Comparative Analysis and Design of T Beam Bridge Deck by Courbon's Method and Finite Element Method

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***Abstract*—T beam bridge deck is a structural element composed of deck slab rigidly integrated with main longitudinal girders. In structural analysis, the finite element method is a numerical procedure for modeling of complex geometry and irregular shapes as easier as varieties of finite elements are interconnected at different nodes provides the solution domain of problem. In this study, a simple span T-beam bridge was analyzed using courbon's method by considering IRC loadings. Further the same bridge model is analyzed using finite element method for both deck slab and T beam integral with girders using STAAD V8i SS6 software for four different spans of 25m, 30m, 35m and 40 m. All analysis is carried out with suitable IRC Vehicular Loadings. Both FEM and Courbon's analysis are subjected to IRC class AA and IRC 70R tracked vehicular loading system in order to obtain maximum bending moment and shear force. From analysis it is observed that the results obtained from courbon's method are greater than the results obtained from finite element analysis, this shows that the rational computations are conservative and staad values impart reasonable design. The value of shear force in rational method is less than that of finite element analysis due to load combinations and maximum SF occurs in IRC class AA Tracked vehicle.**

***Index Terms*—Prestressed T-beam, Courbon's method, IRC Class AA and 70R Loads, STAAD V8i SS6**

I. INTRODUCTION

In the field of bridge construction, the significance of T-beam bridge decks have been increased due to its higher performance to carry live loads. It 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. Now conventional bridge types are being replaced by prestressed bridges because of their cost efficiency, better stability and serviceability. These Prestressed bridge types are using a unique technique which avoids tension due to concrete weakness. These type of bridges can have the span range between 20m to 40m whereas the conventional bridge span is between 10m to 20m. In this study, for a post tensioned T-beam bridge deck analysis is done for four different spans 25m, 30m, 35m and 40m using Courbon's method and Finite element analysis using staad. All These four spans are analyzed for two different IRC loadings cases IRC Class AA tracked and IRC Class 70R tracked. For every deck span, two lanes are provided and those Bending Moment and Shear Force values are observed for each span.

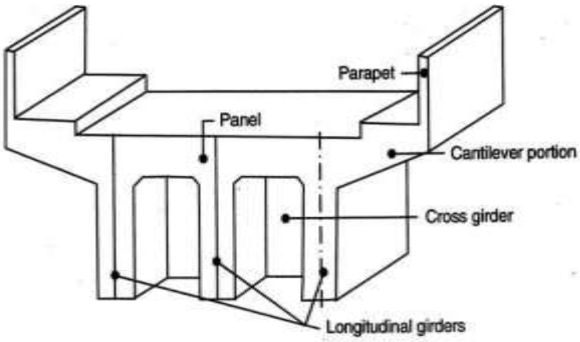

Figure.1: Typical section of a bridge showing various parts

II. LITERATURE REVIEW

David B. Beal performed a series of static live load tests on two concrete T-beam bridges to evaluate stress induced in tension reinforcement and transverse load distribution factors. The consequences of these findings on the load rating process are discussed and a strategy for rating older reinforced concrete T-beam bridges is proposed [1]. A simple span T-beam bridge was analyzed by Maher using AASHTO specifications and Loadings as a one dimensional structure, then a three-dimensional structure was carried out by using finite element plate for the deck slab. The results obtained from the finite element model are smaller than the results obtained from one dimensional analysis, which means that the results obtained from AASHTO loadings are conservative [2].

David L.Brown focus on integrated analytical and experimental research, conducted for exploring objective, global condition assessment and evaluation of bridge serviceability and safety, is summarized [3]. Praful analyzed T-beam bridge by using I.R.C.Loadings as a one dimensional structure using rational methods. The same T-beam bridge is analysed as a three-dimensional structure using finite element plate for the deck slab and beam elements for the main beam using software and the finite element model results are lesser and economical [4].

The finite element method is a general method of structural analysis in which the solution of a problem in continuum mechanics is approximated by the analysis of an assemblage of finite elements which are interconnected at a finite number of nodal points and represent the solution domain of the problem. From the results obtained, the BM and SF from manual calculations subjected to IRC loadings are conservative. [5]. Kalyanshetti proposed to conduct "dynamic analysis of bridge deck" for various span of bridge by varying no. of longitudinal girders. The detailed study is carried out for T Beam Bridge for two lane and four lane of spans 15m, 20m, 25m, 30m, 35m using IRC class A loading. For analysis SAP2000 software is used. Finally, to envelope the serviceability, the bridge responses are obtained [6].

R.P. Shriram conducted "effectiveness of Courbon's theory" for various spans of bridge by varying number of longitudinal girders. In this project STAAD software is used in which bridge models are analyzed using grillage method. Also the study reveals that Courbon's theory gives higher values of bending moments for exterior girder. Therefore the problem of over estimation of load on exterior girder is solved by using Modified Courbon's equation [7].

III. METHODOLOGY

Analysis of T-beam bridge is carried out by rational method for different spans i.e.25m, 30m, 35m and 40m. Analysis of both rational method and finite element analysis are performed using suitable IRC Codes. Further the loading class provided are IRC Class AA and 70R tracked vehicle loading. FEM Analysis of T-Beam Bridge is carried out by using Staad Pro V8i Software for different spans. Comparison of both models analysed by rational method and finite element analysis from Staad Pro will be done.

Loads acting on Bridge

Dead Load

Dead or permanent loading is the gravity loading due to the structure and other items permanently attached to it. It is simply calculated as the product of volume and material density. Superimposed dead load is the gravity load of non-structural parts of the bridge. Such items are long term but might be changed during the lifetime of the structure.

Live Loads

Road bridge decks have to be designed to withstand the live loads specified by Indian Roads Congress (I.R.C:6-2000 Section II) Live load means a load that moves along the length of the span. These loads are categorized based on their configuration and intensity. Classification of several loadings are IRC class AA loading, IRC class70R loading, IRC class A loading and IRC class B loading.

IRC Class AA Loading

Two different types of vehicles are specified under this category grouped as tracked and wheeled vehicles. The IRC Class AA tracked vehicle (simulating an army tank) of 700 KN and a wheeled vehicle (heavy duty army truck) of 400 kN.

IRC Class 70 R Loading

IRC 70 R loading consists of the following three types of vehicles. a) Tracked vehicle of total load 700 KN with two tracks each weighing 350 kN. b) Wheeled vehicle comprising 4 wheels, each with a load of 100 KN totaling 400 kN. c) Wheeled vehicle with a train of vehicles on seven axles with a total load of 1000 kN.

Impact Load

The impact factors to be considered for different classes of I.R.C. loading as follows: a) For I.R.C. class A loading The impact allowance is expressed as a fraction of the applied live load and is computed by the expression, $I=A/(B+L)$ Where, I=impact factor fraction A=constant having a value of 4.5 for a reinforced concrete bridges and 9.0 for steel bridges. B=constant having a value of 6.0 for a reinforced concrete bridges and 13.5 for steel bridges. L=span in meters. For span less than 3 meters, the impact factor is 0.5 for a reinforced concrete bridges and 0.545 for steel bridges.

IV. ANALYSIS OF T BEAM BRIDGE

The distribution of live load among the longitudinal girders can be estimated by any of the following rational methods. The rational methods used for T beam analysis are Courbon's Method, Guyon Massonet Method and Hendry-Jaegar Method. This study has been done using the Courbon's Method.

Courbon's Method of Analysis

Courbon's method is the simply applicable when the following conditions are satisfied: a) The ratio of span to width of deck is greater than 2 but less than 4 b) The longitudinal girders are interconnected by at least five symmetrically spaced cross girders c) The cross girder extends to a depth of at least 0.75 times the depth of the longitudinal girders. Analysis of T-beam bridge deck using courbon's method for IRC Class AA Tracked Loading over a span of 30m.

Preliminary Details

Clear width of roadway = 7.5m, Footpaths = 1m wide
Thickness of wearing coat = 100mm, Spacing of cross girders = 5m c/c
Live load IRC class AA tracked vehicle
Materials: M-40 for deck slab, M-50 for girders, 7mm diameter high strength strands with ultimate tensile strength at 1500MPa.
Cable consists of 12 strands anchored at the end with a suitable diameter anchor block.

Permissible Stresses and Design Constants

The permissible compressive stresses in the concrete at transfer and at working loads as recommended in IRC 18 are
$f_{ct} < 0.5 f_{ci} = 0.5 \times 40 = 20$MPa Loss ratio = 0.8
Permissible compressive stress in concrete under service loads (f_{cw}) = 16.5MPa
Allowable tensile stress in concrete at initial transfer of prestress (f_{tt}) = 0
Allowable tensile stress in concrete under service loads (f_{cw}) = 0
Maximum Bending Moment due to Dead Load
a) Weight of Deck Slab = 0.25 X 24×1×1 = 6 KN
b) Weight of Wearing Course = 0.1 X 22×1×1 = 2.2KN
c) Total Weight = 8.2KN

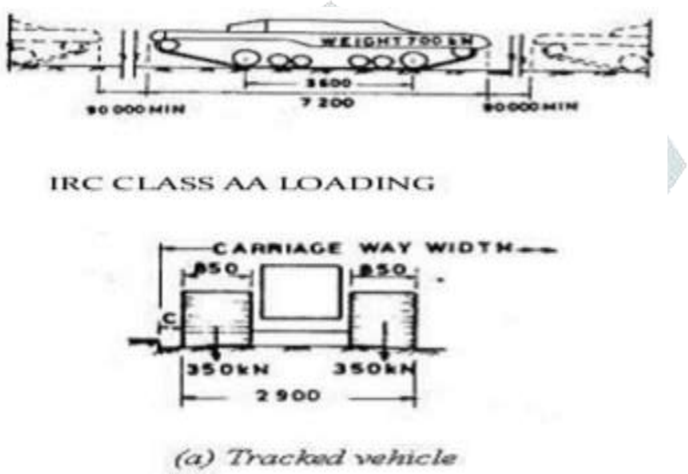

Figure.2: IRC Class AA Loading

Longitudinal Girder and Cross Girder Design

a) Reaction Factor Bending Moment in Longitudinal Girders by Courbon's Method for Class AA Tracked Vehicle

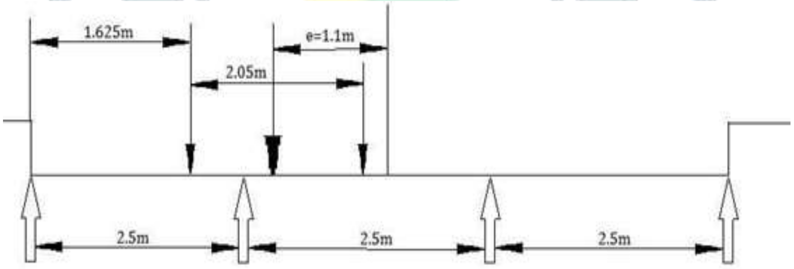

Figure.3: Showing Eccentricity and Clearance

Minimum Clearance Distance = 1.2 + 0.85/2 = 1.625m
e = 1.1m, P = w/2
From Courbon's theory, the reaction factor $R_x = \left(\frac{\sum W}{n}\right)\left[1 + \left(\frac{\sum I}{\sum_{dx}{}^2} . I\right) dx . e\right]$
I = Moment of Inertia of each longitudinal girder.
d_x = Distance of the girder under consideration from the central axis of the bridge.
W = Total concentrated live load, n = number of longitudinal girders.
e = Eccentricity of live load with respect to the axis of the bridge.
For outer girders R_A = 0.382W and for inner girders R_B = 0.294W
b) Dead load from slab for girder - Dead load of deck Slab is calculated as follows,
Weight of 1. Parapet Railing = 0.800KN/m,
2. Footpath = (0.3 x1x24) = 7.2KN/m,
3. Deck slab = (0.25x1.1x24) = 6KN/m,
Total = 14KN/m,
Total Dead load of Deck = (2×14) + (8.2×7.5) = 89.5KN
It is assumed that dead load is shared equally by all girders.
Therefore, DL/girder = 22.37KN

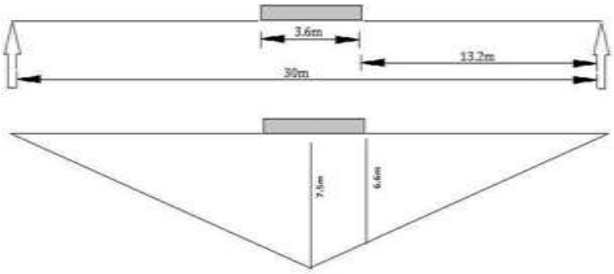

Figure.4: Influence Line for Bending Moment in Girder

Reaction of W2 on Girder B = 63KN
Reaction of W2 on Girder A = 287KN
W1 and W2 refers to IRC Class AA tracked load transferring on both sides of wheel tracks.
BM at center of girder = 0.5(7.5+6.6) × 700 = 4935KNm
Impact factor (For class AA Loads) = 10%
Bending Moment including Impact and reaction factor for outer girder is = (4935x1.1x0.382)
= 2073.687 KN
Bending Moment including Impact and reaction factor for inner girder is = (4935x1.1x0.294)
= 1595.97KN

Live Load Shear

For computing the maximum Live load shear in the girders, the IRC Class AA Loads are provided
Total load on Girder B = (350+63) = 413 KN
Maximum reaction in girder B = (413x28.2)/30 = 388KN
Maximum reaction in girder A = (287x28.2)/30 = 270KN
Maximum live load shears with impact factor in
Inner girder = (388x1.1) = 427 KN
Outer girder = (270x1.1) = 297 KN

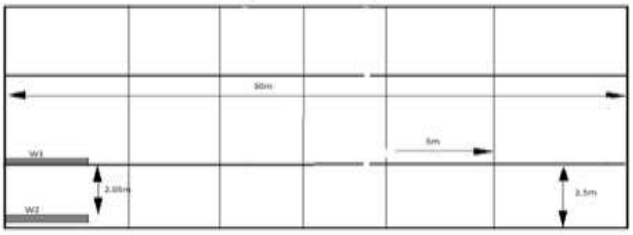

Figure.5: Position of IRC Class AA Tracked Load for Maximum Shear

Dead load BM and SF in Main Girder

The depth of the girder is assumed as 1500mm
Sectional properties of the main girder are as follows
Width of flange = 1200mm, Depth of flange = 250mm
Width of web = 300mm, Depth of web = 1400mm
Cross girder = 250mmx300mm
Self weight per meter run of girder = 10.2kN-m
Reaction of cross girder on Main girder = 12kN
Reaction from deck slab on each girder = 22.37kN
Total dead load/m on Girder = (21.66+10.08) = 32.74kN/m
Mmax = 3948.75kNm, Dead load Shear at Support = 520.5kN

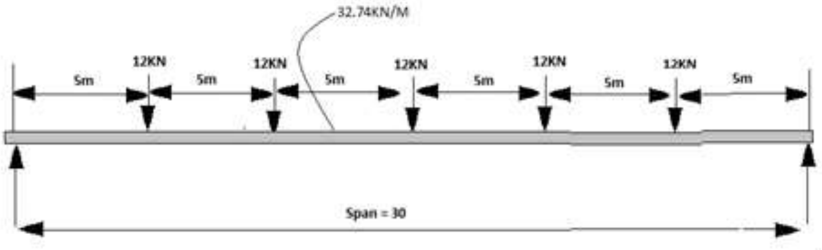

Figure.6: Dead Load on Main Girder

The values for both Bending Moment and Shear Force for the span of 30m are calculated by rational method and those results are tabulated below. From the computed values, the total shear force (DL + LL) and total bending moment of outer girder and inner girder are obtained.

Results of Shear Force and Bending Moment in KN and KN.m

Table 1 Results of Shear Force

Shear Force	**Dead Load Shear Force**	**Live Load Shear Force**	**Total Shear Force**
Outer Girder	520.5 KN	297 KN	817.5 KN
Inner Girder	520.5 KN	427 KN	947.5 KN

Table 2 Results of Bending Moment

Bending Moment	**Dead Load Bending Moment**	**Live Load Bending Moment**	**Total Bending Moment**
Outer Girder	3948.75 KN.m	2026.62 KN.m	5975.37 KN.m
Inner Girder	3948.75 KN.m	1560 KN.m	5508.75 KN.m

Finite element method of analysis

For finite element modelling of the bridge structure staad pro software is used. The bridge models are analyzed to conduct a comparative study of simply supported T-beam bridge with rational method and finite element method. The finite element method is a well-known tool for the solution of complicated structural engineering problems, as it is capable of accommodating many complexities in the solution. The finite element method has a number of advantages; they include the ability to Model irregularly shaped bodies and composed of several different materials. Handle general load condition and unlimited numbers and kinds of boundary conditions.

At the nodes, degrees of freedom (which are usually in the form of the nodal displacement and or their derivatives, stresses, or combinations of these) are assigned. Models which use displacements are called displacement models and models based on stresses are called force or equilibrium models, while those based on combinations of both displacements and stresses are called mixed models or hybrid models. Displacements are the most commonly used nodal variables, with most general purpose programs limiting their nodal degree of freedom to just displacements.

Analysis Procedure

1) Create the structural model including member properties and support conditions. 2) Go to the command menu and the vehicle loading. 3) Define the position of the vehicle in load window. 4) Then performing staad analysis. 5) Proceed with the same procedure to get the maximum support and span moments by changing the transverse and longitudinal position of vehicle. 6) Proceed with analysis and post-processing in the normal way. Staad Pro model has been created and illustrated in the following diagrams provided while performing finite elemental analysis.

Staad Model of T-Beam Bridge

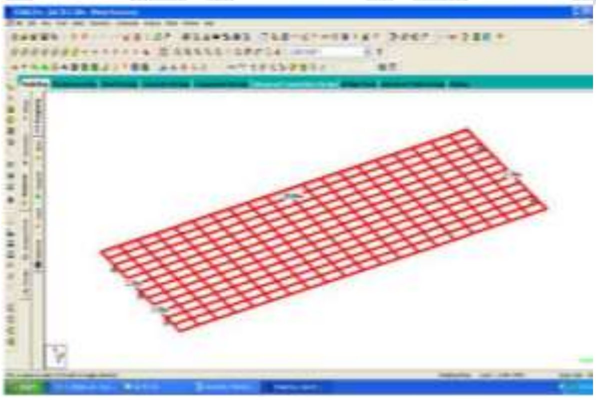

Figure.7 Deck Slab Model

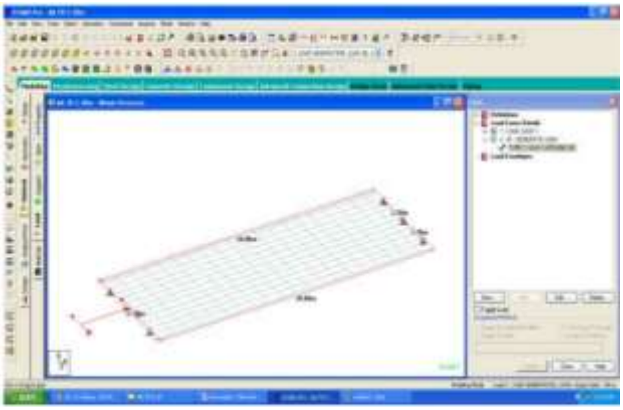

Figure. 8 Details of the Vehicle Initial Position

Figure. 9 Plate Consisting Mesh of Finite Elements

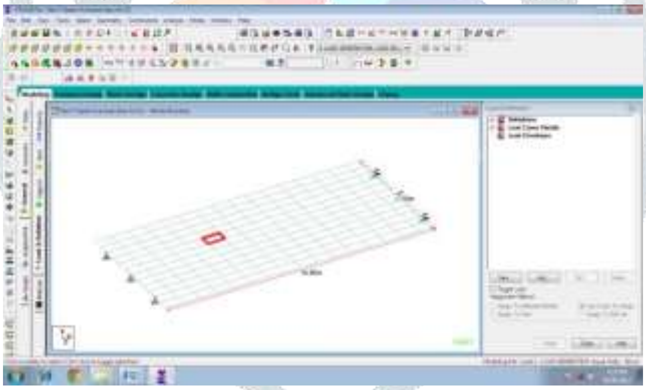

Figure. 10 Single Element of FEM Plate Model

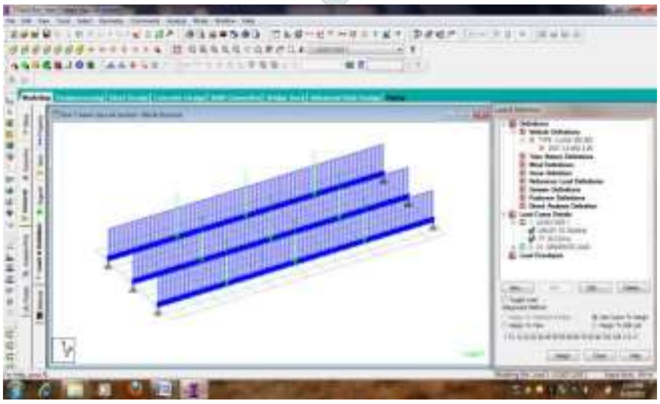

Figure. 11 Dead Load Acting on the Longitudinal Girders

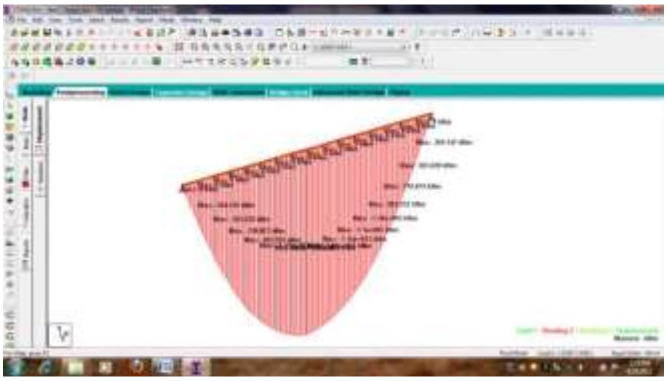

Figure. 12 Maximum Dead Load Bending Moment

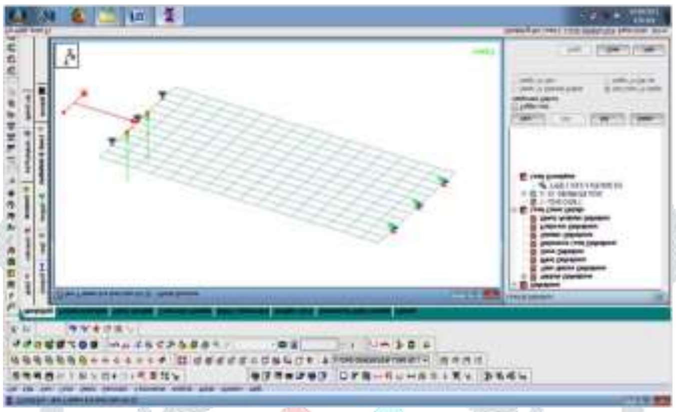

Figure. 13 Position of IRC Class AA Tracked Vehicle

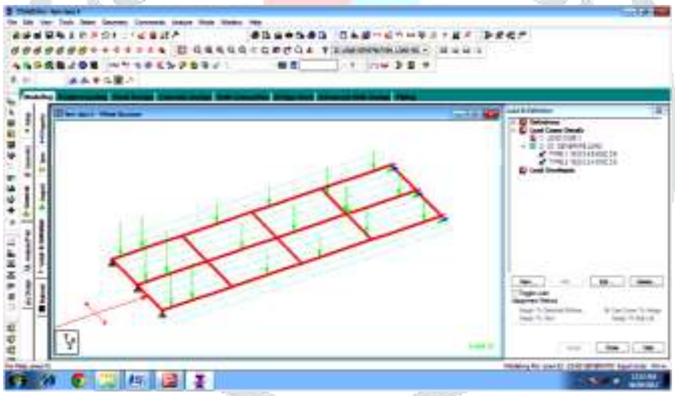

Figure. 14 Position of Live Load for IRC Class AA Loading

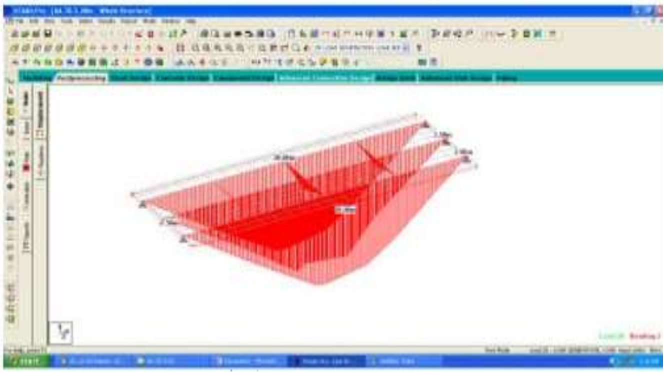

Figure. 15 Bending Moment Diagram

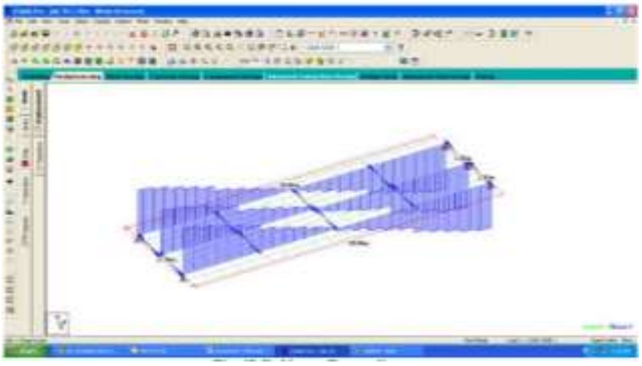

Figure. 16 Shear Force Diagram

V. RESULTS AND DISCUSSIONS

The obtained result of both Bending Moment and Shear Force values for various spans and type of loadings are compared in the following table and bar chart.

Table. 3 Comparison of Bending Moments for Class 70R Loading

T Beam Span		Courbon Bending Moment	Staad Bending Moment
25 m	*Outer Girder*	4462 KN.m	3590 KN.m
	Inner Girder	4003 KN.m	3295 KN.m
30 m	*Outer Girder*	5975 KN.m	5032 KN.m
	Inner Girder	5508 KN.m	4988 KN.m
35 m	*Outer Girder*	7881 KN.m	6142 KN.m
	Inner Girder	7330 KN.m	6083 KN.m
40 m	*Outer Girder*	9777 KN.m	7874 KN.m
	Inner Girder	9142 KN.m	7429 KN.m

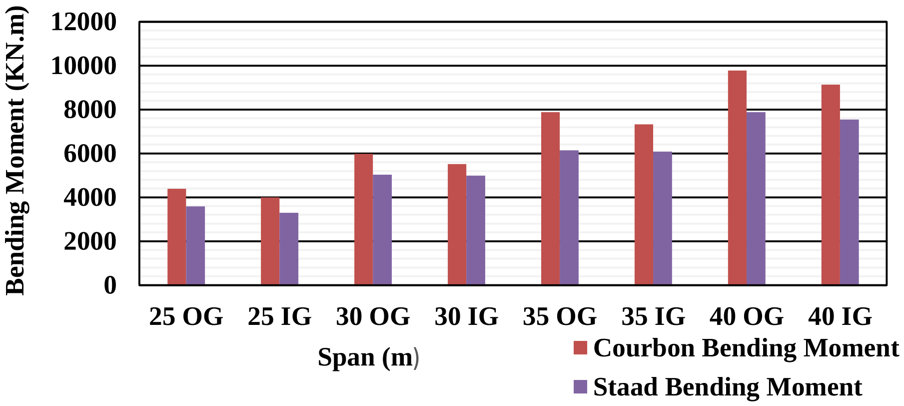

Figure. 17 Bending Moment Chart for Class 70R Loading

Table. 4 Comparison of Bending Moments for Class AA Loading

T Beam Span		Courbon Bending Moment	Staad Bending Moment
25 m	*Outer Girder*	4361 KN.m	3590 KN.m
	Inner Girder	4039 KN.m	3487 KN.m
30 m	*Outer Girder*	6022 KN.m	5076 KN.m
	Inner Girder	5544 KN.m	5019 KN.m
35 m	*Outer Girder*	7928 KN.m	6211 KN.m
	Inner Girder	7366 KN.m	6134 KN.m
40 m	*Outer Girder*	9829 KN.m	7937 KN.m
	Inner Girder	9285 KN.m	7523 KN.m

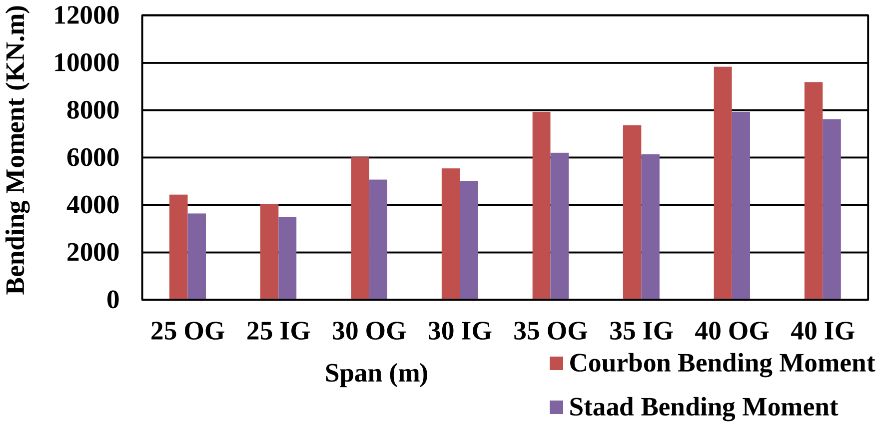

Figure. 18 Bending Moment Chart for Class AA Loading

Table. 5 Comparison of Shear Forces

T Beam Span		**Courbon Shear Force**	**Staad Shear Force**
25 m	***Outer Girder***	738.5 KN	879.4 KN
	Inner Girder	853.1 KN	905.1 KN
30 m	***Outer Girder***	817.5 KN	996 KN
	Inner Girder	947.5 KN	1035 KN
35 m	***Outer Girder***	922.1 KN	1114 KN
	Inner Girder	1060 KN	1125 KN
40 m	***Outer Girder***	1010 KN	1206 KN
	Inner Girder	1151 KN	1246 KN

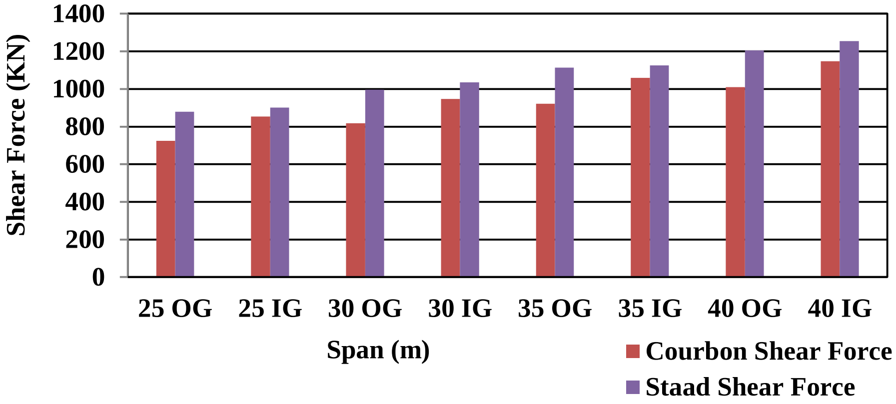

Figure.19 Shear Force Chart

VI. CONCLUSION

The comparison between various spans of bridge deck was conducted based on the analytical model of T beam bridge deck by Courbon's method and Finite element method by Staad Pro. By using Courbon's method and FEM, the bridge deck is analysed by varying the span, the spans provided for analysing deck are 25m, 30m, 35m and 40m. For 30m span, the value of Bending Moment in rational method is 9% for Inner Girder for class AA higher than that of staad analysis and there is minimum variation between them. For 35m span, the value of Bending Moment in rational method is 22.04% for Outer Girder for Class AA higher than that of FEM analysis and there will be maximum variation. Based on this study, Courbon's method with Class AA tracked load is the critical loading case because 70R tracked loading gives less Bending Moment values in the longitudinal girder as compared to finite element method. Both Bending Moment and Shear force results were analyzed and it was found that the results obtained from the finite element model are lesser than the results obtained from courbon's method, which means that the results obtained from one of the rational method i.e. courbon's method is conservative and from FEM using staad pro provides reasonable design of bridge deck.

REFERENCES

[1] David B. Beal, “Strength of Concrete T-Beam Bridges”, Special Publications, Journal of Bridge Engineering, Vol-88, November 1985.

[2] Dr. Maher, Dr. Eyad and Dr. Emad, “Design of T-Beam Bridge by Finite Element Method and AASHOT Specification”, Journal of Applied Sciences, Vol-8, January-June 2008.

[3] Brown L, “Condition Assessment for Bridge Management” Journal of Infrastructure Systems, Vol-2, Issue 3, September 1996.

[4] Praful N.K, Balaso Hanumant, “Comparative Analysis of T-Beam Bridge by Rational Method and STAAD PRO”, International Journal of Engineering Sciences & Research Technology, June 2015.

[5] R.Shreedhar, Spurti Mamadapur, "Analysis of T-beam Bridge Using Finite Element Method" IJEIT, Volume 2, Issue 3, September 2012.

[6] Supriya Madda, Kalyanshetti M.G, “Dynamic Analysis of T-Beam Bridge superstructure” International Journal of Civil and Structural Engineering, 2013.

[7] M.G. Kalyanshetti and R.P. Shriram, “Study of Effectiveness of Courbon’s Theory in the Analysis of T-beam Bridges”, IJSER Vol-4, Issue3, March 2013.

[8] IRC 5-1998, “Standard Specifications and Code of Practice for Road Bridges” Section- I, General Features of Design, the I.R.C., New Delhi, India, 1998.

[9] IRC 6-2000, “Standard Specifications and Code of Practice for Road Bridges”, Section II, loads and stresses, The Indian Roads Congress, New Delhi, India, 2000.

[10] IRC: 21-2000 I.R.C Standard specification and code of practice for Road Bridges, Section-III, Cement Concrete (Plain and Reinforced) - (Third Revision)

[11] “Design of Bridges” by Krishna Raju, Fourth Edition, Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi.

[12] “Essential of Bridge Engineering” by D.J. Victor, Sixth Edition, Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi.