ASPS Conference Proceedings 1: 1863-1870 (2022)

Proceedings of

12th Structural Engineering Convention-An International Event (SEC 2022)

Available at https://asps-journals.com/index.php/acp

Finite Element Analysis of Bridge Deck Using MATLAB

Ahmad Farhan [1, *], U.K. Dewangan [2]

[1] Department of Civil Engineering, M.Tech Student, National Institute of Technology, Raipur, 492013, India
[2] Department of Civil Engineering, Professor, National Institute of Technology, Raipur, 492013, India

Paper ID - 030287

Abstract

Bridges are the most common types of structures generally adopted when there is a obstacle in the path such as water body, valley, road etc without closing the way underneath. Moving live load is one of the critical loading for which bridge superstructure need to be analysed by developing model as realistic as possible. Even though various conventional methods are present for the analysis of bridge superstructure but finite element analysis gives us more realistic behavior of structure. The objective of the thesis is to develop a finite element model of T-beam slab bridge ,bridge pier and pier footing and analyse to study behavior of bridge superstructure for moving live load as per Indian road congress standards given in IRC:6-2017 and IRC: 112-2011 and the dead load of the structure.

In my work, bridge deck is modelled as Mindlin-Reissner plate element which is two dimensional plate in which shear deformations effect is considered whereas longitudinal girders ,cross girders and diaphragms are modelled using Euler-Bernoulli's grid element which are a one dimensional element . A MATLAB code is developed to model T-beam slab composite action in which beam elements is modelled in plane of plate element so that the nodes of beams are coincide to the nodes of the plate by doing such center of gravity of the beam coincides with the plate element ignoring offset present between them. Moving live load analysis is performed using step by step method in which load moves in longitudinal as well as transverse direction giving the worst case for maximum bending moments, shear forces and deflections. Then Moving live load analysis for 2 lane T-beam bridge is carried out for IRC Class 70R wheeled vehicle and compare the result by modeled in sap2000,2016 of same dimension and the effect of the number of cross girders in the deck span on bending moments, shear forces and deflections of longitudinal girders is presented.

Keywords: Bridge Superstructure, Mindlin-Reissner plate , Euler-Bernoulli's grid element, T-beam bridge , sap2000,2016, IRC Class 70R wheeled

1. Introduction

T beam and slab decks are the most common types of superstructures generally adopted in most of national highways in the country. A T-beam slab deck generally comprises of longitudinal girders with an integral continuous slab between the T beams and cross girders to provide torsional rigidity to the bridge deck. The longitudinal girders are normally spaced at intervals of 2 to 3m and the spacing between cross girders 4 to 5 m equally divided along the span (Raju, 2017). Reinforced concrete tee beams are ideally suited for spans in the range of 10 to 25m (Raju, 2017). For longer span lengths, the depth of T girder being large, the total dead loads are abnormal with larger magnitudes of reinforcements in the T girders.

2. Types of Tee Beam Slab Decks

Basically, there are three types of T beam and slab decks developed for use as highway bridges. The features of these types are:

1) Deck with girder and slab in which the beams and slab are cast monolithically without any cross girders. In this case the deck slab is designed as a one way slab spanning between the girders. This type of deck developed in the early stages does not possess torsional rigidity and hence not currently used.
2) Deck with girder, slab and diaphragm where the slab is casted monolithically with the girders. Girders are connected with diaphragms provided at the end supports and at intermediate locations without extending up to the deck slab. This type is marginally better in resisting loads due to improved torsional rigidity in comparison of first one.
3) Deck with Girder, slab and cross beams are cast monolithically to form an integrated bridge deck possessing superior flexural and torsional rigidity. This type evolved after several research investigations is the most commonly used system used at present in highway bridge decks.

*Corresponding author. Tel: +919713588671; E-mail address: farhanahmad496@gmail.com

Proceedings of the 12th Structural Engineering Convention (SEC 2022), NCDMM, MNIT Jaipur, India| 19-22 December, 2022

Published online: December 19, 2022
doi:10.38208/acp.v1.731

3. Literature study and review

Manohar R, B S Suresh Chandra- Finite Element Analysis of slabs, cross girders and
main girders in RC T-Beam Deck Slab Bridge.
The following are the conclusions made from this study.

-In case of deck slab

1. As the size of the slab increases bending moment and deflection increases.
2. As the depth of the deck slab increases bending moment decreases .
3. The bending moment obtained from the models which are subjected to the IRC CLASS AA Tracked loading are more than Those subjected to the IRC CLASS 70R loading.

-In case of girders

4. As the span of the bridge increases ,the shear force ,bending moment and deflection increases
5. The bending moment obtained from the models which are subjected to the IRC CLASS AA Tracked loading are more than Those subjected to the IRC CLASS 70R loading.

Pooja C, Arun L, Thejashwini – Analysis and Design of bridge deck using grillage method , as per IS code

1. Grillage model is the most popular computer-aided method for analyzing bridge decks. This is because it is easy to comprehend and use. This has been proved to be accurate for a wide variety of bridge types.
2. Grillage model values are dependent upon the property specification of individual grillage beams.
3. The maximum values of bending moment and shear force are 464 kNm and 316 kN, for 70R tracked vehicle.
4. The finer grillage mesh, provide more accurate result

S.Basila hamed and S.S.Kalaiyarassi -Comparative analysis and design of tee-beambridge deck by rational method and finite element method using staad pro. In this study using courbon's method and staad pro, the bridge deck is analyzed by varying the span of the bridge deck, the spans used are 25m,30m,35m,40m. based on this study , courbon's method gives the average results with respect BM values in the longitudinal girders as compared to guyon massonet method. the results are analyzed and it was found that the results obtained from the finite element model are lesser than the results obtained from one dimensional analysis which means that the results obtained from irc loading are conservative and fem gives economical design.

4. Research significant

In case when girder is rigidly attached to plate as in T-beam concrete slab, it is necessary to assume that the beam acts together with an effective section of the plate to resist the total bending moment and for that effective width of plate which is resisting the bending can be calculated from specified engineering codes. When beam is modelled in plane of the plates, effective moment of inertia must be calculated for the beam and this should be equal to total moment of inertia of T-beam modelled about its centroid minus the moment of inertia of the effective plate. The number of elements along the length of the bridge for the deck slab should be same as that for longitudinal girder elements for composite action. In case of load modelling, the wheel loads are applied as concentrated vertical loads at the nodes and when the wheel load location does not coincide with a node, it is distributed as four concentrated forces to the all four nodes of the element, such that loadings are statically equivalent.

Regarding boundary conditions, the support conditions are modelled as concentrated at single nodes and only vertical translation of node at support location needs to be constrained.
For mesh automation and refinement, longest edge bisection method provides good quality triangular mesh. Similarly, the method can be extended for rectangular 4 node finite element mesh generation.

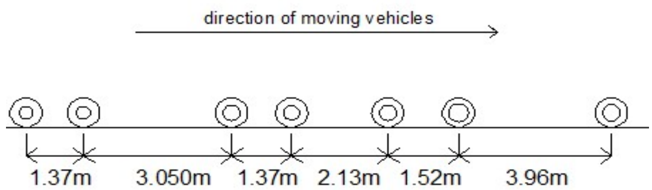
5. Methodology

The following method is used in order to analyse the T-beam slab deck using the Finite Element Computation:

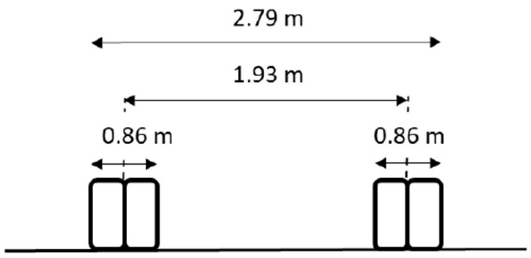
1. Finite element automation for mesh generation and refinement
1.1. Development of automatic mesh generation code with the Finite Element automatic mesh refinement.
1.2. To develop a 3 noded triangular or 4 noded quadrilateral element in Finite element for the Plane stress case for the analysis of beam.
1.3. To check the effect of mesh refinement on beam deflection.
2. To develop the stiffness matrix
2.1. Euler-Bernoulli's Grid element using MATLAB code.
2.2. Mindlin-Reissner plate element using MATLAB code.
3. Modelling of IRC Class 70R wheeled load for live load FE analysis of bridge deck in MATLAB.
4. Modelling of dead load FE analysis of bridge deck in MATLAB.
5. Analysis of T-beam section for monolithic T-beam action between the Plate and the grid Element.
6. To find effect of number of cross girders in bridge deck on longitudinal beam deflection and bending moments.

6. IRC 70R Loading

For carriage width from 5.3m to 9.6m (2 lane bridge deck), only one lane of CLASS 70R is required as load combination (table 2, IRC: 112-2011). IRC 70R (wheeled) loading for the analysis is shown below

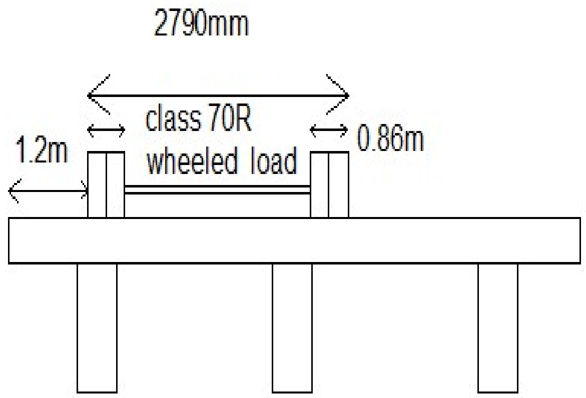


Class 70R (wheeled) - longitudinal position (IRC: 6-2017)



'L' type Class 70R wheel spacing, (IRC: 6-2017)

7. **Carriageway width for two lane should not be less than 7.5m as per clause 104.3.1 (IRC:5-2015).**



Typical Class 70R load combination for 2 lane carriageway

8. **Bridge specification**

Length of span	16m
Width of span	7.5m
Poission's ratio	0.15
Modulus of elasticity	27386*10^6 N/m2
Thickness of slab	0.2m
Width of girder	0.3m
Depth of girder	1.4m
Spacing between longitudinal girder	2.5m
Cantilever portion	1.15m
Characteristic strength of concrete	25 N/mm2
Yield strength of steel	415 N/mm2

Meshing refinement
In longitudinal direction=64
In lateral direction =30
Loading Parameter
Dead load consideration
Live load IRC 70R Wheeled loading

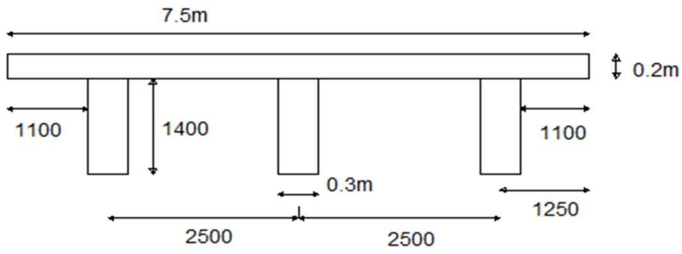
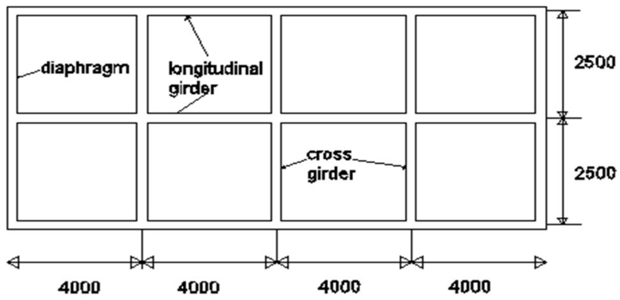


Fig. 1 Cross section of bridge deck, (Raju, 2017)



Cross section of bridge deck, (Raju, 2017)

9. **SAP result**

Tables 9.1 and table 9.2 shows the bending moment and shear force values from SAP analysis from dead load and live load (class 70R wheeled loading). Graph of bending moment and shear force is prepared in fig 9.4 and fig 9.5 . results are analysed.

a. **Dead load result**

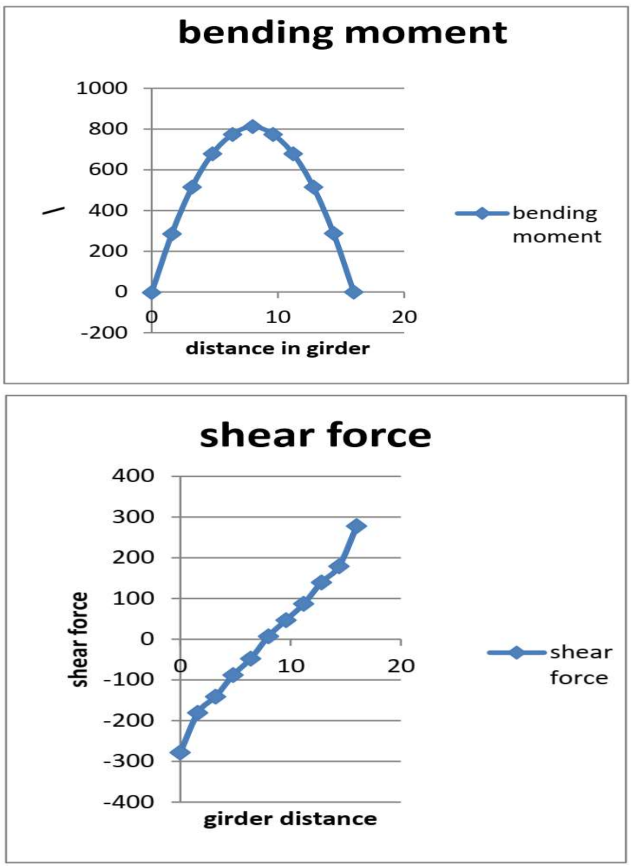
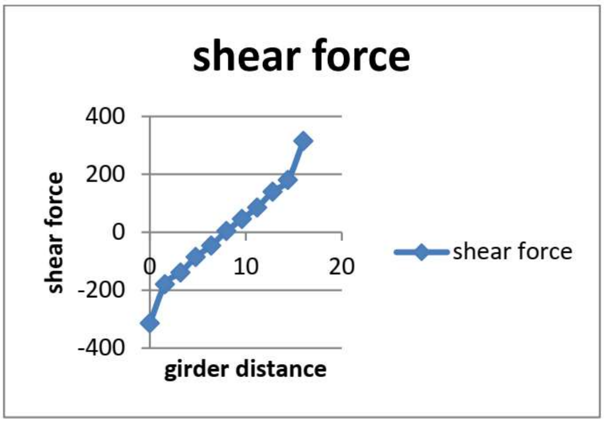


Fig 9.4 BM and SF of the right and left extreme girder on Dead load



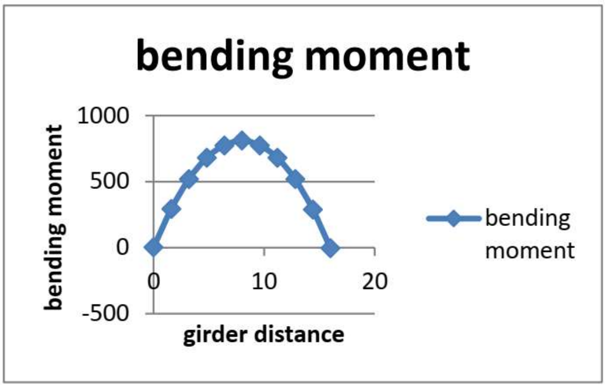


Fig 9.5 BM and SF of the interior girder on Dead load

Table 9.1 BM and SF on Left exterior girder/right exterior girder

Considered point	Bending moment (kNm)	Shear force (kN)
0	-3.0583	--277.67
1.6	285.9342	-180.36
3.2	515.1869	-140.49
4.8	678.136	-87.74
6.4	773.607	-47.32
8	812.27	7.67
9.6	773.6575	47.27
11.2	678.0968	87.109
12.8	515.6289	139.815
14.4	287.3842	179.622
16	-0.33084	278.05

Table 9.2 BM and SF on interior girder

Considered point	Bending moment(kNm)	Shear force (kN)
0	1.801347	-313.99
1.6	291.6943	-179.28
3.2	518.419	-139.075
4.8	679.9433	-85.55
6.4	773.8497	-45.3511
8	810.7426	4
9.6	773.8443	45.64
11.2	679.8139	85.81
12.8	517.3949	140.32
14.4	288.6045	180.91
16	-3.53955	315.172

b. Live load result (IRC 70R Wheeled loading)

Table 9.3 to table 9.5shows the maximum bending moment at different point on the left exterior, interior, and right exterior girder when the vehicles is moving.

Table 9.3 Maximum Bending point at considered point on Left exterior girder

Considered point	Maximum Bending point at considered point (kNm)
0	617.6887
1.6	466.0729
3.2	505.317
4.8	652.0204
6.4	730.1562
8	818.916
9.6	729.76
11.2	652.9783
12.8	493.8627
14.4	248.2989
16	2.819722

Table 9.4 Maximum Bending point at considered point on Interior girder

Considered point	Maximum Bending point at considered point (kNm)
0	83.74218
1.6	427.3749
3.2	639.4724
4.8	781.5044
6.4	911.4719
8	876.8774
9.6	910.9601
11.2	781.5482
12.8	648.3613
14.4	458.4807
16	0.245273

Table 9.5 Maximum Bending point at considered point Right exterior girder

Considered point	Maximum Bending point at considered point (kNm)
0	44.22878
1.6	413.9519
3.2	796.765
4.8	1184.957
6.4	1479.883
8	1565.691
9.6	1585.914
11.2	1410.471
12.8	1129.769
14.4	692.2612
16	1.959336

10. MATLAB result (FEM)

Dead load of deck

Table 9.6 shows the bending moment, shear force and deflection due to dead load and fig 9.6 to fig 9.8 are the plots for it. Loads are symmetrically divided at every nodes so the values at every girder is same. Max BM and SF are almost same as the result obtain from analytical method.

Table 9.6 deflection, BM and SF on Left exterior /interior /right exterior girder

Considered point	Deflection (in m)	Bending moment (in 10^6 N/m^2)	Shear force (in 10^5 N)
0	0	-0.0000	-2.8215
1.6	0.0013	-0.3940	-2.3549
3.2	0.0025	-0.7180	-1.8890
4.8	0.0035	-0.9598	-1.1735
6.4	0.0042	-1.1066	-0.7073
8	0.0045	-1.1836	-0.2408
9.6	0.0044	-1.1657	0.4742
11.2	0.0040	-1.0655	0.9403
12.8	0.0032	-0.8953	1.6552
14.4	0.0021	-0.6178	2.1220
16	0.0009	-0	2.5876

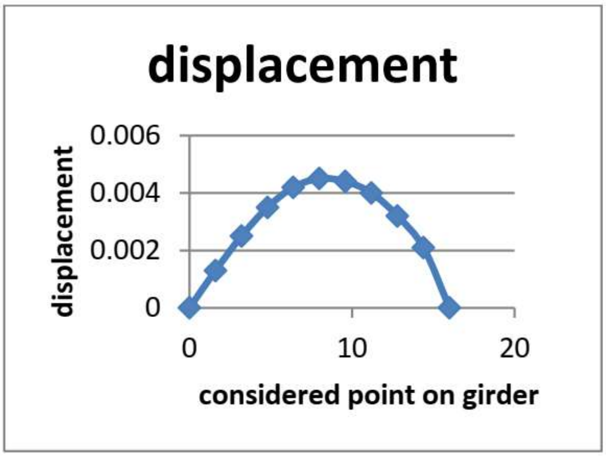


Fig 9.6 displace of the girders due to dead load

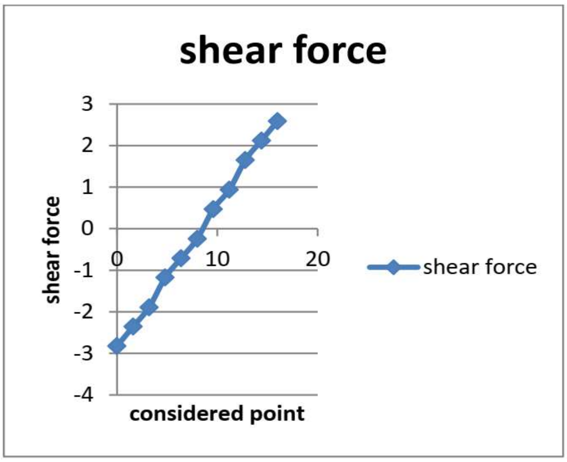


Fig 9.8 shear force on girders due to dead load

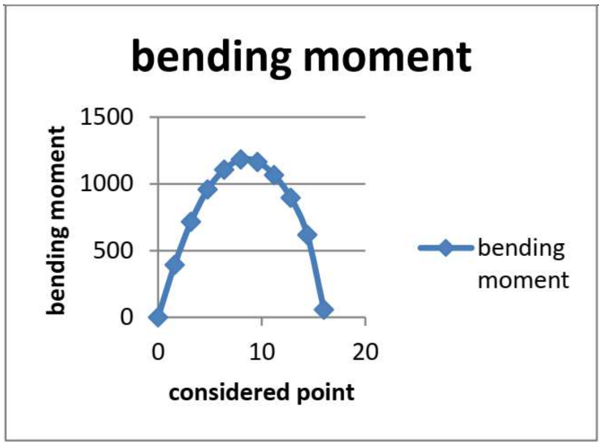


Fig 9.7 bending moment on girders due to dead load

70R wheeled loading result of deck

From MATLAB fem analysis ,the maximum values of the bending moment in outer and inner girder is given in the table and maximum shear force and

maximum deflection in the girders is given in the table 9.7.

Below fig 9.9 , graph shows the difference in maximum bending moment in outer and inner girder which is approx 2.5%.

Table 9.7 maximum values of BM,SF and deflection

case	Maximum Bending Moment (KNm) Outer inner	Maximum Shear Force (kN)	Deflection (mm)
16m span ,3 longitudinal girder, 3 cross girder	813.07 793.92	232.93	3.729

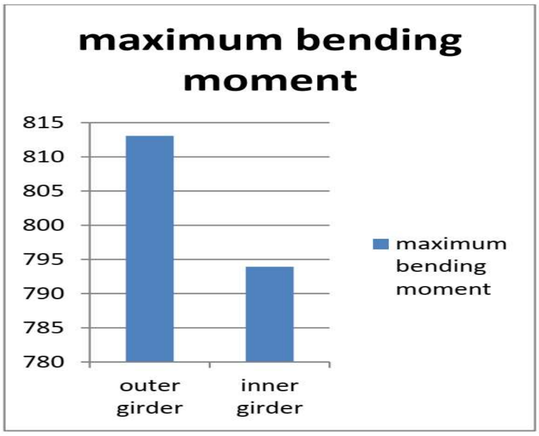


Fig 9.9 Comparative result on outer girder and inner girder

Deflections at cross girder nodes for vehicle movement at various positions

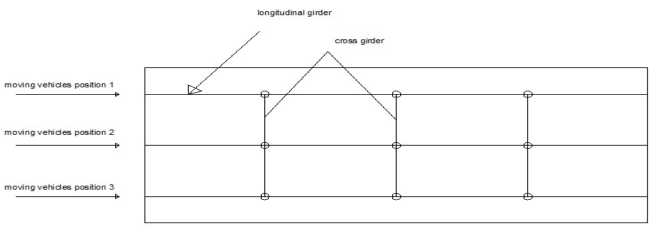


Fig 9.10 deflection for the cross girder nodes by moving vehicles at various position

For deck with 3 intermediate cross girders, and 2 diaphragm at both edges the deflections at the nodes shown in Fig.9.10 are evaluated for various horizontal load positions of moving load. When load moves at position 1 (1.2 m away from edge), maximum deflection at every point is obtained and among every values node 4 has maximum values which is longitudinal center of span. So for load step in which maximum deflection is obtained due load position 1, deflections at all other nodes of cross girders are also obtained. Similarly for all the load position of vehicle i.e. position 1, position 2, position 3, deflections at all nodes is tabulated below in Table 9.8.

Comparision between MATLAB and SAP results

1. Dead load

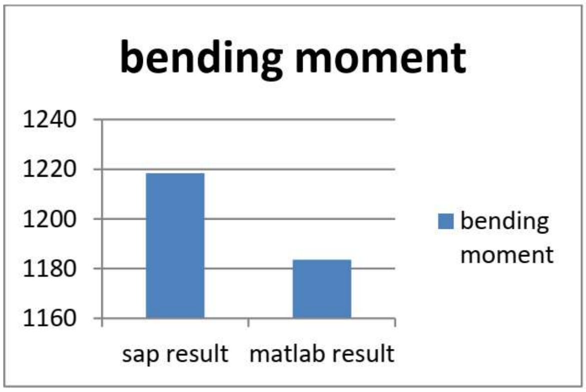


Fig 9.11 bending moment results comparison with SAP and MATLAB

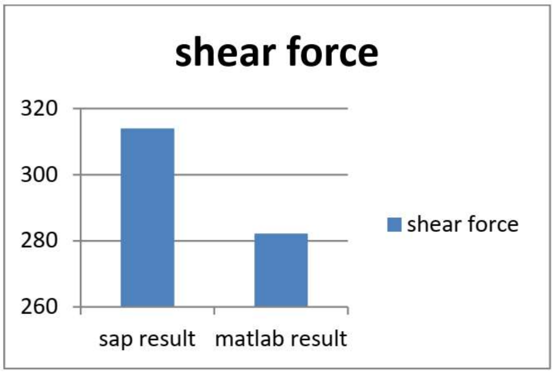


Fig 9.12 Shear force result comparision with SAP and MATLAB

Table 9.8 maximum deflection values on cross girder when load is moving on three different girders

Deflections at Nodes shown in figure	Deflection at various points when Maximum deflection is obtained when load is moving on outer girder Position 1 (mm)	Deflection at various points when Maximum deflection is obtained when load is moving on inner girder Position 2 (mm)	Deflection at various points when Maximum deflection is obtained when load is moving on outer girder Position 3 (mm)
1	2.651	2.564	2.499
2	2.589	2.596	2.589
3	2.499	2.564	2.651
4	3.729	3.613	3.524
5	3.643	3.648	3.643
6	3.524	3.613	3.729
7	2.645	2.560	2.495
8	2.582	2.587	2.582
9	2.495	2.560	2.645

2 Live load

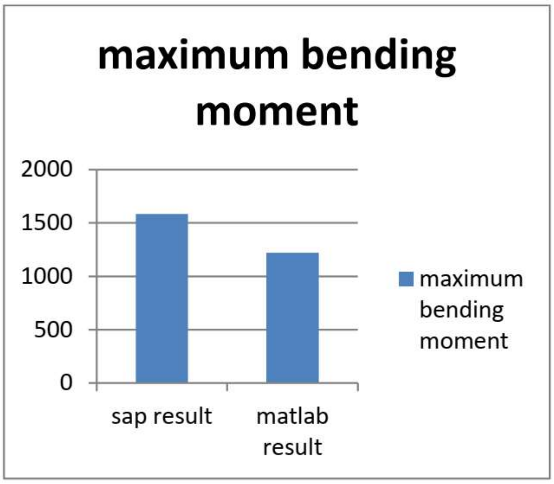


Fig 9.13 bending moment results comparison with SAP and MATLAB for live load

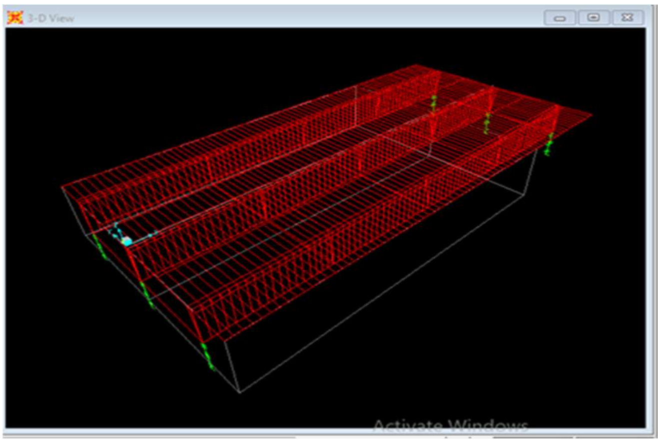


Fig 9.15SAP 3D model

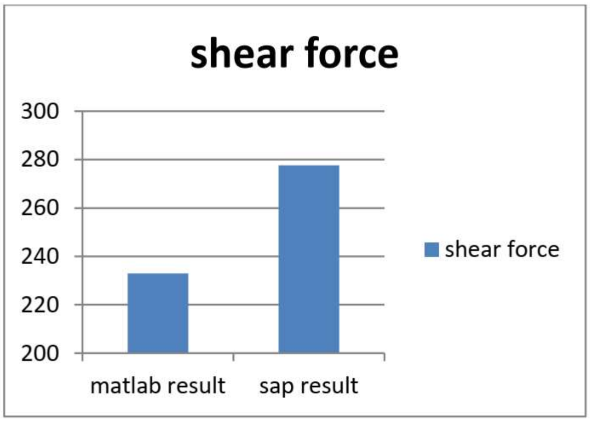


Fig 9.14 Shear force result comparision with SAP and MATLAB for live load

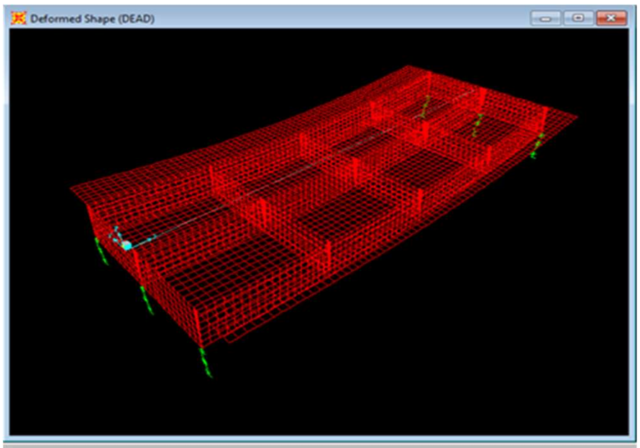


Fig 9.16 Deformed shape in SAP2000

Above is comparing results for the values of bending moment and shear force , in SAP2000 and MATLAB. we can clearly observe that the values in MATLAB is little lower than the values I am getting from SAP2000 for both dead load and vehicles moving load(Class 70R wheeled loading condition).the differences in the results for bending moment is 2.96% and 14.7% in dead load and live load. Similarly for shear force is 9.6% and 12.9%

11. Conclusion

The modelling and analysis of T-beam slab bridge deck is performed using MATLAB. The T-beam slab bridge deck is analyzed for three cross girders and two diaphragm in span and providing 3 number of longitudinal girder. Bridge deck is analyzed for moving live load and dead load and results are compared with the SAP analysis of the T-beam bridge of same specification.
The following conclusions are getting from the live load analysis and dead load of T-beam slab bridge deck using finite element method are as follows:

Live load analysis for IRC Class 70R wheeled vehicle and compare with the SAP2000

1. Bending moment , I am getting on the inner longitudinal girder is lesser than the outer girder.
2. Max Bending Moment due to moving live load occurs near the mid span.
3. Maximum deflections due to live load is observed in outer girders for all cases.
4. SAP2000 ,2014 version have inbuilt bridge design parameter and make us easy to built any type like T-beam bridge ,Solid slab bridge and box girder bridge.
5. The result I am getting is more in SAP 2000.
6. MATLAB results for the live load needs some factored multiplication (factor of safety) fifty percent to compare the result with SAP.

Dead load analysis and compare with the SAP2000

1. Bending moment , shear force and deflection are same for the outer girders and different from the inner girder.
2. Bending moment are more in the inner girder as compare to the outer girder in both the MATLAB and SAP2000 analysis.
3. Results for the shear force and bending moment is same from sap and even example given in the book (Design of bridges " by N KRISHNARAJU)

Disclosures

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