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AN ANALYTICAL INVESTIGATION OF CONVENTIONAL AND CURVED COMPOSITE BOX GIRDERS FOR ELEVATED BRIDGES WITH DIFFERENT BRACING SYSTEMS

K.R.Manigandan and P.Saranya

PG Students, Department of Civil Engineering, SKP Engineering college, Tiruvannamalai, TamilNadu.
manigandankr07@gmail.com saranyaparamasivam04@gmail.com

***Abstract*- Composite bridges are structures that combine materials like steel, concrete, timber or masonry in some combination. The behavior of the composite structure is heavily influenced by the properties of its component materialsBridges constructed with concrete deck slab system over steel girders are frequently used in bridge construction for their economic and structural advantages. Steel Concrete Composite (SCC) box girder bridges are considered in modern highway system due to its better performance, greater economy, higher torsional rigidity and good aesthetic appearance. SCC box girder bridge construction is suitable for long span curved and continuous bridges. The complexity nature of composite box girder bridges makes it difficult to accurately predict their structural response under external loading. However, this difficulty in the analysis and design of composite box girder bridges can easily be handled by the use of finite element software. In this project work, the structural behavior of horizontally straight and curved SCC box girder bridges with different bracing systems are studied in detail using finite element software - SAP 2000 advanced version 14. The main parameter considered in this study is the effect of different types of internal and top bracing systems on the behavior of three-span continuous SCC twin box girder bridges with trapezoidal cross section.**

***Keywords*- SCC, Bracing systems, FEM.**

I INTRODUCTION

The behavior of the composite structure is heavily influenced by the properties of its component materials. For example, the use of a concrete slab on a steel girder uses the strength of concrete in compression and the high tensile strength of steel. Looking at the basic behavior of a composite structure, the two fundamental effects to be considered are: the differences between the materials and the connection of the two materials. Stronger, stiffer materials like steel attract proportionally more load than materials such as concrete. If there is no connection then the materials will behave independently, omitting the positive effects, but if adequately connected the materials act as one unit (i.e. as a single structure). Hence, connections in the form of shear connectors are necessary in composite structures. Most common composite structures are either precast, pre-stressed concrete beams with a cast in-situ concrete slab or steel girders with a concrete slab.

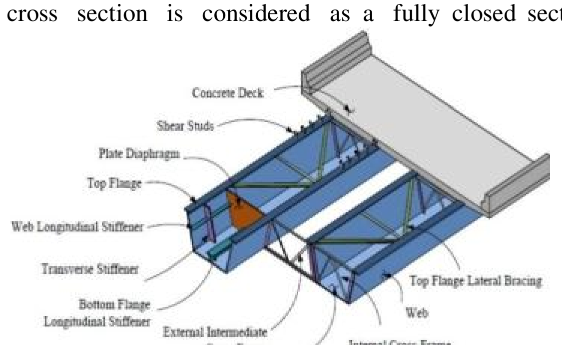
Steel-concrete composite box girders may advantageously be used for bridges with long spans and for bridges with significant horizontal curvature. The boxes may be complete steel boxes with an overlay slab or an open box where the concrete slab closes the top of the box. The advantages of this form are that: (i) access direction of the bridge. A drawback of the open box girder bridge is that they develop high torsional rigidity only after the concrete slab has gained sufficient strength, which makes it more sensitive to lateral instability during construction.

Although the steel box girder bridge construction became popular after the second world war, there were a series of disastrous accidents that motivated research on box girder bridges. The fourth Danube bridge in Austria collapsed during construction and it was followed by three major disasters after 2 years in which more than fifty people lost their lives. These failures led bridge engineers to examine the design rules and methods of analysis used for box girder bridges.

II. STEEL BOX GIRDER BRIDGE

The steel box girder may be defined as a longitudinal structural member with four steel plates, two webs and two flanges, arranged to form a closed box section as shown in the Fig. 1.1 a. However, in modern highway structures, a more common arrangement is the box girder with open top which is usually referred to as the tub girder. In this case, two steel webs with narrow top flanges similar to those of the plate girders are joined at their bottoms by a full-width bottom flange

In this project work twin box girder bridge as shown in the Fig. 1.1 is taken into consideration. The essential components of the twin box girder bridges and their arrangements are shown in the Fig. 1.1. During the construction stage, however, the behaviour is not well understood. The usual practice of assuming the system to be non-composite during construction. requires substantial top flange bracing to form a quasi-closed box section. The non composite steel section must support both the fresh concrete and the entire construction loads hence steel box girders are at their critical stage during construction. The box girder cross section possesses a high torsional stiffness after the concrete deck gains its full strength since the cross section is considered as a fully closed section



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II BRACINGS IN BOX GIRDER BRIDGE

Bracing systems are necessary in box girder bridge to prevent the excessive distortion or twist of sections. Bracing systems commonly consist of a horizontal truss attached to the girder near its top flange to increase its torsional stiffness. The distortion of the cross section is reduced by using internal cross frames and diaphragms. External bracing between the interior and exterior box girders may be necessary in the case of very sharply curved bridges in order to control the deflections and rotations of the girders, thereby facilitating the placement of the concrete roadway deck. However external bracings are not taken into account in this project work. The following bracing systems are used

i. Top Lateral bracings

ii. Cross frames or Internal bracings

I Top Lateral Bracings

The top lateral bracing system in composite tub girders is only required for the construction load. A lateral bracing system is usually installed at the top flange level to form a quasi-closed box and thereby increase the torsional stiffness during construction. Once the concrete roadway deck is completely hardened, the composite concrete deck takes over the structural function provided by the lateral bracing system. Single diagonal (SD type) and crossed diagonal (XD type) bracing systems which are shown in Fig. 1.2 are the most preferred examples for a lateral bracing system. Also eccentric bracing systems (K type and inverted K type) as shown in Fig. 1.2 are also taken into consideration.

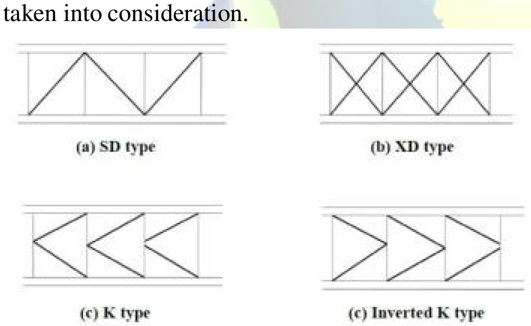

Fig 1.2 Plan view of top bracings

II Internal Bracings

Box girders need to be stiffened internally to resist distortional loads and maintain their cross-sectional shapes. Box sections distort primarily due to torsional moments caused by eccentrically applied loads. Cross-sectional distortion may alter the profile geometry of the girder flanges. Distortion can be controlled by the installation of cross-frames that are spaced along the girder. Examples of preferred types of internal bracing in the box section are single diagonal (SD type) frames, cross shaped (X type) frames, eccentric (V type) frames as shown in Fig. 1.3

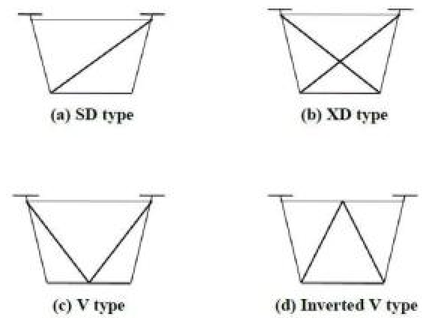

Fig 1.3 Internal cross frames

III. Objectives Of Project

The following are the major objectives of the project:

i. To model the SCC twin box girder bridge using four noded shell element (for flanges, webs and deck slab) and two noded frame element (for bracings) by SAP 2000 software.

ii. To study the behavior of straight and horizontally curved SCC twin box girder bridges for IRC loadings.

iii. To investigate the effect of different types of internal and top bracing systems on the behavior of SCC twin box girder bridges.

iv. To identify the most appropriate bracing system for the chosen SCC twin box girder bridge.

IV METHODOLOGY.

The observations from literature review showed that the finite element method is the best approach to analyze the composite bridges and to investigate their behavior. The finite element method of analysis is generally the most powerful, versatile and accurate analytical method of all the available methods and has rapidly become a very popular technique for the computer solution of complex problems in engineering. It is very effective in the analysis of complicated structures such as that of a box girder bridge with complex geometry, material properties and support conditions and subjected to a variety of loading conditions.

V FINITE ELEMENT METHOD

The finite element method is a numerical procedure for solving problems in engineering and mathematical physics. In structural problems, the solution is typically concerned with determining stresses and displacements. Finite element model gives approximate values of the unknowns at discrete number of points in a continuum. This numerical method of analysis starts by discretizing a model. Discretization is the process where a body is divided into an equivalent system of smaller bodies or units called elements. These elements are interconnected with each other by means of certain points called nodes. An equation is then formulated combining all the elements to obtain a solution for one whole body. In the case of small displacements and linear material response, using a

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displacement formulation, the stiffness matrix of each element is derived and the global stiffness matrix of the entire structure can be formulated by assembling the stiffness matrices of all elements using direct stiffness method. This global stiffness matrix, along with the given displacement boundary conditions and applied loads is then solved, thus the displacements and stresses for the entire system are determined. The global stiffness matrix represents the nodal force-displacement relationships and can be expressed by the following equilibrium equation in matrix form:

[F] = [K] [U] (3.1)

Where,

[K] = global stiffness matrix,

[U] = nodal displacement vector, and

[F] = nodal load vector.

Since finite element analysis involves lot of numeric calculations, it is not suitable for manual calculation for complex structures. This method is ideally suited for computer applications softwares are used and so finite element softwares are used.

VI SAP 2000 SOFTWARE

The commercially available finite-element software SAP2000 is a powerful engineering program to provide a wide range of useful engineering capabilities suitable for practical structural engineering applications. SAP 2000 is based on the idea of transferring the physical structural members into objects using the graphical user interface. The software is capable of modeling any complicated structure by dividing it into small and manageable pieces.

The finite element program contains several types of objects. Point objects are automatically created at the corners or ends of all other objects. Line objects are to represent frame, cable and tendon elements. Connecting two joints using link elements can be modeled using line objects. Area objects are to model shell elements with three or four–node three-dimensional element, which combines separate membrane and plate-bending behavior. The membrane behavior includes translational in-plane stiffness components and rotational stiffness components in the direction normal to the plane of the element. The plate bending behavior includes two-way, out of plane, plate rotational stiffness components and translational stiffness component in the direction normal to the plane of the element. Shell elements are to represent slab, walls or any other thin walled members. The graphical interface of the program is used to draw the model and select the appropriate objects to represent the actual physical structure. As closer the representation of the physical member to the finite-element model as more accurate the results obtained by the finite-element analysis. The number of elements should be sufficient to accurately describe the geometry of the actual structure. Changes in thickness and material properties need to be considered and introduced in the finite-element model.

For moving load analysis, lanes, vehicle and vehicle class shall be modeled and defined. The lane width can be specified in the program as well as the distance between the vehicle and the lane edge. Multiple lanes can be defined as per the actual traffic pattern on the bridge. Truck and lane loads can be represented in the program by number of concentrated and distributed forces. Each truck axles can be represented by single or double loads with defined axle width. The minimum or the maximum distances between each axel can be specified in the program. Vehicle class can be used to combine several vehicles together to run on the bridge at the same time. In the moving load analysis case, the program creates first the influence surface for each straining actions. Once the influence surface is calculated, the envelope for each bridge response can be evaluated. The vehicles are automatically located at each possible location along the lanes and within the width of the lanes to produce the maximum and minimum response quantities throughout the structure.

For each load case, the program automatically creates a corresponding stiffness matrix of the full structure and accordingly solving the system of linear equations. The software considers each loading position on the bridge to obtain the influence surface as a linear static analysis case. Load combinations option available in the software can be used to combine the results of analysis cases to obtain the determined values used for the design of the structural members. Moving load analysis available in SAP 2000 is used to determine the response of a bridge structure subjected to live loads. The maximum and minimum displacements, forces and stresses due to multiple-lane loads on bridges can be obtained using the SAP2000 software. Due to the above mentioned capabilities and advantages of SAP 2000 software it is used in this project to study the behavior of composite box girder bridge.

VII PROBLEM DESCRIPTION

Twin box girder bridge with trapezoidal cross section is taken into consideration with three span continuous support. The geometric features of the bridge roadway alignment based on the IRC code of practice is tabulated in the table 1.1 and table 1.2

General Features	Value/Load
Number of span	3
Total span	180m
Effective span	60m
Number of lane	2
Total width	10.5m
Carriage way	7.5m
Foot path	1.5m on each side
Vehicle Load	IRC Class 70R
Load on foot path	1.5 kN/m^2

Table 1.1: General features of straight bridge

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General Features	Value/Load
Number of span	3
Total span	180m
Effective span	60m
Number of lane	2
Total width	10.5m
Carriage way	7.5m
Foot path	1.5m on each s
Vehicle load	IRC Class 70
Load on foot path	1.5 kN/m^2
Co-efficient of friction	0.15
Super elevation	7%
Radius of curvature	360m

Table 1.2 General features of curved bridge

The geometric features of the bridge roadway alignment based on the IRC code of practice are shown in Fig.3.1. And Fig. 3.2 shows the cross-sectional dimensions based on the guidelines from American Association of State Highway and Transport Officials (AASHTO) Load and Resistance Factor Design (LRFD) bridge specification

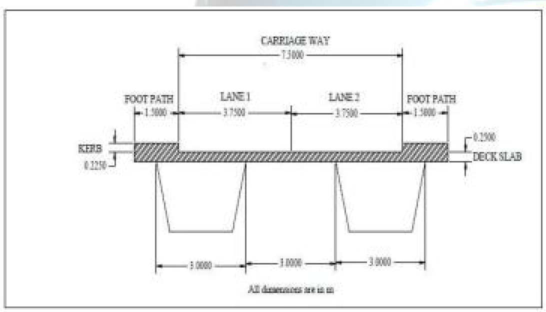

Fig 1.4 Twin box girder bridge

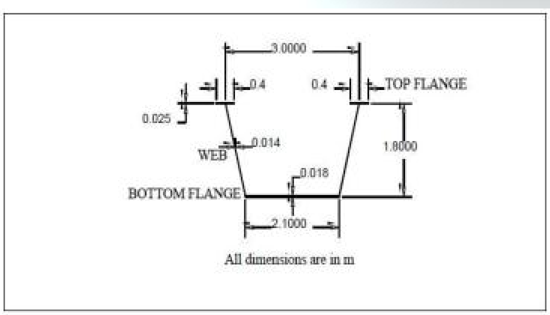

Fig 1.5 Cross-sectional dimensions

The main parameter considered in this project work is the effect of bracings on the behavior of composite box girder bridge. Hence various bracing systems are provided for the box girder bridges to be analyzed. The arrangements of the different bracing systems at 3m panel spacing for straight and horizontally curved box girder bridges are as shown in the following figures 1.6 to 1.8

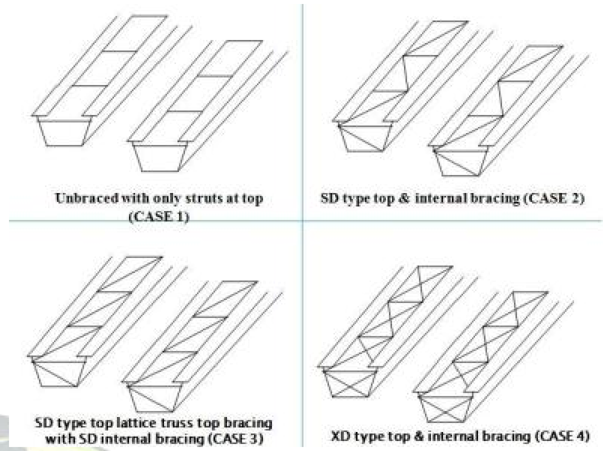

Fig 1.6 Showing case 1-4 on straight bridge.

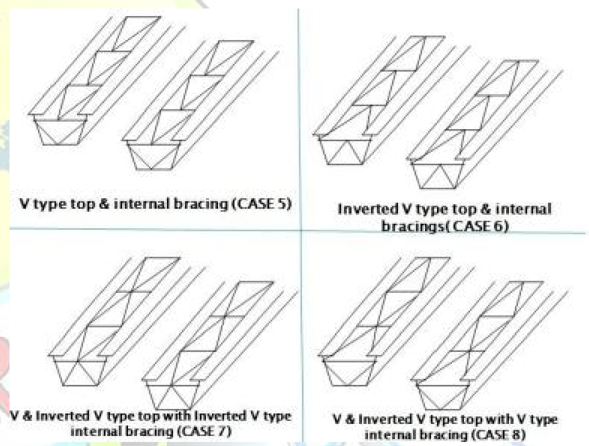

Fig 1.7 Showing case 5-8 on straight bridge.

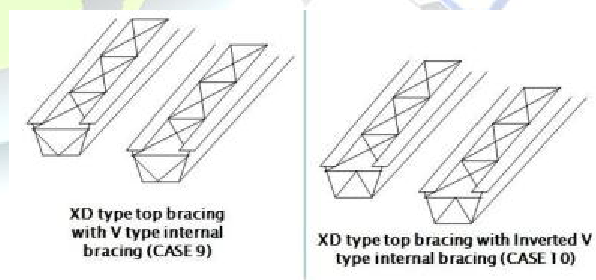

Fig 1.8 Showing case 9 & 10 on straight bridge

For Horizontally curved bridge the same combination of top and internal bracings as mentioned above is provided for all the cases with same cross-sectional dimensions and with same panel spacing of 3m as shown in the following figures from Fig 1.9 to 1.11

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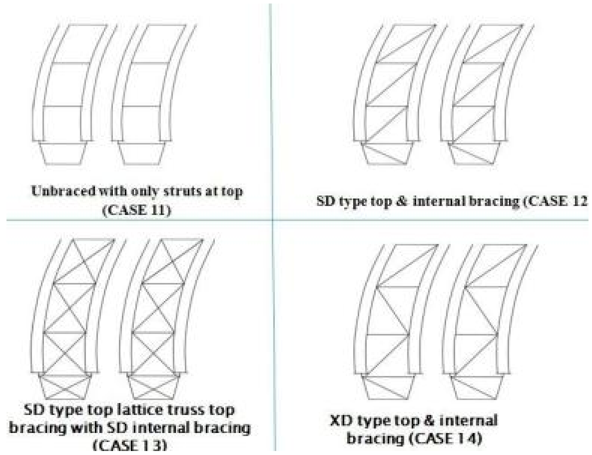

Fig 1.9 Showing case 11-14 on curved bridge.

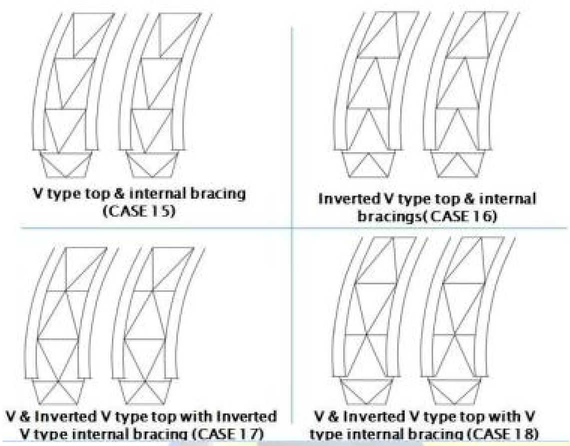

Fig 1.10 Showing case 15-18 on curved bridge.

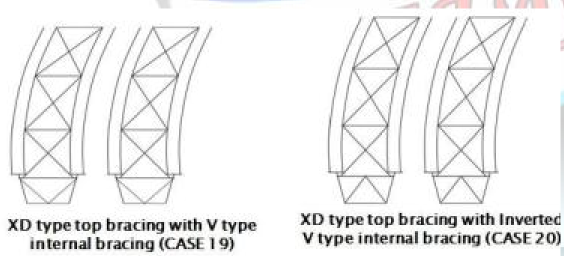

Fig 1.11 Showing case 19 & 20 on curved bridge

Totally 20 bridge models are taken into consideration by altering the top and internal bracing system as shown in the above figures

VIII FINITE ELEMENT MODELING

A. GENERAL

The finite element technique was used to model three-span continuous SCC box girder bridges by SAP 2000 software. Three-dimensional finite element models were modeled in such a way to represent the actual physical structural geometry, materials, boundary conditions, loads and locations of the bridge components such as: concrete deck slab and steel girders with webs, bottom

sections explain the step by step procedure involved in developing all FEA bridge models that are taken into consideration.

B.GRID SYSTEM

The first step in modeling involves in defining the grid lines for the bridges. In SAP 2000 software there is no limit to the number of grid systems in a model and they can be rotated in any direction or placed at any origin within the model. For straight bridges, grid lines with cartesian co-ordinates were used and for curved bridges, grid lines with cylindrical co-ordinates were used. The grid lines were defined in such a way that the length of the bridge is along X-direction, the width of the bridge is along the Y-direction and depth of bridge section was along Z-direction.

C.MATERIAL MODELING

In SAP2000 software, it is fundamental that after defining the grid lines material properties were defined so that the final results would be more accurate and acceptable. The bridge slab is made of M35 grade concrete while the rest of the box girder is made of high strength weather resistance steel. In this study, it was assumed that steel and concrete materials were homogenous and elastic. The material properties for concrete and steel are mentioned in the table 1.3 and 1.4.

Properties	Value
Weight per unit volume	2.356×10^{-5} N/mm^3
Modulus of elasticity (E)	27789.38 N/mm^2
Poisson's ratio (U)	0.2
Co-efficient of thermal expansion (A)	9.9×10^{-6} per °C
Shear modulus (G)	11578.91 N/mm^2
Compressive strength (f_{ck})	35 N/mm^2

Table 1.3 Material properties of M35 grade concrete

Properties	Values
Weight per unit volume	7.697×10^{-5} N/mm^3
Modulus of elasticity (E)	199947.98 N/mm^2
Poisson's ratio (U)	0.3
Co-efficient of thermal expansion (A)	1.170×10^{-5} per °C
Shear modulus (G)	76903.07 N/mm^2
Minimum yield stress (F_y)	345 N/mm^2
Minimum tensile stress (F_u)	448.16 N/mm^2
Effective yield stress (F_{ye})	379.21 N/mm^2
Effective tensile stress (F_{ue})	492.97 N/mm^2

Table 1.4 Material properties of steel.

D ELEMENT MODELING

SAP2000 software has a three and four noded formulation for shell elements. The formulation combines the membrane and plate-bending behavior. The shell elements

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above mentioned formulation. To model the bridges, the three-dimensional shell element in SAP2000 software was used for the bottom flanges, webs, and deck slabs. It has four corner nodes with six degree of freedom each, three displacements (U1, U2, U3) and three rotation (R1, R2, R3). Two noded frame elements were used to model the bracing members. The frame element uses the three- dimensional beam-column formulation which includes the effects of biaxial bending, torsion, axial deformation and biaxial shear deformations. The element behavior includes two-way, out-of-plane, plate rotational stiffness components and a translational stiffness component in the direction normal to the plane of the element. Four- point numerical full integration formulation is used for the shell stiffness. The four noded elements are more accurate than the three noded elements. Therefore, the four noded elements were used to model the plate components of the bridges. After deciding the elements its sectional properties were defined based on the proposed cross-sectional dimensions and materials. For frame elements Indian Standard Angle (ISA) sections were selected from 'Auto Select' option by which after analysis the software will automatically selects the suitable angle sections for all bracings.

E. GEOMETRIC MODELING

Geometric modeling involves in locating all the elements in a proper sequence along the grid lines to form a required structural model. First the frame elements and then the shell elements were located along the grid lines to represent the exact structural shape of the bridge. All the elements are exactly interconnected with each other to form a homogeneous material by 'Auto Area mesh' option. The frames were given partial fixity conditions by releasing the moment in any one direction probably in Z-direction. Fig.1.12 shows typical arrangement of different elements along the grid line during modeling.

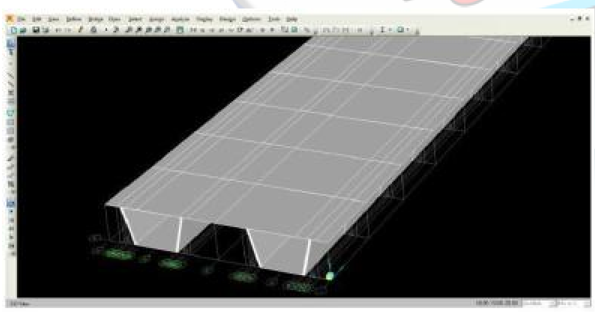

Fig 1.12 Box girder bridge during modeling

F. SUPPORT CONDITIONS

There were three different boundary restrains considered in modeling the bridges namely roller support, hinged support and fixed support. Hinged support was located at one end and roller support was located at other end. And fixed boundary conditions were located at the intermediate supports. The hinged support permits rotation in all direction but arrests translation in all direction. The roller support permits rotation and Y-directions but arrests translation in Z-direction (downward direction). And fixed support condition does not permit rotation and translation in all direction. Each support was located at 60m interval thus enabling equal span length. The location of different support conditions are shown in Fig 1.13

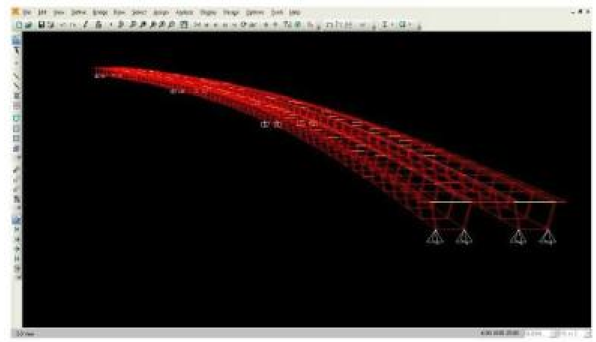

Fig 1.13 Bridge model with different supports

G.BRIDGE LAYOUT AND LANES

In order to apply vehicle load, bridge layout and lanes must be pre-defined. The bridge layouts were defined at the center line of the roadway based on the length and direction of the roadway. For curved bridges suitable curved bridge layouts were defined according to the radius of curvature of the bridge. Then lanes were defined along the bridge layout indicating its length and width. Also the distance between the vehicle and lane edge should be defined. After defining the bridge layout and lanes the complete model of a bridge structure was obtained. Fig. 1.14 and Fig. 1.15 shows completely developed composite box girder model for straight and horizontally curved bridges respectively.

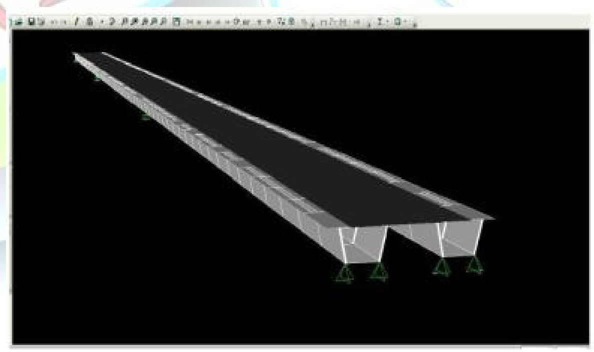

Fig 1.14 Straight bridge model

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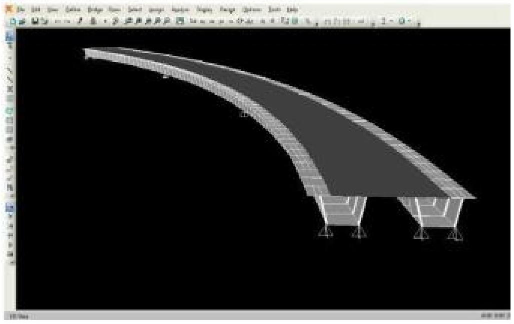

Fig 1.15 Curved bridge model

H. LOAD COMBINATION

Next step was to define specific loads to model a wide array of loading conditions. First load cases were defined for dead load and live load. Then bridge load was defined from the vehicles list and vehicle classes for IRC class 70R loading shown in Fig. 1.16. Further the load combination was defined for dead load, live load on foot path and moving load.

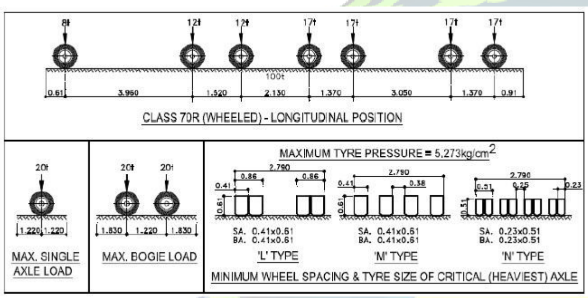

Fig 1.16 IRC class 70R loading

I.ANALYSIS

It is fundamental that before analysis the load cases were checked and then was set to run analysis. Immediately after analysis the deflected shape was displayed for the selected load combination. Further results can be obtained in the form of graphical simulation, tables and charts. During analysis the various steps involved are shown in Fig. 1.17

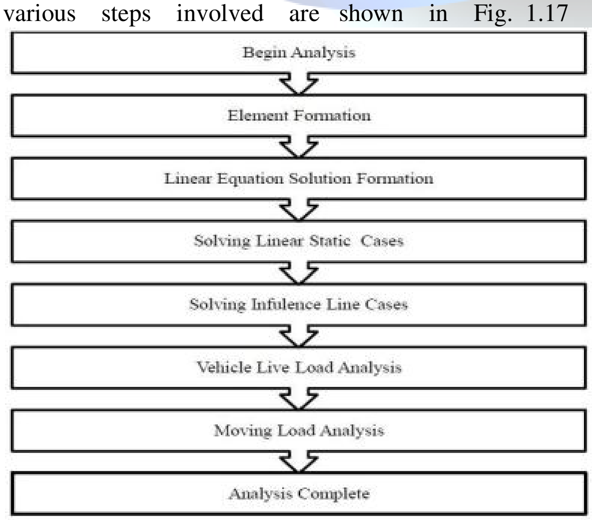

Fig 1.17 Flow chart for steps in analysis.

J. DESIGN OF STEEL FRAMES

Finally after analysis the steel frame for different bracing systems were designed based on IS 800-2000 code of practice. Fully integrated steel frame design includes member size optimization and implementation of design codes. SAP2000 allows user to interactively view design results at any frame member, change the parameters or section properties, and display the updated member results.

VIII RESULTS AND DISCUSSION

A. GENERAL

In this chapter the results from the finite element analysis are presented for all the 20 bridge models that are taken into consideration which includes 10 straight bridge models and 10 horizontally curved bridge models. All the 20 bridge models were analyzed for the same loading conditions to study their structural responses. The results from the analysis are used to study and compare the effect of different bracing system for the straight and horizontally curved bridge models. Also the bracing systems were designed for all the 20 bridge models. Finally the suitable bracing system is identified for straight and curved bridge based on strength and economy. Further a comparative study is carried out between straight and horizontally curved bridge model having similar bracing system.

B. STRAIGHT BRIDGES

Totally 10 straight bridge models with different bracing systems were analyzed and designed. Based on the finite element analysis result it was observed that due to the effect of different bracing systems there was a considerable changes in the deflection, support reactions, support moments, cross-sectional deformations and stress distributions. However in order to identify the most suitable bracing system based on strength and economy the deflection, base reactions and design results of all the bridge models are taken into considerations.

Initially from the SAP 2000 analysis results it was found that the design is safe for all the 10 cases of bridges investigated with different bracing systems, because the *von mises stress* everywhere in the bridge is less than the yield stress of the material. The deflection in different bridge models due to the external load conditions are tabulated in table 1.5. And in order to clearly identify the deflection along the span length a graph is plotted as

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shown in Fig. 1.18

Span Length (m)	Maximum Deflection (mm)									
	Case1	Case2	Case3	Case4	Case5	Case6	Case7	Case8	Case9	Case10
0	0	0	0	0	0	0	0	0	0	0
15	30.4	30.4	24.9	29.1	30.8	29.6	29.6	12.7	30.5	29.4
30	40.1	41.1	41.4	39.3	41.6	40.3	40	17.5	41.3	39.7
45	23.8	23.9	23.8	22.8	24.2	23.2	23.2	10	24	23
60	0	0	0	0	0	0	0	0	0	0
75	22.9	23	27.5	21.9	23.3	22.4	22.4	9.6	23.1	22.2
90	36.8	37.5	36.6	25.4	37.4	36	36	15.8	37.1	35.8
105	24.5	24.6	14.5	23.5	24.8	23.9	29.3	10.3	24.7	23.8
120	0	0	0	0	0	0	0	0	0	0
135	31.2	31.2	31.1	30.1	31.4	30.5	30.5	12.8	31.3	30.3
150	56.2	56.5	56.4	54.4	51.8	55.2	55.2	23.6	56.5	55.3
165	45.7	45.9	45.6	44.2	46	44.8	44.8	18.9	45.8	44.6
180	0	0	0	0	0	0	0	0	0	0

Table 1.5 Deflection in straight bridges

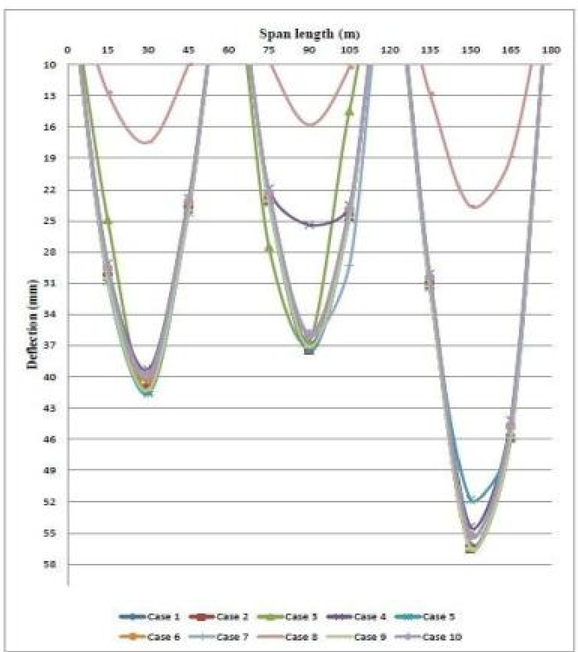

Fig 1.18 Deflection graph for straight bridges

It is evident from the deflection result that maximum deflections in all the 10 bridge models are within the deflection limit (Span length/800 = 75.5mm). The effect of different bracing systems played a significant role in controlling the deflection in the bridge models. Case-8 bridge model has the less deflection when compared to other bridge models. Next the overall structural output result is taken into considerations. The structural output is in the form of different base reactions with resultant forces and moments as shown in table 1.6

Cases	Resultant Force F_Z (kN)	Resultant Moment M_X (kN-m)	Resultant Moment M_Y (kN-m)
Case 1	21047.99	110501.9	-1804328
Case 2	23842.85	125179.8	-2055838
Case 3	21134.57	110958.3	-1812113
Case 4	21231.1	111461.2	-1820739
Case 5	21100.56	110777.9	-1809181
Case 6	21097.78	110763.4	-1808798
Case 7	21097.41	110761.4	-1808773
Case 8	20504.12	107644.3	-1809472
Case 9	21214.74	111377.4	-1819442
Case 10	21218.58	111397.5	-1819653

Table 1.6 Base reactions for straight bridges

Observation from table 1.6 clearly indicates that the bracing system has a significant effect on the support reactions and moments. Also it is evident that Case-8 has lesser support reaction and moment which would result in an economical sub-structure design. Further there are not much greater changes in the moment along the transverse direction of the bridge.

Finally the design results are compared to identify the economical bracing system. In order to identify the economical bracing system the overall self-weight of the angle sections required for different bracing systems are shown below in table 1.7.

Cases	Self-weight of Bracing System (kN)	No. of Angle Sections
Case 1	10.772	122
Case 2	105.638	364
Case 3	97.351	364
Case 4	192.274	606
Case 5	63.341	606
Case 6	60.568	606
Case 7	60.196	606
Case 8	66.906	606
Case 9	177.528	606
Case 10	181.359	606

Table 1.7 Bracing details in straight bridges

Finally it can be stated that from all the above results, case-8 is identified as the most suitable bracing system for straight bridge based on strength and economy .As the bridge model has lesser deflection, less support reactions and moments there by enabling economical sub-structure design and also the self-weight of bracing is comparatively lesser than other bracing systems. Hence case-8 bracing systems with v-type internal bracing and alternate v and inverted v-type top bracing system is recommended for straight bridge.

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C. HORIZONTALLY CURVED BRIDGES

Similar to that of straight bridge models, totally 10 horizontally curved bridge models with different bracing systems were analyzed and designed. Based on the finite element analysis result it was observed that due to the effect of different types of bracing systems there was a considerable change in the deflection, support reactions, supports moments, cross-sectional deformations and stress distributions. However in order to identify the most suitable bracing system based on strength and economy the deflection, base reactions and design results of all the bridge models are taken into considerations.

Initially from the SAP 2000 analysis results it was found that the design is safe for all the 10 cases of bridges investigated with different bracing systems, because the *von mises stress* everywhere in the bridge is less than the yield stress of the material. The deflection in different bridge models due to the external load conditions are tabulated in table 1.8. And in order to clearly identify the deflection along the span length a graph is plotted as shown in Fig. 1.19

Span Length (m)	Maximum Deflection (mm)									
	Case 11	Case 12	Case 13	Case 14	Case 15	Case 16	Case 17	Case 18	Case 19	Case 20
0	0	0	0	0	0	0	0	0	0	0
15	36.5	33.4	34.0	31.5	26.8	31.8	31.8	33.1	32.6	31.7
30	50.7	46.1	54.9	44.3	44.7	44.8	43.9	44.7	44.8	43.9
45	30.2	27.5	27.3	25.8	27.5	26.1	26.1	27.5	27.6	26.0
60	0	0	0	0	0	0	0	0	0	0
75	30.8	27.1	26.9	25.4	26.9	25.1	25.7	41.7	29.6	25.7
90	48.9	43.2	43.0	40.6	41.6	41.3	41.3	27.8	41.6	41.2
105	32.6	21.2	28.5	26.8	27.8	27.3	27.3	35.3	27.8	27.12
120	0	0	0	0	0	0	0	0	0	0
135	41.7	38.4	38.2	36.3	35.7	36.8	36.7	63.1	35.4	36.7
150	55.6	69.1	68.7	65.3	63.0	65.9	54.2	55.2	63.2	66.8
165	61.2	55.1	55.5	56.3	49.6	53.2	53.2	49.6	49.8	53.2
180	0	0	0	0	0	0	0	0	0	0

Table 1.8 Deflection in curved bridges

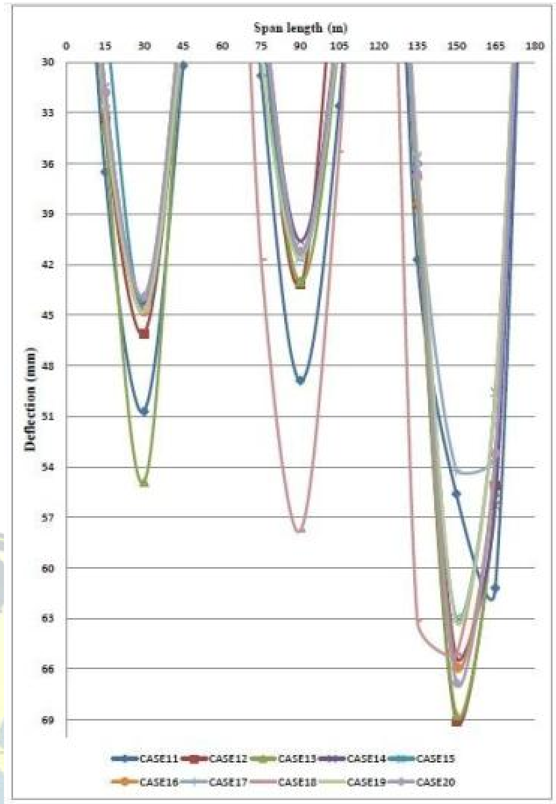

Fig 1.19 Deflection for curved bridges.

It is evident from the deflection result that maximum deflection for all the 10 curved bridge models are within the deflection limit (Span length/800 = 75.5mm). The effect of different bracing systems played a significant role in controlling the deflection in the bridge models. Next the overall structural output result is taken into considerations. The structural output is in the form of different base reactions with resultant forces and moments as shown in table 1.9

Cases	Resultant Force-F_z (kN)	Resultant Moment-M_x (kN-m)	Resultant Moment M_y (kN-m)
Case 11	17530.67	1645960	-5686683
Case 12	18538.42	1646644	-5689346
Case 13	17538.72	1646691	-5689428
Case 14	17518.99	1643488	-5683112
Case 15	17515.69	1643213	-5681963
Case 16	18858.74	1649009	-5696200
Case 17	17542.36	1647017	-5690687
Case 18	17542.85	1647063	-5690861
Case 19	17544.54	1647198	-5691452
Case 20	17543.93	1647137	-5691243

Table 1.9 Base reactions for curved bridges

Observation from table 1.9clearly indicates that the

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reactions and moments. Also it is evident that case-17 has lesser support reaction and moment which would result in an economical sub-structure design. Further there are not much greater changes in the moment along the longitudinal and transverse direction of the bridge.

Finally the design results are compared to identify the economical bracing system. In order to identify the economical bracing system the overall self weight of the angle sections required for different bracing systems are shown below in table 1.10

Cases	Self -weight of Bracing System (kN)	No. of Angle Sections
Case 11	16.268	122
Case 12	23.97	364
Case 13	23.97	364
Case 14	31.672	606
Case 15	28.213	606
Case 16	44.148	606
Case 17	27.667	606
Case 18	28.213	606
Case 19	30.035	606
Case 20	29.49	606

Table 1.10 Bracing details in curved bridges

Finally it can be stated that from all the above results, case-17 is identified as the most suitable bracing system for horizontally bridge based on deflection, support reaction, space for internal inspection and also based on economy .As the bridge model satisfies the deflection limit, has less support reactions and moments there by enabling economical sub-structure design and also the self-weight of bracing is comparatively lesser than other bracing systems. Hence case-17 bracing systems with inverted v-type internal bracing and alternate v and inverted v-type top bracing system is identified as the suitable bracing system for horizontally curved bridge.

X. CONCLUSION

Composite box girder bridges are used in modern highway system because of their profitable and structural advantages. Therefore an extensive parametric study was conducted using SAP2000 software in order to examine the effect of different types of top and internal bracing systems in straight and horizontally curved bridge models. Totally 20 types of three-span continuous bridge models were analyzed to investigate the effect of bracings on deflection, support reaction, moment and weight of bracings. Based on the finite element results the following conclusions are drawn:

1. The effect of different internal and top bracing systems significantly affects the deflection, support reactions, moment and stress distribution in both straight and horizontally curved bridges.

2. Based on strength and economy, bridge with v-type internal bracing and alternate v-type and inverted v-type top lateral bracing was found to be much suitable and economical bracing system for straight bridge.

3. Based on strength and economy, bridge with inverted v-type internal bracing and alternate v-type and inverted v-type top lateral bracing was found to be much suitable and economical bracing system for horizontally curved bridges.

4. Also comparative study between straight and curved bridges with similar bracing system suggests that SCC box girder bridges are much suitable and economical for bridges with curved alignment.

5. Further it can also be believed that the information available in this investigation will be of considerable use to the engineers who are in the process of multi-span design of box girder bridges.

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