International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-8 Issue-6, August, 2019

A Non-Linear Finite Element Modelling of Composite Beam to CFST Column Connection

D. R. Panchal, H. D. Devani

Abstract: The use of steel and concrete composite structure is increasing day by day especially the use of CFST columns in multistory composite building frames due to the reason that they can significantly reduce overall construction time by eliminating the need of formwork and sometimes even reinforcing bars. However, creating an ideal joint between composite beam and CFST column is quite challenging task from design, analysis and construction point of view. This connection behaviour can best be understood by its moment-rotation curve. So, here attempt has been made to model this composite connection numerically with the software which uses Finite Element Methods as a tool and results are validate. The composite connection possesses all three kinds of non-linearity, that are, geometric, material and boundary/contact nonlinearities. It is known that composite connection is nothing but the combination of bare steel connection and reinforced concrete slab with proper shear transfer mechanism and so first a bare steel connection and reinforced concrete beam is modelled. An explicit representation of connection is not necessary as long as the adequate features are captured. So attempt has been made to optimize the connection where ever it is possible. Usually design engineers design composite structure while neglecting the "composite action"in during the analysis. Sometimes these composite actions contribute much in resisting the applied load.

Keywords: CFST Column, Composite Action, moment rotation curve, Finite Element Method.

I. INTRODUCTION

Designing of structures for bridges and buildings mainly concerned with provision and support of load-bearing horizontal surfaces, which we call it as slabs for buildings. Except in some long-span structures these horizontal surfaces or slabs are made up of RCC (Reinforced Cement Concrete) for the reason that no other material provides better resistance to corrosion, fire, abrasion with same amount of strength combined with low cost.

Economical span of that horizontal surface/slab is little more than that at which it's thickness becomes sufficient to resist the point load to which it may be subjected or, in buildings, to provide sound insulation required. Now materially there are two choices to construct those beams/ribs namely, Steel or RCC. RCC is preferred over Steel due to the monolithic action between them (slab and beam) makes it possible for substantial breadth of slab to act as top flange for supporting beam/rib.

At spans more than about 10m and also when loss of strength for steel by fire is not of much an issue, as in most bridges, steel beams are more economical then of RCC. But when beams are made up of steel and slab of RCC, steel beams or steel framework should be designed to carry whole load of RCC slab and it's loading, because longitudinal shear cannot transfer between RCC slab and Steel beam, there will be slip.

But by about 1950 development of shear connector allowed transfer of longitudinal shear force between RCC slab and steel beam, with that it is possible to have T-beam action that had long been used in RCC construction. The term 'Composite Beam' referred to this type of beam and structures designed considering this type of action are called Composite Structures

II. COMPOSITE JOINT

According to Eurocode, a Composite joint is a joint between a composite member and another composite, steel, or reinforced concrete member, in which reinforcement is taken into account in design for the resistance and stiffness of the joint. Various types of joints which are present in typical composite frame buildings are,

- The base plate connections of composite columns
- composite column splices
- Beam-to-Column shear connections
- Beam-to-Column moment connections and semi-rigid connections
- Composite Beam-to-Beam Splices

III. MODELLING OF JOINT BEHAVIOUR

After predicting rotational behaviour of connection or joint for applied loading, it needs to be represented mathematically in such a way that it can be used by design softwares like ETBAS, STADD Pro., SAP2000 etc…

It should be noted that the connection rotational deformability has a destabilizing effect that gives rise to additional drift as a result of the decrease in effective stiffness of the members to which the connections are attached. The increase of the frame sensitivity to second-order effects plays a very important role in the load-carrying capacity and ductility supply of semi-rigid frames.

Revised Manuscript Received on October 30, 2019.
* Correspondence Author
Dr. D. R. Panchal*, Assistant Professor, Applied Mech. and Struct. Engineering Department, M. S. University of Baroda, Vadodara, Vadodara, India. Email: panchaldr@gmail.com
Mr. H. D. Devani, Post Graduate Scholar, Applied Mech. and Struct. Engineering Department, M. S. University of Baroda, Vadodara, Vadodara, India. Email: hddevani@gmail.com

Advanced methods of structural analysis require a very accurate modelling of the beam-to-column joint behaviour and in order to closely reproduce the expected behaviour of joints, panel zone and each side of connection should be modelled separately. In which diagonal spring provided in panel zone accounts for shear deformation of panel zone and the rotational spring on either side of panel zone accounts for the flexural deformability of the corresponding connections. Above mentioned modelling of joint can be significantly simplified with a negligible loss of accuracy by using two separate rotational spring elements whose M-θ curve accounts for the rotational behaviour of the panel zone as well as for the connection behaviour. So accurate prediction of M-θ curve is necessary in order to do a reliable structural analysis, and which can be done with multi-linear or curvilinear M-θ curve. For simplified methods of structural analysis linear or bilinear model of M-θ curve can be utilized. It should be recognized that there is very important interaction between the joint modelling, the method of global structural analysis and the joint classification. For linear elastic analysis, linear spring can be used, due to the fact that in linear elastic analysis joints are classified based on stiffness criterion only, that are pin, rigid or semi-rigid. Conversely, if the rigid-plastic method of global analysis is used, where the joint flexural resistance is of concern, there joint modelling can be based on bilinear rigid-plastic moment-rotation curve. Joints in this case are classified as either nominally pinned, partial strength or full-strength. Finally, if elastic plastic analysis has to be carried out, bilinear or multilinear/curvilinear moment-rotation curve should be used. In this case Joint classification is based on stiffness and strength criterion.

IV. FE MODELLING OF COMPOSITE CONNECTION

Figure 1, shows the various parts taken to model composite connection. These parts are partitioned to have a good quality of mesh as shown in Figure 1. In the current FE model steel sheeting is not modelled as the solution was not converging. As the connection region is hogging moment region and the primary use of steel sheeting is to resist tension induced in the mid span of composite beam, it can safely be excluded from FE model. Further, as it was discussed, a Composite joint is a joint between a composite member and another composite, steel, or reinforced concrete member, in which reinforcement is taken into account in design for the resistance and stiffness of the joint, so to model or capture the effect of composite joint one has to model reinforcement accurately.

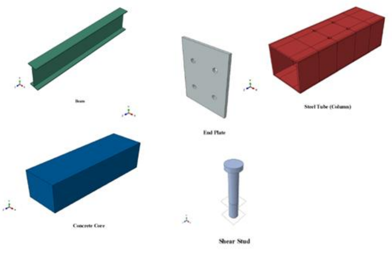

Fig. 1. Diffrent parts used to model Composite Connection

V. ASSEMBLY AND INTERACTIONS

Figure 2, shows the final assembly of composite connection.

A. Contacts

The tangential interaction between end plate and column and concrete core and column was modelled with 0.25 coefficient of friction and “hard”contact was used for normal behaviour. These contacts were modelled with finite sliding formulation and surface to surface discretization. All the other interaction like slab and column, slab and beam etc. were considered as frictionless with “hard”contact formulation.

B. Bolt Modelling

Bolts are modelled as beam element with kinematic coupling constraint. These are shown in Figure-3.

C. Constraints:

Tie constraint is used between endplate and beam due to beam is directly welded to the endplate. Further, the tie constraint was also used between stud connector and beam for the reason stud connectors are directly welded to the top of the steel beam. As shown in Figure 1, partition is made at 1/3 rd of the length of the stud connector to avoid over constraint issues, because stud is tied to beam as well as embedded into slab. So, upper portion of the stud only embedded into the slab part. At the cantilever end of steel beam rigid body constraint is used as shown in the Figure-3 and the reason for this is also explained in previous chapter.

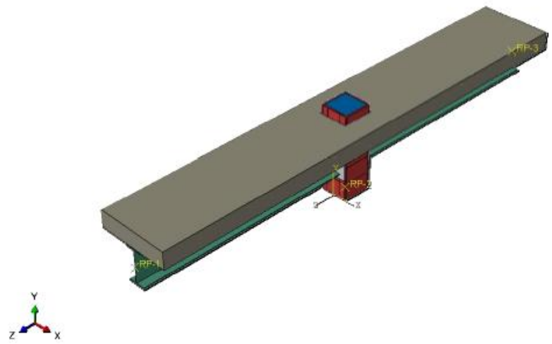

Fig. 2 Assembly of composite connection.

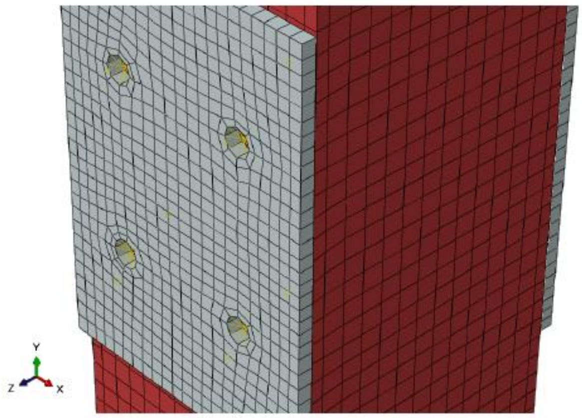

Fig. 3 Bolt Modelling with Kinematic Coupling

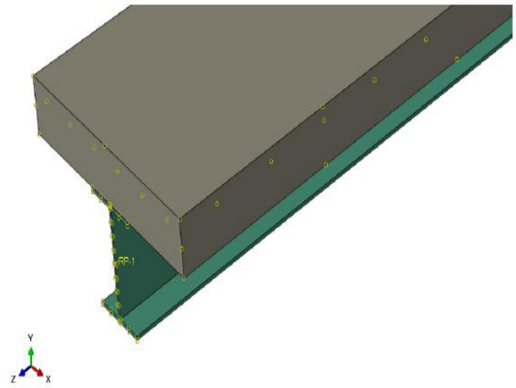

Fig. 4. Rigid Body Constraint End Of Steel Beam

Reinforcement and upper portion of the stud connector are embedded into the RCC slab as shown in Figure 4. It is used to specify an element or a group of elements that lie embedded in a group of host lements whose response will be used to constrain the translational degrees of freedom of the embedded nodes (i.e., nodes of embedded elements). It is used to model a set of rebar-reinforced membrane, shell, or surface elements that lie embedded in a set of three-dimensional solid (continuum) elements; a set of truss or beam elements that lie embedded in a set of solid elements; or a set of solid elements that lie embedded in another set of solid elements.

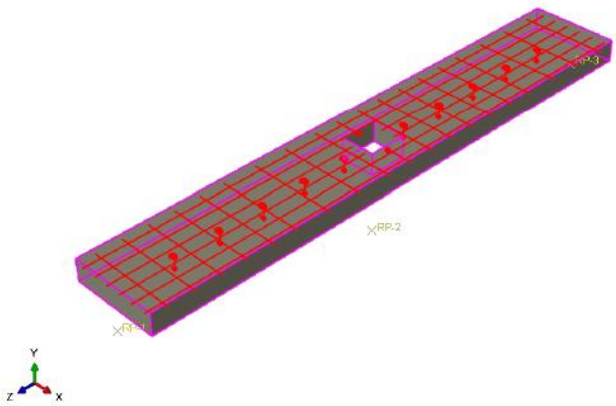

Fig. 5. Embedded Constraint

Rigid body constraint was also used on the lower part of the column as shown in Figure 6 for the application of load.

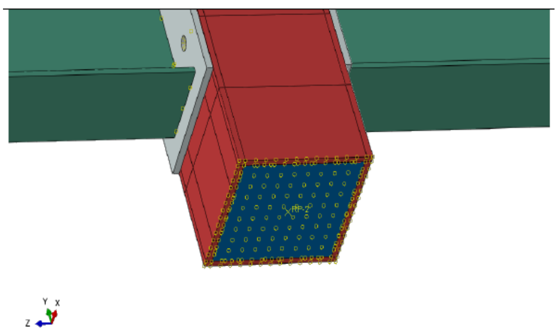

Fig. 6. Rigid Body Constraint on the lower face of the column

VI. ANALYSIS PROCEDURE

In the first step bolt preloading is applied with Static-General type of analysis with initial and maximum time increments taken as 0.05 and minimum increment size allowed is 10^{-15}. In the second step using linear perturbation, critical buckling load was predicted for the first 6 modes. The displacement field was requested as an output file in ".fil"format with *NODE FILE command. This file is used to introduce imperfections in the Riks method of analysis with *IMPERFECTION command. In the third or loading step Static-General and Static-Riks both the method is utilized for results comparison.

All the parts are meshed with 3-D elements except bolts and reinforcement, which are meshed with beam elements and truss elements respectively. For 3-D parts, reduced integration elements with enhanced hourglass control (C3D8R) are used while for bolts B31 and for reinforcement T3D2 elements are used. Mesh density, types of elements, mesh verification, problems associated with 3-D elements etc. are discussed.

As discussed earlier in the first step of analysis bolt pretension force of 216kN was applied that is 70% of the yield strength of the bolt material. In the subsequent step that is of loading, for Newton-Raphson method displacement control loading was used with 60 mm of displacement and for Riks method only unit load, that is, 1kN load was applied. The solution will stop in Riks method when the problem becomes unstable. The Boundary conditions are taken as mentioned in the experiments and shown in the Fig. 6.

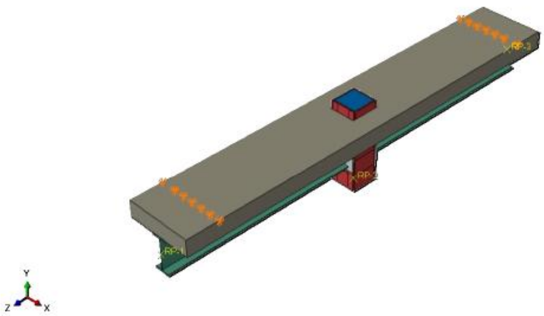

Fig. 7 Boundry condition

VII. RESULTS AND DISCUSSIONS

Figure 8 compares the Force-Displacement curve of current FE model with Arc-Length method and Newton-Raphson method to the FE model developed by A. Ateai and M.A. Bradford. It can be said that current model predicts the response of composite connection with sufficient accuracy and also Newton-Raphson method able to predict the response till 33mm of displacement. However, Newton-Raphson method was not able to capture the local buckling of compression flange. Figure 9 compares the moment-rotation response of the current FE model of composite connection specimen CJ1 with that of the FE model developed by A. Ateai and M.A. Bradford and Experiments performed by Loh et al. (2006). It can be said that current FE model overestimates the response of the connection in the initial range of loading.

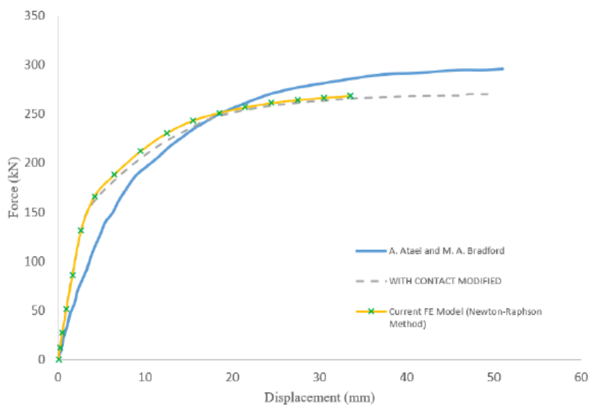

Fig. 8. Force-Displacement Curve Comparison

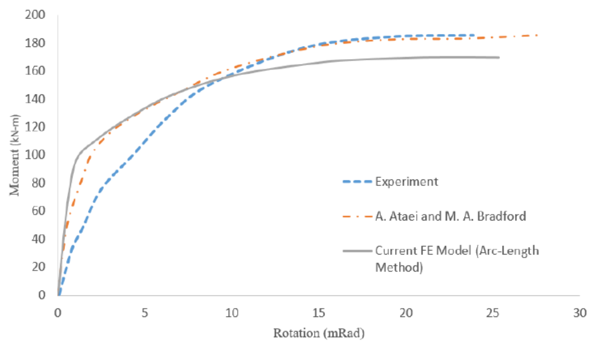

Fig. 9. Moment-Rotation Curve Comparison

VIII. CONCLUSION

FE modelling can indeed be used to predict the behaviour of Composite Connection in a very cost-effective manner compared to the experiments. However, FE modelling cannot replace the valuable insights given by experiments and also to validate the results of a FE model one need the experimental results. When the response of composite connection specimen CJ1 compared with the response of the bare steel specimen SJ6, it is observed that composite connection provide much higher resistance strength and energy absorption capacity compared to bare steel specimen and one has to consider "Composite Action"in a composite structure to come up with economical design.

Various researchers have suggested that the use of arc-length method is necessary to solve the composite connection and denied the use of Newton-Raphson method due the reason that it diverges at very low load level. But in the current study it is shown that the Newton-Raphson method can also be used to solve the composite connection problem to a certain level. However, Newton-Raphson method sometimes may not be able to capture the buckling of structure or its component and it certainly cannot be used to capture post buckling or unstable collapse response of connection. For that one has to use arc length method or explicit dynamics method.

It is also proved that an explicit representation of connection is not always necessary as long as the adequate features are captures, that is, bolt can indeed be modelled by 1-D beam elements with kinematic coupling, and by doing that one can reduce the various causes of non-convergence of the solution. Similarly, steel sheeting is not modelled in the current FE model of composite connection, due to the solution was not able to converge and still when the results are compared with FE model developed by other researcher, the current FE model behaved quite well. This is because in the hogging moment region, composite connection resists the applied load primarily with reinforcing bars. In the sagging moment region one has to model steel sheeting.

The current FE model does not able to capture exact behaviour of composite connection when compared with experiments, the reason for that is that there are tons of parameters involved in the FE modelling of composite connection like material modelling, contact modelling, solver type, parallelization techniques, meshing of the components, type of elements used etc. each and every parameter will affect the response of the connection to a certain extent. Among these various parameters, material modelling is the most challenging task for FE modelling and especially for concrete. But overall behaviour of the current FE model was quite good.

REFERENCES

1. A. Azizinamini, Monotonic Response of Semi-Rigid Beam to Column Connections, Msc Thesis, Department Of Civil Engineering, University Of South Carolina, Columbia (1982).
2. Mohammad Jobaer Hasan, Mahmud Ashraf, Brian Uy Moment-Rotation Behaviour of Top-Seat Angle Bolted Connections Produced from Austenitic Stainless Steel (2017), School of Engineering and Information Technology, The University of New South Wales, Canberra, Act 2610, Australia
3. Linear Elastic Behaviour, 22.2.1, Abaqus 6.14 Analysis User's Guide.
4. Classical metal plasticity, 23.2.1, Abaqus 6.14 Analysis User's Guide.
5. Static stress analysis, 6.2.2, Abaqus 6.14 Analysis User's Guide.
6. Abaqus Analysis User's Guide, Part VI: Elements.
7. Carreira, D. J., and Chu, K. H. (1985). "Stress-strain relationship for plain concrete in compression."ACI Struct. J., 82(6), 797–804.
8. Michel Samaan, Amir Mirmiran, Member, ASCE, and Mohsen Shahawy, Model of Concrete Confined by Fiber Composites, J. Struct. Eng., 1998, 124(9): 1025-1031.
9. Jeeho Lee and Gregory L. Fenves, A Plastic-Damage Concrete Model for Earthquake Analysis of Dams, Earthquake Engineering and Structural Dynamics, Earthquake Engg. Struct. Dyn. 27, 937-956 (1998).
10. Venkatesh Patnana, A.Y. Vyavahare, Moment Rotation Curves for Semi Rigid Connections, Dept. of Applied Mechanics VNIT, Nagpur, India (2016).

AUTHORS PROFILE

Dr. D. R. Panchal is currently Assistant Professor in Applied Mechanics and Structural Engineering Department at Faculty of Technology and Engineering, The Maharaja Sayajirao University of Baroda, Vadodara. He has more than 17 years of teaching, research and corporate experience. He has published more than 50 research papers in various International & National Journals, Conferences. He has published books also. He is member of several Indian and International professional bodies. His research interest includes Composite steel-concrete structures, Earthquake resistance structures and Computer aided analysis and design of multi storey buildings.

Mr. Harsheel Devani was M.E. civil research scholar in Applied Mechanics and Structural Engineering Department at Faculty of Technology and Engineering, M. S. University of Baroda, Vadodara. He obtained his B. Tech. civil degree from Gujarat Technological University (GTU), S.V.I.T-VASAD, Anand, Gujarat, India.