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Parametric Study of Horizontally Curved Pre-Stressed Concrete Continuous Box Girder Bridges

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Abstract — *bridges are the key elements in any road network system as they facilitate free and uninterrupted movement of traffic. The main objective of this study is to compare the analytical results of horizontally curved box girder bridges having different parameters. This paper comprises of analytical results of nine curved bridges having different parameters in terms of span length and deviation angle. The results obtained are in terms of shear force, bending moment and torsional moment. It is observed from the results that with increasing deviation angle there is an appreciable increase in the value of torsional moment.*

Keywords- *Grillage Analogy, STAAD BEAVA, Continuous span, Pre-stressed Box Girder*

I. INTRODUCTION

Grillage Analysis is a widely used computer aided technique for bridge deck analysis. In this method, the actual decking system is represented by an identical grillage of beams. This method is applicable to bridge decks with simple as well as complex configurations with almost the same ease. The longitudinal members should be parallel to the edges while the transverse members can be orthogonal to the longitudinal members or parallel to the supports. The software used for the analysis is “STAAD PRO v8i” while the geometry of the bridge is prepared in AUTOCAD 2016.

II. LITERATURE SURVEY

Vesmavala and Sarode (2014) did a parametric study on horizontally curved box girder bridges for torsional behavior and stability. The purpose of their study was to show that, due to the effect of horizontal curvature of the box girders, torsional moments are predominant. Numerous models for curved box girders were analysed using LUSAS FEA software for different parameters such as span lengths, radii and loadings. The flexural and torsional behavior, stability and mid-span deflections of the curved box girders were discussed. They concluded that there is no significant variation in the bending moments and the shear forces for Dead Load, Super Imposed Dead Load and Live Load for the specific span length with different radii. The torsional moments increase greatly with the decrease of the span radius of the box girder. There is more variation in torsion with span radius below 200m, while there is less variation for span radius above 300m. Jaggerwal and Bajpai (2016) did a parametric study of skew bridges using Grillage Analogy method. The purpose of their study was to analyse the skew bridges using Grillage Analogy and to compare the results based on various parameters. The varied parameters were span and skew angle of the bridges. The effect of these parameters was observed on maximum live load bending moment, maximum live load shear force and maximum live load reaction. Live Load “Class A Vehicle” were applied as per IRC 6 guidelines. The spans used were 10 m, 15 m, 20 m and 25 m. They concluded that Grillage analogy is an accurate and versatile method for a wide range of bridge decks. The increase in bending moment up to 40 degree angle is less. Sharp increase is observed at higher skew angle. With increase of skew angle, appreciable increase in torsion is seen.

III. GRILLAGE ANALYSIS

When a bridge deck is analyzed by the method of Grillage Analogy, there are essentially five steps to be followed:

(a) Idealization of physical deck into identical grillage
(b) Evaluation of elastic inertia of members of grillage
(c) Application and transfer of loads to nodes of grillage
(d) Determination of force responses and design envelopes
(e) Interpretation of the results

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In present study, three models of continuous span each for span length of 40m, 45m, and 50m are considered. For a particular span length, the considered deviation angles are 15º, 30º, and 45º. Live load application is done using STAAD BEAVA. The Bridge Engineering Automated Vehicle Application (B.E.A.V.A) is an additional module to STAAD.Pro and it works with structural models that are generated using STAAD.Pro. All the relevant code instructions for loading definitions and traffic lane calculations are incorporated in BEAVA. Live load generation for curved bridges cannot be done using STAAD.Pro due to the curved geometry. Hence use of STAAD BEAVA is necessary. As per the study on grillage method by Shreedhar and Kharde (2014), following points are considered while converting a bridge deck into identical grillage:

(a) Grid lines are placed along the centre line of beams.
(b) Longitudinal grid lines are placed at 0.3D from the edges for Slab Bridge, where D is the depth of the deck.
(c) Grid lines are placed at lines joining bearings.
(d) A minimum of five grid lines are adopted in longitudinal direction.
(e) Grid lines are ordinarily taken at right angles.
(f) Grid lines are placed such that they coincide with CG of the section.

IV. BOX SECTION

Two span continuous curved bridges having a carriageway width of 7.5m are considered for analysis purpose. The single cell box girder shown in the Figure 1 is considered.

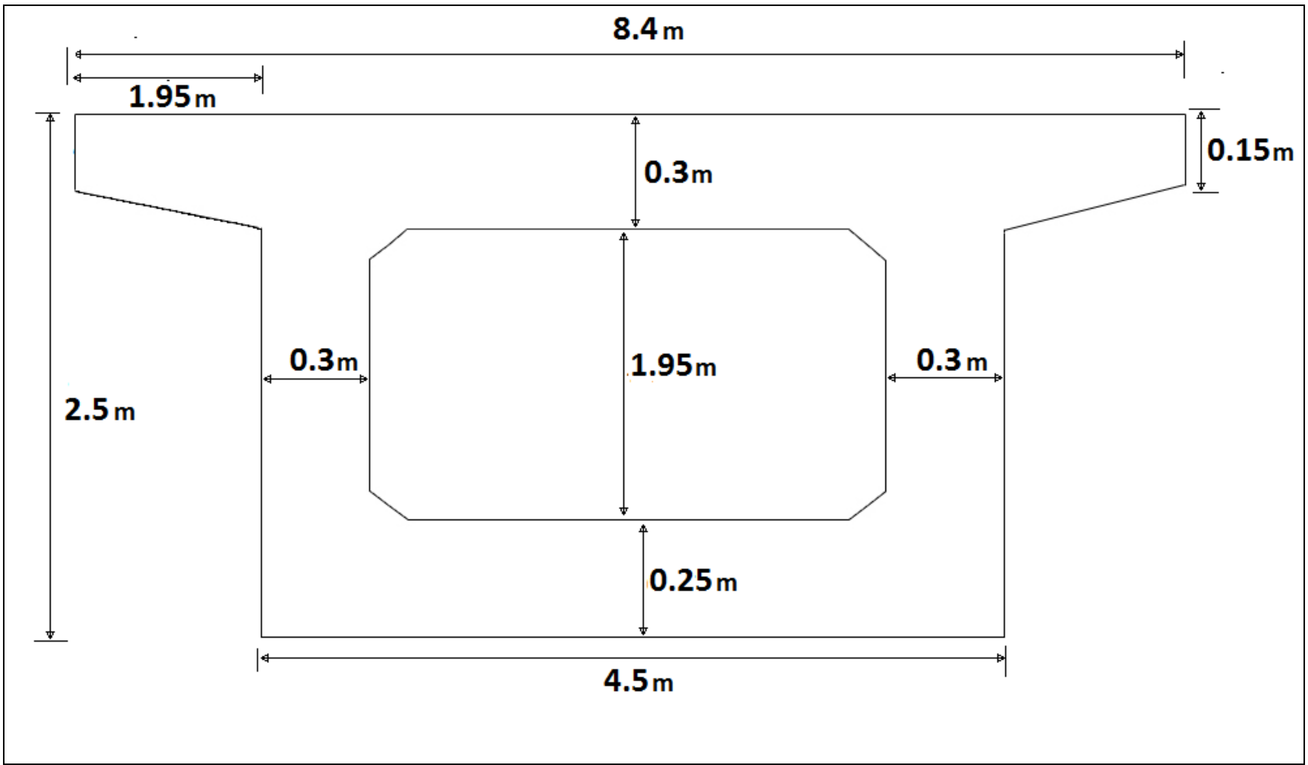

Figure 1. Box Section

V. LOADING ON BRIDGE

Total load acting on bridge comprises of Dead Load, Super Imposed Dead Load, and Live Load. Dead Load acting on the bridge comprises of the load due to self-weight of the bridge. The load due to crash barrier, wearing coat, and railing are considered under the calculation of Super Imposed Dead Load. Live Load comprises of the load due to moving vehicles. For calculation of Live Load, two load combinations are considered and the worst of these combinations is to be considered as per IRC-6 2014. In the first combination, two lanes of Class-A vehicle are considered and in the second combination one lane of Class-70R vehicle are considered.

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VI. MODELLING

A. Geometrical details

Geometry of the curved bridges are prepared using AUTOCAD 2016. Roller supports are provided as the end supports while pinned supports are provided as intermediate supports and are restrained against rotation at x-axis. Roller supports are provided so as to avoid the differential temperature stresses. The grillage model of a 45º curved bridge is shown in the Figure 2. Loading is applied on the two longitudinally highlighted grid lines shown in the Figure 2.

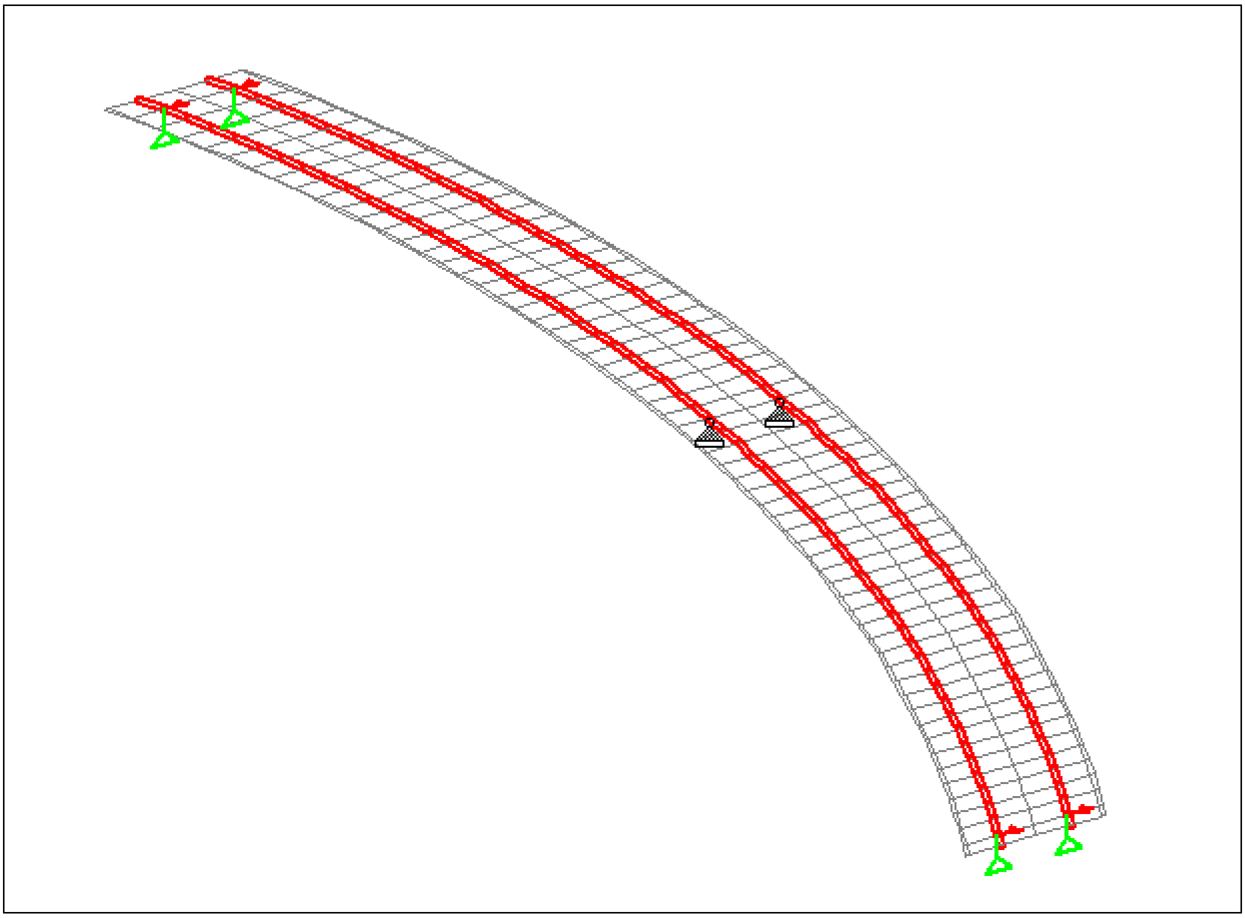

Figure 2. Grillage Geometry

B. Deck Definition and Influence Surface Generation:

In order to apply live load, deck definition is done. Figure 3 shows creating and editing of a deck in BEAVA.

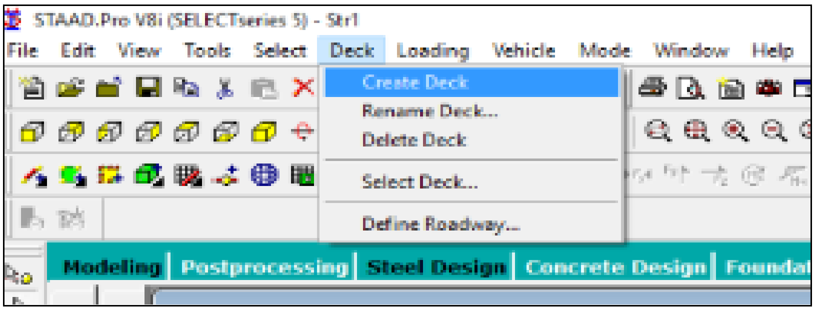

Figure 3. Deck Definition

While designing any part of the bridge the live loads are to be placed such that it causes the maximum effect for the part under consideration. The relationships between load position and critical effects have led to the construction of influence lines and surfaces. BEAVA generates all the influence surfaces required during analysis.

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C. Carriageway Definition

Once the Deck area has been defined the boundary of live load movements is provided so that code requirements pertaining to load application may be imposed. Hence, carriageways are to be defined. The carriageway is assigned to the deck based on the radius and deviation angles of both the kerbs as shown in the Figure 4 for a 30° curved bridge. Carriageway for the curved grillage model is shown in the Figure 5.

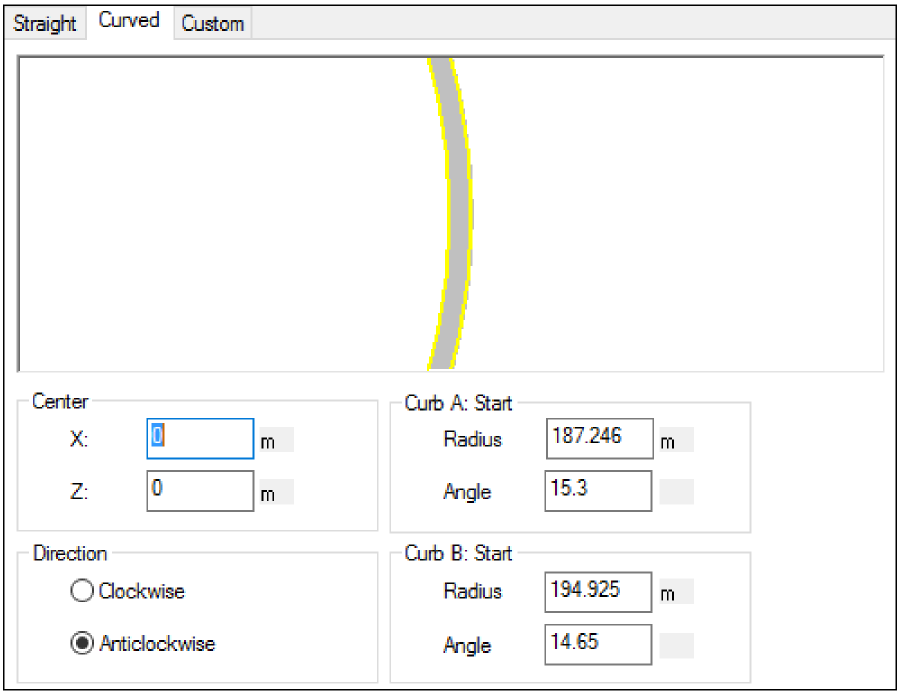

Figure 4. Roadway Definition

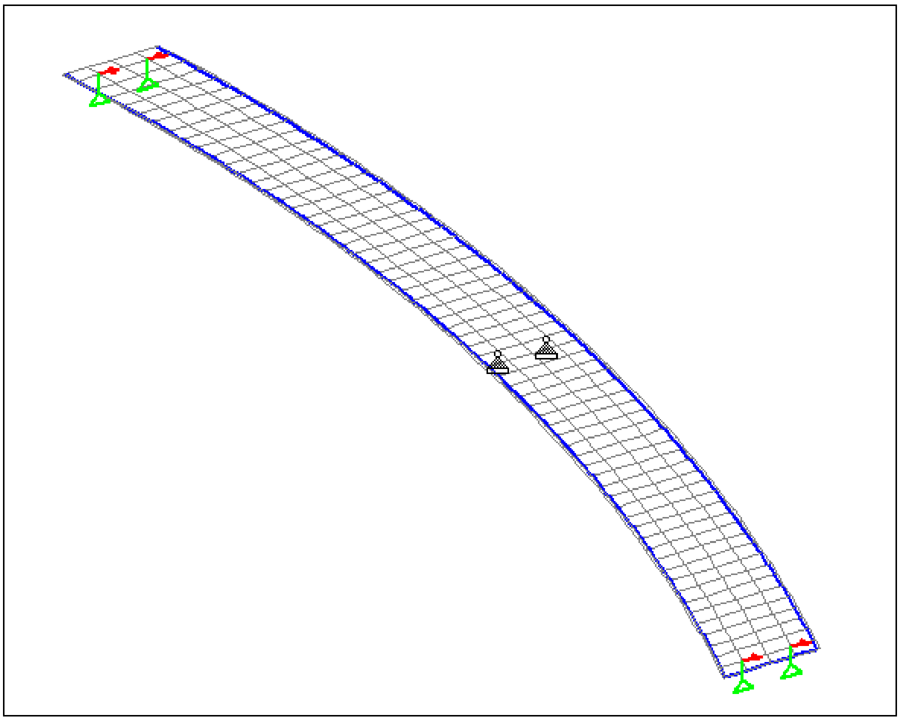

Figure 5. Carriageway

D. Load Application:

Moving load generation is automatically done in STAAD BEAVA after the design code and the type of vehicle are chosen. BEAVA's loading patterns are converted to STAAD.Pro load cases for the computation of live load. The Dead Load is calculated with respect to each grid line and applied directly to the respective grid lines. Load due to wearing

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coat is calculated and divided among the main grid lines while the load due to kerb is calculated and assigned to the grid lines passing through centre of gravity of the kerb.

VII. RESULTS AND DISCUSSIONS

The consideration of results in grillage analysis is different from other analysis techniques. The total value of a particular effect at a particular span length is found by adding the individual values obtained for both the grillage lines at that particular span. The calculation of torsional moment for a 45° curved bridge having a span length of 40 m is shown in Tables below. Torsional moment due to Dead Load and Live Load are shown in the Tables 1 and 2 respectively. Table 3 shows the total torsional moment. The two span bridges are divided in 9 equal parts to study the behavior of bridge at various span lengths.

Table 1. Torsional Moment due to Dead Load

Sr. No.	Line 1	Line 2	Total
1	1345.883	2167.087	3512.97
2	321.255	490.216	811.471
3	197.807	220.089	417.896
4	169.891	182.791	352.682
5	49.653	49.947	99.6
6	172.739	184.168	356.907
7	137.178	149.94	287.118
8	400.987	497.648	898.635
9	1326.956	2121.153	3448.109

Table 2. Torsional Moment due to Live Load

Sr. No.	Line 1	Line 2	Total
1	826.65	883.438	1710.088
2	553.402	642.249	1195.651
3	271.112	306.997	578.109
4	495.141	484.792	979.933
5	457.84	458.325	916.165
6	449.18	253.63	702.81
7	328.519	376.181	704.7
8	576.415	611.183	1187.598
9	818.641	869.032	1687.673

Table 3. Total Torsional Moment

Sr. No.	DL	70R	Total
1	3512.97	1710.088	5223.058
2	811.471	1195.651	2007.122
3	417.896	578.109	996.005
4	352.682	979.933	1332.615
5	99.6	916.165	1015.765
6	356.682	702.81	1059.492
7	287.118	704.7	991.818
8	898.635	1187.598	2086.233
9	3448.109	1687.673	5135.782

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Similarly, the calculations for shear force and bending moment for all the models are carried out. The values of obtained results are compared based on their deviation angle and span length.

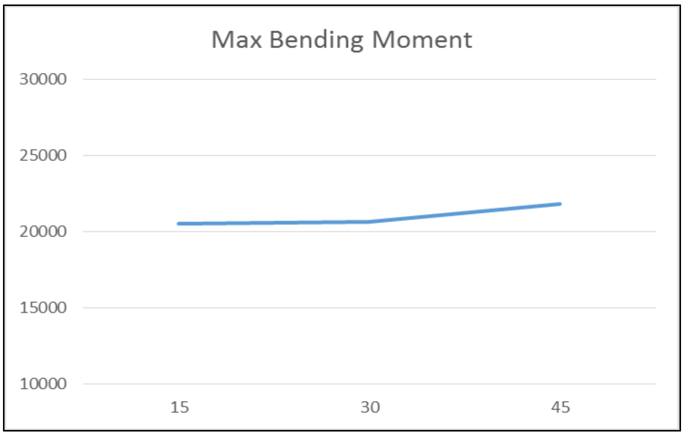

Figure 6 (a). Max. BM (kN.m) vs. Deviation angle for 40 m span

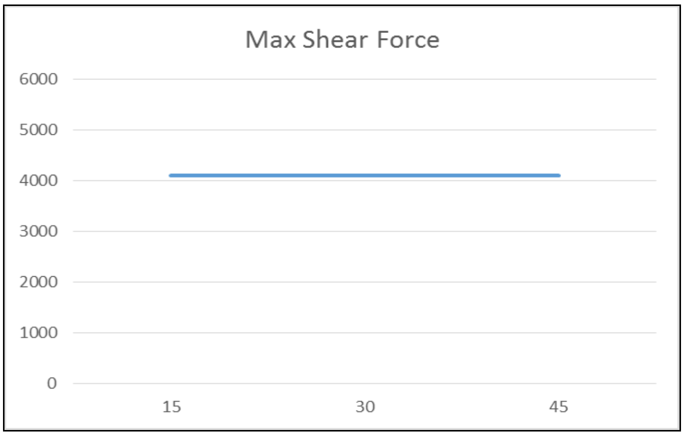

Figure 6 (b). Max. SF (kN) vs. Deviation angle for 40 m span

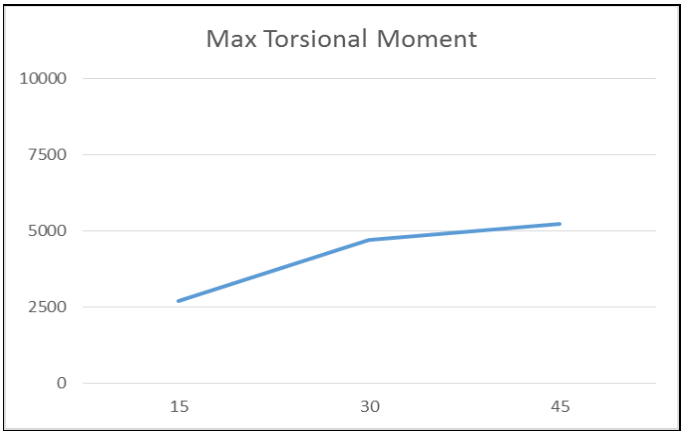

Figure 6 (c). Max. TM (kN.m) vs. Deviation angle for 40 m span

The comparison of maximum bending moment values for different deviation angles for 40 m span bridges is shown in the Figure 6(a). Figure 6(b) represents the comparison of maximum shear force values for different deviation angles for 40 m span bridges. Figure 6(c) shows the comparison of maximum torsional moment values for different deviation angles for 40 m span bridges. From the Figures 6(a), 6(b), 6(c), it can be seen that shear force and bending moment undergoes minor changes compared to torsional moment with increase in deviation angle. The value of torsional moment for 45º deviation angle is almost two times the value of torsional moment for 15º deviation angle.

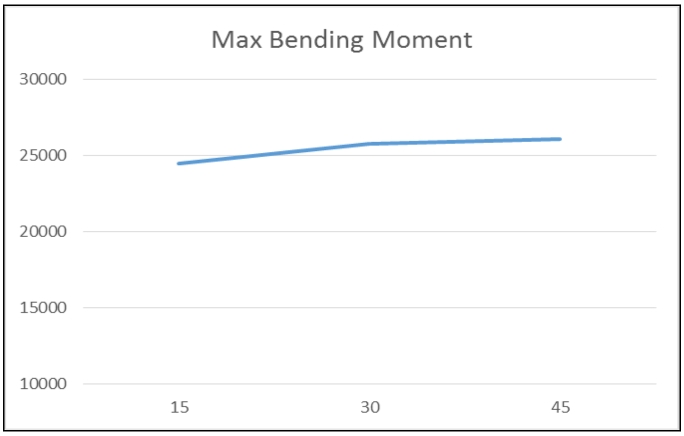

Figure 7 (a). Max. BM (kN.m) vs. Deviation angle for 45 m span

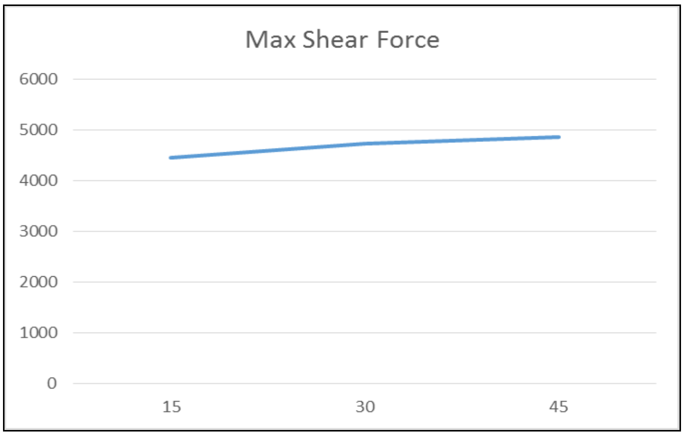

Figure 7 (b). Max. SF (kN) vs. Deviation angle for 45 m span

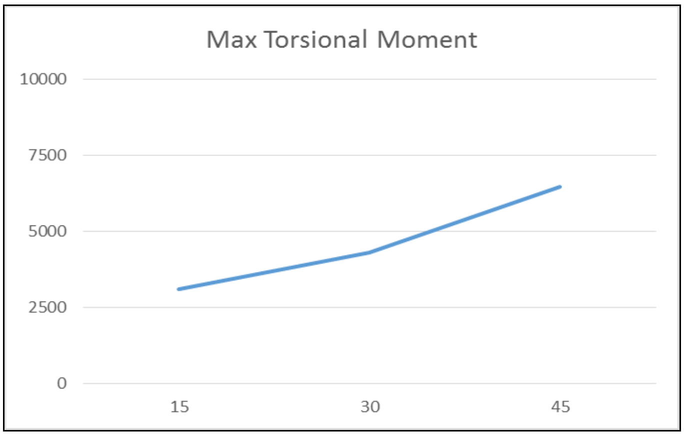

Figure 7 (c). Max. TM (kN.m) vs. Deviation angle for 45 m span

The comparison of maximum bending moment values for different deviation angles for 45 m span bridges is shown in the Figure 7(a). Figure 7(b) represents the comparison of maximum shear force values for different deviation angles for 45 m span bridges. Figure 7(c) shows the comparison of maximum torsional moment values for different deviation angles for 45 m span bridges. From the Figures 7(a), 7(b), 7(c), it can be seen that shear force and bending moment undergoes minor changes compared to torsional moment with increase in deviation angle. The value of torsional moment for 45º deviation angle is more than two times the value of torsional moment for 15º deviation angle.

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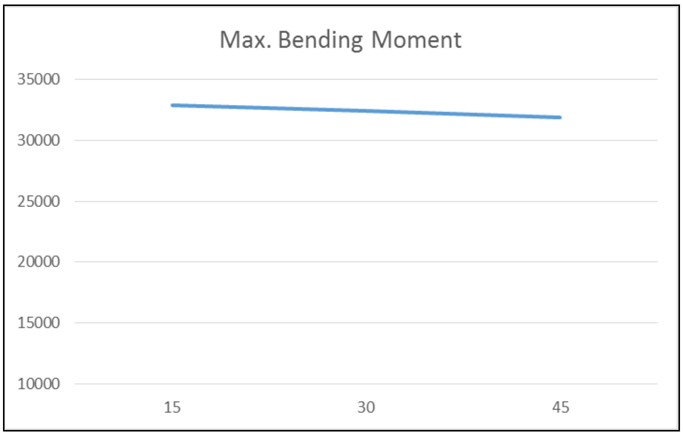

Figure 8 (a). Max. BM (kN.m) vs. Deviation angle for 50 m span

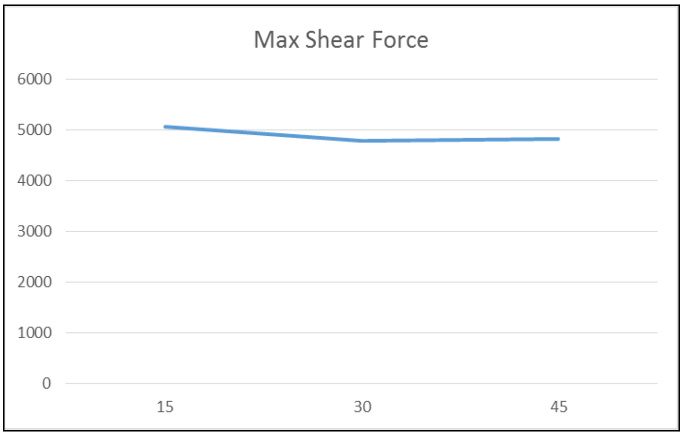

Figure 8 (b). Max. SF (kN) vs. Deviation angle for 50 m span

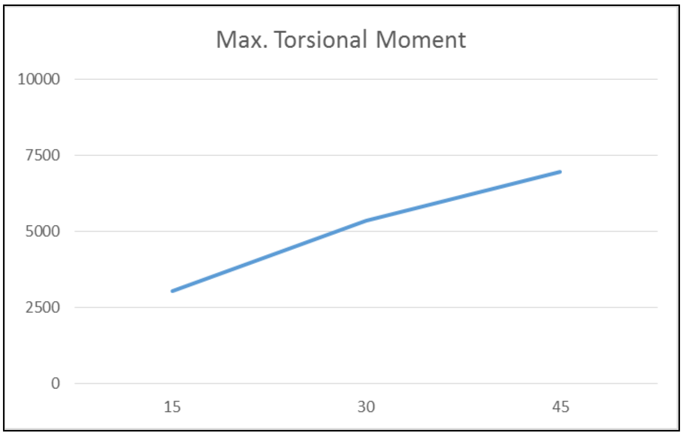

Figure 8 (c). Max. TM (kN.m) vs. Deviation angle for 50 m span

The comparison of maximum bending moment values for different deviation angles for 50 m span bridges is shown in the Figure 8(a). Figure 8(b) represents the comparison of maximum shear force values for different deviation angles for 50 m span bridges. Figure 8(c) shows the comparison of maximum torsional moment values for different deviation angles for 50 m span bridges. From the Figures 8(a), 8(b), 8(c), it can be seen that shear force and bending moment undergoes minor changes compared to torsional moment with increase in deviation angle. The value of torsional moment for 45 º deviation angles is more than two times the value of torsional moment for 15º deviation angle.

VIII. CONCLUSIONS

- It can be seen that, there is a slight increase in bending moment with increase in deviation angle.
- It is observed from the results that the value of torsion depends on both span-length and deviation angle.
- It can be concluded that shear force and bending moment undergoes minor changes compared to torsional moment, with increase in deviation angle.

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- The value of torsional moment for 45º deviation angle is almost 200% the value of torsional moment for 15º deviation angle for a particular span.

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