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Seismic Response of Skew Bridges

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ABSTRACT

The majority of bridge decks that are made now days are usually some skew or arched. Tight geometry is usually placed on main road structures as a result of right of way restrictions in congested urban areas. If a road alignment crosses a stream or the other obstruction at an inclination totally different from 90°,a skew crossing is also necessary. Skew bridges are one of the most economical and satisfying construction in such conditions. Additionally skew bridges are common at main road interchange, stream crossing and alternative extreme grade changes wherever skew geometry is important as a result of space limitations.

In truthful which means, the plan of bridge might seem like parallelogram in plain view. This condition happens once bridge alignment isn't actual perpendicular or creating some angle to crossing. The term angle of skew or skew angle is mostly applied to the difference between alignments of an intermediate or end support and a line square to the longitudinal axis of the bridge above. Thus, on straight bridge, the skew angle at all supports would ordinarily be the same and also the term skew angle can be applied to the bridge as a whole. The simple type of bridge is right deck however demand of skew bridge is increasing because of various factors.

1. INTRODUCTION

An inclined bridge is one in which axis of substructure isn't perpendicular to longitudinal axis of construction. Skew in a bridge may result from several factors, as well as manmade and natural factors, complex intersection, house limitations, and mountainous terrain. Conventionally the skew angle isn't considered in style as a parameter that may differentiate the structural behaviour from straight counterparts (zero skew angle bridges).

For a very long time, inclined bridges are analysed, designed and constructed within the same manner as straight bridges regardless of magnitude of the skew angle. many style factors were treated constant manner for inclined and straight bridges, that results in failure of bridge structure. once inclined bridges are subjected to seismic activity, they cause a different downside. However, the force flow in skew bridges is much a lot of difficult than in right-angle bridges. Analytical calculations alone don't give sufficient accuracy for structural design. hence numerical analysis must be performed, in which a skew bridge can be modelled in many ways that with different degrees of sophistication.

In right-angle bridges the load path goes straight towards the support in the direction of thespan. In skew bridges this is often not the case. For a solid slab skew bridge the load tends to require ashort cut to the obtuse corners of the bridge as shown in Figure 1-1. In bridge decks supportedby longitudinal girders this impact happens too, although less pronounced. this variation in direction of the load path in terribly skew bridges brings about the following special characteristics.

a)Significant tensional moments in the deck slab
b) Decrease in longitudinal moment
c) Increase in transversal moment
d)Concentration of reaction forces and negative moments at the obtuse corners
e) Small reactions and a chance of uplift reaction forces at the acute corners

Although many advances have been made to study the performances of straight bridges during a seismic activity, significant uncertainty remains with regards to the seismic performance of skewed bridges. Skewed bridges pose a different problem during seismic activity. As stated in the previous section, it's difficult to establish the principal axes for skewed bridges as vibration modes of translation don't lie along longitudinal and transverse directions of the bridge.

In spite of having large number of experiences from past earthquake failures, which gives the importance of this mechanism, as well as the empirical vulnerability methodologies that acknowledge skew as a primary vulnerability factor in bridges, there are only few attempts to Comprehend this mechanism.

1.1 Objectives

The project study covers the following objectives:-
1.To Study the effect of skewness on bridge structure on various spans ranging from small to medium spans.
2.To Study the seismic response of straight and skew bridges with comparison of results.
3.To explore IRC 6:2014 (Clause no. 219.1.1) for wider range of application referring to skew.

2. SUMMARY

Based on literature it has been observed that, the experimental investigations have shown that there is uplift at acute angled corners and significant tensional moments at obtuse corners. Many researchers have considered two types of skew, one is length wise skew and another one is width wise skew. Also in length wise skew, researchers have considered two types, i.e. skew span constant and clear span constant.

The use of the rigid deck or stick model is not recommended for the dynamic analysis of skew bridges with large skew angles

3. METHODOLOGY

3.1 General

This chapter covers a three-D model of bridge using the SAP2000v14 subjected to Response spectrum analysis with skew angles variable from 0 to 50 degrees, within which the reinforced concrete deck slab is taken into account for varied types of bridges.
Types of bridge that area unit modelled as,
1. Simply supported deck slab bridges of spans 5m, 7.5m, 10m, 12.5m, 15m and 18m.
2. Continuous deck block bridge of varied lengths and spans 5m span-11numbers, 7.5m span-8numbers, 10m span-5numbers, 12.5 m span- 4 numbers, 15m span-3numbers and 18m span-4number.The bearing conditions for every combination are considered differently.
3. Integral deck slab bridge monolithic with pier of 15m span-3numbers and 20m span-3 numbers.

The response spectrum method has been used for obtaining forces and moments induced due to earthquakes.
Uncoupled modal response has been combined using SRSS method of combinations.
The other data considered in the analysis
Importance factor I = 1
Response reduction factor R = 5
Soil type - I (hard soil)
Zone factor – zone III = 0.16

The various skew angles used in the analysis of all bridges (simply supported, continuous and integral) are 0, 10, 20, 30, 45 and 50 degrees.
The type plans prepared by PWD, Maharashtra are used for simply supported bridges of span 5m, 10m. 12.5m, 15m and 18m simply supported span are designed according to IRC codal provisions.
Continuous and integral bridges are designed appropriately according to codal provisions.
Vehicles considered are IRC 70R (1 lane) and class A (2 lane)

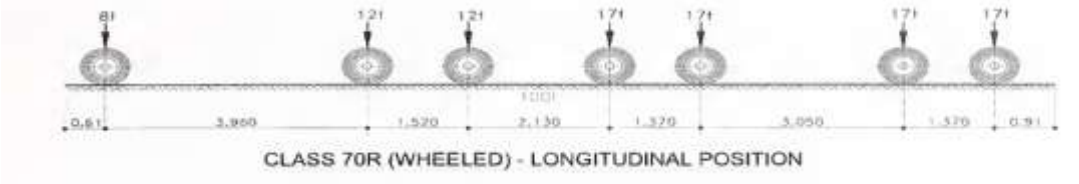


Figure 0-1 IRC class 70R vehicle

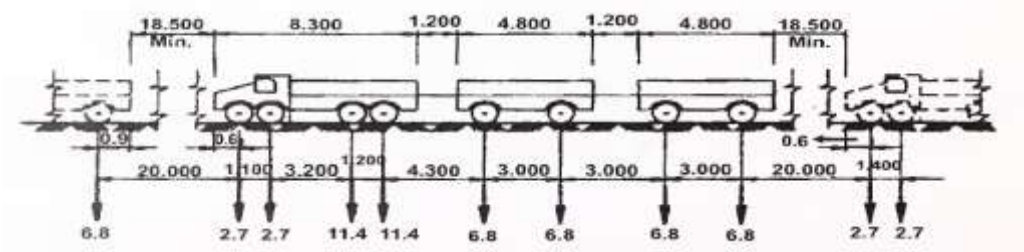


Figure 0-2 Class A train of vehicles

Table 0-1 Provisions of IRC loading on bridges as per carriageway width

Sl. No.	Carriageway Width (CW)	Number of Lanes for Design Purposes	Load Combination
1)	Less than 5.3	1	One lane of Class A considered to occupy 2.3 m. The remaining width of carriageway shall be loaded with 500 kg/m²
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	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	5	
6)	20.1 m and above but less than 23.6	6	

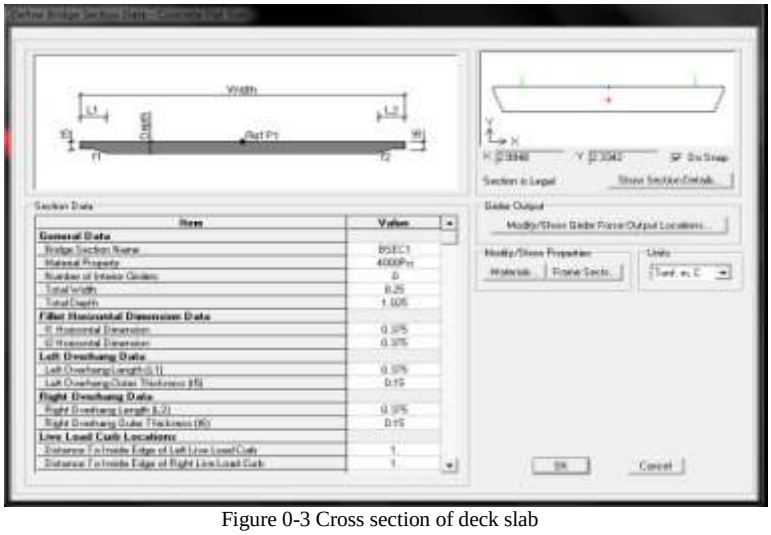


Figure 0-3 Cross section of deck slab

3.2 Geometrical Details of bridges

As discussed in the earlier paragraphs, the following geometrical data is reported in the following Table 3-2.

Table 0-2 Geometrical details of various bridges

Sr. No.	Type of Bridge	Span (m)	Skew angle (m)	Length (m)	Depth of slab (m)
1	Simply Supported	5	0, 10, 20, 30, 45	5, 5.07, 5.32, 5.77, 7.07	0.425
2	Simply Supported	10	0, 10, 20, 30, 45	10, 10.1, 10.6, 11.5, 14.1	0.725
3	Simply Supported	12.5	0, 10, 20, 30, 45	12.5, 13.7, 13.3, 14.4, 17.6,	0.875
4	Simply Supported	15	0, 10, 20, 30, 45	15, 15.2, 16, 17.3, 21.21,	1.025
5	Simply Supported	18	0, 10, 20, 30, 45,	18, 18.27, 19.15, 20.78, 25.45,	1.2
6	Continuous	5	0, 10, 20, 30, 45, 50	55, 55.8, 58.5, 63.5, 77.8, 85.6	0.35
7	Continuous	10	0, 10, 20, 30, 45, 50	50, 50.8, 53.2, 57.7, 70.7, 77.78	0.55
8	Continuous	12.5	0, 10, 20, 30, 45, 50	50, 50.8, 53.2, 57.7, 70.7, 77.78	0.7
9	Continuous	15	0, 10, 20, 30, 45, 50	45, 45.7, 47.88, 51.96, 63.63, 70	0.825
10	Continuous	20	0, 10, 20, 30, 45, 50	60, 60.92, 63.85, 69.28, 84.85, 93.34	1.025

11	Integral	15	0, 10, 20, 30, 45, 50	45, 45.7, 47.88, 51.96, 63.63, 70	0.75
12	Integral	20	0, 10, 20, 30, 45, 50	60, 60.92, 63.85, 69.28, 84.85, 93.34	0.925

4. ANALYSIS OF BRIDGES

4.1 Introduction

As listed in, in all the types of bridges are analysed for dead load, live load, and earthquake load in longitudinal and transverse direction. The following assumptions are made in the analysis.

a) Simply supported bridge

I. Bearing with following conditions are used:-

Bearing I		Bearing II	
Translation vertical	Fixed	Translation vertical	Fixed
Translation normal to layout line	Fixed	Translation normal to layout line	Fixed
Translation along layout line	Free	Translation along layout line	Fixed
Rotation about vertical	Free	Rotation about vertical	Free
Rotation about normal to layout line	Free	Rotation about normal to layout line	Free
Rotation about layout line	Free	Rotation about layout line	Free

II. The span is assumed to rest on abutments at both ends.

III. Foundation spring is assumed fixed and linked to bearings which in turn are linked to slab bottom using links.

b) Continuous bridges

I. Bearing with following conditions are used:-

Type of Bearing	**Vertical Dir.**	**Transverse Dir.**	**Longitudinal Dir.**
Bearing 1 (B1)	Fixed	Free	Fixed
Bearing 2 (B2)	Fixed	Fixed	Free

II. The span is assumed to rest on abutments at both ends.

III. Foundation spring is assumed fixed and linked to bearings which in turn are linked to slab bottom using links.

IV. Single line bearing is modeled over continuity region of slab.

V. Pier of Height equal to 6 m are provided.

VI. Bent is located at 100 mm at from the bottom of soffit of slab.

All the bridges have been modelled in SAP14 2000 Bridge, considering the end conditions as discussed in the assumption. The results of the simply supported are presented in the subsequent sections.

4.2Simply supported Slab Bridge (SSB)

4.2.1 Simply Supported 5m span

This Slab Bridge is taken from PWD type plans Government of Maharashtra. The depth of the slab is taken as 0.425m. The width of the carriageway is 8.25m i.e. two lane bridge. The bridge is situated in zone III with medium soil conditions. The importance factor for bridge is taken as 1. The Grade of concrete for deck slab is M25. The Grade of steel is Fe 500.

Below are the notations for moments are forces which are given in following tables

M3- Moment about horizontal axis

M2- Moment about vertical axis

T- Torsional moment

V2- Vertical shear

V3- Horizontal shear

A- Axial Force

Table 0-3Analysis results SSB 5 m span for Dead load

Angle of Skew	DL					
	M3	M2	T	V2	V3	A
0	25.7	0	0	20.53	0	0
10	25.24/-1.21	15.4/-1	-6.18	20.85	-3.23	0
20	24.01/-5.03	31.76/-5.61	-12.31	21.84	-7.02	0
30	22.13/-12	51/-16	-18	23.7	-11.75	0
45	18.5/-32.7	93.8/-50.5	-28.37	29	-20.42	0

Table 0-4Analysis results SSB 5 m span for Live load

Angle of Skew	LL					
	M3	M2	T	V2	V3	A
0	33.7	-57.5	49.48/-49.48	25.8	11.5/-11.5	0
10	36.35/-8.7	65.9/-28	30.34/-46.5	27.52	5/-13	0
20	39.5/-24.23	99.31/-27.41	31.18/-62.50	32.9	3/-18.875	0
30	40.41/-39.7	120/-45	20/-64	36.3	0.39/-23	0
45	43.5/-85.44	196/-119	13.6/-78	44.62	0/-38.35	0

Table 0-5Analysis results SSB 5 m span for Earthquake in X

Angle of Skew	EQ X					
	M3	M2	T	V2	V3	A
0	0.18	0	0	0.15	0	0.6
10	0.177	0.21	0.07	0.145	0.12	0.58
20	0.164	0.232	0.124	0.14	0.136	0.54
30	0.145	0.373	0.17	0.12	0.16	0.51
45	0.21	0.72	0.18	0.13	0.32	0.5

Table 0-6Analysis results SSB 5 m span in Earthquake in Y

Angle of Skew	EQ Y					
	M3	M2	T	V2	V3	A
0	0	0.6	0.13	0	0.35	0
10	0.07	0.45	0.09	0.1	0.26	0.19
20	0.06	0.37	0.09	0.11	0.21	0.239
30	0.11	0.42	0.15	0.12	0.21	0.33
45	0.2	0.57	0.2	0.15	0.25	0.52

4.2.2 Simply Supported 10m span

This Slab Bridge is taken from PWD type plans Government of Maharashtra. The depth of the slab is taken as 0.725m. The width of the carriageway is 8.25m i.e. two lane bridge. The bridge is situated in zone III with medium soil conditions. The importance factor for bridge is taken as 1. The Grade of concrete for deck slab is M25. The Grade of steel is Fe 500.

Below are the notations for moments are forces which are given in following tables

M3- Moment about horizontal axis
M2- Moment about vertical axis
T- Torsional moment
V2- Vertical shear
V3- Horizontal shear
A- Axial Force

Table 0-7Analysis results SSB 10 m span for Dead load

Angle of Skew	**DL**					
	M3	**M2**	**T**	**V2**	**V3**	**A**
0	175.73	0	0	70.29	0	0
10	172.4/-7.2	70.03	-38.59	71.37	-7	0
15	170.2/-16.5	106.58/-7.31	-57.7	72.77	-11	0
20	167.42/-30	145/-19	-76.58	74.8	-15.51	0
30	163/-71	234/-68	-113.8	81.17	-26.16	0
40	160/-139.5	353/-154	-151.9	91.76	-38.89	0
45	160/-190	433/-220	-172	99.4	-46.17	0

Table 0-8Analysis results SSB 10 m span for Live load as per

Angle of Skew	**LL**					
	M3	**M2**	**T**	**V2**	**V3**	**A**
0	105	79.8/-79.8	68.3/-68.3	43.65	8/-8	0
10	111.36/-16.50	124.5/-42.25	43/-89	46.52	4/-12.1	0
15	113/-28	149/-32	33/-100	48.27	2.7/-14.5	0
20	115/-44	178/-27	27/-115	50.42	2/-17.3	0
30	116/-90	250/-66	27/-148	59.43/-59.9	1.5/-24	0
40	108/-153	346/-136	24/-171	66.19	1.16/-32	0
45	112.4/-200	411/-185	22/-186.6	70.32	1.2/-36	0

Table 0-9Analysis results SSB 10 m span for Earthquake in X

Angle of Skew	EQ X					
	M3	M2	T	V2	V3	A
0	1.45	0	0	0.65	0	1.95
10	1.4	0.92	0.63	0.63	0.33	1.8
15	1.36	1.32	0.82	0.62	0.49	1.83
20	1.31	1.75	1	0.61	0.65	1.81
30	1.19	2.35	1.45	0.53	0.78	1.55
40	1.33	3.41	1.5	0.56	1.02	1.57
45	1.75	4.45	1.51	1.55	1.2	1.55

Table 0-10Analysis results SSB 10 m span in Earthquake in Y

Angle of Skew	EQ Y					
	M3	M2	T	V2	V3	A
0	0	3.16	0.65	0	1.28	0
10	0.28	2.91	0.58	0.17	1.2	0.52
15	0.41	2.83	0.5	0.25	1.16	0.8
20	0.52	2.87	0.44	0.32	1.13	1.05
30	0.73	2.28	0.85	0.44	0.78	1.54
40	1.18	2.38	1.06	0.53	0.86	2.06
45	1.34	2.72	1.07	0.56	0.84	2..5

4.2.3 Simply Supported 12.5 m span

This bridge has been designed for dead load and live load, class 70R- 1 Lane or class A 2 Lane whichever governs the design as per book by D. J. Victor (8).

The depth of the slab is taken as 0.865m. The width of the carriageway is 8.25m i.e. two lane bridge. The bridge is situated in zone III with medium soil conditions. The importance factor for bridge is taken as 1. The Grade of concrete for deck slab is M25. The Grade of steel is Fe 500.

Below are the notations for moments are forces which are given in following tables

M3- Moment about horizontal axis

M2- Moment about vertical axis

T- Torsional moment

V2- Vertical shear

V3- Horizontal shear

A- Axial Force

Table 0-11Analysis results SSB 12.5 m span for Dead load

Angle of Skew	DL					
	M3	M2	T	V2	V3	A
0	319.73	0	0	106.57	0	0
10	316.26/-13.26	112.53/-1.37	-71.22	108.19	-9	0

20	307.4/-54.6	233.3/-31.5	-141.1	113.4	-19.91	0
30	296.6/-129.5	375.6/-111.3	-210.2	123.03	-33.75	0
45	321.62/-344.44	703.94/-365.52	-317.5	150.72	-60.5	0

Table 0-12Analysis results SSB 12.5 m span for Live load as per IRC 6

Angle of Skew	LL					
	M3	M2	T	V2	V3	A
0	158.7	103.92/-103.92	103.22/-103.22	54.5	8.31/-8.31	0
10	163.32/-24.22	160.11/-54.95	64.9/-131.82	56.94	4.22/-12.5	0
20	166.8/-64.6	225.83/-39.5	46.62/-170	61	2.44/-17.5	0
30	161.18/-111.61	286.4/-76.05	28.9/-183..9	67.5	1.3/-22.5	0
45	173.11/-259.72	476.23/-209.6	31.25/-245.85	77.8	1.5/-34.1	0

Table 0-13Analysis results SSB 12.5 m span for Earthquake in X

Angle of Skew	EQ X					
	M3	M2	T	V2	V3	A
0	2.67	0	0	1	0	3.16
10	2.56	2.72	1.35	0.94	0.66	2.76
20	2.37	3.66	2.07	0.9	1.14	2.4
30	2.13	4.78	2.5	0.83	1.55	2.6
45	3.21	7.54	3.11	0.82	1.65	2.15

Table 0-14Analysis results SSB 12.5 m span in Earthquake in Y

Angle of Skew	EQ Y					
	M3	M2	T	V2	V3	A
0	0	5.37	1.55	0	1.55	0
10	0.72	4.54	1.37	0.35	1.55	1.4
20	1.11	5.37	1.23	0.44	1.7	1.58
30	1.2	4.6	1.62	0.63	1.44	2.6
45	2.73	5.8	2.54	0.8	1.49	4.03

4.2.4 Simply Supported 15 m span

The depth of the slab is taken as 1.025m. The width of the carriageway is 8.25m i.e. two lane bridge. The bridge is situated in zone III with medium soil conditions. The importance factor for bridge is taken as 1. The Grade of concrete for deck slab is M25. The Grade of steel is Fe 500.

Below are the notations for moments are forces which are given in following tables

M3- Moment about horizontal axis
M2- Moment about vertical axis
T- Torsional moment
V2- Vertical shear
V3- Horizontal shear
A- Axial Force

Table 0-15Analysis results SSB 15 m span for Dead load

Angle of Skew	DL					
	M3	M2	T	V2	V3	A
0	542.64	0	0	150.74	0	0
10	537.56/-21.84	162.38/-2.24	-118.27	153.04	-10.8	0
20	550/-90	341.5/-48	-234	160.38	-24.4	0
30	540.4/-213.2	551.81/-170	-347.6	174.04	-41.64	0
45	540/-568	1040.5/-558	-528	213.14	-75.35	0

Table 0-16Analysis results SSB 15 m span for Live load as per IRC 6

Angle of Skew	LL					
	M3	M2	T	V2	V3	A
0	215	100.9/-100.9	113.7/-113.7	60.34	6.72/-6.72	0
10	218.5/-27.4	161.2/-49.5	67.9/-150	62.65	3.15/-10.5	0
20	225.5/-74.9	234.22/-36	48.6/-198.1	67.43	1.85/-15.4	0
30	218.83/-130	300/-82.6	30/-215.27	73	1/-20	0
45	225.87/-295	500/-230	32/-279	81.64	1.10/-31	0

Table 0-17Analysis results SSB 15 m span for Earthquake in X

Angle of Skew	EQ X					
	M3	M2	T	V2	V3	A
0	4.44	0	0	1.4	0	4.77
10	4.23	6.51	2.11	1.3	1.51	4
20	3.87	7.92	3.22	1.23	1.9	3.5
30	3.38	8.71	3.95	1.2	2.29	3.5
45	5	13.76	4.3	1.21	2.75	4.15

Table 0-18Analysis results SSB 15 m span in Earthquake in Y

Angle of Skew	EQ Y					
	M3	M2	T	V2	V3	A
0	0	5.37	1.55	0	1.55	0
10	0.72	4.54	1.37	0.35	1.55	1.4
20	1.11	5.37	1.23	0.44	1.7	1.58
30	1.2	4.6	1.62	0.63	1.44	2.6
45	2.73	5.8	2.54	0.8	1.49	4.03

4.2.5 Simply Supported 18m Span

The depth of the slab is taken as 1.2m. The width of the carriageway is 8.25m i.e. two lane bridge. The bridge is situated in zone III with medium soil conditions. The importance factor for bridge is taken as 1. The Grade of concrete for deck slab is M25. The Grade of steel is Fe 500.

Below are the notations for moments are forces which are given in following tables

M3- Moment about horizontal axis
M2- Moment about vertical axis
T- Torsional moment
V2- Vertical shear
V3- Horizontal shear
A- Axial Force

Table 0-19Analysis results SSB 18 m span for Dead load

Angle of Skew	Dead					
	M3	M2	T	V3	V2	A
0	836.5	0	0	0	185	0
10	832.5/-29.25	177.21	160.53	-9.4	188.6	0
20	806/-121	375/-40	-319.7	-21.71	197	0
30	803.38/-289	612/-173	-477.21	-37.88	213.65	0
45	872/-780	1062/-602	-739	-65.4	262.89	0
50	955/-1070	1341/-845	-848	-78	-289	0

Table 0-20Analysis results SSB 18 m span for Live load as per IRC 66

Angle of Skew	Live (70R)					
	M3	M2	T	V3	V2	A
0	297.49	96.36/-96.36	126.05/-126.05	5.35	67.27	0
10	293/-30	151/-50	73/-169	2.74/-8.13	69.20	0
20	292.96/-81.47	217/-37	52.25/-217	1.71/-11.83	72.78	0
30	288./-142	280/-72.8	31.5/-236.4	-15.75	77.02	0
45	309/-317	410/-209	35/-303	22	85	0
50	310/-373	460/-264	25/-299	-23.9	86.5	0

Table 0-21Analysis results SSB 18 m span for Earthquake in X

Angle of Skew	EQ X					
	M3	M2	T	V3	V2	A
0	14.5	0	0	0	3.8	13.65
10	14.11	9.59	8	2.099	3.47	12.67
20	13.15	16.15	9.83	3.77	3.47	11
30	11.53	20.95	11.4	4.46	3.3	10.47
45	17	33.04	12.05	5.41	3.59	17.42
50	21	44	12.51	6.38	3.37	19.18

Table 0-22Analysis results SSB 18 m span in Earthquake in Y

Angle of Skew	EQ Y						
	M3	M2	T	V3	V2	A	m2 entire bridge
0	0	5.9	2	8.92	0	0	41
10	2.3	6.21	2.32	8.7	0.51	3.78	40.23

20	4.49	6.4	3.36	8.26	0.93	7.16	39.8
30	6.95	7.01	5.46	7.33	1.61	10.05	37.55
45	12.15	9.08	9.9	8.17	3.34	11.31	38.65
50	14.5	14.2	9.81	9.75	3.76	13.6	53.21

4.2.6 Discussion on Simply supported bridges

For dead load:

It has been observed that, moment in horizontal (M3) direction reduces as the skew angle increases till 30 degrees, and increases after 30 degrees due to exponential increase in length.

As skew angle increases, torsion goes on increasing. Torsional moment (T) is observed at the ends of the bridge due to uplift at the acute angled corners.

Due to the bearing conditions provided moment about vertical axis (M2) is also induced due to skew angle. The negative moment is observed at the mid span and positive moment is observed at the ends of the deck slab.

The region of sagging moment reduces as the skew angle increases.

As the aspect ratio goes on decreasing, the moment about vertical axis (M2) goes on increasing exponentially.

For Live load:

Live load being eccentric it is seen that both M2 and T are seen with M3. The positive and negative moments are observed at the respective ends simultaneously as the live load travels across span.

At 45 degrees, the negative T and positive M3 are observed to be same, hence the region of torsional moment is observed to be same as bending moment.

For Earthquake in X:

At 0 degrees only, M3 is seen since the component of the earthquake force in transverse direction is zero. But as the skew angle increases, the component of earthquake force in longitudinal direction reduces which can be deduced from decreasing value of axial force (A) and M3. Due to increasing skew angle, component of earthquake force in transverse direction is seen to be increasing as both increase in the value of M2 and T is observed.

For Earthquake in Y:

At 0 degrees only, M3 is seen since the component of the earthquake force in longitudinal direction is zero. But as the skew angle increases, the component of earthquake force in transverse direction reduces which can be deduced from decreasing value of axial force (A) and M2. Due to increasing skew angle, component of earthquake force in longitudinal direction is seen to be increasing as both increase in the value of M3 and T is observed.

Another observation is vertical shear for both Earthquake in X and Earthquake in Y, at 45 degrees is same, which correlates the values for both the earthquake in X and Y.

4.3 Continuous Bridge (CB)

4.3.1 Continuous deck slab bridge 10m × 5 Spans, (50 m length)

The bridge has been designed for dead and live load and braking force. The design has been carried using IRC SP-66 (Design of continuous bridges). The depth of the slab is taken as 0.55 m. The width of the carriageway is 8.25 m i.e. two lane bridge. The bridge is situated in zone III with medium soil conditions. The importance factor for bridge is taken as 1. The Grade of concrete for deck slab is M25. The Grade of steel is Fe 500.

Below are the notations for moments are forces which are given in following tables

M3-
Moment about horizontal axis
M2- Moment about vertical axis
T- Torsional moment
V2- Vertical shear
V3- Horizontal shear
A- Axial Force

Bearing conditions:-

Type of Bearing	**Vertical Dir.**	**Transverse Dir.**	**Longitudinal Dir.**
Bearing 1 (B1)	Fixed	Free	Fixed
Bearing 2 (B2)	Fixed	Fixed	Free

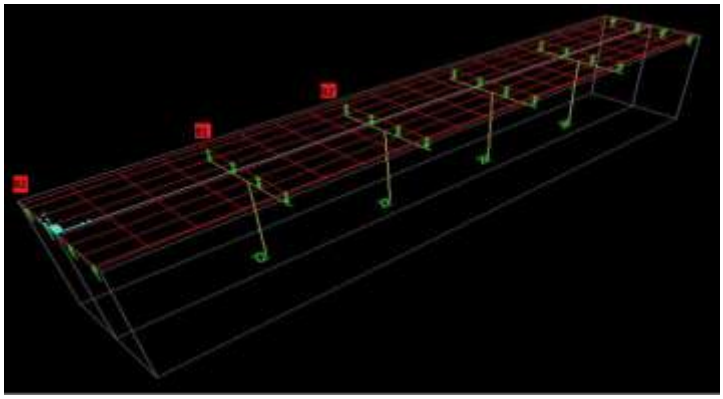


Figure 0-4 Bearing conditions

Table 0-23Analysis results CB 10 m span of 50 m length for dead load

Angle of Skew	DEAD (Tm)					
	M3	M2	T	V3	V2	A
0	70/-110	0	0	0	64.5	0
10	73.72/-114.32	8.54/- 8.58	2.75/- 5.74	0.58	65.06	0.32
20	84.89/-126.52	6.77/- 6.77	5.23/-12.33	0.65	68	0.87
30	95.48/-152.16	14.74/-14.02	8/- 21.6	0.93	73.36	2.08
45	135/-236	49.25/-49.27	8.79/-42.97	1.24	88.28	6.54
50	146/- 290	66.05/-66.05	8.29/-54	1.48	97.2	9.59

Table 0-24Analysis results CB 10 m span of 50 m length for live load as per IRC 6

LIVE LOAD- 70R (Tm)						
Angle of Skew	M3	M2	T	V3	V2	A
0	80.77/-69	-68	103/-103	10.99/-10.99	50.41	0.38
10	86/-77.62	-55.5	74.62/-94.27	8.92/-8.8	52.33/-53.187	0.74
20	98.69/-91.29	-33.6	67.8/-102.65	8.45/-8.53	56.31/-56.90	1.66
30	111/-116.86	-19.7	65/-121.75	7.16/-7.06	65.66/-61.63	6.374
45	151/-190	-21.5	64/-154	7.45/-7.45	75.03/-75.03	10
50	168/-233	-38.64	72/-171	7.51	82.77	11.86

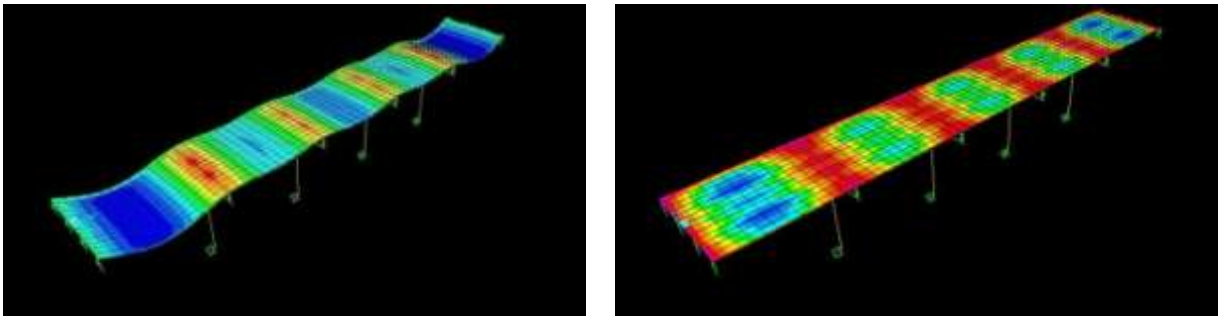
Table 0-25Analysis results CB 10 m span of 50 m length in Earthquake in X

Angle of Skew	EARTHQUAKE X					
	M3	M2	T	V3	V2	A
0	3.105	0	0	0	0.42	11.91
10	4.07	9.78	4.47	3.83	0.53	11.939
20	6.82	19.02	8.38	7.88	0.83	12
30	10.80	27.34	11.04	12.00	1.28	12.05
45	16.48	46.06	12.43	17	1.9	11.73
50	17.66	86.74	12.62	18.69	2.07	11.31

Table 0-26Analysis results CB 10 m span of 50 m length in Earthquake in Y

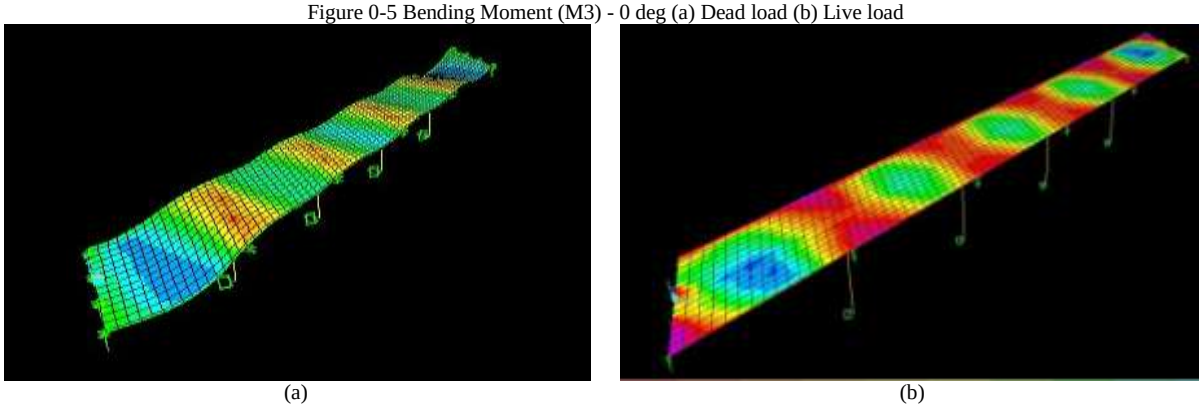
Angle of Skew	EARTHQUAKE Y					
	M3	M2	T	V3	V2	A
0	0	46.7	7.38	18.05	0	0
10	2.17	45.56	7.5	17.95	0.5	1.98

20	4.65	42.2	8.22	17.53	0.86	4.09
30	7.79	**37.86**	9.96	16.60	1.14	6.532
45	16.56	39	13.28	14.36	1.8	11.22
50	21.07	62.4	14.4	13.34	2.18	13.062



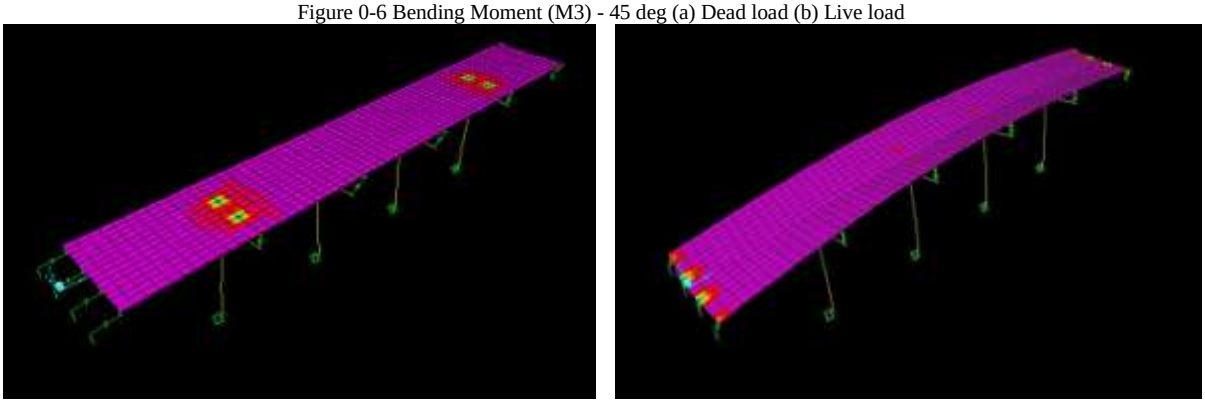
(a) (b)

Figure 0-5 Bending Moment (M3) - 0 deg (a) Dead load (b) Live load



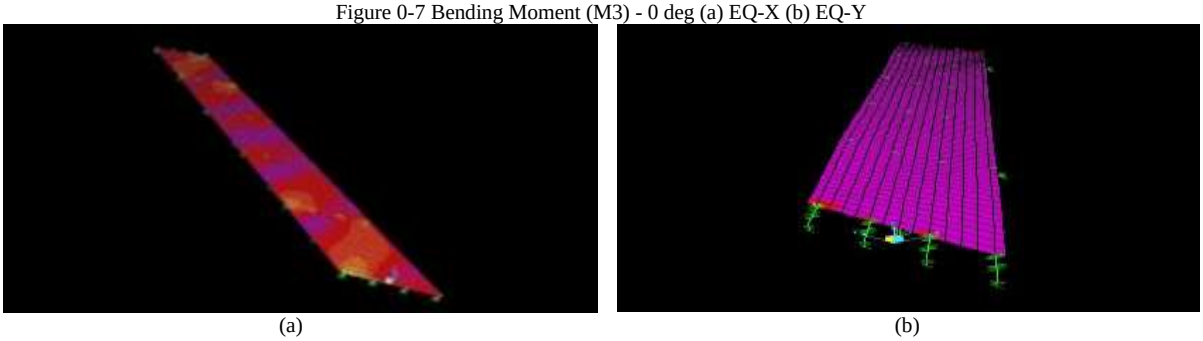
(a) (b)

Figure 0-6 Bending Moment (M3) - 45 deg (a) Dead load (b) Live load



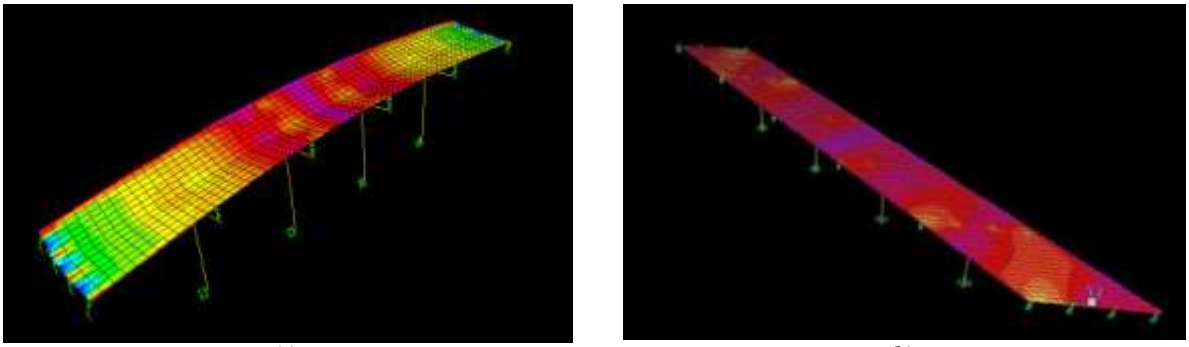
(a) (b)

Figure 0-7 Bending Moment (M3) - 0 deg (a) EQ-X (b) EQ-Y



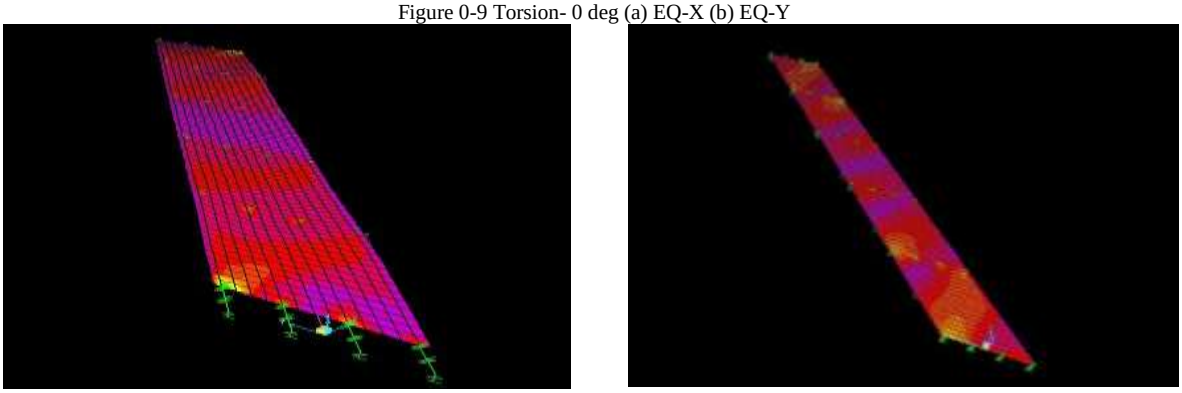
(a) (b)

Figure 0-8 Bending Moment (M3) - 45 deg (a) EQ-X (b) EQ-Y



(a) (b)

Figure 0-9 Torsion- 0 deg (a) EQ-X (b) EQ-Y



(a) (b)

Figure 0-10 Torsion- 45 deg (a) EQ-X (b) EQ-Y

4.3.2 Continuous deck slab bridge 5m × 11 Spans, (55 m length)

The bridge has been designed for dead and live load and braking force. The design has been carried using IRC SP-66 (Design of continuous bridges). The depth of the slab is taken as 0.35 m. The width of the carriageway is 8.25 m i.e. two lane bridge. The bridge is situated in zone III with medium soil conditions. The importance factor for bridge is taken as 1. The Grade of concrete for deck slab is M25. The Grade of steel is Fe 500.

Below are the notations for moments are forces which are given in following tables

M3- Moment about horizontal axis
M2- Moment about vertical axis
T- Torsional moment
V2- Vertical shear
V3- Horizontal shear
A- Axial Force

Bearing conditions:-

Type of Bearing	Vertical Dir.	Transverse Dir.	Longitudinal Dir.
Bearing 1 (B1)	Fixed	Free	Fixed
Bearing 2 (B2)	Fixed	Fixed	Free

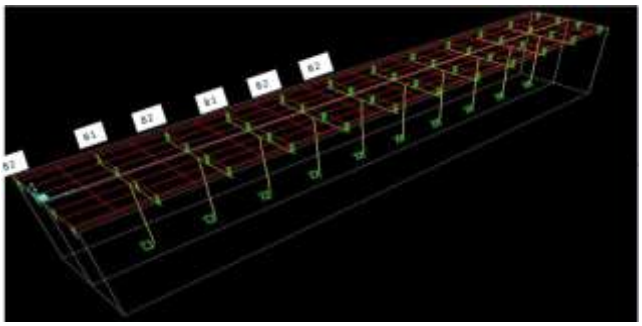


Figure 0-11 Bearing conditions

Table 0-27Analysis results CB 5 m span of 55 m length for dead load

Angle of Skew	DEAD (Tm)					
	M3	M2	T	V3	V2	A
0	286.60/-359.85	0	0	0	143.6	0
10	285.13/-371.64	3.962	-17.321	0.065	145.65	0.78
20	305.7/408.67	9.95	-39.114	0.185	151.99	1.89
30	343.1/-483.75	16.43	-70.87	0.24	163.69	4.3
45	465.97/-739.63	19.92	-156.25	-0.49	196.62	13.5

Table 0-28Analysis results CB 5 m span of 55 m length for live load as per IRC 6

LIVE LOAD- 70R (Tm)						
Angle of Skew	M3	M2	T	V3	V2	A
0	171.34/-117.94	0	-132.5	0	67.43	0
10	177.89/-128.91	6.68	97.82/-124.613	0.143	70.312	0.76
20	193.45/147.55	21.32	80.5/-144.69	0.57	72.79	1.74
30	223/-177	39.46	78.5/-173.27	1.06/-1.12	78.53	4.5
45	280.99/-266.54	80.42	80.3/-232	0.86/-2.51	85.47	16.84

Table 0-29Analysis results CB 5 m span of 55 m length for Earthquake in X

Angle of Skew	EARTHQUAKE X					
	M3	M2	T	V3	V2	A
0	2.99	5.48	0.156	0.8316	0.3275	0.6943
10	3.67	4.634	4.47	2.03	0.491	6.64
20	6.03	8.9	8.56	4.11	0.78	6.69
30	9.7	13.08	11.85	6.25	1.19	6.72
45	15.909	26.28	14.13	9.95	1.98	6.51

Table 0-30Analysis results CB 5 m span of 55 m length for Earthquake in Y

Angle of Skew	EARTHQUAKE Y					
	M3	M2	T	V3	V2	A
0	0	27.02	4.23	11.55	0	0
10	2.04	26.04	5.77	11.47	0.56	1.1
20	4.2	24.34	6	11.22	1.16	2.28
30	6.8366	22.36	8.1	10.66	1.63	3.649
45	15.11	26.24	13.62	9.93	1.69	6.21

4.3.3 Continuous deck slab bridge 12.5m × 4 Spans, (50 m length)

The bridge has been designed for dead and live load and braking force. The design has been carried using IRC SP-66 (Design of continuous bridges). The depth of the slab is taken as 0.7 m. The width of the carriageway is 8.25 m i.e. two lane bridge. The bridge is situated in zone III with medium soil conditions. The importance factor for bridge is taken as 1. The Grade of concrete for deck slab is M25. The Grade of steel is Fe 500.

Below are the notations for moments are forces which are given in following tables

M3- Moment about horizontal axis
M2- Moment about vertical axis
T- Torsional moment
V2- Vertical shear
V3- Horizontal shear
A- Axial Force

Bearing conditions:-

Type of Bearing	**Vertical Dir.**	**Transverse Dir.**	**Longitudinal Dir.**
Bearing 1 (B1)	Fixed	Free	Fixed
Bearing 2 (B2)	Fixed	Fixed	Free

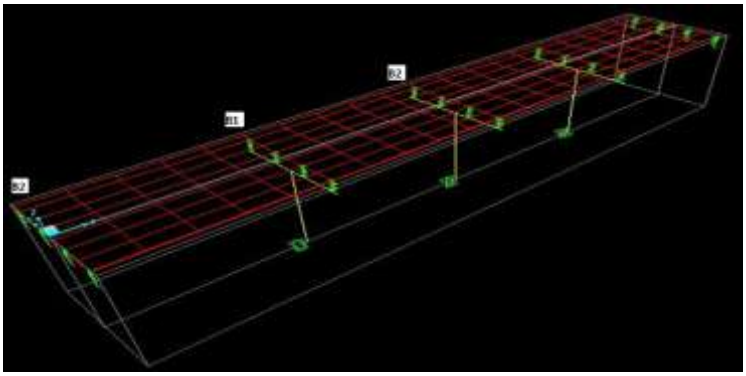


Figure 0-12 Bearing conditions

Table 0-31Analysis results CB 12.5 m span of 50 m length for dead load

Angle of Skew	DEAD (Tm)					
	M3	M2	T	V3	V2	A
0	286.60/-359.85	0	0	0	143.6	0
10	285.13/-371.64	3.962	-17.321	0.065	145.65	0.78
20	305.7/408.67	9.95	-39.114	0.185	151.99	1.89
30	343.1/-483.75	16.43	-70.87	0.24	163.69	4.3
45	465.97/-739.63	19.92	-156.25	-0.49	196.62	13.5

Table 0-32Analysis results CB 12.5 m span of 50 m length for live load as per IRC 6

LIVE LOAD- 70R (Tm)						
Angle of Skew	M3	M2	T	V3	V2	A
0	125.46/-91.8	171.83	101.78	7.19	61.18	0.35/-0.158
10	135.8/-101.9	172.41	88.22/-109.22	7.11/-6.96	63.09	1.01/-0.56
20	152.89/-121.5	153.48	78.38/-126.35	6.69/-6.50	65.84	2.55/-1.16
30	173.8/-152.90	134.27	74.20/-148.55	6.22/-5.93	73.08	5.97/-2.15
45	216.8/-226.15	129.74	70.65/-188.67	5.95/-5.49	81.52	13.02/-5.47

Table 0-33Analysis results CB 12.5 m span of 50 m length for Earthquake in X

Angle of Skew	EARTHQUAKE X					
	M3	M2	T	V3	V2	A
0	2.99	5.48	0.156	0.8316	0.3275	0.6943
10	3.67	4.634	4.47	2.03	0.491	6.64
20	6.03	8.9	8.56	4.11	0.78	6.69
30	9.7	13.08	11.85	6.25	1.19	6.72
45	15.909	26.28	14.13	9.95	1.98	6.51

Table 0-34Analysis results CB 12.5 m span of 50 m length for Earthquake in Y

Angle of Skew	EARTHQUAKE Y					
	M3	M2	T	V3	V2	A
0	0	27.02	4.23	11.55	0	0
10	2.04	26.04	5.77	11.47	0.56	1.1
20	4.2	24.34	6	11.22	1.16	2.28
30	6.8366	22.36	8.1	10.66	1.63	3.649
45	15.11	26.24	13.62	9.93	1.69	6.21

4.3.4 Continuous deck slab bridge 15m × 3 Spans, (45 m length)

The bridge has been designed for dead and live load and braking force. The design has been carried using IRC SP-66 (Design of continuous bridges). The depth of the slab is taken as 0.825 m. The width of the carriageway is 8.25 m i.e. two lane bridge. The bridge is situated in zone III with medium soil conditions. The importance factor for bridge is taken as 1. The Grade of concrete for deck slab is M25. The Grade of steel is Fe 500.
Below are the notations for moments are forces which are given in following tables
M3- Moment about horizontal axis
M2- Moment about vertical axis
T- Torsional moment
V2- Vertical shear
V3- Horizontal shear
A- Axial Force
Bearing conditions:-

Type of Bearing	**Vertical Dir.**	**Transverse Dir.**	**Longitudinal Dir.**
Bearing 1 (B1)	Fixed	Free	Fixed
Bearing 2 (B2)	Fixed	Fixed	Free

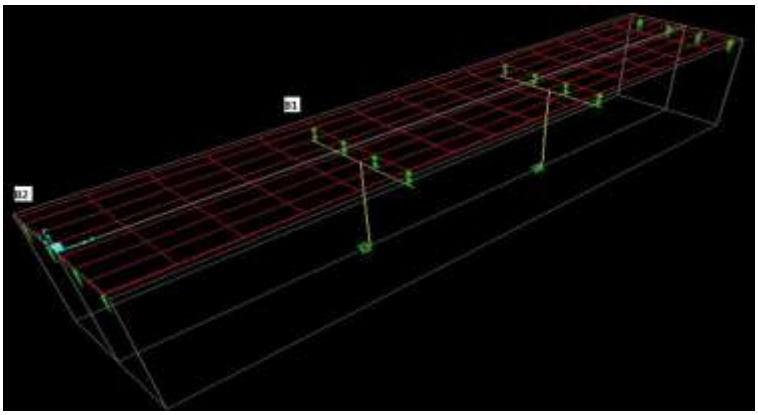


Figure 0-13Details of 15m Span Length- 45 m Continuous

Table 0-35Analysis results CB 15 m span of 45 m length for dead load

Angle of Skew	DEAD					
	M3	M2	T	V3	V2	A
0	286.60/-359.85	0	0	0	143.6	0
10	285.13/-371.64	3.962	-17.321	0.065	145.65	0.78
20	305.7/408.67	9.95	-39.114	0.185	151.99	1.89
30	343.1/-483.75	16.43	-70.87	0.24	163.69	4.3
45	465.97/-739.63	19.92	-156.25	-0.49	196.62	13.5

Table 0-36Analysis results CB 15 m span of 45 m length for live load as per IRC 6

Angle of Skew	LIVE LOAD- 70R					
	M3	M2	T	V3	V2	A
0	171.34/-117.94	0	-132.5	0	67.43	0
10	177.89/-128.91	6.68	97.82/-124.613	0.143	70.312	0.76
20	193.45/147.55	21.32	80.5/-144.69	0.57	72.79	1.74
30	223/-177	39.46	78.5/-173.27	1.06/-1.12	78.53	4.5
45	280.99/-266.54	80.42	80.3/-232	0.86/-2.51	85.47	16.84

Table 0-37Analysis results CB 15 m span of 45 m length for Earthquake in X

Angle of Skew	EARTHQUAKE X					
	M3	M2	T	V3	V2	A
0	2.88	0	0	0	0.38	6.61
10	3.67	4.79	4.47	2.03	0.49	6.64
20	6.03	8.9	8.56	4.11	0.78	6.69
30	9.7	13.08	11.85	6.25	1.19	6.72
45	15.909	26.28	14.13	9.95	1.98	6.81

Table 0-38Analysis results CB 15 m span of 45 m length for Earthquake in Y

Angle of Skew	EARTHQUAKE Y					
	M3	M2	T	V3	V2	A
0	0	27.02	5.95	11.55	0	0
10	2.04	26.04	5.8	11.47	0.56	1.1
20	4.2	24.34	6.05	11.22	1.16	2.28
30	6.8366	22.36	8.1	10.66	1.63	3.649
45	15.11	26.24	13.62	9.93	1.69	6.21

4.3.5 Continuous deck slab bridge 20m × 3 Spans, (60 m length)

The bridge has been designed for dead and live load and braking force. The design has been carried using IRC SP-66 (Design of continuous bridges). The depth of the slab is taken as 1.025 m. The width of the carriageway is 8.25 m i.e. two lane bridge. The bridge is situated in zone III with medium soil conditions. The importance factor for bridge is taken as 1. The Grade of concrete for deck slab is M25. The Grade of steel is Fe 500.
Below are the notations for moments are forces which are given in following tables
M3- Moment about horizontal axis
M2- Moment about vertical axis
T- Torsional moment
V2- Vertical shear
V3- Horizontal shear
A- Axial Force
Bearing conditions:-

Type of Bearing	**Vertical Dir.**	**Transverse Dir.**	**Longitudinal Dir.**
Bearing 1 (B1)	Fixed	Free	Fixed
Bearing 2 (B2)	Fixed	Fixed	Free

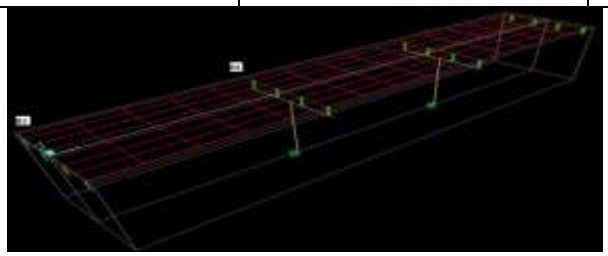


Figure 0-14 Bearing conditions

Table 0-39Analysis results CB 20 m span of 60 m length for dead load

Angle of Skew	Dead					
	M3	M2	T	V3	V2	A
0	564/-704	0	0	0	212	2.95
10	579/-731	17.37/-20	-31.25	0.4469	215.74	3.83
20	625/-803	27.13/-27.13	-69.05	0.455	225.33	6.8
30	709/-946.68	30.37/-30.37	-123.26	0.255	242.46	12.87
45	980/-1457	177/-108	-285	10.11	290.96	43.16

Table 0-40Analysis results CB 20 m span of 60 m length for live load as per IRC 6

Angle of Skew	Live (70R)					
	M3	M2	T	V3	V2	A
0	269.69/ -171.64	0.85	158.06	0.013/-0.015	78.39	1.86/-2.33
10	299/-184	13.86/-14.58	150.34/- 186.38	0.354/-0.36	79.86	4.64/-2.69
20	306/-207	31.88/-11.64	129/-185	0.43/-0.43	82/-74	4.25/-4.5
30	353/-237	46.110/-46.156	101/ -205.66	0.61/-0.91	85.211/-85.211	13.75/-7.28
45	421/-354	225/-213	120/-224	14/-12	90/-91	36/-27

Table 0-41Analysis results CB 20 m span of 60 m length for Earthquake in X

Angle of Skew	EQ X					
	M3	M2	T	V3	V2	A
0	11.2	0	0	0	0.862	14.24
10	17.16	6.5	6	3.14	0.9717	14.22
20	23.6	11.82	11.26	6.04	1.27	14.2
30	25.72	18.2	15.17	10	1.71	13.96
45	27.58	28.82	20.54	16.55	2.86	12.78

Table 0-42Analysis results CB 20 m span of 60 m length for Earthquake in Y

Angle of Skew	EQ Y					
0	M3	M2	T	V3	V2	A
10	0	33.22	0.651	17.41	0	0
20	1.73	31.74	1.19	17.36	0.18	2.53
30	12.5	29.56	4.1257	17.1167	0.5167	5.224
40	18.96	29.46	8.79	16.6638	1.2208	8.18
45	23.49	24.59	10.77	14.84	2.356	12.4

4.3.6 Discussion for continuous bridge

For Dead load:

M3 value is observed to be increasing for the all the bridges analysed as continuous bridges. Torsional moment (T) is observed to be less as compared to respective simply supported bridge. The M2 moment is seen to be rapidly increasing after 30 degrees for all the spans.

Hogging moment is present at the intermediate supports, and sagging moment is present at mid span.

In case of moment about horizontal axis for the cases considered it is observed that there is an exponential increase in the value.

For Live load:

At 0 degrees, a nominal value of torsional moment (T) is observed due to eccentricity of load. Moment about vertical axis (M2) and moment about horizontal axis (M3), reaches a same value at 45 degrees. In case of continuous bridges due to live load and bearing conditions given axial forces are developed in the deck. As skew angle increases the axial forces due to live load also increases.

For Earthquake in X:

As skew angle increases, the length of bridge increases resulting in increase in earthquake force. As observed, unlike simply supported bridges the M3 value goes on increasing due to increasing earthquake force. The component of earthquake force in transverse direction increases with increase in skew angle. It is also seen that M2 and M3 become nearly equal at 45 angle of skew. The reduction in component of earthquake force in longitudinal direction can be observed via decrease in the value of axial force.

For Earthquake in Y:

The increase in component of earthquake force in longitudinal direction can be observed via increase in the value of axial force. Unlike M3 for earthquake in X, as observed here M2 value is continuously decreasing for every increase in value of skew. Moment about horizontal axis is increasing as the component in the longitudinal direction is increasing.

It is observed that the M2 and V3 and M3 and V2 go hand in hand i.e. if M2 increases V3 increases.

5. CONCLUSION

- It can be concluded that effect of earthquake is not found to be significant. The value of forces and moments due to earthquake are very less (i.e. order of 10% of Dead load)
- As observed above, all the parameters such as bending moment, torsion, and shear seem to be increasing till skew angle of 45 degrees, and a sudden changes is observed at 45 degrees.
- In case of continuous bridge, the design bearing(that is end conditions) play an important role while considering effect of earthquake

- Continuity of deck slab tends to provide better stability and thus reduces torsion in bridges.
- In Continuous bridges, there is an abrupt increase in the value of moment about vertical axis (M2), for earthquake in longitudinal direction, for increasing angle of skew.
- For integral bridges, the axial forces seem to more evenly distributed, when observed for earthquake forces.

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