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FINITE ELEMENT ANALYSIS OF CURVED STEEL GIRDERS WITH TUBULAR FLANGES

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Abstract— A tubular flange girder is an I-shaped steel girder of either rectangular or circular tubes as top and bottom flanges. Unlike a conventional curved I-girder tubular flange girder has large torsional stiffness which shows unnoticeable cross section distortion, and is, therefore, an interesting substitute girder for horizontally curved steel bridges. Finite element models of curved hollow tubular flange girder are presented in this paper, considering second order effects, initial geometric imperfections, and residual stresses. A parametric study is performed to study the effects of residual stresses, initial imperfections, thickness of stiffeners and number of stiffeners, their load carrying capacity. Finite element results are compared to conventional curved I-girder, differences of them will be summarized.

INTRODUCTION

Kim & Sause: Addressed the behavior of straight tubular flange girders with a round concrete filled tube as the compression flange and a flat plate as the tension flange (CFTFGs). They summarized several advantages of CFTFGs relative to conventional I- girders for bridges such as: (1) the concrete filled tubular flange provides more strength, stiffness and stability than a flat flange with same amount of steel, and (2) fewer cross frames are needed for CFTFGs to maintain lateral torsional stability compared to similar I girders, which reduces the fabrication and erection effort needed to construct a bridge.

Dong & Sause: Investigated the flexural strength of straight hollow tubular flange girder girders (HTFGs) with rectangular tubes for both the compression and tension flanges. The effect of stiffeners, geometric imperfections, residual stresses, cross section dimensions and bending moment distribution on the lateral torsional buckling flexural strength of HTFGs were studied and formulas for determining the flexural strength of HTFGs were evaluated.

Fan & Sause: Conducted the theoretical analyses of individual curved tubular flange girders and systems of multiple curved tubular flange girders braced by cross frames. The analyses method of Dabrowski was extended and used for the theoretical analyses. They also developed finite element model of curved tubular flange girders with curved I-girders.

Pi et al.: studied the non-linear behavior of curved I- girders. Under vertical loading, a curved I-girder develops both primary bending action and non-uniform torsion action and vertical deflections are coupled together to produce second order bending about the minor axis. The second order effects are significant for I-girders with

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large initial curvatures.

Pi & Bradford: Proposed formulas for the design of curved I-girders against the combined bending and torsion actions.

Jun Dong & Richard Sause: Studied the effects of second order nonlinear behavior of individual curved hollow tubular flange girders with rectangular tubes for both the compression and tension flange. The tubes and webs are sufficiently compacted. So that local buckling does not control the girder strength. The FE models include material inelasticity, second- order effects, geometric imperfections and residual stresses.

Finally, the behavior of individual CHTFGs is compared with the behavior of corresponding curved I-girders and the advantages of CHTFGs summarized.

Objectives

Using finite element model to study the following

- Effect of Residual Stresses as span varies.
- Effect of Geometric Imperfection.
- Effect of number of stiffeners. Effect of stiffener thickness
- Cross section dimension on load carrying capacities

Methodology

The analytical investigation process essentially consists of following.

1. Identification of parameters for analysis.
2. Finite element modelling of the desired section in ABAQUS.
3. Model validation.
4. Nonlinear load displacement study for the identified parameters.
5. Results and Discussions.

FINITE ELEMENT MODEL

For the present study, the finite element models were developed for an individual girder with simply supported boundary conditions and considering a uniformly distributed vertical load over the span. The important aspects of the models are considered below.

a) Coordinate system

The geometry of the curved girder is easily described within a cylindrical coordinate system whose origin is located at the center of curvature. The global 1, 2 and 3 axes are defined in the radial(lateral), circumferential(longitudinal), and vertical direction. Let D1, D2, D3, DR1, DR2 and DR3 are the displacements and rotations about the global coordinates 1, 2 and 3 axes respectively.

b) Boundary and load conditions

Simply supported boundary conditions are applied at the ends. At each end section, the vertical displacement (D3) of the nodes of the bottom wall of the bottom tube, the lateral displacement (D1) of all the nodes along the line through the web mid surface, and the twist rotations about axis-2 (DR2) of all the nodes on the section are restrained. The longitudinal displacement (D2) of the centroid of the web is restrained at only the left end section. The FE models are loaded with a distributed vertical load that is uniform over the span.

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c) Mesh convergence studies

In FE analysis mesh size is a critical, it closely relates to accuracy, computing time and complexity level. For the present studies by comparing the ultimate load capacities, it was found that an optimized FE mesh size of 60mm was adopted.

d) Material properties

An elastic perfectly plastic material is used for the steel. In the elastic range young's modulus is 200GPa and poisson's ratio is 0.3. The yield strength of the steel is 345MPa.

e) Analysis method

Nonlinear load displacement analyses with material inelasticity and second order effects were used to study the behavior of curved hollow tubular flange girders and curved I- girders. The modified Riks method available in ABAQUS was used for these analyses.

f) Controlling of cross section distortion

Transverse web stiffeners are usually used to reduce web distortion in I-girders, and for a CHTFGs, transverse web stiffeners also reduce the tube distortion where the stiffeners are attached to the walls of the tubes. Therefore, are introduced into the CHTFG FE models to reduce the cross section distortion. The stiffener elements are modelled using 3D shell element and are connected to the cross section by constraining the nodes in the stiffeners to the corresponding nodes in the flanges and web.

Diaphragms are commonly used to control distortion of box like cross sections. To avoid the need to install diaphragms within the tubes and simplify CHTFG fabrication, diaphragms are introduced only at the ends of the tube to reduce the tube distortion. In the FE models, the tube diaphragms are modified using three-dimensional shell element and are connected to the cross section by constraining the nodes in the diaphragms to the corresponding nodes in the tubes.

Load Capacity of CHTFGs

a) Effect of residual stresses

The effect of residual stresses on the load capacity of tubular flange girder as the span varies will be discussed along with the results of L/R=0.1 and L/R=.45.The results obtained for the tubular flange girder are then compared with the results of the curved I- girder with residual stresses. For a tubular girder (TG) without residual stresses and with L=27m and L/R=.45, the distribution of normal stresses across the top and bottom walls of the tube at the mid span cross section under the girder self-weight is considered. Due to the flange lateral bending moment introduced by the torsion in the girder, the maximum normal stress is located at the flange tips and side walls are small after cold bending of the tubes. Thus the residual stresses are small at the location of maximum stress is compressive for the inner layer and tensile for the outer layer of the top and bottom walls of the tubes. Only a small region of the flange has large residual stress, and the tubes can carry increasing loads after these small region yield.

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Effect of initial geometric imperfections

The initial geometric imperfections used in the present study are derived from the elastic buckling analysis results and introduced into the FE models for the nonlinear load-displacement analyses. Two combination of buckling shapes and imperfection magnitude are considered. For the initial imperfection, the elastic buckling shape for mode 1 is scaled so that maximum top flange lateral deflection is L/1000, where L is the span. Initial imperfection is a combination of the first two buckling mode shapes, where the mode shape 1 is scaled so the maximum top flange lateral deflection is L/1000 and the mode shape 2 is scaled so the maximum top flange lateral deflection is L/2000, and the two shapes are added together

a) Effect of stiffener thickness

Nonlinear load displacement analyses were performed on the model with distortion with seven intermediate stiffeners, which are uniformly distributed along the span between the bearing stiffeners. The span was varied from 15m to 120m, and the stiffener plate thickness was either 12.7mm, 25.4mm or 50.8mm

b) Effect of number of stiffeners

Nonlinear load displacement analyses were performed on the model with distortion with different number of web stiffeners. For all cases, bearing stiffeners were included at the supports, and the number of intermediate transverse web stiffeners between the bearing stiffeners was varied. The intermediate stiffeners are uniformly distributed. It is found that as the number of stiffeners increases, the load carrying capacity of model with distortion with stiffeners approaches the load carrying capacity of model without distortion, indicating that cross section is not reducing the load capacity

PARAMETRIC STUDY

a) Effect of cross section depth

The girders have the same flange width, flange depth and Flange thickness but web thickness is adjusted to keep the cross section constant, a change in cross section depth is equivalent to a change in the web depth. Thus the tube dimensions are constant for each girder, the variation in depth influence only the vertical bending and the warping behavior for the girders. The St.Venant shear stress, cross section rotation, of the girder has only negligible change with increase in depth. As a result bending normal stress, the total normal stress, the vertical shear stress, the vertical displacement decreases with increasing depth

b) Effect of tubular flange depth

The tubular flange depth, is varied, while the cross section depth, the tubular flange width, the tubular flange thickness are constant. The web thickness is varied to keep the cross section area constant. The theory says that as flange depth decreases St.Venant shear stress increases, the bending normal stress decreases, the warping stress increases. The cross section rotation, the vertical displacement are influenced by both bending and torsion. The contribution from torsion increases as flange depth decreases as a result that shows an impact on rotation and vertical displacement. As flange depth varies the change in the bending normal stress and the warping normal stress have different trends. Since warping normal stress has a more significant change than the bending normal stress. Hence based on the above discussion, it is observed that the tubular flange depth is a significant parameter to reduce the warping normal stress, St. Venant shear stress, displacement and rotation.

c) Effect of curvature

The curved tubular flange girder and the curved I girder are used to study the effect of girder curvature. The cross section dimensions and the girder arc span length are kept constant, but the radius of curvature is varied so that the ratio L/R is varied from .1to .45. Unlike the other parameter studies described previously, which used the full dead load as the load applied, for this study of girder curvature, the girder Self-weight is used as the applied load. A graph was plot between the maximum stress and the displacements for the single tubular flange girder and the single I girder as the girder curvature varies. It was shown that single curved I-girder develops much larger stresses and displacements than the single curved tubular flange girders for the same L/R value. The slope of the curve at each point for the single I- girder is much larger than that for the single tubular flange girder. Therefore, as L/R increases, the rate of increase in the stresses and displacements for the single curved I- girder is significantly larger than for the single curved tubular flange girder.

a) GEOMETRIC AND MATERIAL NON LINEARITY

Initially buckling modes were established by doing linear perturbation analysis. Under concentrated point loading, the Eigen values were obtained from which the elastic buckling load was calculated. In the next step, the RIKS analysis was performed to establish non-linear behaviour wherein geometrical non linearity was incorporated. Material non linearity was also incorporated as a function of span. An imperfection scale factor of span/1000 was adopted and introduced in the distortional buckling mode. Finally load carrying capacity was obtained

RESULTS AND DISCUSSIONS

General

Linear and nonlinear analysis is carried out for curved hollow tubular flange girder, subjected to self-weight loading and various parameters are studied and the results are discussed below. Comparison of results for all parameters such as effect of residual stresses as span varies, effect of geometric imperfections, effect of stiffener thickness, effect of number of stiffeners, curvature effect, variation of maximum bending stresses with L/R ratio, variation of vertical displacement with L/R ratio, variation of maximum total normal stress with L/R ratio and variation of top flange lateral bending moment along the span for the confined L/R ratio are discussed.

The results are then compared to the curved I-girder along with them, the difference in load carrying capacities of a model with distortion and model without distortion are discussed. The load carrying capacity of a girder with the variation of uniformity of stiffeners of a model with distortion to the model without distortion is shown in a graphical representation. The effect in the variation of parameter dimensions and their influence on various parameters such as total normal stress, warping stress, rotation, displacement, maximum normal stress are taken into account for the generation of the required result. Failure modes of columns with different arrangements are studied with the stress distribution diagrams using ABAQUS.

a)

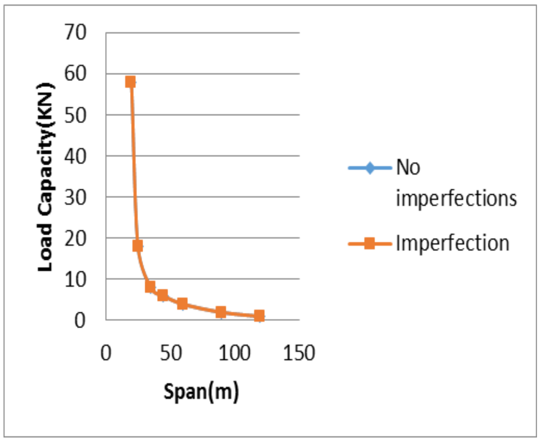

Fig:1 Effect of geometric imperfection as span varies **b)**

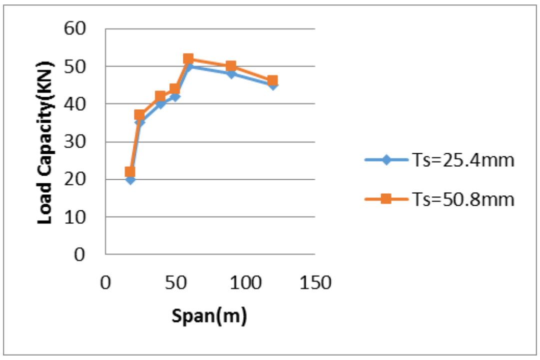

Fig:2 Variation of load capacity with span and thickness

c)

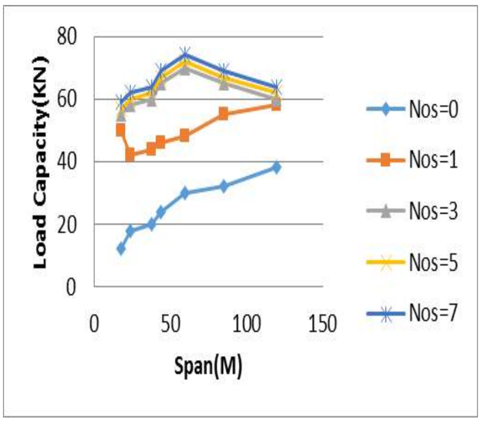

Fig:3 Variation of load capacity with span and number of stiffeners

d)

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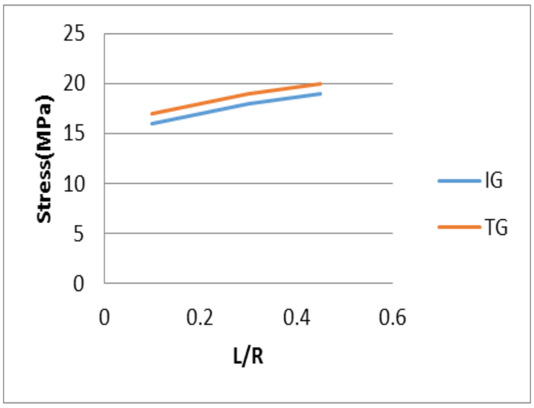

Fig:4 Variation of bending stress

e)

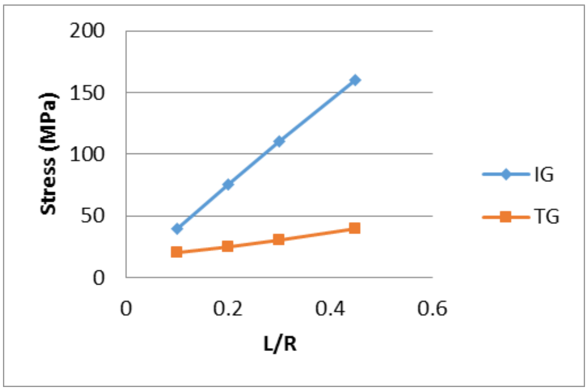

Fig:5 Variation of normal stress

f)

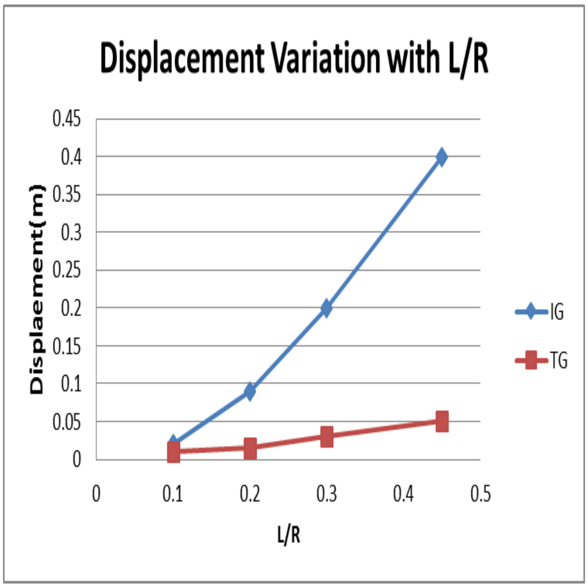

Fig:6 Displacement variation with L/R

CONCLUSIONS

a) Fig:1 shows that geometric imperfection does not show any variation in the load carrying capacity.
b) Fig:2 shows that as thickness increases the load carrying capacity is slightly increased but variation is not significant.
c) Fig:3 shows that as the number of stiffeners increases the load carrying capacity increases gradually upto a certain number of stiffeners and then the variation is not significant.
d) Fig:4 shows that when compared to solid curved I-girder, hollow curved girder shows little improvement in the bending stress variation.
a) Fig:5 shows that when compared to solid curved I-girder, hollow curved girder shows significant improvement in the variation of normal stress. Fig:6 shows that when compared to solid curved I-girder, hollow curved girder shows significant improvement in the displacement variation with L/R variation

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