deflection values are 60.42 % and 48 % respectively.

Loading carrying capacity of retrofitted specimens is higher than control specimens. For control specimen 60kN is the ultimate load. For concrete jacketed specimen with 20 mm thickness 8.40 %in the load carrying capacity, for steel retrofitted specimen it is 25% increase and for glass fiber with same thickness results in 33.33 % increase in load value. For retrofitted specimens with 40 mm thick increase in load carrying capacity are 16.7 %, 33.33 % and 50 % higher than control specimen. Stress values in rebar and concrete for retrofitted specimens are higher than control specimens. Because retrofitted specimen carries more load compared to control specimen.

5. CONCLUSION

1. Comparison between the load-deflection results obtained from ANSYS for control and retrofitted specimens shows that the yield load and ultimate load has significantly increased for the retrofitted specimen.
2. The higher value of yield load and ultimate load for the retrofitted specimen is associated with lower deflections as compared to the control specimen.
3. Load carrying capacity and reduction in deflection for 40 mm thick retrofitting specimens are higher than that of 20 mm thick specimens.
4. The results show that the use of GFRP wrapping sheets can be considered as the best retrofitting technique compared to the other two techniques when the increasing of the load carrying capacity is the target. While, the use of Steel plate jacketing with proper thickness is the best option when the decreasing of maximum deflection is the target.
5. The failure was along the beam and the column portion of the joint of the control specimen which is to be avoided. In the case of concrete jacketed specimens, the failure was at the jacketing zone.

6. Increasing retrofitting thickness results in reduction in deflection value and increase in load carrying capacity. But we can't increase the thickness above a limit.

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