3D FE modelling of composite box Girder Bridge

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Abstract

The complexity nature of composite box girder bridges makes it difficult to accurately predict their structural response under loading. However, that difficulty in the analysis and design of composite box girder bridges can be handled by the use of the digital computers in the design. An intricate geometry such as that of composite box girder bridges can be facilely modelled using the FE technique. The method is also capable of dealing with different material properties, relationships between structural components, boundary conditions, as well as statically or dynamically applied loads. The linear and nonlinear structural response of such bridges can be predicted with good accuracy using this method.

A major interest in this paper is to perform three-dimensional FE analyses of composite box girder bridge to simulate the actual bridge behaviour. ANSYS FE package is used to develop the models which offer different element types and physical contact conditions between concrete deck and steel girder. Predictions of several FE models are assessed against the results acquired from a field test. Several factors are considered, and confirmed through experiments especially full shear connections which are obviously essential in composite box girder. Numerical predictions of both vertical displacements and normal stresses at critical sections fit fairly well with those evaluated experimentally. The agreement between the FE models and the experimental models show that the FE model can aid engineers in design practices of box girder bridges.

Introduction

Although three dimensional Finite Element (FE) modelling is probably the most involved and time consuming, it is still the most general and comprehensive technique for static and dynamic analyses, capturing all aspects affecting the structural response. The other methods proved to be adequate but limited in scope and applicability.

Due to recent development in computer technology, the method has become an important part of engineering analysis and design. For the time being, FE computer programs are used practically in all branches of engineering. Also FE method has been used to simulate successfully the behaviour of bridges.

A three-dimensional solid FE model was created by Jennifer B.J. Chang and Ian N. Robertson [1] in 2003 using ANSYS to study thermal loadings. Considering longitudinal strains, modal analysis, and deformations, this model simulated a three span, 220-meter concrete bridge built to replace an existing six span concrete bridge spanning the Kealakaha Stream. In the same year H.K. Ryan et al. [2] submitted a three-dimensional finite-element model in which the concrete slab and the steel girder were modelled with four-node shell elements.

The stress analysis of a long-span cable stayed bridge using FE analysis compared very well with a full-scale static experimental loading performed by Lertsima et al. [3] in 2004. Magdy S.S.[4] at the same year employed three dimensional FE analysis to investigate the static and dynamic responses of continuous curved composite box girder bridges. Yamaguchi et al [5] in 2005 conducted three-dimensional nonlinear FE analysis of two-plate-girder bridge to obtain dry shrinkage and pre-stressing. The dynamic interaction between a heavy truck and highway is presented by the FE analysis by Kwasniewski et al. 2006 [6]. Also the studies conducted by El-Lobody and Lam [7] in 2003 and Chung and Sotelino in 2006 [8] used FE modelling to predict the stress and deflection of steel-concrete composite girders.

Lei Zheng [9] in 2008 developed several 3-D FE models using ANSYS to propose new distribution factor equations of live load moment and shear for steel open-box girder bridges. The structural behaviour of bridge deck slabs under static patch loads in steel-concrete composite bridges was studied by using a non-linear 3D-FE analysis models with ABAQUS software by Zheng et al. in 2009 [10]. Non-linear FE models of Svinesund Bridge which links Norway and Sweden were developed in 2009. Multi- response objective function was introduced by Schliuie et al., [11], which allow the combination of static and dynamic measurements to obtain a solid basis for parameter estimation.

A three-dimensional FE simulation of the composite continuous box-girder bridge with corrugated steel webs was performed by Jianyong Song [12] et al. in 2010. Jaturong Sanguanmanasak et al.[13] in 2010 presented three-dimensional FE analysis model of composite steel-concrete bridges to simulate the actual bridge behaviour, Thai trucks are loaded at possible locations of the bridge to obtain the maximum stresses on the bridge.

In present study, main attention is focused on developing representative numerical models for a composite box girder bridge. To achieve this aim several FE models of a laboratory specimen are developed using different approaches available within ANSYS software. The performance of test model was published by H.K. Ryu et al. [2] in 2003. Modelling details and results of different models are presented. The acquired results from numerical models are assessed against test results and performances of models are detailed.

Experimental composite box girder bridge model

H.K. Ryu et al. [2] presented test results of a two-span continuous composite box girder bridge in 2003. Figure 1 depicts geometrical configuration of the bridge model in conjunction with boundary conditions. The numerical evaluation in present study are undertaken to simulate behaviour of presented model.

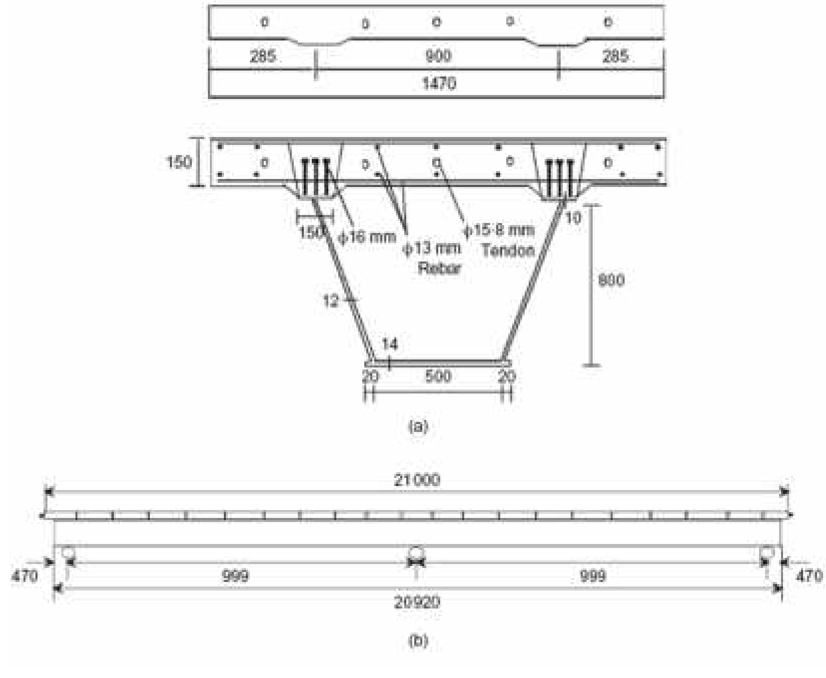


Figure 1 Continuous bridge model: (a) cross-section; (b) elevation (dimensions in mm)

The height of the steel section was 800 mm and the thickness of the precast concrete slab was 150 mm. The slab width was 1470 mm, as shown in Figure 1(a). Twenty-one precast panels 980 mm long were installed on the top flange of the steel girder. Each precast panel has six block-outs for stud shear connectors which are installed on the top flanges of the steel girder to achieve full shear connection. The thicknesses of the upper flange, web and lower flange were 10 mm, 12 mm and 14 mm respectively.

Material properties

Yield stress and tensile strength of steel material used to build box section are 240 MPa and 520 MPa, respectively. Elastic modulus of steel is 190 GPa. 28 days compression strength of concrete used to build deck portion is 35.5 MPa and of the concrete and mortar, the average value of all the precast concrete panels for 28 days compressive strength is 35.3 MPa. Elastic modulus of concrete is 30 Gpa.

Experimental model loading

Two concentrated loads were applied at the mid-spans of the composite bridge by an MTS closed-loop electrohydraulic testing system of 2000 kN capacity, as shown in Figure 2.

Static tests for observation of the elastic behaviour of the model were performed with 250 KN value for each span. Displacements of the continuous beam were measured at each mid-span with linear variable differential transformers (LVDTs).

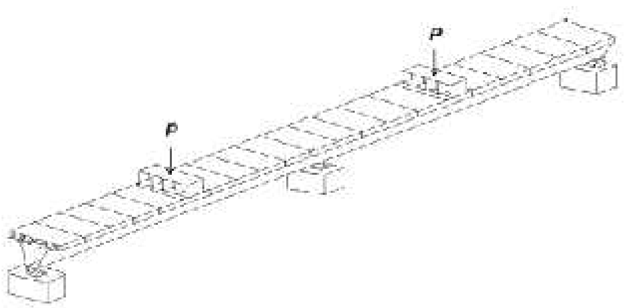


Figure 2 Bridge loading

FE models

Composite box Girder Bridge models were simulated using a commercial FE program ANSYS. Since the materials were stressed in elastic limits in the study of H.K. Ryu et al. [2], linear analysis of bridge models are undertaken in present study. The slab and the box girder were connected by rigid links because full interaction between slab and steel girder was assumed. Figure 3 presents FE model 1 which is developed using shell elements both in concrete deck and steel box girder portions. Point load is applied in this model as shown in Figure 3. Model 2 differs from model 1 in having different loading at mid-spans in order to represent line loading. The vertical translation degrees of freedom of the nodes across the width of the deck are coupled as shown in Figure 4.

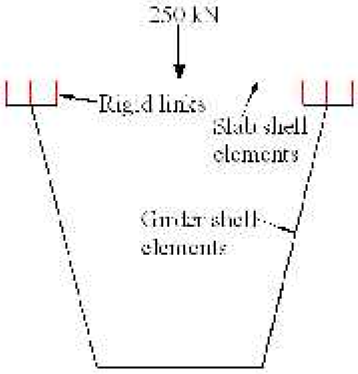


Figure 3 FE Model 1

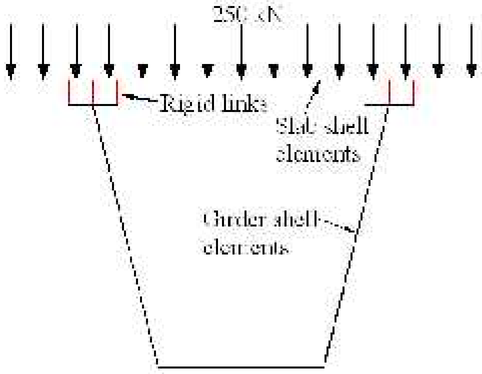


Figure 4 FE Model 2

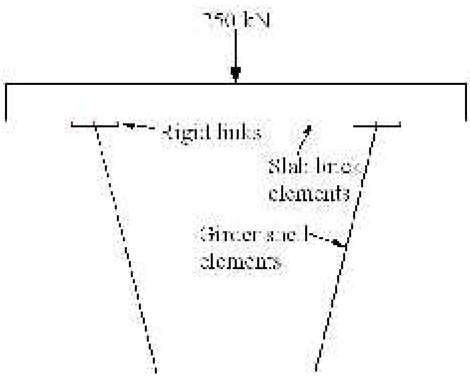
Coupling is a way to force a set of nodes to have the same DOF value. Similar to a constraint, except that the DOF value is usually calculated by the solver rather than user-specified. A coupled set is a group of nodes coupled in one direction.

Thickness of concrete deck portion is considerable compared to steel and other geometrical details. Another convenient way to represent this thickness is to adopt 3D brick elements. Since the cross section is prismatic, employing 3D brick elements would not cause complicated modelling approach. In order to evaluate performance of this modelling technique against shell models and test results Models 3 and 4 are developed using 8 nodes brick elements. Brick elements are just used to model concrete deck portion of bridge where shell elements still represent the steel box portion as with models 1 and 2. The loading condition which makes models 1 and 2 different also creates the difference between models 3 and 4. Figures 5 and 6 present the details of models 3 and 4.

In this study, the top concrete flanges were divided into thirty four square elements for an appropriate aspect ratio of the elements and four divisions for each top steel flange. The bottom flanges were divided into ten elements and webs were divided into twenty square elements. The longitudinal two spans were divided into 160 elements.

Two models are made using Shell 181 Elements-which are four-node elements with six degrees of freedom at each node-, for steel webs, concrete top flange, and the steel bottom flange. The plate thicknesses and the material properties are required input for Shell181. Also another two models are made using Shell181, for steel bottom flanges and webs. While solid185 elements are used for 3-D modelling of concrete top flanges. They are defined by eight nodes having three degrees of freedom at each node. The mpc184 rigid element are used to model a rigid constraint between two bodies, steel and concrete in this case which are used to transmit forces and moments in all above models.

Boundary conditions are handled in such a way to represent simply supported conditions of test specimen.



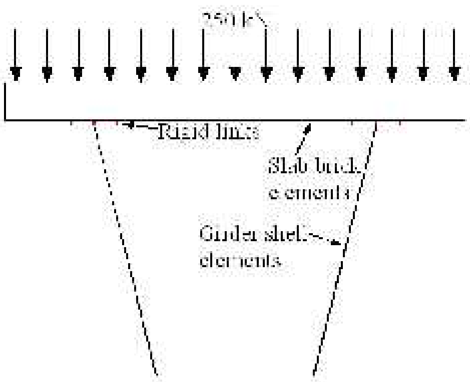


Figure 4 FE Model 3　　　　Figure 5 FE Model 4

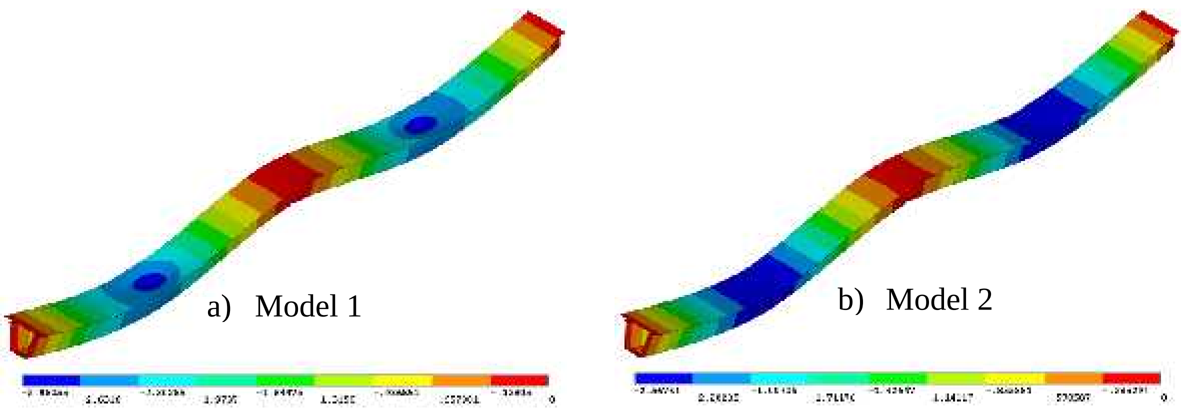
Numerical results and discussions

The results by the ANSYS finite element analysis (FEA) using Mod 1-mod 4 are shown in Table 1 and Figures 7-9 together with the loading-test results and the design values. It is observed that the design analysis tends to overestimate the stress and the vertical displacement measured in the loading test. The differences at the mid-span of mod 4 are as much as 0.2 mm or 8 % in the vertical displacement.

Obtaining displacements and stresses from the finite element, ANSYS models can be utilized in understanding the composite box bridge behaviour. In addition, it can also be used to compare the stress profiles. In modelling the bridges using ANSYS, a FEA model was created using command prompt line input other than the Graphical User Interface (GUI) can be used. During the static test done by H.K. Ryu et al. [2] in the elastic range of loading, the flexural stiffness of the composite bridge showed linear elastic behaviour. Mid-span deflections from the analysis were compared with the test results. In the experimental test, the mid-span deflection was 2.52 mm and in the analysis performed by same researchers it was 2.76 mm at a load of 250 kN [2]. Deflections results obtained from ANSYS finite elements models model 1 to model 4 can be observed in figures below and they are summarized in Table 1:

Table 1 Deflection results for ANSYS models

Model	Mid span deflection (mm)	Deflection near end support (mm)	Deflection near central support (mm)
Model 1	2.96	0.33	0.33
Model 2	2.57	0.29	0.29
Model 3	3.04	0.31	0.31
Model 4	2.56	0.28	0.28



a) Model 1　　b) Model 2

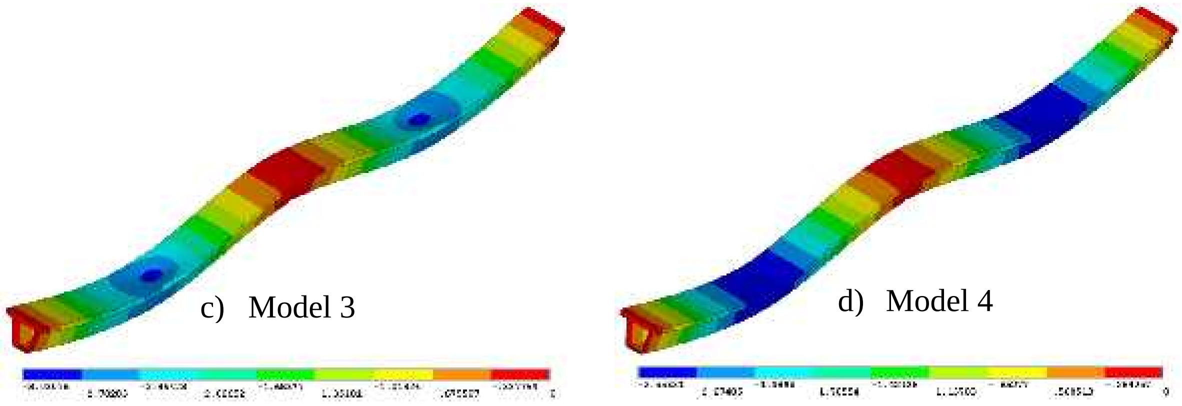


Figure 7 Deflections of numerical models (Magnification factor=400)

It is interesting to note that in the case of model 4(which had steel box girder with shell 181 elements and concrete deck with solid 185 elements and point load with constraint nodes along the line of that load) the best result comparing with experimental test had obtained, so the focusing will be on model 4 to make comparison with experimental data submitted by H.K. Ryu et al. [2]. There is very good agreement between the two set of results whereas in the case of other models show some deviation.

Mid-span deflection from the finite element analysis was compared with the test results as shown in Figure 8. In the test results, the deflection was 2·52 mm and in the analysis it was 2·56 mm at a load of 250 KN.

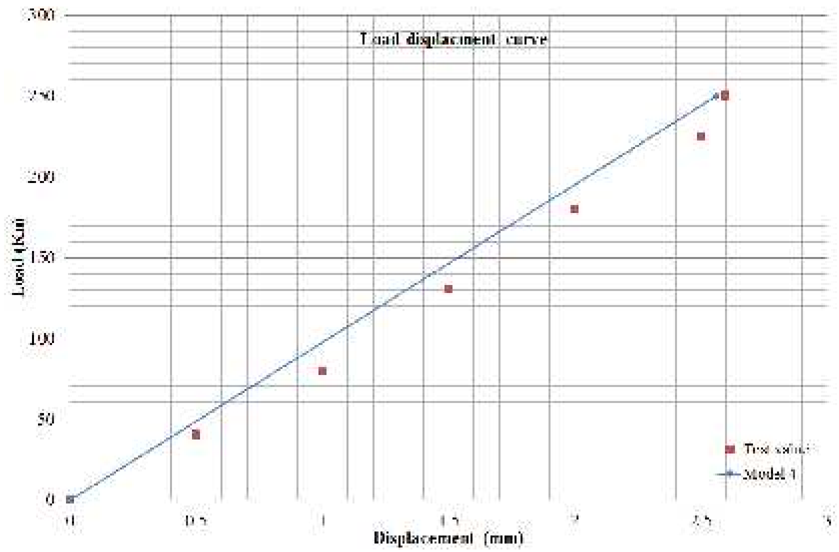


Figure 11 Load- Displacement curve for ANSYS and test results

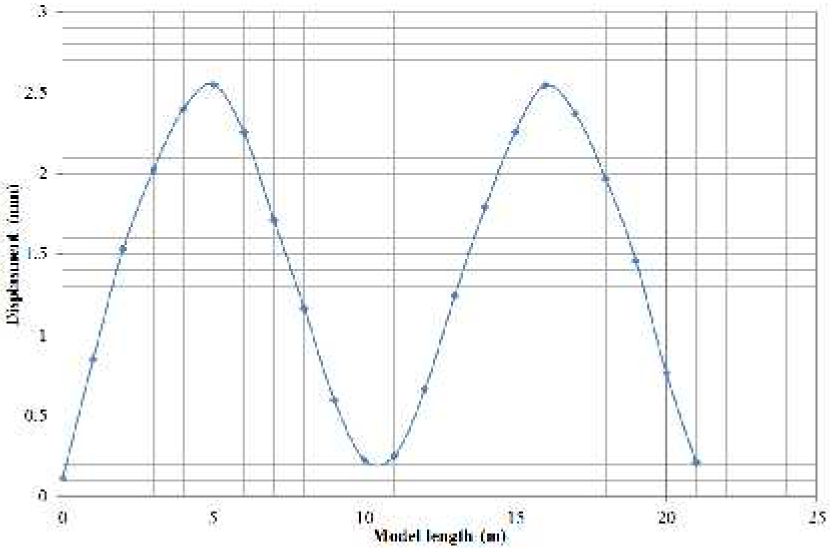


Figure 12 Displacement profile of Model 4

Conclusion

The theoretical three dimensional finite element models developed herein, can predict quite well the elastic behaviour as well as the mode shapes of continuous composite single box girder bridges.

The interaction between the two parts of the bridge in the ANSYS analysis modelled using rigid links to give full interaction between components. The thickness of precast concrete 15 cm is big to simulate using shell elements, so noteworthy difference can be observed (about 2 %) by using 3-D solid elements to model such thickness.

The value of the degree of freedom is coincident for all the points to be coupled, was important thing effects on result of simulation of constrained point load, big difference appeared (15 %) when the loading simulated by Coupling to force a set of nodes to have the same DOF value.

The finite element analysis using ANSYS can simulate the structural behaviour of a steel-concrete composite box girder bridge very well; the results would be in good agreement with those of experimental test. For further study, more complicated three-dimensional finite element modelling should be investigated, for example, modelling of bearing pad included, bracing and diaphragm and more details of pier foundation. Also, the application of a proposed model to various types of composite box girder bridges should be explored, such as curved bridges, high-strength concrete, prestressed concrete bridges.

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