ANALYSIS AND COMPARATIVE STUDY OF COMPOSITE BRIDGE GIRDERS

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ABSTRACT

The composite bridge gives the maximum strength in comparison to other bridges. The design and analysis of various girders for steel and concrete by using various software, in that paper for composite bridge calculate the bending moment for T girder and finding which is more effective. The efforts will make to carry out to check the analysis of bridge by using SAP 2000 software. To determine the static analysis of T girder by using manual method as well as software. The results obtained from the software in structural analysis are compare the results obtained from manual calculations.

Key words: T Girder, IRC AA Loading, SAP2000 Software


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1. INTRODUCTION

T-beam, used in construction, is a load-bearing structure of reinforced concrete, Wood or metal, with a t-shaped cross section. The top of the T-shaped cross section serves as a flange or compression member in resisting compressive stresses. The web of the
beam below the compression flange serves to resist shear stress and to provide greater separation for the coupled forces of bending. [1]

A cross girder at the middle is more effective than two cross girders at the third points and the presence of two cross girders at quarter points in addition to the one at the middle may be and may not improve the load distribution and in both cases the change is small. [2]

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. [3]

Static analysis is used to determine displacements, stresses, etc. under static loading conditions. Static structural analysis is one in which the load/field conditions does not vary with time and the assumption here is that the load or field conditions are gradually applied. [4]

IRC Class A loading bridge responses such as Bending Moment (BM) and deflection are obtained to assess the serviceability. [5]

Due to efficient dissemination of congested traffic, economic considerations, and aesthetic desirability horizontally curved steel box girder bridges have become increasingly popular nowadays in modern highway systems, including urban interchanges. Currently curved girders have replaced straight segments because in urban areas where elevated highways and multi-level structures are necessary, modern highway bridges are often subjected to severe geometric restrictions; therefore they must be built in curved alignment. Even though the cost of the superstructure for the curved girder is higher, the total cost of the curved girder system is reduced considerably since the number of intermediate supports, expansion joints and bearing details is reduced. [6]

The process undergoes many manual iterations before the design can be finalized making it a slow and very costly process. [7] The typical multi-girder steel-concrete composite bridge, which consists of a number of steel girders with bracing in between and a slab on top, and a ladder deck bridge, which consists of two main girders with a number of secondary cross girders in between that support and act with a deck slab. [8]

The relative economy of the box-girder bridges contributed greatly to its popularity, as it has relatively slender and unencumbered appearance. The structural simplicity of the box-girder bridges, particularly in continuous structures of medium to long spans, has been well demonstrated. The efficiency of the cross-section for positive and negative longitudinal bending moments, as well as torsional moments is apparent even to casual observer. [9] The deck and the steel support girders acted in a non-composite manner. This was evident from visual inspection of the bridge that there had been obvious differential movement between the deck and the girders, this was also evident from the results of the tests that were run. [10] The steel girders, defined as beam elements, were positioned on a separate plane of nodes parallel with the deck. The girder nodes were defined by copying a nodal layer of the deck to a new plane. [11]

The main objectives of the proposed work are:

1. To study the structural behavior of bridge under Static analysis.
2. To identify the suitability of the composite Bridge girder.
3. Compare its results numerically to know the suitability of the composite bridges for Experiments have shown that steel material when coated with resin and used performs better. SAP2000 is used to perform Finite Element Analysis of the composite member using which, basic structural properties of the composite are calculated.

2. PIGEAUD’S METHOD
Pigeaud’s method for the design of bridge slab consist of series chart that are used for determine the longitudinal and transverse BM in a bridge slab due to a wheel load occupying a small rectangular area. The slab of loaded area is assumed to transmit at a 45° angle.

From geometry of pressure area the width u and the length v calculated, according to the geometry of slab and beam system, the slab span between diaphragm B and the slab width between longitudinal beams L are calculated, and from the distance B/L, u/B and v/L are determined. The ratio B/L determines which chart to use and plotting the value of u/B & v/L result in a moment M1 or M2 which are functions of B and L respectively. (The charts are solutions to the LaGrange equation for wide ranges of slab dimension ratios and ratios of sides to loaded areas.) From the determinations of M1 and M2, MB and ML are calculated from the following equations where 0.15 is Poisson’s ratio for concrete:

\[ M_B = (M_1 + 0.15M_2) \times W \text{ in-lb/in} \]
\[ M_L = (M_2 + 0.15M_1) \times W \text{ in-lb/in} \]

Where W is the concentrated load or wheel load in pounds. MB and ML are the transverse and longitudinal moments per unit width respectively and can be considered positive at the mid span of the panel and negative over the supports. [11]

3. PROBLEM STATEMENT
The problem taken for the comparison, typical bridge span without pre stressing or post tensioning is considered, the bridge is analyzed for the two continuous spans with three piers in series to get the proper load distribution on the pier. The CLASS 70 R Tracked loading is considered or the analysis as per IRC code. Solution of above problem solving by pigeadu’s method.

3.1. Required data
- Effective Span =16.000 m.
- Total length of Deck =8.700 m.
- Carriage way width =7.500 m.
- Width of Parapet including Kerb =0.600 m. Width of Footpath =1.000 m
- Thickness of Slab =0.200 m. No of Longitudinal Girder =4.000 m
- Height of Longitudinal Girder =1.500 m.
- Spacing of Longitudinal Girder =2.500 m
- Cantilever Length =1.125 m, Thickness of Web =0.250 m.
- Thickness of Footpath=0.350 m, Thickness of Kerb =0.450 m.
- Thickness of Parapet =0.200 m, Height of Parapet above Kerb =0.900 m.
- No of Cross Girder =5.000 m. Spacing of Cross Girder Spacing =4.000 m.
- Thickness of Cross Girder =0.300 m. Height of Cross Girder =1.500 m.
Density of RCC =25.000kN/m3. Wearing Coat Thickness =0.080m.
Density of Wearing Coat =22.000kN/m3.

**Solution-Design of Deck Interior Slab Panel**

3.1.1 *Live Load*

Considering 70R Tracked vehicle =2.500m which is placed at the center of panel as shown in fig. Contact area of vehicle is, 0.84m in transverse direction, 4.57m in longitudinal direction.

![Figure 1 Loading placed Center of panel](image)

\[ u = 0.84 + (2 \times 0.08) = 1.00 \text{m} \]
\[ v = 4.57 + (2 \times 0.08) = 4.73 \text{m} > 4.00 \text{m} \]

Hence, \( v = 4.00 \)

\[ M_u = 1.00 \frac{u}{B} = 1/2.5 = 0.4 \]
\[ v/L = 4/4 = 1.00 \]

\[ K = B/L = 2.5/4 = 0.625 \text{ say } 0.7 \]

Referring to Pigeaud's curves corresponding to 'K'=7' values, the values of moment Coefficients are,

\[ m_1 = 0.08, \ m_2 = 0.03. \]

70R Tracked load for two track =700.00KN
70R Tracked load for one track =350.00KN.

\[ M_B = W \times (m_1 + (0.15 \times m_2)) = 350 \times (0.08 + (0.15 \times 0.034)) = 29.575 \text{KNm.} \]

\[ M_L = W \times (m_2 + 0.15 \times m_1) = 350 \times (0.03 + (0.15 \times 0.08)) = 14.7 \text{KN-m.} \]

As the slab is continuous, the design bending moments are obtained by applying the continuity factor as, 40% is given by, \( M_B = 1.4 \times 29.575 = 41.41 \text{KN-m} \)

\( M_L = 1.4 \times 14.7 = 20.58 \text{KN-m} \)
3.1.2 Dead Load
Dead weight of slab = 0.200 \times 25.000 = 5\,\text{KN/m}^2.
Dead weight of wearing coat = 0.080 \times 22.000 = 1.76\,\text{KN/m}^2.
Total weight = 6.76\,\text{KN/m}^2.
Dead load bending moments are computed using Pigeaud’s Curves
Dead Load = 6.76\,\text{KN/m}^2.
Total DL on panel = (6.76 \times 4 \times 2.5) = 67.5\,\text{KN}.
Plate load and self-weight = 3.16 + 5.05 = 8.21\,\text{KN}.
Total D.L = 67.5 + 8.21 = 75.71\,\text{KN}.

\( u / B \) = (v / L) = 1 as panel is loaded with UDL,
\( K = B / L = 2.500 / 4.000 = 0.625 \)
From Pigeaud’s Curves read out the Co-efficient are \( m_1 = 0.04 \), \( m_2 = 0.02 \).
Taking the continuity effect, the design moments are,
\[ M_B = (W) \times (m_1 + 0.15 \times m_2) = 75.71 \times (0.04 + (0.15 \times 0.02)) = 3.25\,\text{KIN} \times \text{m}. \]
\[ M_L = (W) \times (m_2 + 0.15 \times m_1) = 75.71 \times (0.02 + (0.15 \times 0.04)) = 1.96\,\text{KIN} \times \text{m}. \]
As the slab is continuous, the design bending moments are obtained by applying the continuity factor as 40%,
\[ M_B = 1.4 \times 3.25 = 4.55\,\text{KIN} \times \text{m}. \]
\[ M_L = 1.4 \times 1.96 = 2.744\,\text{KIN} \times \text{m}. \]

3.1.3 Design parameters
Grade of concrete = M - 35 = 35N/mm^2.
Grade of Steel Fe = Fe - 415 = 415N/mm^2.
According to IRC-21:2000
Design Constants: \( \sigma_{cbc} = 11.67\,\text{N/mm}^2 \), \( \sigma_{st} = 200\,\text{N/mm}^2 \), \( m = 10 \).
\[ k = (m \times \sigma_{cbc}) / (m_{cbc} + \sigma_{st}) = (10 \times 11.667) / ((10 \times 11.66) + 200) = 0.37 \]
\[ j = 1 - (k/3) = 1 - 0.373 = 0.88 \]
\[ Q = 0.5 \times \sigma_{cbc} \times j \times k = 0.5 \times 11.667 \times 0.88 \times 0.37 = 1.89 \]
\[ \text{N/mm}^2 \]
\[ d_{eq} = \sqrt{(45.96 \times 1 \times 10^6) / (1.89 \times 1000)} = 159.9\,\text{mm}. \]
Diameter of rod = 16 mm
Overall Depth Provided = 250 mm
Clear Cover = 40 mm
Center of reinforcement = 8 mm
Effective depth Provided = 202 mm < \( d_{eq} \).

Hence OK.

Area of Steel required = \( (M \times 10^6) / (j \times \sigma_{st} \times d) \)
Area of Steel Required = (23.32 \times 10^6) / (0.877 \times 200 \times 202) = 658.18\,\text{mm}^2/\text{m}.
Minimum reinforcement required = 0.12 \%
of cross sectional area = 0.12\% \times 1000 \times 250 = 300\,\text{mm}^2/\text{m}.
\( A_{st} \text{req} > A_{st} \text{min} \)
\( A_{st} \text{req} = 658.18\,\text{mm}^2/\text{m} \)
Steel Provided = \text{Pro steel/m} = \text{Provide 16 mm dia, 150mm c/c 804 mm}^2/\text{m}.

Total Steel Provided on Embankment Face = 804\,\text{mm}^2/\text{m}.
OK and SAFE
Area of Steel Required = 45.96 \times 10^6 / 0.877 \times 200 \times 202 = 1297.18\,\text{mm}^2/\text{m}.
Minimum reinforcement required = 0.12 \% of cross sectional area = 0.12\% \times 1000 \times 250 = 300\,\text{mm}^2/\text{m}.
Analysis and Comparative Study of Composite Bridge Girders

Ast req > Ast min
Hence required $A_{st} = 1297.18 \text{mm}^2 / \text{m}$.

Steel Provided = Pro steel/m = Provide 16mm dia, 150mm c/c = $1297.18 \text{mm}^2 / \text{m}$.
Total Steel Provided on Embankment Face = 1407.43 mm$^2 / \text{m}$. Hence OK.

3.1.4 DESIGN OF CANTILEVER SLAB
Bellow figure shows the cantilever portion of the Tee beam and slab bridge deck with dimensional details of cantilever projection, kerb, handrails and footpath

a) Dead Load Calculation
i) Deck slab = $(0.2 \times 1.00 \times 25) = 5 \text{KN/m}$.
ii) Haunch at support = $(0.10 \times 25) = 2.5 \text{KN/m}$.
iii) Foot path = $(0.35 \times 1.00 \times 25) = 8.75 \text{KN/m}$.
iv) Kerb above Footpath = $(0.10 \times 0.60 \times 25) = 1.5 \text{KN/m}$.
v) Parapet = $(0.90 \times 0.20 \times 25) = 4.5 \text{KN/m}$.

Total load = $(5 + 2.5 + 8.75 + 1.5 + 4.5) = 22.25 \text{KNm}$. Moment = $(22.25 \times 1 \times 0.5) = 11.125 \text{KNm}$.

b) Live Load Calculation
Here only footpath live load is considered, because footpath is covering the whole cantilever portion. According to IRC-6:2010, Cl: 209.

![Uniformly distributed load on Cantilever](image)

**Figure 2** Uniformly distributed load on Cantilever

i. Footpath load taken 5.00KN/m. Taking Moments at the support = $2 \times 0.40 \times 0.2 = 0.16 \text{KN-m}$

ii. Maximum Bending Moment at Support

Dead Load Moment = $11.125 \text{KN-m}$ Live Load Moment = $0.16 \text{KN-m}$ Total Moment = $11.285 \text{KN-m}$. 

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4. SAP 2000 SOFTWARE

![Figure 3 Section of Bridge](image)

**T-SECTION**

*a) live load*

Load for one lane (W) = 350KN

Area of rectangle\(A_R\) = \((B \times L) = (2.5 \times 4) = 10\ m^2\)

Area load \(A\) = \((W/A_R) = 350/10 = 35\ \text{KN/m}^2\)

Area of triangle = \((1/2 \times B \times B) = (1/2 \times 2.5 \times (2.5/2))\)

=1.5625 \text{m}^2 \ 2 \times 1.5625 = 3.125 \text{m}^2

Area of trapezoidal\(A_T\) = \((A_R - 3.125)/2 = 3.4375\m^2\)

Point load on trapezoid = \((A_T \times A) = (35 \times 3.4375) = 120.3125\ \text{KN}\)

UDL on one trap \((120.3125/4) = 30.078125\ \text{KN/m}\)

UDL on two trap = 60.156 \text{KN/m}

point load on triangle = \((\text{Area of triangle} \times A) = 1.5625 \times 35 = 54.6875\ \text{KNm}\)

UDL on triangle = 54.6875/2.5

= 21.875 \text{KN/m}
**b) Dead load**

Total point load = Point load of slab + Point load plate load = 3.16KN.
Self-weight of Box girder = 3.05KN

\[ W = 67.6 + 3.16 + 5.05 = 75.81\text{KN} \]

Area of rectangle \( A_R = (B \times L) = (2.5 \times 4) = 10 \text{ m}^2 \)

Area load \( A = W / A_R = 75.81 / 10 = 7.581\text{KN/m}^2 \)

Area of triangle \( = \frac{1}{2} \times \frac{1}{2} \times 2.5 \times (2.5/2) = 1.5625 \text{ m}^2 \)

Area of trapezoidal \( A_T = (A_R - 3.125)/2 = 3.4375\text{m}^2 \)

Point load on trapezoid \( = A_T \times A = 7.581 \times 3.4375 = 26.05969\text{KN}. \)

UDL on one trap \( = 26.05969/4 = 6.514922\text{KN/m} \)

UDL on two trap \( = 13.02984 \text{KN/m} \)

Point load on triangle \( = \text{Area of triangle} \times A = 1.5625 \times 7.581 = 11.84531 \text{KN/m}^2 \)

UDL on triangle \( = 11.84531/2.5 = 4.738 \text{KN/m} \)

![Figure 4 Bending Moment of T section for long span](image-url)
5. RESULTS

5.1. Variation in the manual analysis and in SAP2000 comparison

Table 1 Bending moment in KNm

<table>
<thead>
<tr>
<th></th>
<th>Short Span</th>
<th>Long span</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual</td>
<td>SAP</td>
<td>Manual</td>
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<tr>
<td>T</td>
<td>23.3</td>
<td>25.88</td>
</tr>
</tbody>
</table>

6. CONCLUSIONS

The variation of 10% is seen in between manual and SAP analysis for T section along short span.
Analysis and Comparative Study of Composite Bridge Girders

Figure 6 Variation in BM for short span T section

The variation of 3% is seen in between manual and SAP analysis for T section along long span.

Figure 7 Variation in BM for long span T section

Above graph shows the bending moment variation in the T-girder calculated manually. Every section has its own significance according to the load carrying capacity whereas in T section only one flange and web is the results in low resistance against torsion. Above graph shows the variation in the bending moment along short span and long span, due to increase self-weight of girder Similarly in T section SAP values are slightly more than manual values.

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