



A PARAMETRIC STUDY OF CURVED PRESTRESSED CONCRETE BOX GIRDER

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Abstract

Prestressed concrete sections are very much cheaper and effective as compared to reinforced concrete and therefore it has a wide use cases in bridges especially and other civil engineering structures. But nowadays curved geometry of bridges is the new trend going on, due to various reasons such as lack of space for transportation, construction in some densely populated areas to avoid traffic congestion. The use of computer software to model elements is much faster, and extremely cost efficient as compared to experimental studies in every engineering field. Here we are proposing a design and analysis which involves the use of a computer software.

Literature referenced to curved girder in general is very much insufficient to satisfy the need. Thus attempt is made to expand the knowledge regarding curved bridges and other structures. For large span bridges, box girder are ideally suitable due to their high torsion rigidity as compared to other sections. Hence parametric study of curved box girder using latest IRC codes is undertaken. Parameters such as prestressing force, angle of curvature and tendon location. It has been observed in these system that stress variation are different as compared to straight girder. Span length is considered constant through the whole variation in section. Analysis of prestressed curved box girder is done by using finite element based Midas Civil16 v2.2 software.

The aim of this study is to correlate the total shear, torsion and bending of prestressed concrete girder of structure according to different models corresponding to the above mentioned parameters and to assess the ambiguity associated with these models.

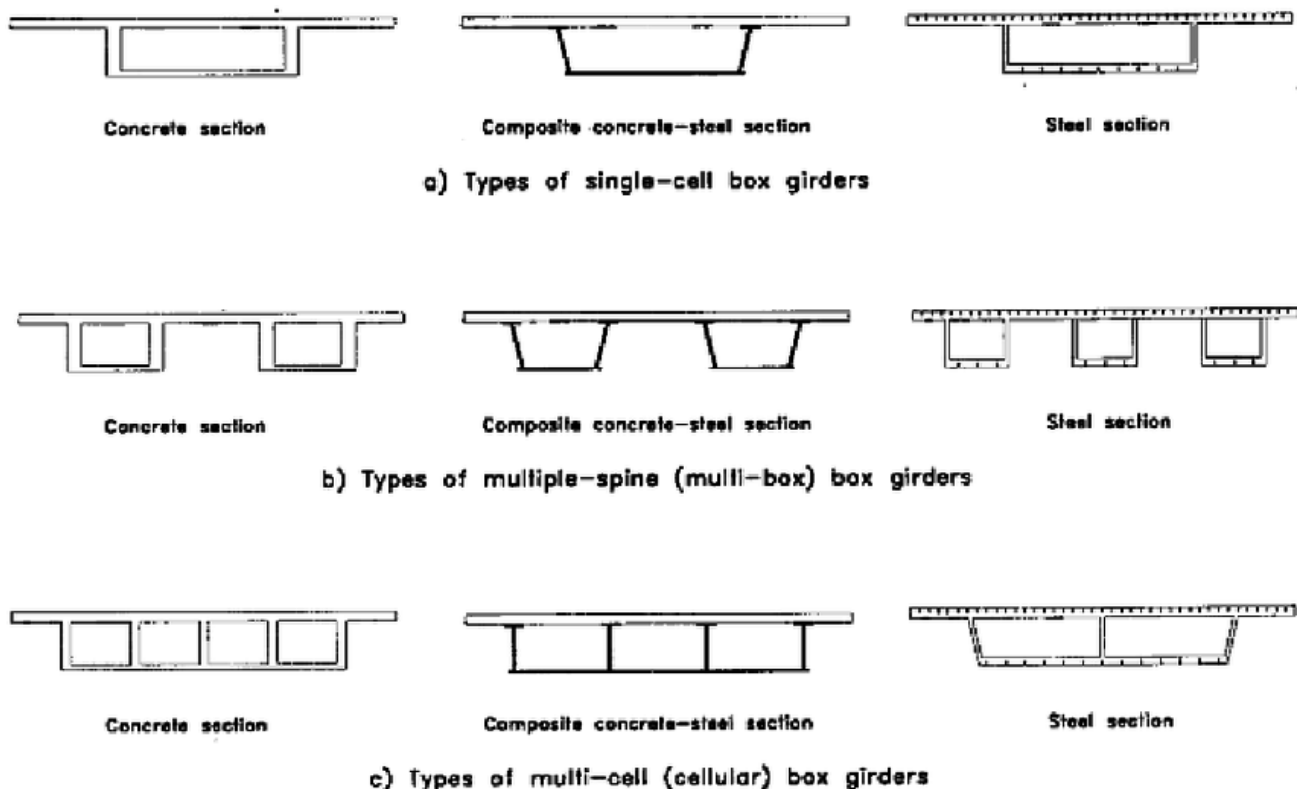
Keywords

Girder, prestressed concrete, reinforcement concrete, torsion, bending, shear, structure, bridge, curved geometry.

Introduction

Prestressed concrete has large application range in construction field. As compared to reinforced concrete, prestressed bridges are widely used because of their high load bearing capacity. Also their performance is enhanced due to slender section and high load capacity. It is very cheap for construction field because of their perfect use of material. The geometry of bridges varies according to the requirement of construction, Curved geometry of bridges is a necessity due to various reasons like lack of space in cities for construction, for long span bridge prestressed concrete is best. It is mandatory to use curved geometry when gradual change in direction is observed and as such direct point of intersection is not possible.

The literature reading of curved prestressed geometry is limited and designers mostly use the codes mentioned for the straight geometry, stress variation in curved geometry is different as compared to the straight bridge.



Source:

https://www.researchgate.net/figure/266912823_fig1_Figure-1-Box-Girder-Cross-Sections

Various girder sections like I-section, T-section, Box girder, hollow core girder, void slab girder, solid slab are used for different span of bridge. Figure 1 illustrates the various types of box girders. Small span bridges are constructed using reinforced cement concrete. As prestressed concrete carries high load over long span, it is used for construction in long span bridge. Span length governs selection of type of section for bridge. For Span length upto 35m.

I section are used. As span length goes on increasing section becomes thick and uneconomical. Box girder offer solution for such problems. Due to geometry of box girder they offer high stability as they resist torsion and are slender section. Box girder offers high torsional rigidity as compared to I and T girder, hence it is selected for study. Also box girder are suitable to carry heavy load over large span of bridge. Prestressed concrete sections are economical compared to reinforced concrete and hence, have a wide use in bridges, buildings

and other structures.

Problem Statement

Parametric study of curved prestressed box girder is undertaken. For study purpose 54m span of bridge curved in plan is considered. Twin cell box girder with prestressing configuration is considered. Parameters such as curvature of girder, prestressing force, compressive strength and tendon location are varied. Stress variation for these cases is studied in detail along with displacement and tendon elongation. Resultant stress and torsional stress are also studied.

Scope

The current study seeks to determine the behaviour of prestressed curved box girder under various parameters as follows-

- To study effect of curvature on resultant stresses, displacement, tendon elongation and torsional stresses.
- To study effect of variation in prestressing force in curved box girder on resultant stresses, displacement, tendon elongation and torsional stresses.
- To study effect of variation in compressive strength in curved prestressed box girder on resultant stresses, displacement, tendon elongation and torsional stresses.
- To study effect of tendon location variation on resultant stresses, displacement, tendon elongation and torsional stresses.

Studies made

Only a few investigations have dealt with the influence of stresses related to curved geometry of different types of girders. Literature pertaining to curved geometry of bridge is scarce. Few of them are denoted below-

Khaloo et al (2007) In recent research published in Journal of Bridge Engineering, ASCE flexural behaviour of flexural behavior of horizontally curved prestressed post-tensioned box bridges is studied by using three dimensional and refined finite-element modeling and analysis. Bridge length, section geometry, and material properties are the same in all the models, while angle of curvature varies from 0° to 90° . AASHTO codes are considered and for analysis ANSYS software has been used. The results of analysis show that in curved bridges, stress distribution is significantly different in comparison to straight bridges. Also, the level of stresses at some locations of section width is considerably high.

It is proposed to vary the distribution of the prestressing tendons across section width in order to optimize the bridge capacity. Results show that by proper redistribution of prestressing in section width, significant reduction in resultant stress is possible. Uniform distribution of prestressing across the soffit in horizontally curved bridges results in nonuniform distribution of flexural stresses under gravity loading. This nonuniformity becomes greater by increasing the curvature angle.

Therefore, the optimum capacity of the section will not be used. Contrary to straight bridges, the neutral axis is not horizontal and stress contours are not parallel in curved bridges. Based on numerous analyses performed in this study, it is proposed to redistribute prestressing tendons across

the section width. This approach reduces critical stresses substantially and leads to enhanced design of prestressed curved bridges.

Ibrahim et al(2010) This paper presents the results of a parametric study of the flexural behavior of continuous concrete members prestressed with external tendons. The behavior at ultimate limit states is evaluated. A nonlinear analysis model, based on the three dimensional finite element method, ANSYS computer program (10.0) was used. The nonlinear material and geometrical analysis were adopted. The results obtained show good agreement with experimental results. This research was carried out to study the effects of several factors on the overall behavior of externally prestressed beams in terms of the values of compressive concrete strength and effective prestressing stress. That behavior was slightly affected compared with experimental results. The undeviated external tendons mobilized lower nominal flexural resistance and inelastic deflection than deviated tendons did. The increase in the beam capacity in the beam subjected to loads at the third span is greater than in the beam with a single load at the mid – span. The result of increasing the effective depth is that the ultimate load capacity is essentially increased. A numerical nonlinear analysis model, based on the Finite Element Method (FEM) using ANSYS computer program, was developed to predict the entire load – deflection response of continuous concrete members with external prestressing. The accuracy of the analysis was verified by means of comparisons with experimental results. The numerical model reproduced the experimental results of load–deflection response; the results predicted by the model were in very good agreement with experimental data. A parametric study was carried out using the nonlinear analysis method to evaluate the response of continuous concrete members with external prestressing tendons. This paper investigates the effects of some factors on the flexural behavior at ultimate related to the external prestressing system, concrete strength, initial prestressing stress, effective depth of the external tendons, loading arrangement and tendon profile. It was found that as the compressive strength of concrete increased, the ultimate load capacity increased. For different values of effective prestressing stress, the ultimate load increased substantially when the effective stress increased. Tendons without deviators produce lower nominal flexural strength than tendons with deviators. Single concentrated loads produce less significant second – order effects because they mobilize low post – elastic deflection in comparison with two – third point loads. The ultimate load in the beam subjected to loads at the third span is greater than in the beam with a single load at the mid- span. The effective depth of the external prestressing tendon has a significant effect on the ultimate load. It was found that the tendon profile has a clear effect on the ultimate load capacity. The ultimate load increased with different draped tendon profiles compared to undraped profiles.

Sarode et al (2014) The horizontally curved alignments for the urban interchanges or highway bridges are becoming more common and it is necessary to construct the structures curved in plan. Due to the effect of horizontal curvature of the box girders, torsional moments are predominant. Also the support reactions on the outer supports increase whereas on inner support decreases, which may leads the instability of the box girder. The outer web is longer than the inner web due to which the

mid-span deflections are more at the outer web than the inner web. In this paper, the numerous models for curved box girders are analysed using LUSAS FEA software for different parameters such as span lengths, radii and loadings and the flexural and torsional behavior, stability and mid-span deflections of the curved box girders of various parameters are discussed. Finite Element analysis software to access the more accurate bending moments, shear, torsion, mid-span deflections and support reactions. The conclusions made in this study are as follows:

It is observed that there is no significant variation in the bending moments and the shear forces for DL, SIDL and LL for the specific span length with different radii. The torsional moments increase greatly with the decrease of the span radius of the box girder. There is more variation in torsion with span radius below 200m, whereas less variation for span radius above 300m. The mid-span deflections at the soffit of the outer and inner webs vary significantly with radius of curvature of the box girder. For radius less than 200m there is considerable variation in the deflections. Such variation in mid-span deflection shall be accounted while achieving the required superelevations of the deck. From the reactions, it is observed that the box girders having the factor of safety against overturning less than 1.5 are not feasible. The sharp radius below 100m shall be avoided. If such sharp curves are unavoidable then it may require structural changes to the cross-sectional dimensions to stabilize or hold-downs or tension bearings are introduced to stabilize the box girders which may increase the construction cost.

Song et al(2007) The current American Association of State Highway and Transportation Officials AASHTO Load and Resistance Factor Design Specifications impose fairly strict limits on the use of its live-load distribution factor for design of highway bridges. These limits include requirements for a prismatic cross section, a large span-length-to-width ratio, and a small plan curvature. Refined analyses using 3D models are required for bridges outside of these limits. These limits place severe restrictions on the routine design of bridges in California, as box-girder bridges outside of these limits are frequently constructed. This paper presents the results of a study investigating the live-load distribution characteristics of box-girder bridges and the limits imposed by the LRFD specifications. Distribution factors determined from a set of bridges with parameters outside of the LRFD limits are compared with the distribution factors suggested by the LRFD specifications. For the range of parameters investigated, results indicated that the current LRFD distribution factor formulas generally provide a conservative estimate of the design bending moment and shear force. The current AASHTO Design Specifications provide a set of distribution factor formulas for estimating the distribution of bending moment and shear force effects in the interior and exterior girders of highway bridges. These distribution factors, when combined with the critical bending moment and shear force from the simple beam-line analysis, are routinely used for the design of highway bridges. The current LRFD specifications, however, impose fairly strict limits on the use of its live-load distribution factor formulas, including requirements for a prismatic cross section, a large span-length-to-width ratio, and a small plan curvature. Refined analyses using 3D models are required for design of bridges outside of these limits. Results pertaining to a study of the restrictions imposed by the LRFD specifications are presented in this paper. Box-girder bridges

outside the limits of the LRFD specifications are analyzed using the standard truck loading from the LRFD specifications. Results indicate that the current LRFD specifications distribution factor formulas for box-girder bridges generally provide a conservative estimate of the design bending moment and shear force, even for bridges outside of the specifications limits. Distribution factors are generally more conservative for exterior girders than for interior girders. For the range of parameters investigated in this study, the current set of distribution factors appears applicable to box-girder bridges with nonparallel girders, to bridges with a length-to-width ratio as small as unity, and to curved bridges with an angular change as large as 34° . However, because of the small set of bridges used in the study, results presented should not be construed to imply an overall conservatism of the LRFD formulas; further study of the limits with a more extensive parameter range is warranted.

Khairmode et al (2016) Prestressed concrete structures are widely used in all over the world. They give better performance with smaller cross sections. The prestressed concrete construction is more suitable for medium and long span bridges with heavy loads. Now the prestressed concrete system is also used in curved bridge with long span. It has become challenge to analyze this bridge deck due to geometric complexities and interaction between bending and torsion. In this paper, the analysis of horizontally curved prestressed concrete box girder bridge deck is studied by using three dimensional modeling and analysis. Section geometry, material properties and radius of curvature are same in all the models while angle of curvature is varying from 0° to 90° and angle of curvature are kept constant as 30° , 60° and 90° and its radius of curvature varying from 25 m to 50m. Analysis is carried out using the IRC Class AA loading. The 3D Finite Element Models are prepared using SAP software. The results for stresses are observed by keeping the same material properties. With increase in the radius of curvature and angle of curvature, the stresses at the top of the prestressed curved bridges increases while stresses at the bottom of the bridges decreases. As the radius of curvature and angle of curvature of prestressed concrete curved bridge increases the mid span vertical deflection goes on decreasing.

Phani Kumar et al (2016) Bridge construction today has achieved a worldwide level of importance. Bridges are the key elements in any road network and use of prestress girder type bridges gaining popularity in bridge engineering fraternity because of its better stability, serviceability, economy, aesthetic appearance and structural efficiency. In this thesis analysis and design of prestressed concrete bridges (Deck Slab, T-Girder and Box Girder) are carried out using IRC:112-2011. The unified concrete code (IRC:112) published by the Indian Road Congress in November 2011 combining the code for reinforced concrete and prestressed concrete structures represents a new generation code, which is significantly different as compared to previous codes (i.e. IRC:21 for RCC structures and IRC:18 for PSC structures). IRC:21 and IRC:18 stands withdrawn, with the publication of IRC:112. The fundamental difference between IRC:112 and old codes is that IRC:112 based on limit state theory while the previous codes were based on working stress design philosophy.

From the analysis and design of post tensioned box girder bridge for various span to depth ratios the following observations are made.

The various span to depth ratio are taken for the analysis of box girder bridges, and for all the cases, deflection and stresses are within the permissible limits. As the depth of box girder decreases, the prestressing force decreases and no of cables decreases. Because of prestressing, more strength of concrete is utilized and also well governs serviceability. New code (IRC:112) requires increased cover for pre tensioned strands as well as post tensioned ducts, which will lead to increased thickness of webs and deck slab / soffit slabs for PSC girders / PSC box girder bridges. For the same cross section and same applied moment, steel difference is quite noticeable compare to WSM, LSM consumes less steel than WSM and its better to change grade of steel rather increasing grade of concrete for more %p steel difference.

Liu Fangping et al (2012) This paper investigates the influence of radius on the deformation of curved box girder bridges under the action of pre-stressed tendons. A spiral pre-stressed concrete box girder bridge in Chongqing is analyzed by using nonlinear finite element program ANSYS. The five different curved bridge models under weight and prestressing were created and the sameness and difference among them are gained and compared by numerical simulation. The results showed: 1. In five different situations, the box girder all occurs the vertical, radial and longitudinal deformation, among which vertical deformation is the main. At the same time, the box section occurred reverse and distortion, and the whole body of the beam rolls out. 2. The value of vertical displacement of mid-span of continuous curved box girder bridges relates with the horizontal radius. When the radius between one hundred meters and one hundred fifty meters, the influence of displacement is most sensitive, on the contrary, when the radius greater than two hundred meters, the influence of displacement is almost no effect to mid-span displacement. Continuous curved box girder bridges occur deformation in the vertical, Transverse and along the bridge under the combined load of weight and pre-stressing, vertical deformation is the main. The box girder cross-section produces reverse and distortion and the structure rolls out. The vertical displacement of continuous curved box girder bridges in mid-span is related to horizontal radius. When the radius is between 100 m and 150 m, displacement increases more rapidly, when the radius is more than 200 m, displacement curve gradually tends to level, the force characteristics is the same as straight bridge.

Advantages and Disadvantages of prestressed concrete

Serviceability: Prestressed concrete is suitable in case with long spans and requirement of heavy loading conditions. Prestressed can be adapted to artistic roles and yield more clearances. Cracks only develop on excessive loading. Under dead load, cambering effect is observed and under live load, deflections are observed to be smaller. They can be precast due to light weight. Shortcoming of prestressing is lack of weight of member. If requirement arises for heavy mass prestress can work.

Safety: Due to prestressing, there is a partial testing of steel and concrete for necessary attributes. Highest stresses are imparted to steel and concrete during testing which would be encountered during lifetime. Overload of prestressed concrete is higher than that of reinforced. Deflection is observed before ultimate failure. Ability to sustain impact load and designed working load is better than reinforced concrete. Corrosion is less, but due to occurrence of cracks corrosion can be serious issue. Prestressed concrete requires more caution during design, construction and erection than its counterpart. Its life is not as long as reinforced concrete. **Economics:** Prestressed concrete comparatively require small amount of steel and concrete to produce same effect as that of reinforced concrete. Saving in use of stirrups is high. Reduction of weight saves handling and transportation cost.

Stronger material does have higher unit cost. Auxiliary and supporting materials are required in higher quantity. More formwork, attention to detail and skilled labor are required. To summarize prestressed concrete is most economical when same members are repetitively being used under heavy loading conditions.

Proposed Model

Twin cell box girder span of 54m is assumed for study, constant for all cases. Width of girder is 12m with depth of 3.3m. M40 grade of concrete along with Fe540 steel is used. Class A and Class 70R loadings are considered for moving load analysis. Analysis is performed using IRC112:2011 and for load and stresses calculation IRC 6 is used. Prestress force of 500KN is applied on both ends of tendon. Post-tensioning method is considered for prestressing of tendons. Parameters considered for study are variation in curvature angle, prestress force and tendon groups. Curvature angle assumed are $0^\circ, 30^\circ, 45^\circ, 60^\circ, 75^\circ, 90^\circ$ with radius of curvature being infinity, 103.13m, 68.75m, 51.56m, 41.25m, 34.37m. Prestressed tendons are provided at soffit level for maximum eccentricity and subsequently increase in moment. Tendons groups are considered having different tendon location distributed all over the box girder. Analysis of stress and loads is done using IRC6:2000. Compressive strength, creep and shrinkage properties, and analysis is done using IRC112:2011. Rigid support is provided at end supports. Bearing pads are simulated by rigid links. Elastic link is provided for connection. Span length is considered to be constant throughout the variation of parameters. Total model of girder is divided into 108 elements longitudinally for ease of analysis.

Curvature

Variation in curvature for below mentioned cases is considered. Along with change in curvature, prestressing force of above models is also varied. Total 30 cases of simulated model are analyzed. Table 1 contains information regarding different radii considered for study to vary the curvature.

Table 1 Radii of curve

Curvature Θ	0°	30°	45°	60°	75°	90°
Radius of curvature (m)	∞	103.1	68.75	51.56	41.2	34.37

Figures 2 and 3 denoted below are of Geometry of curved box girder. Plan view of box girder with variation in radii are mentioned. Cross section of girder with span length of 54m is denoted. Fig. 2 and 3 illustrates both plan and cross section of girder. Center-line of girder is denoted in plan view along with various radii considered.



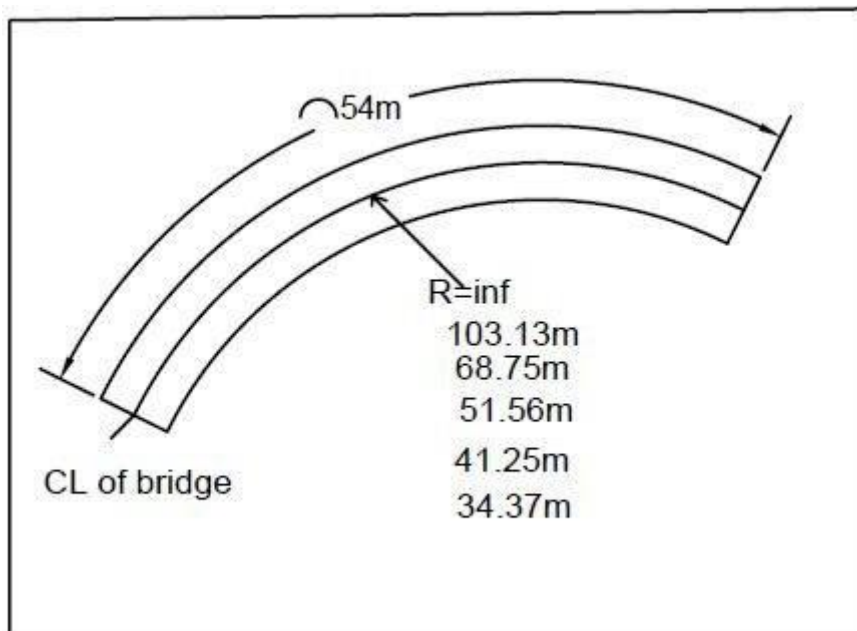


Figure 2 Geometry of curved box girder- (a) plan view

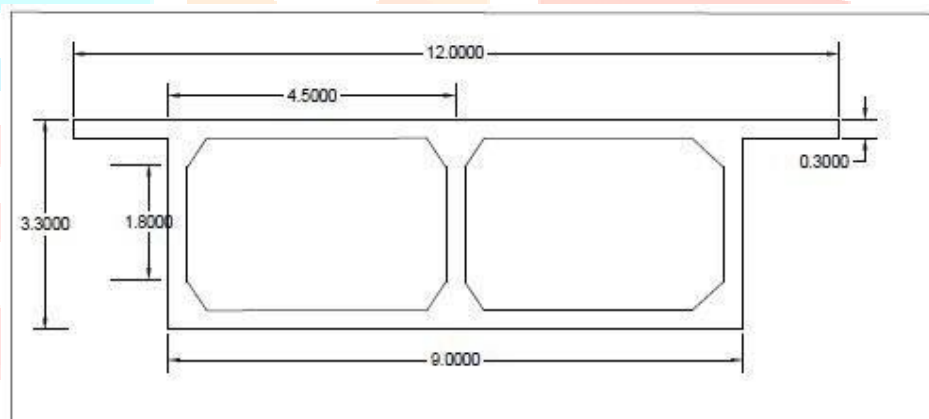


Figure 3 Geometry of curved box girder- (b) Cross section of girder

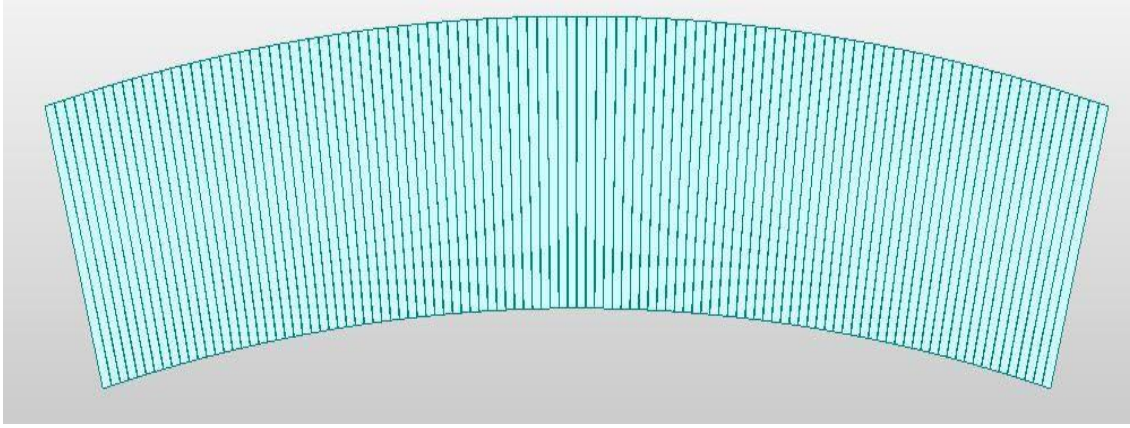


Figure 4 Model of 30° curve

Figure 4 illustrates model of 30° curve provided to box girder. Modeling is completed using Midas Civil software. Radius of curvature considered for 30° model is 103.1m.

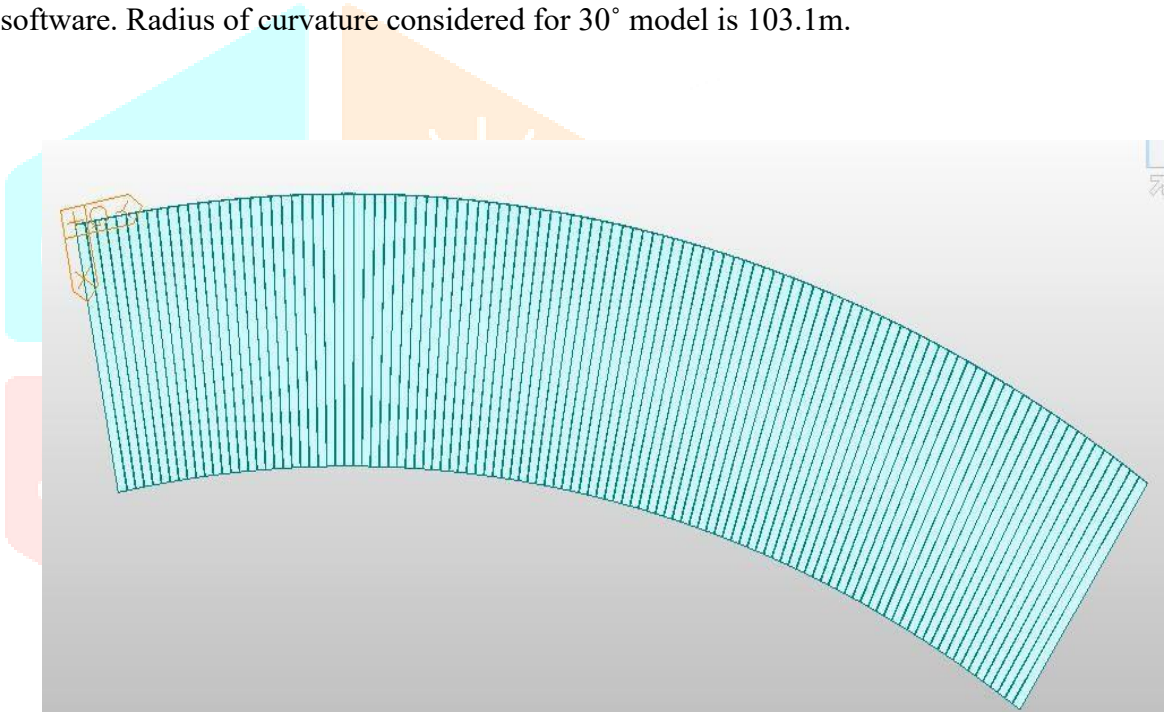


Figure 5 Model of 45° curve

Figure 5 illustrates model of 45° curve provided to box girder. Modelling is completed using Midas Civil software. Radius of curvature considered for 45° model is 68.75m.

Compressive Strength

Compressive strength of curved box girder is varied in parametric study. Variation is done to study the effect of compressive strength on prestressed curved box girder. Compressive strength is varied from M40 to M60 with interval of 5 grade of concrete. For variation in compressive strength cases, 500kN of prestressing force is considered. All cases of curvature of girder comprising of total 30 cases are analyzed. The various compressive strength considered for parametric study are:

Table 2 Cases considered for Compressive Strength

Curvature	Cases considered
0°	M40, M45, M50, M55, M60 - 6 cases
30°	M40, M45, M50, M55, M60 - 6 cases
45°	M40, M45, M50, M55, M60 - 6 cases
60°	M40, M45, M50, M55, M60 - 6 cases
75°	M40, M45, M50, M55, M60 - 6 cases
90°	M40, M45, M50, M55, M60 - 6 cases

Effect of compressive strength on parameters such as resultant stresses, torsional stress, tendon elongation and displacement are studied.

Prestressing Force

Prestressing force is varied from 400kN to 600kN with an interval of 50 kN. To analyze the effect of variation in prestressing force on curved box girder, this study is undertaken. The various prestressing force varied on tendons are as follows-

Table 3 Cases considered for Prestressing force

Prestressing force-	Curvature
400KN	0°, 30°, 45°, 60°, 75°, 90°-6 cases
450KN	0°, 30°, 45°, 60°, 75°, 90°-6 cases
500KN	0°, 30°, 45°, 60°, 75°, 90°-6 cases
550KN	0°, 30°, 45°, 60°, 75°, 90°-6 cases
600KN	0°, 30°, 45°, 60°, 75°, 90°-6 cases

Parameters considered are resultant stresses, torsional stress, tendon elongation and displacement for study of curved prestressed box girder.

Tendon Location

Tendons placed in curved box girder are varied for all cases of curved girder from straight girder to 90°. Tendon groups are considered according to tendon location. Tendon locations are varied

Tendon Group 1-

Tendon group 1 consists of all prestressing tendons being placed in webs. For all cases of curves from straight girder to 90° curved girder. Tendon group 1 is illustrate in Figure 12

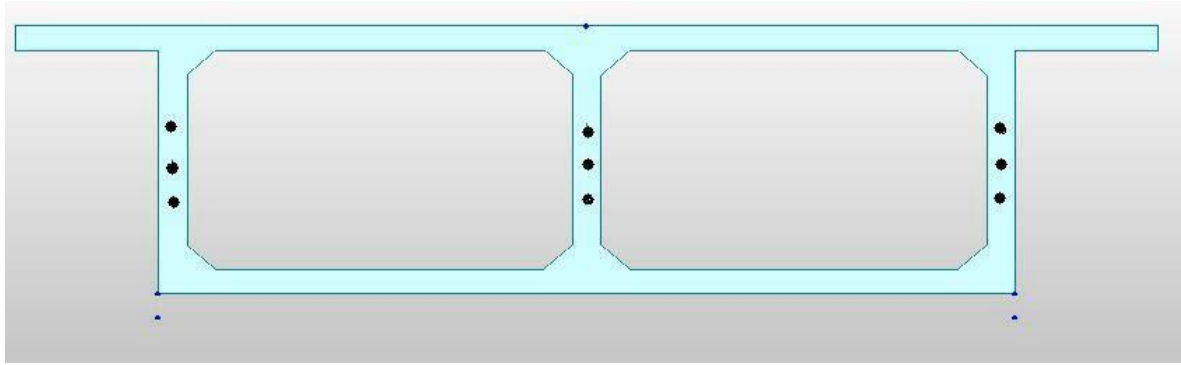


Figure 6 Tendon group 1

a. Tendon Group 2

Tendon group 2 consists of all prestressing tendons being placed in webs except at central web. Numbers of prestressing tendons are same for all tendon groups. For all cases of curves from straight girder to 90° curved girder. Figure 31 depicts tendon group 2 as follows-

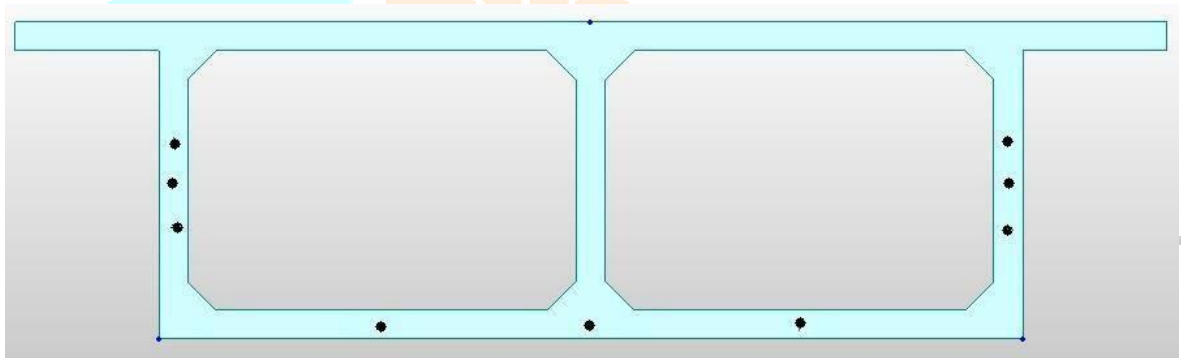


Figure 7 Tendon group 2

c Tendon Group 3

Tendon group 3 consists of all prestressing tendons being placed in soffit. For all cases of curves from straight girder to 90° curved girder. Intentionally tendons are placed at soffit position for maximum eccentricity and subsequently maximum moment. Tendon group 3 is illustrated in figure 14 as follows-

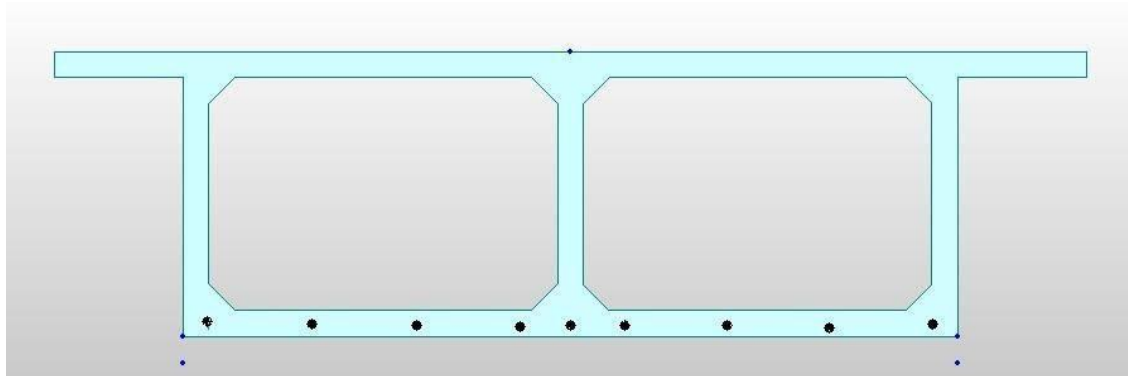


Figure 8 Tendon group 3

Analytical Work

Manual Design of prestressed box girder is completed with help of Krishna Raju[1]. Brief design steps are mentioned below and detailed design is explained in annexure at end. Design steps to be adopted for analysis and design of prestressed box girder are mentioned. Design for straight prestressed post-tensioned girder using IRC 6, IRC 18, IRC 21 is calculated in annexure. Also analysis of all cases of girder is done using finite element based MIDAS civil software.

Design steps adopted for analysis of twin cell box girder are mentioned below- a Assuming dimensions of twin cell box girder for study

b Assuming permissible stresses for concrete grade and steel conforming to IRC 18-2000 and IRC 21-2000.

c Assuming cross section of box girder.

d Design of slab panel.

e Dead load bending moment f Live load bending moment

g Design bending moment and shear force

h Design of top slab section and reinforcement i Check for shear stress in slab

j Design of web girder

k Dead load bending moment

l Live load bending moment in continuous web girder. m Live load shear force in girder

n Design bending moment and shear force o Check for minimum section modulus

p Prestressing force

q Check for stresses at service loads

r Check for ultimate flexural strength s Check for ultimate shear strength

t Supplementary reinforcement u Design of end block

Input in Midas

✚ Units Preference- Setting the units to kN and meter's is completed in this stage.

✚ Material Properties- Input of material properties of grade of concrete used and steel is done for various sections.

✚ Defining Section – Dimension of various sections of girder are defined.

✚ Time Dependent Material Properties- Material properties of compressive strength are defined.

✚ Time Dependent Material Link- Creep and shrinkage properties are included. ✚ Creating Nodes- Node of origin at Centre is defined.

✚ Creating Elements- Elements like girder, end diaphragms, internal diaphragms, cross beams are created.

Modelling Checks- Duplicate elements are eliminated and intersection of nodes is done. Group Definition – Various groups like structure group, Boundary group and load group are defined. Structure group

includes construction stages like CS1, CS2, CS3. These construction stages are activated according to the stages in construction period. In boundary group temporary supports are provided and elastic links. These elastic links act like elastic pad bearings and design of the same is eliminated. Various loads acting on structure are segregated into load groups. Load group for self-weight, super-imposed dead load, crash barrier load and wearing course load are grouped accordingly.

Results and Interpretation

Analysis of various models of prestressed curved girder are done. 30 models comprising of variation in prestressing force and curvature are analyzed. For compressive strength variation, 30 models comprising of M40 to M60 grade of concrete are analyzed. Another 12 models of tendon group variation comprising of change in tendon location are analyzed. Total 72 models of curved box girder are analyzed. Results obtained from these models are graphically represented below, tabulated and interpreted as follows-

Effect of curvature

Figure 9 illustrates the different intensity contours for displacement of curved prestressed concrete box girder. Various color combinations are denoted to illustrate intensity of displacement. It is observed that on both sides of girder the intensity is low depicted by blue and green color followed by yellow and cream color showing slightly higher displacement value. Followed by Red color signifying severe displacement and goes on reducing till supports.

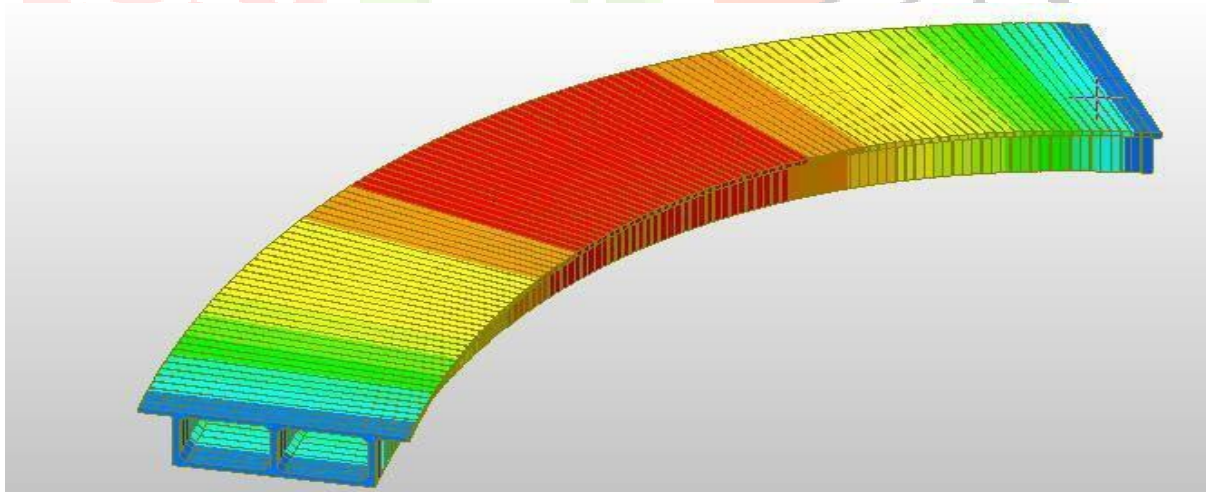


Figure 9

Figure 10 illustrates effect of curvature on displacement when prestressing force 400kN is applied on box girder. For 0° and 30° displacement is same. Steep increase of 396% is observed from 30° to 45°. For curvature 60° to 90°, 45.29% increase in displacement is observed

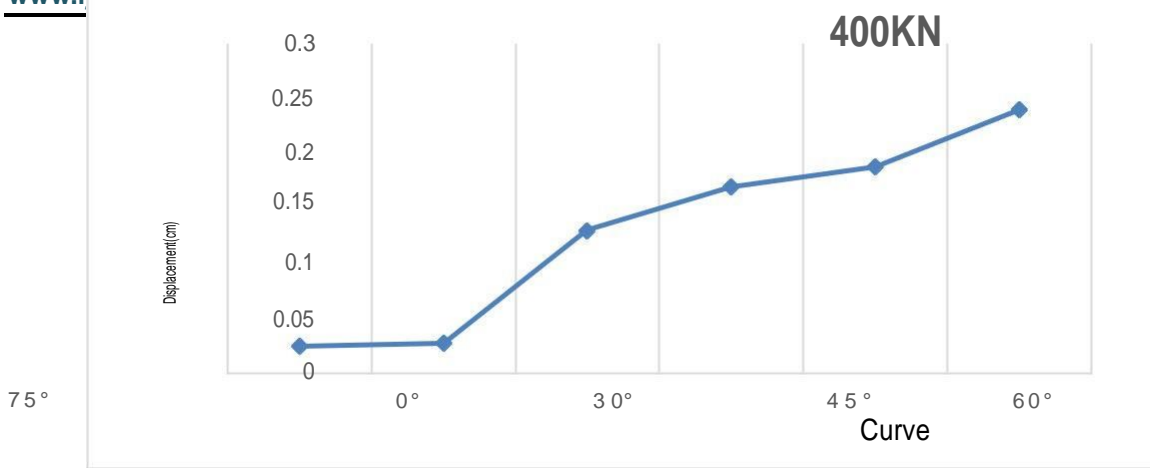


Figure 147 Effect of 400 kN prestressing force on displacement

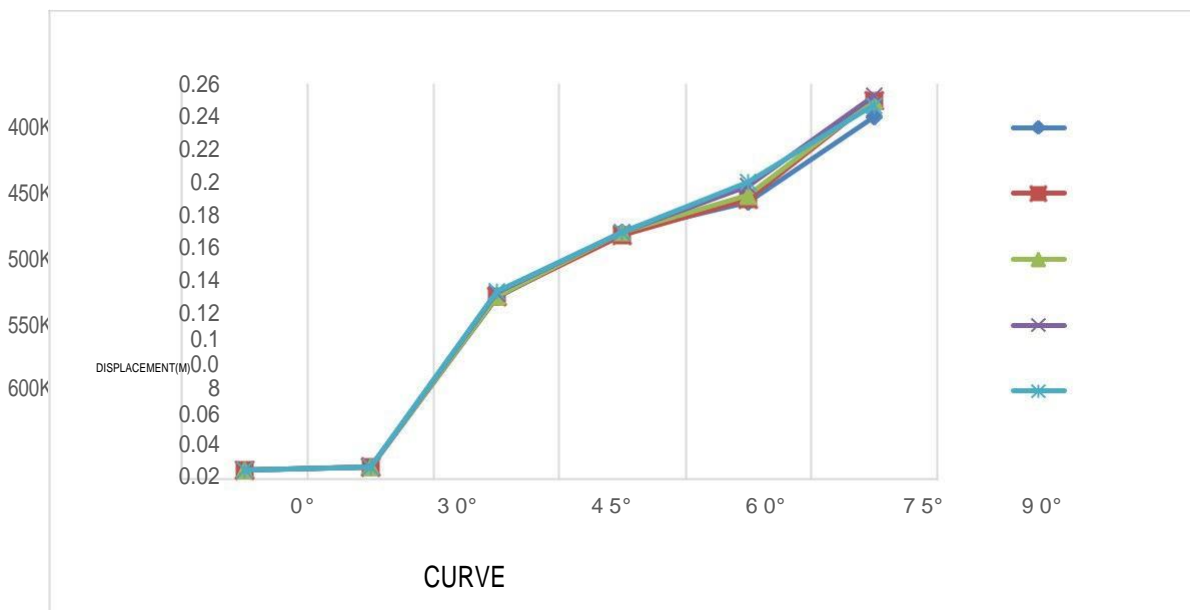


Figure 11 Effect of prestressing force on displacement

Figure 18 illustrates effect of prestressing force on displacement for all cases of curvatures. For 0° and 30° displacement is same and steep increase is observed from 30° to 45°.

Different curvature ranges tendon elongation are tabulated in below table. Table 4 indicates various tendon elongation on girders. It is observed that increase in prestressing force above 500kN, elongation of tendon is same throughout girders. For prestressing forces up to 450 kN changes in elongation are observed from range of 0.0543m to 0.0679m for different curvature. As the curvature increases tendon elongation increases linearly. Effect of variation in prestressing force on curved box girder is reviewed.

For curvature of box girder, the vertical displacement in downward direction is considered at mid-span of girder for all cases of curvature. Displacement due to change in compressive strength is tabulated in Table 6.

Table 1 Displacement due to compressive strength variation

Compressive strength	Displacement(mm) Curvature					
	0°	30°	45°	60°	75°	90°
M40	-26.07	-28.157	-48.054	-73.175	-84.0557	-110.6423
M45	-26.436	-28.157	-42.194	-73.056	-81.686	-91.7457
M50	-25.900	-28.157	-45.496	-71.174	-69.716	-87.0507
M55	-26.2581	-28.157	-44.4196	-69.845	-66.483	-83.211
M60	-26.0794	-28.157	-43.44	-67.957	-75.985	-79.486

Negative values denote displacement in downward direction. Figure 30 illustrates Effect of compressive strength on Displacement. Increase in compressive strength leads to decrease in displacement. For M45 as curvature varies from 0° to 90° increase in displacement by 246% is observed. For curvature 90°, as compressive strength increases, from M40 to M60 decrease of 28% in displacement is observed.

Tendon Elongation

Tendon Elongation for different tendon groups is tabulated in Table 9. Less than 1% increase is observed in variation of curvature from 0° to 90°. Less variation is observed in tendon elongation due to tendon location change.

Table 5 Tendon Elongation

Tendon group	Tendon Elongation(mm)					
	0°	30°	45°	60°	75°	90°
Tendon group 1	66.8105	66.8556	66.8386	66.8375	66.489	67.4
Tendon group 2	67.8997	67.9092	67.9273	67.927	67.6095	67.9366
Tendon group 3	67.8998	67.9092	67.9273	67.9275	67.6095	67.939

Resultant stress due to tendon group variation

Resultant stress at soffit and slab level are considered. Inner and outer edges of curvature are considered for tendon group variation. Figure 34 illustrates effect of resultant stress due to tendon group variation. Resultant stress at external edge of slab is illustrated below. It can be observed from figure that resultant stress due to tendon group 1 are high as compared to others. Resultant stress due to tendon group 2 are minimum and hence tendon group 2 can be considered optimum.

Conclusion

Parametric study of curved prestressed concrete box girder is carried out. Effects of variation in curvature from 0° to 90°, effects of variation in prestressing force from 400kN to 600kN, effects of variation in compressive strength and effects of variation in tendon location are observed and denoted. Box girder of 54m span is investigated for above variation in parameters. Results for the same are specified in previous chapter. From the parametric study, it is concluded that-

- Increased curvature in prestressed curved box girder leads drastic increase in displacement.

Effect of curvature on tendon elongation is moderate. Torsional stresses increase as curvature

increases in girder. For curvature from 45° to 75° , 85.6% increase in torsional stress is observed.

✚ For prestressing force above 500kN for all range of curvature, tendon elongation is same.

Prestressing force leads to drastic increase in torsional stresses. Displacement is moderately ✚ affected by increase in prestressing force.

As compressive strength increases, decrease of 28% in displacement is observed. Effect of compressive strength variation on resultant and torsional stresses is moderate.

✚ Even distribution of tendons in soffit leads to eccentric distribution of resultant stress.

This distribution of resultant stress becomes greater as curvature is increased.

6.1.FUTURE SCOPE

- ❖ Different types of girder for curved bridges can be studied.
- ❖ Bursting force, losses in prestress for curved bridges need to be studied.
- ❖ Specific empirical formulas with respect to parametric study for curved bridge configuration can be studied and derived.
- ❖ Also parametric study with respect to different girders, different span length, cable profile segmental bridges and cantilever bridge can be undertaken.

