Analysis of Integrated Skew Bridge for Seismic Loading

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Abstract— Bridges are the structures which are built over road, railway, etc for the purpose of providing passage over the obstacles. Bridges undergo expansion and contraction due to temperature changes which is the major concern. Here durability is the major design consideration. Routine inspection and maintenance is required. Bridges are classified based on material of construction, Function, form of superstructure, inter span relation, method of construction, span and type of service and duration of use. Integral bridges are built monolithically as one structure. They are also called as skew angled; integral abutment bridges, rigid frame bridges and joint less bridge. In integral bridges abutments are constructed integral with deck and girder. These bridges have no expansion joints and sliding bearings. As integral bridges provide greater redundancy they will be stiffer compared to the conventional bridges. The behaviour of 25m single span skew angled integral bridge is investigated with varying skew angle from 0 to 60 degree with0interval of 150degree Comparison between various loads like dead load, moving loads seismic loads by considering Zone II and loads combination like and UDICON (referring to IRC-6) for Bending moments, Time period and Base Shear. IRC class AA Vehicular load is considered for the study. From the results obtained we can conclude that the bending moment at mid and end span will be maximum for the bridge skewed for 60 degree angle.

Keywords: Skew Bridge, Seismic Loading, Loads and Load Combinations

I. INTRODUCTION

A. General

Roads are lifeline for the modern transport and bridges are an integral part of it. Bridges are the structures which are built over road, railway, etc for the perseverance of provided that road over the obstacles. Bridges undergo increase and reduction due to heat changes which is the major concern. Here durability is the major design consideration.

Bridges were existed since Paleolithic period and Stone Age. In 100B.C, 2104 years ago Romans constructed the arch bridge where arch design provides even distribution of stress and natural concrete was made of mud and straw. In 700 A.D, 1304 years ago in china great stone bridge which is low bridge, shallow arch, and allows boats and water to pass through it. In 1900, truss bridges were constructed using wood considering mechanics of design. In 1920, suspension bridges were constructed using steel in suspending cable. In 2000, prestressed concrete were constructed.

B. Skew Integral Bridge

Integral bridges are built monolithically as one structure. They are also called as skew angled; integral abutment bridges, rigid frame bridges and joint less bridge. In integral bridges abutments are constructed integral with deck and girder. These bridges have no expansion joints and sliding bearings. As integral bridges provide greater redundancy they will be stiffer compared to the conventional bridges. Integral bridges are economical as compared to regular jointed frames. Skew integral bridge systems are common in highways, River crossings and for extreme grade changes when skewed geometry is necessary with limitations in space. The demand for skew bridges is growing due to need of complex intersections and problems with space limitations in urban areas. If a road alignment crosses a river or any other obstructions at an inclination angle other than 90^0, then the skew bridge construction may be necessary. Design and analysis for skew angled bridges are complicated to right angled bridges. The skew angle has a considerable effect on behavior of the bridge. As in case of solid slab skew bridge the load path tends to drop off from supports to obtuse corners. This kind of behavior results in the coupling of transverse and longitudinal response at one of the obtuse corner.

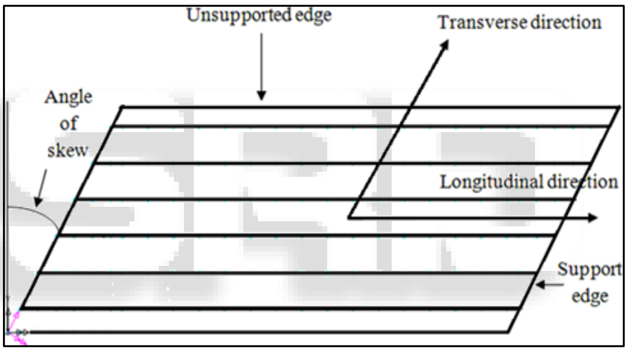

Fig. 1.1: plan of skew angle

C. History of Skew Integral Bridge

The use of integral abutments to tie bridge superstructure to foundation piling started in United States many years ago. This type of construction is growing steadily popular. Today most of the state highway agencies have developed design criteria for bridges without expansion joints. First integral bridge was built in United States in the year 1938. In mid-1960's construction of continuous bridges with integral abutments was favourable construction practice in many states of United States.

D. Types of Integral Bridge System

- Fully integral bridge system.
- Semi integral bridge system.
- Seamless bridges.

Fully integral bridge system is the bridge structure where the superstructure (beams and deck) and substructure (abutments) are connected directly. The superstructure and substructure of the bridge move together into and away from backfill during thermal contraction and expansion. And there are no bearings and expansion joint devices. They can be multi span continuous structures with intermediate piers.

Semi integral bridges are multiple span or single span structures with rigid foundation. In these bridges, the concrete deck is continuous with the approach slabs. At the end of the Decks, the expansion joints are eliminated thus there is no continuity between the superstructure and the abutments. As to allow the horizontal movement between the abutments and deck, conventional bearings are provided. Control joints are provided at the end of the approach slabs are detailed to slide in between the wing walls. Due to economy, durability, performance and simplicity of the integral bridge system in recent years is leading to growing interest in semi integral bridge system.

The bridge length, part of adjoining roadways and approach slab. In these bridges system, the bridge movements are dispersed in transition zone at bridge ends after the abutments. The thermal tensile forces are managed by closing and opening of micro cracks and the thermal compression forces transfers to base soil. In design of seamless bridge system, spacing and crack width are the important parameters. In the seamless bridge system, the top slab is in the transition zone and the secondary slab is few feet deep in the base soil. Hence these two slabs are connected via small piles.

E. Skew Angle

Skew angle is the angle between centerline of the bridge and abutments are not perpendicular to each other. As the skew angle increases the stresses in slab differs significantly as compared to the straight slab. A load on the slab passes to the support in proportion to rigidity of the possible paths. Hence most of the applied load tends to reach the support in a direction of normal line to the faces of the piers and abutments. Thus the maximum stress planes are non-parallel to the center line of bridge and slab tends to get twisted. Obtuse angled end of slab support has larger reaction than the other end of the slab support i.e. the reaction of obtuse angle end of slab support becomes twice the average reaction.

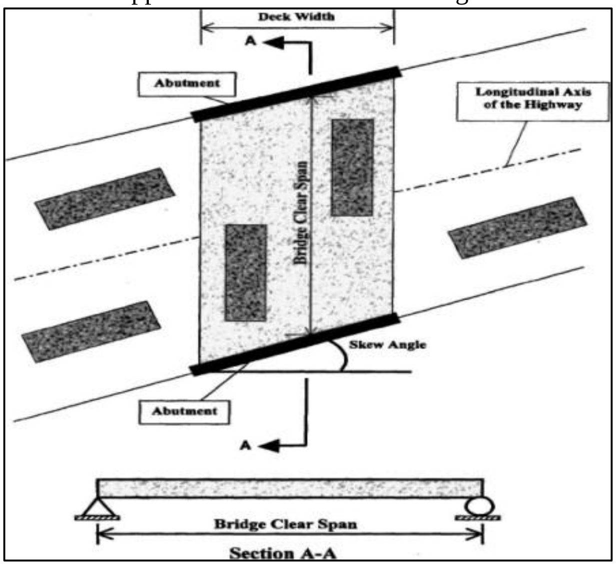

Fig. 1.4: skew angle

F. Objectives

– The behavior of 25m single span skew angled integral bridge is investigated with varying skew angle from 0 to 60 degree with interval of 15 degree.
– Comparison between various loads like dead load, moving loads seismic loads by considering Zone II and loads combination like and UDICON (referring to IRC-6) for Bending moments, Time period and Base Shear.

II. METHODOLOGY

SAP2000 is integrated software for structural analysis and design. In this software complex models are meshed and generated with powerful built in templates like simple beams, storage vessels, 3D truss, different types of bridge structures, pipes and dam structures.

Procedure involved in modeling of skew integral bridges is as follows:

– Modeling and analysis of skew integral bridges is done using SAP2000-
– Finite element analysis software. Totally five models are modeled with skew angle ranging from 0^o to 60^o with varying interval of 15^o.
– Here the girder is modeled as a Deep beam and the Pier is modeled as Compression Member.
– Transverse and longitudinal girders are modeled using grillage method i.e in this method the deck slab is represented by an equivalent grillage of beams which provides more accuracy in results.
– The support condition considered in this present study is hinged support.
– The material and sectional properties are specified and assigned to frame and area elements respectively.
– Vehicles, vehicle classes are defined and assigned as per IRC-6 2014 and suitable lane dimensions are defined.
– Loads and load combinations are defined and assigned as per IRC-6 2014.

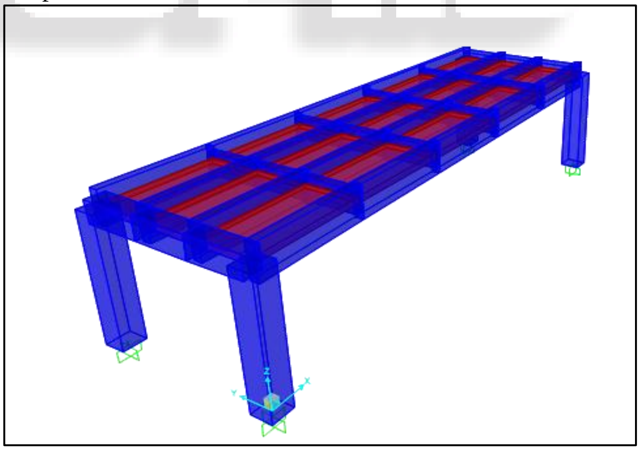

Fig. 3.1: Three-dimensional model skew integral bridge in SAP2000

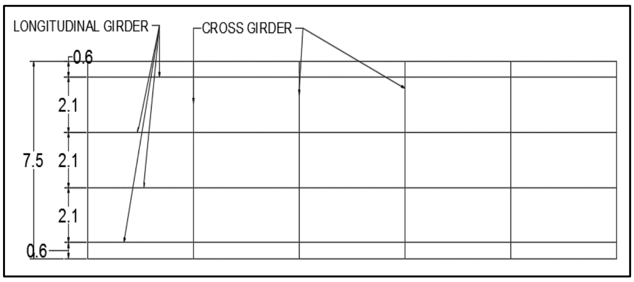

Fig. 3.2: Plan view of 0^0 skew integral bridge

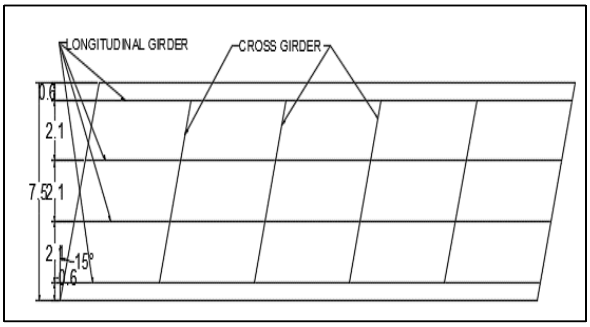

Fig. 3.3: Plan view of 15^0 skew integral bridge

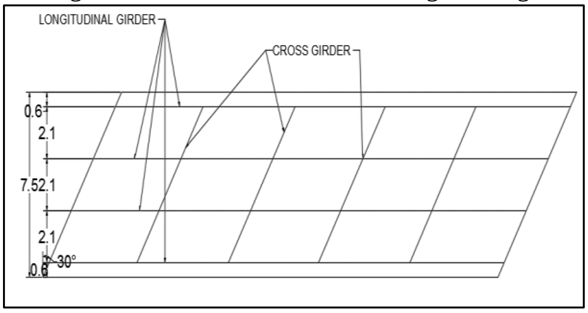

Fig. 3.4: Plan view of 30^0 skew integral bridge

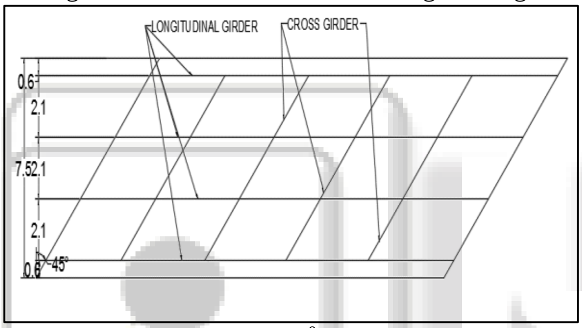

Fig. 3.5: Plan view of 45^0 skew integral bridge

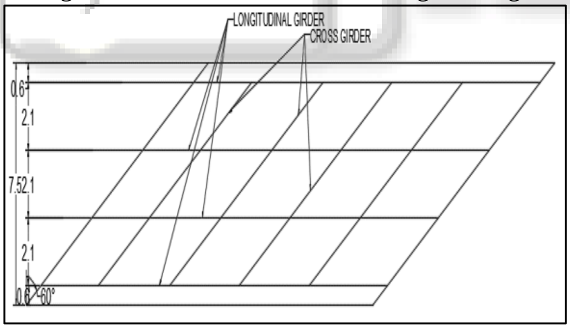

Fig. 3.6: Plan view of 60^0 skew integral bridge

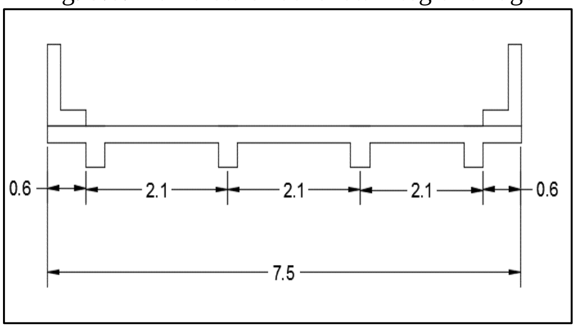

Fig. 3.7: Cross Sectional view of skew integral bridge

III. Loads and Load Combinations

A. Dead Load:

Dead loads are the permanent loads acting on the structure. These are the loads which are transferred throughout the lifespan of structure. The dead load carried by a girder or member shall consist of the portion of the weight of the superstructure which is supported wholly, the girder including its own weight and superimposed load of footpaths, wearing coat. The values of dead loads are considered according to Indian standard codes i.e. IS 875 (PART-1).

B. Live Load:

Live loads applied on bridge are vehicle loads which includes brake load and impact load as per IRC 6 2014. As specified in IRC 6 Table 2-live load combination, for carriage width more than 5.3m and more than 9.6m one lane of class 70R or two lanes of class A TR can be considered.. Class 70R loading can be adopted for all roads where permanent bridges and culverts are constructed. But bridges designed for this loading should also be checked for class A loading under certain conditions such as heavier stresses that may occur under class A loading.

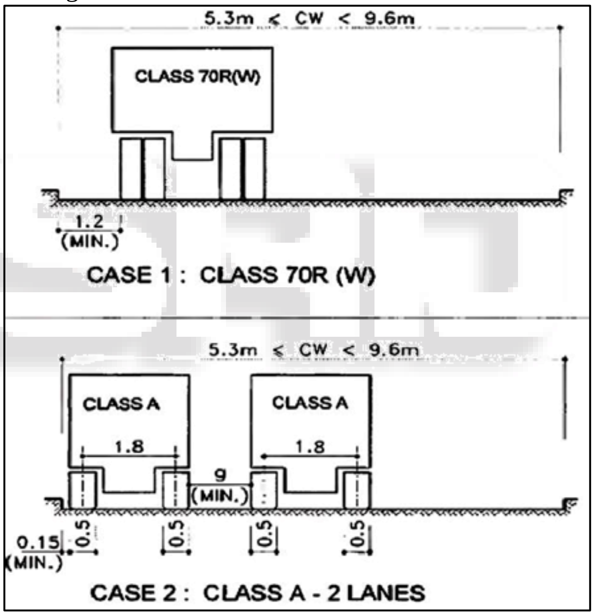

Fig. 3.8: Live Load combination as per IRC 6 2014 code

For span lengths more than 9m for RCC structures the impact load of 10% increment of the live load as per IRC 6 clause 208.

Pedestrian load is considered referring to IRC 6 206, for spans of 30m and above below formula is used to calculate the pedestrian load. The load is applied due to pedestrian traffic should be treated to uniformly distributed over the pathway.

The live load on footpath for designing main girder should be taken as, for span length of more than 7.5m and not exceeding 30m, the intensity of load is reduced from 4.25 KN/m^2 to 3 $KN/m^{2.}$

S.No	Carriageway Width (CW)	Number of Lanes for Design Purposes	Load Combination (Refer Table 6A for diagrammatic representation)
1)	Less than 5.3 m	1	One lane of Class A considered to occupy 2.3 m. The remaining width of carriageway shall be loaded with 500 kg/m^2
2)	5.3 m and above but less than 9.6 m	2	One lane of Class 70R OR two lanes for Class A
3)	9.6 m and above but less than 13.1 m	3	One lane of Class 70R for every two lanes with one lanes of Class A on the remaining lane OR 3 lanes of Class A
4)	13.1 m and above but less than 16.6 m	4	One lane of Class 70R for every two lanes with one lane of Class A for the remaining lanes, if any, OR one lane of Class A for each lane.
5)	16.6 m and above but less than 20.1 m	5	
6)	20.1 m and above but less than 23.6 m	6	

Fig. 3.9: Live load combination.

C. Seismic loading

The response spectrum method has been used for obtaining forces and moments induced due to earthquakes.

The other data considered in the analysis

Importance factor I = 1.

Response reduction factor R = 5.

Soil type - I (hard soil)

Zone factor – zone II = 0.10.

D. Load Combination

Stresses for design can be calculated for several combinations of loads. Load combinations are considered according to IRC 6-2014.

LOAD COMBINATION	LOAD CASE TYPE	LOAD
UDICON 1	Linear static	1.5DL
UDICON 2	Linear static	1.2(DL+EQX)
UDICON 3	Linear static	1.2(DL-EQX)
UDICON 4	Linear static	1.2(DL+EQY)
UDICON 5	Linear static	1.2(DL-EQY)
UDICON 6	Linear static	1.5(DL+EQX)
UDICON 7	Linear static	1.5(DL-EQX)
UDICON 8	Linear static	1.5(DL+EQY)
UDICON 9	Linear static	1.5(DL-EQY)
UDICON 10	Linear static	0.9DL+1.2EQX
UDICON 11	Linear static	0.9DL-1.2EQX
UDICON 12	Linear static	0.9DL+1.2EQY
UDICON 13	Linear static	0.9DL-1.2EQY

IV. RESULTS AND DISCUSSIONS

A study on integral bridge with varying skew angles ranging from 0º to 60º with an interval of 15º is carried out for bending moment, Time period and Base shear variations for load cases such as dead load and vehicle load i.e. class 70R or class AA.

BENDING MOMENT FOR DEAD LOAD				
SKEW	GIRDER 1	GIRDER 2	GIRDER 3	GIRDER 4
0	496	463	463	496
15	488	457	457	488
30	502	492	492	502
45	626	576	576	626
60	756	711	711	756

Table 4.1: Mid span bending moment for dead load

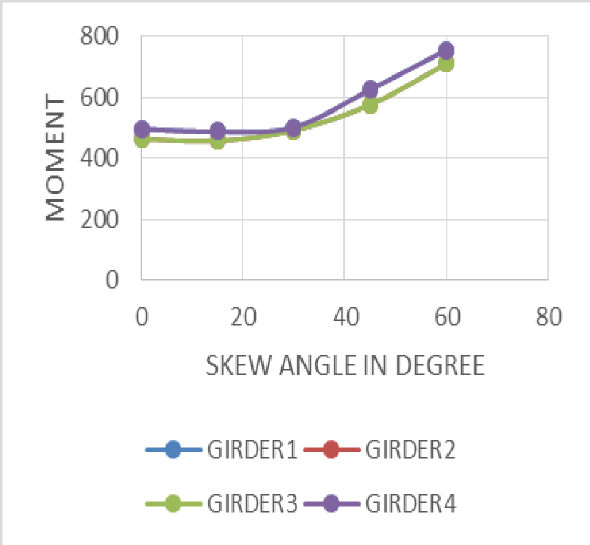

Fig. 4.1: Moment v/s skew angle.

BENDING MOMENT FOR VEHICLE LOAD				
SKEW	GIRDER 1	GIRDER 2	GIRDER 3	GIRDER 4
0	333.13	277.01	283.09	328.94
15	360.87	292.39	293.06	352.44
30	368.97	293.06	297.07	366.59
45	392.02	310.91	313.01	388.22
60	393.98	315.96	314.73	393.98

Table 4.2: Mid span bending moment for vehicle load.

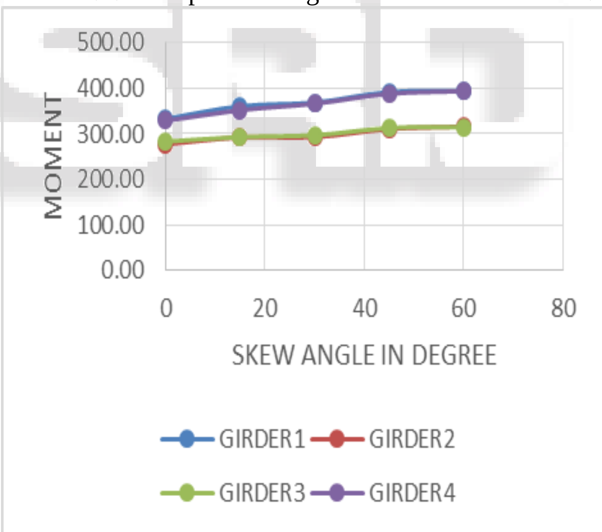

Fig. 4.2: Moment v/s skew angle.

BENDING MOMENT FOR UDCON				
SKEW	GIRDER 1	GIRDER 2	GIRDER 3	GIRDER 4
0	742	693	693	742
15	727	686	686	727
30	730	686	686	730
45	790	757	757	790
60	1058	853	853	1058

Table 4.3: Mid span bending moment for UDCON.

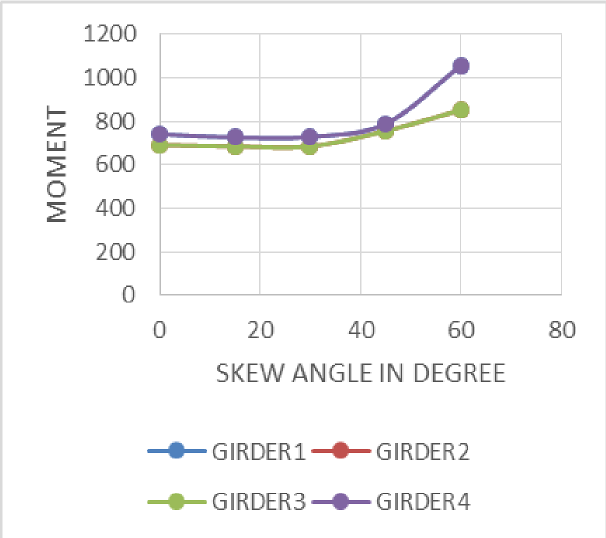

Fig. 4.3: Moment v/s skew angle.

BENDING MOMENT FOR MODAL LOAD				
SKEW	GIRDER 1	GIRDER 2	GIRDER 3	GIRDER 4
0	2193	2067	2067	2193
15	2214	2060	2060	2214
30	2205	2086	2086	2205
45	2279	2086	2086	2279
60	2496	2086	2086	2496

Table 4.4: Mid span bending moment for Modal load.

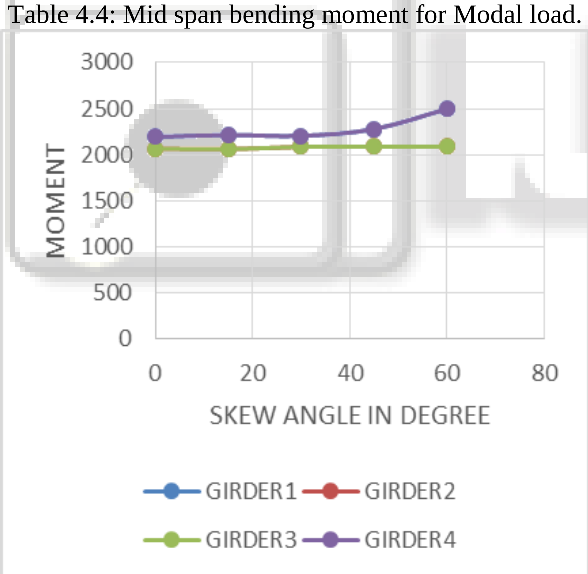

Fig. 4.4: Moment v/s skew angle.

BENDING MOMENT FOR DEAD LOAD AT ENDS				
SKEW	GIRDER 1	GIRDER 2	GIRDER 3	GIRDER 4
0	-1033	-129	-129	-1033
15	-984	-129	-129	-984
30	-984	-129	-129	-984
45	-907	-142	-142	-907
60	-396	-416	-416	-396

Table 4.5: Bending Moment at end span for dead load.

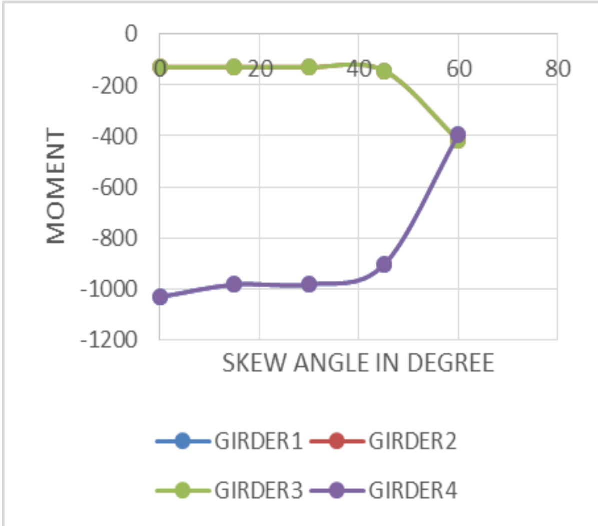

Fig. 4.5: Moment v/s skew angle.

BENDING MOMENT FOR VEHICLE LOAD AT ENDS				
SKEW	GIRDER 1	GIRDER 2	GIRDER 3	GIRDER 4
0	-189	-157	-157	-189
15	-218	-187	-187	-218
30	-245	-198	-198	-245
45	-264	-238	-238	-264
60	-231	-273	-273	-231

Table 4.6: Bending Moment at end span for Vehicle load.

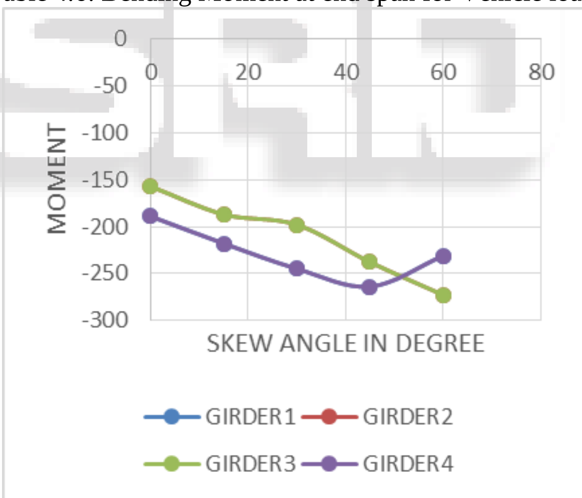

Fig. 4.6: Moment v/s skew angle.

BENDING MOMENT FOR UDCON AT ENDS				
SKEW	GIRDER 1	GIRDER 2	GIRDER 3	GIRDER 4
0	-1550	-194	-194	-1550
15	-1477	-194	-194	-1477
30	-1414	-186	-186	-1414
45	-1360	-213	-213	-1360
60	-594	-122	-122	-594

Table 4.7: Bending Moment at end span for UDCON load.

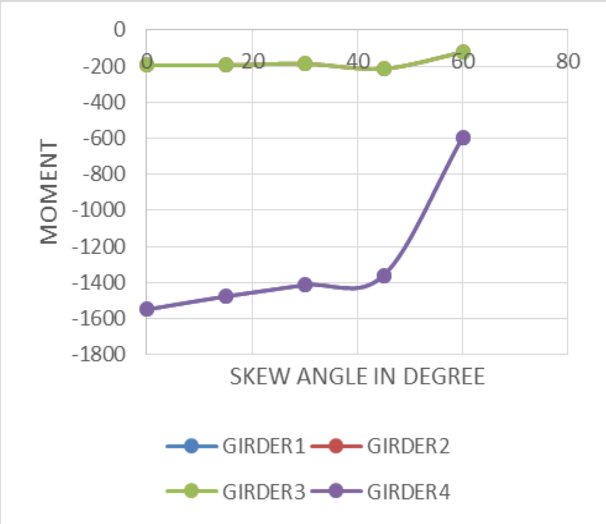

Fig. 4.7: Moment v/s skew angle.

A. *Time Period*

A system is said to be vibrating in a normal mode when all its masses attain maximum values of displacements and rotations simultaneously, and pass through equilibrium positions simultaneously.

Modal Periods					
MODAL	0 DEGREE	15 DEGREE	30 DEGREE	45 DEGREE	60 DEGREE
1	0.336	0.339	0.339	0.347	7.504
2	0.303	0.301	0.301	0.295	4.857
3	0.269	0.265	0.265	0.253	1.716
4	0.203	0.203	0.203	0.204	0.428
5	0.199	0.197	0.197	0.189	0.220
6	0.164	0.164	0.164	0.163	0.212
7	0.132	0.132	0.132	0.132	0.135
8	0.106	0.105	0.105	0.103	0.122
9	0.095	0.095	0.095	0.095	0.097
10	0.081	0.081	0.081	0.079	0.096
11	0.079	0.079	0.079	0.079	0.084
12	0.059	0.059	0.059	0.057	0.079

Table 4.9: Modal time period for all skew bridges.

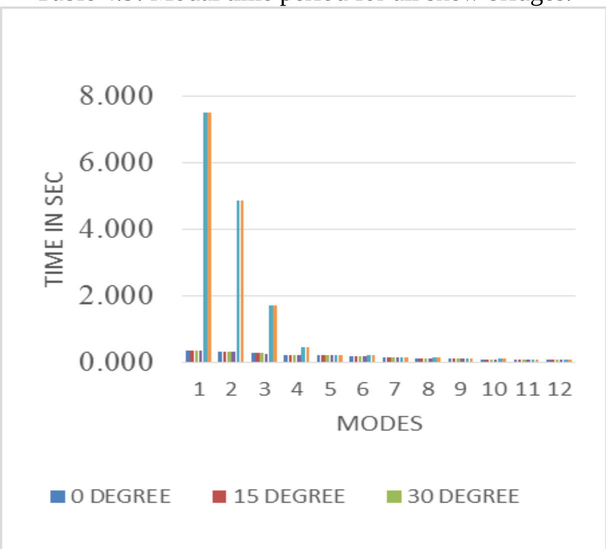

Fig. 4.9: Plot mode v/s time period.

B. *Base Shear*

Base shear is an estimate of the maximum expected lateral force on the base of the structure due to seismic activity.

Base Shear					
LOADS	0 DEGREE	15 DEGREE	30 DEGREE	45 DEGREE	60 DEGREE
DEAD	4247.68	3756.295	3151.851	2483.714	2691.143
EQX	-148.041	-132.426	-132.426	12.667	-87.008
EQY	-148.041	-132.426	-132.426	-12.667	-87.008
UDCON1(1.5*DL)	6371.52	5634.442	4727.776	3725.571	4036.714
UDCON4(1.2*(DL+EQX))	5097.216	4507.554	3782.221	2980.457	3229.371
UDCON10(0.9DL+1.2EQX)	3822.912	3380.665	2836.665	2235.343	2422.028

Table 4.10: Base shear for all skew bridges.

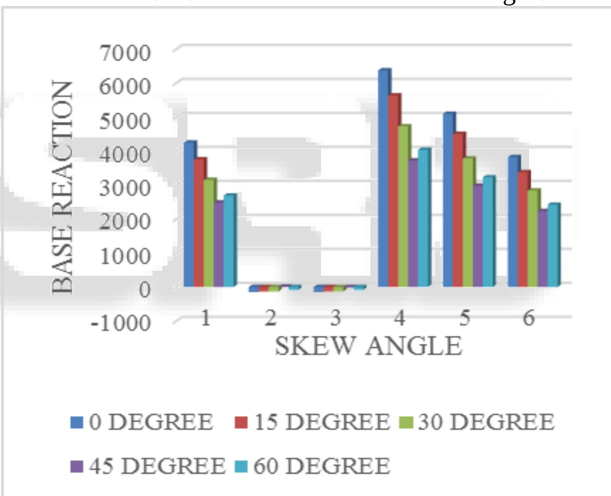

Fig. 4.10: Moment v/s skew angle.

V. Conclusion

Based on the results of the project done, the following conclusion may be drawn:

1) Conventional 1D girder and 2D gird methods of analysis are capable of predicting accurate construction responses in many situations, however, there are definite bridge geometries where significant reductions inaccuracy can be expected.
2) As in present day traffic situations in many areas of India, construction of skew integral bridges cater high speed and efficient traffic movements and are explored more than even before. Thus in some cases of construction, providing skew angle to the bridges become necessary thus taking into account of the variation in parameters such as bending moments, torsion, Base shear and Considering Seismic analysis with respect to varying

skew angle in correctly designing of bridges with skew becomes important.

3) In the present study IRC Class AA/70R Vehicle is considered, because of its maximum load we can take from the codal provisions to find the bending moment and shear at mid and end spans of the bridge.
4) Varying the angles we can see that increase in moments at mid span, for 0 degree 496KN and 756 for 60 degree for Dead load.
5) Varying the angles we can observe that increase in moments at mid span, for 0 degree 333 KN and 393 for 60 degree for Vehicle load.
6) For varying angles we can observe that increase in moments at mid span, for 0 degree 742 KN and 1058 for 60 degree for Load combination.
7) Similarly for the end moment reactions for the longitudinal girder we can observe that the moments are more for the varying the angles.
8) For seismic evaluation we can see that modal the model time period obtained is within the limits i.e., for 0 degree 0.336 and for 60 degree 7.504.
9) Similarly base shear results are considered for the evaluation of the structure here we can observe that increase in the angle decreases in the base shear for 0 degree 4247.68 and for 60 degree 2691.14 KN.

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