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Parametric Study on Behaviour of Skewness on PSC Box Girder Bridges

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Abstract – *Skew Bridges are the most required type of bridge but always evaded due to their complex analysis and design, as even in the Indian Standard it didn't have any specific clause regarding this type of bridge. Mostly, engineers adapt and design a skew bridge as a straight bridge on a field. This paper presents a parametric study on the behaviour of skewness on PSC Box Girder Bridge. The Maximum Shear Force, Bending Moment, Torsion Moment and Displacement under Dead Load and IRC Class A Vehicle load are evaluated, using the finite element-based software CSi Bridge v22. In total, 50 bridge models are considered for the present study. The impact of different parameters is calculated. As geometry is considered, then Trapezoidal Sections are more efficient than the Rectangular. Skewness of a bridge affects insignificantly on 10° and 20° bridges, but bridges with higher degree skew angle requires careful in-depth analysis. Shear Force decreases insignificantly as the skew angle increases. The hogging bending moment in the skew bridge increases, where the sagging moment decreases as the skew angle increases. Torsion is the biggest factor as it changes radically as the skew angle increases. In 2 and 3 Span bridges, the bending moment suddenly changes at 60°. In the skew bridge a displacement is less than the straight bridge.*

Key Words: Skew Angle, Box Girder Bridge, Bending Moment, Shear Force, Torsion, Displacement, Finite Element Method.

1. INTRODUCTION

The easiest and shortest route of transportation is required for the ideal traffic flow. For that, it is required to cross various obstacles and barriers. Bridges are used to avoid these ground-based obstacles and cut-short long route to short. The Box Girder Bridge section is the most used but very complex than the normal girder bridge. As Box Girder Bridge is efficient in terms of economy and structural function nowadays engineers prefer this bridge section. For the fastest route requires a simple alignment without curves and turns, but sometimes cross alignment is not perpendicular to the road alignment, in that case Skew Bridges are considered. Skew bridges are very complex to analysis and design. The road alignment and cross obstacle alignment coincide with each other, other than the right angle is known as Skew Angle. Most engineers design the skew angle up to 20° as the straight bridge.

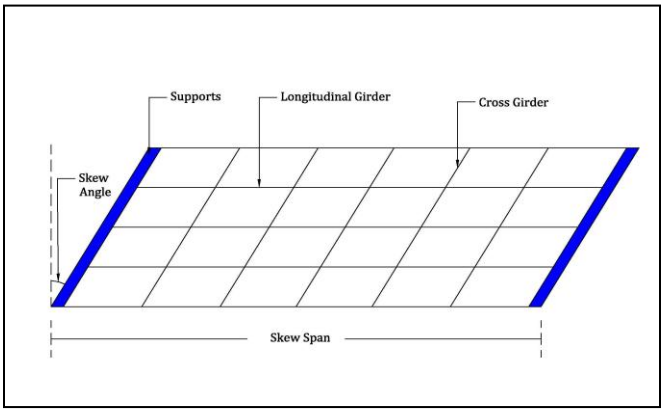

Figure 1 : Skew Bridge Layout

2. LITERAURE SURVEY

Preeti A. et al. (2019) This paper presents a study on simply supported, single cell, skew reinforced cement concrete box-girder bridge. The maximum bending moment and maximum shear force in interior and exterior girders under the IRC class-A wheel load are evaluated, using the finite element-based software SAP 2000 v.14.0.0. In total, 56 bridge models are considered for investigation. A convergence study is carried out on bridge model to select the appropriate mesh size for ensuring the reliable results. The influence of the identified design parameters is investigated. The presence of skew angle reduces the bending moment and increases the shear force in both the girders. [12]

Nidhi G. et al. (2019) Analysis of RCC box girder bridge is carried out for three different box girder sections, i.e. single, double and triple cells using finite element technique by linear static method of analysis. Bridge models are studied with the variation of degree of curvature, which is varied from 0° to 60° at an interval of 6°. Load cases considered are dead load and live load conforming to Indian Road Congress (IRC). The variation of bending moment, torsional moment, shear force and deflection is studied which are found to be increased with curvature. It has been estimated that the increased deflection in single, double and triple cell box girder bridges is about 295%, 280% and 245%, respectively, in between 0°(straight) and 60° curved bridges. This study states that the design of curved bridges is not a simple task which needs to be performed with utmost care. [11]

Praveen N. et al. (2018) They investigated the influence of skew angle as well as other design parameters. Following are the conclusions made from the study, for sagging moment under dead & moving loads the bending moment increases with increase in skew angle. For hogging moment under dead load, the bending moment reduces with increase in skew angle but it rises under moving load with increase in skew angle. Under dead load the shear force reduces with rise in skew angle & under moving load the shear force increases with rise in skew angle. Under dead load & under moving load torsional moment increases with rise in skew angle. They used SAP 2000 with IRC Class AA Loading. [10]

Tanmay G. et al. (2017) Several experimental and numerical studies have been made to examine the effect of skewness on the structural response of box-girder bridges subjected to static and/or dynamic loads. The aim of their research to review the literature published on the structural behavior of skew box-girder bridges subjected to static & dynamic loads including seismic effects. Moreover, this study also reviews the effect of skewness on load distribution among the multi-spine/cell box-girders bridges and presence of diaphragms in the bridge. According to their result, Bridges with skew angle lower than 20° are simple enough to design by few modifications in right bridge guidelines, however, for bridges with high skew angle a careful in-depth analysis is needed. Very long bridges tend to negate the skew effect but in short bridges high skew angle can generate a variety of extra forces which must be accounted in while designing. [9]

Bhalani R. and, Dipak J. (2016) They performed parametric study on effect of curvature and skew on box type bridge. A static analysis for dead load and moving load and a model analysis performed. Results states that by increasing radius of curvature for same skew angle, time period is decrease. So that time period value is more compare to straight bridge, also by increasing radius of curvature for same skew angle, value of deflection is decrease. So that deflection is more in curved bridge. As increasing value of radius of curvature, value of bending moment is also decrease in dead load plus super dead load and moving load case. [7]

Shrikant B. and Dr. Valsson V. (2016) presents comparative study based on the analytical modeling of simply supported RC Box Girder Bridge for various Skew angles using Staad Pro. Based on this study Deflection occurs for Live Load Combination case - II of various Skew angles result is increase by (1.750%) with increase in Skew angle are compared. Bending moment occurs for Live Load Combination case - II of various Skew angles result is increase by (1.525%) with increase in Skew angle are compared. Shear force occurs for Live Load Combination case - II of various Skew angles result is increase by (1.376%) with increase in Skew angle are compared. Torsional Moment occurs for Live Load Combination case - II of various Skew angles result is increase by (135.36%) with increase in Skew angle are compared. Support Reaction occurs for Live Load Combination case - II of various Skew angles result is increase by (0.001%) with increase in Skew angle are compared. [8]

Pranathi R. and Karuna S. (2015) presents comparative study on normal and skew bridge of PSC box girder performed. A finite element analysis performed to conclude that magnitude of shear force reduced with increase in skew angle under dead load in multi span deck where in single span shear force remained same in all models compared with straight deck under dead load. So no. of span also affects the skew bridges. Bending moment has reduced with increase in skew angle under dead load in single, two and three spans deck. But under moving load there is slight reduction in bending moment up to 20° and then increased for 30° and further reduced for 40° skew angle only on single span deck. [5]

Sujith P. S. et al. (2015) The objective of the project was to compare finite element method and grillage method. It can be concluded that analysis by using finite element method gives more economical design when compared with the grillage analysis. With increase in the skew angle, the stresses in the slab differ significantly from those in a straight slab. Reaction increased with increasing skew angle. Finite element method gives more economical design and accurate when compared with the grillage analysis. Uplift or negative reaction at the acute corner. Maximum or high reaction at the obtuse corner. [6]

3. AIM AND OBJECTIVES

Aim:

The aim of this study is to analyze the different parameters of PSC Box girder bridges to variation in its skew angle from 0° to 60° with an interval of 10°, with different loading, no. of lanes, no. of cells, no. of span which shows the behaviour of slab with forces and moments.

Objectives:

- To conduct parametric comparison of Rectangular and Trapezoidal Box Girder Bridge deck.
- To conduct the analysis of PSC box girder bridge with different skew angle from 0° to 60°.
- To study the effect of different loads.
- To compare the variation in maximum shear forces and bending moments for different skew angle from 0 to 60 degree under dead load and IRC loading.
- To understand effect of Torsion moment in skew bridges.
- To study the effect of span length, no. of lanes and no. of span with respect to forces and moments.
- To understand displacement in all modelled bridge.

- To generate graphical charts based on above study, which could simplify to understand behaviour of skew bridges.

4. PROBLEM STATEMENT

Total 50 bridges are analyzed to find out the behaviour of skewness on bridge section using CSi Bridge software. The skew angle of the bridges varies from 0°, 10°, 20°, 30°, 40°,50° and 60°. No. of lanes and spans are varying to determine behaviour of skewness on bridge with different parameters. Prestress tendons are configured on the model based on prestressing done on the existing bridge as built drawing. The IRC Load specified in IRC 6-2016, Class A vehicle is used for live load loading.

The bridges under this study are simply supported bridges. Following bridges are modelled and analyzed from 0° to 60°. No. of Lanes in Two Cell bridges are 3:

- Two Cell Trapezoidal box girder 25 m span length having single span.
- Two Cell Trapezoidal box girder 40 m span length having single span.
- Two Cell Rectangular box girder 50 m span length having single span.
- Two Cell Trapezoidal box girder 50 m span length having single span.
- Two Cell Trapezoidal box girder 50 m span length having 2 spans.
- Single Cell (2 Lanes) Trapezoidal box girder 50 m span length having single span.
- Three Cell (4 lanes) Trapezoidal box girder 50 m span length having single span.
- Two Cell Trapezoidal box girder 75 m span length having 3 spans.

The carriageway width is depended upon the no. of cells. A box girder bridge consists of a top and bottom slab connected by vertical webs to form a cellular or box like structure. Thickness of the web is 300 mm. Top and bottom width of slab is 240 mm. The overall depth of the section is 2.5 m.

The geometry of the models is based on the Gadi River bridge constructed as part of **NH348** (JNPT National Highway). Their dimensions are modified to satisfy structural design provisions. Following are the material properties, from the reference of Indian Standards and from available drawing of the bridge:

Concrete Properties:[21]

1) Grade of concrete = M45 = 45 N/mm^2
2) Young's modulus (E) = 3.35 $\times$ 10^7 kN/m^2
3) Poisson's ratio (υ) = 0.2
4) Shear Modulus (G) = 1.39 $\times$ 10^7 kN/m^2
5) Coefficient of thermal expansion (A) = 5.5 $\times$ 10^{-6}
6) Specific comp. strength of concrete (fc') = 45 kN/m

Tendon Properties:[22]

1) Type of pre-stressing – Post tensioning
2) Diameter of the pre-stressing cable = ASTM 0.5
3) Pre-stressing Strand = 13mm (0.5" strand)
4) Modulus of Elasticity = Eps = 1.968 $\times$ 10^8 kN/m^2
5) Elastic shortening stress = 20684.274 kN/m^2
6) Creep stress = 34473.79 kN/m^2
7) Shrinkage stress = 48263.31 kN/m^2
8) Steel relaxation stress = 34473.79 kN/m^2
9) Curvature coefficient = 0.15
10)Wobble coefficient = 6.56 $\times$ 10^{-4}
11)Anchorage Slip = 6.35 $\times$ 10^{-3} m
12) Coefficient of thermal expansion (A) = 1.17 $\times$ 10^{-5}
13)Minimum yield stress = Fy = 1689.9 $\times$ 10^3 kN/m^2
14)Minimum tensile stress = Fu = 1861.58 $\times$ 10^3 kN/m^2

Rebar Properties:

1) Grade of steel= HYSD500 = 500 N/mm^2
2) Young's modulus (E) = 2.00 $\times$ 10^8 kN/m^2
3) Poisson's ratio (υ) = 0.3
4) Coefficient of thermal expansion (A) = 1.17 $\times$ 10^{-5}
5) Minimum yield stress = Fy = 5 $\times$ 10^5 kN/m^2
6) Minimum tensile stress = Fu = 5.45 $\times$ 10^5 kN/m^2

Loading

1. Dead Load: Self-weight of the model was not taken as a lump of mass. Rather, all the element such as shell or solid elements are loaded by gravity load. Thus, self-weight is accounted for in the model automatically. Additionally, load due to wearing course is taken 1.4364 kN/m^2 in this study. Also, load due to crash barriers is taken as 5.1079 kN/m at two sides of the deck.

2. Live Load: For all bridges Class A type vehicle loading is consider. This type of vehicle loading is used in the design of all permanent bridges. It is considered as standard live load of bridge. Greater stresses are attained under class A loading. Class A loading includes of a wheel load train inclusive of a driving vehicle and two trailers of specified axle spacings.[23]

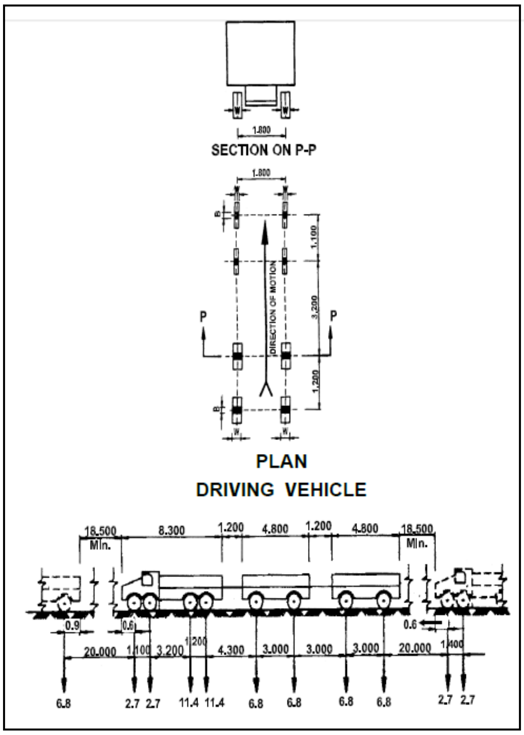

Figure 2 : Class A Vehicle (IRC 6: 2016 Clause 204.1) pg. no. 12

5. METHODOLOGY

Finite Element Method

The finite element method is the most powerful technique of analysis arising from the direct stiffness method. Sienkiewicz, Desai - Abel and Martin - Carey did revolutionary work in this field. Finite element analysis, also called the finite element method, is a method for numerical solution of field problems. Finite element analysis involves lot of numerical calculations. Hence it is not a suitable method for hand calculations. The method is ideally suited for computer applications and has developed along with developments in computer technology. In engineering this method used for the analysis of beams. space frames, plates, shells, folded plates, foundations, rock mechanics problems. Both static and dynamic problems can be handled by finite element analysis. This method is used extensively for the complex structure like analysis and design of ships. aircrafts, space crafts, electric motors and heat engines. [18][19]

Finite Element Analysis involves different stages: To solve problem suitable field variables and the elements are selected then separate the sequences. After that select interpolation function then find properties of the element. Accumulate element properties to get global properties. Apply the boundary conditions, to get the nodal unknown solve the system equation and to get the required value make the supplementary calculations.[20]

In order to achieve mentioned objectives for this type of bridges, the scope of this study is as follows:

• The method to analyze bridges is Finite Element Method.
• Analysis of FEM model of box girder bridge by using CSi Bridge v22 software.
• The models are for different skew angle i.e. from zero degree to 60 degree with an interval of 10 degree.
• The box girder bridges analyzed only for Dead Load and Live Load. IRC Class A Vehicle used for live load loading.
• The self-weight is applied by CSi Bridge with density of concrete taken as 25 kN/m^3. The length is mentioned in Meter (m), the forces are mentioned in Kilo Newton (kN), the moments are mentioned in Kilo Newton Meter (kN.m) and Vertical Displacement are mentioned in Millimeter (mm).
• The guideline for loading as per IRC Codes.
• The carriageway width of varies for all bridges depend upon the no. of box cells.
• The deck of the bridges supported by rolling supports at each end. These supports prevent translation only perpendicular to the deck surface (i.e., in the Z direction). Therefore, in all models the two corners of the deck are restrained against the X and Y directions to prevent instability of the decks.
• The analysis has been carried out for the mentioned loading and the results are obtained for Shear Force, Hogging and Sagging Bending Moment, Torsion Moment and Vertical Displacement.
• After this parametric study of different skewed bridges done, concluding remarks prepared after comparative study.

6. ANALYSIS

The structures under consideration are simply supported box girder bridges. The loads have been categorized into following parts:
1. Dead Load (Self weight + Wearing Course + Crash Barriers)
2. Live Load (IRC Class A Vehicle)

CSi Bridge: Modelling, analysis, and style of bridge structures are combined into CSi Bridge to form the final word in computerized tools modified to satisfy the wants of the engineering skilled. the suitability with that all of those tasks is skilled makes CSi Bridge the primary adaptable and productive package program within the trade. After modelling, CSi Bridge provides choices for the assignment of load cases and combos. Vehicle loading are generated consistent with codification (AASHTO LRFD, Canadian, Indian etc.) and assigned consistent with model pure mathematics. A series of templates for assignment and close load conditions create CSi Bridge intuitive and sensible. once the first object-based model has been translated into a finite-element model and subjected to load cases and combos, the analysis method follows directly.[16]

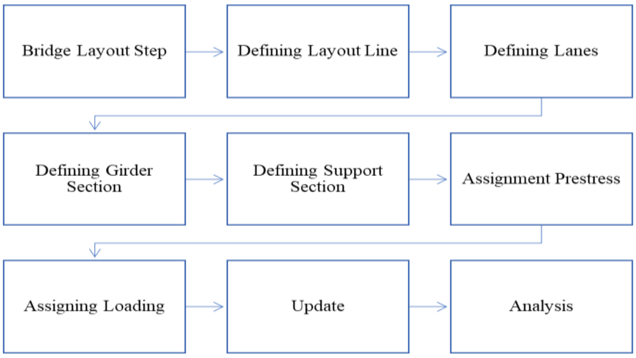

Figure 3 : Flow chart of Modelling in CSi Bridge

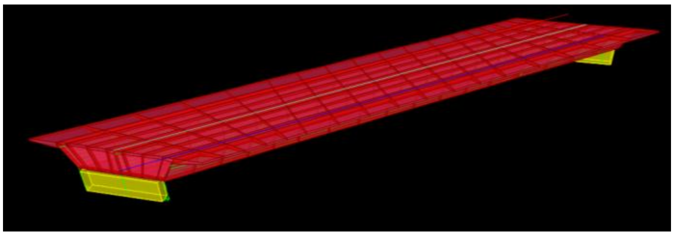

Figure 4 : 3D Finite Element Model in CSi Bridge

7. RESULTS AND DISCUSSION

7.1 COMPARISON BETWEEN RECTANGULAR AND TRAPEZOIDAL SECTION

To determine the section of box girder for further study, comparative study of Rectangular and Trapezoidal Girder bridge. [14]

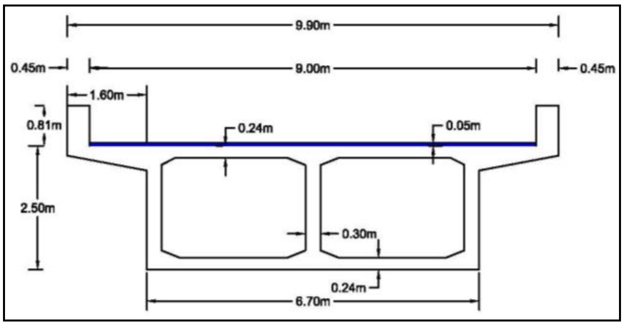

Figure 5 : Rectangular Box Girder Section

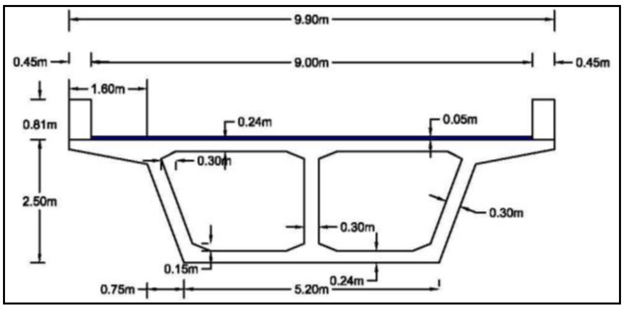

Figure 6 : Trapezoidal Box Girder Section

Table 1: Comparison between Rectangular and Trapezoidal Section

	Rectangle	Trapezoid
	DL + LL	DL + LL
Shear Force (kN)	6113.49	5898.02
Hogging Bending Moment (kN.m)	15157.92	18024.93
Sagging Bending Moment (kN.m)	58828.50	52918.72
Torsion Moment (kN.m)	1866.12	1850.73
Displacement (mm)	56.79	55.49
Cross-Sectional Area (m^2)	6.35	5.99

From the results obtained from the analysis following conclusions are drawn-

1) Central deflection in rectangular section is higher than that of trapezoidal section.
2) Shear force and Bending Moment is more in the rectangular section.
3) Torsion effect is insignificant.
4) With same specification of slab width, carriageway, girder width Trapezoidal Section area is less than the rectangular section.
5) Hence, Consumption of concrete and steel is more in rectangular section than in trapezoidal section.
6) Use of the trapezoidal section will increase the aesthetic appearance of the bridge.

From above comparison, all model sections modeled in Trapezoidal Section.

7.2 SKEW EFFECT WITH DIFFERENT PARAMETERS

As literature survey suggest with skew angle geometry of bridge section also affect the result. To understand the effect of different parameters, following parameters are considered for this study: Span Length, No. of Span and No. of Lanes. For Span Length are 25m, 40m and 50m are considered for comparative study. For No. of Span Single Span Bridge, Two Span Bridge and Three Span Bridge are considered with span length of 25m, 50m and 75m respectively. For No. of Lanes 2 Lanes, 3 Lanes and 4 Lanes are considered with single cell box girder, two cell box girder and three cell box girders respectively.

7.2.1 EFFECT OF SPAN LENGTH ON SKEW BRIDGE

To study the effect of span length, three different spans considered 25m, 40m and 50m respectively.

Shear Force

Table 2: Effect of Span Length on Skew Bridge due to Shear Force

Skew Angle	Shear Force(kN)		
	25 m Span	40 m Span	50 m Span
	DL + LL	DL + LL	DL + LL

0°	3397	4895	5898.3
10°	3383	4888	5896.9
20°	3370	4886	5895
30°	3350	4876	5884.5
40°	3330	4869	5873.6
50°	3301	4857	5856.6
60°	3294	4843	5843.5

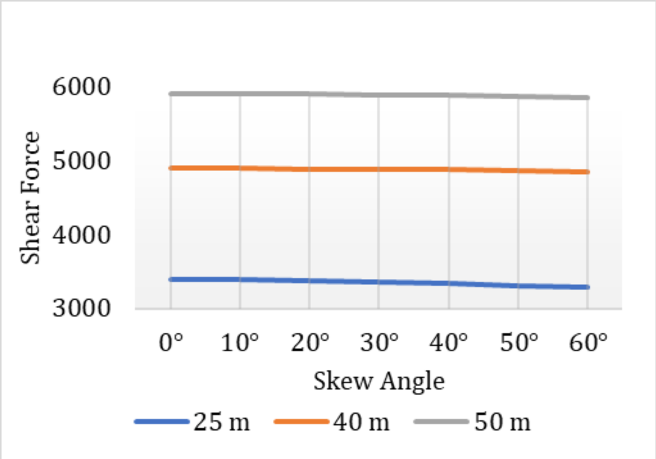

Figure 7: Effect of Span Length on Skew Bridge due to Shear Force

Bending Moment

Table 3: Effect of Span Length on Skew Bridge due to Hogging Bending Moment

Skew Angle	Hogging Bending Moment(kN.m)		
	25 m Span	40 m Span	50 m Span
	DL + LL	DL + LL	DL + LL
0°	4394.61	11705	18024.9
10°	4546.23	11917	18336.1
20°	4755.31	12426	19142.4
30°	5244.84	13623	20940.7
40°	6340.64	15946	24308.2
50°	7678.71	18928	28742.8
60°	9046.62	21981	33419.5

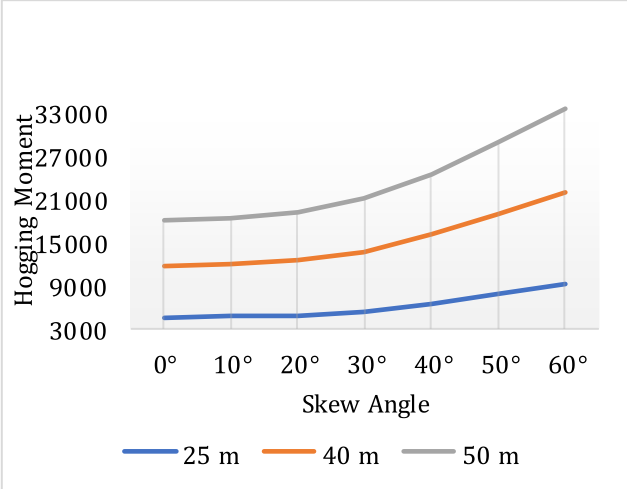

Figure 8: Effect of Span Length on Skew Bridge due to Hogging Bending Moment

Table 4: Effect of Span Length on Skew Bridge due to Sagging Bending Moment

Skew Angle	Sagging Bending Moment(kN.m)		
	25 m Span	40 m Span	50 m Span
	DL + LL	DL + LL	DL + LL
0°	15006	35552	52918.7
10°	14945	35439	52688.9
20°	14777	34998	51915
30°	14317	33838	50117.4
40°	13224	31514	46763.8
50°	11759	28399	42252.2
60°	13561	24815	37079.2

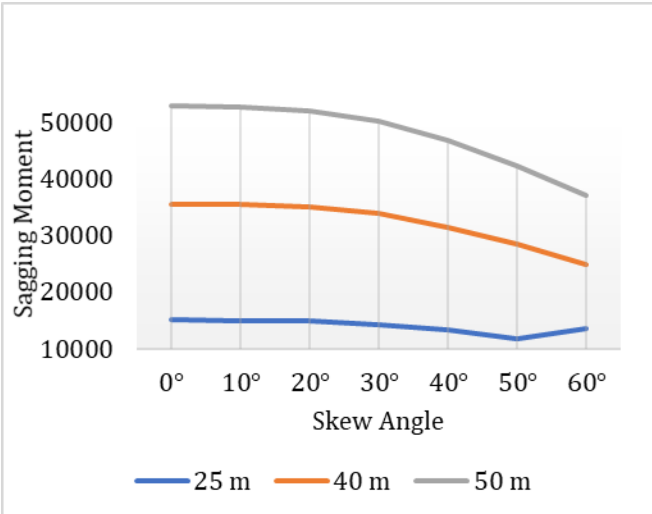

Figure 9: Effect of Span Length on Skew Bridge due to Sagging Bending Moment

Torsion Moment

Table 5: Effect of Span Length on Skew Bridge due to Torsion Moment

Skew Angle	Torsion Moment (kN.m)		
	25 m Span	40 m Span	50 m Span
	DL + LL	DL + LL	DL + LL
0°	1534.57	1738.12	1850.73
10°	2648.17	4137.81	5468.96
20°	3878.21	6915.32	9508.08
30°	5095.68	9571.84	13280.64
40°	6272.4	11847.67	16544.99
50°	7062.27	13247.05	18450.33
60°	4699.25	13477.55	18582.34

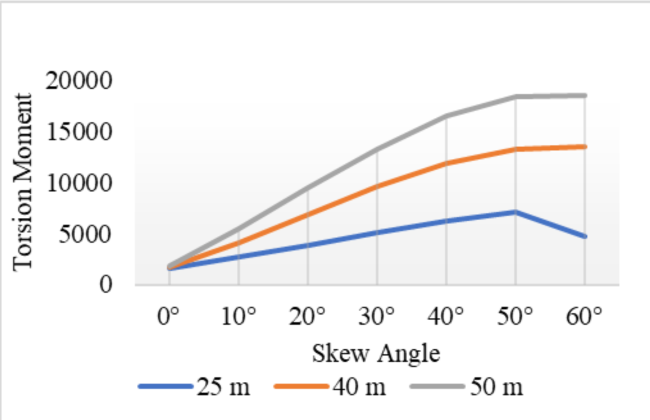

Figure 10: Effect of Span Length on Skew Bridge due to Torsion Moment

Displacement

Table 6: Effect of Span Length on Skew Bridge due to Displacement

Skew Angle	Vertical Displacement in mm		
	25 m Span	40 m Span	50 m Span
0°	4.1721	23.79	55.49
10°	4.1449	23.68	55.19
20°	4.1012	23.30	54.18
30°	3.9745	22.30	51.756
40°	3.6603	20.35	47.18
50°	3.2556	17.75	41.04
60°	2.9886	14.79	34.08

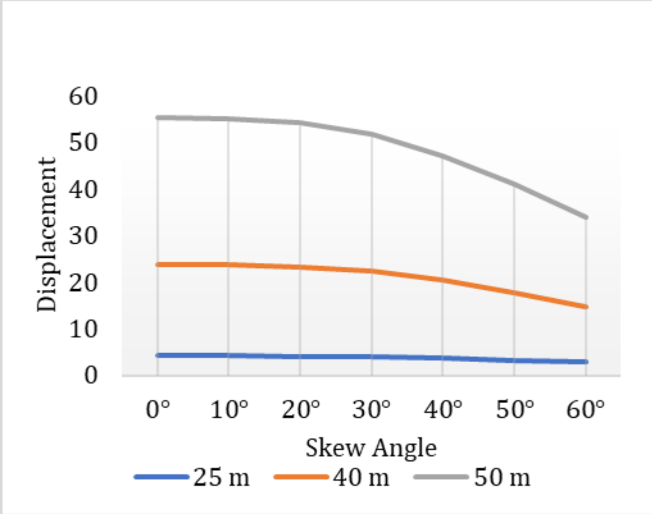

Figure 11: Effect of Span Length on Skew Bridge due to Displacement

As we know shear force decreases as the skew angle increases, but in longer span decrement is less than 1 % where in shorter span it is more than 3 %. Hogging moment increment is more in short span bridge. As observed in the table in 25m span bridge Hogging Moment increases up to 105% as compare to 40m and 50m bridge having almost 87% and 85% respectively, where in sagging moment decrement is less in short span bridge. Torsion moment increases as the skew angle increases, significant increment in longer span. In 25m span bridge it increases maximum in 50° bridge up to 360% as compare to straight bridge, where in other bridges torsion increases in 60° up to 675% and 904% in 40m and 50m respectively. As table suggest in short span vertical displacement is less, also as the skew angle increases displacement decreases.

7.2.2 EFFECT OF NO. OF SPAN ON SKEW BRIDGE

Shear Force

Table 7: Effect of No. of Span on Skew Bridge due to Shear Force

Skew Angle	Shear Force(kN)		
	Single Span	2 Span	3 Span
	DL + LL	DL + LL	DL + LL
0°	3397	3851	3803
10°	3383	3841	3799
20°	3370	3824	3789
30°	3350	3788	3776
40°	3330	3717	3756
50°	3301	3627	3738
60°	3294	3475	3684

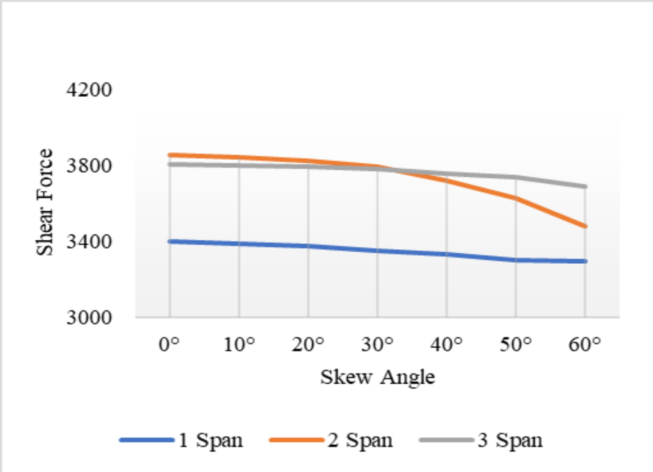

Figure 12: Effect of No. of Span on Skew Bridge due to Shear Force

Bending Moment

Table 8: Effect of No. of Span on Skew Bridge due to Hogging Bending Moment

Skew Angle	Hogging Bending Moment(kN.m)		
	Single Span	2 Span	3 Span
	DL + LL	DL + LL	DL + LL
0°	4394.61	14869	13488
10°	4546.23	15004	13691
20°	4755.31	14990	13931
30°	5244.84	14648	14231
40°	6340.64	13739	14610
50°	7678.71	12340	14774
60°	9046.62	10585	14156

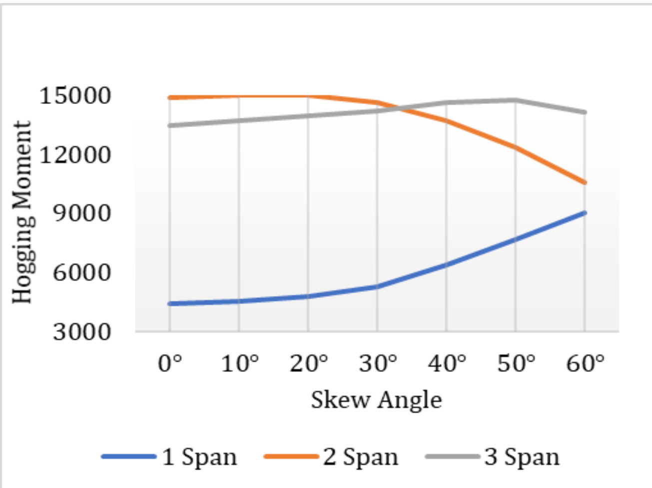

Figure 13: Effect of No. of Span on Skew Bridge due to Hogging Bending Moment

Table 9: Effect of No. of Span on Skew Bridge due to Sagging Bending Moment

Skew Angle	Sagging Bending Moment(kN.m)		
	Single Span	2 Span	3 Span
	DL + LL	DL + LL	DL + LL
0°	15006	12205	12954
10°	14945	12139	12901
20°	14777	12020	12748
30°	14317	11894	12582
40°	13224	11791	12478
50°	11759	11522	12235
60°	13561	14344	15105

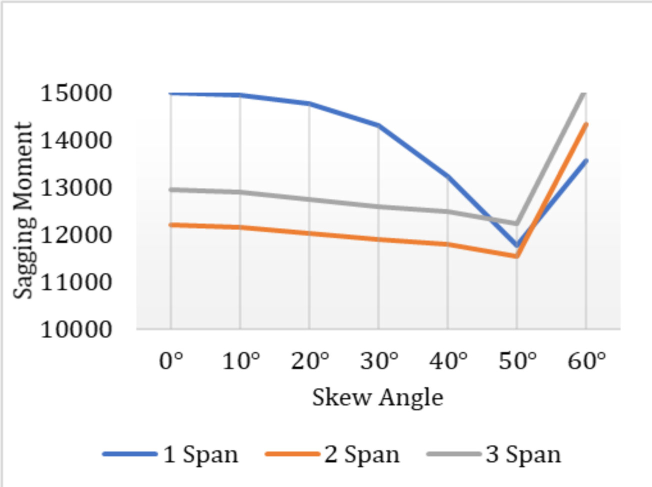

Figure 14: Effect of No. of Span on Skew Bridge due to Sagging Bending Moment

Torsion Moment

Table 10: Effect of No. of Span on Skew Bridge due to Torsion Moment

Skew Angle	Torsion Moment (kN.m)		
	Single Span	2 Span	3 Span
	DL + LL	DL + LL	DL + LL
0°	1534.57	1626.46	1660.74
10°	2648.17	2185.55	2264.72
20°	3878.21	2775.33	2927.33
30°	5095.68	3426.07	3651.69
40°	6272.4	4221.3	4425.29
50°	7062.27	5199.99	5138.05
60°	4699.25	3908.78	3231.3

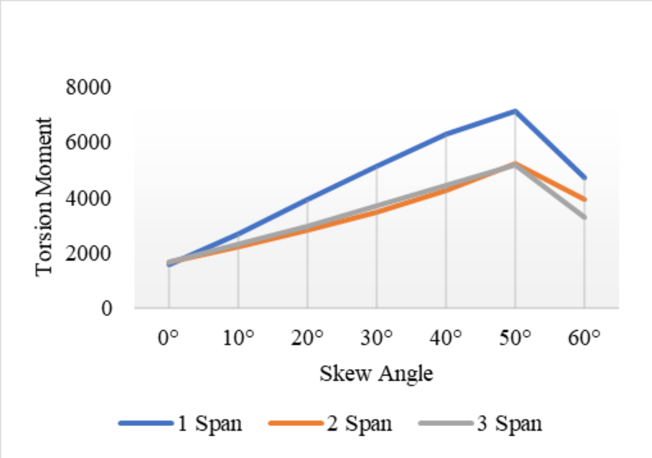

Figure 15: Effect of No. of Span on Skew Bridge due to Torsion Moment

Displacement

Table 11: Effect of No. of Span on Skew Bridge due to Displacement

Skew Angle	Vertical Displacement in mm		
	Single Span	2 Span	3 Span
0°	4.1721	3.1169	3.4506
10°	4.1449	3.0884	3.4279
20°	4.1012	3.0959	3.4141
30°	3.9745	3.1899	3.4774
40°	3.6603	3.4535	3.7180
50°	3.2556	3.7117	3.9787
60°	2.9886	3.9942	4.0812

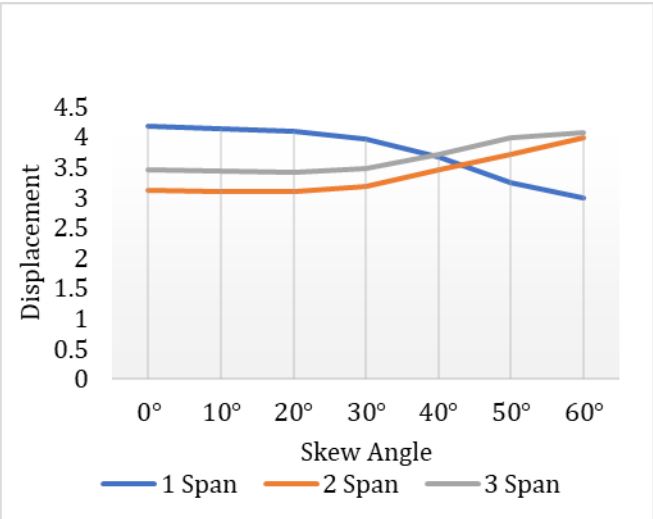

Figure 16: Effect of No. of Span on Skew Bridge due to Displacement

As we know shear force increment is insignificant. Hogging moment Decrement in 2 span bridge, as compare to increment in other bridges. For 2 and 3 span bridge Sagging Moment increases at 60° after reducing till 50°. Torsion moment here increases till 50° as the skew angle increases, but then decreases at 60°. As these bridges are with shorter span vertical displacement is very less.

7.2.3 EFFECT OF NO. OF LANES ON SKEW BRIDGE

Shear Force

Table 12: Effect of No. of Lanes on Skew Bridge due to Shear Force

Skew Angle	Shear Force(kN)		
	2 Lane	3 Lane	4 Lane
	DL + LL	DL + LL	DL + LL
0°	4239	5898.3	7942
10°	4243	5896.9	7944
20°	4240	5895	7936
30°	4246	5884.5	7923
40°	4240	5873.6	7921
50°	4236	5856.6	7907
60°	4223	5843.5	7863

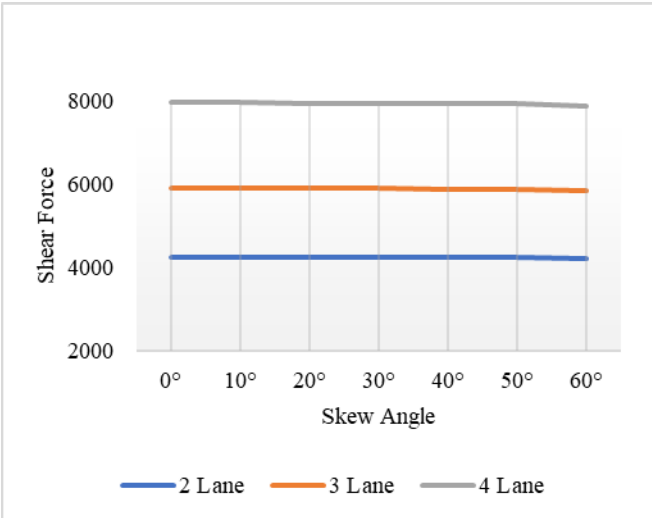

Figure 17: Effect of No. of Lanes on Skew Bridge due to Shear Force

Bending Moment

Table 13: Effect of No. of Lanes on Skew Bridge due to Hogging Bending Moment

Skew Angle	Hogging Bending Moment(kN.m)		
	Single Span	2 Span	3 Span
	DL + LL	DL + LL	DL + LL
0°	13626	18025	9782
10°	13885	18336	11176
20°	14810	19142	14749
30°	15620	20941	20995
40°	17244	24308	30907
50°	20037	28743	38646
60°	23714	33420	42465

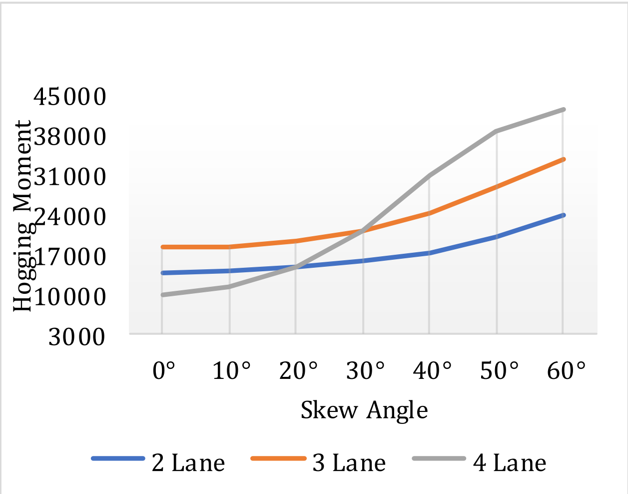

Figure 18: Effect of No. of Lanes on Skew Bridge due to Hogging Bending Moment

Table 14: Effect of No. of Lanes on Skew Bridge due to Sagging Bending Moment

Skew Angle	Sagging Bending Moment(kN.m)		
	Single Span	2 Span	3 Span
	DL + LL	DL + LL	DL + LL
0°	37082	52919	86390
10°	36907	52689	85085
20°	36045	51915	81624
30°	35284	50117	75518
40°	33721	46764	65578
50°	30972	42252	57243
60°	27198	37079	51842

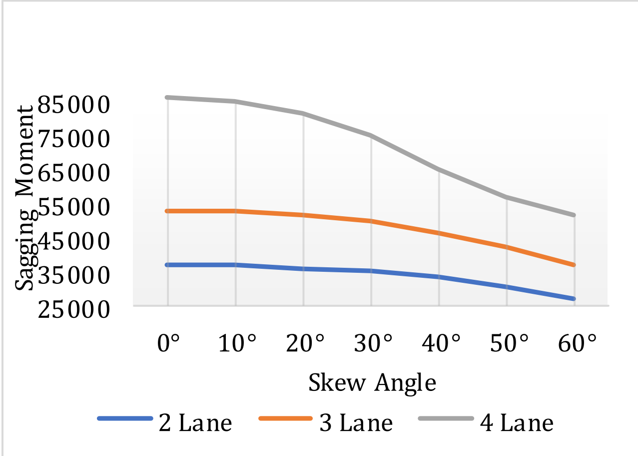

Figure 19: Effect of No. of Lanes on Skew Bridge due to Sagging Bending Moment

Torsion Moment

Table 15: Effect of No. of Lanes on Skew Bridge due to Torsion Moment

Skew Angle	Torsion Moment (kN.m)		
	2 Lane	3 Lane	4 Lane
	DL + LL	DL + LL	DL + LL
0°	1095.4	1850.73	3246.75
10°	3163.1	5468.96	11359.25
20°	5466.8	9508.08	19166.54
30°	7641.36	13280.64	25746.26
40°	9794.69	16544.99	28299.23
50°	11502.15	18450.33	29312.97
60°	12304.97	18582.34	29720.76

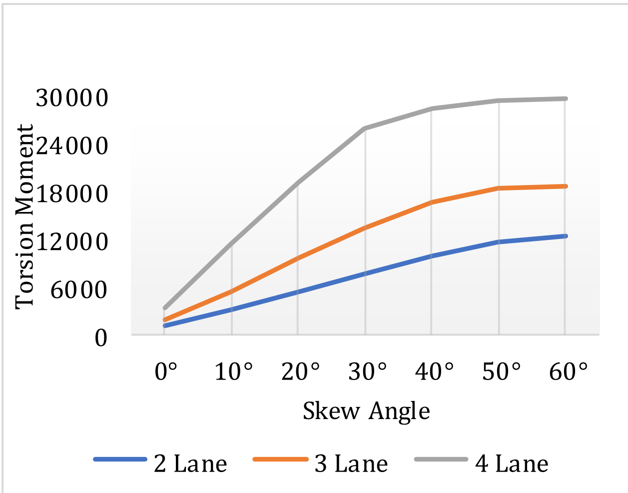

Figure 20: Effect of No. of Lanes on Skew Bridge due to Torsion Moment

Displacement

Table 16: Effect of No. of Lanes on Skew Bridge due to Displacement

Skew Angle	Vertical Displacement in mm		
	2 Lane	3 Lane	4 Lane
0°	59.12	55.49	66.20
10°	58.8	55.19	64.95
20°	56.97	54.18	61.72
30°	55.5	51.75	55.74
40°	52.3	47.18	46.46
50°	46.6	41.04	38.74
60°	38.7	34.08	34.07

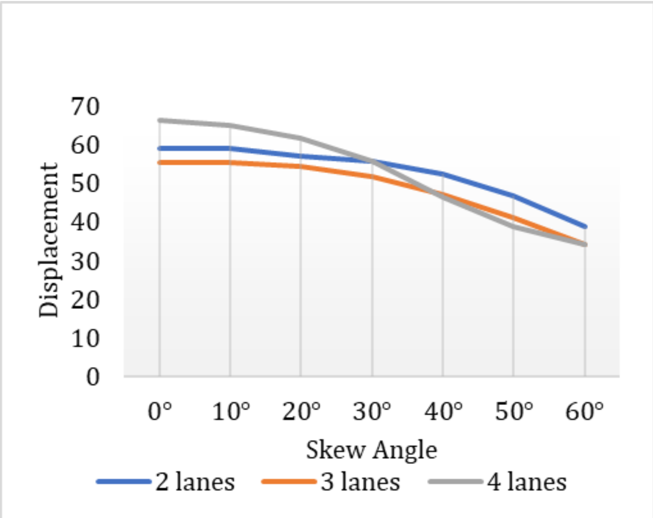

Figure 21: Effect of No. of Lanes on Skew Bridge due to Displacement

Shear force remains insignificant as the skew angle increases. Sagging moment is decreases as the skew angle increases, where hogging moment increment in 4 lane bridge is significantly more as compare to others. Torsion moment increment in 2 lane bridge is more than the 4-lane bridge. As these bridges having longer span, vertical displacement is more.

8.CONCLUSIONS

The effect on bridge of Dead Load and Live Load i.e. IRC Class A vehicle loading are different for skewed bridge. In the present study on the basis of different parameters following conclusions are drawn:

- A literature review was completed in this study to summarize the behaviour of skew bridges, analysis and research. The study is mainly focused on the bending moment, shear force and Torsion analysis in skew bridges.
- As study suggested, three-dimensional finite element analysis by CSi Bridge v22 is suitable for assessing the behaviour of skew bridges.
- Trapezoidal box girder section is more efficient than the rectangular box girder section.
- Bridges with skew angle lower than 20° are simple enough to design by few adjustments as the right-angle bridge, because skewness of bridge affects insignificantly for 10° and 20° bridges, but for bridges with high skew angle a careful in-depth analysis is needed.
- Insignificant reduction in shear force occur as the skew angle increases i.e., as we observed from 0° to 60° shear force decreases continuously.
- Hogging bending moment increase and sagging moment decrease with increasing in skew angle for all types of bridges and in all load case which consider in study.
- Hogging Bending Moment increment is more in short span, single span and in 4 lane bridges. Sagging Bending Moment decrement is less in short span bridge, more in 4 lane bridge and in 2 & 3 span bridge sagging moment suddenly increases at 60°.
- While designing skew bridges, torsion moment should be considered as a major factor, as observed in all parameters and in all section's torsion moment increases immensely as compared to bending moment and shear force as the skew angle increases. Torsion moment increment is more in 2 lane bridge than 4 lane bridge.
- As observed in all cases maximum vertical displacement is more in right angle bridge than the skewed bridge. Also, displacement is less in short span.
- As observed Span Length, No. of Span and No. of Lanes affect significantly in skew bridges.

9. SCOPE FOR FURTHER STUDY

- In the present work only bridge deck is considered, for further research study regarding bearings, bents, piers and others structural components may be considered.
- As we observed short span bridge of box girder showing variation in ratios, study for suitable type of bridge may considered.
- In the present work Dead and Moving Loading is considered, for further research study regarding

seismic behaviour or different IRC vehicle loading on skew bridges may be consider.

- A detailed economic analysis of different skew section bridges may be considered to find out necessary of bridge type to construct.

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