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Static and Dynamic Behaviour of Post Tensioned Skew Bridges by using FEM Techniques

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Abstract – *A Skew bridge is a bridge that built obliquely from bank to bank. An attempt has been made to understand the behavior of the skew bridges with different skew angles and FEM techniques. This paper includes different techniques and related works that have been done for different skew angle on bridges by using CSi bridge software. The various load criteria on bridges were considered as per Indian Road Congress and its amendments. The behavior of the skew bridges with the different length, skew angles are generally inter-related. The change in the different dimensions of the bridge can affect the various parameters like bending moment, shear force and torsional effects. This section summarizes the conclusion of this study on effect of skew on the behaviour of girder bridge analysis. Generally, the value of bending decreases with increase in the skew angle, the value of shear force and Torsion increases with increase in skew angle. For the combination of dead load and live load, it was observed that, bending moment, moment due to torsion, and equivalent design bending moment was increased gradually with increase of skew angle from 0° to 60°. It has been observed that for all bridge models considered in this study, the longitudinal Displacement is 0.13 m maximum for 60˚ skew.*

***Key Words*: Static analysis, Class AA, Class 70R, Bending Moment, Shear and Torsional Forces, Dynamic analysis, mode shapes and frequencies.**

1. INTRODUCTION

Bridge is a structure which is lying on two end supports over a recession, impediment and junction of a stream or valley. RC (reinforced concrete) skew bridge have been used widely during construction in hilly regions, mainly consists of Post-tensioned I-section girders, piers, abutments, bearings, cast-in-situ deck slabs and then crash barriers. In between the abutments and deck slabs the girders are provided to support the structure. At the intersection of deck slabs, top level piers and at abutments bearings are provided, which transmits the load from the super structure to the lower sub structures. These structural components increase load carrying capacity and strength of the whole structure. The skew angle of the bridge is the angle of tendency allying the normal to center-line of bridge and center-line of abutment. In case of straight bridges, the angle of skew will be same at all the supports and in case of skew bridges/ curved bridges the angle of the skew will be different at each support. If angle is zero degree, it is called a normal bridge. Otherwise if there is an angle in between the perpendicular to longitudinal axis of bridge and abutment line, it is called a skew bridge. The skew angle of the bridge is the angle of tendency allying the center-line of bridge and abutment. In this study, an effort has been made to study the effect of skew angle bridges on the behavior of Post-tensioned I section girder Bridges subjected to various Real Time Vehicular Loadings. The work also focused on the skew angle effect in various design parameters such as bending moment (BM), shear forces (SF) and Torsion on simply supported 3-lane Post-tensioned I section girder skew bridges. The skew-bridge analysis has been performed by using the updated CsiBridge 2018 methods of analysis yield less accurate results and uneconomical designs.

2. SCOPE & OBJECTIVES

The behavior of Post-tensioned I section girder with cast-in-situ deck slab is considered in this work. The present study focuses on the effect of skew angles on the behavior of Post-tensioned I-section Girder Bridge with following the skew angles being considered i.e. varying from 0^0 to 60^0. The span of the bridge is 25 meters with a 12m wide cast- in- situ deck slab. This project has following objectives

a) To study the skewness effect on design parameters such as Shear force, Bending moment and Torsion.
b) To study the Post-tensioned I section girder bridges behavior considering skew-angle effect.
c) To study the behavior of cast-in-situ deck slab bridge.
d) To study the effect of various loads on the skew bridges.
e) To study the effect of skewness on maximum Live Load Bending Moment, Shear Force at critical sections.
f) To check the characteristics of deflection and behavior of Post-tensioned I section bridges.
g) To study the outcome of skew angles on various components like abutment forces and the Dynamic Load Factor.
h) To compare the analysis results with manual calculations.

3. METHODOLOGY

The behaviors of the skew bridges are analyzed and tabulated using the CsiBridge software. The five different models with different cases considering various skew angles such as 0°, 15°,30°, 45°, 60°, having span of 25 m and width of 12 m is considered. Post-tensioned I-girder bridges are chosen for the generation of models.

The girder is having the dimensions, over all depth of 1750 mm, width of top flange 1200 mm, depth of top flange 150 mm, bottom width 600mm, bottom depth 325 mm, and thickness of the web is 300mm. The other parameters defined are bearings, diaphragms and crash barriers. The models are analyzed for dead load and live load on the skew bridge. The various results are extracted in the form of excel and the plotting of graphs for the values such as skew angle v/s shear force, bending moment and torsion are to be carried out.

Table -1: Angles and Span of the bridge sections.

SL. NO	SKEW ANGLES in degrees	SPAN in m
1	0	25
2	15	25
3	30	25
4	45	25
5	60	25

3.1 Size and shape of RCC Post-tensioned I-girder and cast-in-situ deck slab:

Details of bridge section for Deck section:

a. Top slab thickness, t_1 = 0.2m
b. Horizontal dimension, f_1 = 0.6m
c. Overhang length, L = 1.5m
d. Outer thickness, t_3 and t_4 = 0.2m
e. Type of slab = Cast in situ deck slab section

Details of bridge Girder section:

a. Overall depth of girder, D_1 = 1.75m
b. Depth of flange, D_2 = 0.15m
c. Width of flange, B_1 = 1.2m
d. Width of flange, B_2 = 0.6m
e. Width of web, B_3 = 0.3m
f. Type of Girder = RCC Post-tensioned I-Girder
g. Total number of girder =5 system of girder
h. Type of Tendon = Plain cold drawn stress relieved wire conforming to IS: 1785, Part 1, Using 7-strands of 15.2mm diameter in a cable.
i. Tendon Profile: Linear Parabolic with 1900 kN of jacking force.
j. Concrete Grade = M40.

4. CSi BRIDGE MODEL

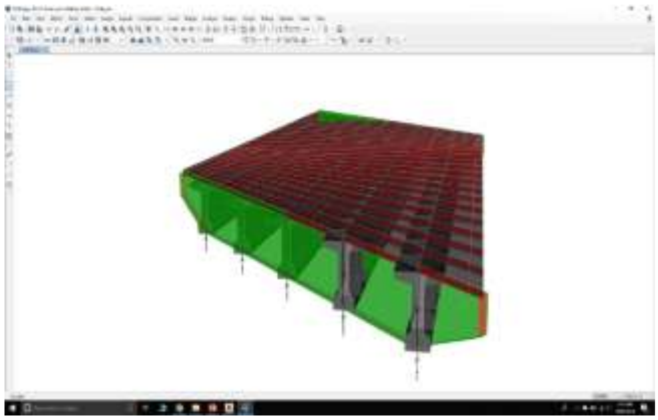

FIG -1: Side view of the model

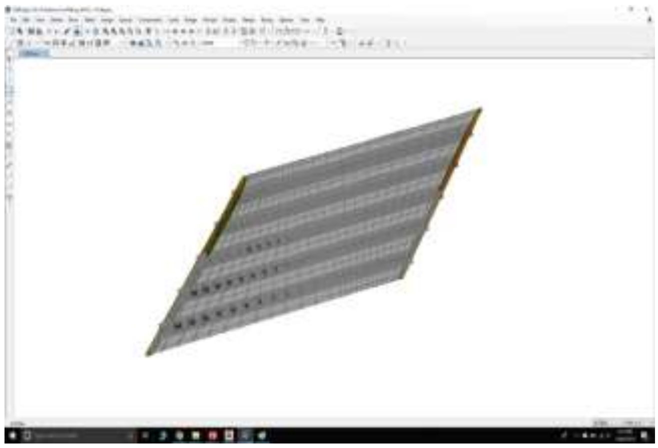

FIG -2: Top view of the model

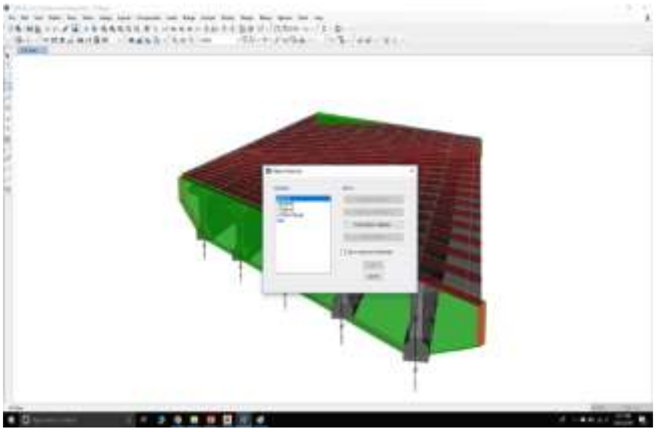

FIG -3: Material data

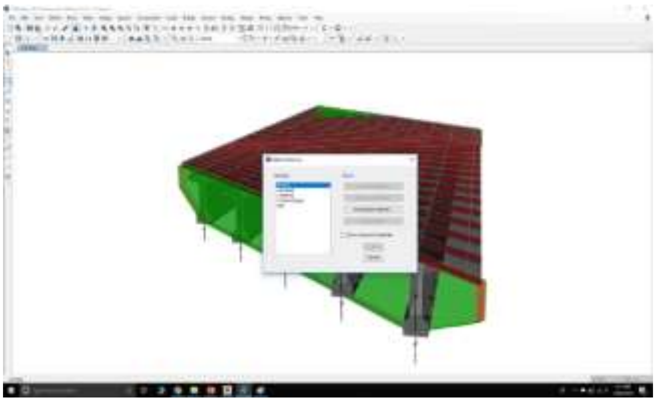

FIG -4: Lane data

5. RESULTS AND DISCUSSIONS

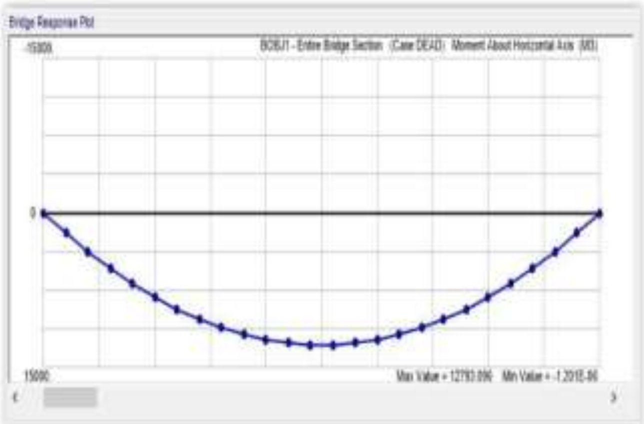

FIG -5: BM due to Dead Load

5.1 BENDING MOMENT: The results of bridge of span 25 meter and 12 meter wide with skew angle zero degree as shown in figure. Due to Live load and Dead load the max. BM occurs at centre of span. Max. BM for live load and dead load are, M_{XLL}= 6219.7202 kN-m and M_{XDL}=12793.096 kN-m.

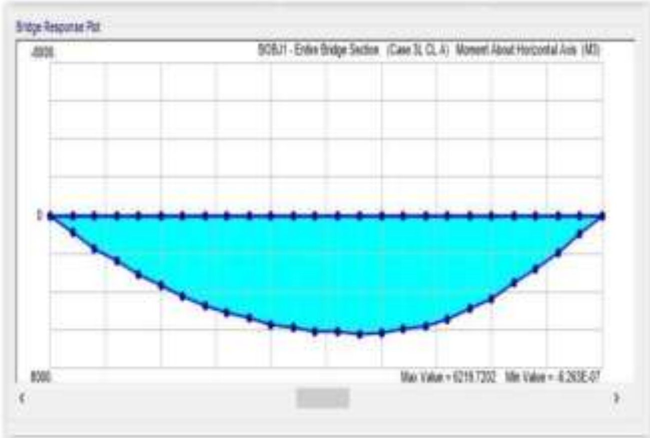

FIG -6: BM due to class AA Loading

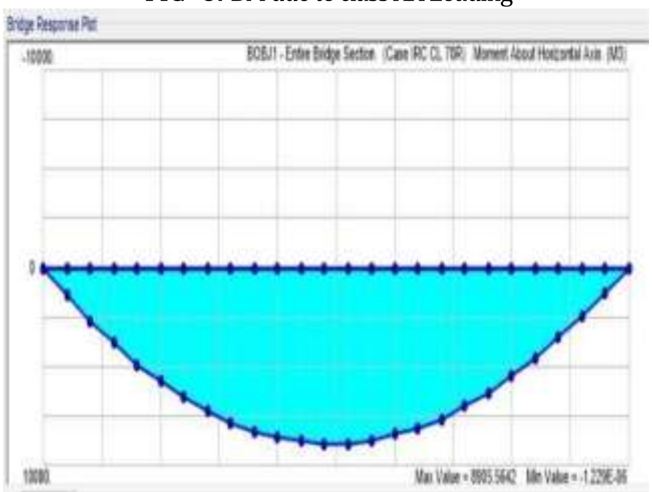

FIG -7: BM due toClass-70R loading

Table -2: Maximum Bending Moment values

SL NO.	BENDING MOMENT	MAX. VALUE kN-m
1	DEAD LOAD	12793.096
2	CLASS AA LOADING	6219.7202
3	CLASS 70R LOADING	8905.5642

5.2 SHEAR FORCE: The maximum shear force occurs at support section due to applied dead load and live load on the skew bridge. Shear force due to crash barrier, Class AA and class 70-R loading are shown in figure. Max SF for dead load, Mx = 2050.1757 kN, for crash barrier Mx = 250 kN and class AA loadings Mx = 979.7079 kN respectively.

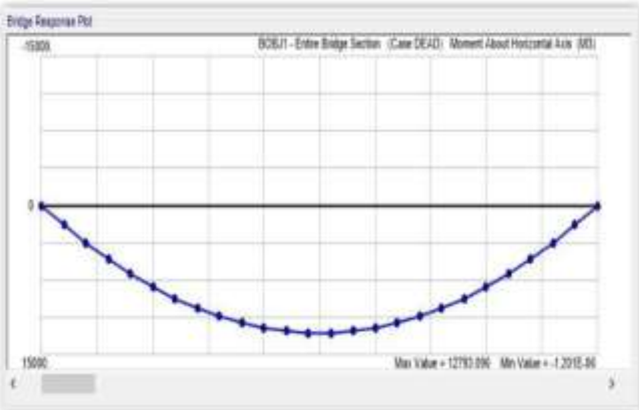

FIG -8: SF due dead load

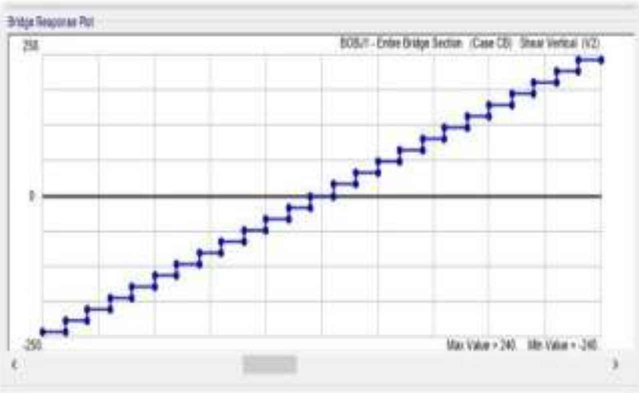

FIG -9: SF due dead load

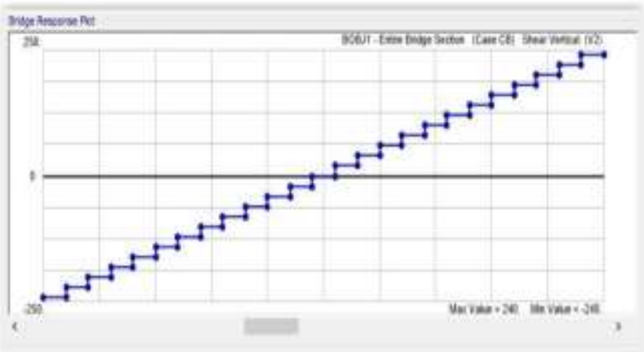

FIG -10: SF due Crash Barrier

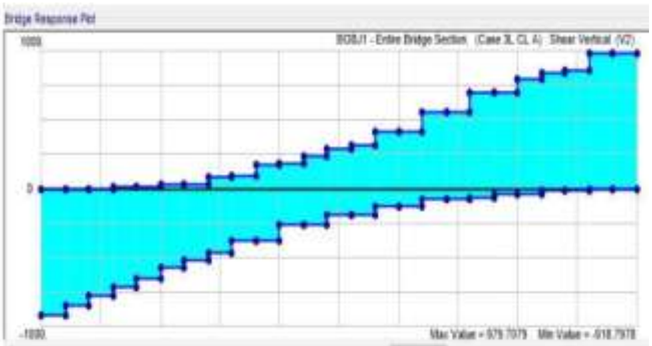

FIG -11: SF due to Class AA Loading

Table -3: Maximum Shear Force values

SL NO.	SHEAR FORCE	MAX. VALUE kN-m
1	DEAD LOAD	2050.175
2	CRASH BARRIER	8905.5642
3	CLASS AA LOADING	979.7079

5.3 TORSION:

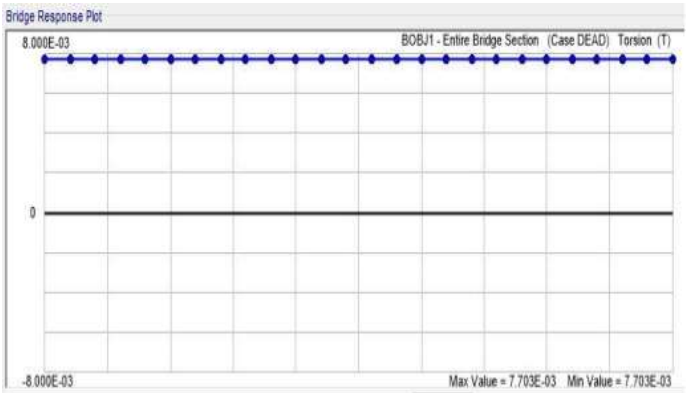

FIG-12: Torsion due to dead load

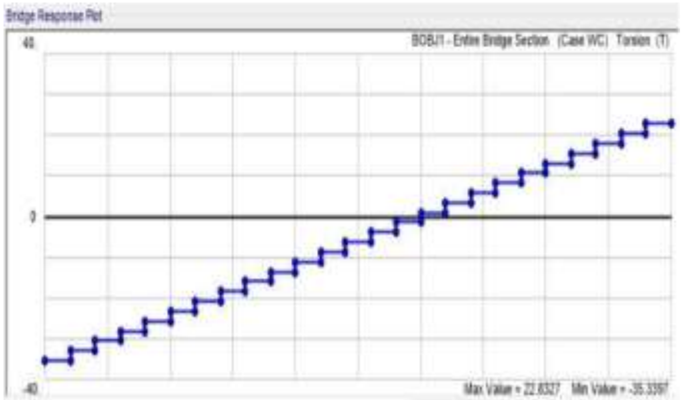

FIG -13: Torsion due to Wearing coat

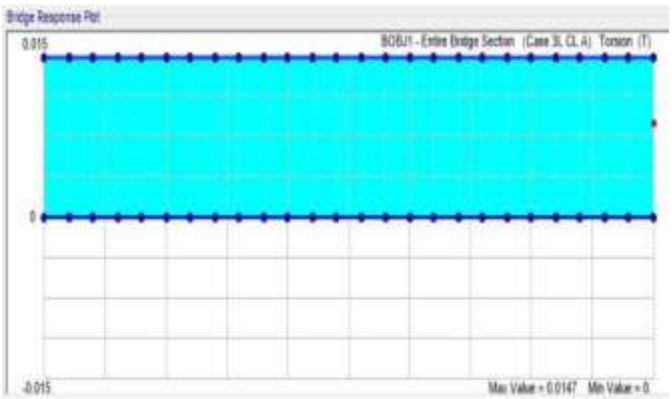

FIG -14: Torsion due to Class-AA Loading

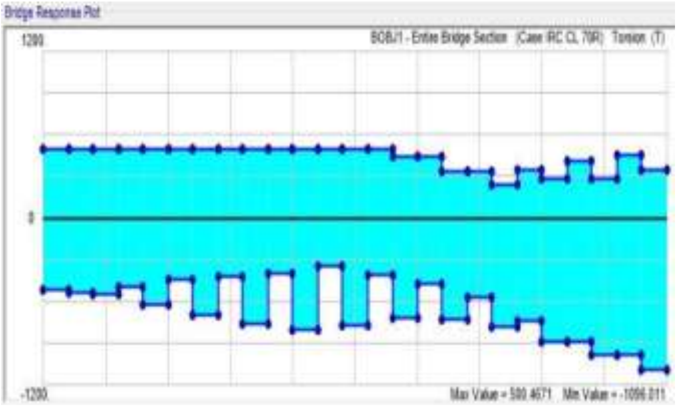

FIG -15: Torsion due to Class-70R Loading

From the above Maximum torsion T_{max} = 8.00 E-03 kN-m and the torsion due to the wearing coat is T_{max} = 22.832 kN-m. From figure the maximum torsion is 0.0147. The maximum value of torsion due to class 70R loadings is T_{max} = 500.4671 kN-m and minimum value is T_{min} = - 1096.001kN-m.

5.4 ANALYSED PARAMETERS DIAGRAMS

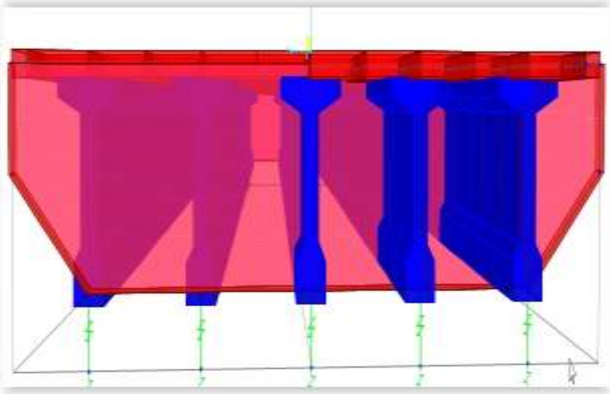

FIG -16: Cross section of bridge

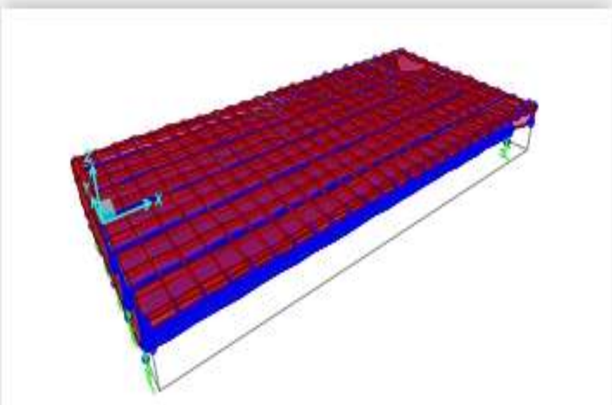

FIG -17: Plan for skew bridge ϴ=0°

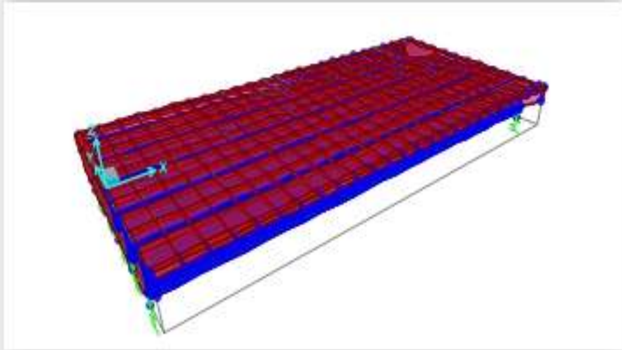

FIG -18: Plan for skew bridge ϴ=15°

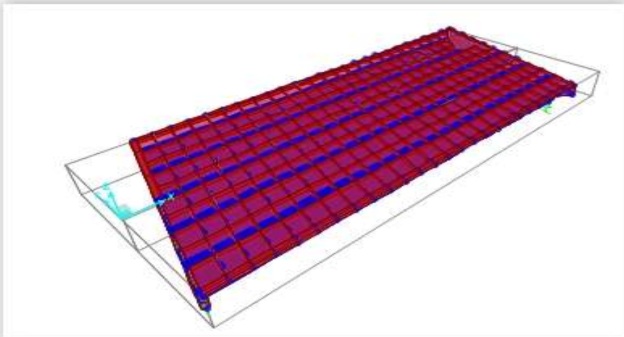

FIG -19: Plan for skew bridge ϴ=30°

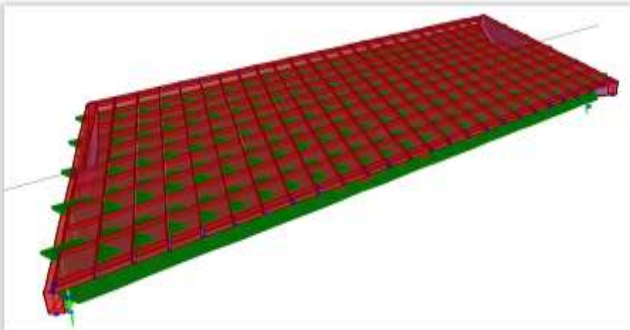

FIG -20: Plan for skew bridge ϴ=45°

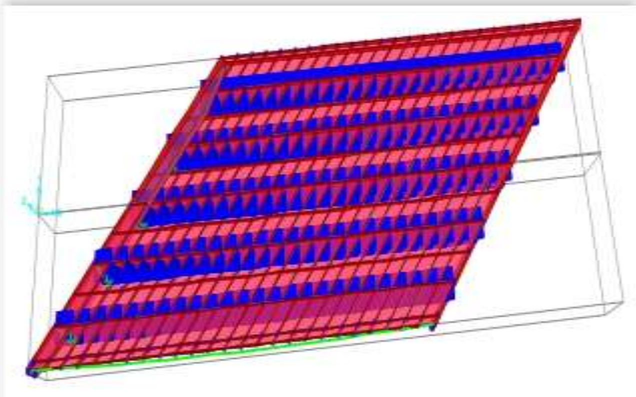

FIG -21: Plan for skew bridge ϴ=60°

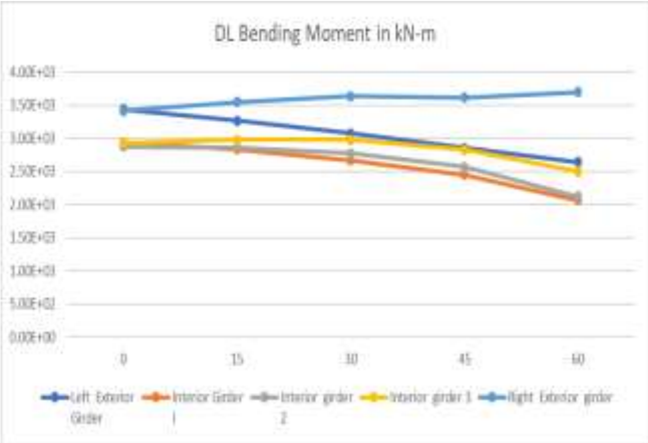

Chart -1: Skew angles v/s Dead Load Bending Moment

Table -4: Dead load Bending Moment

SA	Left Ext Girder	Interior Girder 1	Interior Girder 2	Interior Girder 3	Right Ext.Girder
0	3440.03	2935.83	2877.91	2930.16	3419.19
15	3266.72	2832.78	2860.63	2981.40	3545.96
30	3077.01	2671.63	2771.64	2975.74	3635.21
45	2852.89	2450.34	2567.39	2830.32	3618.14
60	2642.66	2067.69	2126.53	2497.41	3696.05

The various curves as seen in the chart -1 are because of Dead load on the skew bridge, it's been seen that BM decreases as skew angle will increase and it is based on skew angle and span. There is no effect on right exterior girder and for dead load left exterior girder and interior girder 1, 2, 3 it's linearly reducing that successively have an effect on the behaviour of skew bridges, (SA=Skew Angles).

Table -5: Dead load Shear Force

SA	Left Ext Girder	Interior Girder 1	Interior Girder 2	Interior Girder 3	Right Ext. Girder
0	-603.11	-402.28	-401.64	-402.64	-634.86
15	-678.19	-407.89	-402.42	-395.16	-592.426
30	-727.05	-415.04	-402.47	-394.63	-539.06
45	-785.28	-426.62	-389.29	-383.82	-493.94
60	-1435.74	-403.68	-630.04	-385.82	-488.65

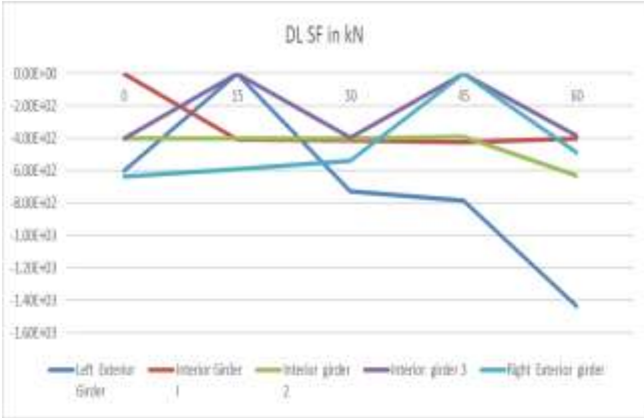

Chart -2: Skew angles vs Dead load shear force

SF increases with the increase in skew angle except for interior girder 1, 2, 3 it's virtually same and doesn't have an effect on the bridges (chart -2). The SF in left exterior girder and right exterior girder is modification because of live load and dead load on the bridges. Shear force is most at 45^{o} and 60^{o} for each right and left exterior girder.

Table -6: Dead Load Torsion

SA	Left Ext Girder	Interior Girder 1	Interior Girder 2	Interior Girder 3	Right Ext Girder
0	-24.90	-31.1	-46.70	-30.00	-24.20
15	-44.75	-80.18	-60.74	-19.98	-3.048
30	-68.97	-141.79	-84.90	-80.73	-26.23
45	-96.57	-210.03	-221.03	-175.15	-81.93
60	-99.04	-288.23	-288.23	-215.55	-96.90

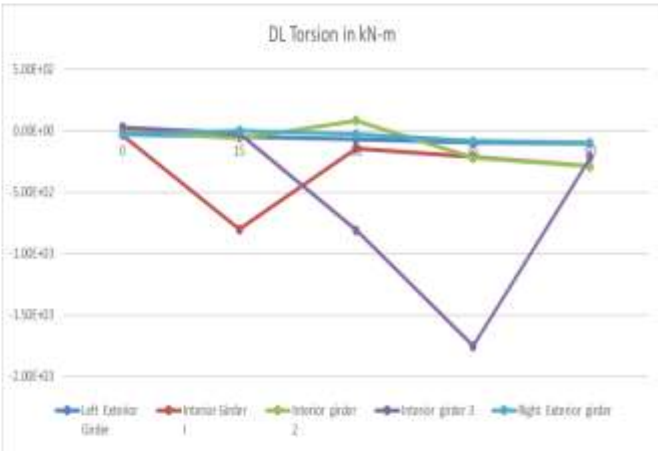

Chart -3: Skew angles vs Dead Load Torsion

As we will see from the top of chart -3 that the torsional moment is increasing on the bridge girders because the skew angle is magnified. The interior girder 2 that is at the centre is experiencing maximum torsion compared to the other girders. Since, the tributary space preoccupied by central girder is additional as we tend to increase the skew angle.

Table -7: Live Load Bending Moment

SA	Left Ext Girder	Interior Girder 1	Interior Girder 2	Interior Girder 3	Right Ext Girder
0	335.55	290.08	258.62	288.10	334.36
15	323.02	2827.05	2562.80	2933.17	3449.82
30	2078.35	2011.19	2114.84	2687.72	3327.04
45	2712.88	2371.40	2202.39	2635.92	3274.21
60	2442.44	1949.19	1766.24	2141.72	2960.90

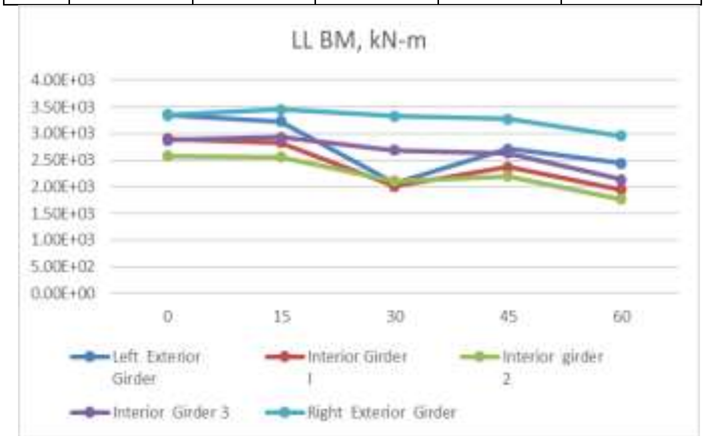

Chart -4: Skew angles vs Live Load Torsion

Table -8: Torsion (LL+DL)

Skew angle	Dead Load Torsion	Class-AA	Class-70R
0	0.0224	151.36	473.87
15	341.22	233.05	493.76
30	1062.75	443.26	627.72
45	2071.34	1550.22	902.23
60	3343.71	5406.63	2398.62

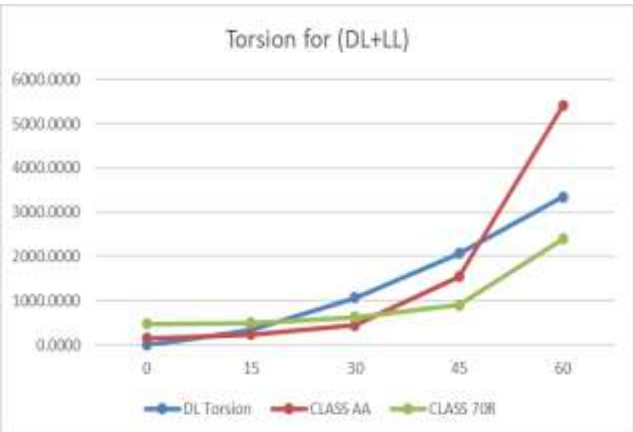

Chart -5: Skew angle vs Torsion

Live load torsional moment will increase with the rise in skew angle. It can be concluded that utmost torsion in I-girder skew bridge is detected compared thereto that of straight bridges because the skew angle will increase.

5.5 DYNAMIC MODE SHAPES AND FREQUENCIES

MODE SHAPE 1

These mode shapes for the 0^0 and 15^0 skew angles are longitudinal for 30^0 and 45^0 skew there is a slight dominance of shear mode. Usually as expected we can clearly see an increasing trend in the corresponding natural frequencies as the skew increased. For 60˚ skew the mode is shear and torsional with dominance of shear of 25% and torsion of 65%. We can also see that the frequency is increasing as the skew angle is increased but for 60˚ skew we see the frequency is reducing by 30% compared to the previous skew angle. This reduction in frequency can be interpreted by studying the modal mass participation as given in fig. The decrease in fundamental frequency for skew angle of 60° most likely happens as a fact of the torsional modes are control for long bridges with higher skewness, while bending modes are controlled for non-skew bridges (0˚&15˚ skew).

MODE SHAPE 2

The mode shape-2 is a transverse shear mode, from the above figure we can see for 0^0 and 15^0 skew the mode is having a pure transverse shear mode this is associated by the natural frequencies of 7.01 & 7.08Hz, there is no marginal change between the 0^0 and 15^0 skew natural frequencies. As, we go for higher skews more than 30^0 the natural frequency in having an increasing trend with dominance of both longitudinal and transverse shear modes even the natural frequency is increasing about 20% with respect to the previous skews. However, it was found that the natural frequency for 60^0 was 11.9% less than the previous skew it was also found that the modal mass participating was less for 60^0 skew. We can see a decreasing trend in the natural frequency for 45^0 and 60^0 skews, this is due to the fact that the torsional mode is dominating for these skew angles.

MODE SHAPE 3

Usually the third mode is a torsional mode, from the above figure we can see for 0^0 and 15^0 skew the mode is having a pure torsional mode this is associated by the natural frequencies of 8.23 & 8.18Hz, there is no marginal change between the 0^0 and 15^0 skew natural frequencies. As, we go for higher skews more than 45^0 the natural frequency in having an increasing trend with dominance of all the three modes longitudinal, shear & torsion. However, it was found that the natural frequency for skews 45^0 and above there was a slight diminishing trend (nearly 6.5%) in the natural frequency, which may be due to the less contribution of lateral stiffness due to the end beam. These phenomena can be explained by the theory of plate's vibration. The results are tabulated as below

6. Conclusion

The behavior of the Skew bridges with the diverse or various length, skew angles are for the most part between are generally inter-related. The change in the different dimensions of the bridge can affect the various parameters like Bending Moment, Shear Force and the Torsional impacts. This area outlines the conclusion of the study on impact of skew on the conduct of girder support bridge examination.

Following are the major conclusions:

1. Generally, the value of bending declines with increment in the skew angle, the value of SF and the Torsion increment with the increase in the skew angle.
2. FEA results of DLBM (dead load) and LLBM (live load) bending moments (longitudinal) decreases as the skew angle increases, the max. Transverse moment will also increase with the increment in the skew angle. Then the max. Torsional moment increases with the increment in skew angle and the max. Longitudinal stresses decline with the skew angle up to 30° and thereafter it will increase.
3. For combination of Dead Load and Live Load, it was seen that, bending moment, moment due to torsion, and equivalent design bending moment was increased gradually with the increment in the skew angle from 0° - 60°.
4. Structural responses for dead load bending moment decreases at the left exterior girder and increases at right exterior girder. The dead load shear force will be maximum at left exterior girder and dead load torsion will be maximum at right exterior girder.
5. It has been seen that for all the bridge models in this extent, the Longitudinal Displacement is 0.13 m maximum for 60˚ skew.
6. With the increase in the skewness, longitudinal displacement increases during Ground motion.
7. A comparison of bent D/C (design capacity) ratio shows that as compare to other skew bridge models, 60˚skew bridge have bent D/C ratio nearly 55% more in transverse direction and nearly 20% more in longitudinal direction. All other 0˚, 15˚, 30˚ and 45˚ skew bridges are having almost same bent D/C ratio in both directions.
8. The dynamic conduct of Skew bridge is concentrated dependent upon the mode shapes and their frequencies. The modes 1 & 2 have experienced translation effect along global Z direction and mode 3 have experienced with torsional effect.
9. In case of the Mode shape 1 - the 0^0 and 15^0 skew angles are longitudinal, for 30^0 and 45^0 skew there is a slight dominance of shear mode and for 60^0 skew the mode is shear and torsional with dominance of shear of 25% and torsion of 65%. The frequency is increasing as the skew angle is increased but for 60^0 skew the frequency is reducing by 30% compared to the previous skew angle.
10. Mode shape 2 is a transverse shear mode, for 0^0 and 15^0 skew the mode is having a pure transverse shear mode, there is no marginal change in natural frequencies for 0^0 and 15^0 angle. There will be decreasing trend in the natural frequency for 45^0 and 60^0 skews, this is due to the fact that the torsional mode is dominating for these skew angles.
11. In mode shape 3 for 0^0 and 15^0 skew is having a pure torsional mode this is associated by the natural frequencies with no marginal change. For higher skews more than 45^0 the natural frequency in having an increasing trend with dominance of all the three modes longitudinal, shear & torsion.

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