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COMPARATIVE ANALYSIS OF HORIZONTALLY SKEWED COMPOSITE I-GIRDER BRIDGES

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ABSTRACT: *Analysis and design of modern intersections requires the utilization of slab bridges of different kinds of geometry with various boundary conditions. A number of methods for deck analysis are evolved in past 30 years. The Grillage Analogy method is the most widely used Computer-Aided method. It is not only reliable but accurate for different types of bridges. The gird is formed by constituting the designed arrangement of structural members connected together at discrete nodes. It also works absolutely fine when it comes to heavy skew, isolated supports and edge stiffening. The bending and torsional moments are related to the deformation of beam elements with two ends through their torsional and bending stiffness. The present study reports the major variations that arise in the distribution of Shear Force, Bending Moment and Torsion due to the change in skewness in Composite I-girder bridges. It also studies the torsional and Non-Torsional behavior of I-girders. The behavior of bridge decks are researched extensively under different loadings.*

Keywords: Deck; Bridge; Skew; Torsional; Grillage; STAAD Pro

1. INTRODUCTION

Girder bridges are the most regular and least complex type of crossing over between two Focuses. The span length and the site conditions frequently direct the kind of bridge that can be plausible at a given site. There are physical and monetary impediments, and the bridge choice procedure regularly begins by thinking about a straightforward culvert, advancing to a slab or girder framework, and eventually advancing to truss and other progressively complex frameworks if and whenever required. Remember that there are frequently exemptions to the prescribed bridge type choice driven by extraordinary site conditions, ecological guidelines, political impact, and numerous different factors. Initially, the girder choice depended on time-demonstrated depth-to-span ratios that controlled deflections and served the capacity of conveying the load. The essential capacity of these ratios is to control live load deflections furthermore, vibrations; notwithstanding, present day innovation is continually driving these ratios toward progressively lean and productive frameworks.

2. GRILLAGE ANALOGY METHOD

Grillage analogy is presumably is a standout amongst the most mainstream computer-aided methods for examining bridge decks. The method comprises of genuine decking arrangement of the bridge by a proportionate grillage of beams. The method consists of 'converting' the bridge deck structure in to a network of rigidly connected beams at discrete nodes i.e. idealizing the bridge by an equivalent grillage. The deformations at the two ends of a beam element are related to the bending and torsional moments through their bending and torsional stiffness.These moments are written in terms of the end-deformations employing slope defection and torsional rotation- moment equations. The shear force in the beam is also related to the bending moment at the two ends of the beam and can again be written in terms of the end-deformations of the beam. The shear and moment in all the beam elements meeting at a node and fixed end reactions, if any, at the node, are summed-up and three basic static equilibrium equations at each node namely

$\sum F_z = \sum M_x = 0$ and $\sum M_r = 0$

In general, a grid having 'n' nodes will have '3n' nodal deformations and '3n' equilibrium equations relating to these. Back sub situation in the slope deflection and torsional moments at the two ends of ends of each beam element. Shear forces are computed from bending moments and external loads.When a bridge deck is analyzed by the method of Grillage Analogy, there are essentially five steps to be followed for obtaining design responses:

i) Idealization of physical deck into equivalent grillage
ii) Evaluation of equivalent elastic inertias of members of grillage
iii) Application and transfer of loads to various nodes of grillage
iv) Determination of force responses and design envelopes and
v) Interpretation of results

2.1 Grillage Idealization of Slab-on-Girders Bridge

The idealization of beam and Slab Bridge by an assembly of interconnected beams seems to confirm more readily to engineering judgment than for slab bridges. The T-beams and I-beams are by far the most commonly adopted type of bridge decks consisting of longitudinal girders at definite spacing, connected by top slab, with or without transverse cross-beams. Usually, the diaphragms connecting the longitudinal girders are provided at the supports.

The logical choice of longitudinal grid lines for T-beam or I-beam decks is to make them coincident with the centre lines of physical girders and these longitudinal members are given the properties of the girders plus associated portions of the slab, which they represent. Additional grid lines between physical girders may also be set in order to improve the accuracy of the result. Edge grid lines may be provided at the edges of the deck of at suitable distance from the edge. For bridge with footpaths, one extra longitudinal grid line along the centre-line of each footpath slab is also provided.

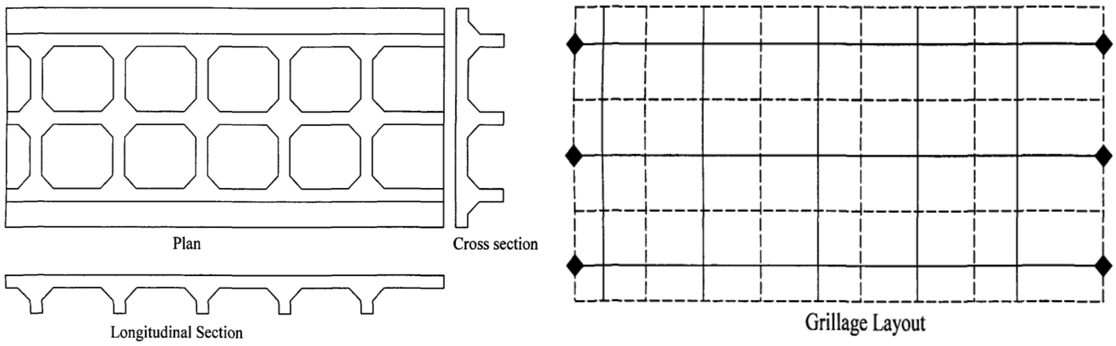


Figure 3.6

2.2 Evaluation of Equivalent Elastic Properties

After the actual bridge structure is simulated into equivalent grillage, consisting of longitudinal and transverse grid lines meeting at discrete nodes, the second important step in grillage analogy method is to assign appropriate elastic properties i.e. flexural and torsional stiff nesses to each member of the grillage so idealized. This needs the computation of equivalent flexural moment of inertia / and torsional inertia *J* for the members of the grillage mesh. This is accomplished by considering isolated sections of the deck as if they are individual beams and the inertias are calculated for each section and allotted to the corresponding grillage beams representing that section. The principles involved and the methodology adopted for evaluating the various flexural and torsional inertias are discussed first.

2.2.1. Flexural Moment of Inertia:

The computation of flexural moment of inertia I of different individual geometrical shapes like slab, T or I beams, box-girders etc. is straight forward and needs no elaboration. However in beams having Tee, L or box sections where slab is cast monolithically with the web of the beam effective flange width of the associated slab is to be considered. The Indian Roads Congress (IRC) recommendations for choosing suitable effective flange width of beams are being followed in India for road bridges and will be further discussed elsewhere in this section.

2.2.2 Torsional Inertia, J:

The torsional inertia J often referred to as the Saint-venant torsion constant also is generally not a simple geometrical property of the cross section as the case with flexural moment of inertia / and needs careful consideration. There is accurate analytical procedure for the derivation of J. However, the approximate method for the evaluation of J for different cross sections is based on the elastic theory of torsion of prismatic beams [15, 16] and is discussed below:

Saint-Venant [16] derived an approximate expression for computing the torsional inertia J, of open sections which is applicable to all cross-sectional shapes without having reentrant corners. The expression is,

$J= \frac{A^4}{40I_p}$

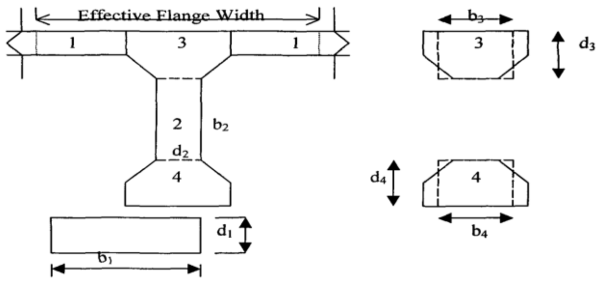
Where A is the area of cross section and I is the polar moment of inertia for a rectangle of sides b and d above expression reduces to,

$J=\frac{3b^3d^3}{10(b^3+d^3)}$

In the case of a thin rectangle where b>5d, the J value is more accurately given by

$J= \frac{bd^3}{3}$

If the cross section has reentrant corners J is very much less than that of above equation. In such cases, the value of J is obtained by notionally sub dividing the section in to rectangular shapes without having reentrant corners and summing the values of J of these elements. The value of J of sub division is a part of wide thin strip for which J=$bd^3/3$. Figure given below shows a T section with reentrant corners and its sub division. Thus if J values of the potions 1, 2, 3 and 4 and designated as J_1, J_2, J_3 and J_4 respectively then,
and for the beam section as a whole.



$J= J_1+ J_2+ J_3 + J_4$

$J_1=\frac{1}{2}(\frac{1}{3}b_1d_1^3)$ $J_2= (\frac{1}{3}b_2d_2^3)$

$J_3=\frac{3d_3^3d_2^3}{10(b_3^2+d_3^2)}$ $J_4=\frac{3d_4^3d_4^3}{10(b_4^2+d_4^2)}$

It may be noted that the value of J of the portion of deck slab forming the flange is to be halved to take into account its continuity in the other direction [16]. Widths b_3 and b_4 of segments 3 and 4 are so adjusted that areas b_3xd_3 *and* b_4xd_4 are same as original areas of the respective segments. While notionally sub-dividing the section, it is worth remembering prandtl's membrane analogy. It is shown that the torsional stiffness of a cross sectional shape is proportional to the volume under an inflated bubble stretched across a hole of the same shape. Thus, care is to be taken so as to obtain the largest numerical value of J of the section as a whole. This is achieved by choosing the elements so that they maximize the volume under their bubbles [15, 16] sib dividing the cross section arbitrarily into rectangles and not trying to maximize the volume under the bubble will result in lower value of J.

2.2.3 Flexural and Torsional Inertias of Grillage Members: Slab-on-Girders Deck:

Slab-on-girders bridge decks consist of a number of beams spanning longitudinally between abutments with a thin slab spanning transversely across the top. T-beam bridges are the common examples under this category. The beams may be cast monolithically with the slab or the precast beams with in-situ slab may be used. The decks may be with or without intermediate and /or end diaphragms. The thin slabs can be thought of as flanges of I or T-beams. When such I or T-beams bend, the flanges are subjected to flexural stresses. An element of the flange away from the rib or stem of the beam has less stress than the one directly over the rib due to shearing deformations of the flange. Shear deformation relieves some amount of compressive stress in more distant elements. This phenomenon is known as shear lag. The variation of compressive stress across the width of flange is accounted for by considering the effective width of flange.

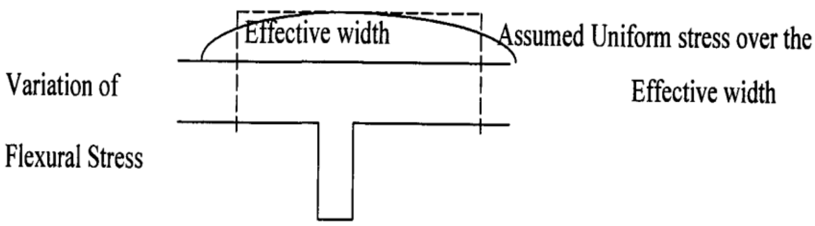


Figure 3.8: Variation of Flexural Stress

For the purpose of calculation of flexural and torsional inertias, the effective width of slab, to function as the compression flange of T-beam or L-beam, is needed.

The flexural inertia of each grillage member is calculated about its centroid. Often the centroid of interior and edge member sections is located at different levels. The effect of this is ignored, as the error involved is insignificant. Once the effective width of slab acting with the beam is decided, the deck is conceptually divided into number of T or L-beams as the case may be. Some portion of the slab may be left over between the flanges of adjacent beams in either direction.

If the construction materials have different properties in the longitudinal and transverse directions, care must be taken to apply correction for this. For example, in a reinforced concrete slab on pre-cast pre-stressed concrete beams or on steel beams, the inertia of the beam element (I or J) is multiplied by the ratio of modulus of elastic ties of beam Eb and slab Es materials to convert it into the inertia of slab material. For example the total torsional inertia in terms of the slab material will be given by

$J = J_1 + (J_2 + J_3 + J_4)\frac{E_b}{E_s}$

J_1 , J_2 , J_3 and J_4 are calculated.

$J_1 = \frac{1}{2}(\frac{1}{3} b_1 d_1^3)$

$J_2 = \frac{3 d_2^3 d_2^3}{10(b_2^2 + d_2^2)}$

$J_3 = (\frac{1}{3} b_2 d_2^3)$

$J_4 = \frac{3 d_4^3 d_4^3}{10(b_4^2 + d_4^2)}$

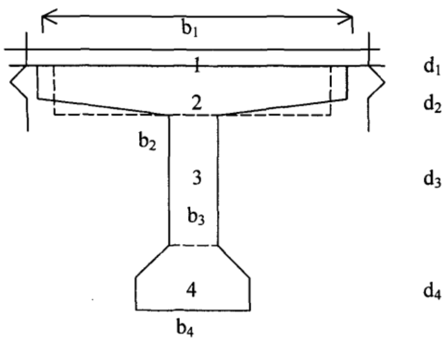


Figure 3.9 Torsional Inertia in Precast Beam with Cast - in - Situ Slab

To curb the effect of torsion equivalent shear and equivalent moment is calculated as per IRC 112-2000 :

a) Equivalent shear, V_e shall be calculated from the formula:

$$V_e = V + V_t$$

Where V_e = Equivalent Shear
V = Transverse Shear
V_t = Shear due to Torsional Moment

For rectangular and flanged beams:

$$V_t = 1.6 \frac{T}{b}$$

Where
T is the torsional moment
b is the breadth of the beam or in case of flanged beams

b) Longitudinal Reinforcement:

The longitudinal reinforcement shall be designed to resist an equivalent bending moment, M_e is given by

$$M_e = M + M_t$$

Where M = Bending Moment at the cross Section
M_t = Bending Moment due to torsion

For Rectangular and Flanged beams:

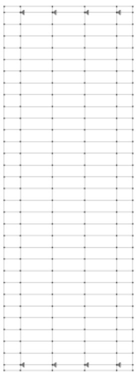
$$M_t = \frac{T*(1+D/b)}{1.7}$$

Where T = torsional moment,
D = the overall depth of the beam
b = Breadth of the beam

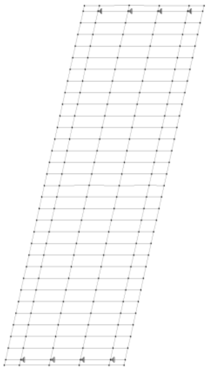
3. DIMENSIONS TAKEN

c/c of bearing of span		=	30.000	m
c/c of expansion joint of span		=	31.000	m
Projection beyond cL of bearing		=	0.480	m
Expansion gap		=	0.040	m
Total width of superstructure		=	12.000	m
Angle of skew		=	0.000	deg
Width of crash barrier,	2 no.s	=	0.500	m
Width of Railing	1 no.s	=	0.500	m
Footpath width provided on	1 sides	=	1.500	m
Carriageway width	1 no.s of	=	9.000	m
No. of Girders		=	4	m
Cantilever at each end of cross section		=	1.500	m
Spacing of girders		=	3.000	m
Length of support portion from cL of bearing at end span		=	2.000	m
Length of flaring web portion		=	2.000	m
Length of normal web portion		=	22.000	m
Total girder length = 22 + 2 x 0.15 + 2 x 2 + 2 x 2			30.300	m
Depth of girder		=	2.000	m
Depth of deck slab		=	0.225	m
Thickness of end diaphragm		=	0.400	m
Depth of diaphragm		=	1.800	m

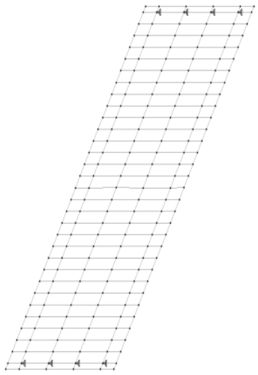
4. STAAD Models for Horizontally Skewed Bridges



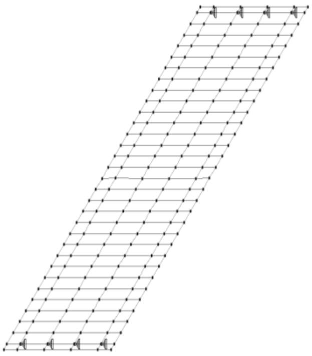
0^0



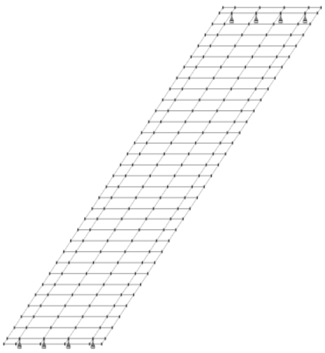
15^0



30^0



45^0



60^0

5. RESULTS AT MID SECTION

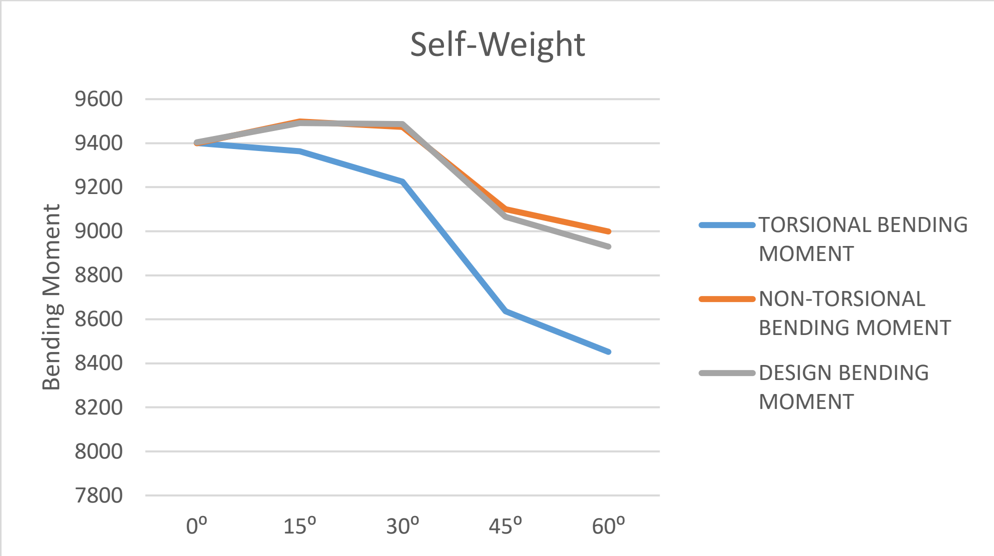
5.1 On Outer Girder

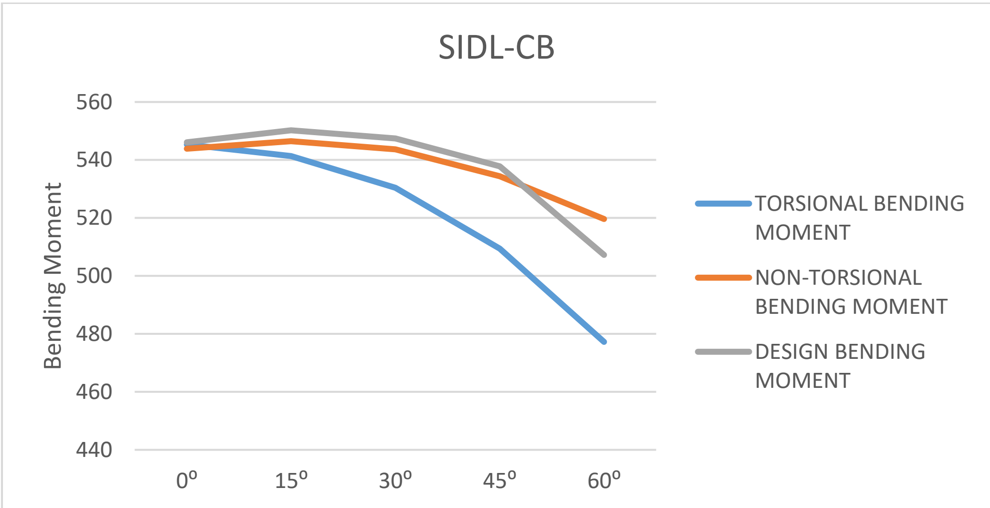
TORSIONAL BENDING MOMENT					
Comparison of Bending Moment (kN-m) at MID In OUTER GIRDERS (G1, G4)					
	SKEW				
Load Case	0^0	15^0	30^0	45^0	60^0
Self Weight	9400.65	9363.137	9225.006	8636.362	8451.98
SIDL-CB	545.347	541.353	530.43	509.382	477.237
SIDL-WC	487.448	485.446	478.199	447.954	437.919
Class 70 RW	2075.523	2034.295	1911.027	1691.31	1470.368
Class A	1460.224	1259.806	1152.378	968.567	1025.309

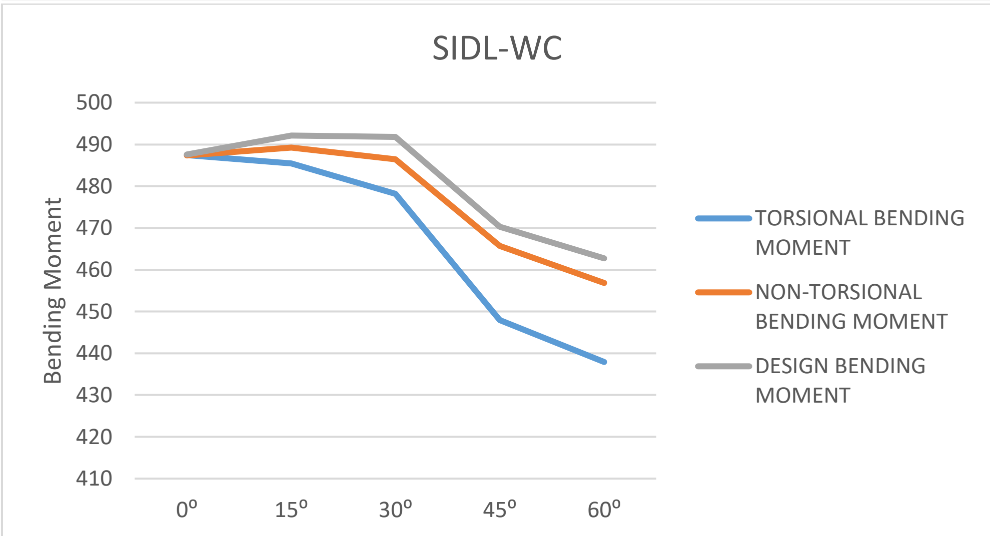
NON-TORSIONAL BENDING MOMENT					
Comparison of Bending Moment (kN-m) at MID In OUTER GIRDERS (G1, G4)					
	SKEW				
Load Case	0^0	15^0	30^0	45^0	60^0
Self Weight	9400.166	9498.569	9473.903	9100.51	8998.872
SIDL-CB	543.866	546.469	543.644	534.423	519.625
SIDL-WC	487.369	489.243	486.419	465.691	456.838
Class 70 RW	2192.948	2147.78	2015.856	1799.047	1469.401
Class A	1450.095	1354.202	1218.095	1055.799	1026.746

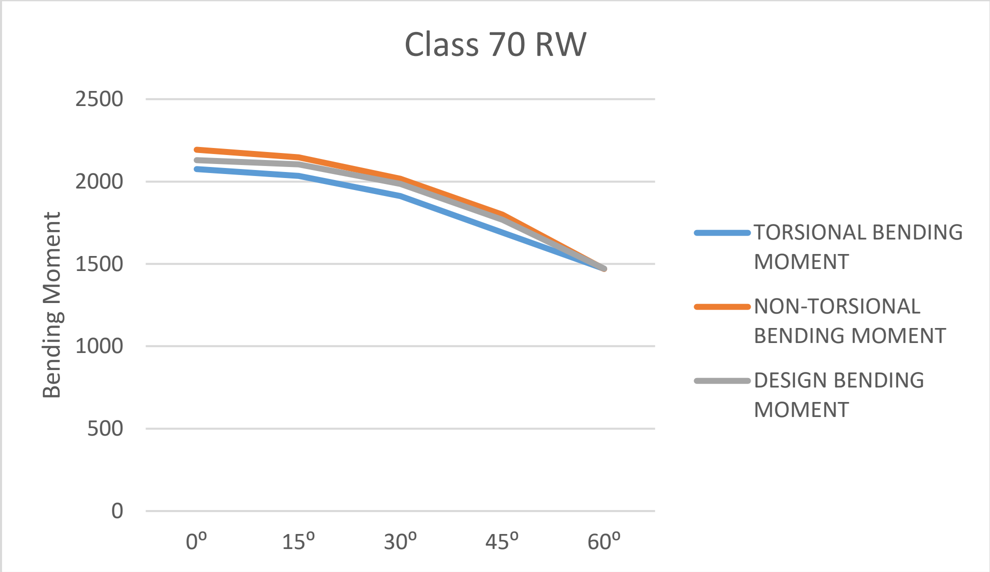
DESIGN BENDING MOMENT					
Comparison of Bending Moment (kN-m) at MID In OUTER GIRDERS (G1, G4)					
	SKEW				
Load Case	0^0	15^0	30^0	45^0	60^0
Self Weight	9404.56373	9491.37131	9486.87071	9065.33357	8930.15647
SIDL-CB	546.113667	550.230451	547.465294	537.801608	507.242882
SIDL-WC	487.621529	492.125412	491.806843	470.30498	462.728804
Class 70 RW	2129.72006	2103.77441	1985.02112	1767.17373	1471.3778
Class A	1468.06518	1302.21973	1197.39467	1023.60327	1026.30802

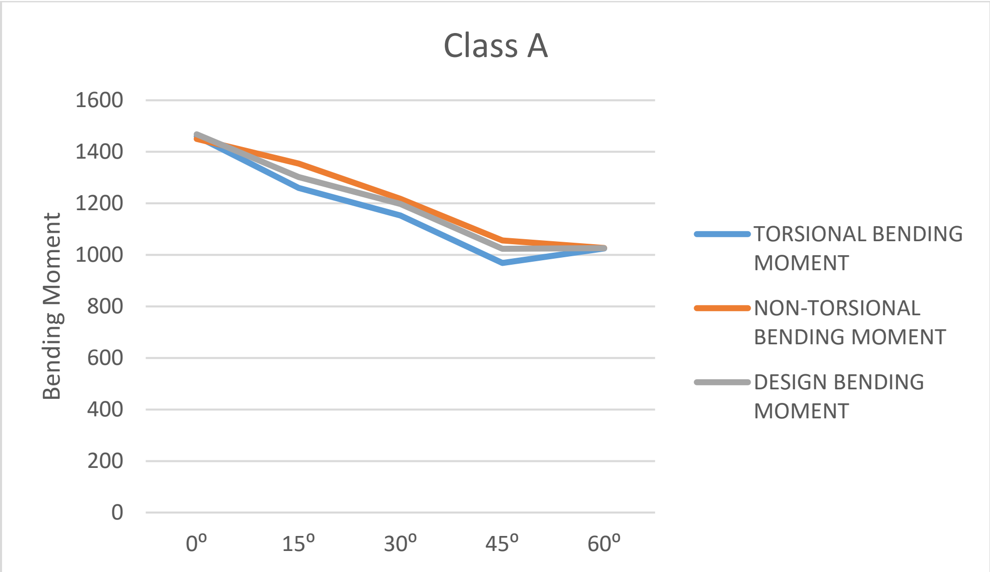
TORSIONAL MOMENT					
Comparison of Torsion (kN-m) at MID In OUTER GIRDERS (G1, G4)					
	SKEW				
Load Case	0^0	15^0	30^0	45^0	60^0
Self Weight	3.992	130.799	267.102	437.551	487.74
SIDL-CB	0.782	9.055	17.376	28.988	30.606
SIDL-WC	0.177	6.813	13.88	22.798	25.306
Class 70 RW	55.281	70.869	75.474	77.381	1.03
Class A	7.998	43.262	45.917	56.137	1.019


Self-Weight
9600
9400
9200
9000
8800
8600
8400
8200
8000
7800
Bending Moment
0°
15°
30°
45°
60°
TORSIONAL BENDING MOMENT
NON-TORSIONAL BENDING MOMENT
DESIGN BENDING MOMENT


SIDL-CB
560
540
520
500
480
460
440
Bending Moment
0°
15°
30°
45°
60°
TORSIONAL BENDING MOMENT
NON-TORSIONAL BENDING MOMENT
DESIGN BENDING MOMENT


SIDL-WC
500
490
480
470
460
450
440
430
420
410
Bending Moment
0°
15°
30°
45°
60°
TORSIONAL BENDING MOMENT
NON-TORSIONAL BENDING MOMENT
DESIGN BENDING MOMENT





5.2 On Inner Girder

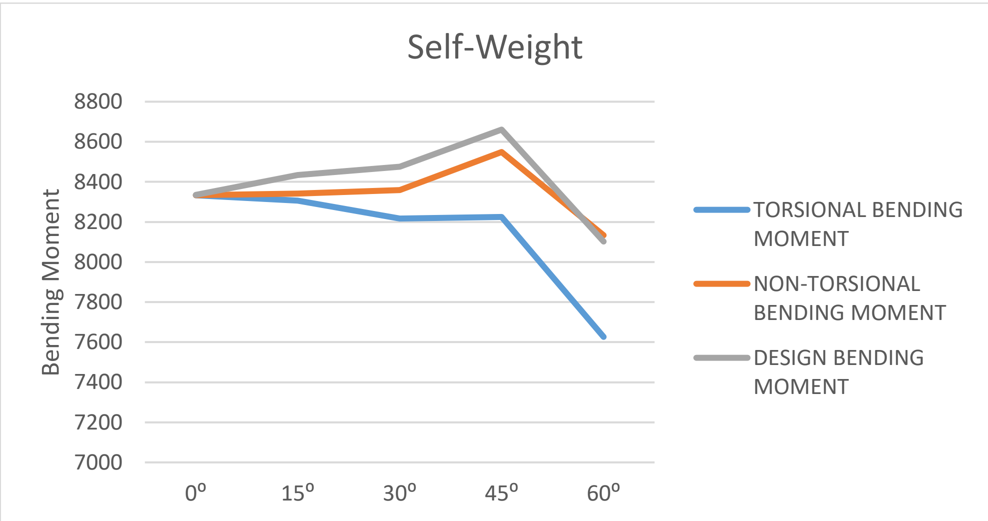
TORSIONAL BENDING MOMENT					
Comparison of Bending Moment (kN-m) at MID In INNER GIRDERS (G2, G3)					
	SKEW				
Load Case	**0^0**	**15^0**	**30^0**	**45^0**	**60^0**
Self Weight	8332.874	8306.208	8217.191	8224.958	7626.246
SIDL-CB	465.586	463.963	459	449.154	424.925
SIDL-WC	431.185	429.897	425.194	425.489	394.638
Class 70 RW	1555.203	1536.284	1502.886	1626.493	1386.99
Class A	1261.058	1004.154	965.885	766.958	780.01

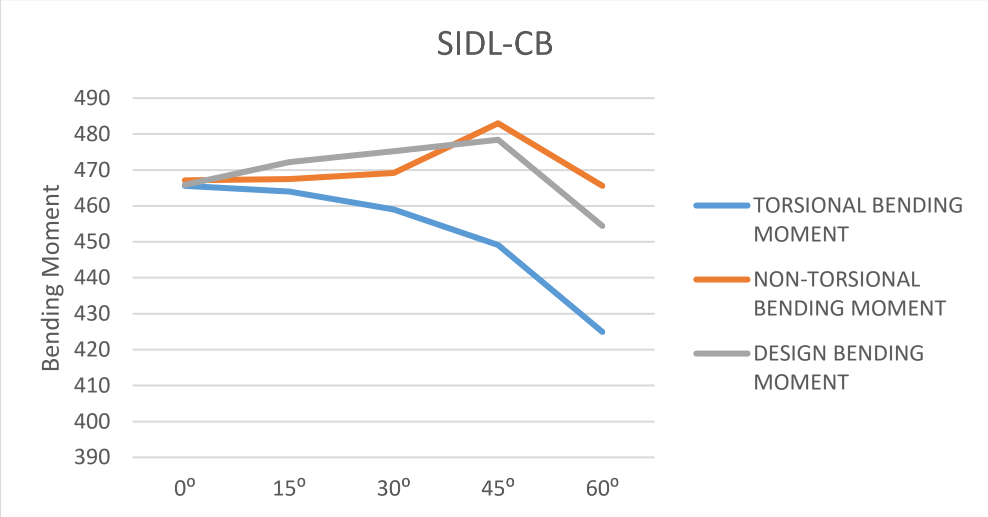
NON-TORSIONAL BENDING MOMENT					
Comparison of Bending Moment (kN-m) at MID In INNER GIRDERS (G2, G3)					
	SKEW				
Load Case	**0^0**	**15^0**	**30^0**	**45^0**	**60^0**
Self Weight	8333.204	8340.738	8359.604	8548.909	8133.492

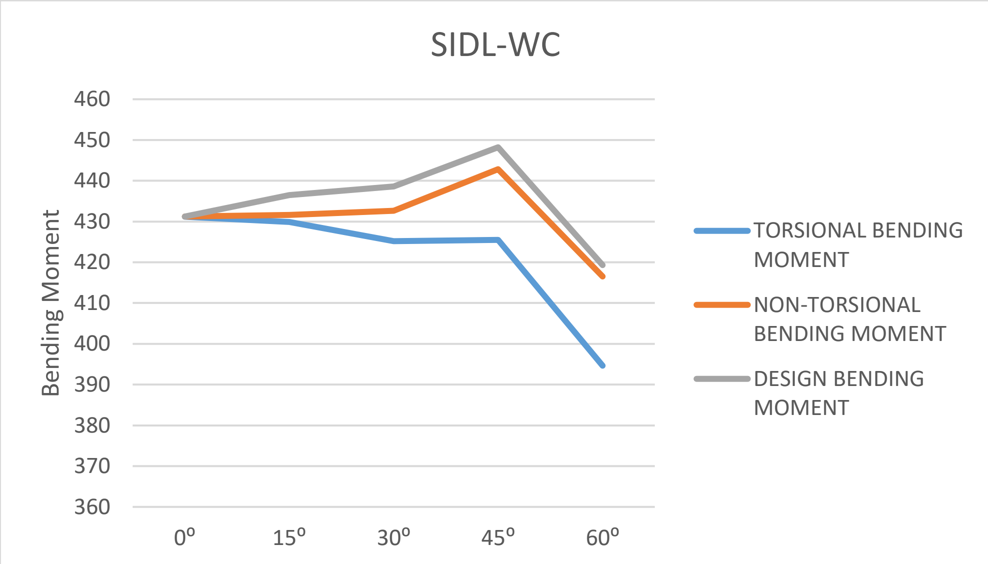
SIDL-CB	467.098	467.486	469.188	483	465.589
SIDL-WC	431.258	431.641	432.633	442.841	416.524
Class 70 RW	1720.95	1705.835	1672.532	1752.243	1387.282
Class A	1248.138	1062.616	1002.056	883.433	780.826

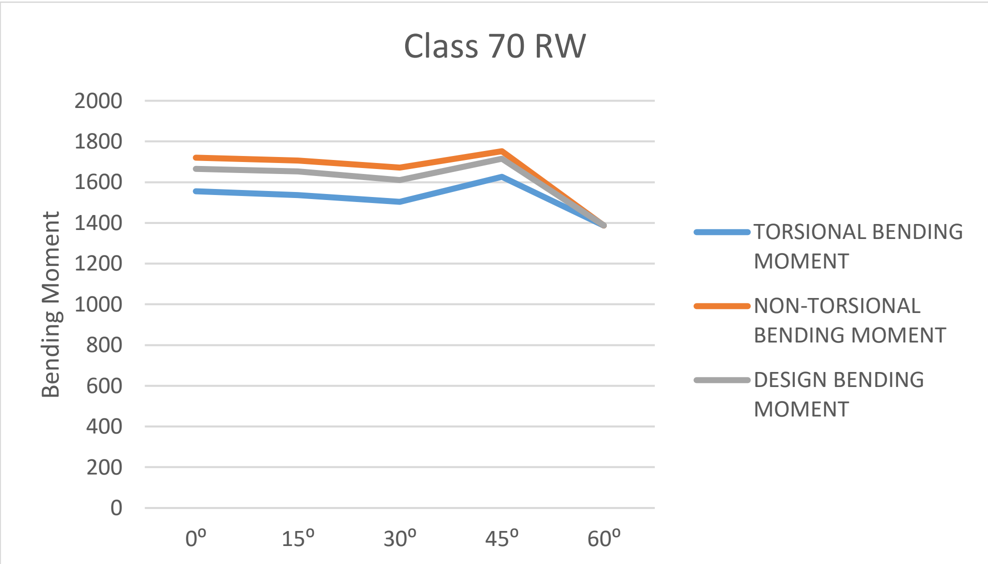
DESIGN BENDING MOMENT					
Comparison of Bending Moment (kN-m) at MID In INNER GIRDERS (G2, G3)					
	SKEW				
Load Case	**0^0**	**15^0**	**30^0**	**45^0**	**60^0**
Self Weight	8334.49263	8433.60604	8476.02924	8660.80506	8102.06365
SIDL-CB	465.906588	472.181627	475.268627	478.415765	454.437745
SIDL-WC	431.256569	436.514647	438.626353	448.222333	419.31349
Class 70 RW	1664.75104	1653.08302	1610.26443	1715.2479	1388.15667
Class A	1278.82271	1053.73537	1016.99971	824.319765	780.983529

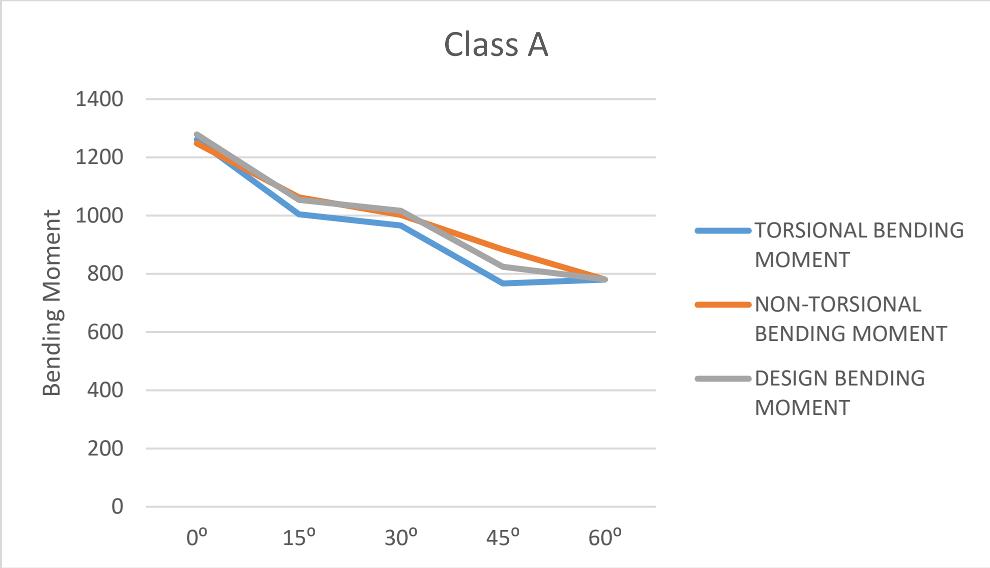
TORSIONAL MOMENT					
Comparison of Torsion (kN-m) at MID In INNER GIRDERS (G2, G3)					
	SKEW				
Load Case	**0^0**	**15^0**	**30^0**	**45^0**	**60^0**
Self Weight	1.651	129.946	264.015	444.564	485.334
SIDL-CB	0.327	8.383	16.594	29.847	30.103
SIDL-WC	0.073	6.75	13.701	23.188	25.169
Class 70 RW	111.739	119.135	109.526	90.53	1.19
Class A	18.120	50.573	52.137	58.509	0.993




SIDL-CB
Bending Moment
490
480
470
460
450
440
430
420
410
400
390
0°
15°
30°
45°
60°
TORSIONAL BENDING MOMENT
NON-TORSIONAL BENDING MOMENT
DESIGN BENDING MOMENT


SIDL-WC
Bending Moment
460
450
440
430
420
410
400
390
380
370
360
0°
15°
30°
45°
60°
TORSIONAL BENDING MOMENT
NON-TORSIONAL BENDING MOMENT
DESIGN BENDING MOMENT


Class 70 RW
Bending Moment
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0°
15°
30°
45°
60°
TORSIONAL BENDING MOMENT
NON-TORSIONAL BENDING MOMENT
DESIGN BENDING MOMENT



6. CONCLUSIONS

The analysis of different bridge decks skewed at various angles such as 0^0, 15^0, 30^0, 45^0 and 60^0 have been done in this dissertation using Grillage Analogy Method in STAAD (Structural Analysis and Design) software. Non-Torsional Analysis of the same is also done. As well as the effect of torsion on the bridge deck have been studied. The equivalent design moments and equivalent design shear are calculated as per IRC: 112-2000. From investigation reported in this dissertation, the following conclusions can be drawn:

- The value of Non-Torsional Bending moment and shear force is almost similar to the calculated value of Equivalent Shear and Bending Moment. In some cases, they are overlapping graphically,
- It also shows that there is considerable difference between Torsional Bending Moment and Equivalent Moment and also between Torsional Shear Force and Equivalent Shear.
- The Shear Force and Bending Moment values of Non-Torsional analysis are higher than the same values of Torsional analysis of same structure.
- It also shows that in most of the cases, Bending Moment and Shear Force are decreasing with increase in skew angle.
- It can give us the liberty to rely on the Non-Torsional Analysis. It will not only save time, but also will reduce the calculations to find equivalent shear and equivalent moment as per IRC: 112-2000.

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