"ANALYSIS OF CONCRETE BOX GIRDER BRIDGES USING CSI BRIDGE 2014"

A Dissertation submitted in partial fulfillment of the requirement for the Award of degree of

MASTER OF TECHNOLOGY

IN

STRUCTURAL ENGINEERING

By

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CANDIDATE'S DECLARATION

I do hereby certify that the work presented is the report entitled "**Analysis of concrete box girder using CSI Bridge 2014**" in the partial fulfillment of the requirements for the award of the degree of "Master of Engineering " in structural engineering submitted in the Department of Civil Engineering, Delhi Technological University, is an authentic record of our own work carried out from December 2013 to July 2014 under the supervision of Prof. Nirendra Dev (Professor), Department of Civil Engineering.

I have not submitted the matter embodied in the report for the award of any other degree or diploma.

Date: 31 July 2014

Yati Aggarwal(2K12/STR/24)

This is to certify that above statement made by the candidate is correct to best of my knowledge.

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ABSTRACT

Bridges are the life-line of nation. Now a days any project not only serves the purpose of need, strength and serviceability but aesthetics is a factor that has occupied the major share in finalizing any project's demand. Thus curved, skewed, sleek, box girders are being constructed these days. Box girders not only look pleasant but also serve the purpose of strength. A parametric study is performed on concrete box girders having different skew angles. Further these box girders are analyzed as post tensioned box girder having different post tensioning forces and comparison is made in responses obtained using CSI Bridge 2014 software. For this purpose four different skewed alignments are considered 0°, 5°, 10°, 15°. Again two post tensioned forces 500Kips, 700 Kips are applied. The various responses like torsion, shear force, deflection, bending moment about vertical axis (M3), bending moment about horizontal axis (M2), modal frequencies, longitudinal stresses at soffit at entire girder are studied. Then a tension check is performed to check the stresses coming on soffit of girder before and after post tensioning. The conclusions drawn from the study are discussed further.

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CHAPTER 1 - INTRODUCTION

Concrete is used for construction of most of the buildings and bridges in India it can be called as back-bone to the infrastructural development of the nation. Prestress 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 1930s, the material has found 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 environment conditions. One of the most commonly used forms of superstructure in concrete bridges is precast girders with cast-in-situ slab. This type of superstructure is generally used for spans between 20 to 40 m. T or I-girder bridges are the most common example under this category and are very popular because of their simple geometry, low fabrication cost, easy erection or casting and smaller dead loads. In this paper study the India Road Loading considered for design of bridges, also factor which are important to decide the preliminary sizes of concrete box girders. Also considered the IRC:18-2000 for "Prestressed Concrete Road Bridges". Analyze the Concrete Box Girder Road Bridges for various spans, various depth and check the proportioning depth.

1.1 OBJECTIVE

The objective of this study is to analyze the concrete box girder bridge in CSI BRIDGE software and To Study the behavior of skewed box girders compared a straight bridge along with the variations in post tensioning load. The bridge model developed is then analyzed for moving load and parametric study is performed onto it.

1.2 SCOPE OF STUDY

The present work is about the study of the behavior of rectangular box girder bridges. Present study is limited to constant span length and variable radius of curvatures. The cross section of the bridge is limited to that of a multi cell rectangular shape. Pre-stressed bridges are considered. Super elevation is not considered in the modeling. Only Linear static analysis is considered for the bridge. The different responses like shear force, bending moment about horizontal axis, bending moment about vertical axis, torsion, deflection, longitudinal stresses, fundamental frequencies are studied. Program CSI Bridge 2014 evaluation is used throughout this study for the structural modeling and analysis of straight and skewed Concrete Box Girder Bridge. This program is commercially available to solve a wide variety of bridges, employs matrix displacement method of analysis based on finite element idealization. This program includes both static and dynamic analysis.

1.3 BEHAVIOUR OF BOX GIRDER

A box girder is a hollow box shaped beam. And the bridge having main beams of box shaped is called box girder bridge. A box girder generally made up of prestressed concrete, structural steel, or a composite of steel and reinforced concrete. Its cross section can be rectangular, trapezoidal.

Box girder bridges are constructed for highway flyovers and for modern elevated structures of light rail transport. The box girder can be used in portal frame bridges, arch bridges, cable-stayed and suspension bridges of all kinds. Box girder decks are cast-in-place units that can be constructed to follow any desired alignment in plan, so that straight, skew and curved bridges of various shapes are common in the highway system. Box girders are suited to construct bridges with significant curvatures because they have high torsional resistance.

A box girder is best suitable for curved or skewed bridge systems due to its high torsional rigidity. High torsional rigidity helps box girders to effectively resist the torsional deformations encountered in curved thin-walled beams. There are following types of box girder cross- sections :

1. Circular c/s
2. Rectangular c/s
3. Trapezoidal c/s

Box girder webs can be vertical or inclined, which reduces the width of the bottom flange. In bridges with light curvature, the curvature effects on bending, shear and torsional shear stresses may be ignored if they are within acceptable range. Treating horizontally curved bridges as straight ones with certain limitations is one of the methods to simplify the analysis and design procedure. But, now a days higher level investigations are possible due to the high capacity computational systems available. It is required to examine these bridges using finite element analysis with different skew angles (i.e. closed box girders).

Design considerations are different in the skewed I-girder bridge design compared with the skewed box girder design. Because the I-girder is an open section and is having very low torsional resistance. The twisting of the I-girder results in significant normal stresses in the flanges. The closed box girder has generally improved torsional resistance over the I-section.

1.3.1 TYPES OF BOX GIRDER BRIDGES

The Box-Girders can be of different forms and geometry, but we can characterize three

basic sections, that are represented below:

1 Based on Geometry

1. SIMPLE MONOCELLULAR BOX GIRDERS:

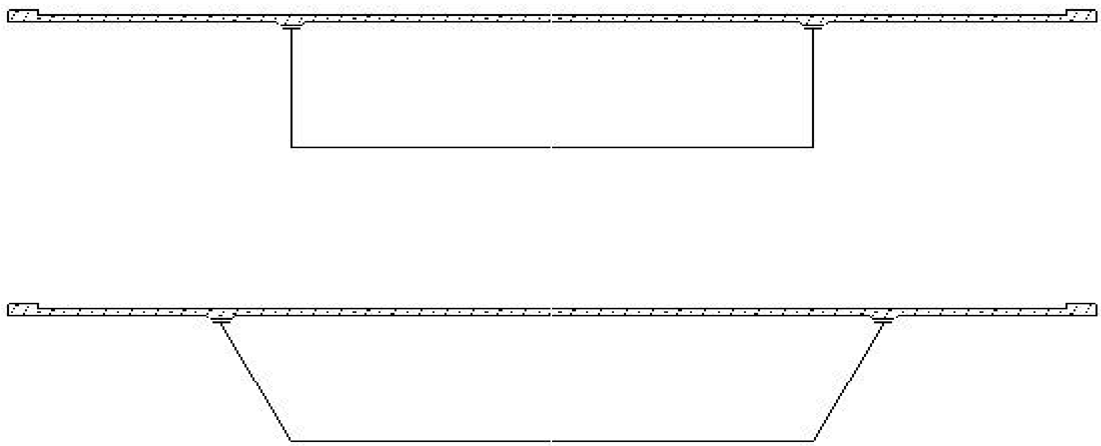


Fig:1.1 Single Cell box girders

2. MONOCELLULAR BOX GIRDERS WITH RIBS OR STRUTS:

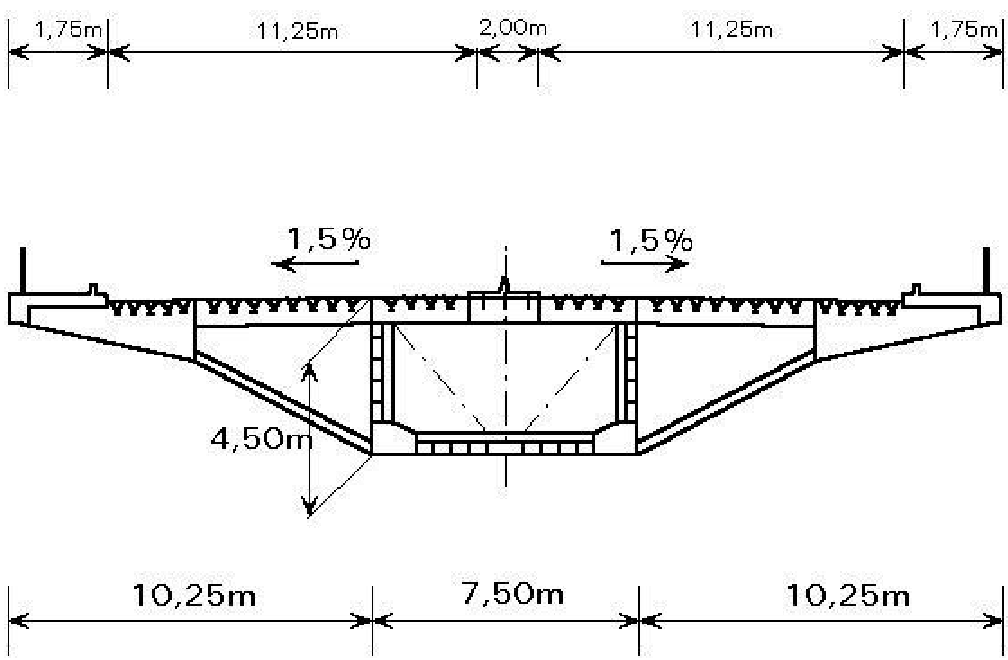


Fig:1.2 Single Cell Box girders with inclined struts

3. DOUBLE-CELL BOX GIRDERS:

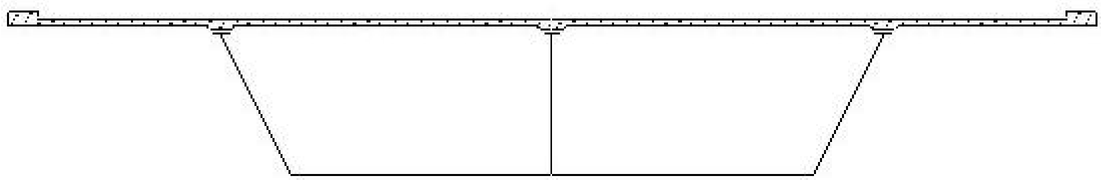


Fig:1.3 Double Cell Box girders

4. COMPOSITE MULTIPLE BOX GIRDERS:

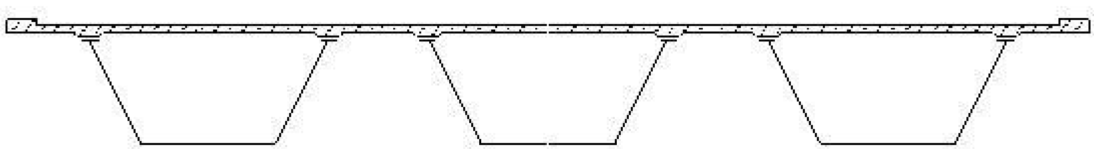


Fig:1.4 Composite Multiple Box girders

2 Based on Materials used

1. Concrete Box Girder:

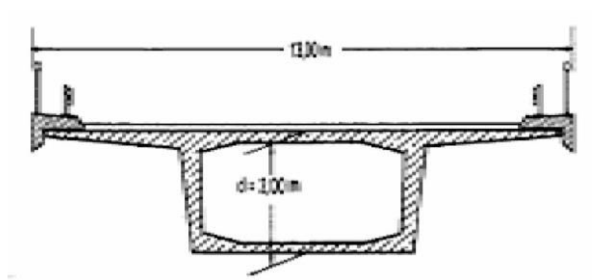


Fig:1.5 Typical single cell Concrete Box Girder cross section

2. Steel Box Girder:

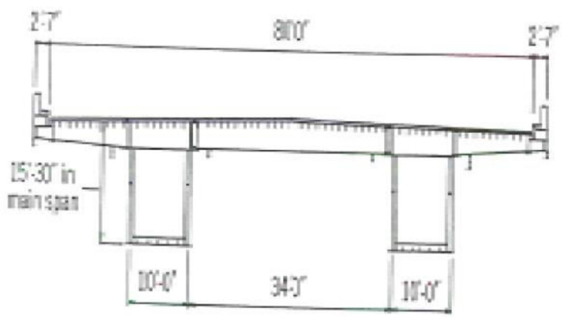


Fig: 1.6 Steel Box girder cross-section

3. Composite Concrete Box Girder:

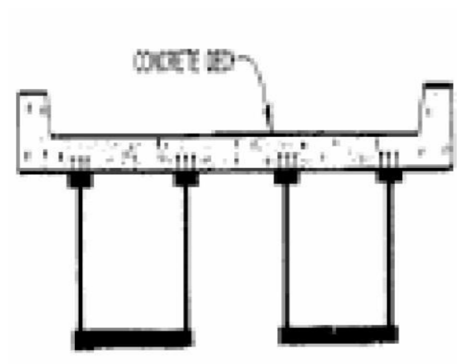


Fig:1.7 Composite Box girder cross-section

3 Based on reinforcement

1. Reinforced concrete box girders

2. Pre tensioned concrete box girders

3. Post tensioned concrete box girders

4. Segmental box girders

1.3.2 DISTINGUISHING FEATURES

1. A box girder when compared to any another equivalent member of open cross section has high torsional stiffness and strength particularly for structures curved in plan. In straight structures box girders impart efficient support to eccentric loads and to the effective distribution of load in transverse direction.
2. Box girder has large flange width. Increased flange widths make it possible to use large span/depth ratios. This is an advantage if construction depth is limited. It helps in constructing slender structures.
3. The space in between box girder is used for the passage of services such as gas pipes, cables, water mains etc. In some cases bottom flange can also be used as another deck that accommodates traffic.
4. Box girders are easy to maintain because the interior space is directly accessible.
5. Box girders are aesthetically good. This is due slender form and also a result from the uncluttered undersurface. Trapezoidal box girders are more pleasing to the human eye.
6. The shape of the box girder can vary a lot. This makes them easier to design for aerodynamic shapes, which is an advantage especially for long span bridges.

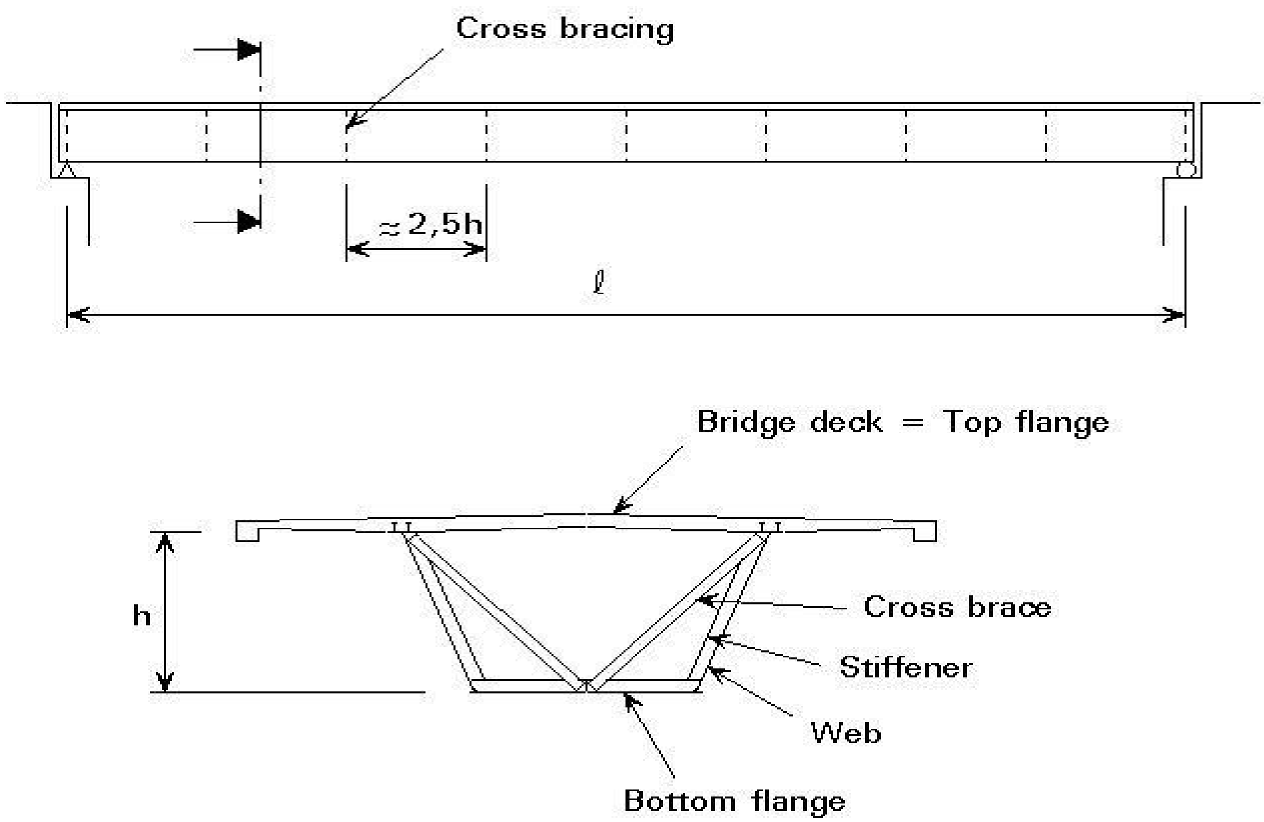


Fig:1.8 Typical components of a box girder bridge with composite concrete deck

Shear keys

A shear key is a shaped joint between two prefabricated elements that can resist shear through the geometric configuration of the joint. Shear keys are provided in the webs and flanges of precast segments of a Box-Girder. They serve two functions. The first is to align the segments when they are erected. The second is to transmit the shear force between segments during construction.

Diaphragms

Diaphragms are adopted in concrete box girder bridges to transfer loads from bridge decks to bearings. Since the depth of diaphragms normally exceeds the width by two times, they are usually designed as deep beams. By the provision of diaphragms, transverse bending stresses caused by the moments, resulting from differential deflection of top and bottom slabs are eliminated. The use of diaphragms at supports which are at definite locations of concentrated loading significantly diminishes the differential deflections near the supports and should always be provided.

1.3.3 ADVANTAGES

1. High stiffness against torsion compared to normal plate girders
2. Smaller economical construction depth when compared to plate girders
3. It has high structural efficiency and torsional strength which minimizes the prestessing force required to resist a given bending moment. Prestressing is not required for spans up to 60m.
4. Their closed shape makes them more efficient in corrosion resistance than plate girders, as the shape drastically reduces the exposed surface area
5. The upper flange can act also as a part of the deck structure
6. Bracings can be hidden in the space available inside the girder and the structure becomes more aesthetic from outside.

1.3.4 DISADVANTAGES

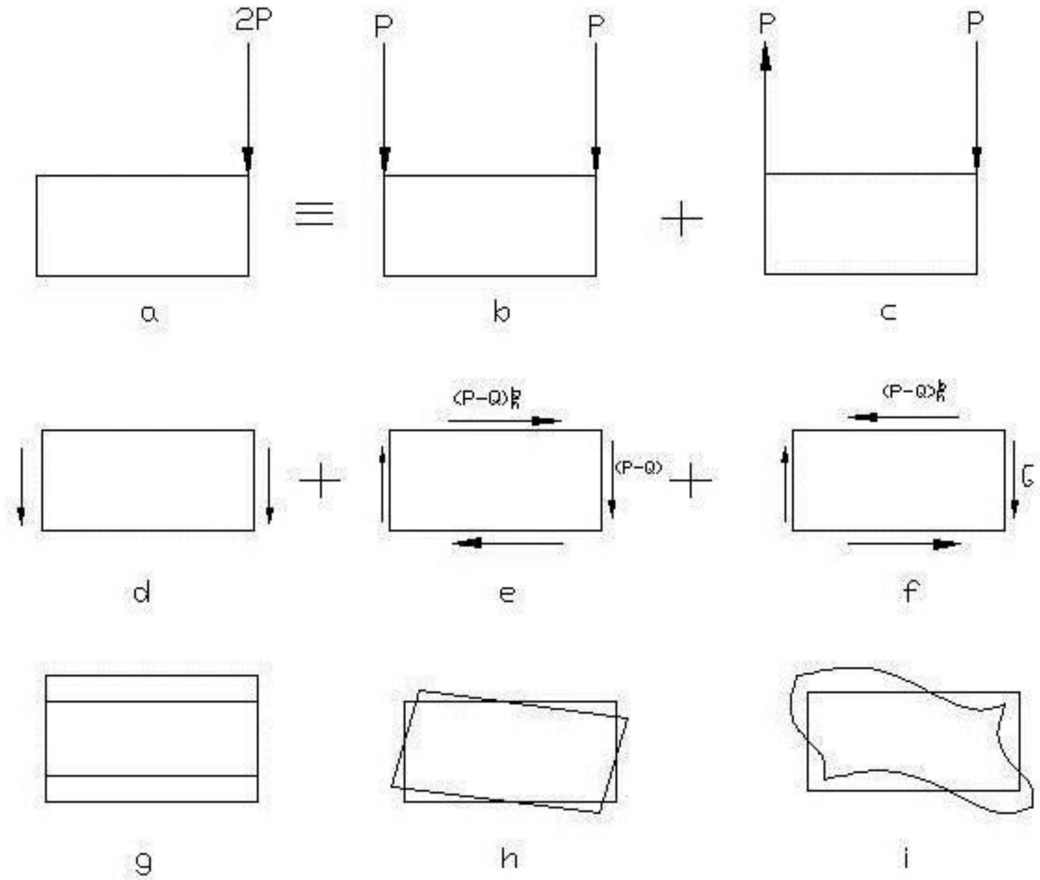
1. One of the main disadvantages of box decks is that they are difficult to cast in-situ due to the inaccessibility of the bottom slab and the need to extract the internal shutter. Either the box has to be designed so that the entire cross section may be cast in one continuous pour, or the cross section has to be cast in stages.
2. Box girders are more expensive to fabricate, and they are more difficult to maintain, because of the need for access to a confined space inside the box.
3. Girders are not efficient as trusses in resisting loads over long spans.
4. Typically higher construction costs compared to I-section steel girder.
5. Design part is complex.

Box girder bridges are reasonable to use when:

1. The spans range from 12 m to 300 m.
2. In girders skewed or curved in plan where there is higher torsion.
3. Fairly low depth is required.

1.3.5 STRUCTURAL BEHAVIOUR OF BOX GIRDER

A structure will be safe when subjected to a design loading if the forces and stresses calculated throughout the structure are in equilibrium with each other and with the design loading, and if they do not anywhere exceed the yield strengths of the material. When box girders are used, two additional effects must be considered, torsion and distortion due to eccentricity in loading. A general loading on a box girder, such as shown in fig for single cell box, has components which bend, twist, and deform the cross section. If the torsional component of the loading is applied as shears fig, the section is twisted without deformation of the cross section. The resulting longitudinal warping stresses are small, and no transverse flexural distortion stresses are induced. However, if the torsional loading is applied as shown in fig, there are also forces acting on the plate elements fig, which tend to deform the cross section. As indicated in fig the movements of the plate elements of the cross section cause distortion stresses in the transverse direction and warping stresses in the longitudinal direction



Torsional warping `   Distortion

Fig 1.9 showing torsional wraping and distorsion

1.3.6 BEHAVIOUR OF BOX GIRDER SUBJECTED TO ECCENTRIC LOADING

When a uniform Box section is subjected to pure torsion then warping is unrestrained and does not give rise to any secondary stresses. But if, a box is supported and torsionally restrained at both ends and then torque is applied in the middle, warping occures and torsional warping stresses are generated. Similar restraint occurs in continuous box sections which are torsionally restrained at intermediate supports.

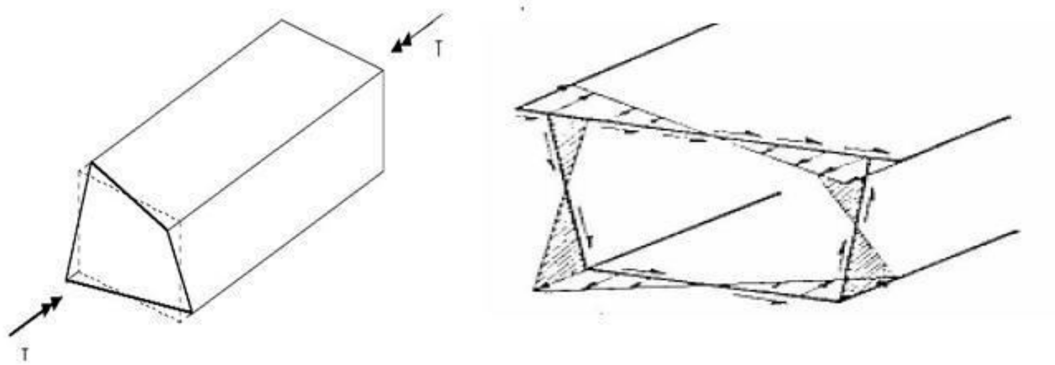


Fig :1.10 Distortional warping stresses

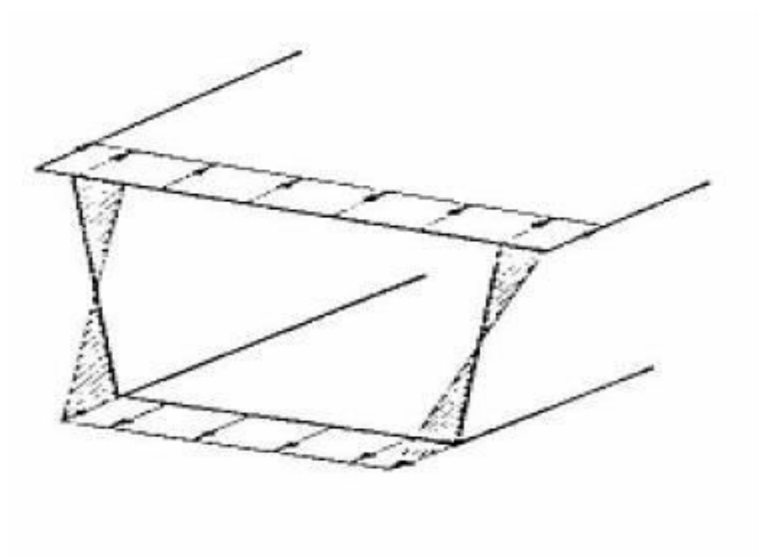


Fig :1.11 Normal stresses due to longitudinal bending

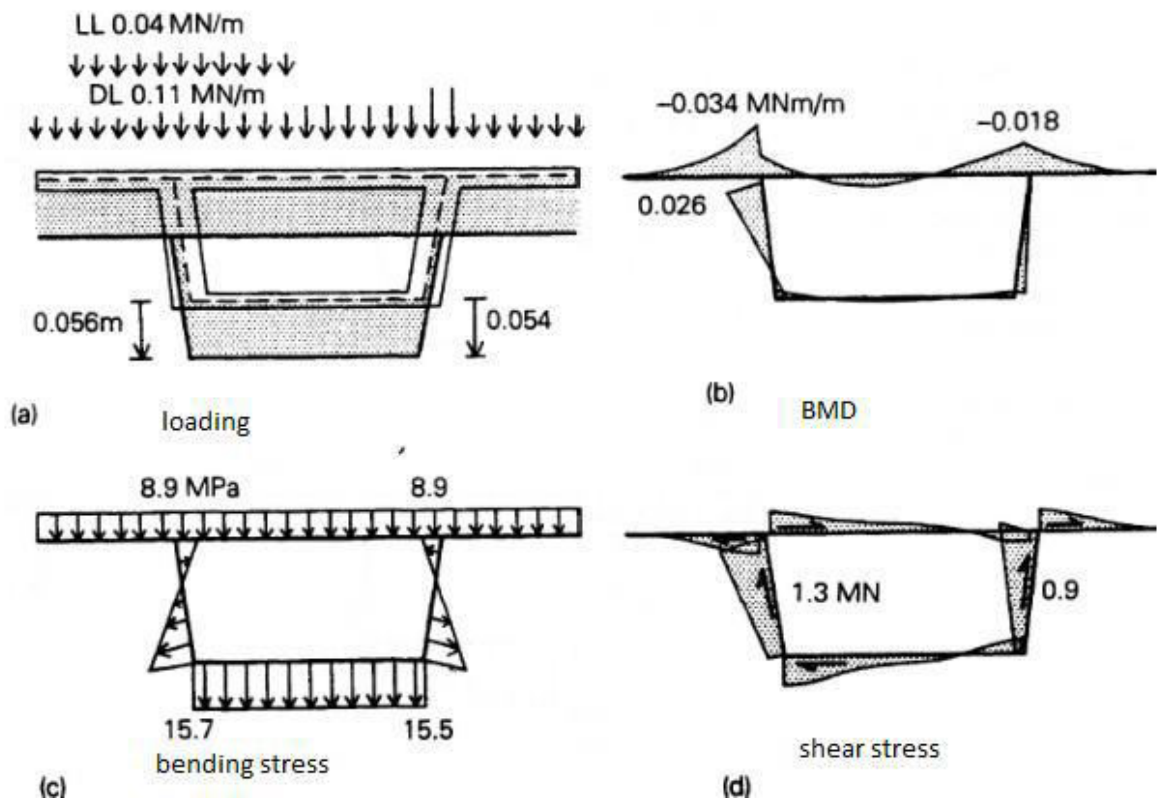


Fig:1.12 Bending moment and stresses due to eccentric loading (Ref Bridge deck behavior, E C Hambly)

1.4 EFFECT OF SKEWS

It is often not possible to arrange that a bridge spans square to the feature that it crosses, particularly where it is important to maintain a relatively straight alignment of a roadway above or below the bridge. Thus a 'skew' bridge is required. This increases the spans but more significantly usually results in the end and intermediate supports being at an angle to the longitudinal axis of the bridge, rather than square to it. Skew bridge supports and horizontal curvature in bridges impart torsional forces that can introduce unexpected stress, displacements, and rotations during construction. As the skew angle or degree of curvature increases, the difficulty of constructing bridges increases. Skews at bridge supports alter the behavior of girders. Historically, skews were avoided whenever possible because the effects were not well understood. Now due to advancement in computer aided design they are being constructed frequently.

CHAPTER 02 – LITERATURE REVIEW

Gupta et al [1] performed study on box girders having different cross sections like rectangular, trapezoidal, circular using SAP2000 software. He performed the linear analysis using three dimensional 4-noded shell elements. He considered the dead load and live load of Indian National Congress 70R loading for zero eccentricity and maximum eccentricity at mid span. He presented a parametric study for deflections, longitudinal and transverse bending stresses and shear lag for these cross-sections.

Haque et al[2]seismic response analysis of a simple span concrete deck girder skewed bridge is carried out for a wide range of skew angles. In this regard, a 3-D model bridge using the finite element method is considered in linear time history analysis. A standard direct time integration approach is employed in the time history analysis. An earthquake ground motion record complying with the design acceleration response spectrum obtained from low to moderate magnitude earthquakes is applied in the longitudinal direction of the bridge. The analytical results have indicated that the skewed bridge responses are quite different from the non-skewed bridge and varying with the skew angles and also on ground motion characteristics. Large skewness is likely to increase base shear, deck acceleration and bearing reactions of the bridge, which may cause an increase in axial forces, shears, moments and torques in the supporting bridge piers.

Halkude [3] explained that a box girder is a beam and hence bending and shear actions exist in longitudinal direction. Due to the thin walled and widespread cross-section, the shear is not uniform even along the width of horizontal plates. When subjected to eccentric loading, the section exhibits torsion. An exact close form solution for such a continuum with a complex behavior is almost impossible. He used the finite strip method for modeling a box girder. He considered only dead load and concluded that with increase in skew angle Mx decreases up to skew angle 300 then it again increases. It is observed that the longitudinal bending moment My decreases and the twisting moments M*xy* increases with an increase in the skew angle.

Ozgur [4] investigated the strength behavior of a representative highly skewed and horizontally curved bridge as well as analysis and design procedures for these types ofstructures. The bridge responses at and above a number of limits in the AASHTO (2007) Specifications are considered. The study includes the evaluation of various attributes of the elastic analysis of the subject bridge. These attributes include: (1) the accuracy of 3-D grid versus 3-D FEA models, (2) first-order versus second-order effects during the construction, (3) the ability to predict layover at bearing lines using simplified equations and (4) the benefit of combining the maximum and concurrent major-axis and flange lateral bending values due to live load compared to combining the maximums due to different live loads when checking the section resistances. The study also addresses the ability of different AASHTO 2007 resistance equations to capture the ultimate strength behavior. This is accomplished by comparing the results from full nonlinear 3-D FEA studies to the elastic design and analysis results. Specifically the use of the 2007 AASHTO moment based one-third rule equations is evaluated for composite sections in positive bending.

Saxena [5] performed a study over a two lane simply supported RCC T- Beam Girder and RCC Box Girder Bridge was analyse for dead load and IRC moving load. He studied bending moment, shear force, cost comparison for both bridges. He concluded that bending moment and shear force under dead load is lesser in T-beam girder and cost for T- beam is less than two cell box girder.

Peckan [6]examined the seismic performance of a three-span continuous concrete box girder bridge with skew angles from 0 to 60 degrees, analytically. The bridge was modeled using finite element (FE) and simplified beam-stick (BS) using SAP2000. Different types of analysis were considered on both models such as: nonlinear static pushover and linear and nonlinear time history analyses. A comparison was conducted between FE and BS, different skew angles, abutment support conditions, and time history and pushover analysis. It is shown that BS model has the capability to capture the coupling due to skew and the significant modes for moderate skew angles. Boundary conditions and pushover load profile are determined to have a major effect on pushover analysis. Pushover analysis may be used to predict the maximum deformation and hinge formation adequately.

Ibrahim[7] performed analytical study using three dimensional finite element methods was performed to investigate the effect of skew angle on behavior of simply supported reinforced concrete T-beam bridge decks. The parameters investigated in this analytical study were the span lengths and skew angle. The finite element analysis (FEA) results for skewed bridges were compared to the reference straight bridges (nonskewed). The geometric dimensions of the T-beam bridge decks and the loading used are in compliance with AASHTO standard specifications. The FEA results and comparison of skewed bridge with straight bridge indicate that max. Live load bending moments and deflections decreases in T- beams for skewed bridges, while max. shear, torsion and supports reactions increases in some T-beams for skewed bridges for all considered span lengths (12, 16, 20 and 24m). This study disagreement with the AASHTO standard specifications as well as the LRFD in recommending that bridges with skew angle less than or equal 20° be designed as straight (non skewed) bridges also it recommended that engineers are better to perform three dimensional finite element analysis for skewed T-beam bridge decks.

Mohti et al [8] made a three-dimensional improved beam-stick models of two-span highway bridges with skew angles varying from 0° to 60° are developed to investigate the seismic response characteristics of skew box girder bridges. The relative accuracy of beam-stick models is verified against counterpart finite element models. The effect of various parameters and conditions on the overall seismic response was examined such as skew angle, ground motion intensity, soil condition, abutment support conditions, bridge aspect ratio, and foundation-base conditions. The study shows that the improved beam-stick models can be used to conduct accurate nonlinear time history analysis of skew bridges. Skew angle and interacting parameters were found to have significant effect on the behavior of skewed highway bridges. Furthermore, the performance of shear keys may have a predominant effect on the overall seismic response of the skew bridges.

Sindhu et al [9] studied The effect of a skew angle on single-span reinforced concrete bridges using the finite-element method. Investigations are carried out on RC slab bridge decks with and without edge beams to study the influence of aspect ratio, skew angle and type of load. The finite-element analysis results for skewed bridges are compared to the reference straight bridges for dead load, IRC Class A loading and IRC 70R loading for with and without edge beam. A total of 90 bridge models are analyzed. The variation of maximum deflection, maximum longitudinal sagging bending moment, maximum torsional moment, and maximum support reaction with skew angle is studied for all 90 bridge deck models. The FEA results of Dead load and Live load bending moments and deflections decreases with increase in skew angle, where as maximum support reactions increases with increase in skew angle and the maximum torsional moment increases with skew angle up to 45 degrees and there after decreases. The benefit of providing edge beam is reflected in significant decrease in deflection, longitudinal bending moment and torsional moment.

Norton [10] made a study on influence of construction sequencing and the 12-hour placement process of the concrete deck to determine their effect on the deflected shape of the skewed bridge and the resulting forces in the girders and diaphragms. Recommendations for improved analysis methods and construction sequences will lead to more confident design and construction of skewed bridges.

Minalu [11] studied, an appropriate finite element modelling technique is looked for, which capable of predicting the three-dimensional behaviour of high skew bridges consisting of a cast in-place concrete deck on precast prestressed inverted T-girders. The effect of the angle of skewness on the internal force distribution was investigated using two finite element modelling techniques. Four skew angles of 0o, 30o, 45o, and 60° were considered for each finite element model. The results show that, live load maximum bending moments in girders of skew bridges are generally smaller than those in right bridges of the same span and deck width. On the contrary, the torsion moment in the obtuse corner of the bridge and the transverse moments in the deck increase with skew angel.

Sisodiya et al [12] performed finite element analysis of single box-girder skew bridges curved in any shape. The bridge may be of varying width and of any support conditions. The procedure of the analysis and the types of the finite elements used to idealize the bridge deck is presented in a separate paper which is limited to skew straight bridges. Results of the analysis of a curved bridge are pre ented here and they are compared with the results of experiments on a model.

CHAPTER 03 - METHODOLOGY

3.1 MODELING OF BOX GIRDER BRIDGE FOR PARAMETRIC STUDY

All the 12 models are modeled in CSI Bridge 2014 for parametric study. A 200 ft long multi-cellular box girder is first modeled as non- post tensioned and straight viaduct. Three models are provided with different skewness. The girder is rectangular in cross section. These geometrically similar models are then modeled with post tensioned load having different prestressed loads. Then the different responses like shear force, bending moment about horizontal axis, bending moment about vertical axis, torsion, deflection, longitudinal stresses and fundamental frequencies are studied.

3.2 DIFFERENT DESIGN LOADS FOR BRIDGE DESIGN

The loads that are to be considered on the superstructure of a typical box girder bridges given in IRC 6:2000 (SectionII)are listed below;

A) Permanent Loads:

- Dead Loads
- Superimposed Dead Loads
- Pressures (earth, water, ice, etc.)

B) Temporary Loads:

- Vehicle Live Loads
- Earthquake Forces
- Wind Forces
- Channel Forces
- Longitudinal Forces
- Centrifugal Forces
- Impact Forces
- Construction Loads

C) Deformation and Response Loads:

- Creep
- Shrinkage
- Settlement
- Uplift
- Thermal Forces

D) Group Loading Combinations.

Although these are various loading present in a typical bridge, for the present parametric study of skew bridges, the scope is limited to Dead Loads, Prestress load and Vehicle live loads only.

1. *Dead Load(DL):* The dead load carried by the girder or the member consists of its own weight and the portions of the weight of the superstructure and any fixed loads supported by the member. The dead load can be estimated fairly accurately during design and can be controlled during construction and service.

2. *Live Load(LL):* Live loads are those caused by vehicles which pass over the bridge and are transient in nature. These loads cannot be estimated precisely, and the designer has very little control over them once the bridge is opened to traffic. However, hypothetical loadings which are reasonably realistic need to be evolved and specified to serve as design criteria. There are four types of standard loadings for which road bridges are designed.
    a. IRC Class 70R loading
3. *Prestress Load*: The post tensioning is done with with 500kips and 700 kips.

3.3 PROBLEM FORMULATION

200 ft long concrete box girder 2 span. Deck is 36 ft wide, with depth varies as parabola. The bridge will support 2 lanes of traffic each of width 14 ft. The bridge is prestressed in concrete deck section.

Deck section properties: Concrete box girder with vertical sides and 3 cells. It has a nominal depth of 5 ft. Vertical diaphragms are placed at the each end of bridge deck. The parametric variation is given to the deck from zero variation at the exterior ends of the span to max of 5 ft to the interior of span that is mid of the bridge.

Bearings: They are placed under the girder top of the abutments at the bridge ends. They are to the transition in vertical and normal to the layout line and in all other directions it is free to move.

Foundation springs: They are fixed in all 6 degree of freedom.

Abutment properties: The abutments are of concrete rectangular sections of 8ft deep and 4 ft wide. The bearings supports over the abutment of length 30 ft and which further rests over the foundation springs. The abutments are skewed according to the considered case.

Bent properties: One bent is provided in the middle of bridge. The skewness is provided according to the case considered.

Column- A circular concrete section with diameter of 5 ft. the length depends over the depth of substructure.3 nos of columns are used. The moment released at top and bottom of columns are fixed.

Bent cap- It is a rectangular concrete cap with 30 ft length, 10 ft depth and 5 ft width. It should be integral with the column.

Tendon properties: The tendons are of area 10 in^2 with parabolic variation and modeled as a load. The tendons are provided in all girders.

3.4 ANALYSIS

The following load cases will be consider for the analysis of prestressed concrete girder bridge:

1. DEAD LOAD CASE is the load of the structure.
2. MOVING LOAD CASE is applied to all lanes with a factor of one and with the vehicle class created.
3. PRESTRESS LOAD CASE is the stress coming onto the structure due to the post tensioning of tendons
4. MODAL LOAD CASE is not considered in this stage of analysis but will consider in further studies.

3.5 MODELS OF BRIDGE

The finite element modeling of one straight and three skewed bridges with or without post tensioning are conducted in CSI Bridge 2014. The four different skew angles are 0°, 5°, 10°, 15° studied. The bridge is having two spans. The different models are listed below:

1. Non post tensioned straight girder. Labeled as (m1).
2. Non post tensioned girder horizontally skewed to 5°(m2).
3. Non post tensioned girder horizontally skewed to 10°(m3).
4. Non post tensioned girder horizontally skewed to 15°(m4).
5. Post tensioned girder with 500kips load and straight in plan (m5).
6. Post tensioned girder with 500kips load and skewed to 5°(m6).
7. Post tensioned girder with 500kips load and skewed to 10°(m7).
8. Post tensioned girder with 500kips load and skewed to 15°(m8).
9. Post tensioned girder with 600kips load and straight in plan (m9).
10. Post tensioned girder with 600kips load and skewed to 5°(m10).
11. Post tensioned girder with 600kips load and skewed to 10°(m11).
12. Post tensioned girder with 600kips load and skewed to 15°(m12).

Table3.1 Material properties.

Material Properties	**Values**
weight /unit volume	25000 N/m3
Young's modulus (E)	32500 e6 N/m2
Poisson's ratio (υ)	0.15
Shear Modulus (G)	1.413 e 10 N/m2
Coefficient of thermal expansion (A)	1.17 e -5/°C

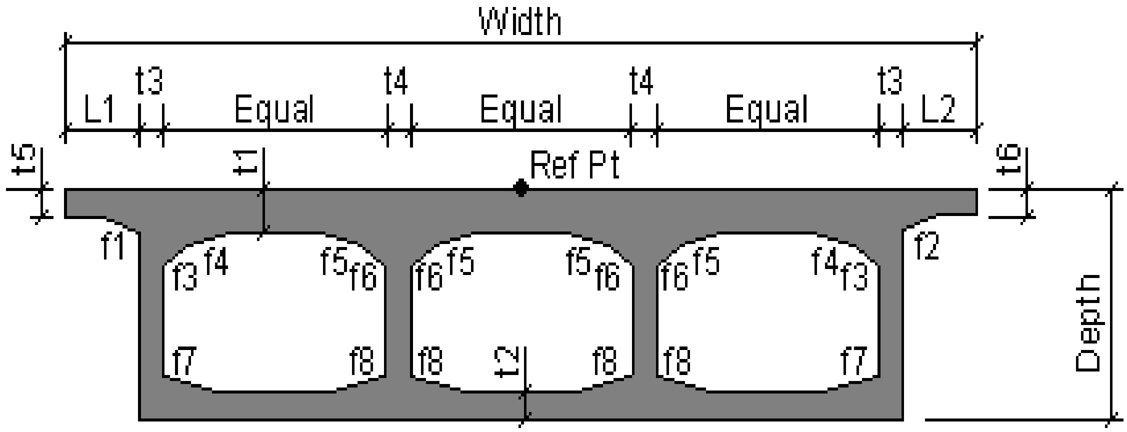


Fig 3.1 Cross section of the girder

Table.3.2 Cross section properties of the girder

ITEM	**NOTATION**	**VALUE (in)**
No of interior girder		2
Total width		432
Total depth		60
Top slab thickness	T1	12
Bottom slab thickness	T2	8
Exterior girder thickness	T3	12
Interior girder thickness	T4	12
Fillet horizontal dimension	F1	18
Fillet horizontal dimension	F2	18
Fillet horizontal dimension	F3	6
Fillet horizontal dimension	F4	18
Fillet horizontal dimension	F5	18
Fillet horizontal dimension	F6	6
Fillet horizontal dimension	F7	18
Fillet horizontal dimension	F8	18
Fillet vertical dimension	F1	6
Fillet vertical dimension	F2	6
Fillet vertical dimension	F3	6
Fillet vertical dimension	F4	6
Fillet vertical dimension	F5	6
Fillet vertical dimension	F6	6
Fillet vertical dimension	F7	6
Fillet vertical dimension	F8	6
Left overhang length	L1	36
Left overhang outer thickness	T5	8
Right overhang length	L2	36
Right overhang outer thickness	T6	8

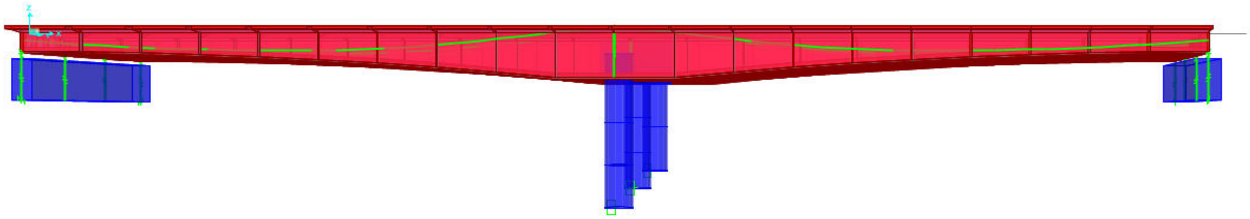


Fig3.2 elevational view of skewed box girder bridge

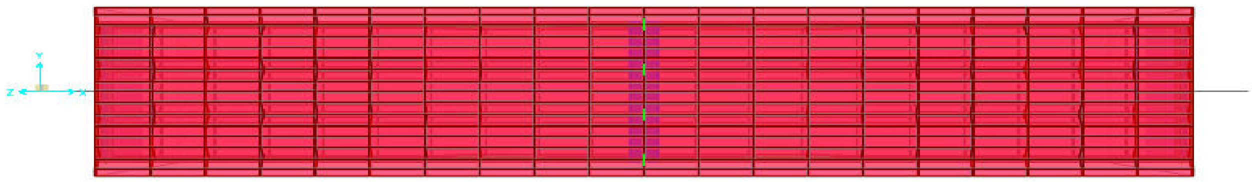


Fig3.3 plan of straight box girder bridge

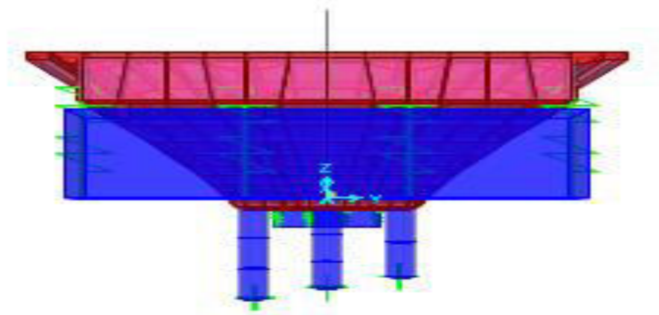


Fig3.4 sectional view of straight box girder bridge

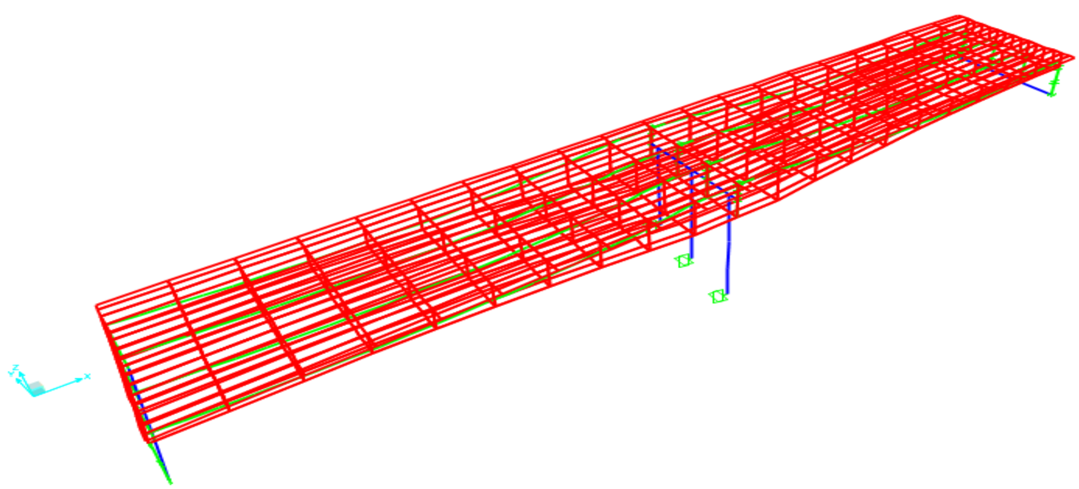


Fig3.5- three dimensional view of box girder bridge

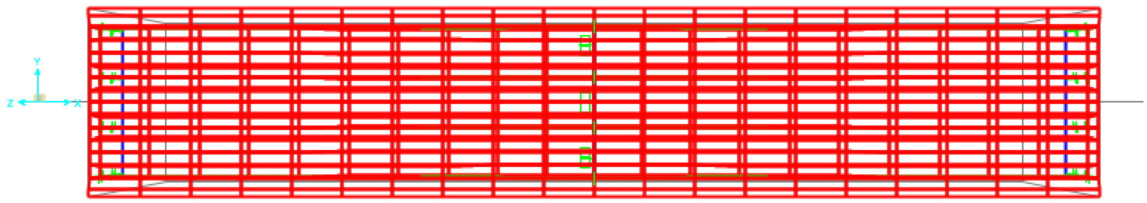


Fig3.6- 0 degree skewed box girder bridge

Fig3.7- 5 degree skewed box girder bridge

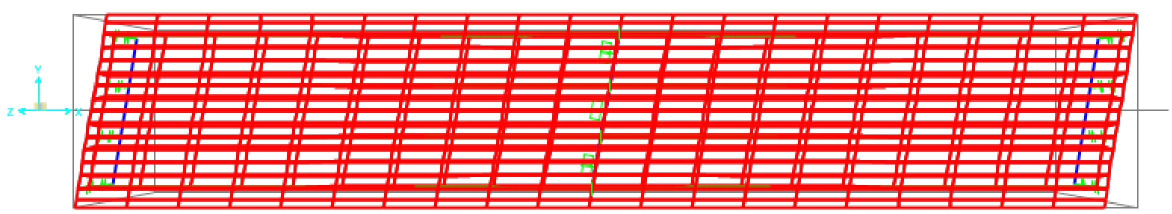


Fig3.8- 10 degree skewed box girder bridge

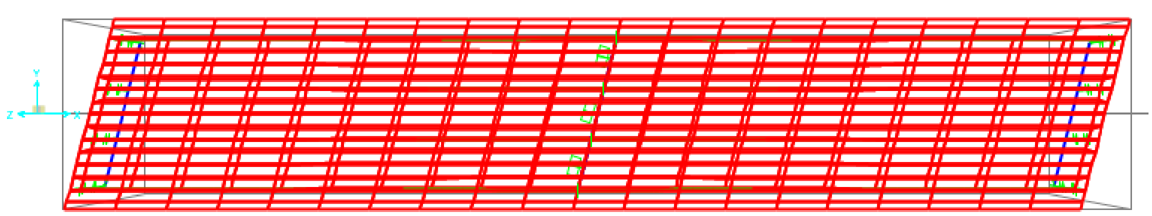


Fig3.9- 15 degree skewed box girder bridge

CHAPTER 04 – RESULT

Analyses of the skewed and straight box girder bridge models with non post tensioning and post tensioning with 500kips load and 700kips load for dead load and moving load are conducted. The responses such as torsion, bending moment along horizontal axis, bending moment about vertical axis, longitudinal stress, deflections , shear force are monitored in each analysis.

4.1 TORSION

Torsion for all the bridge models is considered under dead load and moving load. The variation of torsion is plotted across the span length.

4.1.1 TORSION DUE TO DEAD LOAD

The analysis is conducted for dead load for all the cases. The torsion along the span is monitored and a graph is plotted between torsion and the span length. Fig4.1 is a graph for torsion in non post tensioned case for straight and skewed bridge. Latter graphs are between torsion and span for different skewness separately showing comparison between non post tensioned and post tensioned bridges.

4.1.2 TORSION DUE TO MOVING LOAD

The analysis is conducted for moving load for all the cases. The torsion along the span is monitored and a graph is plotted between torsion and the span length. Fig4.2 is a graph for torsion in non post tensioned case for straight and skewed bridge. Latter graphs are between torsion and span for different skewness separately showing comparison between non post tensioned and post tensioned bridges.

4.2 SHEAR FORCE

Shear forces for all the bridge models is considered under dead load and moving load. The variation of shear force is plotted across the span length.

4.2.1 SHEAR FORCE DUE TO DEAD LOAD

The analysis is conducted for dead load for all the cases. The shear force along the span is monitored and a graph is plotted between torsion and the span length. Fig4.23 is a graph for shear force in non post tensioned case for straight and skewed bridge. Fig 4.15, fig 4.17, fig 4.19, fig 4.21are between shear force and span for different skewness separately showing comparison between non post tensioned and post tensioned bridges.

4.2.2 SHEAR FORCE DUE TO MOVING LOAD

The analysis is conducted for moving load for all the cases. The shear force along the span is monitored and a graph is plotted between torsion and the span length. Fig4.24 is a graph for shear force in non post tensioned case for straight and skewed bridge. Fig 4.16, fig

4.18, fig 4.20, fig 4.22 are between shear force and span for different skewness separately showing comparison between non post tensioned and post tensioned bridges.

4.3 LONGITUDINAL STRESS

Longitudinal stress is studied at bottom section for entire bridge length. Its variations are plotted due to dead and moving load imposed on the bridge.

4.3.1 LONGITUDINAL STRESS DUE TO DEAD LOAD

The analysis is conducted for dead load for all the cases. The longitudinal stress along the span is monitored and a graph is plotted between longitudinal stress and the span length. Fig4.25 is a graph for LS in non post tensioned case for straight and skewed bridge. Fig 4.27, fig 4.29, fig 4.31, fig 4.33 are between LS and span for different skewness separately showing comparison between non post tensioned and post tensioned bridges.

4.3.2 LONGITUDINAL STRESS DUE TO MOVING LOAD

The analysis is conducted for moving load for all the cases. The LS along the span is monitored and a graph is plotted between LS and the span length. Fig4.26 is a graph for LS in non post tensioned case for straight and skewed bridge. Fig 4.28, fig 4.30, fig 4.32, fig 4.34 are between LS and span for different skewness separately showing comparison between non post tensioned and post tensioned bridges.

4.4 BENDING MOMENT (M3)

M3 stands for bending moment about vertical axis. M3 for all the bridge models is considered under dead load and moving load. The variation of M3 is plotted across the span length.

4.4.1 BENDING MOMENT (M3) DUE TO DEAD LOAD

The analysis is conducted for dead load for all the cases. The M3 along the span is monitored and a graph is plotted between M3 and the span length. Fig4.35 is a graph for M3 in non post tensioned case for straight and skewed bridge. Fig 4.37, fig 4.39, fig 4.41, fig 4.43 are between M3 and span for different skewness separately showing comparison between non post tensioned and post tensioned bridges.

4.4.2 BENDING MOMENT (M3) DUE TO MOVING LOAD

The analysis is conducted for moving load for all the cases. The M3 along the span is monitored and a graph is plotted between M3 and the span length. Fig4.36 is a graph for M3 in non post tensioned case for straight and skewed bridge. Fig 4.38, fig 4.40, fig 4.42, fig 4.44 are between M3 and span for different skewness separately showing comparison between non post tensioned and post tensioned bridges.

4.5 BENDING MOMENT (M2)

M2 stands for bending moment about horizontal axis. M2 for all the bridge models is considered under dead load and moving load. The variation of M2 is plotted across the span length.

4.5.1 BENDING MOMENT (M2) DUE TO DEAD LOAD

The analysis is conducted for dead load for all the cases. The M2 along the span is monitored and a graph is plotted between M2 and the span length. Fig4.45 is a graph for M2 in non post tensioned case for straight and skewed bridge. Fig 4.47, fig 4.49, fig 4.51, fig 4.53 are between M2 and span for different skewness separately showing comparison between non post tensioned and post tensioned bridges.

4.5.2 BENDING MOMENT (M2) DUE TO MOVING LOAD

The analysis is conducted for moving load for all the cases. The M2 along the span is monitored and a graph is plotted between M2 and the span length. Fig4.46 is a graph for M2 in non post tensioned case for straight and skewed bridge. Fig 4.48, fig 4.50, fig 4.52, fig 4.54 are between M2 and span for different skewness separately showing comparison between non post tensioned and post tensioned bridges.

4.6 MODAL FREQUENCIES

The table showing frequencies(cycles/sec) of different models are shown below.

Table 4.1 modal frequencies for non post tensioned and 500 kips post tensioning

	NON POSTENSIONED				500KIPS			
	0	5	10	15	0	5	10	15
1	2.5927	2.5606	2.571	2.588	5.5928	2.5376	2.5192	2.5611
2	4.5151	4.4785	4.5043	4.5493	4.5153	4.4569	4.4818	4.5153
3	5.1693	5.1613	5.1742	5.1948	5.1698	5.1018	5.1015	5.189
4	6.3321	6.3341	6.3467	6.3684	6.3323	6.3376	6.3455	6.3675
5	12.083	11.996	11.864	11.667	12.089	12.029	11.848	11.49
6	12.251	12.245	12.237	12.221	12.254	12.229	12.238	12.215
7	13.232	13.23	13.235	13.247	13.237	13.236	13.239	13.236
8	14.778	14.826	14.984	15.223	14.779	14.823	14.979	15.178
9	16.407	16.417	16.498	16.631	16.408	16.431	16.485	16.631
10	20.912	20.841	20.76	20.629	20.914	20.83	20.741	20.609
11	20.92	20.888	20.829	20.728	20.922	20.899	20.824	20.683
12	22.274	22.307	22.311	22.316	22.291	22.17	22.309	22.262

Table 4.2 modal frequencies for 700 kips post tensioning

	700KIPS			
	0	5	10	15
1	2.5928	2.5606	2.8154	205881
2	4.5153	4.4786	4.7529	4.5495
3	5.1698	5.1619	6.3919	5.1957
4	6.3323	6.3344	7.6434	6.3686
5	12.085	11.998	12.263	11.668
6	12.254	12.249	12.398	12.225
7	13.237	13.235	13.247	13.253
8	14.779	14.827	15.098	15.224
9	16.408	16.418	16.903	16.633
10	20.915	20.844	20.866	20.632
11	20.922	20.89	21.276	20.73
12	22.291	22.324	22.969	22.338

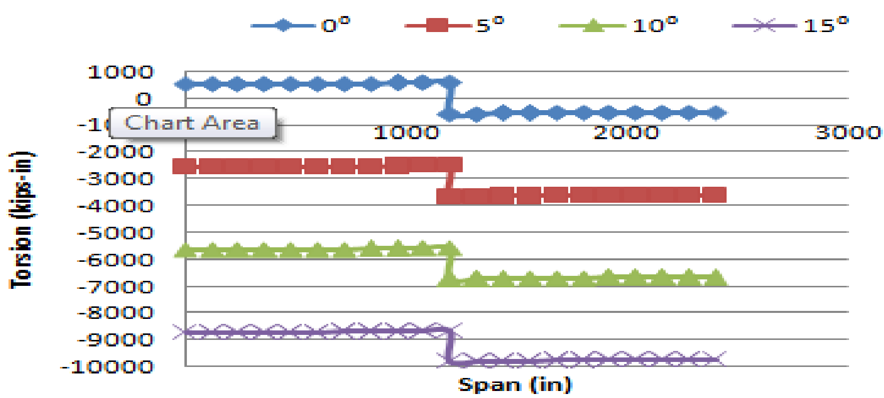


Fig 4.1 graph showing torsion at different skewness due to dead load

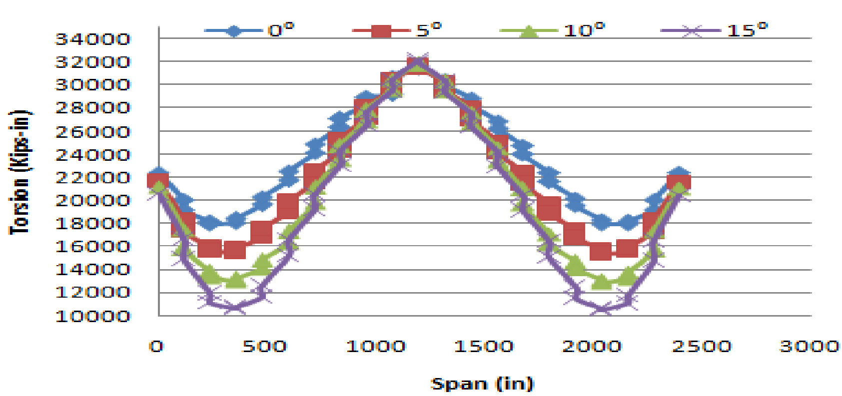


Fig 4.2 graph showing torsion at different skewness due to moving load

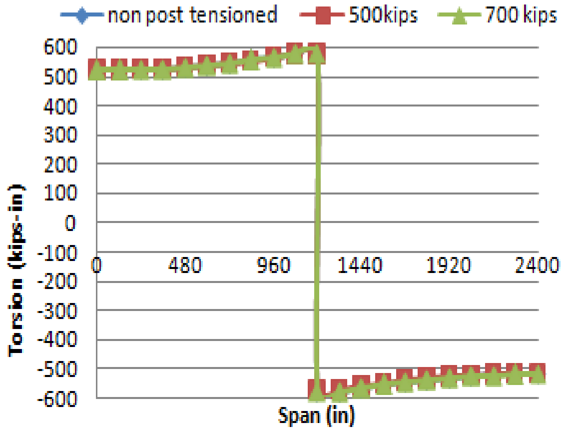


Fig 4.3 graph showing torsion at at 0° skewness due to dead load

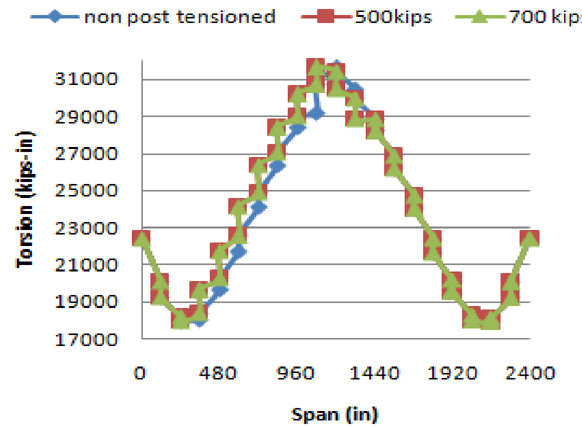


Fig 4.4 graph showing torsion 0° skewness due to moving load

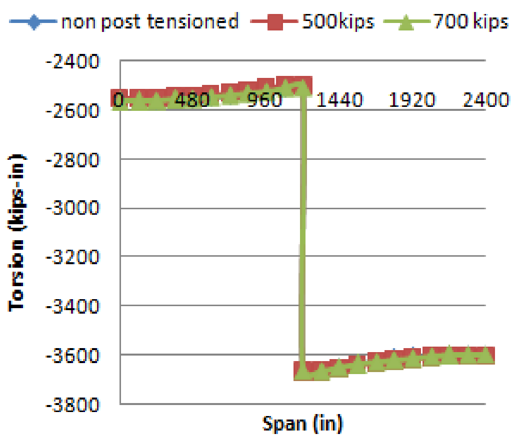


Fig 4.5 graph showing torsion at 5° skewness due to dead load

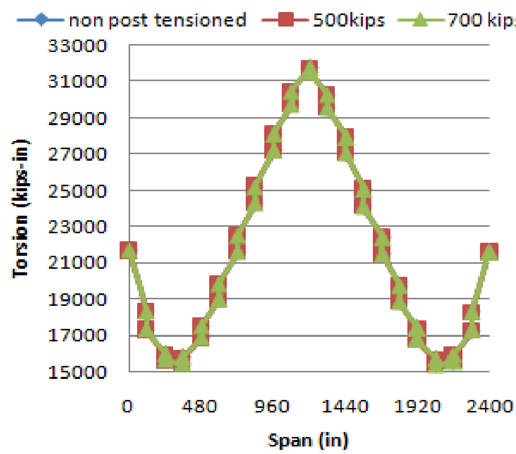


Fig 4.6 graph showing torsion at 5° skewness due to moving load

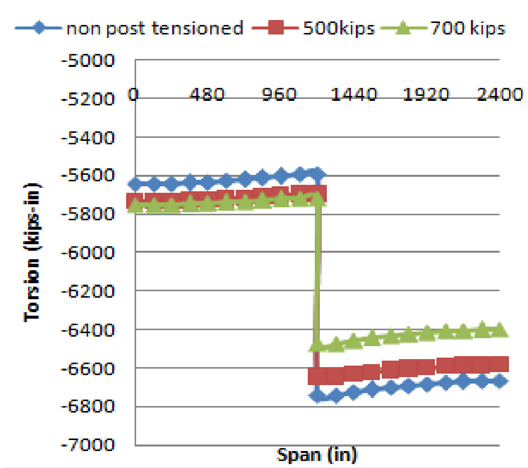


Fig 4.7 graph showing torsion at 10° skewness due to dead load

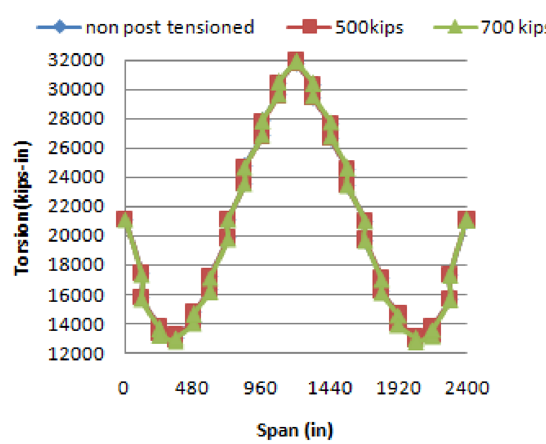


Fig 4.8 graph showing torsion at 10° skewness due to moving load

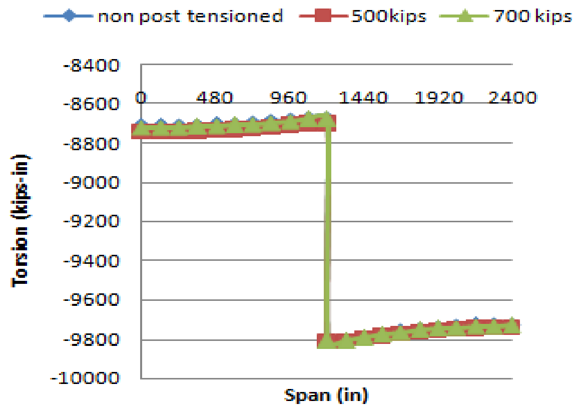


Fig 4.9 graph showing torsion at 15⁰ skewness due to dead load

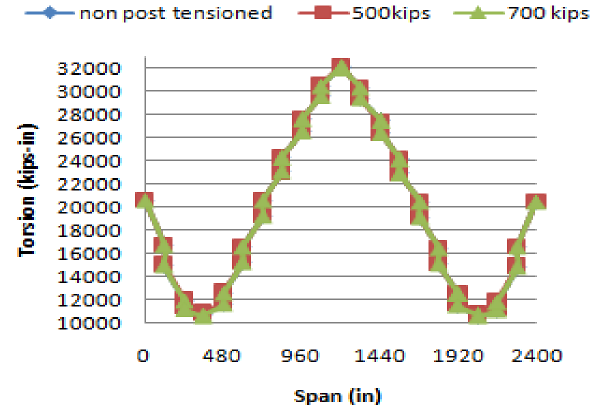


Fig 4.10 graph showing torsion at 15⁰ skewness due to moving load

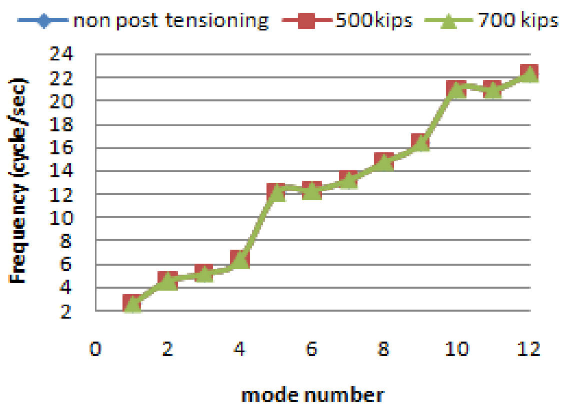


Fig 4.11 graph showing model frequency at 0⁰ skewness

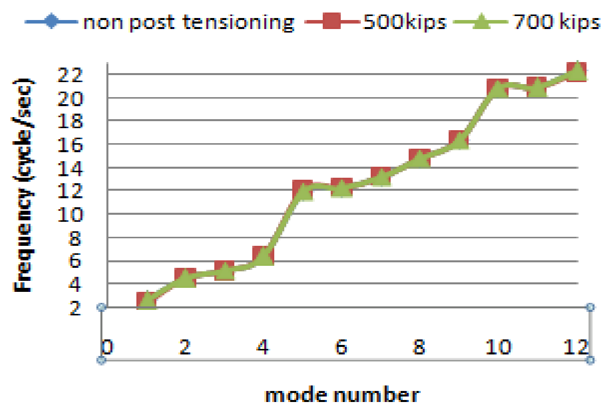


Fig 4.12 graph showing model frequency at 5⁰ skewness

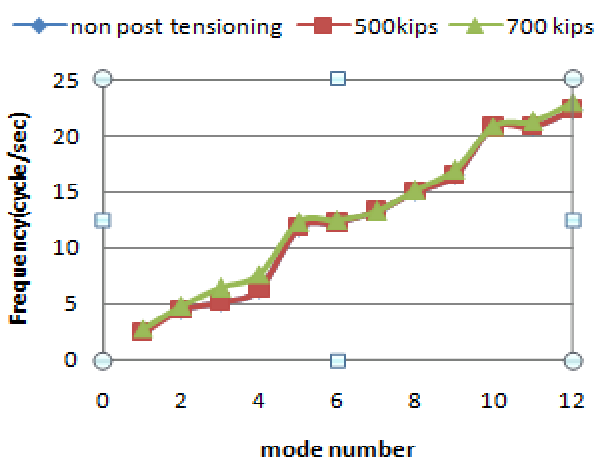


Fig 4.13 graph showing model frequency at 10⁰ skewness

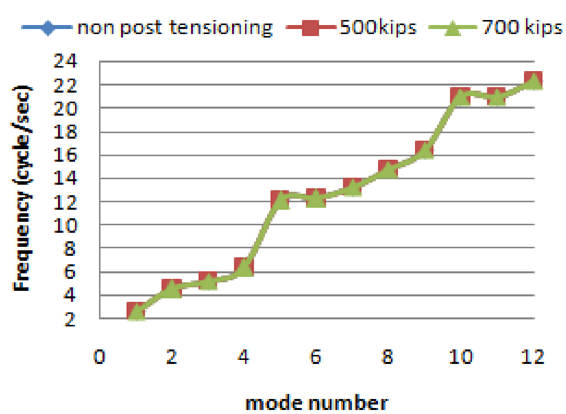


Fig 4.14 graph showing model frequency at 15⁰ skewness

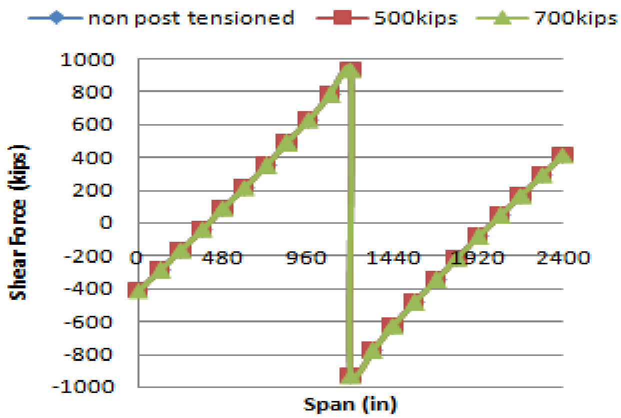


Fig- 4.15 graph showing shear force at 0^{o} skewness due to DL.

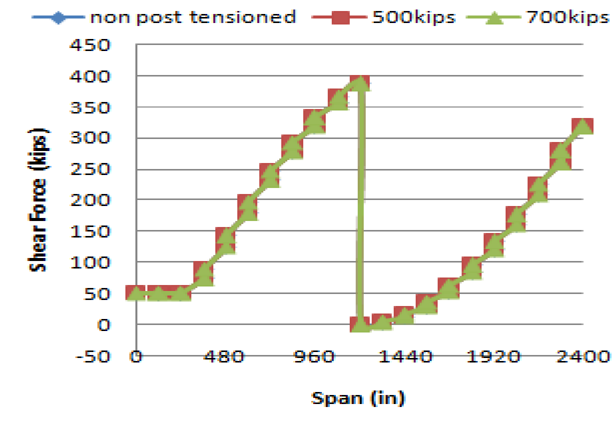


Fig- 4.16 graph showing shear at 0^{o} due to moving load.

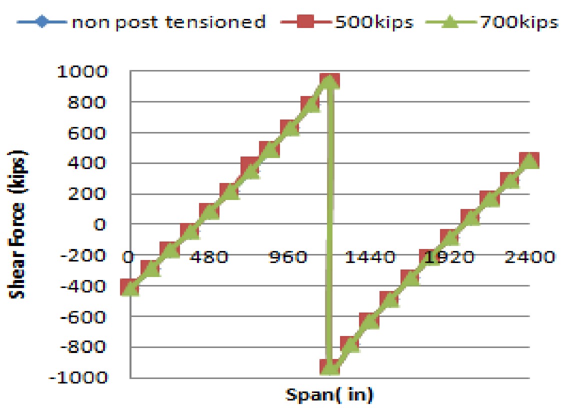


Fig- 4.17 graph showing shear force at 5^{o} skewness due to DL.

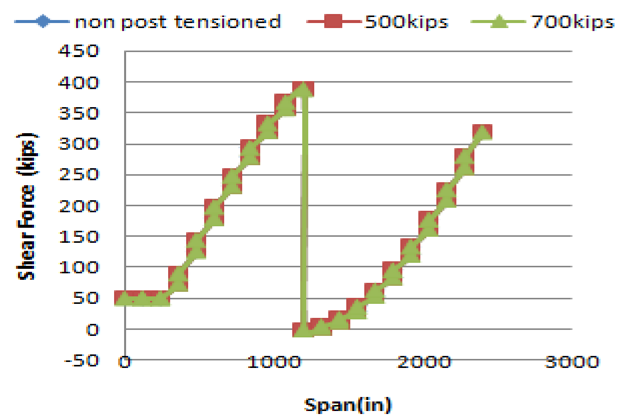


Fig- 4.18 graph showing shear force at 5^{o} skewness due to ML.

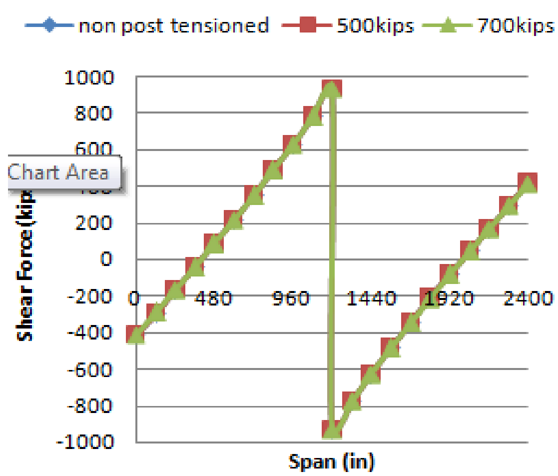


Fig- 4.19 graph showing shear force at 10^{o} skewness due to DL.

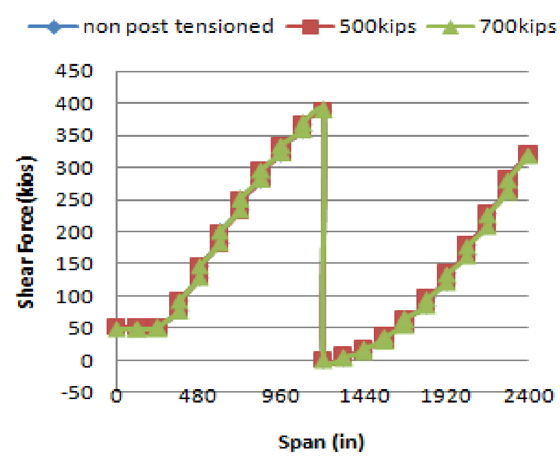
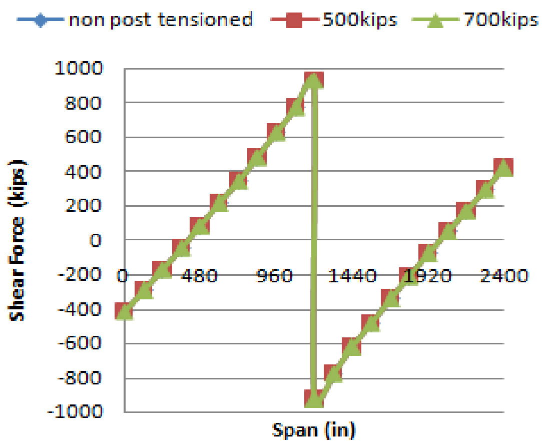
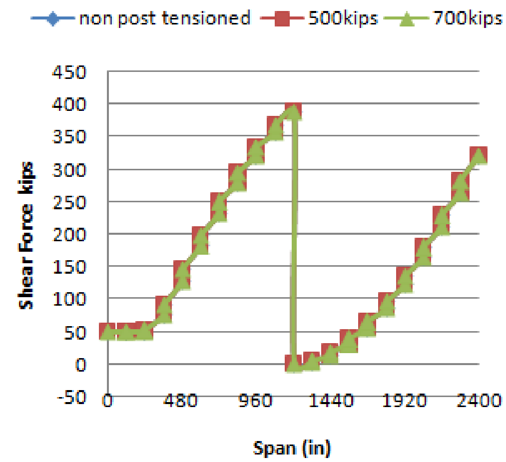


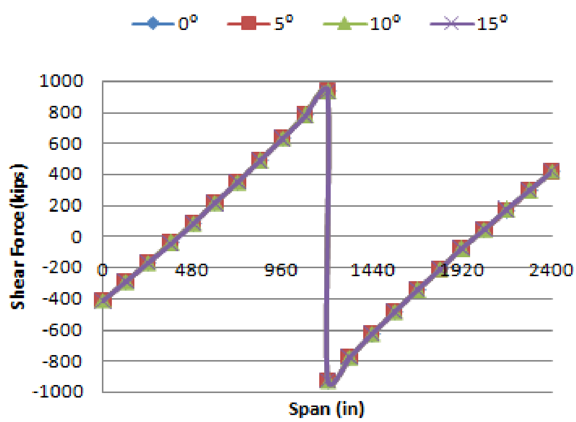
Fig- 4.20 graph showing shear force at 10^{o} skewness due to ML.



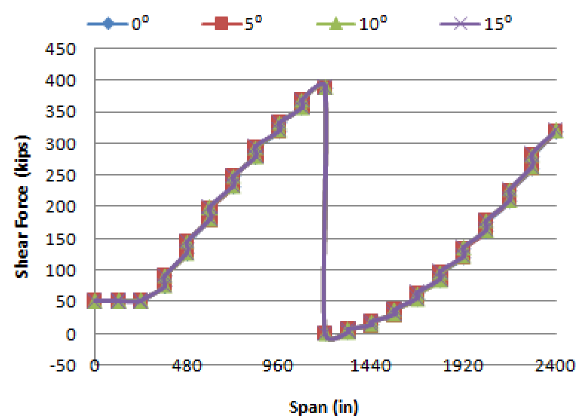
Fig– 4.21 graph showing shear force at 15^{0} skewness due to DL



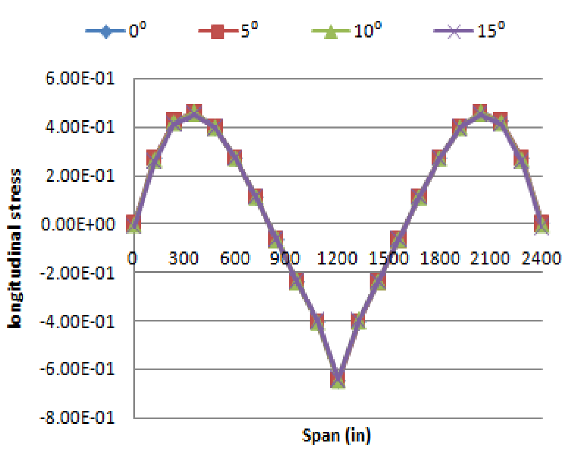
Fig– 4.22 graph showing shear force at 15^{0} skewness due to ML



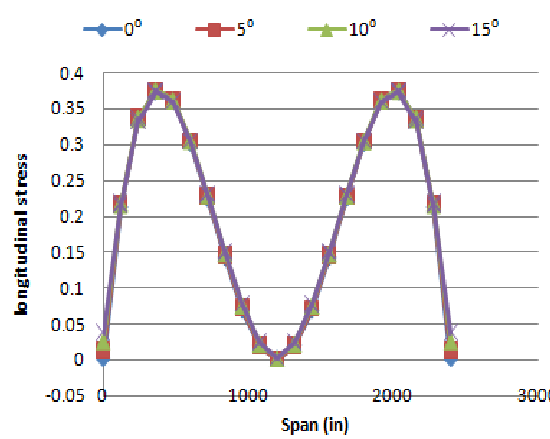
Fig– 4.23 graph showing shear force due to DL.



Fig– 4.24 graph showing shear force due to ML.



Fig– 4.25 graph showing longitudinal stress at soffit due to DL



Fig– 4.26 graph showing longitudinal stress at soffit due to ML

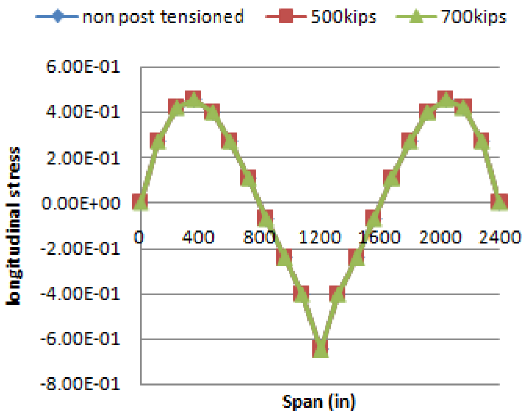


Fig 4.27 graph showing longitudinal stress at 0^{0} skewness due to DL

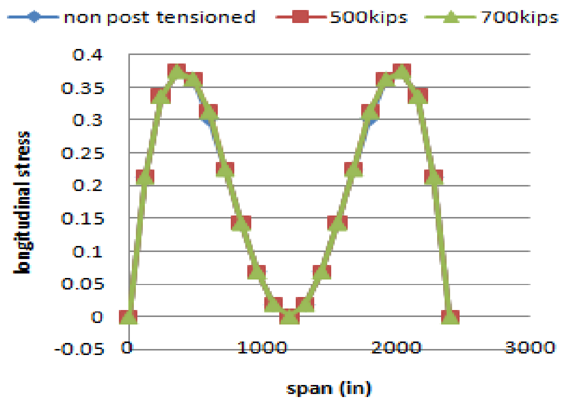


Fig 4.28 graph showing longitudinal stress at 0^{0} skewness due to ML

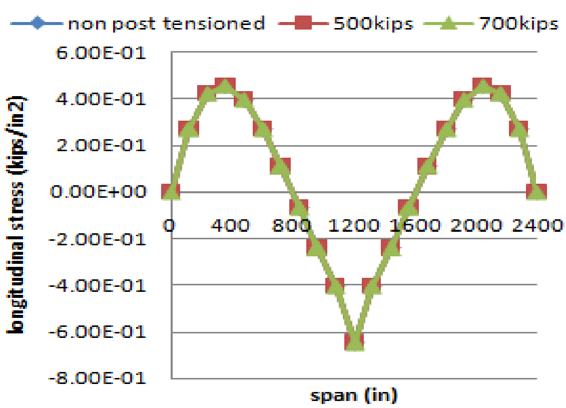


Fig 4.29 graph showing longitudinal stress at 5^{0} skewness due to DL

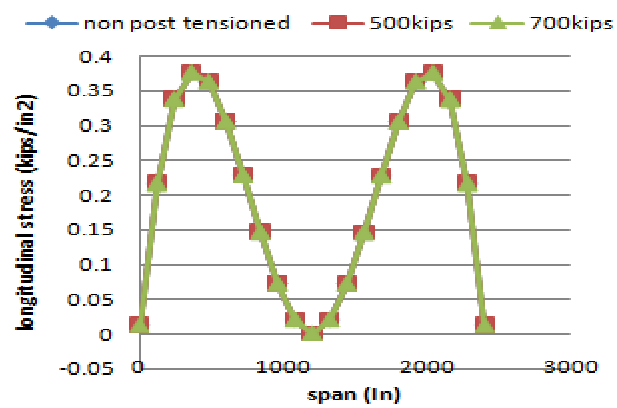


Fig 4.30 graph showing longitudinal stress at 5^{0} skewness due to ML

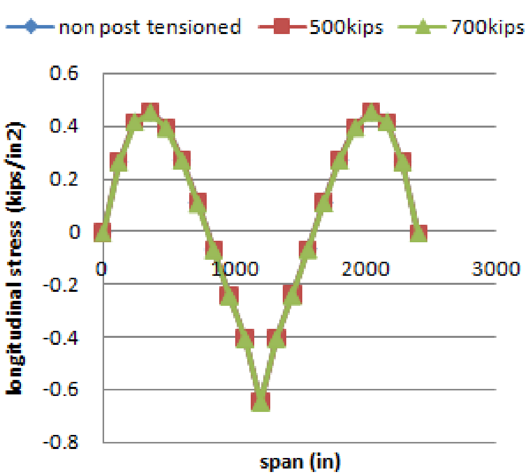


Fig 4.31 graph showing longitudinal stress at 10^{0} skewness due to DL

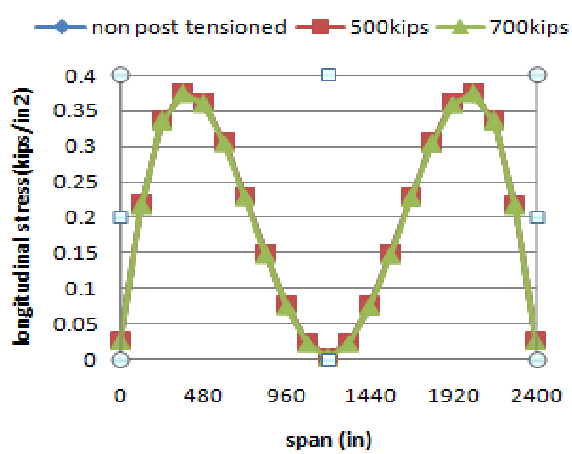


Fig 4.32 graph showing longitudinal stress at 10^{0} skewness due to ML

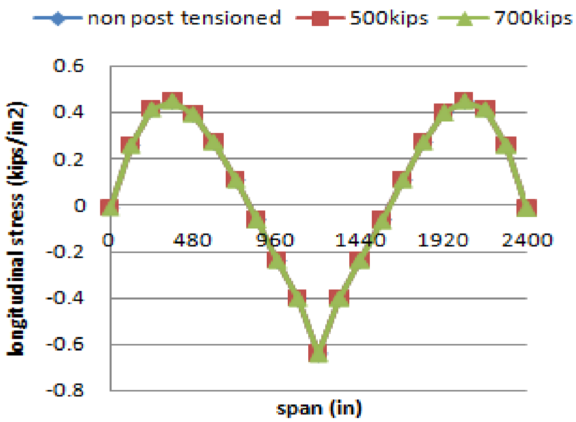


Fig 4.33 graph showing longitudinal stress at 15^0 skewness due to DL

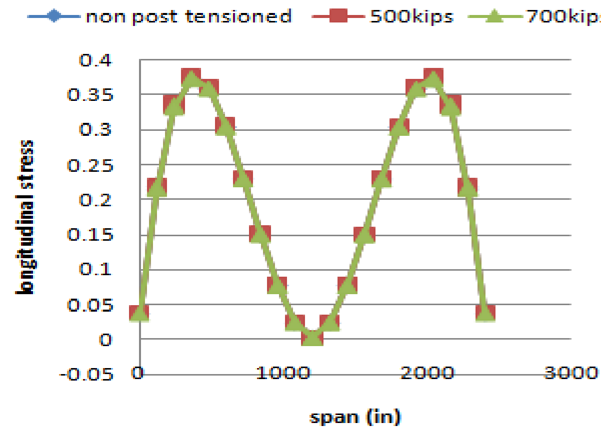


Fig 4.34 graph showing longitudinal stress at 15^0 skewness due to ML

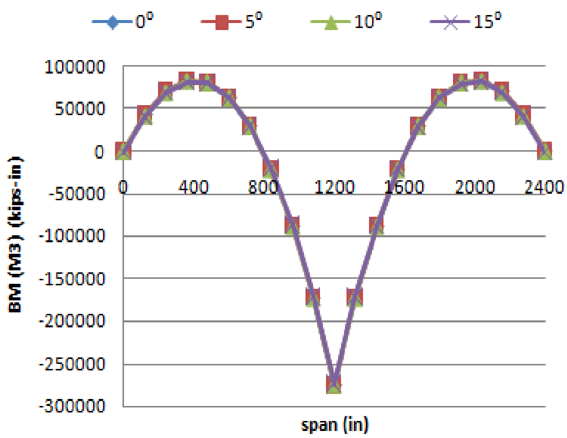


Fig 4.35 graph showing bending moment (M3)due to DL.

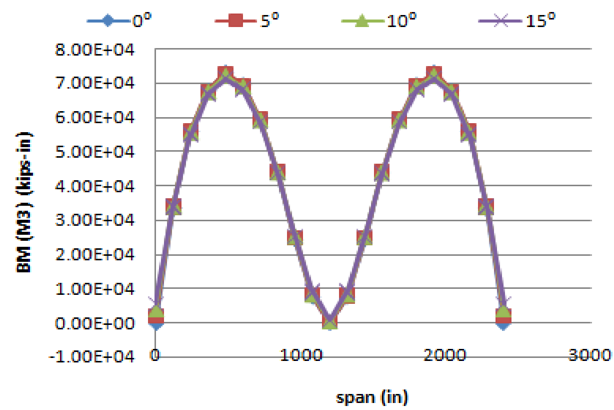


Fig 4.36 graph showing bending moment (M3)due to ML.

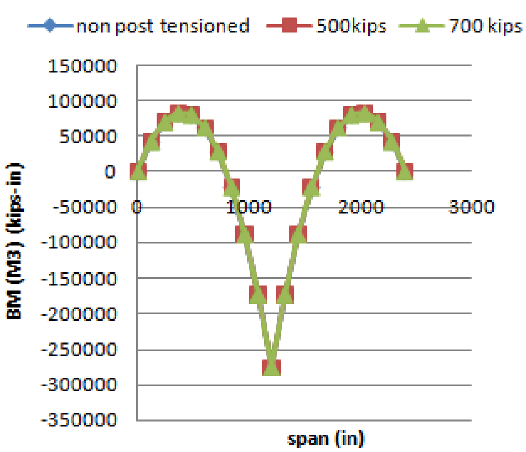


Fig 4.37 graph showing bending moment (M3) at 0^0 skewness due to DL

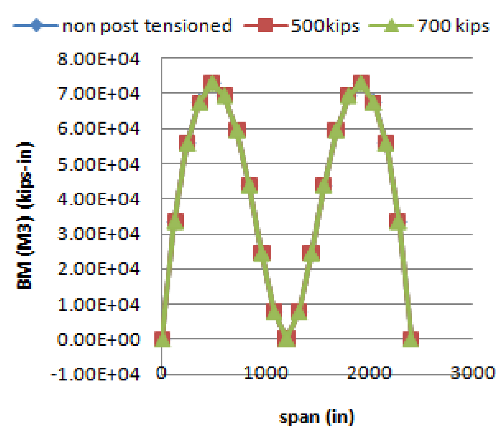


Fig 4.38 graph showing bending moment (M3) at 0^0 skewness due to ML

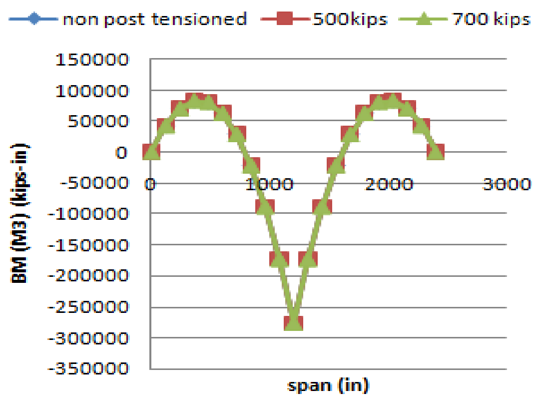


Fig 4.39 graph showing bending moment (M3) at 5^0 skewness due to DL

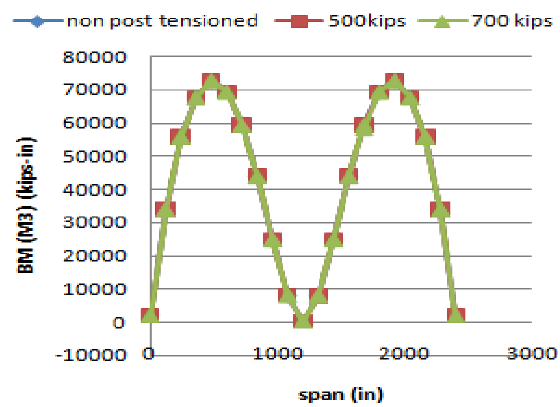


Fig 4.40 graph showing bending moment (M3) at 5^0 skewness due to ML

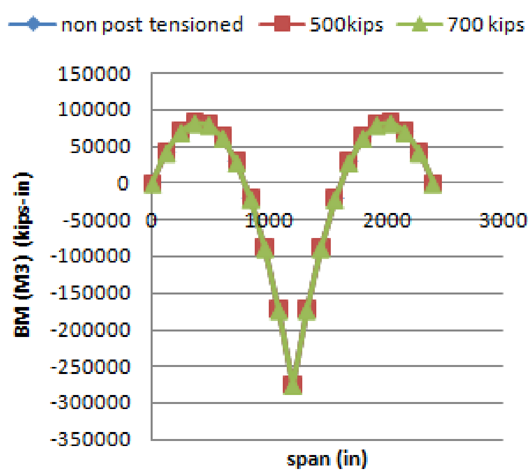


Fig 4.41 graph showing bending moment (M3) at 10^0 skewness due to DL

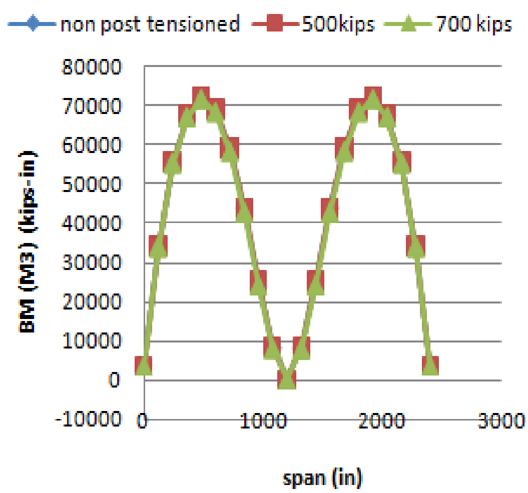


Fig 4.42 graph showing bending moment (M3) at 10^0 skewness due to ML

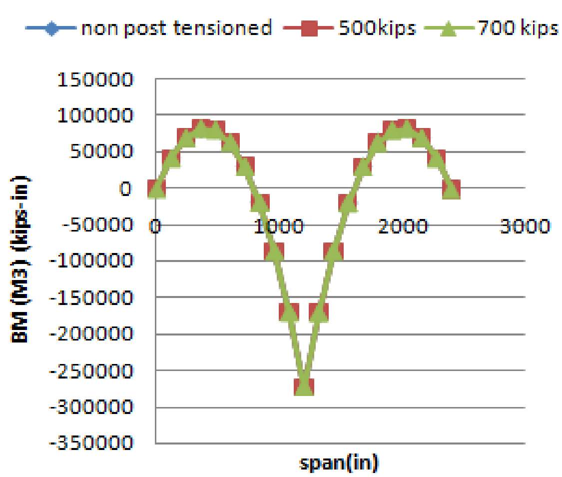


Fig4.43 graph showing bending moment (M3) at 15^0 skewness due to DL

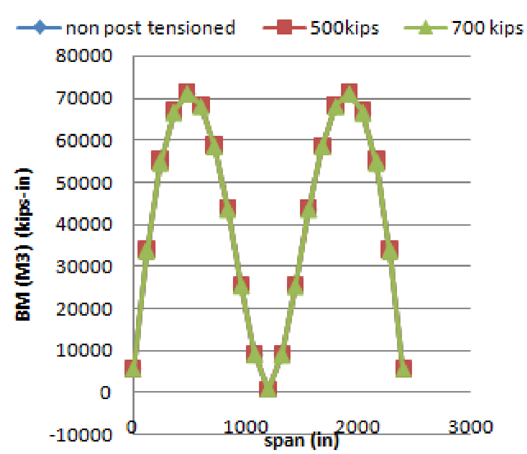


Fig4.44 graph showing bending moment (M3) at 15^0 skewness due to ML

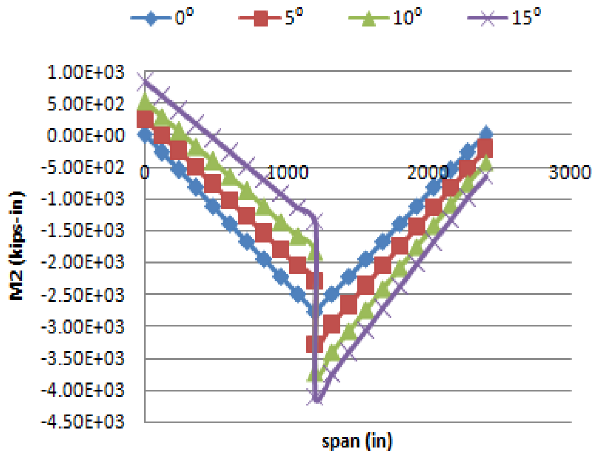


Fig4.45 graph showing bending moment (M2) due to DL(nonposttensioned)

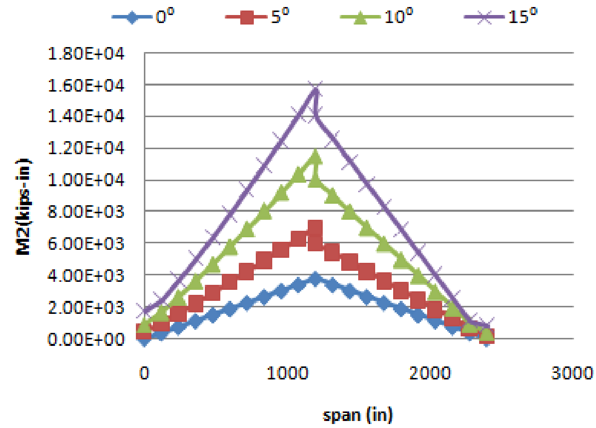


Fig4.46 graph showing bending moment (M2) due to ML (nonposttensioned)

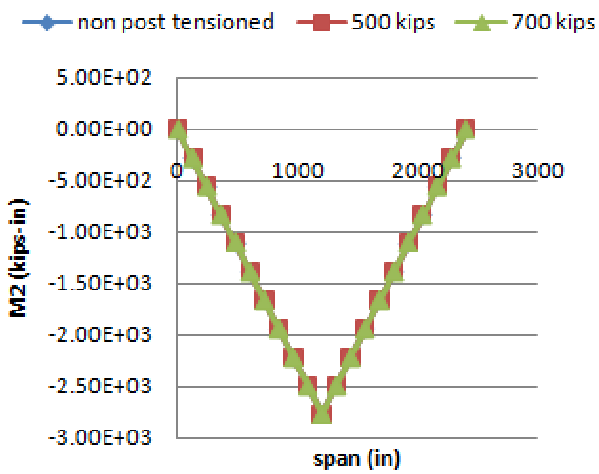


Fig4.47 graph showing bending moment (M2) at 0^0 skewness due to DL

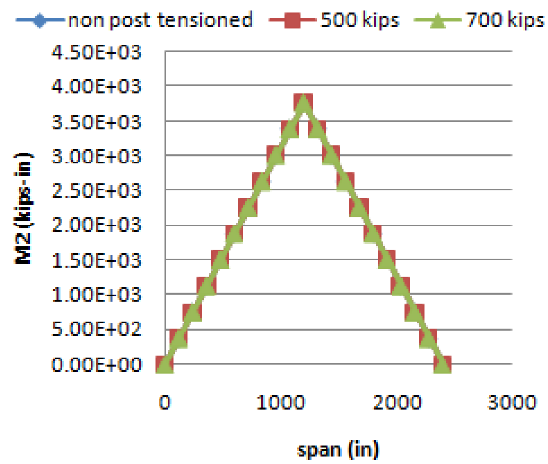


Fig4.48 graph showing bending moment (M2) at 0^0 skewness due to ML

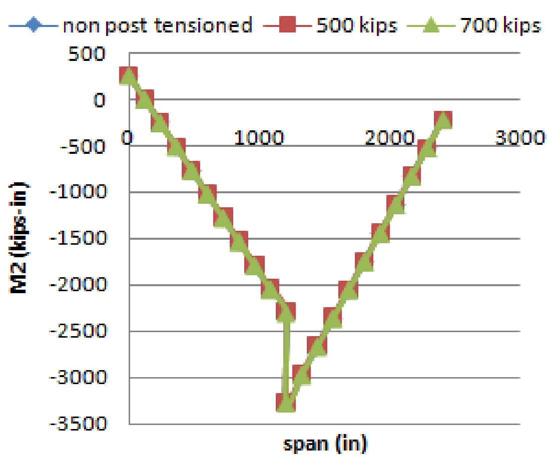


Fig4.49 graph showing bending moment (M2) at 5^0 skewness due to DL

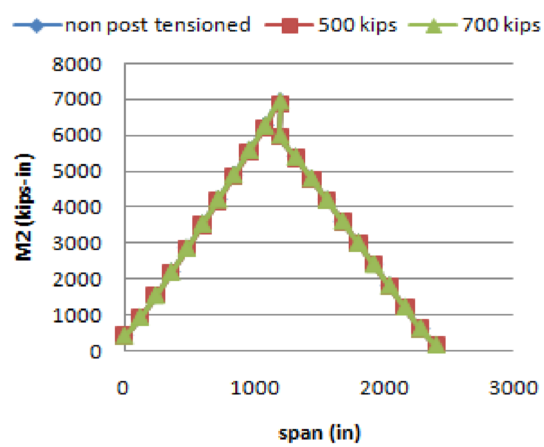


Fig4.50 graph showing bending moment (M2) at 5^0 skewness due to ML

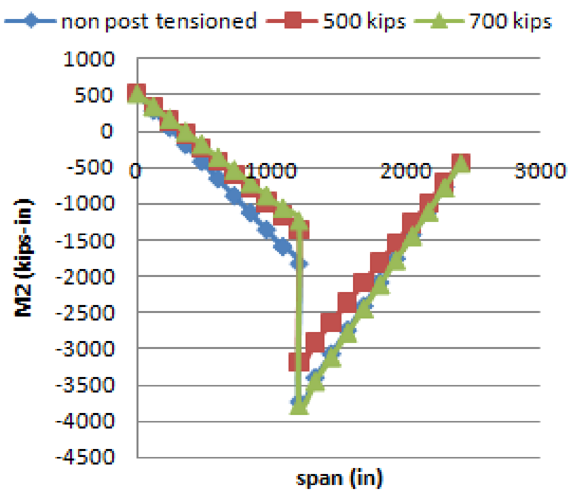


Fig4.51 graph showing bending moment (M2) at 10^0 skewness due to DL

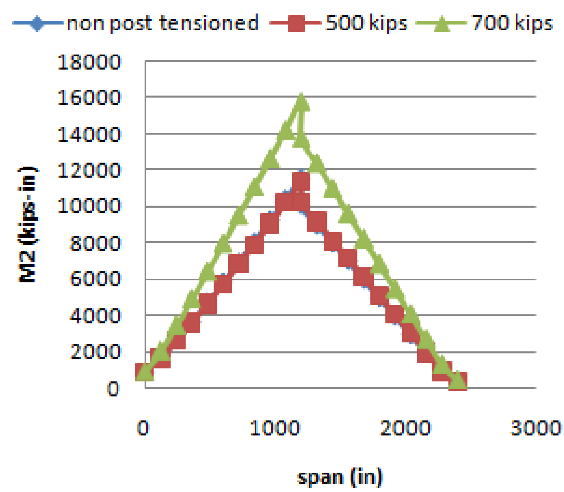


Fig4.52 graph showing bending moment (M2) at 10^0 skewness due to ML

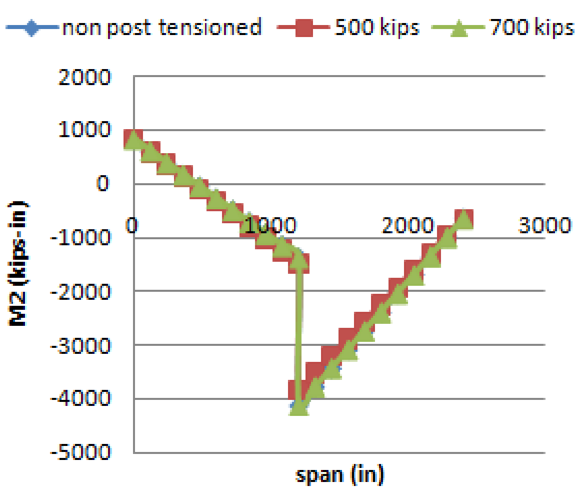


Fig4.53 graph showing bending moment (M2) at 15^0 skewness due to DL

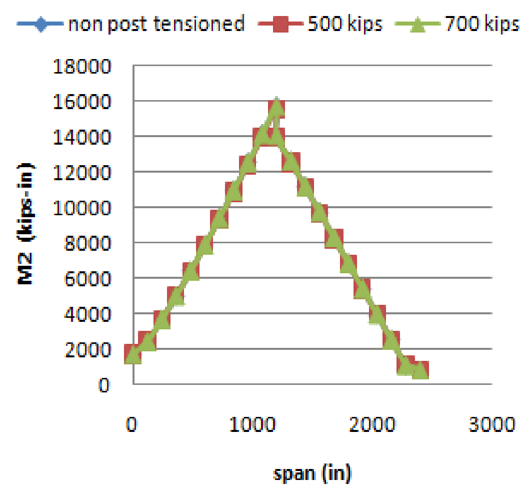


Fig4.54 graph showing bending moment (M2) at 15^0 skewness due to ML

4.7 TENSION CHECK IN POST TENSIONED GIRDERS

Purpose of post tensioning is to reduce the tension coming onto soffit of the girder by imparting additional compressive stress to compensate the tensile stress. It reduces the cross section of the girder required to resist the coming loads. Fig 4.55, fig 4.57, fig 4.59, fig 4.61 are showing the graphs where it is very much clear that without post tensioning tension at soffit of girder is exceeding the permissible limit. On providing the post tensioning the tension at soffit in girders is coming under the permissible limit of .38 $kips/in^2$, this can be clearly seen in Fig 4.56, fig 4.58, fig 4.60, fig 4.62 .

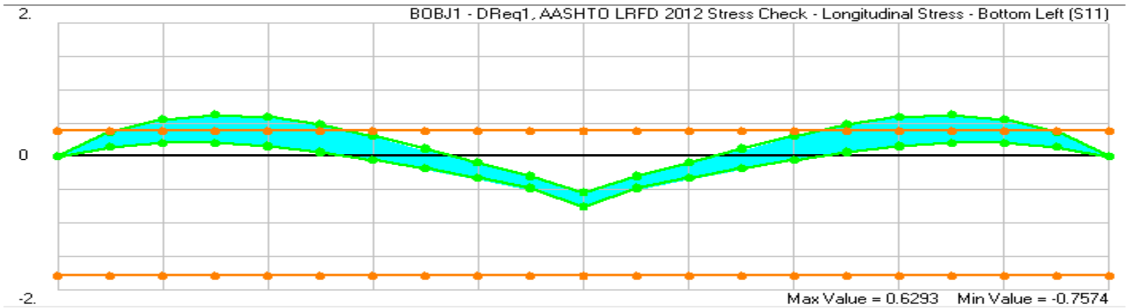


Fig4.55 graph showing tension limit at quarter span is exceeding in straight girder with out post tensioning

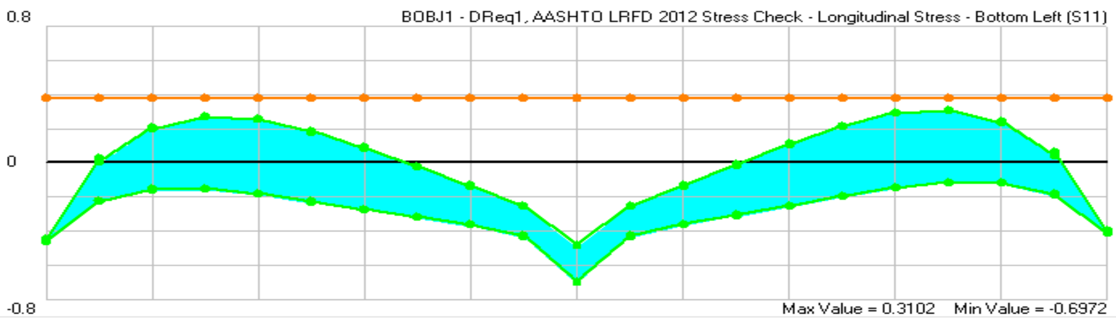


Fig4.56 graph showing tension is under permissible limits in straight girder with post tensioning

Fig 4.57 graph showing tension limit at quarter span is exceeding in 5 degree skewed non post tensioned girder.

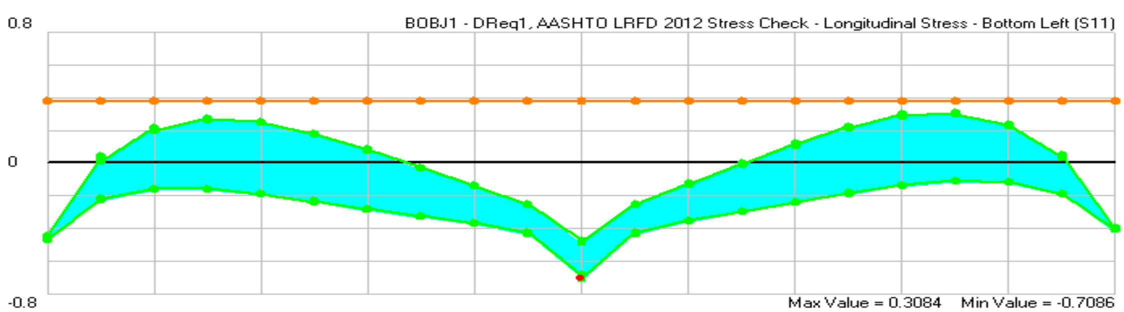


Fig 4.58 graph showing tension is under permissible limits in 5 degree skewed post tensioned girder.

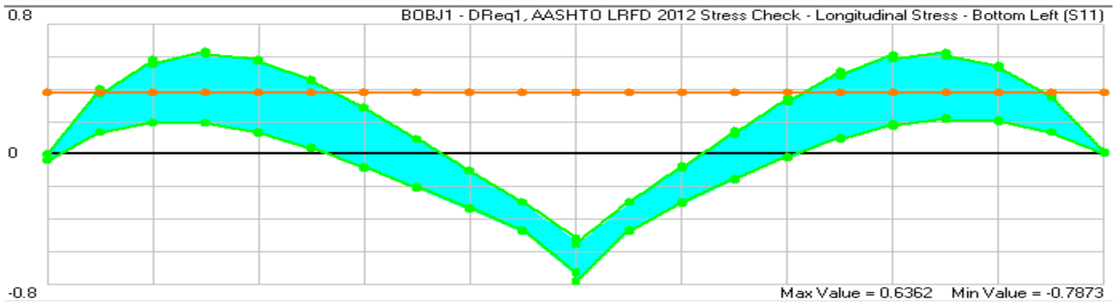


Fig 4.59 graph showing tension limit at quarter span is exceeding in 10 degree skewed non post tensioned girder

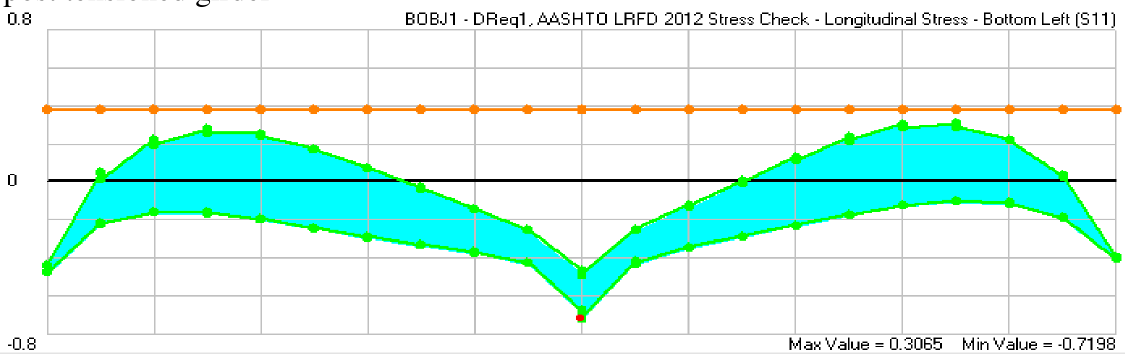


Fig 4.60 graph showing tension is under limit in 10 degree skewed post tensioned girder.

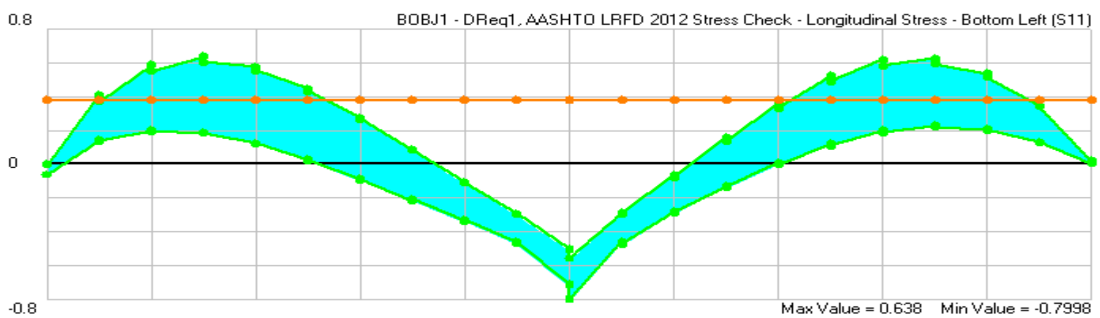


Fig 4.61 graph showing tension at quarter span is exceeding in15 degree skewed non post tensioned girder.

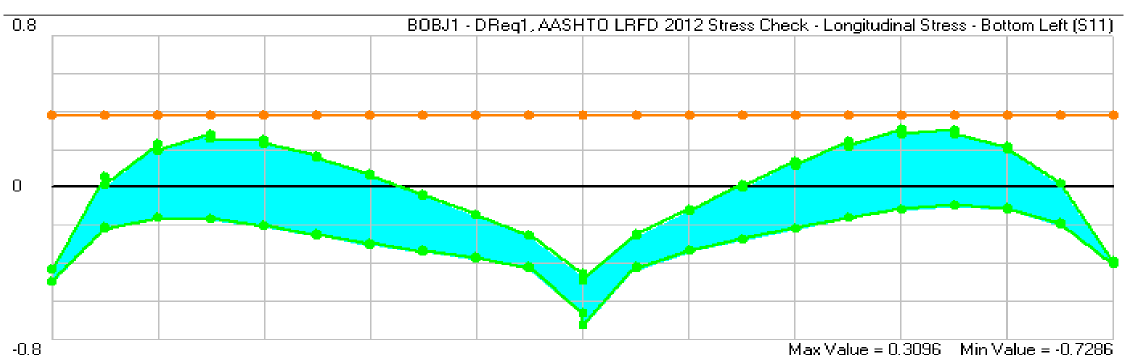


Fig 4.62 graph showing tension is under permissible limits in 15 degree skewed post tensioned girders.

4.8 DEFLECTION

4.8.1 DISPLACEMENT IN LONGITUDINAL DIRECTION

Displacement is studied over entire span at both edges- interior and exterior. Interior edge is the side left side of span and exterior is the right side of span from origin. In this study displacement in longitudinal direction ie U1 is plotted at different skew angles.
Deflection patterns due to dead load and moving load are observed.

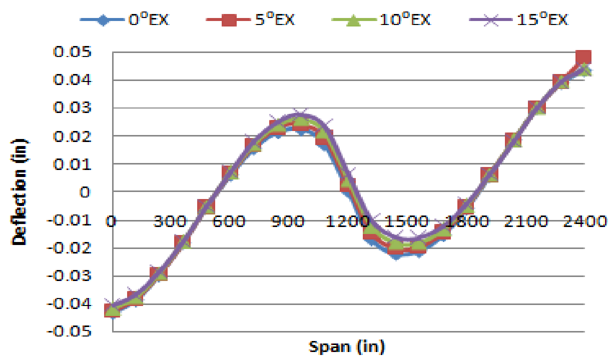


Fig 4.63 graph showing deflection due to dead Load at exterior face in non post tensioned girder

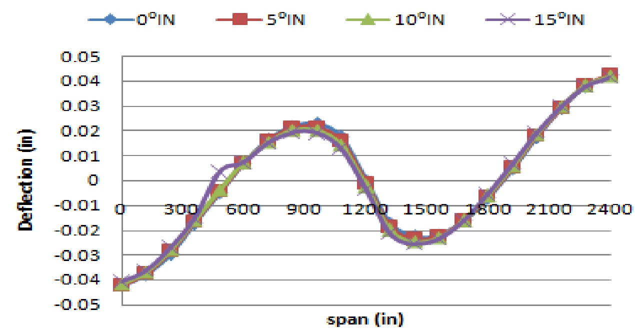


Fig 4.64 graph showing deflection due to dead Load at interior face in non post tensioned girder

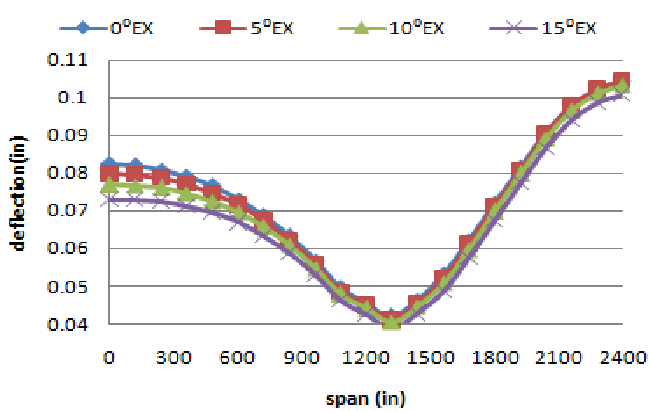


Fig 4.65 graph showing deflection due to moving load at exterior face in non post tensioned girder

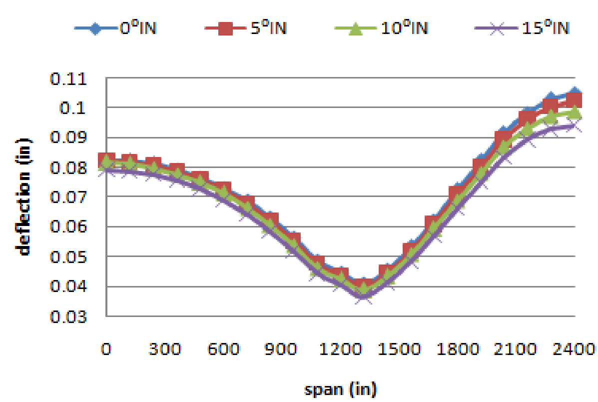
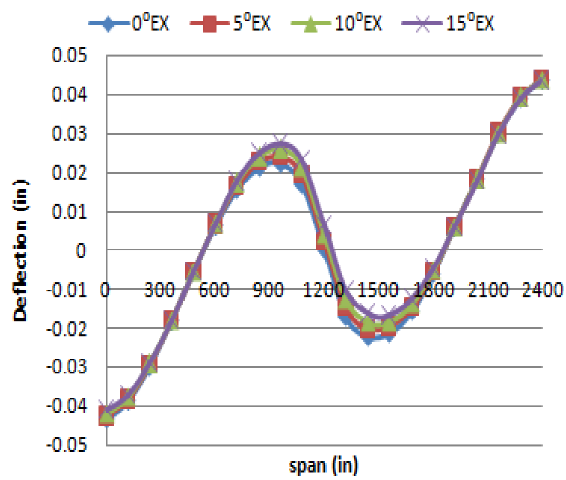


Fig 4.66 graph showing deflection due to moving load at interior face in non post tensioned girder



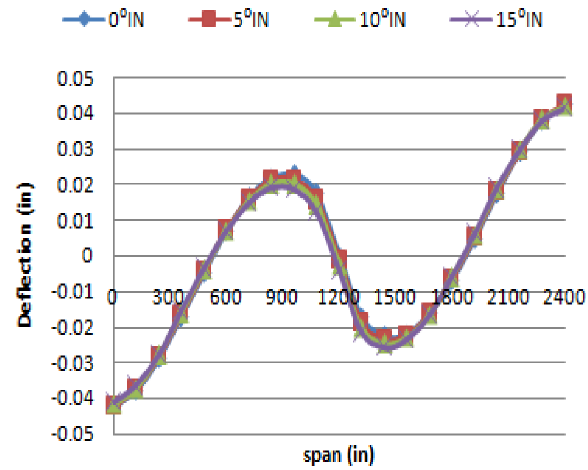
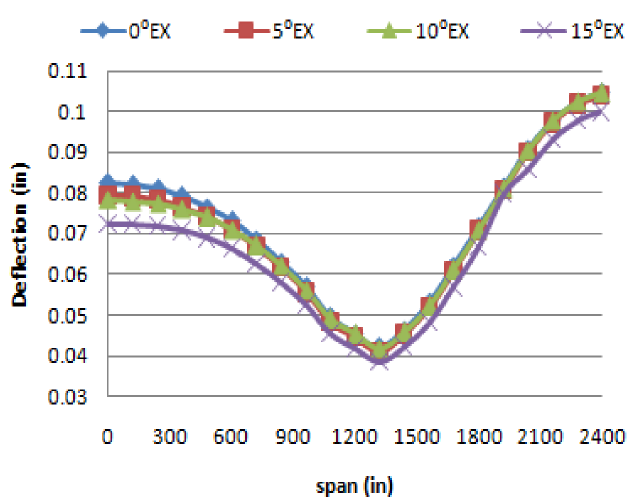


Fig 4.67 graph showing deflection due to dead load at exterior face in post tensioned girder

Fig 4.68 graph showing deflection due to dead load at interior face in post tensioned girder



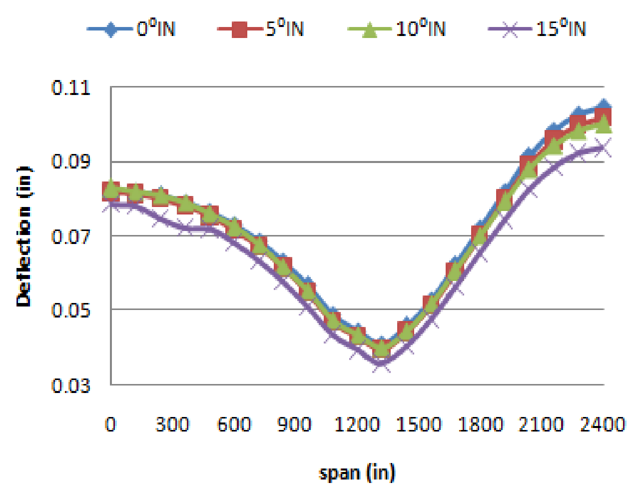


Fig 4.69 graph showing deflection due to moving load at exterior face in post tensioned girder

Fig 4.70 graph showing deflection due to moving load at interior face in post tensioned girder

4.8.2 DISPLACEMENT IN VERTICAL DIRECTION

Displacement is studied over entire span at mid width. this displacement is in vertical direction i.e. U3. Its variation is plotted at different skew angles of the box girder bridge for both dead load and moving load. This study is further extended to compare the effect of post tensioning in non post tensioned girder.

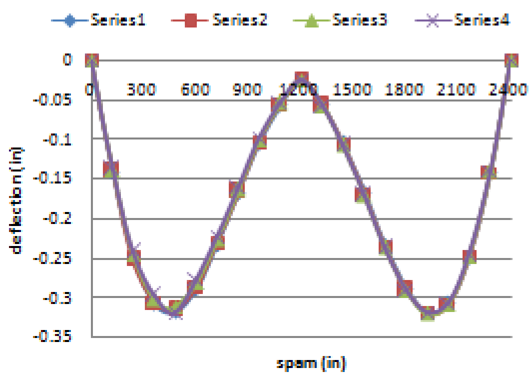


Fig 4.71 graph showing deflection due to dead load in non post tensioned girder

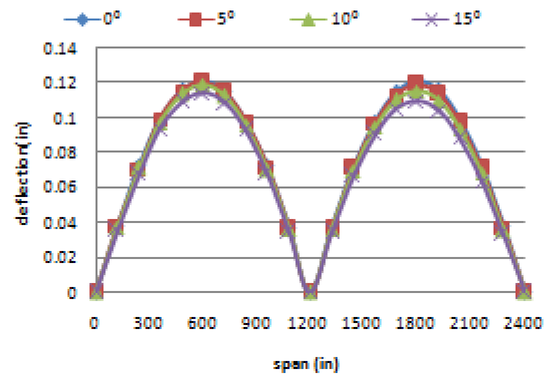


Fig 4.72 graph showing deflection due to moving load in non post tensioned girder

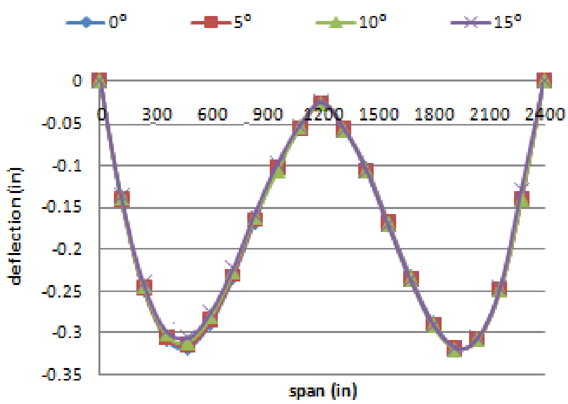


Fig 4.73 graph showing deflection due to dead load in post tensioned girder

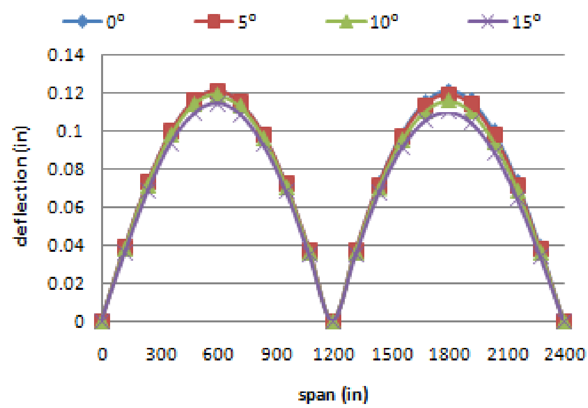


Fig 4.74 graph showing deflection due to moving load in post tensioned girder

CHAPTER 05 – DISCUSSIONS

1. On increasing the skewness in non post tensioned girder bridge torsion increases due to dead load. On first 5^0 increase in skewness from straight to 5^0 change in torsion is about 300%. However, rate of change of torsion with increase in skewness upto 15^0 is decreasing.
2. In case of moving load, torsional forces were decreasing with increase in skewness. The torsional variations are comparable. During first 5 degree skewness the torsion decreases about 3%. Here also the rate of decrease of torsion decreases with increase in skewness. These results are valid upto 15 degree of skewness.
3. Due to change in post tensioned forces at a particular skewness there is no marginal change in torsion. Torsion force variation observed is from .27% to 1.63%.
4. In case of shear force due to dead load at different skewness very less variations are observed.
5. Again shear force due to moving load at different skewness is not varying a lot. The behavior and values are coming almost similar.
6. When at a particular skewness shear force is studied due to non post tensioning, at 500kips post tensioning force and at 700kips post tensioning force, the changes are very less.
7. No change in modal frequency is observed upto three decimal places for different skew angles. As the length and material properties are same for all the models, so the mass for all the models same.
8. Modal frequencies at different loading conditions donot vary.
9. The skewed girders are more longitudinally stressed at bottom as compared to straight ones.
10. Bending moment about vertical axis(M3) decreases with increase in skewness due to dead load. Rate of decrease of bending moment(M3) is varying from .15% to 1.7%.
11. Bending moment (M3) due to moving load is increasing due to increase in skewness of box girder. At mid span increase of about 265% is observed from 10 degree skewness to 15 degree skewness. At the starting end M3 increases about 47% from 10 degree skewed girder to 15 degree skewed girder.
12. Bending moment (M2) changes significantly due to dead load at different skew angles. M2 is the bending moment about horizontal axis (about y axis). The decrease in bending moment at mid span is about 16% from straight to 5 degree skew girders. Then from 5 degree to 10 degree skewness the decrease in M2 is about 20%. Finally from 10 degree to 15 degree the decrease is about 25%. This concludes that rate of decrease of M2 increases with increase in skew angle.
13. Bending moment(M2) due to moving load increases with increase in skew angle of bridge girder.
14. At mid span M2 due to moving load increases about 85% from 0 degree skew to 5 degree skew angle. And from 5 degree to 10 degree skew angle M2

increases about65%. Finally from 10 degree to 15 degree skew girder the bending moment at mid span 36%. This concludes that the rate of increase of M2 with increase in skew angle decreases.

15. In case of M2 we observed a sudden change in value at mid span. This behavior is similar in all skewed girders except straight girders. But the magnitude of this sudden slip increases with increase in skew angle and is maximum in 15 degree skew box girder.
16. On post tensioning the girders the tensile stress coming onto the bottom face of the girder is under permissible limits of .38 kips/in2 (according to AASHTO LRFD 2012) which was earlier exceeding the tensile limits.
17. The same behavior for tension check is observed in all the cases of skewed girder bridges.
18. Deflection in longitudinal direction is studied in non post tensioned girders under dead and moving load. Deflection of skewed girders is compared with that of straight girders. The response is always decreases with increase in skew angle of box girder.
19. Deflection in longitudinal direction is studied in post tensioned girders under dead load and moving load. Deflection of Skewed girders are compared with that of straight girders. In the first quarters deflection decreases with increase in skew angle, in second quarter deflection increases with increase in skew angle. Again in third quarter deflection decreases with increased skewed angle and lastly it increases with increase in skew angle.
20. Displacement in vertical direction due to dead load in non post tensioned case does not varying marginally with respect to the skewness of bridge. However in case of moving load it decreases with increase in skew angle.
21. Displacement in vertical direction due to dead load in post tensioned case varying a bit with decrease in displacement as skew angle increases. However in case of moving load the decrease is noticeable at first quarter span and third quarter span as skew angle increases.

CHAPTER 06 – REFERENCES

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