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RESEARCH ARTICLE

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ALTERNATIVE FORMS OF T-BEAM BRIDGE SUPERSTRUCTURE FOR FOUR LANE BRIDGES – A STUDY BY GRILLAGE ANALOGY

Prof.M.G.KALYANSHETTI[1], K.S.BHOSALE[2]

[1]Department of Civil Engineering
Walchand Institute of Technology, Solapur, Maharashtra State, India
[2] Asst.Professor, Department of Civil Engineering
NBN Sinhgad College of Engg, Solapur, Maharashtra State, India

ABSTRACT

This paper concern with effectiveness of cross beams on T-Beam Bridge. Cross beams are provided mainly to stiffen the girders and to reduce torsion in the exterior girders. These are essential over the supports to prevent lateral spread of the girders at the bearings. Another function of the cross beams is to equalize the deflections of the girders carrying heavy loading with those of the girders with less loading. The thickness of the cross beam should not be less than the minimum thickness of the webs of the longitudinal girders. The depth of the end cross girders should be such as to permit access for inspection of bearing and to facilitate positioning of jacks for lifting of superstructure for replacement of bearings.

Prior to 1956, T-beam bridges had been built without any cross beams or diaphragms, necessitating heavy ribs for the longitudinal beams. In some cases, only two cross beams at the end have been used. The provision of cross beams facilitates adoption of thinner ribs with bulb shape at bottom for the main beams. The current Indian practice is to use one cross beam at each support and to provide one to three intermediate cross beams. Diaphragms have been used instead of cross beams in some cases in the past.

Hence separate study is required for various spans of two lane and four lane bridges with different IRC standard live loads to understand effectiveness of cross beams to stiffen the girders and to reduce torsion in the exterior girders which will lead to effective selection of cross beams.

Key words: Indian Road Congress, Grillage Analogy, Four lane bridges, Cross girders, RC Live Loads, T-Beam Bridge

INTRODUCTION

Cross beams are provided mainly to stiffen the girders and to reduce torsion in the exterior girders. These are essential over the supports to prevent lateral spread of the girders at the bearings. Another function of the cross beams is to equalize the deflections of the girders carrying heavy loading with those of the girders with less loading. The thickness of the cross beam should not be less than the minimum thickness of the webs of the longitudinal girders. The depth of the end cross girders should be such as to permit access for inspection of bearing and to facilitate positioning of jacks for lifting of superstructure for replacement of bearings.

Prior to 1956, T-beam bridges had been built without any cross beams or diaphragms, necessitating heavy ribs for the longitudinal beams. In some cases, only two cross beams at the end have been used. The provision of cross beams facilitates adoption of thinner ribs with bulb shape at bottom for the main beams. The current Indian practice is to use one cross beam at each support and to provide one to three intermediate cross beams. Diaphragms have been used instead of cross beams in some cases in the past.

PROCEDURE

(I) It is easy for an engineer to visualize and prepare the data for a grillage. Grillage Analogy is based on stiffness matrix approach and was made amenable to computer programming by Lightfoot and Sawko in 1959. West conducted experiments on the use of grillage analogy in 1973. He made suggestions towards geometrical layout of grillage beams to simulate a variety of concrete slab and pseudo-slab bridge decks, with illustrations. Gibb developed a general computer program for grillage analysis of bridge decks using direct stiffness approach that takes into account the shear deformation also in 1972. Martin in 1996, then followed by Sawko derived stiffness matrix for curved beams and proclaimed a computer program for a grillage for the analysis of decks, curved in plan in 1967. The grillage analogy has also been used by Jaeger and Bakht for a variety of bridges in 1982.

(II) Grillage Analogy

There are essentially five steps to be followed for obtaining design responses:

I. Idealization of physical deck into equivalent grillage
II. Evaluation of equivalent elastic inertias of members of grillage
III. Application and transfer of loads to various nodes of grillage
IV. Determination of force responses and design envelopes and
V. Interpretation of results.

The method consists of 'converting' the bridge deck structure into a network of rigidly connected beams at discrete nodes i.e. idealizing the bridge by an equivalent grillage as shown in figure1. The deformations at the two ends of a beam element are related to the bending and torsional moments through their bending and torsional stiffnesses.

These moments are written in terms of the end-deformations employing slope-deflection and torsional rotation-moment equations. The sheer force in the beam is also related to the bending moment at the two ends of the beam and can again be written in terms of the end-deformations of the beam. The shear and moment in all the beam elements meeting at a node and fixed end reactions, if any, at the node, are summed-up and three basic statical equilibrium equations at each node namely $\sum F_z = 0$, $\sum M_x = 0$ and $\sum M_y = 0$ are satisfied.

In general a grid having 'n' nodes will have '3n' nodal deformations and '3n' equilibrium equations relating to these. Back substitution in the slope-deflection and torsional rotation-moment equations will give the bending and torsional moments at the two ends of each beam element. Shear forces are computed from bending moments and external loads.

EXPERIMENT AND RESULT: A model of T-beam bridge deck is prepared on STAADPro software and analyzed by Grillage Analogy. The detailed study is carried out for Four Lane Bridges of spans 15m, 20m, 25m, 30m, 35m and 40m with live loads as IRC ClassA and IRC 70R loading. For each span, three systems are considered as follows:

1) Three cross girders system (3 CG)
2) Five cross girders system (5 CG)
3) Seven cross girders system (7 CG)

To illustrate the grillage analogy in bridge deck analysis, detailed calculations are shown for T-beam bridge for following data.

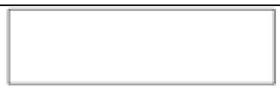
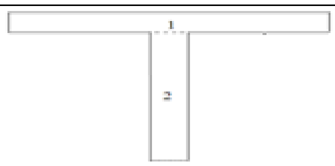
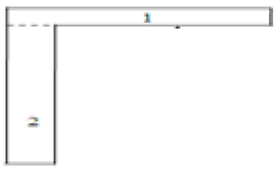
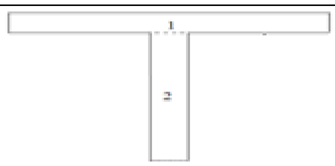
Data:

1) Clear Roadway = 15.2m (Four Lane Bridge)
2) Span of T – Beam = 20m
3) No. of Longitudinal girders = 5
4) c/c of Longitudinal girders = 2.5m
5) Thickness of deck slab = 215mm
6) Thickness of wearing coat = 75mm
7) Web thickness of main & cross girders = 250mm
8) Width & depth of Long girder = 300mm, 1.6m

9) Width & depth of cross girders = 250mm, 1.28m
10) Live Load= 4 trains of IRC class A loading, 2 trains of IRC class 70R loading.

Calculations for sectional properties are done and shown in table-1.

Table - 1 Properties of grillage lines of 20m span four lane bridge with 3cross girders.

Grillage Line	Section	Area(m^2)	Ix (m4)	Iz (m4)	Dire-ction
1,11		0.7300	0.0097	0.0335	Longi.
2,10		1.0688	0.2682	0.0497	Longi.
4,6,8		1.3375	0.3269	0.0544	Longi.
12,24		0.3652	0.0551	0.0058	Lateral
18		0.4103	0.0640	0.0065	Lateral
13-17, 19-23		0.4012	0.0016	0.0057	Lateral
3,5,7,9	(Dummy)	0	10^{-7}	10^{-7}	Longi.

After analyzing the grillage models, results are tabulated as shown in table - 2 & 3.

Table 2: Maximum Dead Load and Live Load BM, Deflection and Torsion in each longitudinal girder with IRC class A-4 trains loading for 20 m span four lane bridge with 3 cross girders.

Long. Girder	D L B M kNm	L L B M kNm	Total BM kNm	D L defl. mm	L L defl. mm	Total defl. mm	Defl / span	D L Torsion kNm	L L Torsion kNm	Total Torsion kNm
1	2483.050	1217.543	3700.593	17.877	8.100	25.977	1/769	56.28	41.83	98.11
2	2779.514	1507.297	4286.811	15.909	8.219	24.128	1/828	31.66	26.36	58.02
3	2620.859	1511.867	4132.726	15.198	8.234	23.432	1/853	0.00	19.27	19.27
4	2779.514	1507.297	4286.811	15.909	8.219	24.128	1/828	31.66	27.47	59.13
5	2483.050	1217.543	3700.593	17.877	8.100	25.977	1/769	56.28	39.58	95.86

Table 3: Maximum Dead Load and Live Load BM, Deflection and Torsion in each longitudinal girder with IRC class 70R-2 trains loading for 20 m span four lane bridge with 3 cross girders.

Long. Girder	D L B M kNm	L L B M kNm	Total BM kNm	D L defl. mm	L L defl. mm	Total defl. mm	Defl / span	D L Torsion kNm	L L Torsion kNm	Total Torsion kNm
1	2483.050	1079.123	3562.173	17.877	6.380	24.257	1/824	56.28	120.34	176.62
2	2779.514	1784.846	4564.360	15.909	10.137	26.046	1/767	31.66	132.96	164.62
3	2620.859	2085.015	4705.874	15.198	11.761	26.959	1/741	0	150.86	150.86
4	2779.514	1784.846	4564.360	15.909	10.137	26.046	1/767	31.66	95.56	127.22
5	2483.050	1079.123	3562.173	17.877	6.380	24.257	1/824	56.28	54.10	110.38

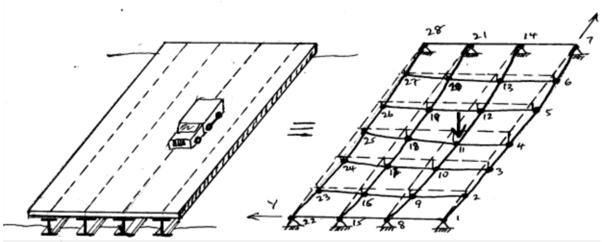


Figure1. Idealization of bridge deck into equivalent grillage

A typical grillage layout in STAAD is shown in figure3. Typical bending moment variation, deflection variation and torsion variation is shown in figure 4, 5 and 6 respectively.

A parametric study is carried out for spans of 15m to 40m for IRC class A loading. Variation in the bending moment, deflection and torsion is studied and are presented in figure 7, 8 and 9.

The same study is carried out for IRC class 70R loading and results are presented in figure10, 11 and 12 for which above all three systems of superstructure are considered. i.e. 3 CG, 5 CG and 7 CG.

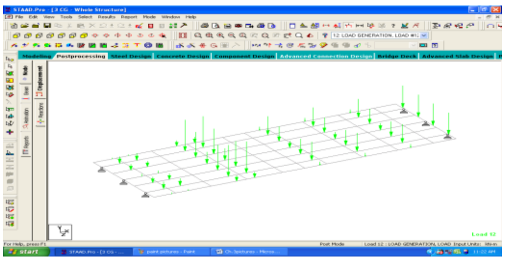


Figure2. Typical Grillage Layout with Loading

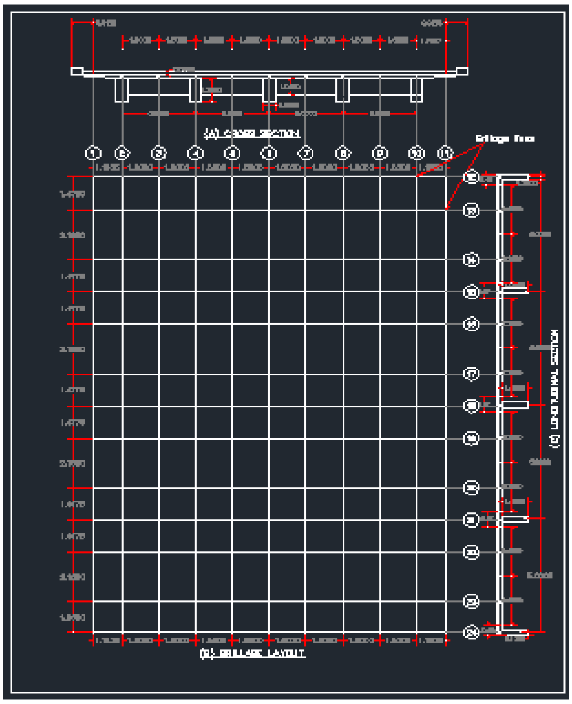


Figure3. Grillage Layout for 20m span four lane bridge with 3 cross girders

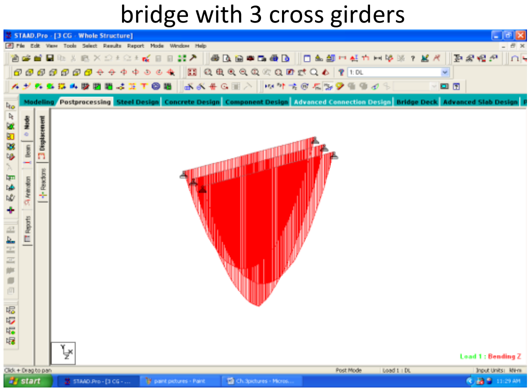


Figure4. Typical Maximum Bending Moment Diagram

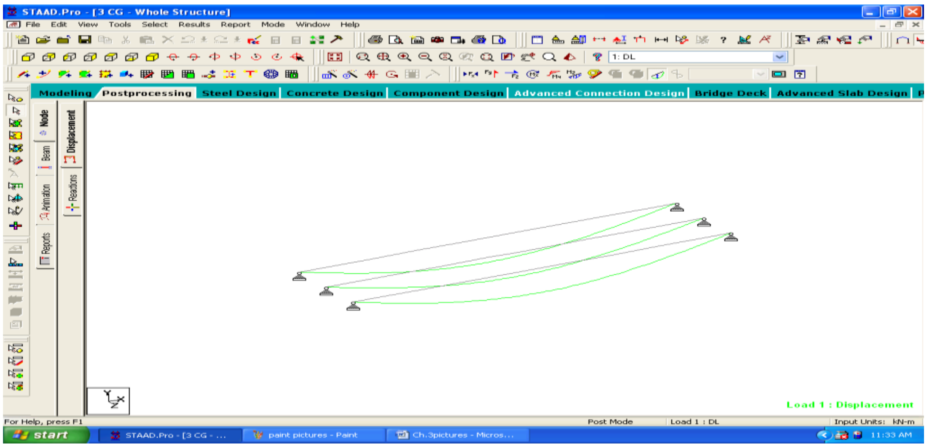


Figure5. Typical Maximum Deflection Diagram

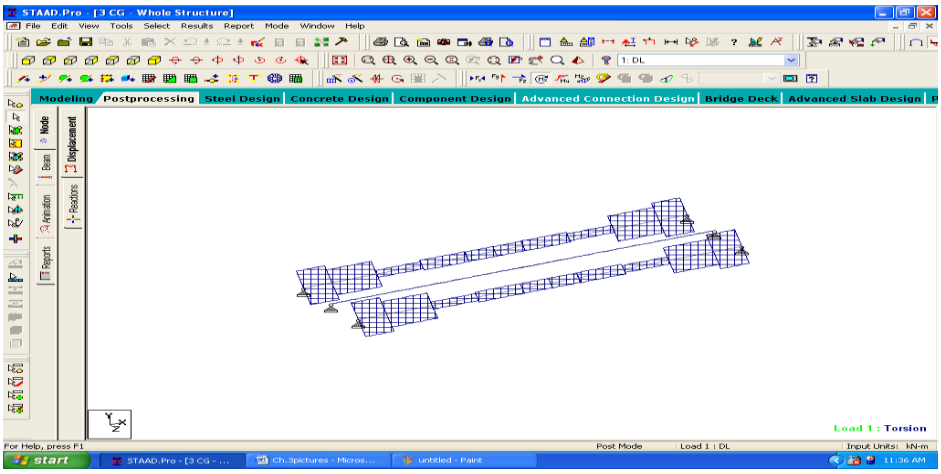


Figure6. Typical Maximum Torsion Diagram

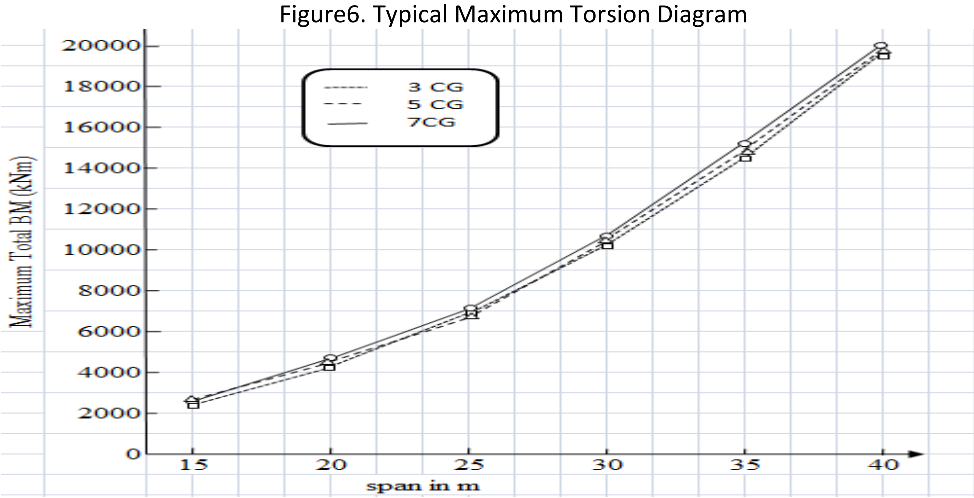


Figure7.Variation in maximum B M in Longitudinal girders w.r.t. span for four lane bridge with IRC class A-4 trains of loading.

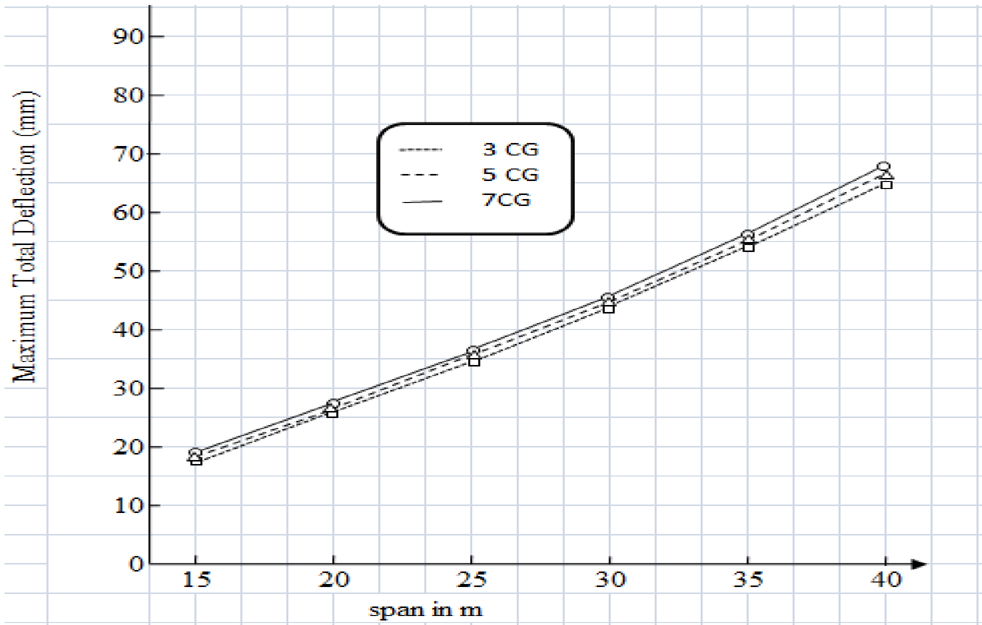


Figure8. Variation in maximum Deflection in longitudinal girders w.r.t. span for four lane bridge with IRC class A-4 trains of loading.

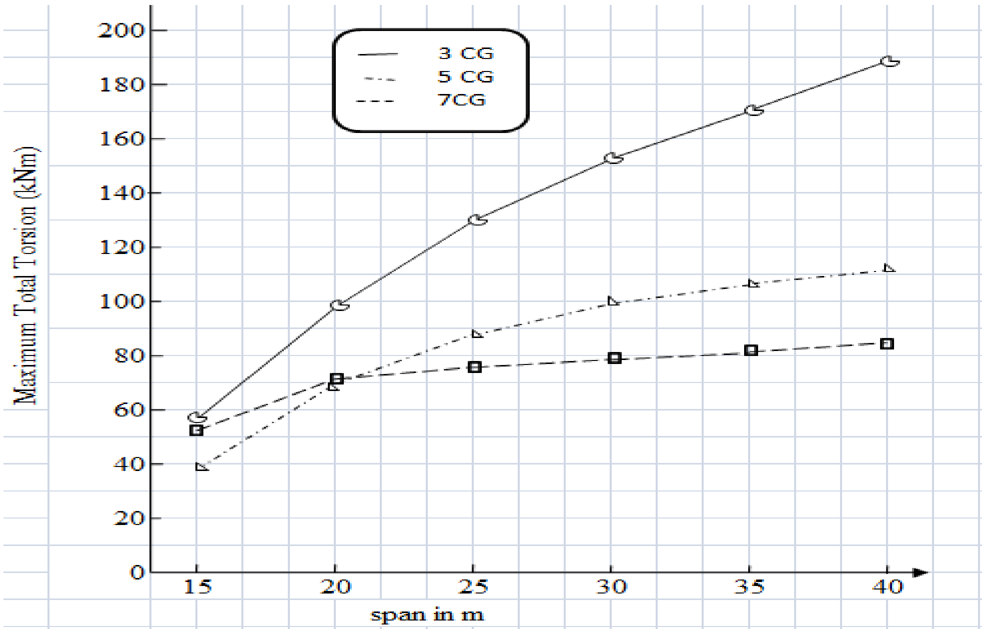


Figure9. Variation in maximum Torsion w.r.t. span for four lane bridge with IRC class A-4 trains of loading.

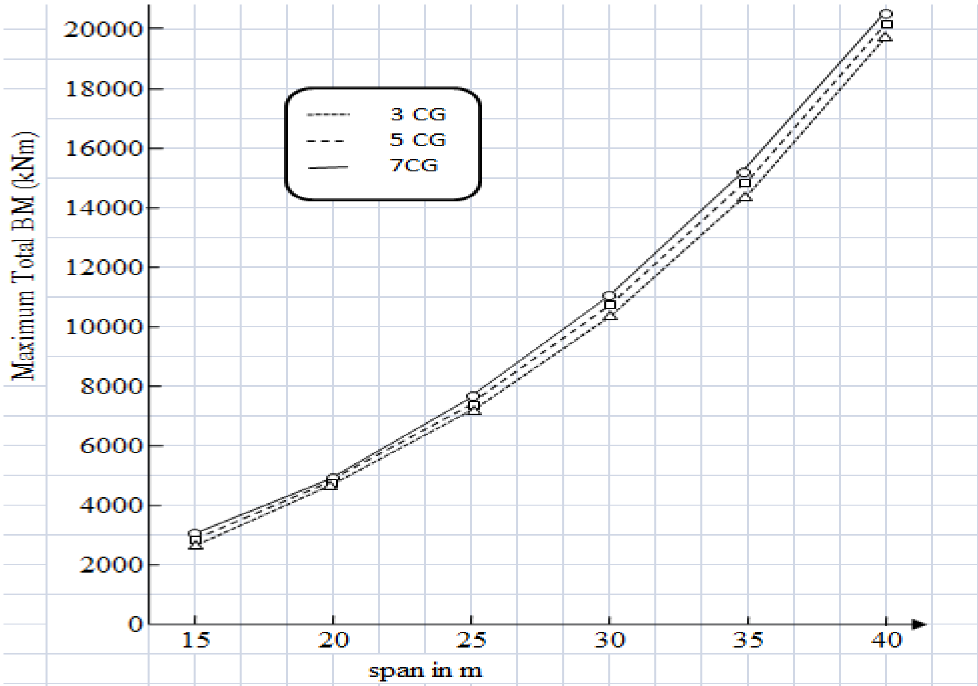


Figure10. Variation in maximum B M in longitudinal girders w.r.t. span of four lane bridge with IRC 70 R two trains of loading.

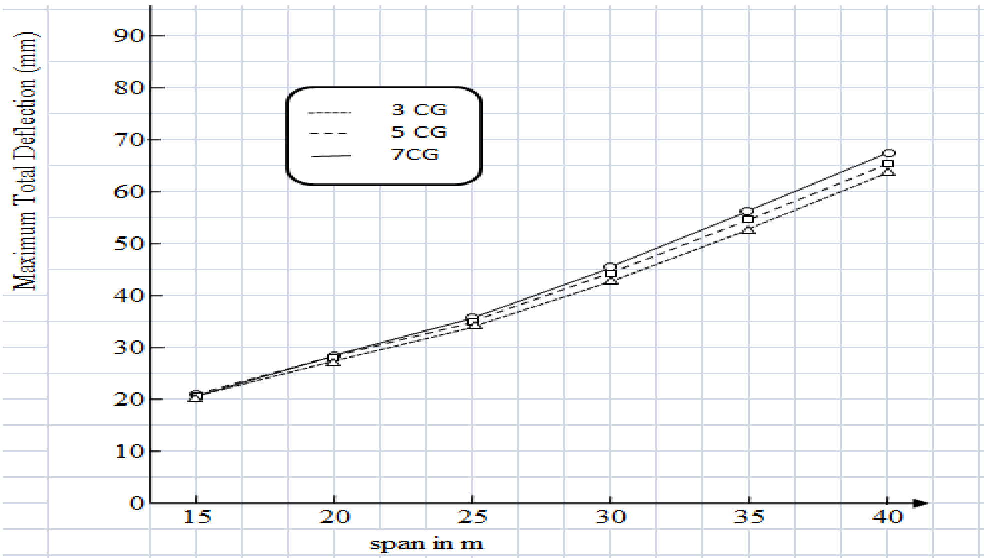


Figure11. Variation in maximum Deflection in longitudinal girders w.r.t. span of four lane bridge with IRC 70 R two trains of loading.

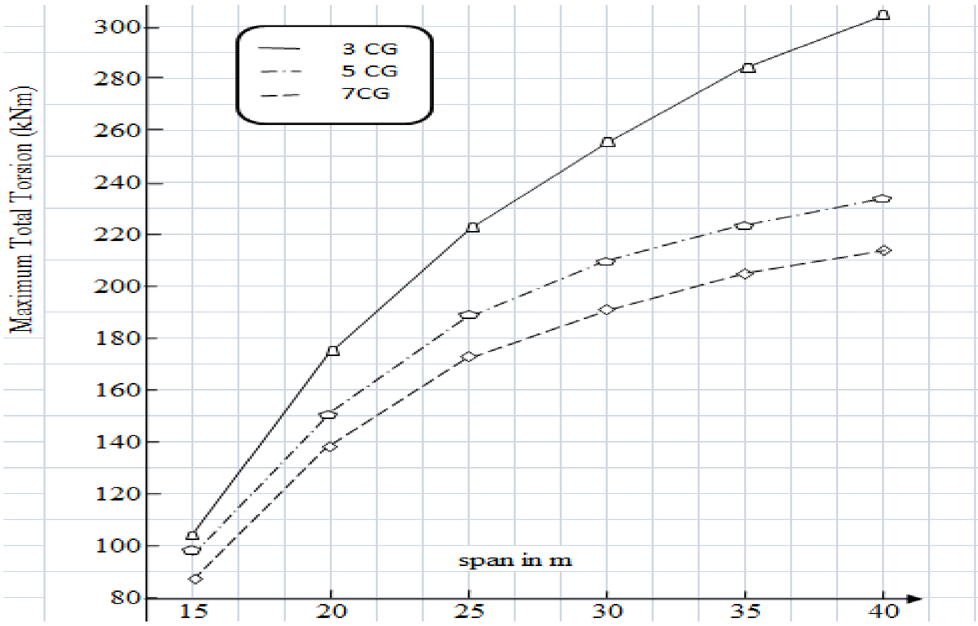


Figure12. Variation in maximum Torsion w.r.t. span of four lane bridge with IRC 70 R two trains of loading.

CONCLUSION

1 Bending Moment in longitudinal girders –

- With the increase in number of cross girders, self weight of bridge increases and hence maximum bending moment increases. Rate of increase in BM is mild upto 25m, beyond that, rate increases. Thus for higher span i.e. greater than 25m, BM in longitudinal girder increases with higher rate.
- The same trend is observed for both IRC classA and IRC class70R loading with almost same bending moment.

2 Deflection in longitudinal girders –

- Cross beams equalizes the deflections of the girders carrying heavy loading with those of the girders with less loading. Hence in all girders deflection is almost same. With the increase in number of cross girders, deflection increases.
- Rate of increase in deflection is more upto 25 to 30m. Beyond this, rate decreases.
- The same trend is observed for both live load. This is because the length of these vehicles (IRC classA, IRC class70R) are in the range of 20 to 25m. Beyond the span of 25m, contribution of live load to deflection reduces. Hence beyond 25 to 30m, rate of increase in BM reduces.

3 Torsion in longitudinal girders –

- For four lane bridges, 5 longitudinal girders are used. For increased number of longitudinal girders, cross girders play very vital role. In our case, it is observed that from 3 CG to 7 CG, torsion in the exterior girders tremendously reduced by almost 80 to 100% for higher spans (25 to 40m) and almost 50 to 70% for spans upto 25m.
- Thus it is concluded that for higher number of longitudinal girders, effectiveness of cross girders is increased manifolds.

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