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NONLINEAR ANALYSIS OF CONCRETE FILLED STAINLESS STEEL TUBULAR COLUMN

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Abstract - *The nonlinear behaviour of concrete-filled stainless steel tubular columns is discussed in this paper. A nonlinear 3-D finite element model was developed for the analysis of the composite columns. The pin-ended axially loaded composite columns had different lengths, which varied from short to long columns. The nonlinear material properties of the composite column's components comprising stainless steel tube and concrete were incorporated in the model. The effect of concrete confinement and interface between the stainless steel tube and concrete infill was also considered allowing the bond behaviour to be modelled. The finite element model has been validated against tests recently conducted on concrete- filled stainless steel tubular columns. The composite column strengths, load–axial strain relationships and failure modes were predicted from the finite element analysis and compared well against that measured experimentally. Furthermore, the variables that influence the composite column behaviour and strength comprising different lengths, external diameter-toplate thickness (D/t) ratios and concrete strengths were investigated in a parametric study. The parametric study has shown that the increase in column strengths owing to the increase in concrete strength is more significant for the columns having L/D ratios less than 6 as well as for the columns having D/t ratios less than 50.The composite column strengths obtained from the finite element analysis were compared with the design strengths calculated using Eurocode 4 for composite columns. It is shown that the EC4, in most cases, accurately predicted the design strength for axially loaded concrete filled stainless steel tubular columns.*

Keywords: *Concrete filled stainless steel tubular column, Nonlinear analysis, Finite Element analysis, contact elements, ANSYS*

INTRODUCTION

Due to the excellent composite action between the steel tube and concrete, concrete-filled steel tubular (CFST) columns are becoming increasingly popular and used in various structures throughout the world. Extensive experimental and analytical studies have been conducted to understand the behaviour of the composite columns from the year 1960s. From these investigations, different design codes have been formulated to reflect the design philosophies and practices in the respective countries, such as Australia, China, Japan, USA and European countries.

In recent few decades, finite element (FE) technique is becoming increasingly popular for modelling CFST columns thanks to the existence of many commercially available software, such as ABAQUS and ANSYS. FE analysis allows the direct modelling of the composite action between the steel and concrete components, and different factors, such as local and global imperfections, residual stresses and boundary conditions, can be considered more precisely. The prediction accuracy of a FE model, however, is greatly affected by the input parameters, especially by the selection of a suitable concrete model. FE analysis is now used routinely for design and research problems. To embrace the development of materials, new FE models may need to be developed to improve the prediction accuracy. To serve this purpose, sufficient test data need to be collected and used to verify the prediction accuracy.

We can say that Ambitious researches related cfst "concrete filled steel tubular" columns started at the beginning of the twentieth century by Swain and Holmes in 1915 , who first attempt to understand the behavior of this type of composite structures then came Kloppel and goder was carried out tests on short columns with different slenderness values and different types of loading axial loading and eccentric . Shams (1997) A detailed analytical study was performed using three dimensional nonlinear finite element analysis to identify the response of CFT columns under axial loading. Based on that study shams concluded the following.It is found that the *Diameter/thickness*, unconfined compressive strength of concrete, and cross-sectional shape have significant effect on the response of CFT columns, and then the relative effect is quantified. The confinement effect in circular columns is higher than in square columns due to a more uniform stress distribution.

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O'Shea and Bridge (1997) made an experimental work to describe the behavior of circular concrete filled steel tubular column, the pipes been used in that research has the diameter to steel pipe thickness ratio range : (55-200) , and length to diameter ratio equal to 3.5 . H. Hu et al. (2003) made a nonlinear finite element model for concrete filled steel tubular columns using abaqus software , the experimental data were collected from Schneider (1998) and Huang et al. (2002) .

Yu , Zha , Ye and She (2009) a unified formulation is proposed to predict the composite compressive strength of circular concrete-filled steel tube (CCFST) columns . The formula is obtained from the analytic solution of an elastic composite cylinder under axial compression . The formula is further calibrated by introducing a number of correlation coefficients that are validated by test results. Suliman Hassan Abdalla (2012) tested a total of one hundred and three specimens the compressive behavior of the Concrete Filled Steel Tubes (CFSTs) and the Confined Concrete Filled Steel Tubes (CCFSTs) under axial compressive loads is experimentally investigated.

Finite Element Modelling

Surface-to-surface contact is usually used for the interaction simulation of the steel tube and concrete. A contact surface pair comprised of the inner surface of the steel tube and the outer surface of concrete core can be defined. "Hard contact" in the normal direction can be specified for the interface, which allows the separation of the interface in tension and no penetration of that in compression. For CFST columns, there is little or no slip between the steel tube and concrete since they are loaded simultaneously. For this reason, the column's behaviour is not sensitive to the selection of friction coefficient between steel and concrete. Friction coefficients of 0.25, 0.3 and 0.6 were used by Schneider, Lam et al. and Han et al. respectively.

Boundary conditions and load application

The concrete-filled stainless steel tubular columns investigated in this study were pinned at both ends. In the tests, the pin-ended columns were achieved by means of designed hinge assemblies. In the finite element (FE) model, the hinge assemblies were modelled as rigid upper and lower plates, which were allowed to rotate about the axis of the plate, direction y–y. The upper and lower end plates nodes were connected to the matching specimen end nodes. The centre of the outside surface of the bottom plate was restrained against all degrees of freedom while that of the top plate, the loading position, was allowed to displace in the vertical direction only, direction z–z. The load was applied in increments and the nonlinear geometry was included in the analysis. The load was applied as a static concentrated load, which is identical to the real situation in pin-ended columns.

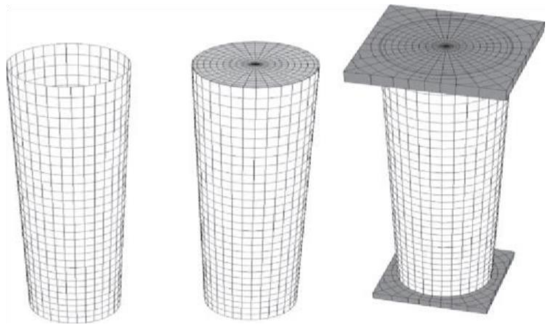
Modelling of confined concrete

The idealized uniaxial response for the compressive stress–strain curves of both unconfined and confined concrete, where fc is the unconfined concrete cylinder compressive strength which is equal to 0.8(f_{cu}), and fcu is the unconfined concrete cube compressive strength. The corresponding unconfined strain (ε_c) is taken as 0.003 for plain concrete as recommended by the ACI Specification. The corresponding unconfined strain (ε_c) is taken as 0.003for plain concrete as recommended by the ACI Specification To define the full equivalent uniaxial stress– strain curve for confined concrete,three parts of the curve have to be identified The first part is the initially assumed elastic range to the proportional limit stress. The value of the proportional limit stress is taken as 0.5 (f_{cc}) as given by Huetal. While the initial Young's modulus of confined concrete (E_{cc}) is reasonably calculated using the empirical equation given by ACI. Poisson's ratio (u_{cc}) of confined concrete is taken as 0.25.

$E_{cc} = 4700\sqrt{f_{cc}}$ MPa

Material modelling of stainless steel section

The measured stress–strain curve for the stainless steel used in the tests was used in this study. The material behaviour provided by ANSYS (using the PLASTIC option) allows for a nonlinear stress–strain curve to be used. The first part of the nonlinear curve represents the elastic part up to the proportional limit stress with Young's modulus of 195 GPa and Poisson's ratio equals to 0.3 were used in the finite element model. Since the buckling analysis involves large in-elastic strains, the nominal (engineering) static stress–strain curves were converted to true stress and logarithmic plastic true strain curves



Part (1) Part (2) Part (3)

Modelling steps of concrete-filled stainless steel tubular columns. Part (1) Modelling of circular tubes using shell elements, Part (2) Modelling of concrete using solid elements and Part (3) Modelling of loading plates using solid elements

Buckling mode (Eigenmode 1) for concretefilled stainless steel tubular columns.

(a) (b)

Comparison of deformed shapes at failure for circular hollow section specimen (a) Experimental and (b) Numerical

(a) (b)

Comparison of deformed shapes at failure for concrete-filled stainless steel tubular long column specimen (a) Experimental and (b) Numerical.

Verification of finite element model

The finite element model of pin-ended axially loaded concrete filled-stainless steel circular tubular columns developed in this study was verified against the tests detailed in Ellobody and Ghazy. The composite column strengths obtained from the tests (P_{Test}) and finite element analyses(P_{FE}) are compared.

It can be seen that good agreement exists between test and finite element results. The mean value of P_{FE}/P_{Test} ratios is 0.99 with the corresponding coefficient of variation (COV) of 0.021

Parametric study and discussions

The verified finite element model was used to investigate the effects of the change in concrete strength, column slenderness and column length on the behaviour and strength of concrete- filled stainless steel circular tubular columns.

The strength of the concrete-filled stainless steel tubular columns investigated in the parametric study (P_{FE}) and failure modes were predicted using the developed finite element model. It can be seen that for the columns having a low Diameter/thickness ratio of 25, the increase in column strength owing to the increase in concrete strength is significant for all column lengths. While, the increase in column strengths for the columns having higher Diameter/thickness ratios of 50 and 75 owing to the increase in concrete strength is more significant for the columns having Length/Diameter ratios less than 6.The concrete crushing failure mode was observed for the columns having compact sections with a Diameter/thickness ratio of 25 and concrete strengths 30 and 60 MPa. The local buckling failure mode was observed for the columns having a higher Diameter/thickness ratio of 75 and Length/Diameter ratios of 3 and 6 as well as observed for the columns having an intermediate Diameter/thickness ratio of 50, Length/Diameter ratios of 3 and 6 and higher concrete strengths of 90 and 120 MPa. The combined (local buckling & concrete crushing) failure mode was observed for the compact columns having a Diameter/thickness ratio of 25 and a Length/Diameter ratio of 6 as well as for the columns having a Length/Diameter ratio of 3 and higher concrete strengths 90 and 120 MPa. Also, the combined (local buckling & concrete crushing) failure mode was observed in the columns having an intermediate Diameter/thickness ratio of 50, Length/Diameter ratios of 3 and 6 and concrete strengths of 30 and 60 MPa. Finally, the flexural buckling failure mode was observed in all columns having a Length/Diameter ratio of 12.

It can be seen that the increase in column strength owing to the increase in concrete strength is significant for the columns having Diameter/thickness ratios less than 50.This is attributed to that, for stockier cross-sections, failure occurs at higher strains, hence the concrete's strength and stainless steel's strain hardening become more significant. While, the strength of the column shaving higher Diameter/thickness ratios of 50 and 75 is more dependent on the local buckling of the stainless steel tube.

Comparison of column strengths with design strengths

The composite column strengths obtained from the finite element analysis (P_{FE}) and the design strengths calculated according to EC4 (PEC4) are compared. Both of the finite element and design strengths are considerably affected by the concrete cube strengths for all columns having different Length/Diameter ratios. Both of the finite element and design strengths have shown that the increase in column strengths owing to the increase in concrete strength is more significant for the columns having Length/Diameter ratios less than 6. It can be seen that the numerical and design strengths are considerably increased as the concrete strengths are increased for the columns having Diameter/thickness ratios less than 50.

CONCLUSIONS

A nonlinear 3-D finite element model, for the analysis of pin-ended axially loaded concrete-filled stainless steel tubular columns, has been developed and reported. The inelastic material properties of stainless steel tube and concrete as well as the effect of concrete confinement have been carefully incorporated in the model. The interface between the stainless steel tube and concrete infill was also modelled allowing the bond behaviour to be modelled. The comparison between the experimental and numerical results has shown that the model can accurately predict the behaviour of concrete-filled stainless steel tubular columns.

The verified finite element model was used to perform parametric studies investigating the effects on the structural behaviour of the composite column strengths owing to the change in the lengths, external diameter-to-plate thickness ratios and concrete strengths. It is shown that the increase in column strengths owing to the increase in concrete strength is more significant for the columns having Length/Diameter ratios less than 6 as well as for the columns having Diameter/thickness ratios less than 50. The composite column strengths obtained from the finite element analyses were compared with the design strengths calculated using Eurocode 4 for composite columns. Generally, it is shown that the EC4, in most cases, accurately predicted the design strength for axially loaded concrete filled stainless steel tubular columns.

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