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Simplified method for the transverse bending analysis of twin celled concrete box girder bridges

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Abstract. Box girder bridges are one of the best options for bridges with span more than 25 m. For the study of these bridges, three-dimensional finite element analysis is the best suited method. However, performing three-dimensional analysis for routine design is difficult as well as time consuming. Also, software used for the three-dimensional analysis are very expensive. Hence designers resort to simplified analysis for predicting longitudinal and transverse bending moments. Among the many analytical methods used to find the transverse bending moments, SFA is the simplest and widely used in design offices. Results from simplified frame analysis can be used for the preliminary analysis of the concrete box girder bridges. From the review of literatures, it is found that majority of the work done using SFA is restricted to the analysis of single cell box girder bridges. Not much work has been done on the analysis multi-cell concrete box girder bridges. In this present study, a double cell concrete box girder bridge is chosen. The bridge is modelled using three-dimensional finite element software and the results are then compared with the simplified frame analysis. The study mainly focuses on establishing correction factors for transverse bending moment values obtained from SFA.

1. Introduction

High structural efficiency and its elegant view make the box girder bridges widely popular and acceptable throughout the world. The various kinds of cross-sections in box girders are single-cell, multi-spine, or multi-cell with vertical or inclined webs. Based on the type of concrete, they can be reinforced or pre-stressed concrete bridges. These bridges are the most favoured economic and aesthetic solutions in the construction of over crossings, under crossings, viaducts, etc. Since box girder is a closed section it can resist structural actions like torsion and bending much better than open cross-sections like T beam. It is obvious that the structural actions in box girder bridges are much more complex when compared with the slab deck type or T beam bridges. Due to external forces, the structural actions exhibited in box girder bridges are longitudinal bending, St.Venant torsion, distortion, torsional warping, distortional warping, shear lag, and some local effects. Due to these factors, a three-dimensional study is inevitable in the case of box girder bridges.

There exist many methods for the study of stresses in bridges [1] like simple beam theory, simplified frame analysis (1974), Knittel’s method (1965), equivalent beam method (1966), Kupfer’s method (1969), Kolbrunne and Hajdins’s method (1966), beam on elastic foundation method (1968), Reissner’s method (1948), grillage theory (1975), folded plate/ shell theory (1957) and finite element method (1971). Among these methods, the most accurate one is the three-dimensional finite element method but the most commonly used method is the simplified frame analysis for the determination of bending moments. Design engineers throughout the world commonly adopt simplified frame analysis for proof checking of the box girder bridges. This helps to avoid the use of costly software and tedious computational works.

As of now the research on SFA is restricted to single cell concrete box girder bridges. Hence in this paper the reliability of SFA on double cell concrete box girder bridge is checked. This is done by
verifying the results obtained from SFA with the results from three-dimensional finite element analysis.

2. Simplified frame analysis (SFA)
Maisel and Roll in 1974 proposed a simplified method for estimating the transverse action of single cell box girder bridges. In this method, a box frame of unit width with fictitious hinged supports at the top of the web locations are assumed for the analysis. Here the frame is loaded with an equivalent line load calculated using the effective width method. This method is used to evaluate the transverse bending moments in the box girder bridges under the application of vehicular load. There are many limitations while using Simplified frame method. They are:
1. Assumption of the rotational and translational fixity at the web top flange junctions
2. Neglect of distortion analysis, which becomes critical at high eccentricity in loading positions.
3. When the loading is exactly on the top of web flange junction, transverse bending moment values are not obtained.
4. Wheel load is modelled as an equivalent line load based on approximate effective width method.
5. Only transverse bending action in the top flange is considered, with no regard to the curvature in longitudinal direction.

Due to these limitations of SFA, the values obtained may be incorrect. To counteract these errors, the values obtained will be usually enhanced by nearly 10% (which is not accurate). By providing exact correction factors to the values obtained from SFA this problem can be solved. Kurien et al [1] have analyzed single cell box girder bridges using both SFA and 3DFEA and established correction factors for the same.

2.1. Modelling of vehicular load in SFA
For a wheel or track load $Q$, with its contact dimensions say $B$ (in vehicle direction) and $W$ (in the direction normal to vehicle) the concentrated load $P$ can be obtained as $Q/b_e$, where $b_e$ is the effective width.

\[ b_e = \alpha x (1 - x/l) + b_w \]  

where,
- $b_w = B + 2c$
- $\alpha$ = Coefficient (provided in IRC: 112-2000)
- $x$ = load position measured from the nearest web
- $l$ = effective span
- $b_w$ = breadth of load concentration area
- $c =$ thickness of the wearing coat

The cross-sectional details of a single cell box girder bridge is shown in figure 1(a) and the frame modelled for SFA with a vehicular load modelled for the same bridge cross section is given in figure 1(b).
3. **Comparative study**

In this paper, a double cell box girder bridge is taken for study. The study focusses on finding appropriate correction factors for transverse bending moments obtained from SFA, so that SFA becomes more reliable to design engineers. The bridge is modelled and analyzed using CSi bridge and the box frame modelled for SFA is analyzed using STAAD software. Transverse bending moment values so found from SFA and 3DFEA are compared. With this view a representative cross-section of a twin celled box girder is chosen for study. The span (L) considered is 30m. Flange thickness is taken as \( t_f \) 0.25m and the interior and exterior web thickness \( (t_w) \) is 0.5m. Total width is 5m. A load of 350kN with contact dimensions 3.5m × 0.75m is placed at 0.875m from edge of the deck at the middle span of the bridge. Cross-sectional details chosen of this twin celled box girder is provided in figure 2.

![Figure 1](image1.png)

**Figure 1.** (a) Cross section of box girder; (b) Frame modelled for SFA bridge - Ref [1] Not to scale.

![Figure 2](image2.png)

**Figure 2.** Cross section of twin celled box girder bridge (All dimensions are in m).
Figure 3. (a) Twin cell box girder bridge modelled for SFA (All dimensions are in m); (b) Transverse bending moment diagram from STAAD.

3.1 Simplified frame Analysis
The simplified box frame modelled for this double cell box-girder bridge supported on fictitious hinge supports is shown in figure 3(a). Load P is applied which is explained earlier in this paper under modelling of vehicular loads. This frame is then analysed using STAAD to get the transverse bending moment values at the web – top flange junctions. The bending moment diagram obtained from STAAD is also shown in figure 3(b).

3.2 Three - dimensional finite element analysis
The same bridge is modelled using the finite element software. Here the deck is modelled using four noded shell elements. Automated meshing options help to mesh the structure and care was taken to see that the aspect ratio requirements are not violated. Deck is supported on simply supported ends. The live loads are applied at mid span as pressure loads, such that the load is dispersed at 45 degrees to the deck slab. Figure 4 depicts a model of the twin celled box girder bridge chosen on which the vehicular load is highlighted.
3.3 Results of Comparison

The transverse bending moment values obtained by SFA and the 3DFEA for the critical elements (AB, AF, BE, CD) in the bridge cross-section are provided in the figure 5(a), 5(b), 5(c) and 5(d). The disparity between the methods can be quantified by introducing a correction factor ($\theta$), defined as

$$\theta = \frac{\text{3DFEA transverse moment}}{\text{SFA transverse moment}}$$

(a)

(b)

(c)

(d)
**Figure 5.** (a) Transverse bending moment in beam element AB (kNm/m); (b) Transverse bending moment in column element AF (kNm/m); (c) Transverse bending moment in column element BE (kNm/m); (d) Transverse bending moment in column element CD (kNm/m)

The correction factors (θ) obtained for the critical elements chosen are tabulated as shown in table 1.

| Element | Correction factors (θ) |
|---------|------------------------|
| AB      | 1.11                   |
| AF      | 1.11                   |
| BE      | 1.04                   |
| CD      | 6.35                   |

It can be seen that the correction factors obtained are comparable to those reported from the study of single cell box girder bridges. More parameters have to be considered like the position of load, span and varying cross-sections.

### 4. Conclusions

The numerical study performed for double cell box girder bridges reveals that SFA fetches quick results compared to 3D FEA. But as explained there are deviations from the actual results. These deviations are similar to those for single cell. Extensive studies with varied cross-section and loading has to be carried out to confirm the reliability of SFA for multi-cell concrete box girder bridges.

### 5. References

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