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Study on Various Finite Element Analysis on Concrete Filled Steel Tube Columns

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ABSTRACT: Concrete Filled Steel Tube Columns are found to be effective in terms of material utilization and there by sustainable development especially in high rise buildings. Numerical modeling of these columns using finite element software is an effective time saver while predicting their performance under loading. This paper summaries various finite element simulation techniques followed by researches in developing the models. The details included in the study covers the material properties of confined concrete and steel, element properties, the interface between tube and concrete, the initial imperfections both in steel tube as well in concrete, the effect of preloading and effect of partial loading etc.

KEYWORDS: Concrete-filled steel tube, CFST, Finite Element, Composite column.

I. INTRODUCTION

The use of composite structures being increased in recent years in construction industry, owing to the effective utilization of its materials. One such attempt was the introduction of Concrete Filled Steel Tube Columns (CFST Columns) in which rectangular or circular steel tubes are filled with concrete. The concrete infill delays the local bucklingof the steel tube, while the steel tube provides confinement to the concreteinfill. CFST columns impart better strength and ductility compared to conventional structural steel or reinforced concrete members. Also, thesteel tube acts as a formwork for placing the concrete, which reduce the cost of construction.Schematic views showingapplications of CFST columns in bridges and high-rise buildings are given in Fig. 1.Numerous studies were conducted to predict their behavior in the past, majority of them are experimental based. Numerical studies were also carried out by various researches, but less in number. Commercially available Finite Element Packages are being used to do the numerical analysis and their proper use makes the predictions correct. This leads to much economical designs of columns with less time. This paperreviews the various numerical finite element models that are develop in the past to predict the behavior of CFST columns in detail.

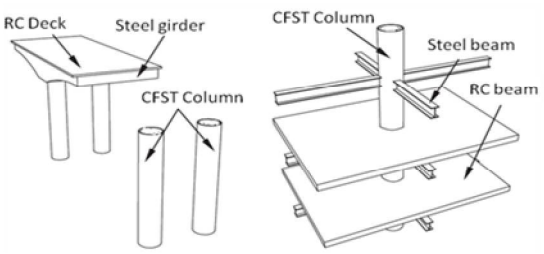

Fig. 1. Various applications of CFST columns

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II. STUDY ON NUMERICAL MODELLING

It can be observed that majority of the analysis has been carried out using the software ABAQUS. Some researchers have used ANSYS to simulate the same. The modeling method adopted to simulate material properties, boundary conditions, interface, geometric imperfections, preloading and partial loadingin these studies are summarized in the following sections.

A. MATERIAL PROPERTIES

The steel is taken as an elastic–plastic material with strain hardening in compression. A hardening rigidity of 2% $E_s$after yield may be adopted. The assumed stress–strain curve taken in [1] is shown in Fig. 2. The steel material behavior was defined using the Von Mises yield surface, associated flow rule, and kinematic hardening. The post-yield hardening modulus was assumed to be equal to Es/100[2]

Concrete may be treated as an elastic material until the confined strength is reached and then as plastic through the Drucker Prager option. The concrete material was modeled using the damaged plasticity material model in [2,3,4,5]. This model accounts for multi-axial behavior using a special compression yield surface to account for different evolution of strength in tension and compression. Typical stress strain relation used by [3,4] is shown in Fig. 3 and the relation in tension is shown in Fig. 4 which is used by [6].

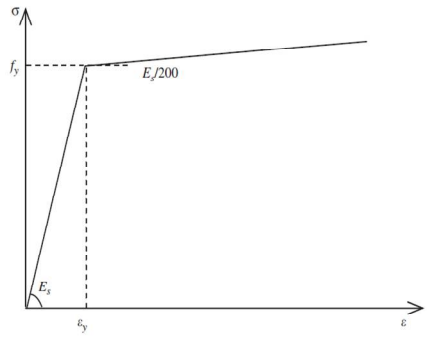

Fig. 2. Stress–strain curve for steel

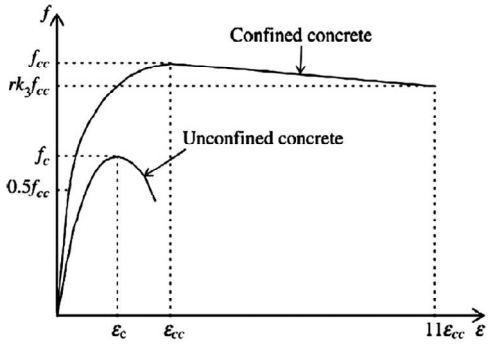

Fig. 3. Stress–strain curve for confined and unconfined concrete

The value of the dilation angle for unconfined concrete was 15°. Other researchers have reported using values between 15° and 30°. The default value of 0.1 was specified for the eccentricity ratio.

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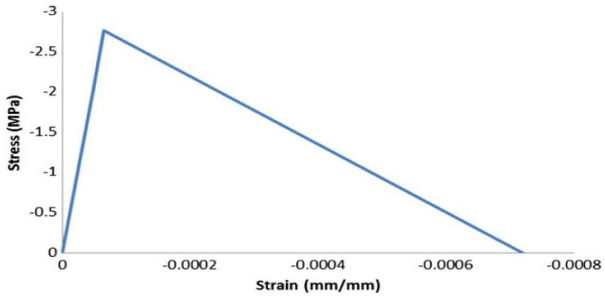

Fig. 4. Tensile Stress strain curve for confined concrete

The smeared cracking behavior in tension was specified using a stress vs. crack opening curve as shown in Fig. 5.

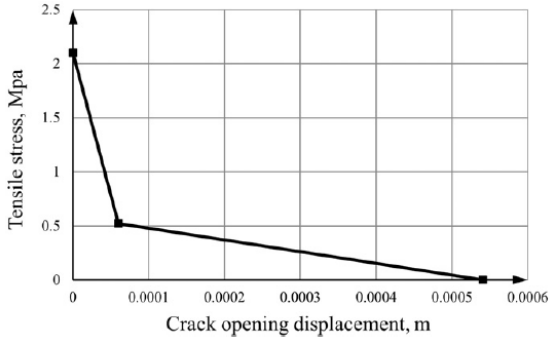

Fig. 5. Tensile stress-crack width based on CEB-FIP

B. Model and Boundary conditions

Because of symmetry of the specimens, only one-eighth of the column needs to be modeled, as shown in Fig. 6.

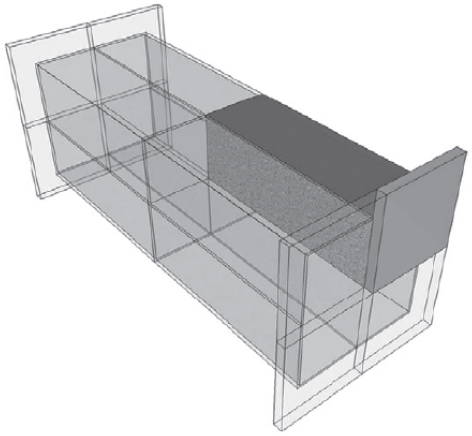

Fig. 6. Modeling only symmetrical region

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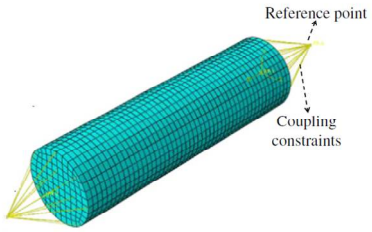

Fig. 7. Finite Element Model showing Boundary conditions

All the displacement degrees of freedom perpendicular to symmetric planes were to set zero using coupling restrained as shown in Fig 7. A rigid platewas used to simulate the end plate. Load was applied on the reference point as static uniform load using the displacement control.

C. *ELEMENT PROPERTIES AND MESHING*

In study [7], the steel shells were modeled as two layers of three dimensional quadratic solid elements C3D20R.The concrete adjacent to the steel walls was modeled as three dimension alquadratic solid elements C3D27R to avoid the intersecting of the concrete through the steel plate, and the rest of the concrete was modeled as C3D20R to reduce the run time. The rigid plate connected tothe top of the steel box was modeled as three-dimensional rigid elementsR3D4.Thesurfaces of the steel box and end plate were set as master surfaces andthe concrete surfaces were set as slave surfaces. A reference point was set on the rigid plate at the position coincidentwith the center of the end plate. Compressive loading was applied through the reference point.

The steel tubes of the CFT members were modeled using a four-node S4R shell elements in [2,3,8]. These elements have: (i) six degrees offreedomper node, and (ii) five section points to compute the stress and strain variations through the thickness, and (iii) reduced integration inthe plan of the elements. The elements model thick shell behavior, butconverge to Kirchhoff's thin plate bending theory with reducing thickness. The concrete infill of CFT members was modeled using eightnode solid elements with reduced integration (C3D8R). These elements have three degrees of freedomper node and reduced integration to calculate the stresses and strains in the elements. The C3D8R elements are computationally effective for modeling concrete cracking.

To select the proper FE mesh size that provides accurate results with minimum computational time, different mesh configurations are to be considered and the one which converge should select. The different mesh arrangement tried by [6] is shown in Fig. 8. In this, the fine meshes Mesh2 and Mesh3converge to similar numerical results as compared with the course mesh (Mesh1), hence, Mesh2 was selected as it provides adequate accuracy and minimum computational time.

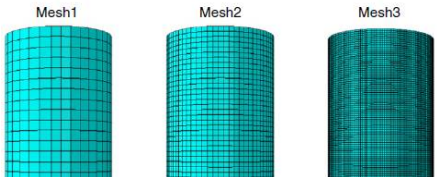

Fig. 8. Mesh convergence study

D. *STEEL CONCRETE INTERFACE*

Simulating the exact action of the interface between concrete and steel both at plastic and elastic stage is a difficult task. This contact were modeled in both the normal and tangential directionsin[2,3].The hard contact pressure-overclosure

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relationship with penalty constraint method was used for interaction in the normal direction. The penalty friction formulation with coulomb friction coefficient equal to 0.55[2], 0.6 [9] and maximum interfacial shear stress equal to 0.41 MP a was used for interaction inthe tangential direction. There was no additional bond between the steel tube and the concrete infill in the model.The steel tube and concrete infill could slip relative to each other when the applied interfacial shear stress exceeded 0.55 times the contact pressure. Same Surface-based interaction with a contact pressure model in the normal direction and a Coulomb friction model in the tangential directions to the surface between steel tube and core concrete were used in [10]

The contact between the stainless steel stiffened tube and the concrete was modeled by interface elements in [11]. The interface elements consist of two matching contact faces of stainless steel stiffened tube and concrete elements. The friction between the two faces was maintained as long as the surfaces remained in contact. The coefficient of friction between the two faces is taken as 0.25 in the analysis. The interface element allows the surfaces to separate under the influence of tensile force. However, both contact elements were not allowed to penetrate each other.

E. GEOMETRIC IMPERFECTIONS

1) Steel tube: Initial imperfections in steel shells are inevitable and are to be considered while analyzing the column. Possible Local buckling was obtained by conducting an eigen value analysis on bare steel tubes (without any filling) [2,3,7]. The amplitude (magnitude) of the geometric imperfection was set equal to 0.1 times the steel tube thickness. First buckling eigen mode shape that has been used by [2,3] to define the geometric imperfection is shown in Fig. 9.

For columns with large slenderness, alateral deflection of L/1000atthemid-heightwasadoptedtoconsider the global initial imperfection by [9]. These long columns suffer from initial imperfections. Hence, to include these imperfections in the simulation of slender columns, the modeling should consist of two steps as explained in [12]. In the first step, an ela sticbuckling analysis, called a linear perturbation analysis, was performed on a perfect slender column too btainits buckling mode. Material plasticity strains and geometric imperfections, based onthe first eigenmode, are then included I nthese cond step of the analysist oobtain the ultimate loads and the failure modes of the slender columns under axial compression. This is called the nonlinear analysis and it uses the modified RIKS method provided in ABAQUS.

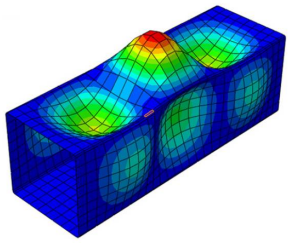

Fig. 9. Model showing imperfections in steel

2) Concrete: There are two types of gaps between concrete and steel tube; circumferential gap and spherical-cap gap, as shown in Fig. 10.

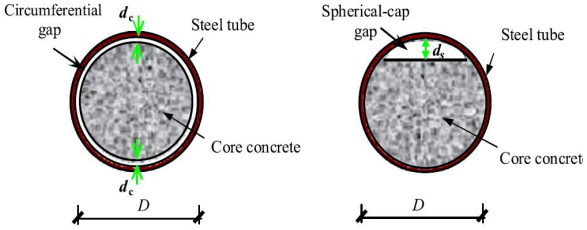

Fig. 10. Imperfection in Concrete

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Circumferential gap is due to various reasons such as shrinkage of concrete temperature variation, negative confining force produced during the initial stage of CFST structures subjected to compression. Other one is due to poor construction practice.

For CFST with as pherical-cap gap, the shear stress at the interface between concrete and the steel tube will keep increasing with the increase of normal contact pressure until it exceeds the surface bond limit. After that, the relative slip is formed and the shear stress is then taken as constant. For a CFST with a circumferential gap has no direct contact with the inner surface of the steel tube at the initial stage. Therefore, both normal contact pressure and tangential shear stress are taken a s zero at the beginning in the finite element model. Then after the contact occurs, the tangential frictional stress relies on the value of normal pressure stress [9,13].

F. PRELOADING AND PARTIAL LOADING

The steel columns are usually installed before inner concrete is placed. The steel columns are thus subjected to preload from constructional activities, self-weight of steel tubes and weight of wet concrete. The reload creates pre-stresses and deformation to the steel tubes, which would affect the load carrying capacity of the column.

In the FEA model [14], initially a preload was applied only on hollow steel tubes by deactivating concrete elements. In the second step, concrete elements were activated, analyzed with the initial deformations due to preload. The column was loaded until failure. During the second step, the preload was remained constant until column failure. The summation of the reaction force from boundary and preload was regarded as the capacity of composite column. The procedure adopted was shown in Fig. 11.Fig. 12 shows the vertical load (N) versus average longitudinal strain (e) under different preload ratios [14].

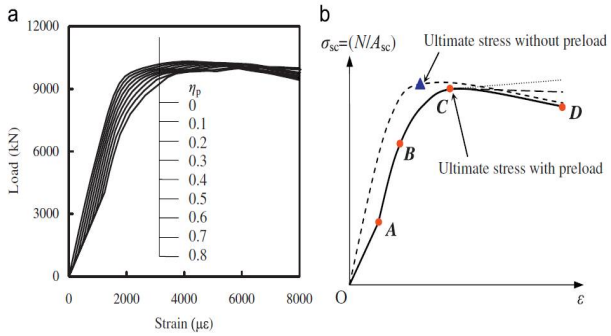

Fig. 11. Loading sequence showing preloading

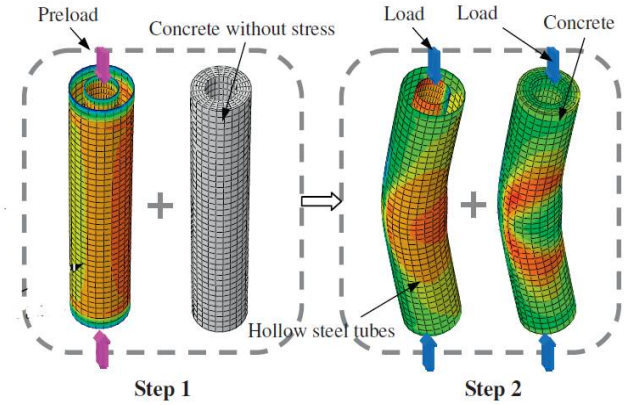

Fig. 12. Axial load Strain variation

It can be seen that generally four stages are presented for the columns with preload on tubes. 1. Preload stage (from point O to point A). During this stage, the preload is applied only on steel tubes. The initial deflection and longitudinal stress occur in the tubes. 2. Elastic stage (from point A to point B). The load is applied on the whole composite section, and the steel and concrete bear the load independently during this stage. The stiffness of the curve is comparable to that

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without preload on tubes. 3. Elastic–plastic stage (from point B to point C). The interaction will be generated between tubes and sandwiched concrete due to the different Poisson's ratio of two materials during this stage. The load increases with the deformation of the specimen, and the confinement provided by the outer steel tube is enhanced as well. When compared to the column without preload on tubes, the ultimate stress is smaller and the average strain corresponding to the ultimate stress is larger, fort he confinement effect of steel tubes will ber educed with the preload. 4. Hardening ordescending stage(from point C to point D). During this stage, the average stress will either increase or decrease due to the confinement effect of the outer tube.

CFST Columns may also subjected to partial compression as in the case of a bridge pier having compressive load form bearings. A 'reference point' on the top surface of the bearing plate was set to model the hinge on the top by [15], and the boundary conditions for the were 'pinned' ,i.e. the translation components of reference point were restricted and the rotations of reference point were setf ree as shownin Fig. 13. The top surface of the bearing plate had the same translation and rotation components as those of the reference point. A uniform axial deformation was applied to the bottom surface of the composite columns, which was similar to the situation in the tests. The deformations were applied in sever alincremental steps, and there sponses were calculated. The failure mode also shown in Fig. 13.

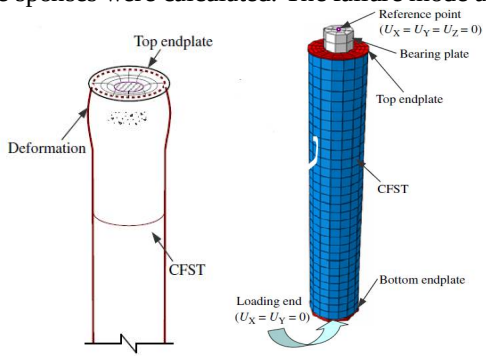

Fig. 13. Partial loading and failure mode

III. CONCLUDING REMARKS

Following conclusion can be drawn from the review of the studies conducted on CFST columns using finite element formulations.The exact behavior of CFST can be simulated using Finite Element software's with high level of accuracy. The initial imperfections, both in steel tube as well in concrete, the effect of preloading, effect of partial loading etc can be easily replicated using the numerical solution explained in this paper which is collected from the various recent previous studies.

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