International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 3.45 (SJIF-2015), e-ISSN: 2455-2585
Volume 4, Issue 01, January-2018

EFFECT OF SKEW ANGLE ON PSC I GIRDER BY USING STAAD PRO

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Abstract— *The effect of a skew angle on single-span RC bridges and PSC bridges are analyzed by utilizing the grillage analysis & the results or outcomes are presented in this paper. Studies are carried out on pre-stressed concrete (PSC) bridge decks to study the influence of skew angle and type of loading. The grillage analysis results of skewed bridges are compared with that of reference to straight bridges for IRC Class A loading and Class 70R Tracked & Wheeled Vehicles. Also, comparative analysis of response of skewed PSC Slab Bridge decks with that of equivalent straight bridge decks is made. The variation of maximum longitudinal bending moment (BM), maximum transverse moment, maximum torsional moment and maximum longitudinal stresses with skew angles are studied for bridge deck replicas. The results obtained for Live load longitudinal bending moment's decreases with an increase in skew angle, whereas a maximum transverse moment increase with an increase in skew angle & also maximum torsional moment increases with an increase in skew angle. The benefit of pre-stressing is reflected in considerable decrease in the longitudinal bending moment, transverse moment and longitudinal stresses. The whole structures or models are analysed with the help of STAAD Pro V8i Version.*

Keywords— *PSC bridge, IRC Class 'A' Loading, Class 70R Tracked and Wheeled Vehicles, Bending Moment, Torsional Moment, Transverse Moment and STAAD Pro V8i.*

I. INTRODUCTION

A. *General:*

Bridges are described as structures which provide a passage over a gap without closing way beneath. Bridges may be needed for a passage of railway, roadway and even for carrying of fluids, bridge site should be so chosen that it gives maximum commercial & social benefits, efficiency and equality. Bridges are nation's lifelines and backbones in the event of war. Bridges symbolize ideals and aspirations of humanity. Bridges can bring people, communities and nations into closer propinquity. They cut down distances, speed transportation and facilitate commerce. Bridges are symbols of humanity's heroic struggle towards mastery of forces of nature and these are silent monuments of mankind's indomitable will to attain it. Bridge construction stands for an important part in communication and is an important factor in progress of civilization, bridges stands as tributes to the work of civil engineer.

Prestressed concrete is ideally suited for the construction of medium and long span bridges. Ever since the development of prestressed concrete by Freyssinet in the early 30's, the material has created a extensive application in the construction of long span bridges, gradually replacing steel which needs costly maintenance due to the inherent disadvantage of corrosion under aggressive environmental conditions. One of the most normally used forms of superstructure in concrete bridges is precast girders which are cast-in-situ blocks or slabs. This type of superstructure is commonly used for spans between 20 to 40 m. T or I-girder bridges are the most familiar example under this type and are very popular because of their simple geometry, low fabrication cost, easy erection or casting and minor dead loads. In this paper study the IRC loading considered for design of bridges, also factor which are vital to decide the preliminary sizes of concrete I girders. Also considered the IRC: 18-2000 code for the "Prestressed Concrete Road Bridges" & "Code of Practice for Prestressed Concrete " of Indian Standard.

B. *Aim and Objective:*

1. To prepare a model of PSC I-Girder and analyse it in STAAD pro software.
2. Design of the Pre-stressed concrete I-Girder as per IRC 112:2011.
3. Analysis of loads and stresses which are acting on the Pre-stressed concrete I-Girder in agreement with IRC 6:2014.
4. Comparative study on straight and skewed bridge of PSC I Girder.

II. METHODOLOGY

A. *Design Philosophy for PSC I Girder:*

The design of the super structure done for the 2 lane loading with footpath & 3 lane loading without footpath loading, critical design values are considered.

a)	Structure Type	Major Bridge
b)	Chainage	209+435
c)	Crossing	Skew
d)	Span arrangement	1 x 45.5 m

e)	Span lengths, L (c/c of bearing)	44.3 m
f)	Skew Angle	30 Deg.

1. *Geometry*

a)	Carriageway Width	9.5m
b)	Overall width	12.5m
c)	Width of Crash Barrier	0.50m
d)	Cross slope	2.0%
e)	Thickness of wearing course	75mm
f)	C/C of the Girder	3.1m
g)	Distance between C/L of Expansion Joint to C/L of Bearing	0.6m
h)	Width of Footway	1.5m
i)	Width of RCC Kerb & Railing	0.5m

B. *Loading:*

a) Dead Load (DL)

Unit weight for Dead loads calculation shall be considered as per IRC: 6-2014.

b) Super Imposed Dead Load (SIDL)

Unit weight for superimposed dead load shall be in conformity with IRC:6-2014. For calculating the dead weight due to wearing coat, thickness of 100mm shall be taken considering future overlay.

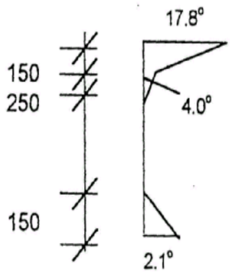
c) Carriageway and Footpath Live Load (LL)

- 1 Lane of Class 70R/ 2 lane of Class A
- 3 Lanes of Class A/1 lane of 70R in combination with 1 lane of class A on third lane

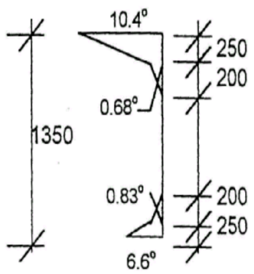
Conforming to IRC 6-2014 shall be considered in analysis and whichever producing severe effect shall be considered in design. Reduction in longitudinal effect for three lane loading shall be considered as per clause 205 of IRC: 6. Pedestrian live load in conformity with clause 206.3 shall be considered over the footpath.

d) Temperature loading (Temperature Gradient)

The Climatic Condition is assumed to be "Moderate". The temperature variation of +/- 15 Deg. shall be considered. The temperature gradient to be considered is shown below:



Temperature Rise



Temperature Fall

Coefficient of thermal expansion $12.0 \times 10^{-6}/^{0}C$ as per IRC: 6-2014.

Poisson's Ratio = 0.2   Modulus of Elasticity as per Table 8 of IRC: 112-2011.

e) Differential Shrinkage and Creep

For differential shrinkage and creep stress calculations the following parameters shall be considered (As per Explanatory Hand Book to BS 5400 By L.A.Clark):

- Differential shrinkage strain = 1.00E-04 ; Creep Factor = 0.43

C. *Structural Analysis:*

a) Method of Analysis for longitudinal Girders

The analysis of the I-Girder for longitudinal flexure shall be carried out using Grillage model on STAAD Pro on the following basis:

- It is proposed to have 4 no's of straight longitudinal beams at 3.1m centre to centre with 1.6m cantilever projection on either side.
- Grillage model has been generated with longitudinal members along the C/L of the I-Girder and with dummy members in between the longitudinal girders and along the outer edges. Suitable transverse members along the cross beams have also been provided.
- Moment and shear force will be calculated separately for inner & outer girders by keeping the loading with minimum eccentricity to crash barrier.
- For the design of the longitudinal Girders stresses and moments shall be determined at End of solid section, End of tapering section and at an every interval of L/8.
- Transverse members of the grillage other than the Cross-diaphragm shall be modelled as slab elements.

b) Method of Analysis for Cross Diaphragm

The analysis of the Cross Diaphragm shall be carried out using Grillage model on STAAD Pro on the following basis:

- The end cross Diaphragm shall be designed both as a continuous beam supported on the longitudinal girders and for the jack up condition.

c) Section properties

- The effective flange width calculation for determination of sectional properties for the longitudinal girders and cross diaphragm shall be done in accordance with IRC: 112-2011.
- The longitudinal members shall have negligible torsion carrying capacity (i.e. we assign very small torsional moment of inertia for the members).

d) Method of analysis for deck slab

- The deck slab shall be designed as a continuous one-way slab supported on the longitudinal girders with cantilever overhang beyond the girders. Live load effects shall be taken based on effective width method.

D. *Prestressing Effects:*

a) Basic Design Assumptions Relating to Prestressing

- It is proposed to use 19T15 cables conforming to Class 2 of IS : 14268 (Low relaxation strands) with Uncoated galvanized Sheathing for prestressing.
- Values of friction and wobble coefficient (f and k) for prestressing strands shall be considered as f= 0.2 and k = 0.0030. (Ref Table 7.1 of IRC 112:2011)
- Relaxation losses shall be computed considering relaxation loss of 2.5% at 0.75 UTS. (Ref Table 6.2 ; IRC:112-2011)
- Ultimate resistance of the T-Girder in flexure shall be checked against yielding of steel and against crushing of concrete as of IRC: 112-2011.
- Maximum jack pressure shall be considered as 75% of ultimate force.
- Duct diameter (Internal) is considered as 100mm. Clear cover protecting cable from the nearest concrete surface is kept as 75mm as per IRC: 112-2011.

b) Proposed Sequence of Prestressing

The girder shall be pre-cast on the ground.

- Prestress First Stage for the cables 2 & 3 after 7 days of casting of girder or after a concrete has attained strength of 30 Mpa whichever is later.
- Prestress second Stage for the cables 1, 4 & 5 after 28 days of casting of girder or after a concrete has attained a strength of 45 Mpa whichever is later
- Transport the girders to the site.
- Launch the precast girders to the position. For launching the girders, holding will be done only on either ends near end diaphragm.
- Erect staging and shuttering for RC top slab by suitable supporting arrangement from web / bottom bulb of girders.
- Cast the top Reinforced Concrete Slab together with cross diaphragm on 35th day.
- Cast the crash barrier on 56 days after casting of girder.
- Lay wearing coat.

III. MODELING AND ANALYSIS

A. *Girder Details:*

Span Arrangement	=	45.500	m
(C/C of expansion joint)	=	45.500	m
(C/C of bearing)	=	44.300	m
Girder beyond centre line of bridge	=	0.600	m

B. *Material Properties:*

Concrete Grade for Deck Slab	=	M – 45
Concrete Grade for Cross Girder	=	M – 45
Concrete Grade of Girder	=	M – 45
Reinforcement	=	500
Clear Cover	=	50 mm
Condition of Exposure	=	Moderate
Cable	=	19 15

C. *Analysis:*

The grillage is the commonly used model for bridge decks and it is relatively easy to use. However, a finite element model is quite probably to still be needed moreover for the analysis of elastic critical buckling of the steel girders supporting wet concrete loading. Consequently, a finite element model shall be considered for all analysis, which would also have the possible advantage of improved modelling of structural response. However, there are several drawbacks of this approach at the present and plenty of designers use a grillage for the most analysis and solely use a finite element model wherever fully necessary.

In this present study the grillage model of PSC I Girder models are done for 45.5m span with square and skew 30^{o} Degree using STAAD.Pro.

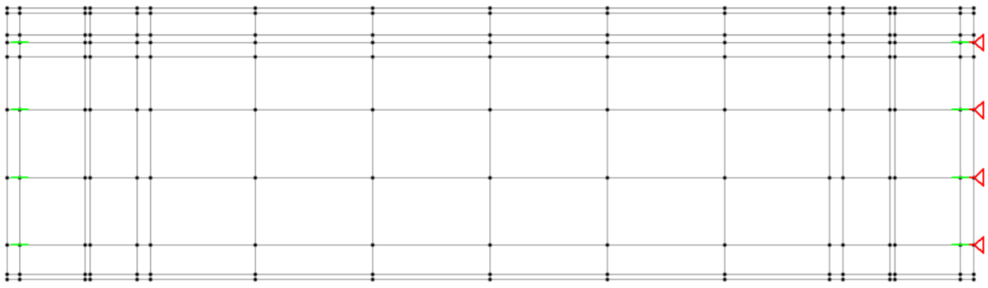


Fig.3.1 Grillage Analysis model of 45.5m Span PSC I Girder with 0^0 Skew

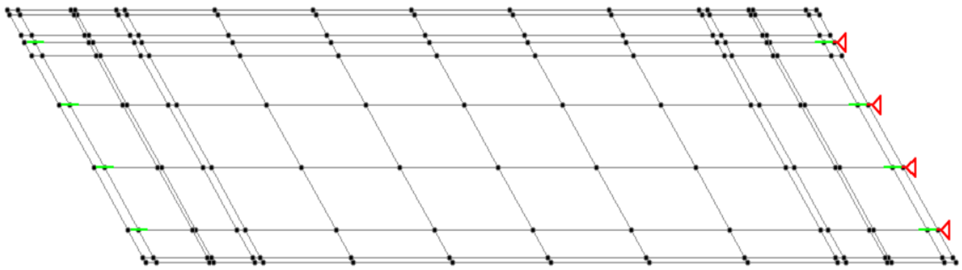


Fig.3.2 Grillage Analysis model of 45.5m Span PSC I Girder with 30^0 Skew

D. *Section Dimensions of PSC I-Girder:*

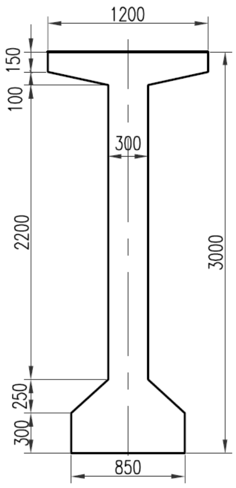


Fig.3.3. Mid-Section Dimensions of PSC I Girder

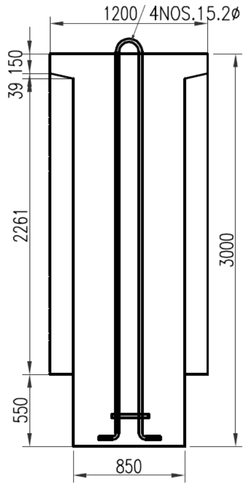


Fig.3.4. End-Section Dimensions of PSC I Girder

E. *Super Imposed Dead Load (SIDL):*

Unit weight of Wet RCC		=	26.00	KN/m3			
Unit weight of RCC		=	25.00	KN/m^3			
Unit weight of PCC		=	25.00	KN/m^3			
Width of Footpath		=	1.500	m			
Average Height of raised Footpath		=	0.075	m			
Weight of Footpath		=	1.5 x 0.075 x 25		=	2.813	KN/m
Footpath Live Load:							
As per IRC: 6-2014, Clause 206.3							
Intensity of Footpath Live load	p	=	(p'-260+(4800/L))*((16.5-w)/15)				
	P'	=	500.00	kg/m^2			
	P	=	348.35	kg/m^2			
		=	3.5	KN/m^2			
Footpath Live Load		=	3.5 x 1.5		=	5.225	KN/m

Construction stage Load:

Addition Shuttering Load considered	=	1.8	KN/m^2
Addition construction stage load considered=		1.8	KN/m^2

IV. ANALYSIS RESULTS

A. *Bending Moment for External Girder With 0^o Skew (t-m):*

SECTION	Support	D from Support	End of Tapering	2L/8	3L/8	4L/8	5L/8	6L/8	End of Tapering	D from Support	Support
DL-Girder Alone	1.2	239.0	367.9	609.6	754.6	802.9	754.6	609.6	367.9	239.0	1.2
DL-Slab Load	0.3	118.7	188.6	323.6	404.6	431.5	404.5	323.6	188.6	118.7	0.3
Construction load	0.1	36.5	58.0	99.6	124.5	132.8	124.5	99.6	58.0	36.5	0.1
Shuttering load	0.1	36.5	58.0	99.6	124.5	132.8	124.5	99.6	58.0	36.5	0.1
SIDL-CB (2LANE)	2.2	68.8	106.6	164.7	215.8	214.3	215.8	164.7	106.6	68.8	2.2
SIDL-CB (3LANE)	0.1	34.5	51.3	69.0	96.7	88.3	96.7	69.0	51.3	34.5	2.2
SIDL W.C	0.1	40.3	64.3	111.6	138.9	149.0	138.9	111.6	64.3	40.3	0.1
FPLL	1.6	25.6	40.7	66.0	84.7	86.5	84.7	66.0	40.7	25.6	1.6
DESIGN LL (2LANE)	4.3	94.8	159.3	311.0	363.3	415.0	364.4	315.6	163.8	96.6	4.4
DESIGN LL (3LANE)	7.5	135.4	225.4	405.2	502.1	542.5	503.9	413.5	237.7	145.7	8.8
TOTAL	9.7	587.3	927.5	1586.5	1961.9	2099.3	1962.9	1591.1	931.8	589.1	12.6
ULS	13.6	803.2	1271.3	2156.0	2691.6	2860.3	2694.2	2168.4	1289.6	818.6	18.3

B. *Bending Moment for External Girder With 30^o Skew (t-m):*

SECTION	Support	D from Support	End of tapering	2L/8	3L/8	4L/8	5L/8	6L/8	End of tapering	D from Support	Support
DL-Girder Alone	1.2	244.9	384.8	637.8	789.6	840.2	789.6	637.8	384.8	244.9	1.2
DL-Slab Load	0.4	143.5	232.8	399.4	499.3	532.7	499.3	399.4	232.8	143.5	0.4
Construction load	0.1	44.2	71.6	122.9	153.6	163.9	153.6	122.9	71.6	44.2	0.1
Shuttering load	0.1	44.2	71.6	122.9	153.6	163.9	153.6	122.9	71.6	44.2	0.1
SIDL-CB (2LANE)	3.2	68.7	106.9	169.6	222.2	221.5	221.4	166.9	98.4	59.6	8.2
SIDL-CB (3LANE)	4.7	34.4	51.9	76.0	103.1	96.7	103.1	76.0	51.9	34.6	8.2
SIDL W.C	0.6	48.5	79.2	137.3	171.0	183.4	171.0	137.3	79.2	48.5	0.6
FPLL	3.4	22.8	35.8	59.5	77.2	79.1	76.9	58.3	31.6	18.2	4.5
DESIGN LL (2LANE)	9.0	79.7	137.4	275.7	323.8	375.8	330.4	283.1	146.7	83.6	8.1
DESIGN LL (3LANE)	16.1	121.9	202.4	372.2	462.9	504.5	469.0	376.1	221.9	137.5	17.3
TOTAL	22.9	608.1	977.0	1679.3	2083.1	2232.6	2088.6	1682.8	973.5	609.0	27.6
ULS	33.6	838.6	1346.0	2301.4	2872.8	3061.6	2882.0	2307.1	1375.2	862.2	40.1

C. *Shear Force for External Girder With 0^o Skew (t):*

SECTION	Support	D from Support	End of tapering	2L/8	3L/8	4L/8	5L/8	6L/8	End of tapering	D from Support	Support
DL-Girder Alone	85.0	64.3	53.6	35.7	17.9	0.0	17.9	35.7	53.6	64.3	85.0
DL-Slab Load	39.9	34.0	29.9	19.9	10.0	0.0	10.0	19.9	29.9	34.0	39.9
Construction load	12.3	10.4	9.2	6.1	3.1	0.0	3.1	6.1	9.2	10.4	12.3
Shuttering load	12.3	10.4	9.2	6.1	3.1	0.0	3.1	6.1	9.2	10.4	12.3
SIDL-CB (2LANE)	22.2	18.9	17.3	9.9	9.7	2.2	9.7	9.9	17.3	18.9	22.2
SIDL-CB (3LANE)	10.8	8.9	7.7	5.1	5.1	1.5	5.1	5.1	7.7	8.9	10.8
SIDL W.C	13.5	11.6	10.3	7.2	3.5	0.3	3.5	7.2	10.3	11.6	13.5
FPLL	8.6	7.4	6.9	4.5	3.7	0.7	3.7	4.5	6.9	7.4	8.6
DESIGN LL (2LANE)	30.4	30.7	30.0	27.9	18.3	17.3	18.8	29.2	30.8	30.8	30.9
DESIGN LL (3LANE)	44.4	44.9	41.7	34.9	26.4	23.0	30.0	38.5	45.3	49.0	47.0
TOTAL	199.5	166.8	148.0	105.1	62.9	24.9	66.5	106.4	148.8	167.8	200.0
ULS	288.7	245.8	216.7	153.5	96.3	38.0	101.8	158.8	222.0	252.0	292.7

D. *Shear Force for External Girder With 30^o Skew (t):*

SECTION	Support	D from Support	End of tapering	2L/8	3L/8	4L/8	5L/8	6L/8	End of tapering	D from Support	Support
DL-Girder Alone	86.8	66.2	54.8	36.5	18.3	0.0	18.3	36.5	54.8	66.2	86.8
DL-Slab Load	48.1	41.1	36.1	24.1	12.0	0.0	12.0	24.1	36.1	41.1	48.1
Construction load	14.8	12.7	11.1	7.4	3.7	0.0	3.7	7.4	11.1	12.7	14.8
Shuttering load	14.8	12.7	11.1	7.4	3.7	0.0	3.7	7.4	11.1	12.7	14.8
SIDL-CB (2LANE)	21.0	17.3	16.6	11.1	9.9	1.7	9.8	11.2	16.8	19.1	21.0
SIDL-CB (3LANE)	9.9	8.6	7.7	4.9	4.9	1.1	4.9	4.9	7.7	9.3	10.0
SIDL W.C	16.3	14.1	12.5	8.7	4.2	0.4	4.2	8.7	12.5	14.1	16.3
FPLL	7.0	6.1	5.7	4.4	3.5	0.7	3.4	4.4	5.7	6.1	7.0
DESIGN LL (2LANE)	25.0	25.2	25.3	25.0	15.9	15.2	17.8	26.1	27.8	27.7	27.4
DESIGN LL (3LANE)	38.5	38.1	35.8	32.9	25.4	22.2	30.1	36.8	41.9	45.4	45.0
TOTAL	204.2	169.9	151.0	109.8	64.8	23.7	69.5	111.0	153.7	176.1	206.7
ULS	296.9	250.0	220.7	161.4	99.6	36.3	106.7	167.3	230.1	263.3	306.7

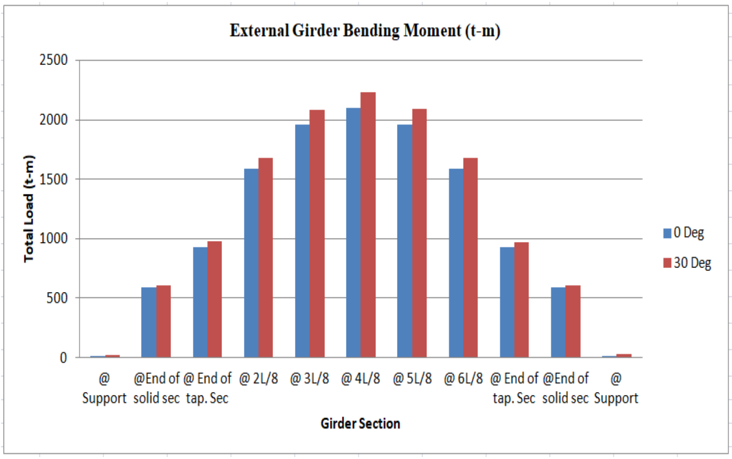


Fig-4.1: Bending Moment for External Girder.

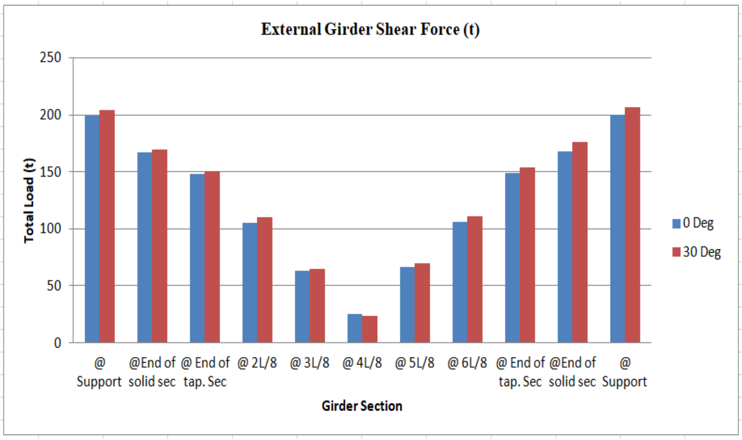


Fig-4.2: Shear Force for External Girder.

E. *Bending Moment for Internal Girder With 0^o Skew (t-m):*

SECTION	Support	D from Support	End of Tapering	2L/8	3L/8	4L/8	5L/8	6L/8	End of Tapering	D from Support	Support
DL-Girder Alone	1.2	239.0	367.9	609.6	754.6	802.9	754.6	609.6	367.9	239.0	1.2
DL-Slab Load	0.3	116.9	185.6	318.4	398.1	424.7	398.1	318.4	185.6	116.9	0.3
Construction load	0.1	36.0	57.1	98.0	122.5	130.7	122.5	98.0	57.1	36.0	0.1
Shuttering load	0.1	36.0	57.1	98.0	122.5	130.7	122.5	98.0	57.1	36.0	0.1
SIDL-CB (2LANE)	0.6	38.6	64.6	130.2	153.4	177.6	153.4	130.2	64.6	38.6	0.6
SIDL-CB (3LANE)	0.5	17.3	31.0	73.2	81.1	100.8	81.1	73.2	31.0	17.3	0.5
SIDL W.C	0.2	41.2	65.2	110.5	138.8	147.2	138.8	110.5	65.2	41.2	0.2
FPLL	0.2	10.7	18.4	39.1	44.5	52.3	44.5	39.1	18.4	10.7	0.2
DESIGN LL (2LANE)	9.1	124.9	170.2	209.7	316.0	291.7	317.1	218.9	180.8	130.5	10.6
DESIGN LL (3LANE)	9.1	124.9	171.3	286.8	371.7	390.8	372.5	299.3	181.0	130.5	10.6
TOTAL	11.5	571.3	872.0	1417.6	1805.5	1896.5	1806.6	1426.8	882.5	576.8	13.0
ULS	16.6	763.2	1160.2	1975.2	2466.3	2637.3	2467.4	1994.0	1174.6	771.5	18.9

F. *Bending Moment for Internal Girder with 30^o Skew (t-m):*

SECTION	Support	D from Support	End of Tapering	2L/8	3L/8	4L/8	5L/8	6L/8	End of Tapering	D from Support	Support
DL-Girder Alone	1.2	244.9	384.8	637.8	789.6	840.2	789.6	637.8	384.8	244.9	1.2
DL-Slab Load	0.4	141.3	229.1	393.0	491.4	524.2	491.4	393.1	229.1	141.3	0.4
Construction load	0.1	43.5	70.5	120.9	151.2	161.3	151.2	120.9	70.5	43.5	0.1
Shuttering load	0.1	43.5	70.5	120.9	151.2	161.3	151.2	120.9	70.5	43.5	0.1
SIDL-CB (2LANE)	5.2	45.6	73.9	135.9	160.0	183.9	158.4	133.2	65.0	36.5	4.6
SIDL-CB (3LANE)	0.9	22.1	37.3	74.0	85.4	101.7	85.4	74.0	37.3	22.1	0.9
SIDL W.C	0.8	49.3	80.0	136.3	171.1	181.4	171.1	136.3	80.0	49.3	0.8
FPLL	2.9	13.4	21.0	37.3	43.1	50.0	42.1	35.5	16.0	8.2	2.9
DESIGN LL (2LANE)	8.6	118.8	170.7	212.7	315.4	288.3	312.4	215.7	172.4	122.6	11.6
DESIGN LL (3LANE)	12.3	118.8	177.4	283.3	370.2	386.4	366.6	293.2	171.8	121.5	14.6
TOTAL	19.0	613.2	959.5	1553.0	1970.7	2067.9	1965.0	1551.6	947.2	602.7	21.5
ULS	23.1	815.5	1285.3	2155.0	2699.4	2876.3	2693.9	2170.0	1277.6	821.3	26.6

G. *Shear Force for Internal Girder with 0^o Skew (t):*

SECTION	Support	D from Support	End of Tapering	2L/8	3L/8	4L/8	5L/8	6L/8	End of Tapering	D from Support	Support
DL-Girder Alone	85.0	64.3	53.6	35.7	17.9	0.0	17.9	35.7	53.6	64.3	85.0
DL-Slab Load	39.3	33.4	29.4	19.6	9.8	0.0	9.8	19.6	29.4	33.4	39.3
Construction load	12.1	10.3	9.1	6.0	3.0	0.0	3.0	6.0	9.1	10.3	12.1
Shuttering load	12.1	10.3	9.1	6.0	3.0	0.0	3.0	6.0	9.1	10.3	12.1
SIDL-CB (2LANE)	11.8	11.9	11.9	12.0	4.5	4.5	4.5	12.0	11.9	11.9	11.8
SIDL-CB (3LANE)	5.2	6.2	6.6	7.9	3.6	3.6	3.6	7.9	6.6	6.2	5.2
SIDL W.C	13.9	11.7	10.2	7.1	3.4	0.3	3.4	7.1	10.2	11.7	13.9
FPLL	3.3	3.5	3.6	3.8	1.4	1.4	1.4	3.8	3.6	3.5	3.3
DESIGN LL (2LANE)	39.8	35.8	27.7	38.4	21.8	33.8	23.7	42.4	32.1	40.1	42.1
DESIGN LL (3LANE)	39.8	35.8	30.6	38.4	21.8	33.6	23.7	42.4	33.4	40.1	42.1
TOTAL	192.9	160.6	136.5	116.7	58.8	40.1	60.8	120.7	140.9	164.9	195.2
ULS	267.6	222.1	192.0	161.0	82.1	57.4	85.0	167.0	196.1	228.6	271.0

H. *Shear Force for Internal Girder with 30^o Skew (t):*

SECTION	Support	D from Support	End of Tapering	2L/8	3L/8	4L/8	5L/8	6L/8	End of Tapering	D from Support	Support
DL-Girder Alone	86.8	66.2	54.8	36.5	18.3	0.0	18.3	36.5	54.8	66.2	86.8
DL-Slab Load	47.4	40.5	35.5	23.7	11.8	0.0	11.8	23.7	35.5	40.5	47.4
Construction load	14.6	12.5	10.9	7.3	3.6	0.0	3.6	7.3	10.9	12.5	14.6
Shuttering load	14.6	12.5	10.9	7.3	3.6	0.0	3.6	7.3	10.9	12.5	14.6
SIDL-CB (2LANE)	12.7	12.5	12.4	11.5	4.5	4.5	4.5	11.5	12.1	12.2	12.5
SIDL-CB (3LANE)	6.6	6.6	6.6	6.6	3.2	3.2	3.2	6.6	6.6	6.6	6.6
SIDL W.C	16.8	14.2	12.4	8.5	4.1	0.4	4.1	8.5	12.3	14.2	16.8
FPLL	3.4	3.3	3.3	3.2	1.2	1.4	1.4	3.1	3.3	3.3	3.3
DESIGN LL (2LANE)	37.7	33.2	27.3	37.4	21.4	35.0	24.1	42.2	29.6	37.4	39.9
DESIGN LL (3LANE)	37.7	33.6	29.4	37.4	21.4	34.4	24.1	42.0	30.8	37.4	39.9
TOTAL	204.7	169.8	145.6	121.0	61.4	41.2	64.3	125.6	147.7	173.7	206.6
ULS	284.2	236.0	204.3	168.0	86.1	59.1	90.2	175.1	206.1	241.4	287.2

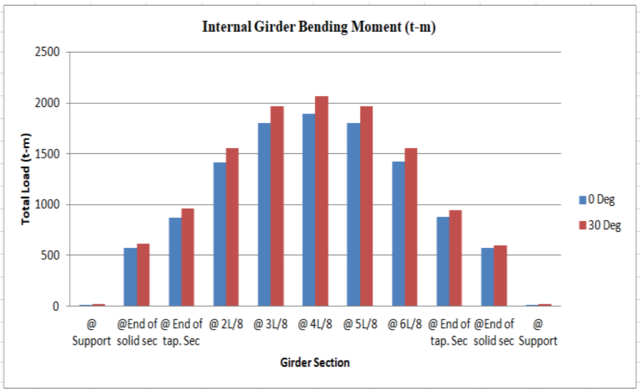


Fig-4.3: Bending Moment for Internal Girder.

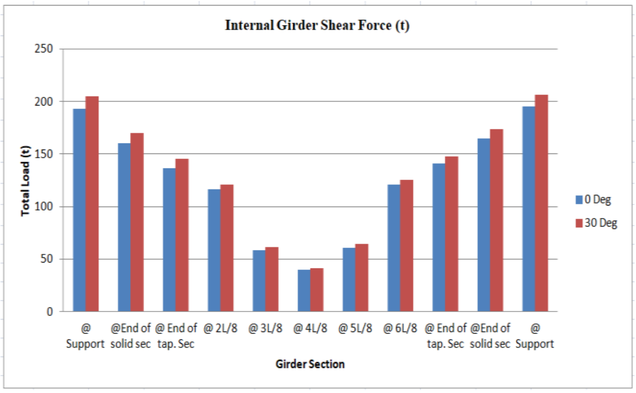


Fig-4.4: Shear Force for Internal Girder.

I. *Torsion Moment for External Girder with 30^o Skew (t-m):*

SECTION	Support	D from Support	End of Tapering	2L/8	3L/8	4L/8	5L/8	6L/8	End of Tapering	D from Support	Support
Construction load	0	0	0	0	0	0	0	0	0	0	0
Shuttering load	0	0	0	0	0	0	0	0	0	0	0
SIDL-CB (2LANE)	8.4174	7.1055	5.6343	1.6543	1.1233	1.7551	1.9351	2.6104	6.4655	8.7046	10.3398
SIDL-CB (3LANE)	7.5457	5.6379	3.3937	1.5296	1.5296	1.4134	1.5296	1.5296	3.4804	5.753	7.5374
SIDL W.C	0.6945	0.689	0.6612	0.5051	0.5486	0.5486	0.5486	0.5051	0.6471	0.6835	0.692
FPLL	0.6945	0.689	0.6612	0.5051	0.5486	0.5486	0.5486	0.5051	0.6471	0.6835	0.692
DESIGN LL (2LANE)	8.8339	8.0738	6.6672	3.094	1.3322	2.1754	2.1754	3.625	6.5096	7.7426	8.4435
DESIGN LL (3LANE)	16.3548	15.0058	12.4804	5.9481	2.9069	4.2199	4.2199	6.8284	13.4189	16.2138	17.6954

J. *Torsion Moment for Internal Girder with 30^o Skew (t-m):*

SECTION	Support	D from Support	End of Tapering	2L/8	3L/8	4L/8	5L/8	6L/8	End of Tapering	D from Support	Support
Construction load	0	0	0	0	0	0	0	0	0	0	0
Shuttering load	0	0	0	0	0	0	0	0	0	0	0
SIDL-CB (2LANE)	7.7583	6.9014	5.3944	1.5531	0.4281	0.8453	1.1081	2.298	6.0562	7.6435	8.6164
SIDL-CB (3LANE)	0.7167	0.69	0.625	0.3952	0.4815	0.4815	0.4815	0.395	0.6248	0.6917	0.7173
SIDL W.C	0.8131	0.7979	0.7226	0.4967	0.5533	0.5533	0.5533	0.4966	0.7245	0.7957	0.8101
FPLL	0.8131	0.7979	0.7226	0.4967	0.5533	0.5533	0.5533	0.4966	0.7245	0.7957	0.8101
DESIGN LL (2LANE)	12.55	10.368	8.123	2.5997	0.8071	1.2703	1.8914	3.3252	8.8878	11.8699	12.8133
DESIGN LL (3LANE)	21.647	19.568	15.5583	5.2995	2.0399	2.0465	3.5595	6.1813	17.0378	21.6503	23.5314

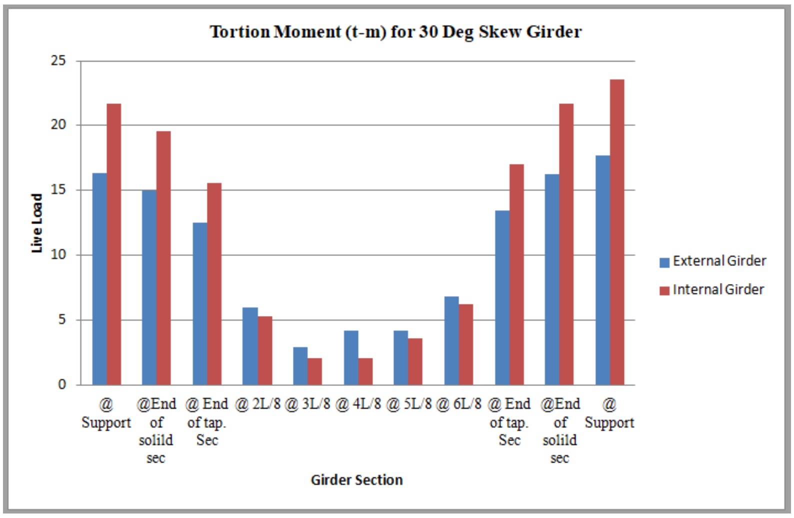


Fig-4.5: Torsion Moment for Live Load.

K. *Transverse Moment for External Cross Girder with 0^o Skew (t-m):*

Loadings		Sagging Moment (t-m)	Hogging Moment (t-m)	Shear Force (t)
DL		1.9	2.9	5.7
SIDL (W.C)		0	0	0
SIDL (C.B)		0.5	2.2	0.9
Pedestrian LL		0.1	0.4	0.2
Maximum Carriageway LL	70R (W & T)	9.0	10.0	20.7
	70R + 1LCA			
	2L Class A			
	3L Class A			
Summation (1.35 DL+1.75 SIDL+ 1.15 FPLL + 1.5 LL) ULS		**16.9**	**22.3**	**40.1**

L. *Transverse Moment for External Cross Girder with 30^o Skew (t-m):*

Loadings		Sagging Moment (t-m)	Hogging Moment (t-m)	Shear Force (t)
DL		5.6	7.6	9.1
SIDL (W.C)		0.8	0.6	0.4
SIDL (C.B)		5.5	13.9	7.1
Pedestrian LL		4.3	6.7	3.1
Maximum Carriageway LL	70R (W & T)	25.3	28.5	20.4
	70R + 1LCA			
	2L Class A			
	3L Class A			
Summation (1.35 DL+1.75 SIDL+ 1.15 FPLL + 1.5 LL) ULS		**59.3**	**80.4**	**56.8**

M. *Transverse Moment for Internal Cross Girder with 0^o Skew (t-m):*

Loadings		Sagging Moment (t-m)	Hogging Moment (t-m)	Shear Force (t)
DL		8.7	0	5.4
SIDL (W.C)		2.1	0	0.7
SIDL (C.B)		0	30.8	9.4
Pedestrian LL		0	7.3	2.0
Maximum Carriageway LL	70R (W & T)	68.6	17.5	22.4
	70R + 1LCA			
	2L Class A			
	3L Class A			
Summation (1.35 DL+1.75 SIDL+ 1.15 FPLL + 1.5 LL) ULS		**118.3**	**76.2**	**57.2**

N. *Transverse Moment for Internal Cross Girder with 30^o Skew (t-m):*

Loadings		Sagging Moment (t-m)	Hogging Moment (t-m)	Shear Force (t)
DL		6.2	1.4	5.9
SIDL (W.C)		2.6	0.1	0.8
SIDL (C.B)		0	35.3	9.3
Pedestrian LL		0.6	8.0	2.1
Maximum Carriageway LL	70R (W & T)	69.0	25.1	32.8
	70R + 1LCA			
	2L Class A			
	3L Class A			
Summation (1.35 DL+1.75 SIDL+ 1.15 FPLL + 1.5 LL) ULS		**117.2**	**96.5**	**73.5**

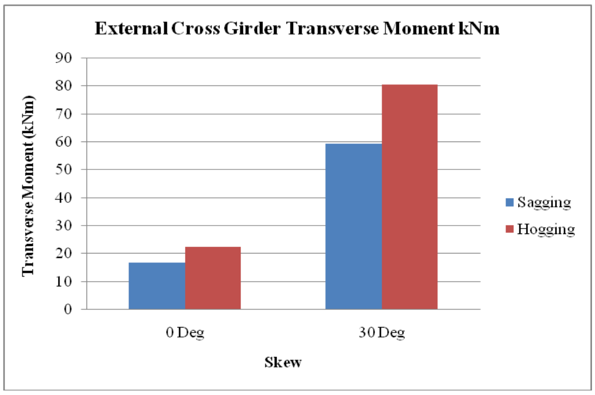


Fig-4.6: Transverse Moment for External Cross Girder.

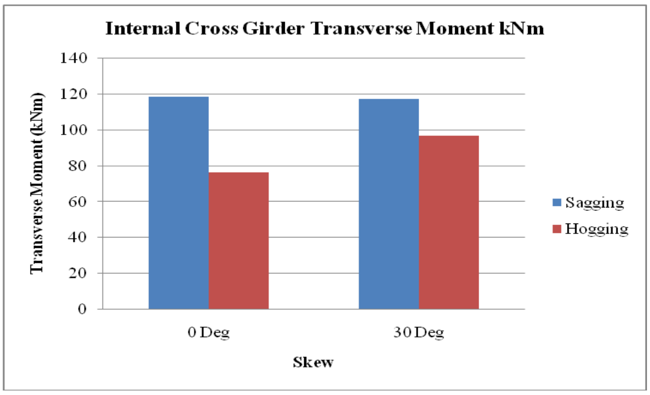


Fig-4.7: Transverse Moment for Internal Cross Girder.

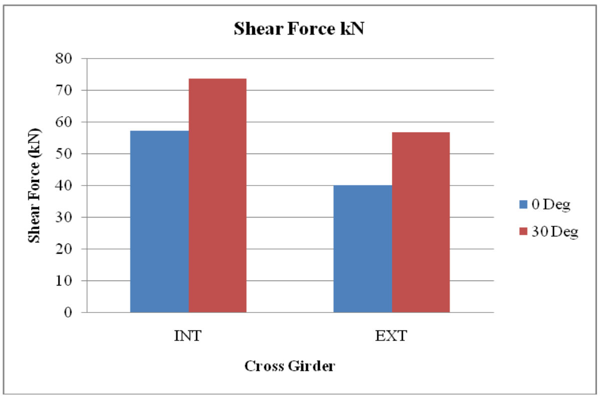


Fig-4.8: Transverse Shear for Cross Girder.

V. CONCLUSIONS

Torsion moment of inertia effect on the PSC I-girder Bridge with different skew angels i.e. 0^o, and 30^o were studied in this research.

- ✓ Depending upon the bending moment diagram obtained from Staad Pro software a parabolic cable profile is provided.
- ✓ Bending moment, shear force and torsion moments are getting from the STAAD grillage analysis results.
- ✓ Analysis and design of 1 lane of Class 70R Tracked and Wheeled Vehicles and 2 lanes of Class 'A' Vehicles and 45.5m span bridge superstructure is carried out in this paper.
- ✓ As skew increases the longitudinal bending moments are increased and the torsion moments also developed.
- ✓ The results tables show that bending moment, shear force and torsion moment at different sections of each girder.
- ✓ Torsion moment is more at end girders compared to inner girder.
- ✓ For straight girder bridge no torsion moment is observed.
- ✓ As skew changes the centre of gravity of bridge also changes so maximum moment does not occurs at centre of the girder for skew bridges.
- ✓ Hence it is concluded that, without torsion moment of inertia property there is torsion moment is occurred with skew effect.

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