SKEW BEHAVIOR IN DESIGN OF STEEL COMPOSITE SUPERSTRUCTURE

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE
OF

MASTER OF TECHNOLOGY
IN
[**STRUCTURAL ENGINEERING**]

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I, KUMAR ANKIT, Roll No. 2K18/STE/503 student of M.Tech. (Structural Engineering), hereby declare that the Project Dissertation titled "**Skew Behavior in Design of Steel composite superstructure**" which is submitted by me to the Department of Civil Engineering, Delhi TechnologicalUniversity, Delhi in partial fulfillment of the requirement for the award of the degree ofMaster of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

Place: Delhi

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CERTIFICATE

I hereby certify that the Project Dissertation titled "**Skew Behavior in Design of Steel composite superstructure**" which is submitted by **Kumar Ankit**, Roll No **2K18/STE/503**, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award ofthe degree of Master of Technology, is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi

Date: 10.08.2021

Nirendra Dev

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ABSTRACT

The skew effect in a bridge makes the designing and analyzing of bridge more complex. Bridge design is more troublesome by considering skew angle in the engineering community, so there is a requirement to study the effect of skew angle on the skewed bridges such as bending moment, shear force, and other parameters. This investigation based on the effect of skew angle on the design of steel composite super structures in bridges. Four models have been created and have been utilized by using Finite element-based software STAAD PRO V8i. Skew angles are taken as 0, 15, 30, and 45 degrees and all models are exposed to IRC class A, IRC class 70R vehicle and Special Vehicle loading. Results for skewed bridges are in examination with the straight or non-skewed bridges.

TABLE OF CONTENTS

List of Figures

List of Tables

List of Charts

CHAPTER-1
INTRODUCTION

1.1 GENERAL

A bridge is a structure which is based on supports over physical hindrance such as hills or important structures, narrow and intersection water body or valley or road for the purpose of providing a passage over the hindrances. It is the main segment for transportation and it is liable for conveying a force flow transport. It can be distinguished on the basis of shear force, compression and tension moment.

1.2 Steel Composite Skew Bridge

Steel composite skew bridge is that type of structure in which the deck slab is casted at site and laid over the shear connectors or shear studs which is placed in steel plate girders / box girders so as to provide good connection between deck slab and steel girders or box girders. Thus, the complex activity take place between concrete and steel I girders. The steel and concrete act jointly in decreasing declination and increasing the combined strength together. Various investigations have been done out scientifically as well as systematically to know the condition of skew bridges exposed to different type of loadings. Due to difficult condition at site, skewed bridge become necessarily important to be reviewed, designed and checked. In recent years, there are large no. of natural or man made deterrents and different level crossings in mountain terrains have been made to meet several prerequisites and due to this reason multi lane expressways, Rail over bridges, Road over bridge and skew bridges have been proposed.

1.3 SKEWED BRIDGE

The angle between perpendicular to the centerline of the span and the centreline of the abutment or pier cap is called as the skew angle or angle of skew. In straight bridge, the skew angle at all supports would normally be the same and the term skew angle can be applied to the bridge as a whole. The angle of skew is different at each support on curved bridge. The design philosophy such as bending moment, shear force and torsion also changes as the bridge length and skew angle changes. This represents an incredible test to structural designers. In prior time, they infrequently used skew bridges as far as feasible due to absence of information or data about structural behavior and construction difficulty. In the current situation, there is rising pattern or trend to provide steel composite bridges in skew compared to straight bridges.

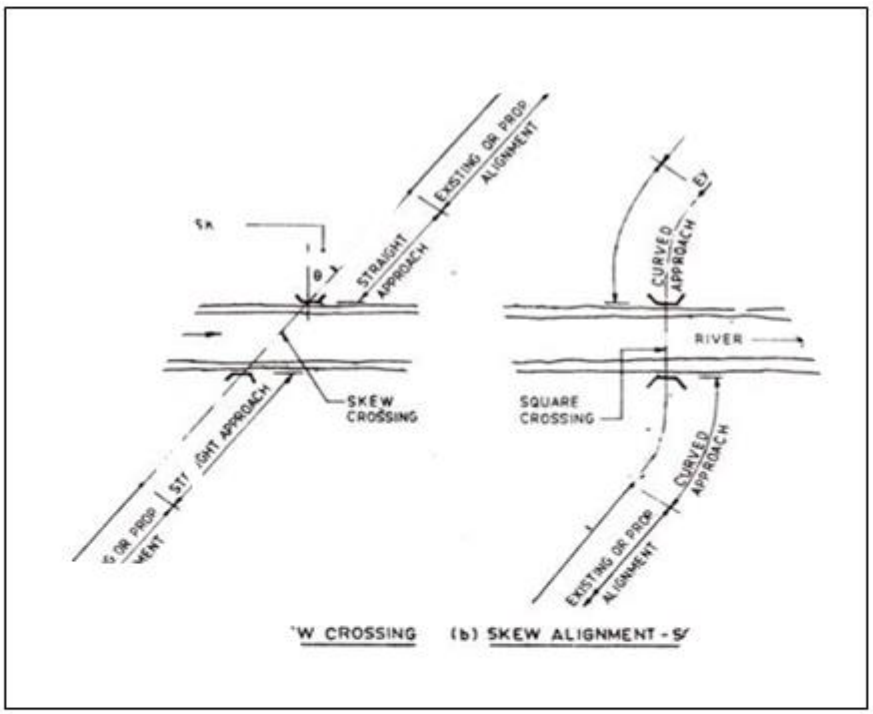

Figure-1.1 Skew and straight alignment

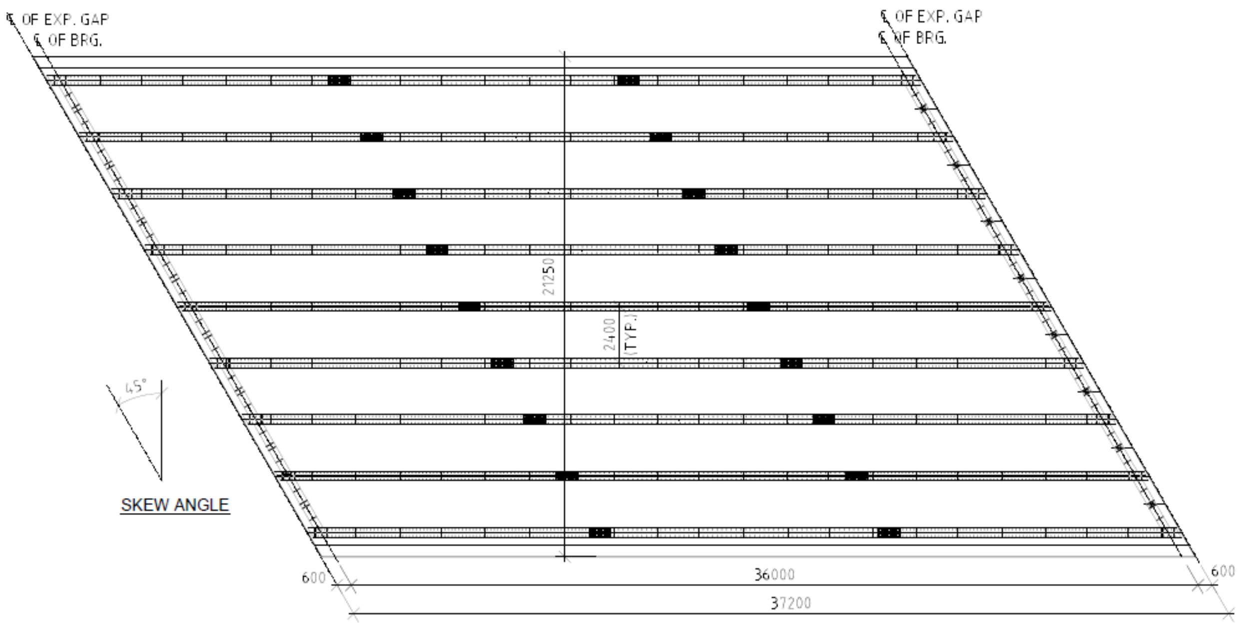

Figure-1.2 Top view of Skewed Bridge

1.4 EFFECT OF BRIDGE DECKS IN SKEW CONDITION

Most of bridge decks constructed in recent times have some form of skew, taper or curve. In straight bridges, the deck slab is perpendicular to the supports and the load path is straight towards the support. Whereas in skewed bridges the load always tries to take short way to reach the nearest support condition and it is more complex problem because in which direction slab will span and the way in which superstructure load will transfer to the nearest supports due to skew condition of the bridge. As the load take the shortest path to the nearest supports and it is bit easier for the non skewed bridge but it is more complicated for the skewed bridge. The structure is designed at any skew angle with the help of computer aided softwares or method of analysis.

Some special characteristics of skew of deck slab are

(i) Maximum bending moment varied in direction across width from close to span at edge and at near perpendicular to abutment in central regions.

(ii) In obtuse corner hogging moment generated

(iii) Torsion generated at deck

(iv) In obtuse corner higher reaction and shear force generated

(v) In acute corner low reaction and possibility of uplift

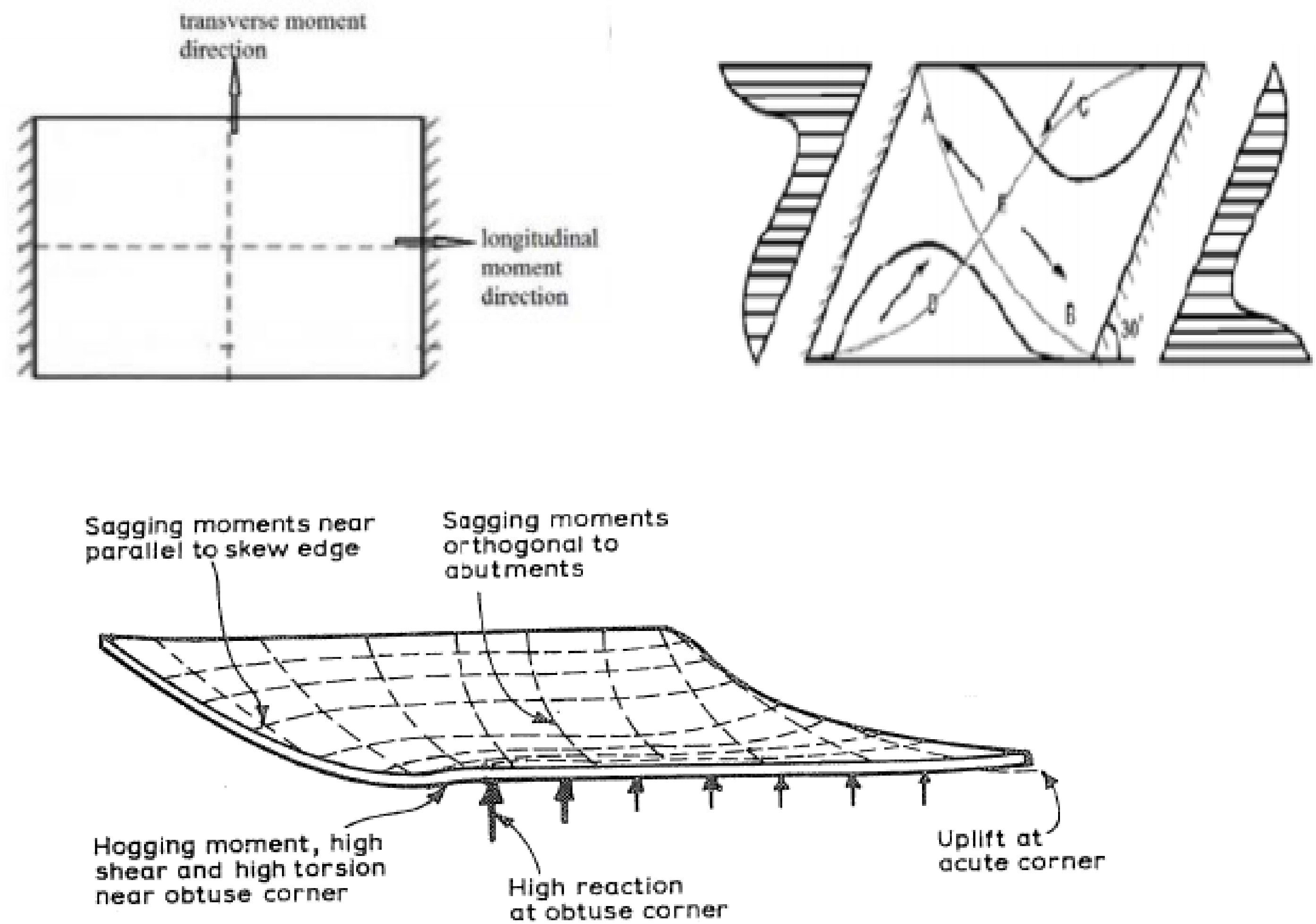

Figure-1.3 Behavior of Deck in higher Skew

The high vertical reaction due to Dead, SIDL and LL load on the bearing acting at the obtuse part is also transferred to the neighboring bearings. It also decreases the stresses i.e stresses due to shear & the torsional stress in the slab and it decreases the moment generated at the top of the deck i.e obtained at the obtuse part. It can also diminish due to uplift at acute corner of bridge deck.

Because of their high torsional stiffness tries to resist the twisting of the deck, it is more important in solid and cellular bridge precast and cast in situ bridge decks.

1.5 Codal provision/ References to cater torsion

As per Cl. 7.4.2 of IRC: 112-2011, "In general, There shall be no particular estimations for resisting torsion will be necessary where the torsional resistance for stiffness of members have not been taken into account in the analysis of the structure."

Also, as per Cl. A4.6.2, "Torsion reinforcement is not determined independently for torsion alone. Instead, the complete longitudinal reinforcement is settled for a imaginary bending moment which is a component of actual bending moment and torsion."

The above clause can be further clarified by the book named as "Bridge Deck Behavior" by **E.C. Hambly**. This book is widely accepted for design and analysis of skew bridges.

In this book says that the torsion less design can be adopted for the beams on many spans that are having twisting stiffnesses, which are low in contrast to bending constraint, such as PSC/RCC I girders having twisting constants of less than 1/10 of the bending constraint and also steel composite girders having torsion constants of less than 1/60 of the bending inertias. Therefore, the design of these bridges can be improved in a safe manner by overlooking the effects of twist totally.

It also says, "The splitting line between the bridges appropriate and not appropriate for torsionless design depends on the skew of the deck as well as the torsion stiffnesses and strengths of the beam. Each designer should check occasionaly, the relative magnitudes of the torsion strengths of the beams and the torques from grillage output."

1.6 ADVANTAGES

- Difficulty in highway design takes place when the calculation of structure cannot oblige straight bridges.
- If compared to straight bridges, it consumes less space.
- Constructed even in built-up areas as if skew bridges are designed properly done.
- Because of absence of space required constructing traditional non skewed bridge, It is more efficient in urban areas.

1.7 DISADVANTAGE

- Force flow is significantly more intricate when contrasted to normal straight bridge
- Under serviceability load condition and seismic load condition skew bridges makes their behavior more complex.
- Difficult from the construction point of view for the launching and erection of plate girders.

1.8 OBJECTIVES

- The principle objective of analysis is to contemplate the effect of skew on entire bridge section in transverse and in longitudinal direction under different load condition such as dead load, superimposed dead load of structure and live load of CLASS A, 70RW and Special vehicle load with the existence of skew angles in bridges section.

- The main principle is to study the structural behaviour in bridge decks under different loading conditions such as dead load of whole structure, superimposed dead load of structure and live load of IRC CLASS A, IRC 70R and Special vehicle loading with the existence of skew angles in bridges section.

- The main principle is to contemplate the differential deflection of each girder along-with structural behaviour of bracking members under various loads such as dead load, superimposed dead load and live load of CLASS A, 70RW and Special vehicle load with the existence of skew angles in bridges section

- The main principle is to contemplate the structure behavior such as stress and deflection characteristic in every individual support of a bridge section under the various load combinations like CLASS A load, 70R load & Special vehicle with different angle of skew.

CHAPTER-2
LITERATURE REVIEW

- **Nagashekhar J, Dr.Manoli Ramesh, Dr. Achar M Mahadev , KS Shiva Kumar (July-2016):** In this venture analysis is performed to determine the skew behavior of bridges i.e precast I girders. The results are derived and displayed in terms of structural parameters such as bending moment & shear force from the analysis. These specifications occur in the girder bridges due to applied dead load and live load of the superstructure. Bridges of 25m length and 12m in width were analyzed for skew angles of 0°, 15°, 30°, 45° and 60°.

- **Manjunath K, H.R. Prabakara, Mahadev M. Achar (Sep.-2016):** In this venture work completed to determine the skew impact on the design of steel composite design of a bridge. Total six models were analyzed with skew angles 0°, 10°, 20°, 30°, 40°, and 50° with span of bridge 3.565m, 7.130m, 10.695m and 14.260m.

- **R Kumar Santhosh , Dr. Achar M Mahadev , Dr. Eramma H (Jan-2019)**: In this paper present that the behavior of skew angle on Bowstring girder-bridge is described briefly in this project. The skew behavior is considered and significant bending moment and shear force is obtained in bottom cross beams when axial force applied in bottom chords, top arches, hangers and top bracings.. The skew angles analyzed for study is 0°, 30°, 45° and 60°.

- **P.M. Kulkarni, P.M. mohite (Aug-2019):** This paper is present that There are insignificant changes in parameters like stresses at top and bottom, longitudinal moment, torsional moment, deflection and required prestressing force for small skew angles i.e. up to10 degree. For higher skew, there is great changes in behavior of structure. As torsional moment is observed to be increased by 1000%, the skew angle incremented from 0° to 60°

- **Madhu Sharma, Naveen Kwatra, Harvinder Singh (2017):** It was observed that Elastic solution for Skew deck slab bridges are accessible in the published literature. The bending moment and deflection obtained by numerous experimentation for standard skew angle i.e. 0° to 60° with load cases applied on the structure. This final expression that are used in routine practices are neither used for design calculations nor used in finite element-based software in design offices. It is advised to prepare a bending moment coefficient for angle 0° to 90° for the ready reference for designer to design a skew slab.

- **Nikhil V. Deshmukh, dr. U. P. Waghe (April 2015):** In this paper article For class A loading the increase in shear force for low skew angle (<15°) the shear force increases linearly. The pattern of increase of shear force with respect to span is straight in nature. There is about 20% increase in shear force when span increases from 4m to 6m. As the skew angle is increase, shear force is decreased about 30% when span change to 6m from 4m from thereon, hear force for each span increase.

- **Abhishek Gaur, Ankit Pal (May2019):** From this paper presents the contribution of different researches in the field of the deck slab structure system, a gap in the research and objective of the research to be conducted. These contributions help to visualize the problem faced by RC deck slab from a new perspective. By evaluating the performance of deck slab bridge with different thicknesses its enhanced economic aspect may be achieved, which shall lead to the direction of the design of safe stronger and more economical bridge.

- **P S Sujith, dr. anna varughese Jiji, Syriac tennu (September 2015)**: In the skew angle, with increment in the angle of skew, the stresses that will come at the skewed deck slab changes significantly from those in a straight deck slab reaction increased with increasing skew angle finite element method gives more prudent design and exact when compared with the grillage analysis. At the acute corner, Uplift effect or negative reaction occur significantly. At obtuse corner, maximum or high reaction occurs significantly.

CHAPTER-3

SPECIFICATIONS

A 6lane bridge model of length 36 m (c/c brg), transverse width 21.25 m and total length 37.2m (c/c exp), has been taken. There are four skew angles of 0, 15, 30 and 45 degrees where modelled to know the behavior on the composite superstructure with the existence of angle of skew in the bridge. There are 9nos of steel girders have been used with c/c spacing between girders is 2.4m. End cross girder, vertical and horizontal bracing members are also provided to avoid the toppling of longitudinal girders. Spherical bearing are resting below the longitudinal girder, depth of wearing course 50 mm and standard crash barrier for the SIDL have been added. The analysis has been done for dead load, SIDL and vehicular load i.e. Class A, Class`70RW & Special Vehicle loading.

Flanged Section	
Component Name: Longitudinal Main Girder	
Total depth	1.581m
Top Flange Width	0.400m
Top Flange thickness	0.036m
Web thickness	0.016m
Web height	1.500m
Bottom Flange Width	0.850m
Bottom Flange Thickness	0.045m
Component Name: End Cross girder	
Total depth	1.332m
Top Flange Width	0.350m
Top Flange thickness	0.016m
Web thickness	0.016m
Web height	1.300m
Bottom Flange Width	0.350m
Bottom Flange Thickness	0.016m

Component Name: Splice member	
Top Flange Outer Cover	(0.400mX0.930x0.02)m
Top Flange Inner Cover	2(0.180mX0.930x0.02)m
Web Cover Plate	(0.640X1.360X0.016)m
Bottom Flange Inner Cover	2(0.400X0.880X0.036)m
Bottom Flange Outer Cover	(0.850X0.800X0.036)m
Component Name: Vertical Braced Frame 2ISMC	
Outside depth	0.125m
Outside Flange Width	0.065m
Flange thickness	0.008m
Web thickness	0.005m
Component Name: Horizontal Braced Frame ISMC	
Total depth	0.130m
Outer Flange Width	0.130m
Flange thickness	0.010m
Web thickness	0.005m
Component Name: Shear Stud	
Diameter of Shear Stud	0.025m
Overall Height of Stud	0.200m
Component Name: Int. Stiffner Plate	
Width of Stiffener	0.160m
Thickness of Stiffener	0.012m
Component Name: Bearing Stiffener Plate	
Width of Stiffener	0.190m
Thickness of Stiffener	0.020m

Length	Sectional Property	Length in m	Location
Length1	End Cross Girder	0	All Section
Length2	X- Braced Frame	6.35	All Section
Length3	X- Braced Frame	11.85	All Section
Length4	SPLICE 1	12.3	All Section
Length5	X- Braced Frame	17.35	All Section
Length6	X- Braced Frame	22.85	All Section
Length7	SPLICE 2	24.6	All Section
Length8	X- Braced Frame	28.35	All Section
Length9	X- Braced Frame	33.85	All Section
Length10	End Cross Girder	36	All Section

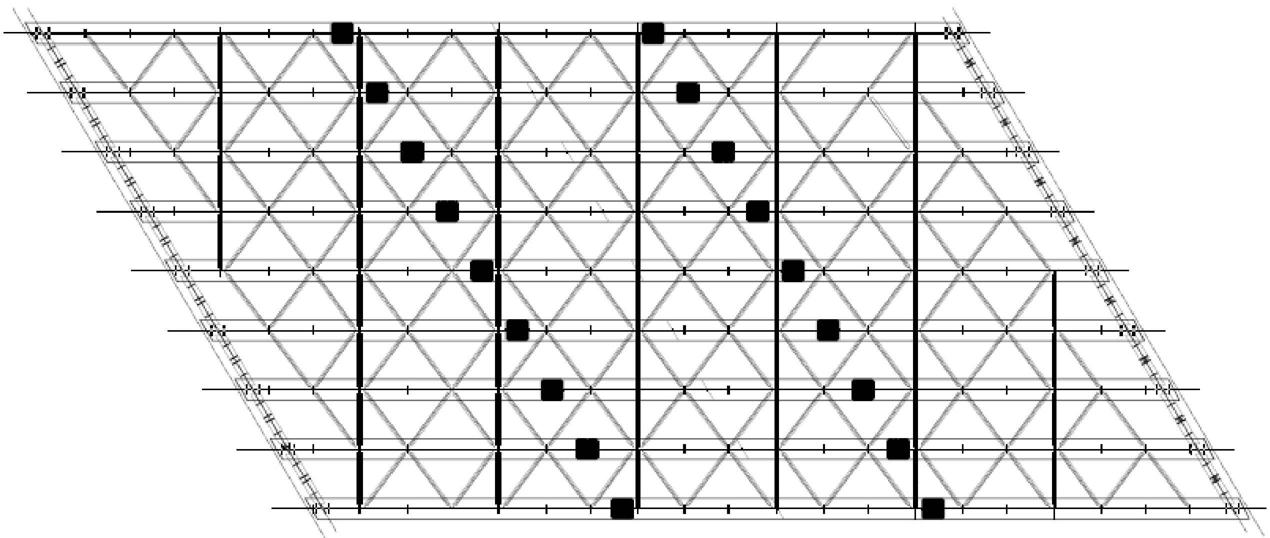

Figure-3.1 Bottom plan view of the Girder showing vertical and horizontal bracing in higher skew angle

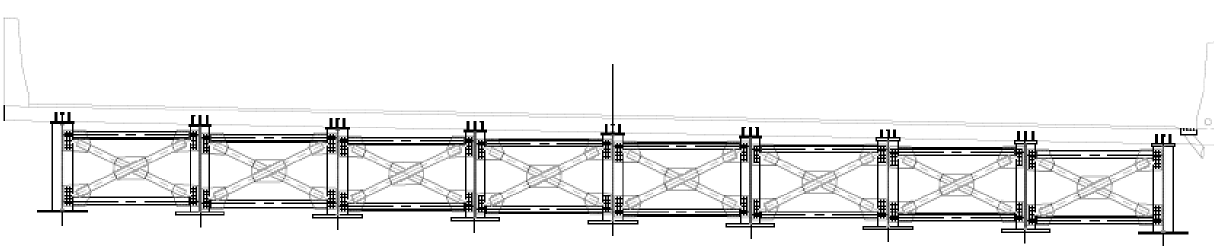

Figure-3.2 Cross section at mid

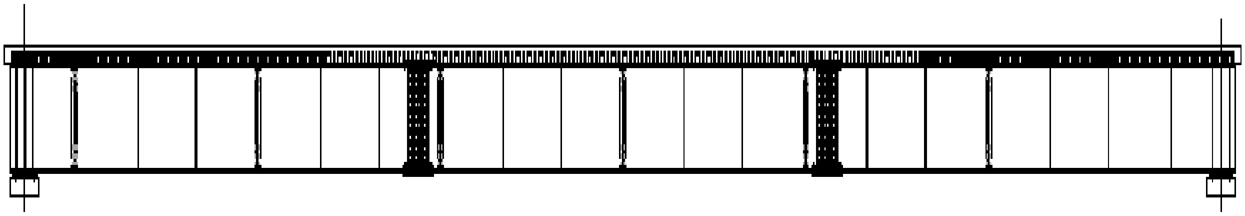

Figure-3.3 Longitudinal Section

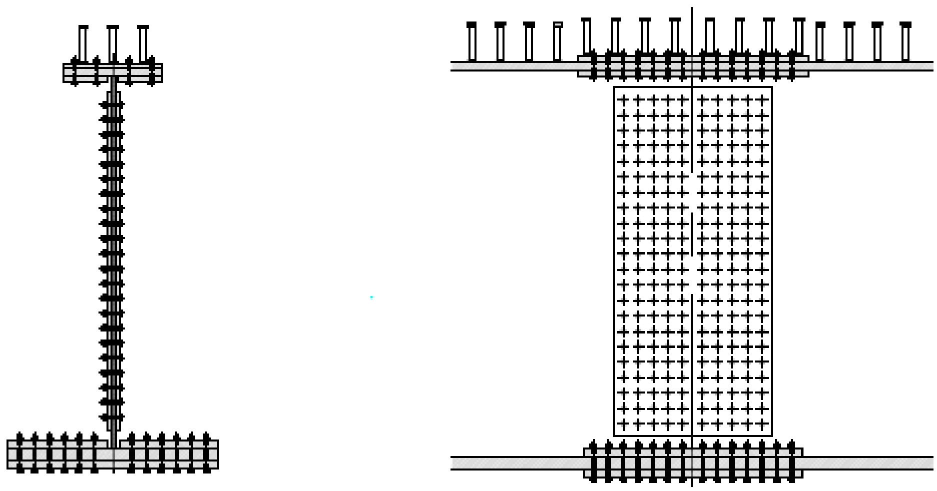

Figure-3.4 Splice section

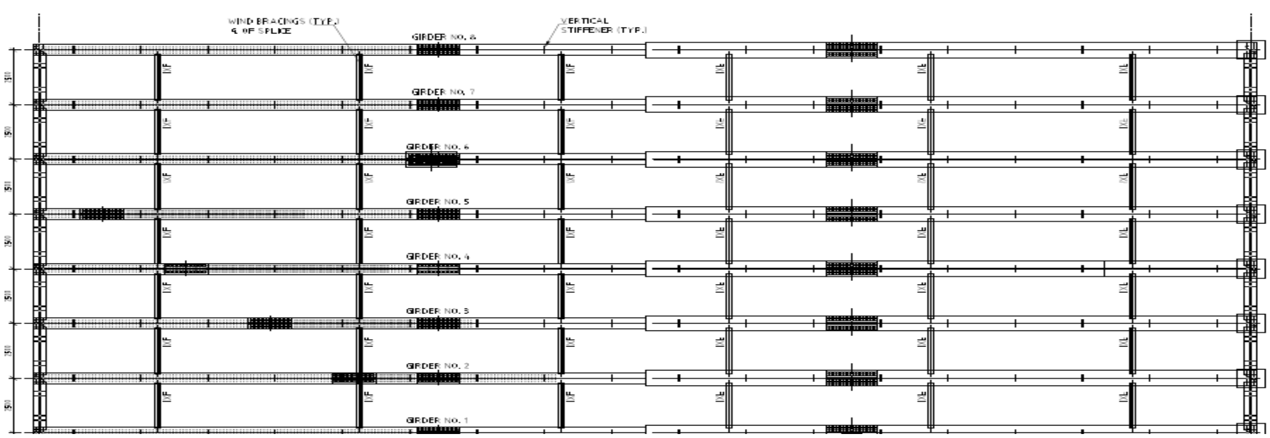

Figure-3.5 Bottom plan view of the Girder showing vertical Bracing in 0° skew angle

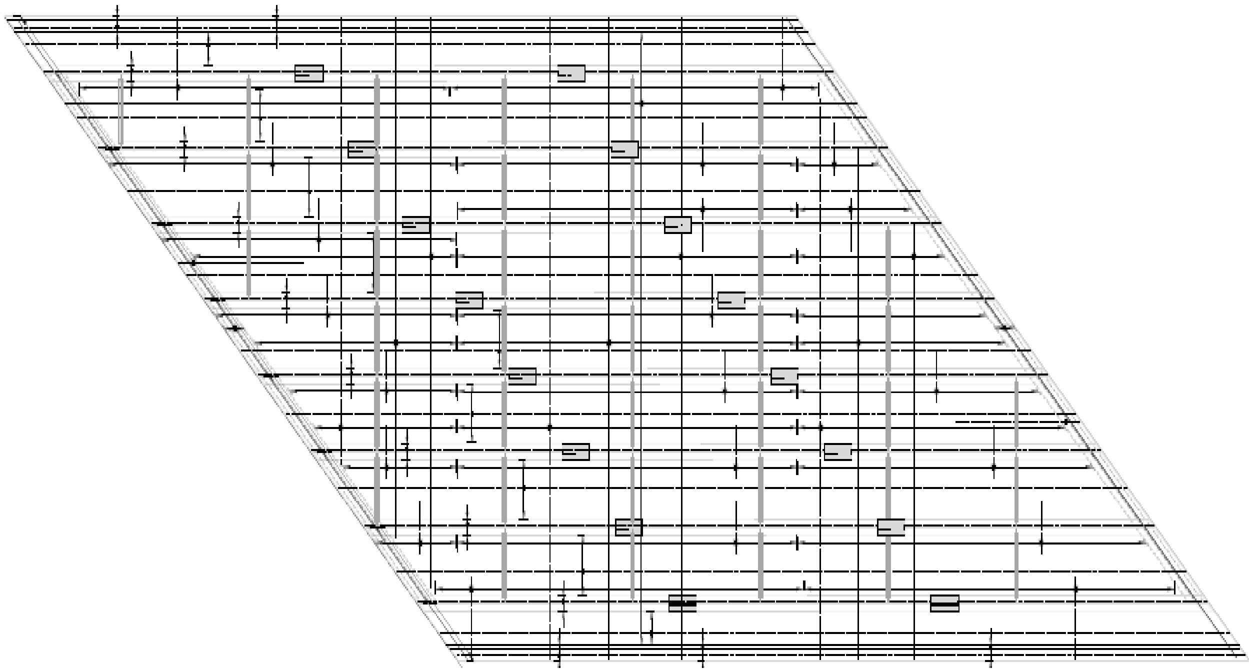

Figure-3.6 Plan view of the reinforcement detail of Deck Slab of higher skew angle

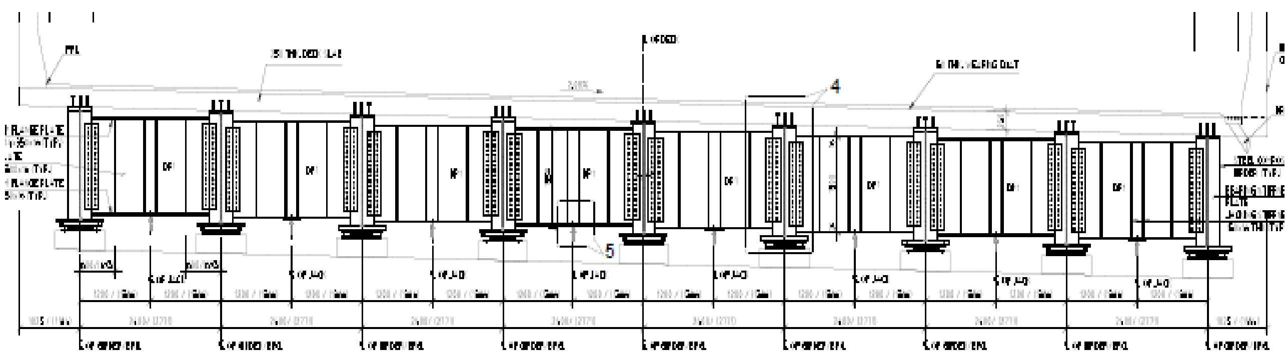

Figure-3.7 Cross Section at End Cross Girder

CHAPTER-4

FINITE ELEMENT ANALYSIS

4.1 INRODUCTION

The modeling is a broadly utilized style of connecting a network of components associated by nodes inside a material continuum. It is a method for connecting a number of small elements discrete joints and it is used for analyzing complicated structures. It is the most valuable technique that can be used for demonstrating and discreting any type of structure whether it is regular or irregular of different dimensions, any type of IRC, IS loadings and higher order elements. Appropriate stiffness equations are determined relating the displacement of the nodes to the node forces between elements and in the same way it can be resolved in a simply supported or in continuous beam in which gadgets are also used to solve simultaneous equation that relate forces and displacements. It tends to be applied in all design structures in all forms and it can be analysed in the appropriate form. It is the most flexible technique to be used at present. It can be most flexible technique to numerous departments apart from structural department such as mechanical and aerospace for heat transfers, liquid and aero-mechanic, electromagnetism, etc. It is significant for investigating troublesome structures for bridges, buildings and other different structures presented to both static and dynamic loadings. Moreover, the different various plans strategy utilized which influence the exactness and relevance of the technique in an unexpected way.

It is the most great and sensible logical method at present because with a sufficiently large computer, the elastic behavior of almost any structure can be analyzed accurately. This technique is awkward to use and is typically costly. Likewise, the decision of component type can be extremely basic and the results can be far more undeniably than those predicted by simpler models such as grillage or space frame. It is probably not to have opportunity to comprehend or confirm the firmness of the element stiffness or to check the enormous amount of computer data.

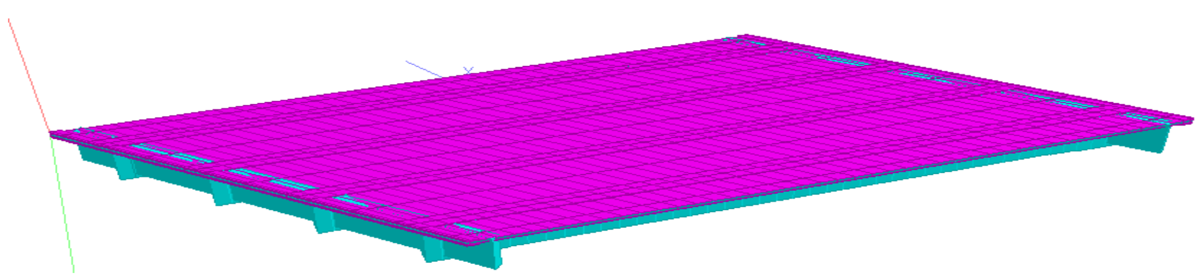

Figure4.1 3D model of skew bridge

4.2 TWO-DIMENSIONAL PLANE STRESS ELEMENTS

Finite element analysis is first shown corresponding to the behavior of plane stress in the analysis. This is probably one of the simplest applications of the method ignoring beams which is continuous and is more related in plane activities of the slabs and webs of beam and slab and cellular bridge decks. It is accepted that the strains inside every component are uniform during twisting with the triangle edges staying straight.

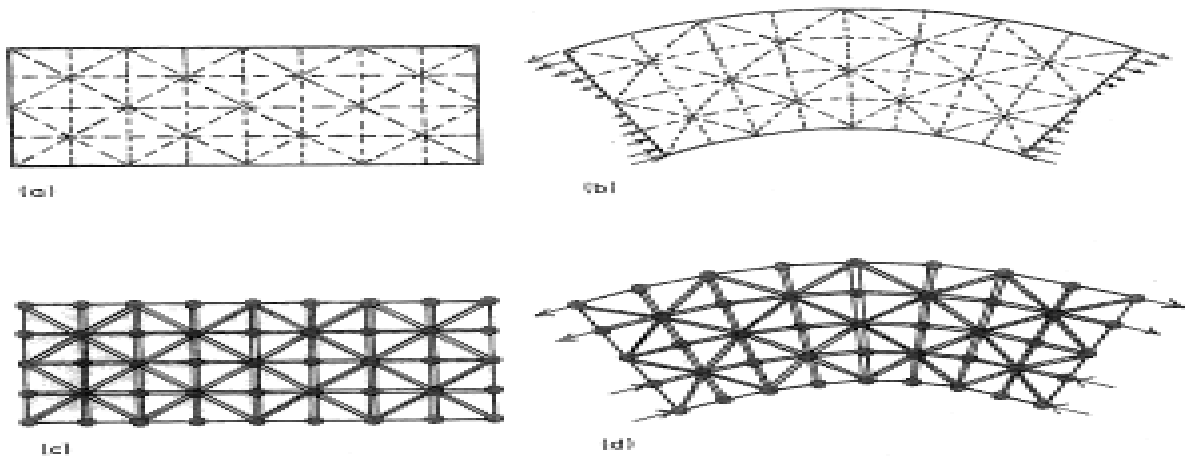

Figure4.2 Bending of Beam in finite element method

4.3 PLATE BENDING ELEMENTS

The finite element technique is frequently utilized for analysis of plate bending behavior of slab bridges. It is like that for plane stress; however, the deflection and force variables are unique and the hypothetical inference of the element stiffness equations presents greater theoretical problems.

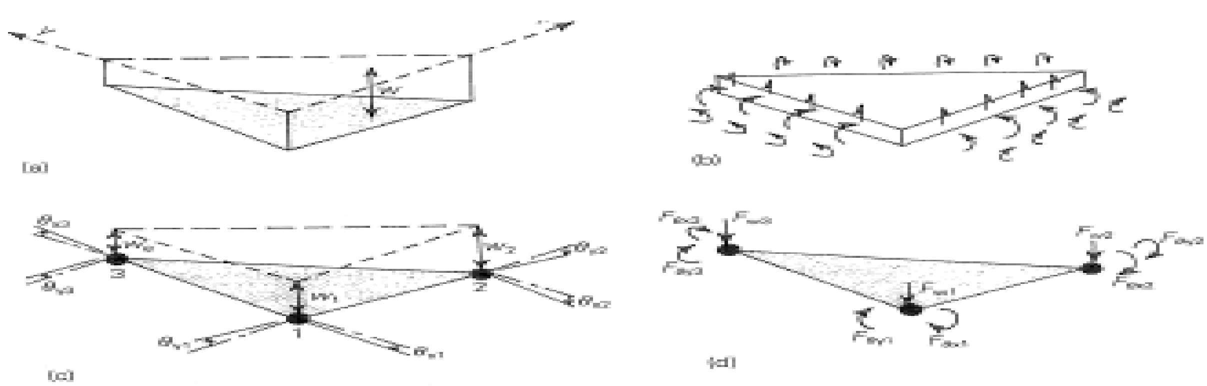

Figure4.3 (a) Triangular plate element (b) edge stress resultants (c) node displacements (d) node forces

4.4 THREE DIMENTIONAL PLATE STRUCTURES AND SHELL ELEMENT

A detailed investigation of a beam and slab or cellular bridge deck requires a three-dimensional analysis. It is the for most part to surmised the behavior of slabs and webs to thin plates. At each crossing of plates lying in various plates there is a convergence between the in-planes forces of one plate and the out of plane forces of the other. It is vital to utilize finite elements which can twist under plane pressure as well as plate bending. It is expected that for flat plates in plane and out of plane forces do not interface inside the plate component is in result the same as a plane stress component in corresponding with the plate bending element.

The components are adjusting individually for plane stress and bending, the relocation are not usually viable along the web/slab intersections except at nodes. Exceptional components are accessible which can address the in-plane twisting of the webs.

Every node must have six levels of opportunity, three deflections and three rotations and solution of the very large number of stiffness equations generated for even relatively simple structures is costly. These outcomes are then used to communicate the appropriation of stress resultants such as the overall moment that are output by the simpler models of continuous beam, grillage or space frame.

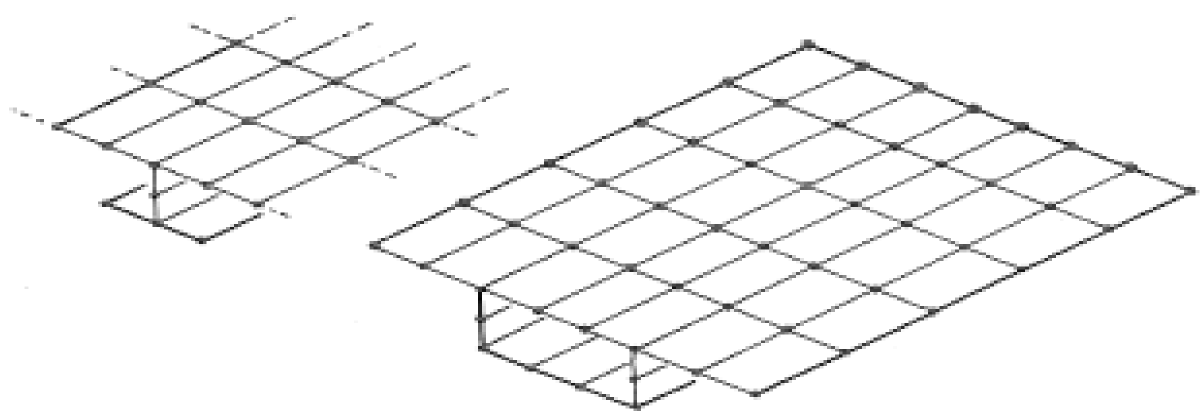

Figure4.4 Three-dimensional shape composed of plate elements

4.5 FINITE STRIPS

Bridge decks which have the similar cross section with a basic and economic type of finite element can be analyzed from end to end called finite strip. The structure is comprised of finite components called strips which can reach from one end to other. The strips are associated by notes which likewise run from one finish to the other. Like folded plate theory the displacement functions for in plane and out of plane disfigurement of the strips. The analytic procedure is also additional something in that stiffness equations are obtained and solved for each harmonic component of the load in turn and the outcome added to give the total pressure disruption. In the finite strip model, the transverse functions are thought to be basic polynomial so that essentially the technique is an estimation to the rigorous elastic folded plate method in which these capacities have a convoluted hyperbolic structure. The computer yield demonstrates discontinuities of shear stream at the strip interface within slabs. These discontinuities which are truly incomprehensible must be streamlined out to reasonable fit. This strategy and limited strip analysis have been produced for curved roundabout structures with the harmonic function used for varieties along circular arcs.

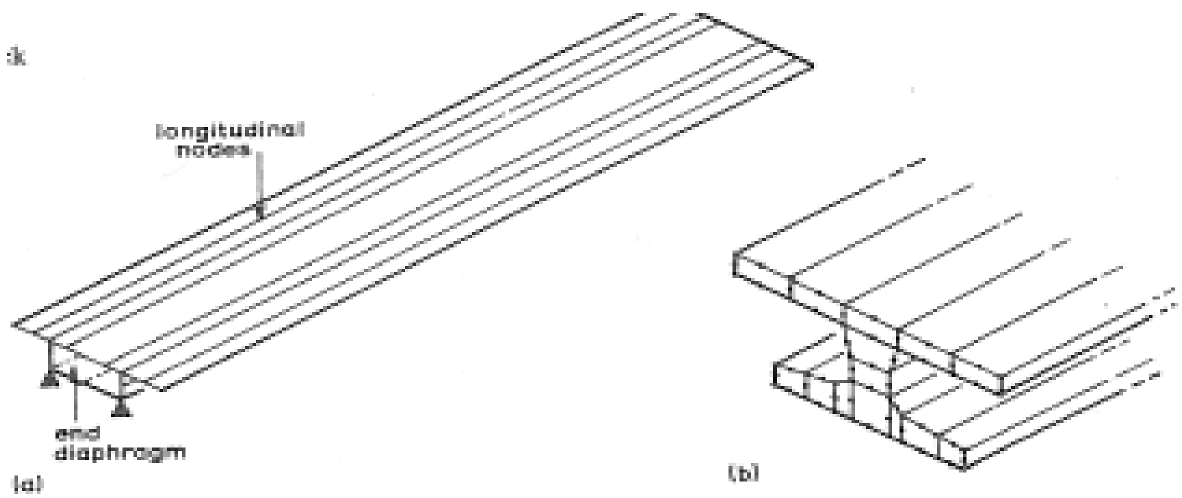

Figure4.5 (a) Finite strip model of box deck (b) finite prism model

4.6 THREE DIMENSIONAL ELEMENTS

Three-dimensional solid element are sometime utilized in the analysis and design of cast in site and precast deck slab because generally these structures are used to minimize weight that's why thinner plates used. Solid elements are utilized for the analysis of nuclear reactors and compounded soil structures. The easiest component comprises of tetrahedral or hexahedra with nodes at the corners. The nodes need only have three degrees of freedom for displacement in the three measurements. More modern components have additional nodes in addition to those at the corners with more degrees of freedom at each node.

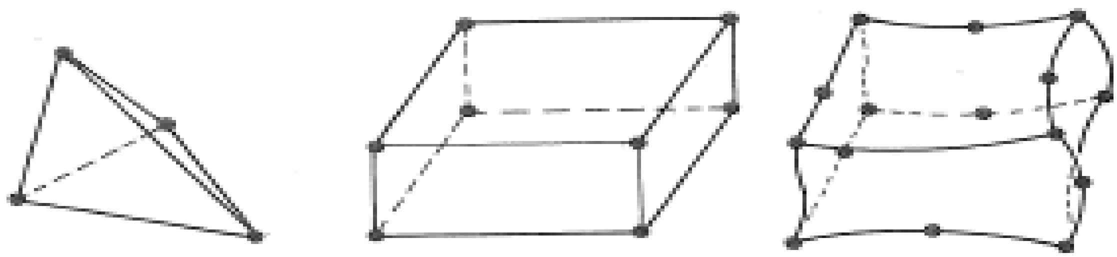

Figure4.6 Three dimensional solid elements

CHAPTER-5

ANALYSIS AND REVIEW

The venture work completed to decide the skew effect on the design of steel composite super structure of a bridge. There are four files to be made for the analysis and modelling having the span of bridge 36m were analyzed for skew angles of 0°, 15°, 30° and 45°.

After analysis, the results are carried out and introduced in term of various parameters related to structure such as bending moment in longitudinal direction, Shear force, Longitudinal deflection and Stress due to dead load, SIDL and live load applied on the superstructure. The change in behavior of structure due to variation in skew angles are represented as follows.

5.1 Bending moment due to Dead load

Load	Skew angles			
	0°	15°	30°	45°
Bending moment due to Dead load (KNm)	3267	3355	3473	4218

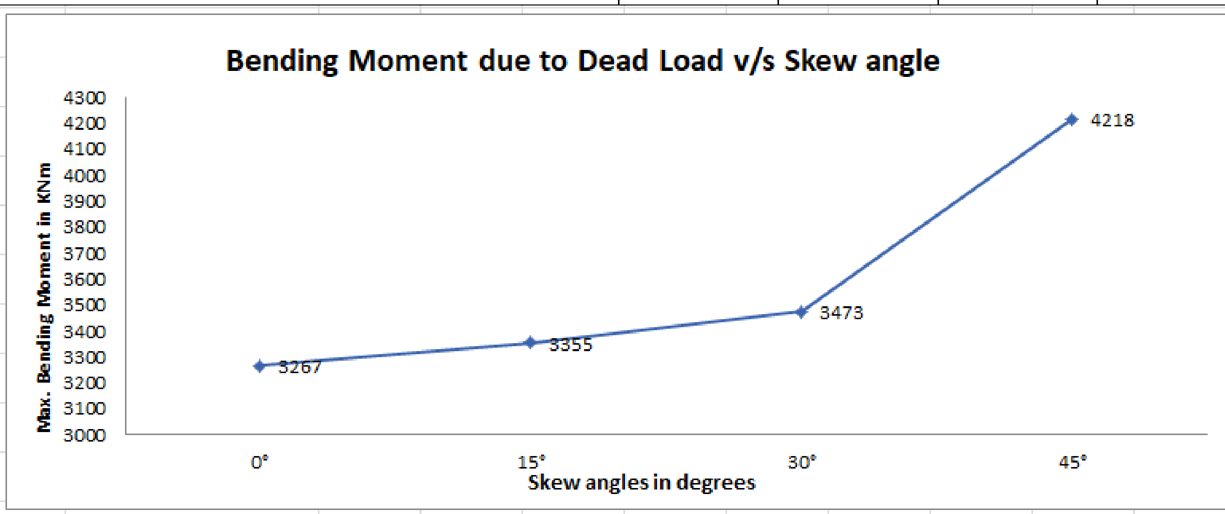

Chart5.1 Bending moment due to Dead load v/s skew angle

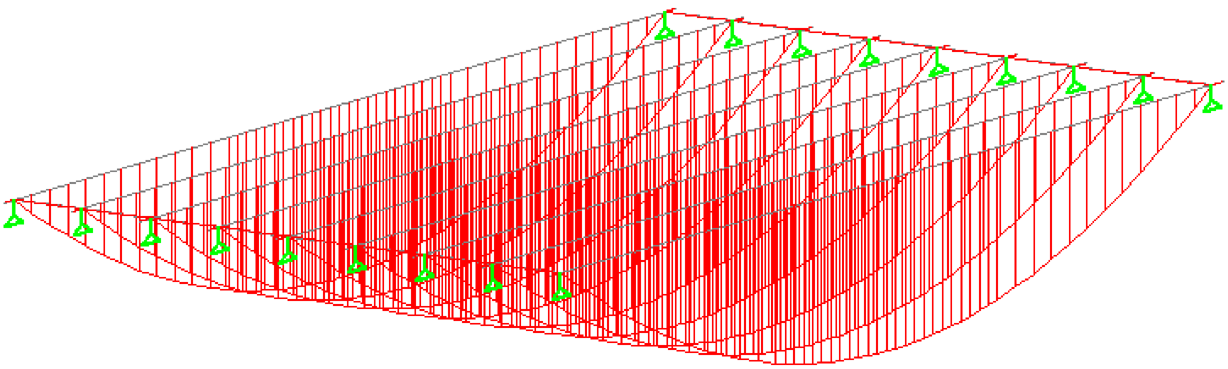

Fig5.1 Bending moment Diagram due to Dead load

The disparity of the bending moment due to dead load for different skew angles of 0°, 15°, 30° & 45°.degrees are presented in chart. It can be represented from the above chart that as the skew angle increases the dead load bending moment also increases.

5.2 Bending Moment due to crash barrier load

Load	Skew angles			
	0°	15°	30°	45°
Bending moment due to Crash Barrier (KNm)	1653	1655	1670	1738

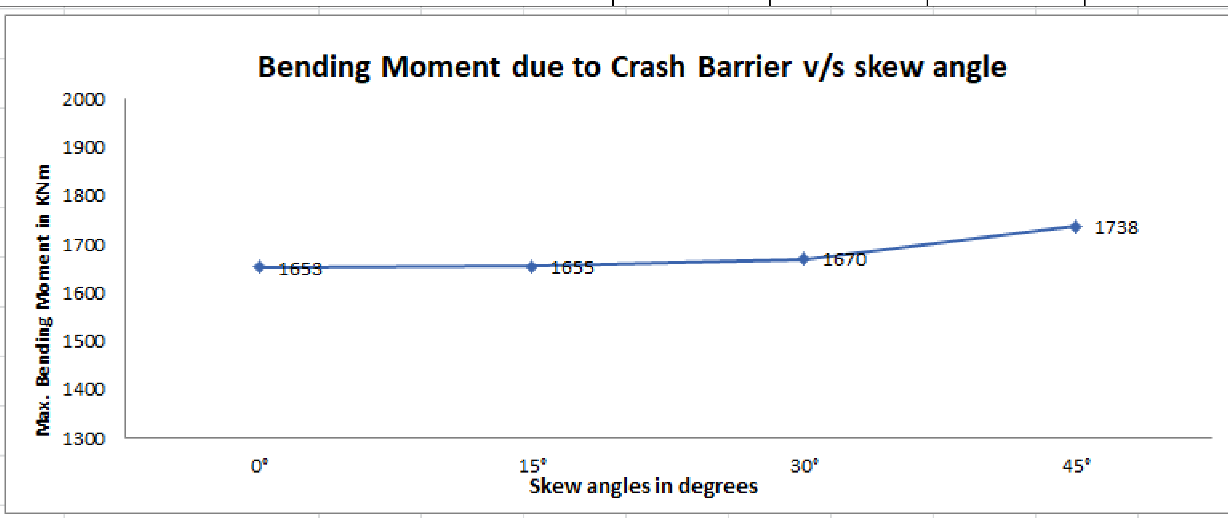

Chart5.2 Bending moment due to crash barrier v/s skew angle

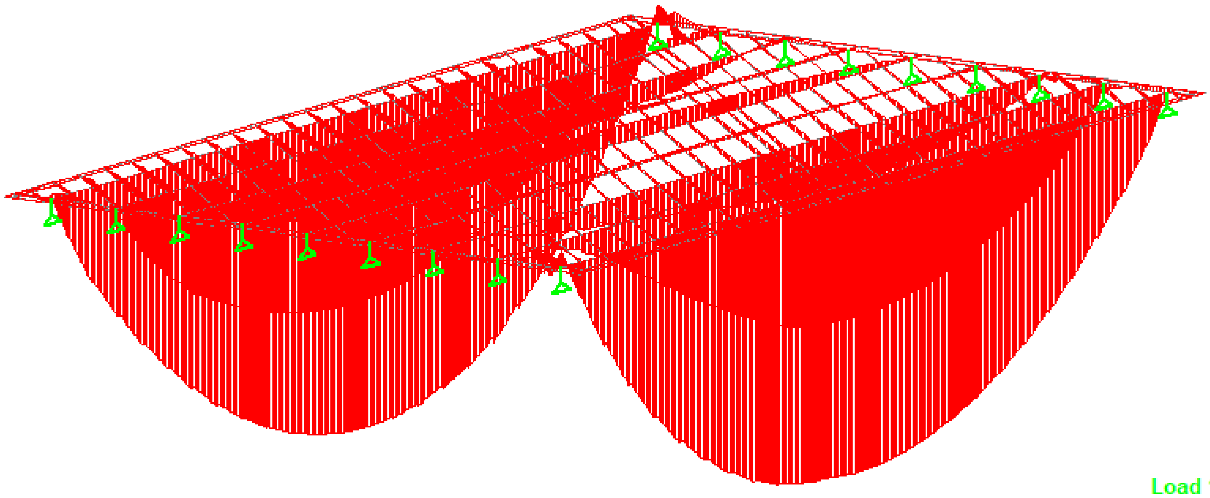

Fig5.2 Bending moment diagram due to crash barrier

The disparity of the bending moment due to crash barrier for varying skew angles of 0°, 15°, 30° & 45°.degrees are represented in above chart. It can be represented that as the angle of skew increases the crash barrier bending moment also increases.

5.3 Bending moment due to Wearing coat

Load Condition	Skew angles			
	0°	15°	30°	45°
Bending moment due to wearing coat (KNm)	413	430	485	607

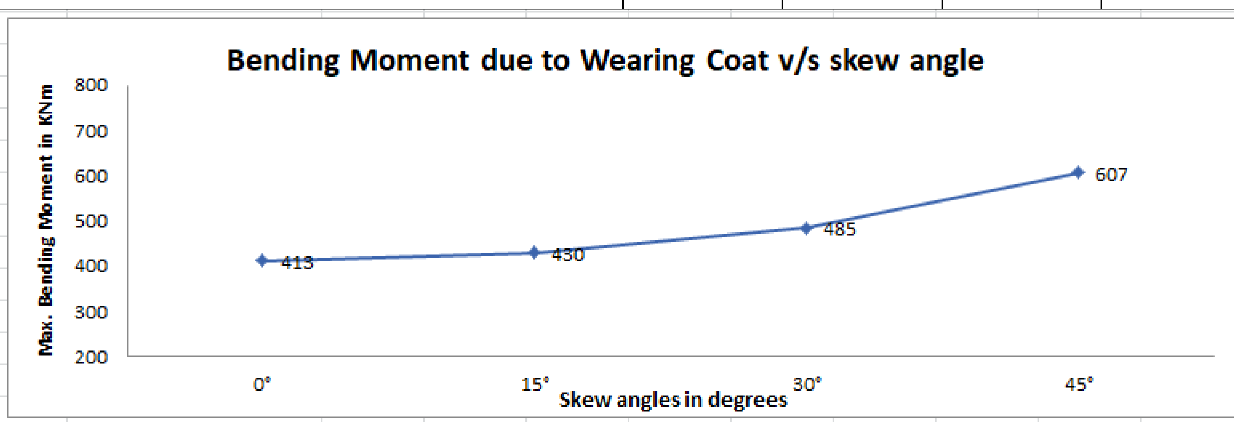

Chart5.3 Bending moment due to wearing coat v/s angle of skew

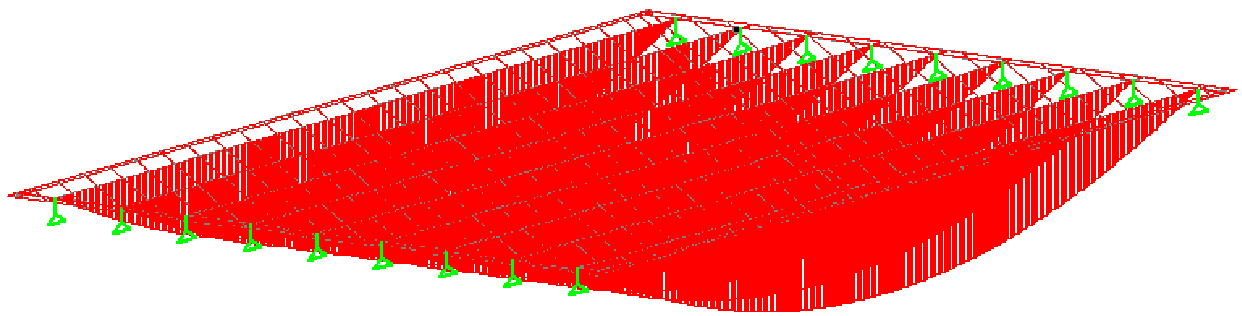

Fig5.3 Bending moment diagram due to wearing coat

The disparity of the bending moment due to wearing coat for different skew angles of 0°, 15°, 30° & 45°.degrees are represented in above chart. It can be represented that as the skew angle increases the wearing coat bending moment also increases.

5.4 Bending moment due to Live load

Vehicular Load Condition	Skew angles			
	0°	15°	30°	45°
270RW+2CLASSA(KNm)	3904	3880	3616	3626
6CLASSA(KNm)	2564	2553	2513	2825
SPECIAL VEHICLE(KNm)	4743	4697	4747	4409

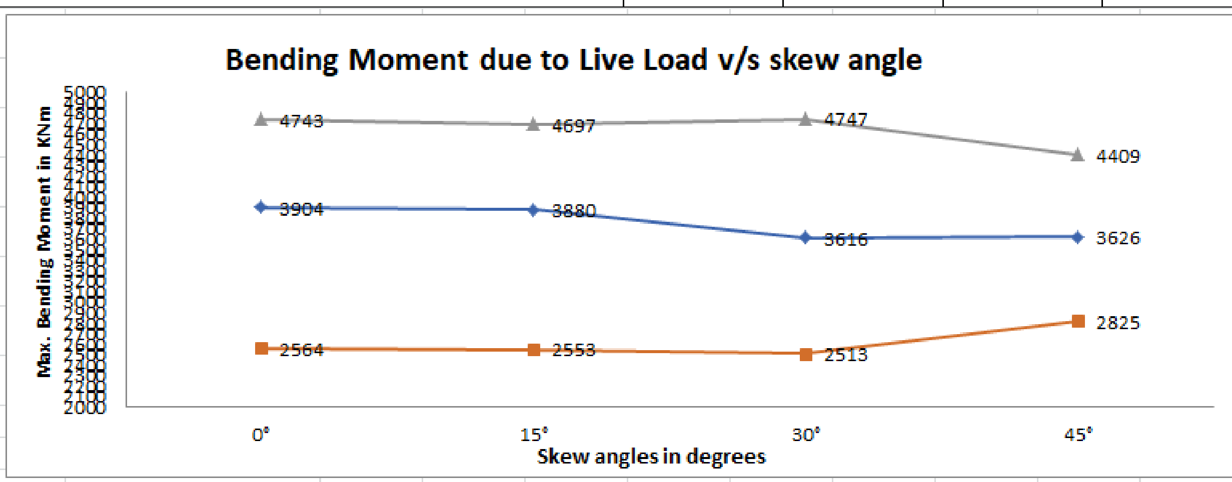

Chart5.4 Bending moment due to Live load v/s angle of skew

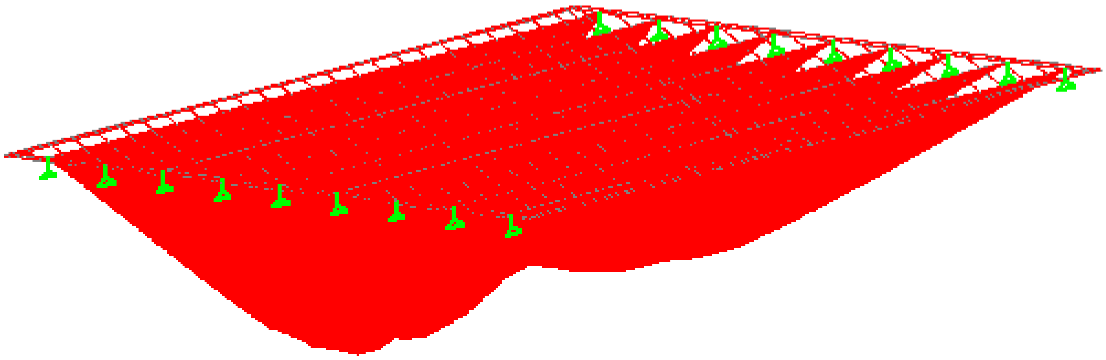

Fig5.4 Bending moment diagram due to Live load

The disparity of bending moment due to vehicular live load for changing skew angles of 0°, 15°, 30° and 45° for 270R+2CLASSA, 6CLASSA and Special vehicle loading are represented in above chart. It can be represented that as the angle of skew increases, bending moment due to live load will decline for few case of loading up to certain skew angle after that the live load bending moment will increase. The bending moment due to live load will decline from 0° to 30° steadily but at 45°, the live load bending moment escalated rapidly compared to other cases. This is due to the skew effect.

5.5 Shear force due to Dead load

Load	Skew angles			
	0°	15°	30°	45°
Shear force due to dead load (KN)	364	374	416	470

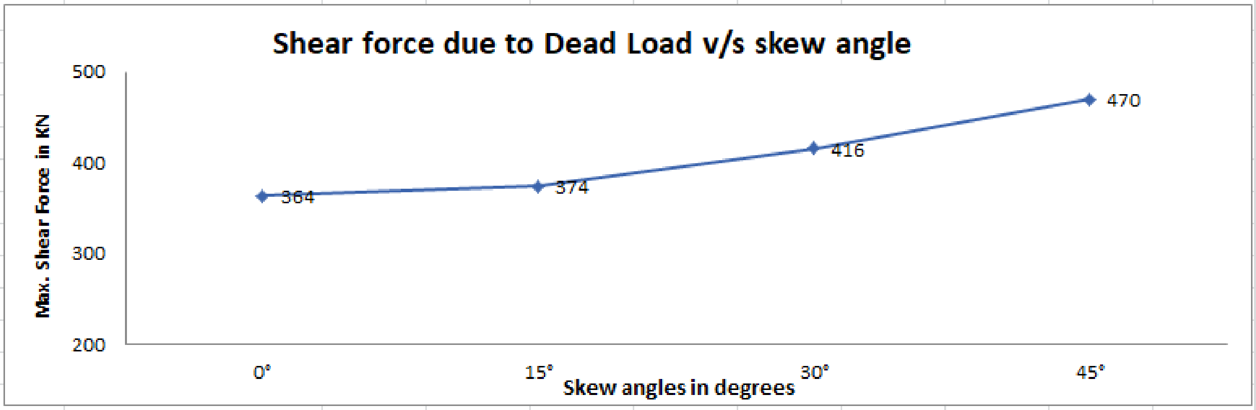

Chart5.5 Shear force due to dead load v/s skew angle

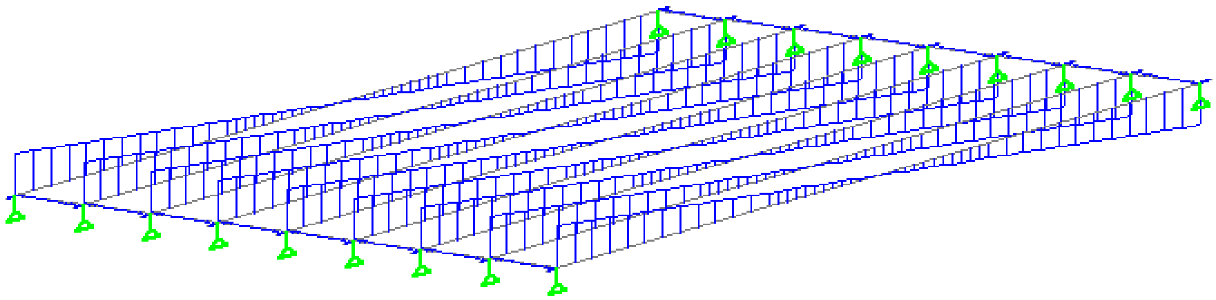

Fig 5.5 Shear force Diagram due to dead load

Above table presented the behavior of angle of skew on dead load due to shear force of the bridge. As the angle of skew escalated, dead load shear force increases. The force due to shear was found to be utmost for 45° skew.

5.6 Shear force due to Crash Barrier

Load Condition	Skew angles			
	0°	15°	30°	45°
Shear force due to Crash Barrier (KN)	241	251	272	296

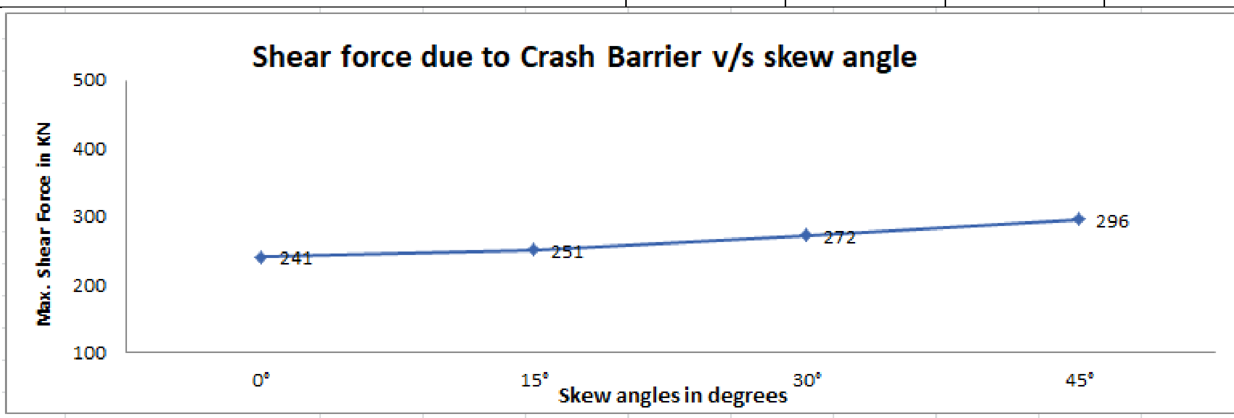

Chart5.6 Shear force due to crash barrier v/s skew angle

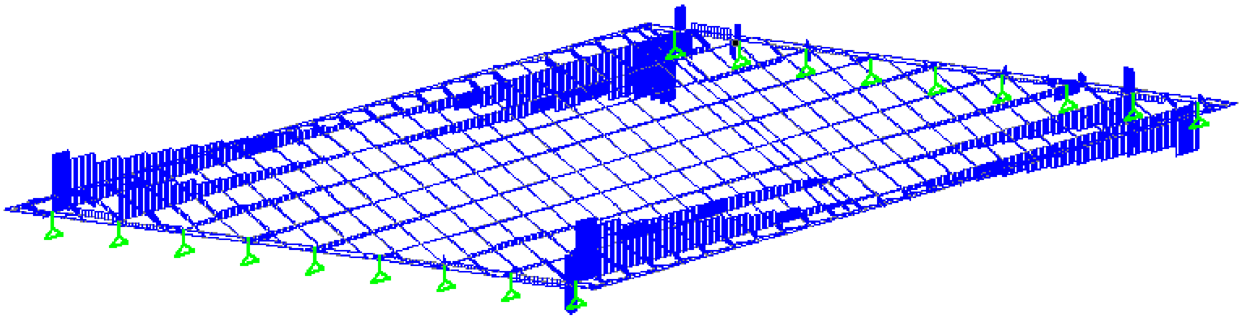

Fig5.6 Shear force diagram due to crash barrier

Above table represents the behavior of angle of skew on crash barrier force due to shear of the bridge. As the angle of skew escalated, crash barrier force due to shear increases. The force due to shear was found to be utmost for 45° skew.

5.7 Shear force due to Wearing Coat

Load Condition	Skew angles			
	0°	15°	30°	45°
Shear force due to Wearing Coat (KN)	46	48	55	71

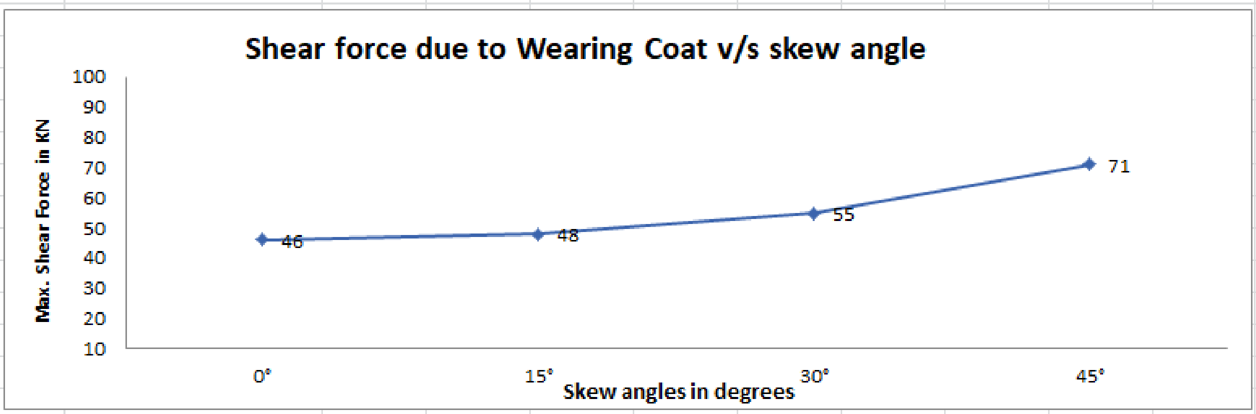

Chart5.7 Shear force due to wearing coat v/s skew angle

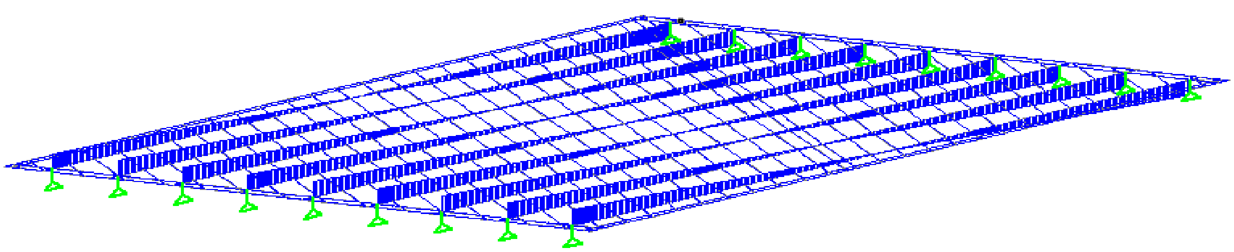

Fig5.7 Shear force diagram due to wearing coat

Above table represents the behavior of angle of skew on wearing coat due to force due to shear on the bridge. As the skew angle escalated, wearing coat shear also increases. The shear was found to be utmost for 45° skew.

5.8 Shear Force due to Live load

Vehicular Load Condition	Skew angles			
	0°	15°	30°	45°
270RW+2CLASSA(KN)	479	490	1725	1215
6CLASSA(KN)	250	405	562	1158
SPECIAL VEHICLE(KN)	485	752	730	860

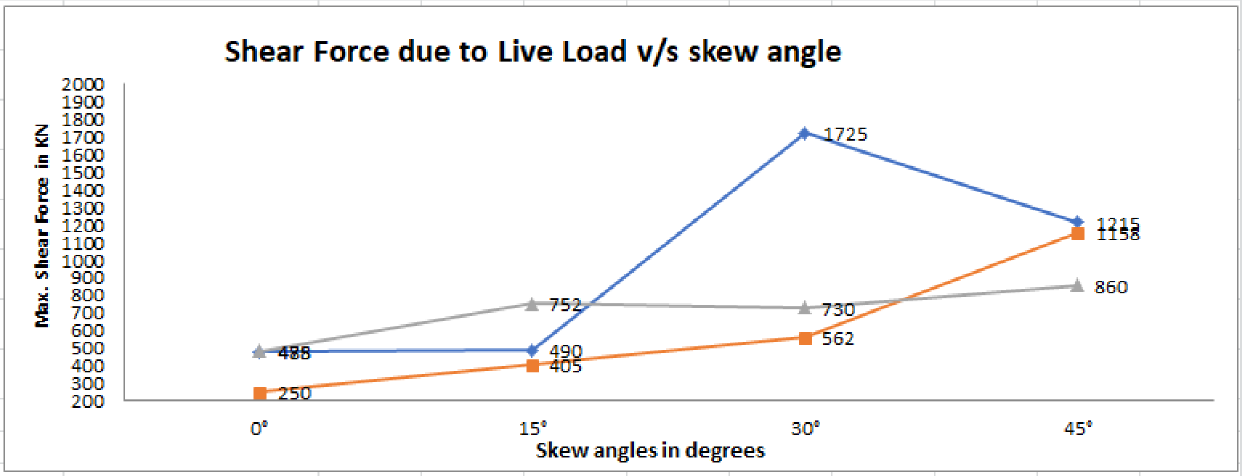

Chart5.8 Shear force due to Live load v/s skew angle

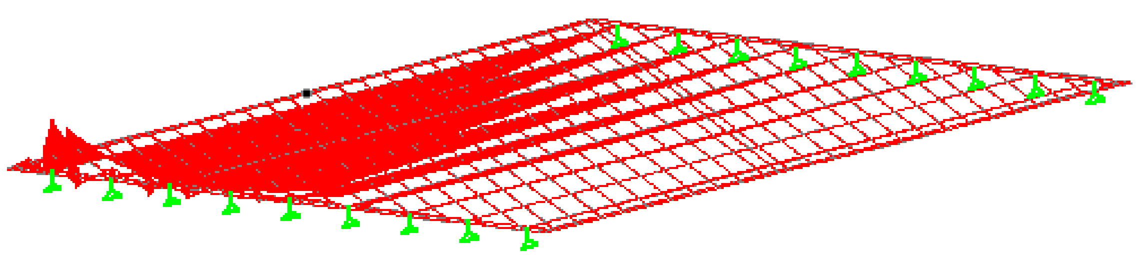

Fig5.8 Shear force diagram due to Live load

The disparity of live load Shear force for different skew angles of 0°, 15°, 30° & 45° for 270R+2CLASSA, 6CLASSA and Special vehicle loading are represented in above chart. It can be represented that as the angle of skew increases, vehicular load shear force increases for few case of loading up to certain skew angle after that the shear force will decline for few case of loading. This is due to the skew effect.

5.9 Torsion due to Dead load

Load Condition	Skew angles			
	0°	15°	30°	45°
Bending moment due to dead load (KNm)	0	2.02	11.92	14.72

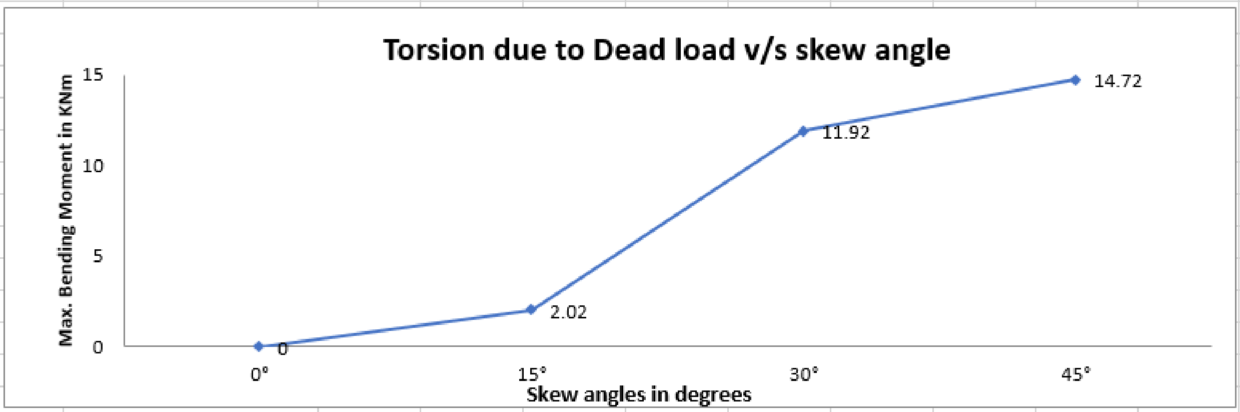

Chart5.9 Torsion due to dead load v/s skew angle

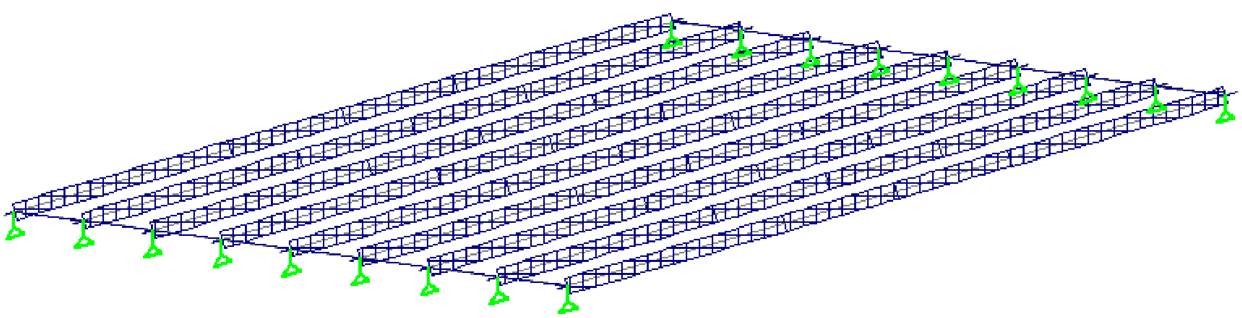

Fig5.9 Torsion diagram due to dead load

The disparity of torsion due to dead load for different angle of skew of 0°, 15°, 30° & 45°.degrees are presented in chart. It can be represented that as the angle of skew increases the torsion due to bending moment also increases.

5.10 Torsion due to Live load

Vehicular Load Condition	Skew angles			
	0°	15°	30°	45°

270RW+2CLASSA(KN)	0	96	28	172
6CLASSA(KN)	0	17	20	259
SPECIAL VEHICLE(KN)	0	0.5	2.5	87

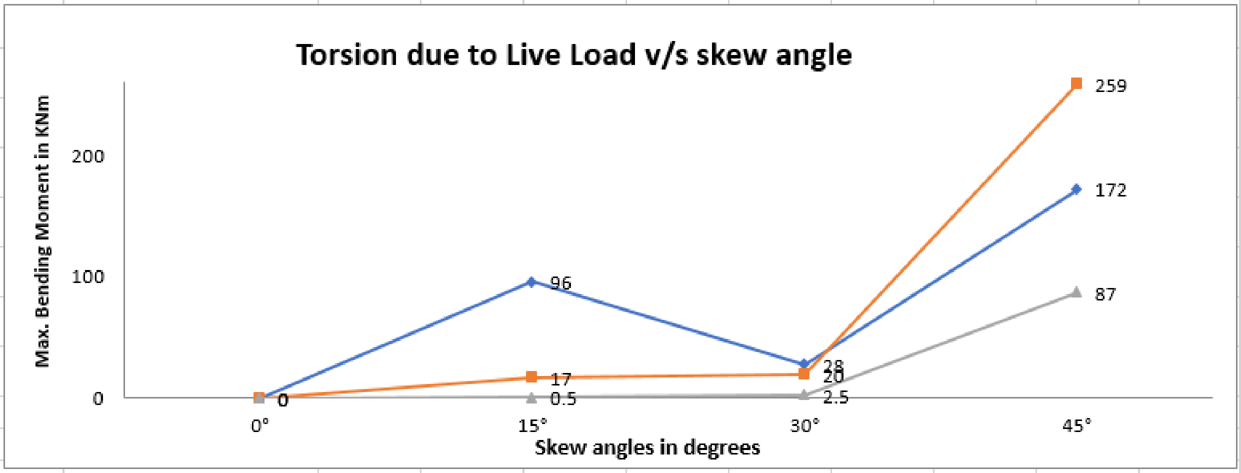

Chart5.10 Torsion due to live load v/s skew angle

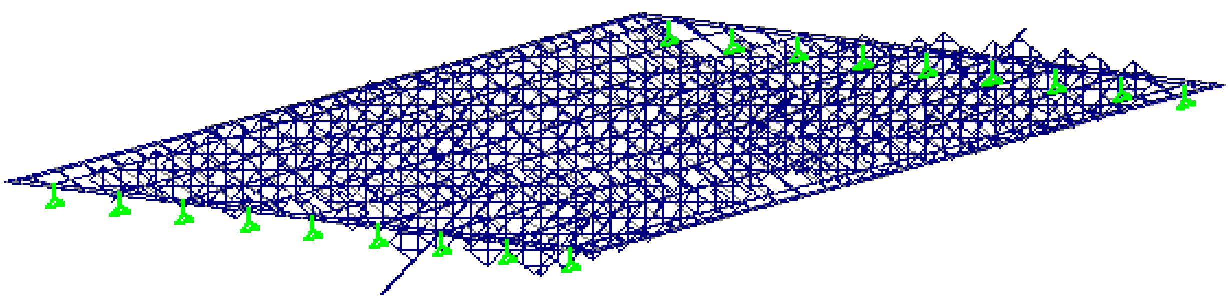

Fig5.10 Torsion diagram due to live load

The disparity of torsion due to vehicular load for different skew angles of 0°, 15°, 30° & 45° for 270R+2CLASSA, 6CLASSA and Special vehicle loading are represented in above chart. It can be represented that as the angle of skew increases, vehicular load shear force increases for few case of loading up to certain skew angle after that the torsion effect will decline for few case of loading. This is due to the skew effect.

5.11 Ultimate Bending moment Vs Skew angle

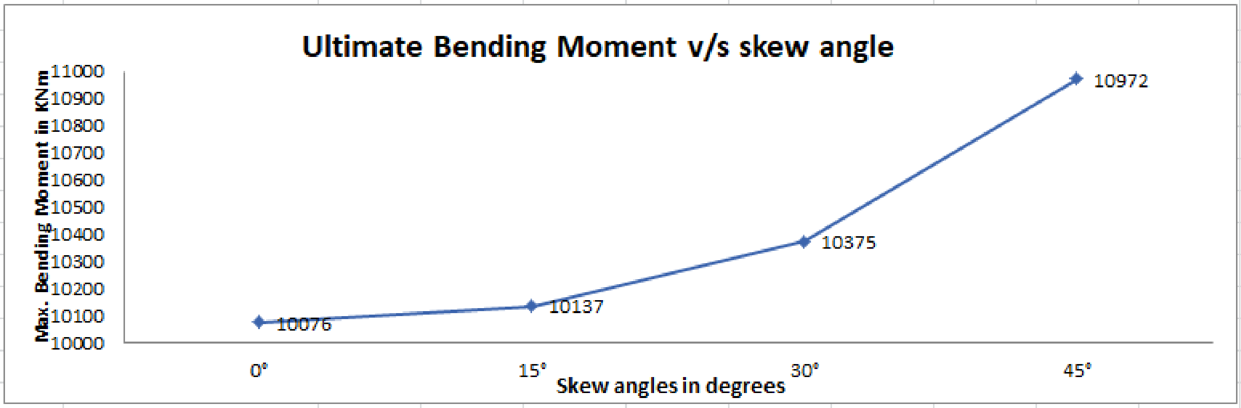

Chart5.11 Ultimate bending moment v/s skew angle

The disparity of angle of skew on ultimate bending moment due to the combined dead load, SIDL, wearing coat and vehicular load is represented in above chart. The chart shows that the bending moment increases as the angle of skew increases in a parabolic form. The obtained values are – 10076 KNm for 0°, 10137 KN-m for 15°, 10375 KNm for 30° and 10972 KNm for 45°.

5.12 Ultimate Shear Force Vs Skew angle

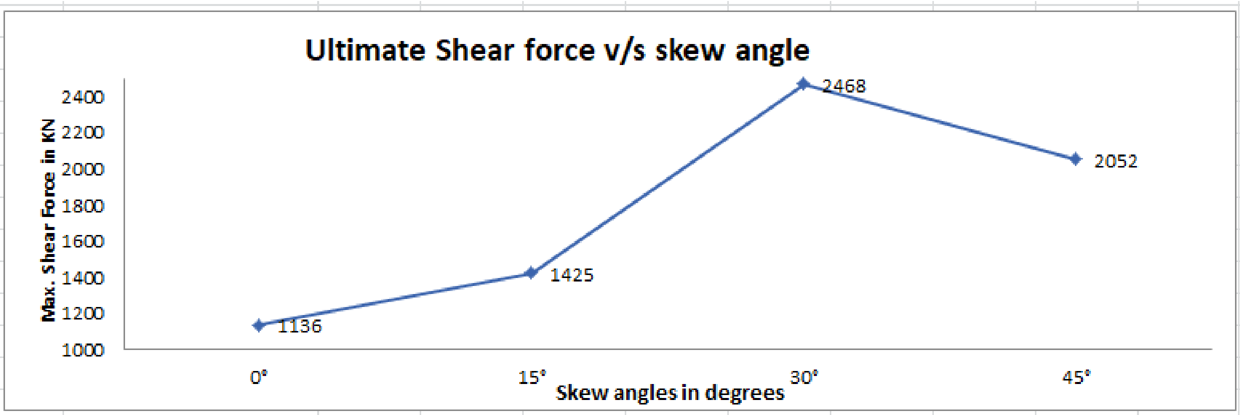

Chart5.12 Ultimate shear force v/s skew angle

The variation of ultimate Shear force for different angle of skew of 0°, 15°, 30° and 45° for 270R+2CLASSA, 6CLASSA and Special vehicle loading are represented in above chart. It can be represented that as the angle of skew increases, vehicular load shear force increases for few case of loading up to certain skew angle after that the shear force will decline for few case of loading. This is due to the skew effect.

5.13 Serviceability Check

Stress	Skew angles			
	0°	15°	30°	45°
Stress at top of Girder (N/mm2)	161.73	163.22	173.58	184.55
Stress at bottom of Girder (N/mm2)	151.91	153.33	161.05	170.55

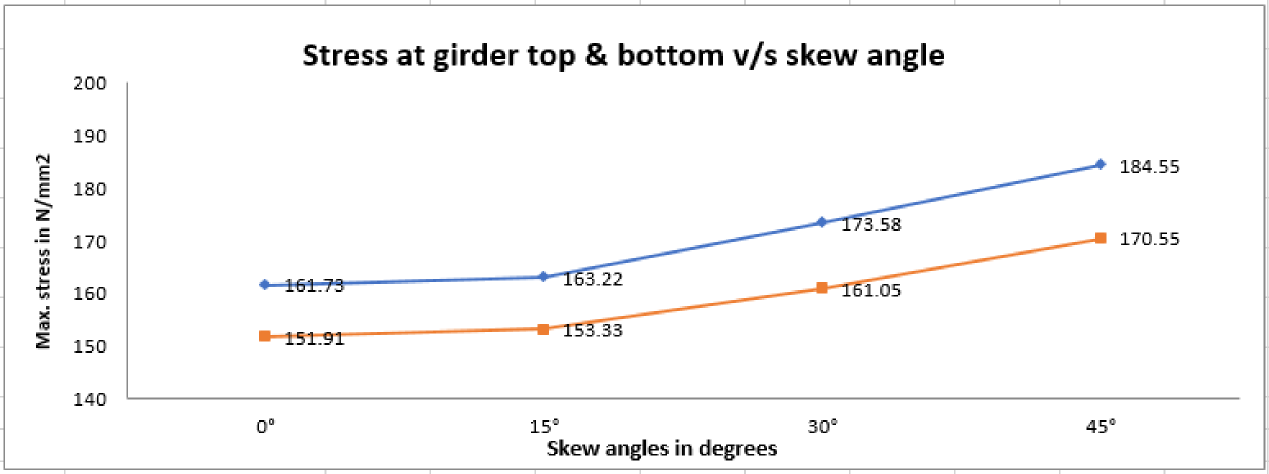

Chart5.13 Stress at girder top & bottom v/s skew angle

The variation of the stress for different angle of skew of 0°, 15°, 30° & 45°.degrees are presented in chart. It can be represented that as the angle of skew increases the stress value at the top and bottom of the girder also increases.

5.14 Differential Deflection of Longitudinal girders

(a) 0° Skew

SR.NO	Description	G1	G2	G3	G4	G5	G6	G7	G8	G9
		mm	mm	mm	mm	mm	mm	mm	mm	mm
1	Deck	1.604	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.604
2	Deck+CB	1.944	1.885	1.768	1.754	1.773	1.754	1.768	1.885	1.944
3	Deck+CB+WC	2.026	1.967	1.851	1.838	1.857	1.838	1.852	1.969	2.026
4	Deck+CB+WC+LL	2.053	2.097	2.151	2.289	2.387	2.369	2.331	2.379	2.365

	Differential Def.	**0.044**	**0.054**	**0.138**	**0.098**	**0.018**	**0.038**	**0.048**	**0.014**	

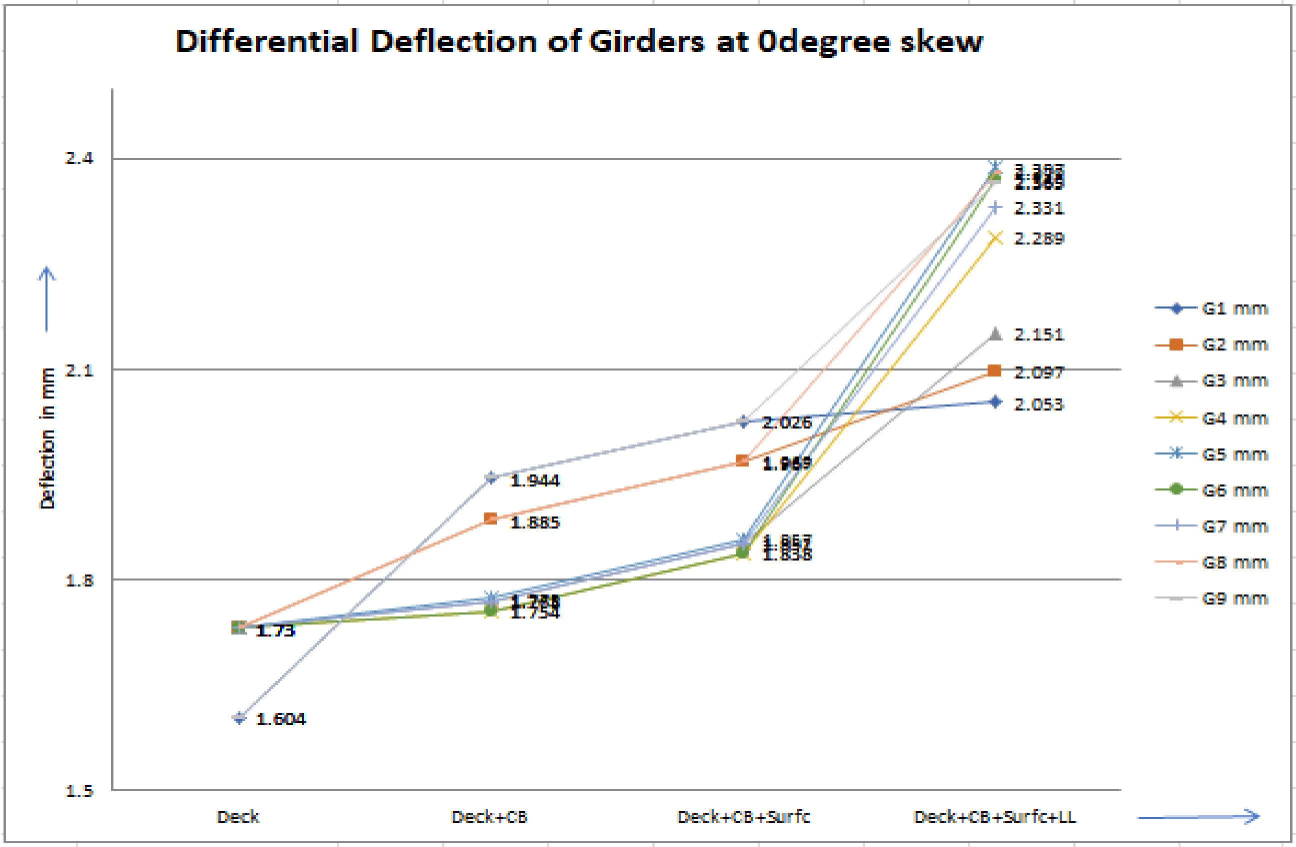

Chart5.14 Differential Defection of Girders at 0° skew v/s various cases

b) 15° Skew

SR.NO	Description	G1	G2	G3	G4	G5	G6	G7	G8	G9
		mm	mm	mm	mm	mm	mm	mm	mm	mm
1	Deck	0	3.012	6.013	8.992	11.938	14.841	17.694	20.475	21.575
2	Deck+CB	0.001	3.027	6.021	8.999	11.955	14.852	17.721	20.487	21.859
3	Deck+CB+WC	0.507	3.036	6.039	9.027	11.993	14.899	17.777	20.551	21.931
4	Deck+CB+WC+LL	0.507	3.066	6.097	9.117	12.137	15.11	18.046	20.864	22.259
	Differential Def.	**2.559**	**3.031**	**3.02**	**3.02**	**2.973**	**2.936**	**2.818**	**1.395**	

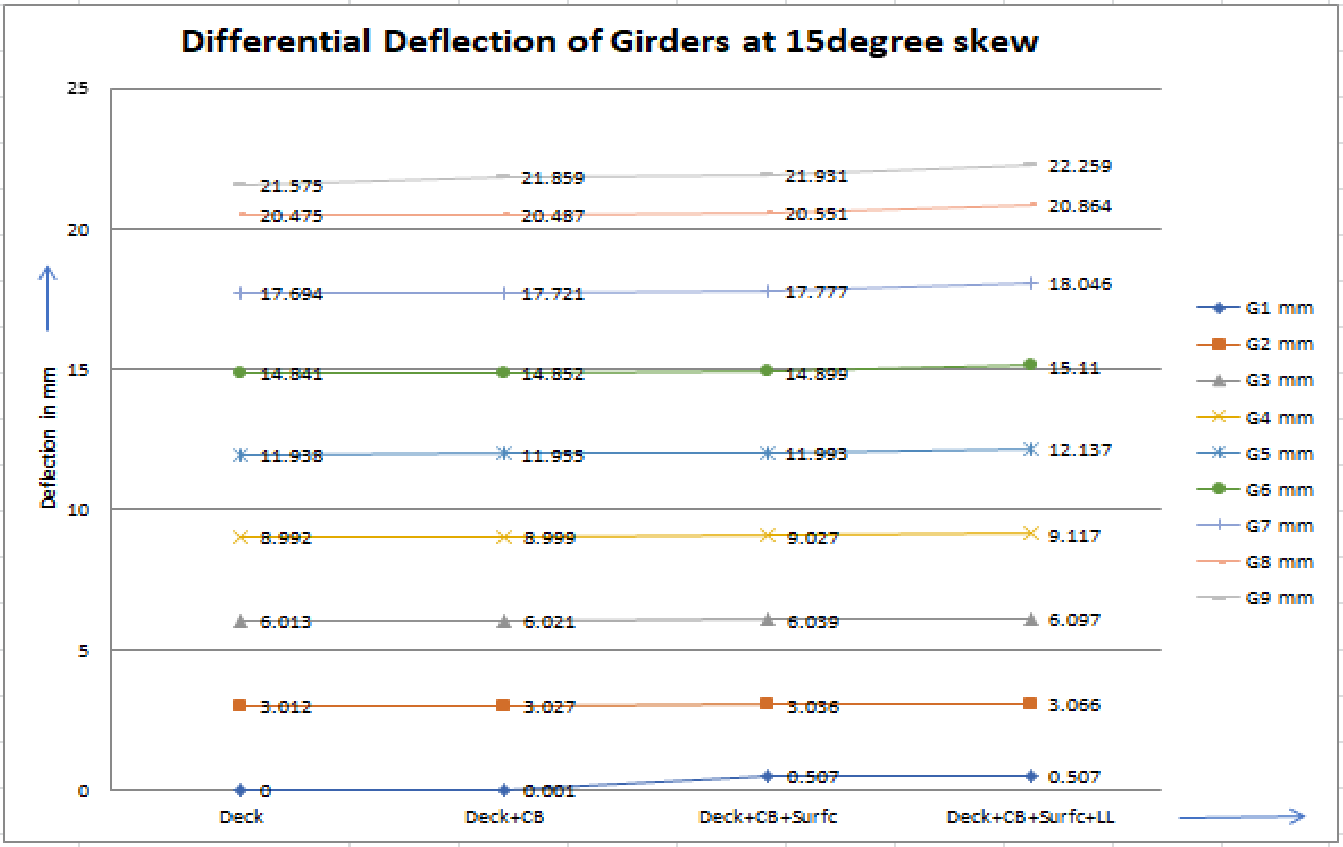

Chart5.15 Differential Defection of Girders at 15° skew v/s various cases

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c) 30° Skew

SR.NO	Description	G1	G2	G3	G4	G5	G6	G7	G8	G9
		mm	mm	mm	mm	mm	mm	mm	mm	mm
1	Deck	5.991	13.572	20.462	27.02	33.153	38.776	43.813	48.813	48.107
2	Deck+CB	7.783	15.076	21.082	27.375	34.053	39.31	45.394	54.589	62.214
3	Deck+CB+WC	8.289	16.096	22.625	29.491	36.562	42.345	48.813	58.340	66.263
4	Deck+CB+WC+LL	9.976	19.37	27.14	35.476	45.538	54.818	63.752	75.091	83.141
	Differential Def.	**9.394**	**7.77**	**8.336**	**10.062**	**9.28**	**8.934**	**11.339**	**8.05**	

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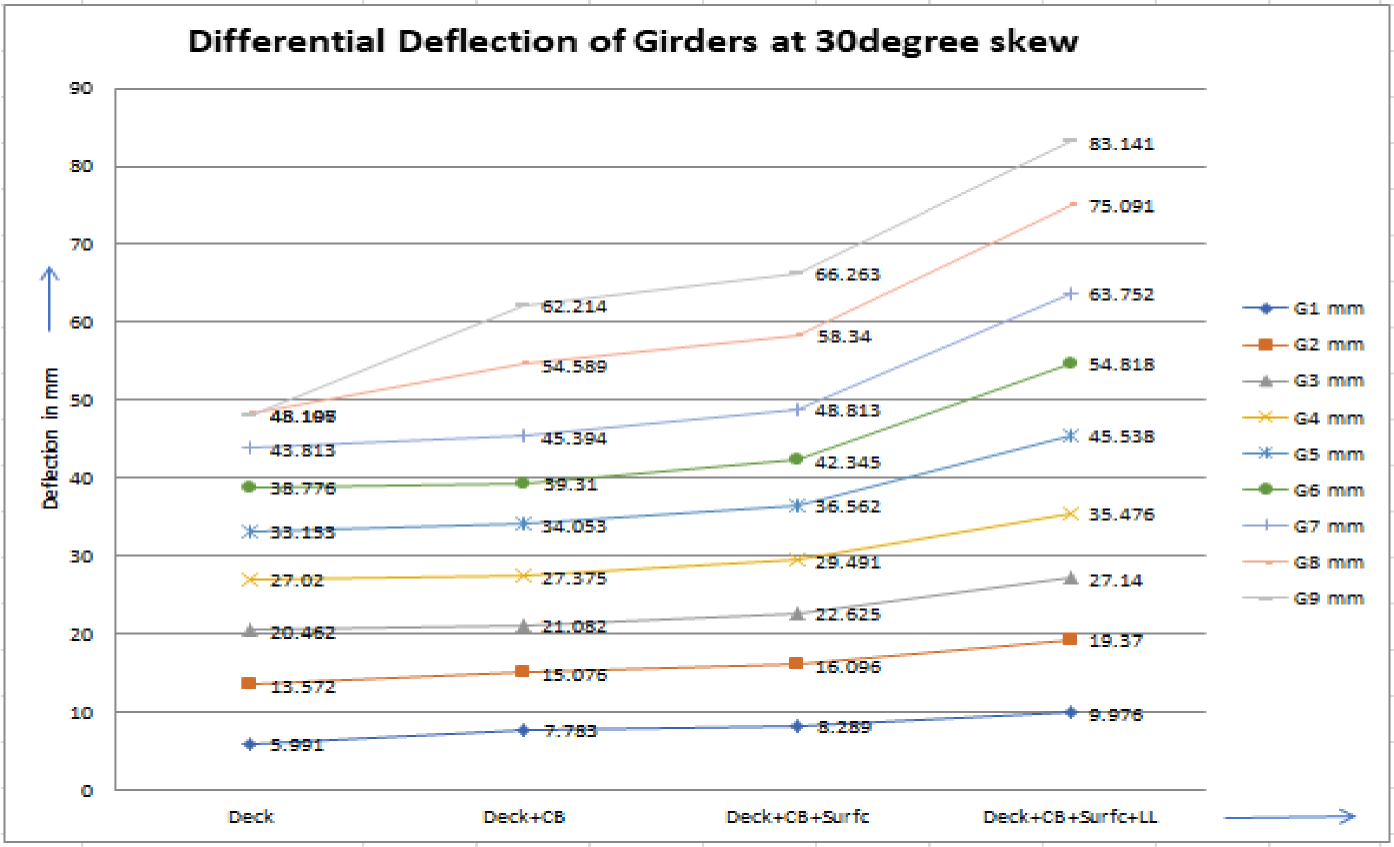

Chart16 Differential Defection of Girders at 30° skew v/s various cases

d) 45° Skew

SR.NO	Description	G1	G2	G3	G4	G5	G6	G7	G8	G9
		mm	mm	mm	mm	mm	mm	mm	mm	mm
1	Deck	1.187	16.474	30.862	43.798	54.609	63.935	66.597	44.072	71.095
2	Deck+CB	1.188	16.513	30.889	43.801	54.635	63.95	66.667	44.345	71.709
3	Deck+CB+WC	1.694	16.549	30.966	43.915	54.781	64.122	66.857	44.546	71.919
4	Deck+CB+WC+LL	3.381	16.616	31.115	44.146	55.153	64.671	67.525	45.316	72.734
	Differential Def.	**13.24**	**14.499**	**13.031**	**11.007**	**9.518**	**2.854**	**22.209**	**27.418**	

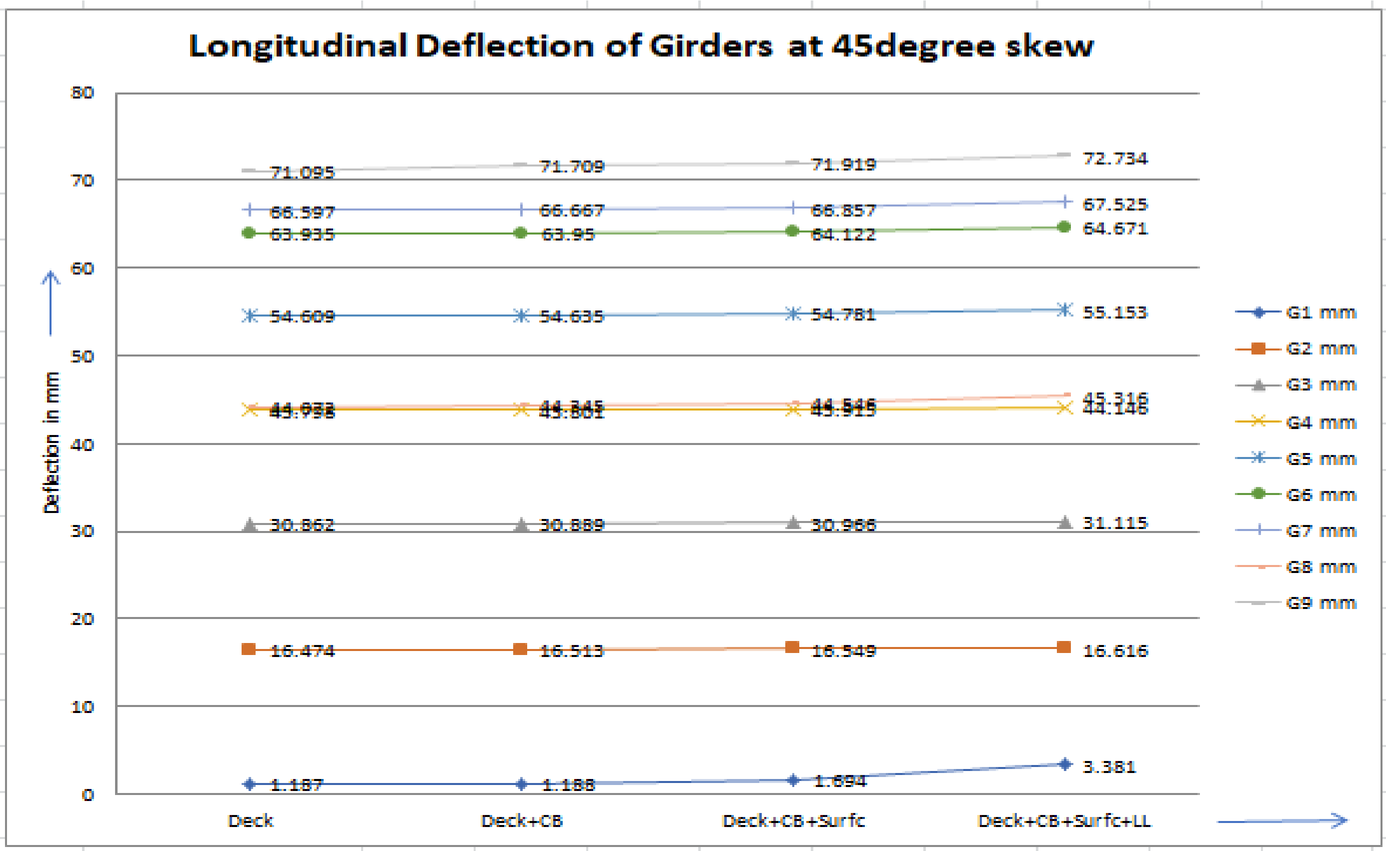

Chart5.17 Differential Defection of Girders at 45° skew v/s various cases

The variation of the Differential Deflection of Girders for different angle of skew of 0°, 15°, 30° & 45°.degrees are presented in chart. It can be represented that as the angle of skew increases the differential deflection of longitudinal girder also increases.

CHAPTER-6

CONCLUSION

The main conclusions ends from this study of the behavior of angle of skew with various loading condition on bending moment & shear force as per IRC 6-2017 code are explained below:

- The study primarily focused on evaluation of bending moment, shear force and stress due to ultimate values in bridges of different angle of skew at critical sections.

- The investigation results obtained have affirmed that the role of finite element model (FEM) in considering the behavior due to angle of skew in bridges and the superstructure design of steel composite Girder is an utmost important.

- As a rule, bending moment & Shear force due to dead load, SIDL, wearing coat & vehicular loading conditions increases with different skew angle for certain cases.

- The value of torsion already added in the bending moment by taking Ixx value tends to zero in angle of skew of the bridge. Hence, this is an crucial phenomenon which can’t be neglected and it also plays major role in design too.

- The exactness of the investigation of skew bridges using finite element analysis may not be gotten from conventional methods. From the investigation results, it can tracked down that the values are exceptionally precise and the use of FEM analysis is defended.

- The examine results acquired have affirmed that the role of stress in the top and bottom of the girder and differential deflection of longitudinal girders increases with increase in skew angles in bridges.

CHAPTER-7

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