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Effect of Web Inclination on Box Girder Bridges

Akash B. More, Shriganesh S. Kadam

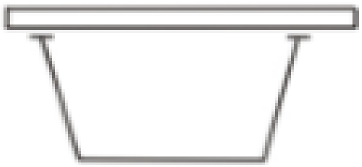
Abstract— Bridge is a key element in any transportation system which provides easy access over physical obstacles like road, valley, water bodies etc. without closing the way underneath. Among various types, use of box girder type bridges are gaining popularity in bridge engineering because of its better stability, serviceability, economy, aesthetics, structural efficiency and rigidity in torsion. In this study, a box girder is analyzed by changing its web inclination angle to the horizontal (90°, 83°, 76°, 69°, 62°) using finite element based software CSi Bridge. Finite element models are developed keeping material properties, span length, boundary conditions as constant parameters. All these models are analyzed for self-weight, including load of wearing coat and crash barrier, and live loads specified by Indian Road Congress (IRC) namely IRC Class 70R and IRC Class-A loading. Responses in terms of torsional moment, longitudinal moment, support reactions, displacement and stresses are determined.

Keywords: Box girder, Web inclination, IRC loading, CSi Bridge, Finite element analysis.

I. INTRODUCTION

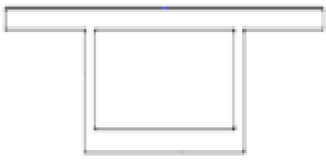
Bridge is a structure providing passage over an obstacle without closing the way beneath. The required passage may be for a road, a railway, pedestrians, a canal or a pipeline. The obstacle to be crossed may be a river, a road or a valley. Initially the naturally available materials like stone and timber were widely used for bridges but now-a-days artificial materials such as cement, concrete and steel are utilized more in construction of bridges [1].A box girder is a girder that forms an enclosed tube with multiple walls. The advantage of the box girder is that it better resists the torsion. The commonly used box girders may be of two type's rectangular box girder and trapezoidal box girder [2].

Sloping webs of the box girders lead to trapezoidal shape, which is where origin of the commonly used name trapezoidal box girder is derived. While the sloping webs produce a sleek appearance to the girders that enhance the overall aesthetics. There are also practical structural reasons for the inclined webs such as reducing the bottom flange width. In addition to reducing the amount of material required for the bottom flange, also some past researchers propose that the web inclination of the box girder tends to reduce distortional effects induced in the box girders [3].Box girder bridges are classified according to their cross section and number of cells. Box girder can be constructed as a single cell, two cells or multi cell. Box girder constructed monolithically with deck called as closed box girder and box girder in which deck constructed separately called open box girder. According to cross section details box girder classified into rectangular, trapezoidal and circular box girder.

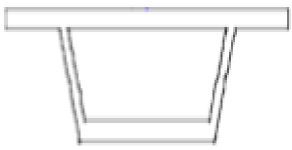


Single Cell Box Girder

Multi Cell Box Girder



Rectangular Cross Section



Trapezoidal Cross Section

In the present study the effect of the possible web slopes on the overall behaviour of the box girder is investigated. Results from the finite element analysis will be presented to show the effect of web inclination on box girder.

II. METHODOLOGY

The analysis of single cell box girders with varying web inclination angle has been carried out using finite element based software CSi Bridge.

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Following steps are carried out to achieve the objectives of the research work.

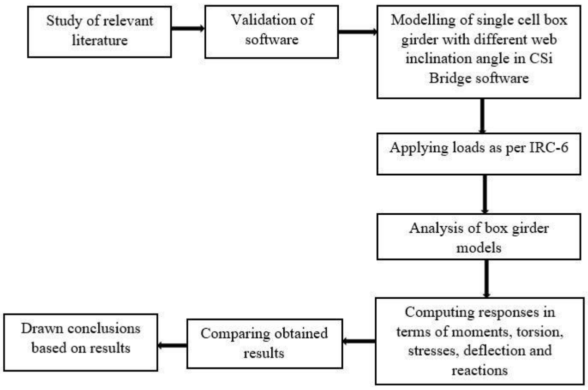

Fig.1. Methodology adopted to achieve the objectives of the research work

III. VALIDATION

To validate the finite element software CSi Bridge, an example from the previous literature Pragya Soni, (2017) [4] is consider in which analysis was done by using another FEM based software MIDAS Civil. CSi Bridge is finite element analysis software which is specially used to analyse different types of bridge structures. The program employs the matrix displacement method of analysis based on finite element idealization. Figure 1 shows the cross-sectional details of box girder model consider for validation. The span length is 29 m and width of deck is 13m. Material properties of the box girder model are given below.

1) Grade of concrete= M40
2) Density of concrete=25 KN/m3
3) Grade of steel= Fe 500

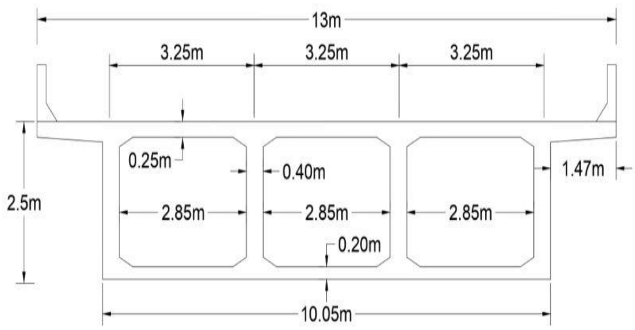

Fig.2. Cross-section of box girder (courtesy Pragya Soni, 2017)

Table-I: Comparison of BM Results for validation

Type of loading	Results from literature/ MIDAS Civil	Results from CSi Bridge	Error %
BM Due to DL	19264 KN-m	21937 KN-m	13.87%
BM Due to SIDL	4410 KN-m	3264 KN-m	17.98%
3 Lanes of Class A	8591 KN-m	8118 KN-m	5.50%
One lane of class 70R for every two lanes with one lane of class A on the remaining lane	6364 KN-m	7877 KN-m	17.77%

Table-II: Comparison of Results for validation

Type of results	Results from literature/ MIDAS Civil	Results from CSi Bridge	Percentage error %
Central Deflection	-14.070 mm	-12.25 mm	12.93%
Bending stresses @ top slab	-3.9 N/mm2	-4.4 N/mm2	12.82%
Bending stresses @ bottom slab	5.1 N/mm2	6.01 N/mm2	17.83%
Shear force maximum	4526.7 KN	4661.36 KN	2.97%
Shear force minimum	3266 KN	3480.19 KN	6.55%

IV. CROSS SECTION AND MATERIAL PROPERTIES

A. Material Properties

The material properties used for models are given below
Grade of concrete M40
Characteristic strength (fck) 40 Mpa
Young’s modulus (Ec) 3.1622 e7 KN/m2
Density of concrete 25 KN/m3
Grade of steel Fe 500
Poison’s ratio 0.2
Coefficient of thermal expansion 5.5 e−6/C

B. Cross Sectional Properties

The preliminary dimensions of all box girders with varying web inclination angle are calculated as per IRC: 18. Figure 3a, 3b, 3c, 3d & 3e shows typical cross-section of box girder with varying web inclination angle.

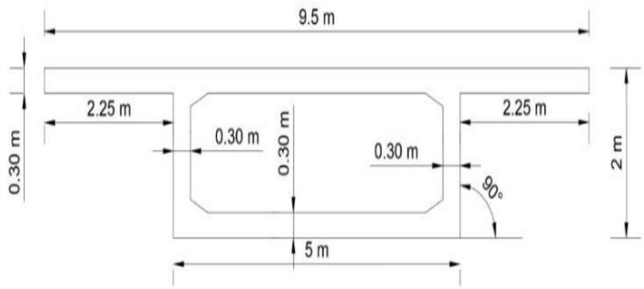

Fig.3a: Cross-section of box girder with web inclination angle 90°

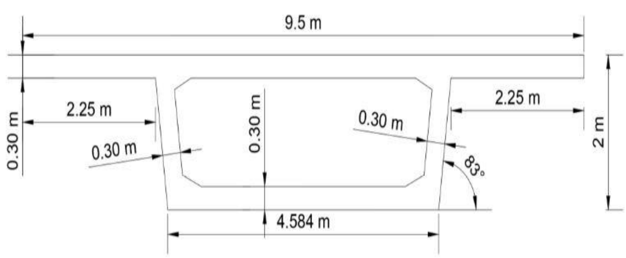

Fig.3b: Cross-section of box girder with web inclination angle 83°

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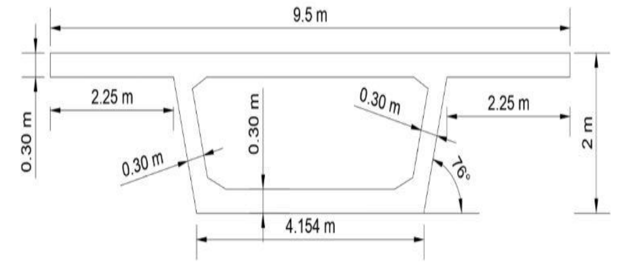


Fig.3c: Cross-section of box girder with web inclination angle 76°

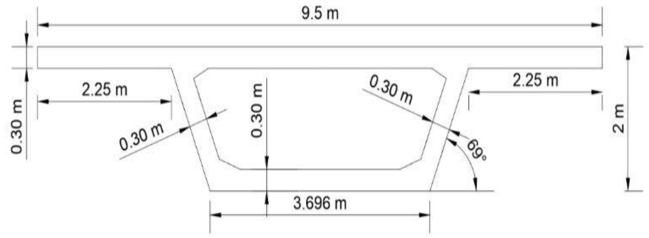


Fig.3d: Cross-section of box girder with web inclination angle 69°

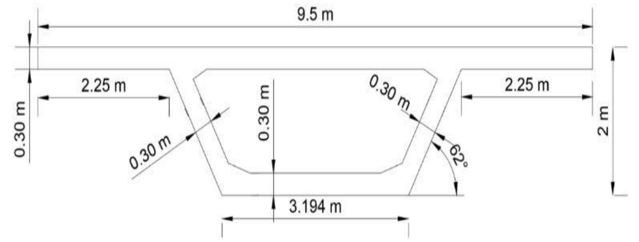


Fig.3e: Cross-section of box girder with web inclination angle 62°

V. LOAD CONSIDERATIONS

The loads considered for analysis of the structure include dead load, superimposed dead load and moving load and are considered as per the specifications given in IRC6:2016 [5]. No earthquake and wind load are considered for the analysis. The details of the loads considered for applying over the structure are as given below:

1. Self-weight – self weight command is used to apply self-weight to the structure.
2. Superimposed dead loads
   a. Crash barrier load- (size: 1m height and 0.5 m thick).
   b. Wearing course load- (65 mm thick wearing course).
3. Live load- IRC Class 70 R and IRC Class A loading.

VI. MODELLING

Total five box girder models with changing web inclination angle by 7° decrement are developed in CSi Bridge software using shell type elements. The cross-sectional details and material properties given above (section III) are adopted to develop the box girder models, keeping the span length (20m), material properties, loading, as constant parameters for all the five models.

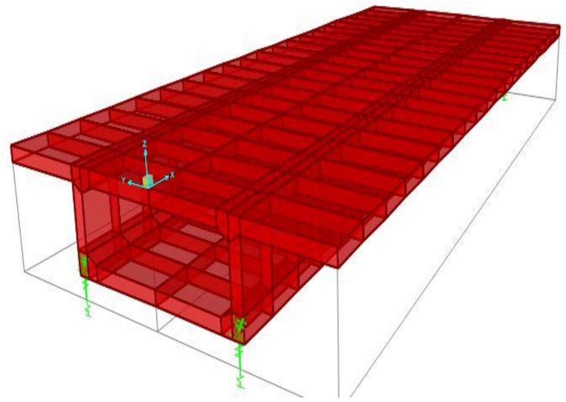


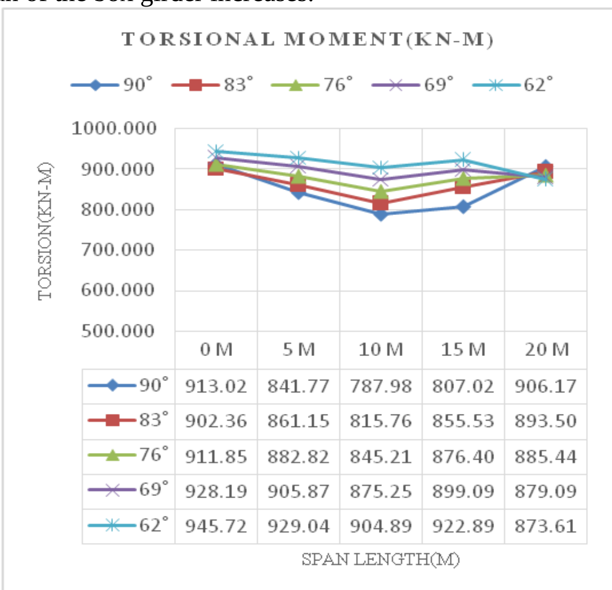
Fig.4. Snapshot of box girder model in CSi Bridge

VII. RESULTS AND DISCUSSION

The response of all box girders under varying web inclination angle are discussed in terms of torsion moments, longitudinal moments, deflection, reactions and stresses at top and bottom of the girder. Comparative study is carried out by comparing results obtained for all the box girders under varying web inclination angle.

A. Torsional Moment

The variation of torsional moment along the span for box girder models under varying web inclination angle for two lanes of IRC class-A loading is shown in Figure 4. The box girder models experiences torsion along the span under moving load. From figure 4 it is clearly seen that as the web inclination angle decreases, the torsional moment along the span of the box girder increases.



	0 M	5 M	10 M	15 M	20 M
90°	913.02	841.77	787.98	807.02	906.17
83°	902.36	861.15	815.76	855.53	893.50
76°	911.85	882.82	845.21	876.40	885.44
69°	928.19	905.87	875.25	899.09	879.09
62°	945.72	929.04	904.89	922.89	873.61

Fig.5. Variation of torsional moment along the span under two lanes of IRC Class-A loading

B. Support Reactions

The maximum vertical support reaction for all box girders with varying web inclination angle are as plotted in Figure 5.

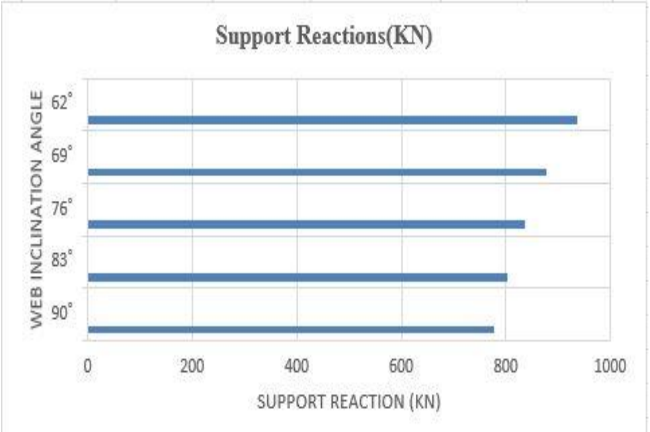


Fig.6. Comparison of support reactions

From figure 5 it is clearly seen that as the web inclination angle of the box girder decreases, the maximum support reaction induced increases.

C. Maximum Deflection

From the results it is found that the deflection in box girder due to self-weight is found to be maximum in all type of loading conditions. Also the maximum vertical deflection is found at the mid-span of the box girder. It is observed from the results that as web inclination angle decreases the deflection in box girder increases.

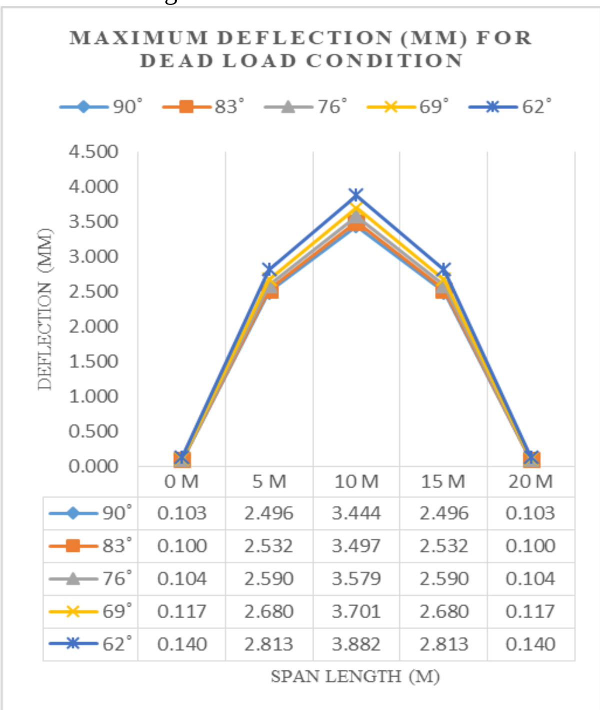


Fig.7. Maximum deflection at 5m interval of span for Dead load condition

D. Longitudinal Moment

When web inclination angle decreases from 90° to 62° the longitudinal moment in the box girder also decreases. Figure 7 shows the variation of maximum longitudinal moments in the box girder with varying web inclination angle due to self-weight.

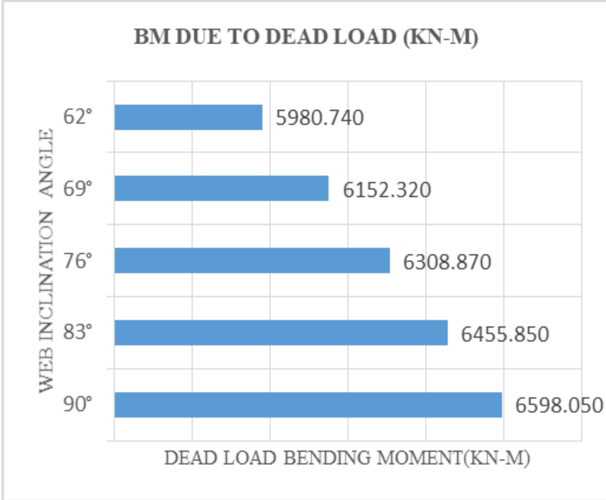


Fig.8. Maximum longitudinal moment due to self-weight

E. Stresses at top and bottom center

Top centre of box girder possesses lower stresses as compared to the bottom centre of the box girder.

From the results and the graph it is observed that, when the web inclination angle decreases, there is no effective change in the stresses at top centre of the box girder. But it is found that the stresses at the bottom centre of the box girder increases.

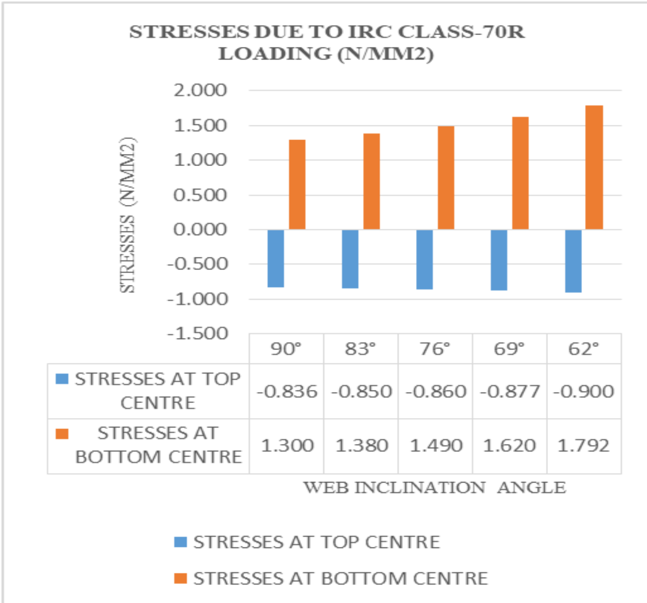


Fig.9. Maximum stresses at top and bottom centre due to IRC class-70R loading

VIII. CONCLUSIONS

1. For class-A loading, torsional moment is maximum at support and it is minimum at center of span. The same torsional moment pattern is observed for all web inclination angles i.e. for 90°, 83°, 76°, 69° and 62°. As web inclination angle increases torsional moment decreases.

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2. For class-70R loading, torsional moment is maximum at beginning of the span and linearly get reduces to end of the span. Unlike torsional moment of class-A loading, torsional moment increases as angle of web inclination increases.
3. The magnitude of support reaction increases as web inclination angle decreases. The maximum percentage of increase (6.33%) is found when angle of web inclination changes from 69° to 62°.
4. As angle of web inclination decreases, the magnitude of deflection increases for both dead load and live load conditions.
5. In case of vehicular loading, no any variation in longitudinal moment is found while changing web inclination angle from 62° to 90° at interval of 7°. But, for dead load condition magnitude of longitudinal moments get increases as the angle of web inclination increases.
6. The tensile stresses at bottom center of box girder increases as web inclination angle decreases for all type of loading conditions. While there is no any considerable change is found in top center tensile stresses for different web inclination angle.
7. Box girder having lesser web inclination angle (62°) possesses lesser magnitude of moments compared with box girder consisting higher web inclination angle, which further reduces the steel requirement while designing. Hence, it is economical to choose low web inclination angle while adopting box type superstructure.

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