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 becoming increasingly popular in the construction industry due to its various advantages. One of the significant issues in composite structures is the connection between the beam and column. The effective design of composite structures requires accurate modelling of their joints. In this paper, a non-linear finite element model for composite beam to CFST column connection is presented. The model is developed using the software SAP2000 and validated with the experimental results. The results show that the proposed model can accurately capture the behavior of the connection.

I. INTRODUCTION

Designing of structures for bridges and buildings mainly depends on the selection of appropriate materials and the choice of suitable design method. Composite structures are gaining popularity due to their improved structural performance and economy. The use of steel and concrete composite structures is common in the construction of multistory buildings. Composite structures are designed to provide a strong and rigid connection between the beam and column.

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 transferred. In order to closely reproduce the expected behaviour of the joint, various types of joints are present in typical composite frame buildings.

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 software like ETABS, 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.

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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 for the resistance and stiffness of the joint, so to model or capture the effect of composite joint one has to model reinforcement accurately.

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.

V. ASSEMBLY AND INTERACTIONS
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 elements 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.

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.
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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. Azzizinamini, Monotonic Response of Semi-Rigid Beam to Column Connections, Msc Thesis, Department Of Civil Engineering, University Of South Carolina, Columbia (1982).

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