Report for end-semester evaluation of CE 499 course

Modelling And Analysis of Steel Arch Bridge

Submitted

By

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CERTIFICATE

It is certified that the work contained in the project report entitled "**Modelling and Analysis of Steel Arch Bridge**" by **Vipul Kumar** (Roll No. 190104097) has been carried out under my/our supervision and that this work has not been submitted elsewhere for the award of a degree or diploma.

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ABSTRACT

It has been years that bridge designers and engineers are not only concerned about stability of bridge structures but being concerned about their efficiency and aesthetic as well. Nowadays, as the need is greater than ever, tied-arch bridges and truss bridges have proven they have been of interest to bridge designers when span range of 40 to 550 m are required. The aim of this project is to discuss about effect of rise to span ratio on the behavior of parabolic steel arch bridge. The deck load is transferred to the arch rib by means of hangers. In the present project with the help of CSI Software SAP2000 for modeling this arch bridge we take 120m long span which is 7m wide 2-lane each lane is 3.5m wide. To investigate the static behavior of arch bridge by varying rise to span ratio when the bridge is subjected to static and vehicle loading. The set of results under dead load and vehicle load specified in India has been analyzed to find out deflections for each rise to span ratio. After determining optimum rise to span ratio 1st ten natural frequency of the bridge is also determined by modal analysis.

ACKNOWLEDGEMENT

First and foremost, I must have to thank my Supervisor **Prof Sudip Talukdar** without their assistance and dedicated involvement in every step throughout the process, this project would have never been completed. I would also like to express my sincere gratitude towards all the people who have contributed their precious time and effort to help me, without them it would have been a great difficulty for me to understand and complete the project. I would especially like to thank my Co-Supervisor and Bridge Engineering course instructor **Prof Kaustubh Dasgupta** for helping me to understand bridge design related Terminology and Methodology.

Date: Signature of the student

Vipul Kumar

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List of Symbols and Abbreviations

Symbol	Description
E	Modulus of Elasticity
v	Poisson's Ratio of Concrete
G	Shear Modulus
Fy	Minimum Yield Stress
Fu	Minimum Tensile Stress
Fye	Expected Yield Stress
Fue	Expected Tensile Stress
mm	Millimeter
m	Meter

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CHAPTER-1

INTRODUCTION

1.1 General

A bridge is a structure that crosses over a river, road, railway, or other obstructions, which permits a smooth and safe passage of vehicles, trains and pedestrians. A bridge structure can be divided into two main parts. First the upper part called superstructure, which consists of the deck, the floor system such as stringers and floor beams and the main trusses or girders, second the lower part called the substructure, which are columns, piers, towers, footings, piles and abutments.

It is well known that the arch bridge is one of the most successful kinds of bridges. The tied arch bridge is basically an improvement in simple arch bridge in which only difference of hangers which is attach with the arch rib and main girder. Depending on types of arch bridges spans varies. Arch bridges are used for medium and long bridges. These types of arch bridges are highly appreciable appearance and significantly utilized structural materials; tied arch bridges have been taken as one of the most popular types of bridges in last decades and have been successfully built all around over the world. With incomparable aesthetics and larger load carrying capacity, the world's longest steel arch bridge of main span 552 m (Chaotianmen Bridge) in the city of Chonqing, built over the river Yangzu and opened for traffic in 2009 is one of the vivid examples in recent decade.

1.2 Structural components of Arch Bridge

The main structural components of Arch bridge are arch rib, hangers, and main girder. Arch ribs are curved type member made up of steel or concrete depending on the designer. The shape of arch ribs is parabolic or circular. Hangers are made up of steel and attach to arch rib and main girder. Main girder is made with steel or sometimes with concrete. Hangers are attaching with arch ribs and main girder to transfer the load from girder to ribs. As the loads pushes down the deck downwards it creates a tension force in hangers that are anchored to both girder and arch ribs. These hangers drag down the arch ribs inducing the compression in arch ribs and these forces are transferred through the arch ribs into substructure. Support conditions in arches are fixed type.

1.3 Types of arch Bridge

1.3.1 Deck Arch Bridge:

A deck arch is one wherever the bridge deck that has a structure that directly supports the traffic loads is found on top of the crown of the arch. The deck arch is understood as an ideal arch.

Fig 1.1 New River Gorge Bridge west Virginia

(https://www.nps.gov/neri/planyourvisit/nrgbridge.htm)

1.3.2 Through Arch Bridge:

It is a bridge made from materials such as steel or reinforced concrete in which the base of an arch structure is below the deck, but the top rises above it, so the deck passes through the arch.

Fig 1.2 Sydney Harbour

(https://en.wikipedia.org/wiki/Sydney_Harbour_Bridge)

1.3.3 Tied Arch Bridge:

Tied arch bridge is a type of arch bridge that consists of rib on both side of the deck, and one tie beam on both arches that support deck. Vertical hangers connected to the arch to support deck from above.

Fig 1.3 Godavari Arch Bridge

(https://en.wikipedia.org/wiki/Godavari_Arch_Bridge)

1.4 Advantages of Arch Bridge

- Better Resistance: It offers a better level of resistance to the imposed loads. It receives additional strength from the aciform design of the bridge and thus provides a higher degree of resistance to the bending forces and associated loads.
- Higher Pressure Resistance: It offers better resistance to the pressure due to the unique arch style of the bridge. It allows the load to be distributed thus ensuring that no part of the bridge is subjected to excessive pressure.
- Many Choices of Construction Materials: It offers great flexibility and options in terms of construction materials. This bridge can also be constructed using stones, bricks and other similar natural materials.

- Sound Structure: The structure of the arch bridge is relatively sound. The modern type of arch bridge is constructed using lighter construction materials that sound even for long spans.
- Strength: It is strong enough and capable of withstanding the loads imposed efficiently.
- Economic and Affordable: It is a relatively economic type of bridge It offers flexibility in terms of construction materials and thus cost-efficient locally available materials can be used.

1.5 Structural Components Behavior of Tied Arch Bridge

1.5.1 Arch Rib:

The arch rib is the main structural member of the arch and is responsible of carrying the different loads generated in the structure. The arch rib can be built as a truss, a box girder, a plate girder, or as a hollow section, depending on its usage. The arch rib doesn't only represent the main load-bearing element of an arch bridge, but also represent the most aesthetic component of the bridge.

1.5.2 Hanger:

The hangers are most important members in an arch bridge to transfer the loads from deck to the arch rib. Generally, they are tension members. The arrangement of these hangers greatly influences the performance of the arch under permanent and transient load. There are three commonly used hanger systems for tied arch bridges. Vertical hangers are referred to as a "Langer" system. The "Nielson" system having inclined hangers and an improvement to that system which is denoted as "Network" system.

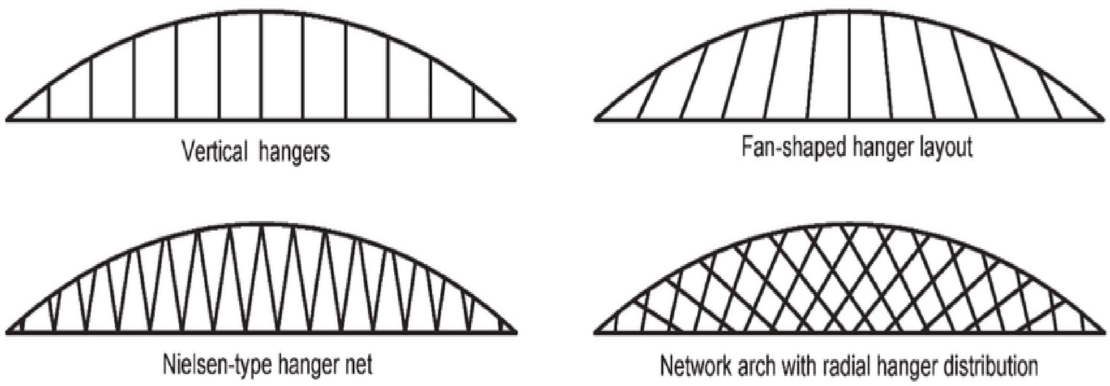


Fig 1.4 Different types of hanger arrangements(https://civilwale.com/tied-arch-bridge/)

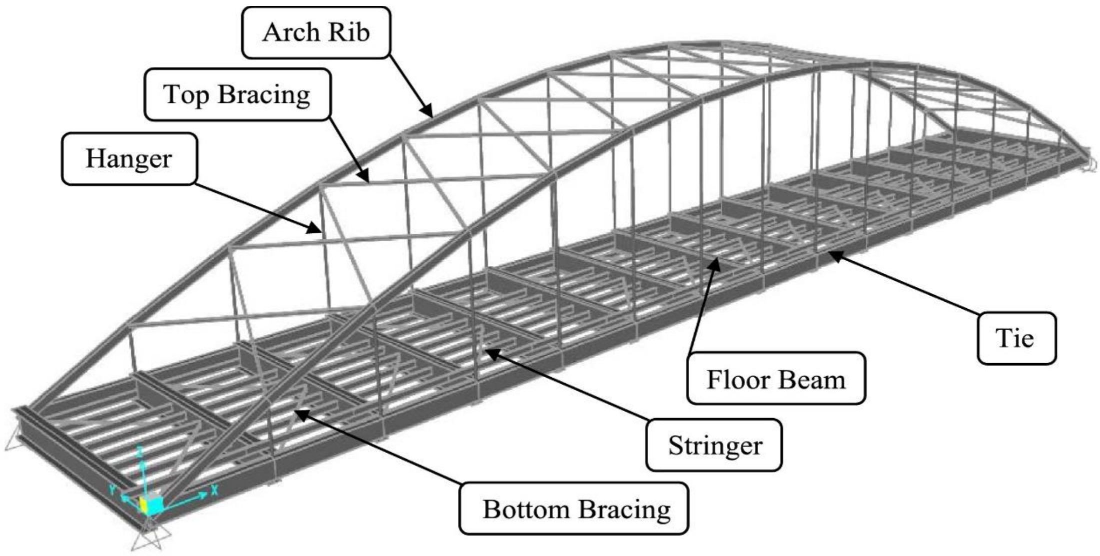


Fig 1.5 Tied-arch bridge with all its elements(https://www.sciencedirect.com/science/article/pii/S096599781831069X)

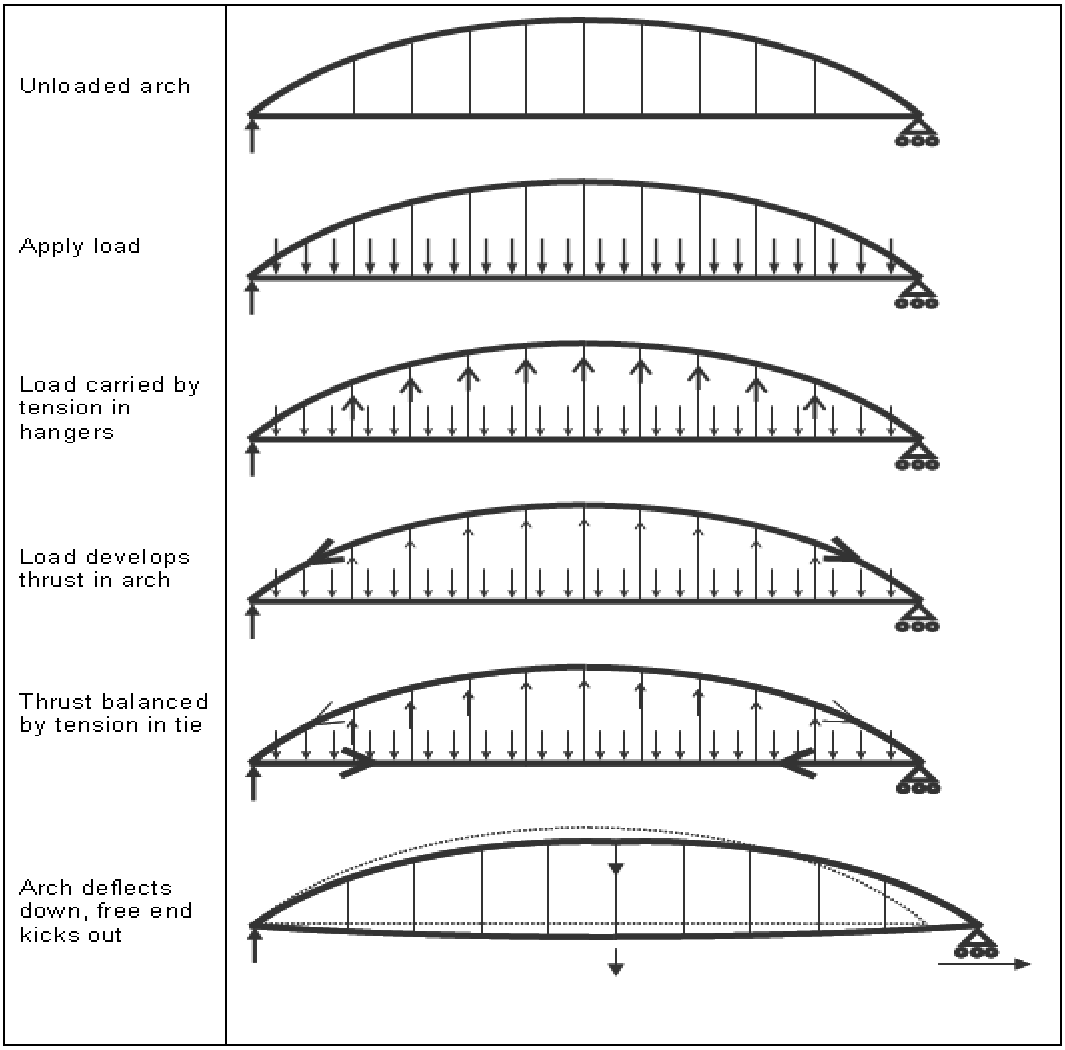


Fig 1.6 Structural Actions of Arch Bridge(https://civilwale.com/tied-arch-bridge/)

1.6 Geometric Profile of Arch Bridge

1.6.1 Parabolic Arch:

Measuring the horizontal distance from the left-hand support, the rise of the parabolic arch at any station can be given by following equation as

$$y = \frac{4h}{L^2} x(L - x) \text{ --(1)}$$

where y is the rise of the center line of the arch, h is the central rise, L is the span of the arch, x is the distance of the station from left hand support. Rise/span ratio is understood as h/L.

Distance from left end(x) in m	Vertical Height of Hanger(y) in m
Start=0	0.0
5	3.833
10	7.333
15	10.5
20	13.333
25	15.833
30	18.0
35	19.833
40	21.333
45	22.5
50	23.333
55	23.833
Mid=60	24.0

Table 1.1 Parabolic Arrangement coordinate of hanger for h/L=0.2(1/5)

Distance from left end(x) in m	Vertical Height of Hanger(y) in m
Start=0	0.0
5	3.1994
10	6.111
15	8.75
20	11.111
25	13.194
30	15
35	16.527
40	17.778
45	18.75
50	19.444
55	19.861
Mid=60	20

Table 1.2 Parabolic Arrangement coordinate of hanger for h/L=0.166(1/6)

Distance from left end(x) in m	Vertical Height of Hanger(y) in m
Start=0	0.0
5	2.737
10	5.237
15	7.498
20	9.522
25	11.307
30	12.855
35	14.164
40	15.235
45	16.068
50	16.664
55	17.021
Mid=60	17.14

Table 1.3 Parabolic Arrangement coordinate of hanger for h/L=0.143(1/7)

Distance from left end(x) in m	Vertical Height of Hanger(y) in m
Start=0	0.0
5	3.833
10	7.333
15	10.5
20	13.333
25	15.833
30	18.0
35	19.833
40	21.333
45	22.5
50	23.333
55	23.833
Mid=60	24.0

Table 1.4 Parabolic Arrangement coordinate of hanger for h/L=0.125(1/8)

CHAPTER-2

LITERATURE REVIEW

2.1 Review of Research paper

1. Wang, Fu-Min, (2009)
    - The Chongqing Chaotianmen Yangtse River Bridge is a steel truss arch bridge with a main span of 552 m.
    - The main span of the bridge is currently the world' s longest span arch bridge.
    - Its design and construction overcame significant technical difficulties. This paper describes the innovative aspects of the bridge regarding selection of structural system, length of main span, and construction technology.
2. Mihai Vlad, and Vladimir Marusceac. (2015)
    - This paper presents the influence of different hanger arrangements for a tied arch bridge with respect to all the variables such as: efforts in arches, ties and hangers.
    - In order to reduce foundation costs, tied arch bridges use the deck to take the role as the tension member taking the forces generated in the ends which make this solution more suitable for openings between 70-200 meters distance range where other type of bridges require large sections or other support systems such as stay cables.
    - The purpose of this paper was to determine the influence of different hanger arrangements using three-dimensional finite element models and the objective was to determine the most suitable solution for a road bridge, with a span of 100 meters, consisting of two inclined steel arches, located on a road with two traffic lanes, subjected to medium traffic.
    - In this paper, for the opening of 100 m, it can be seen more effective the network system with inclined hangers than the vertical hanger system. This system provides a better structural efficiency compared to the configuration with vertical hangers.
3. Alika Koshi and Dr. Laju Kottalil (2016)
    - The behavior of through arch bridge with different arch positions and to compare them with the real structure by using 3D bridge model in ANSYS.
    - They concluded that the deflection increase as the arch position goes downwards.

4. Construction of Arch Bridge on the river YOMOGO at paya Village (2012)
    - A detailed project report was given for each section of the Arch Bridge.
    - Drawings and Dimensions of arch rib, bottom bracing, top bracing, Longitudinal stringer, Hangers etc. were taken as reference from this report for modelling of my project.
5. Xijuan Jiang, Lei Wang and Hong, bin Zhang. (2019)
    - In this paper, a finite element model of a through tied arch bridge was set up to analyze its static and dynamic characteristics under both dead weight and secondary dead load. By static analysis, the maximum deformation of the structure is located at the center of the span. The first ten natural frequencies and modes of the structure were obtained by dynamic analysis, and the in-plane stiffness of the structure is larger than that of out-of-plane stiffness.
6. Fox, G. F., (2000)
    - Based on elastic theory, stresses and deformation in the arch rib of solid web has been derived in this handbook. However, the approach does not discuss the combined theory in which connected hangers and bracings can be included in steel arch bridges used for long span.
7. Victor D. Johnson (Sixth Edition)
    - This book includes different terminology and Methodology related to Bridge engineering design.
    - Standard specifications of road bridges and railway bridges in accordance with Indian Road Congress Bridge Code.
    - It also includes general design Consideration of different types of steel and Concrete Bridges.

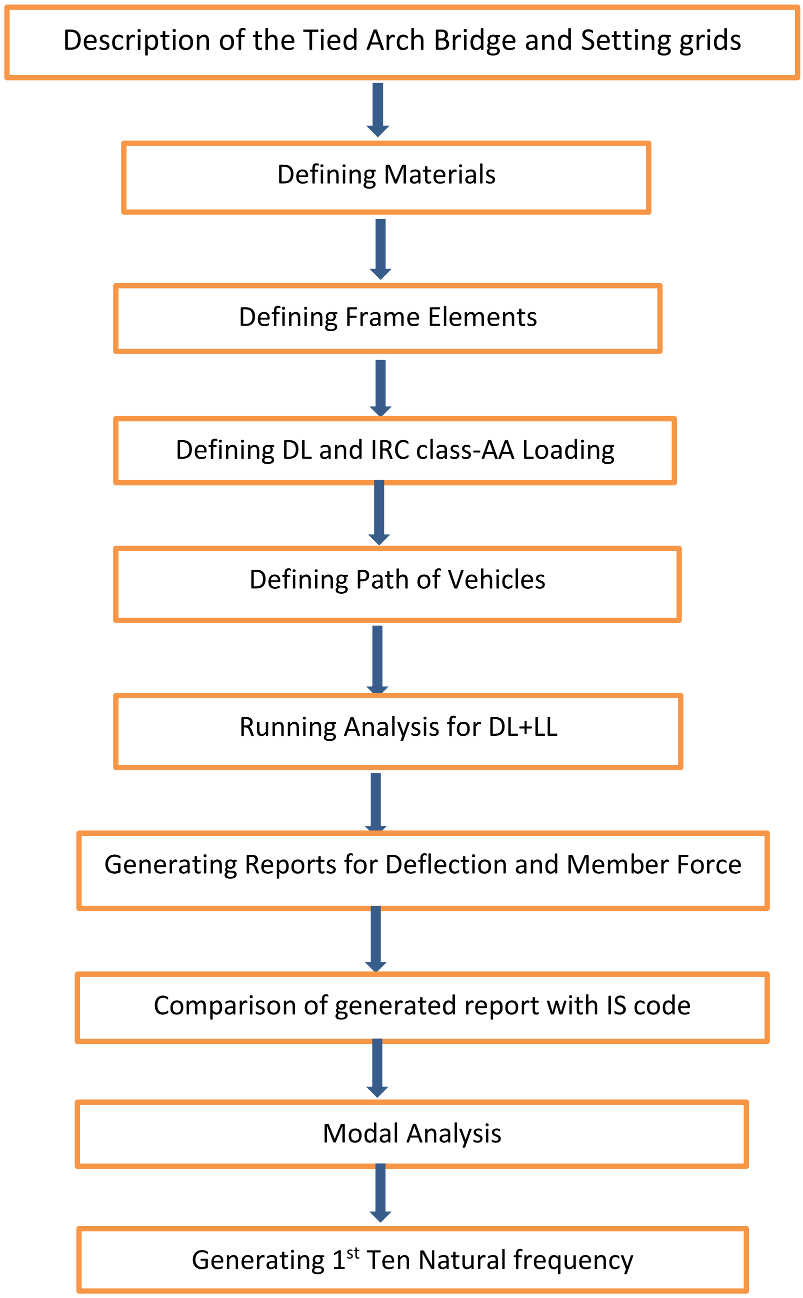
2.2 Scope of study

In recent years, construction of steel arched and tied arch bridges became more common when span range of 40 to 550 meters is required. Countries like China, Australia and United states are the leaders of these bridges in the longest bridge span ranking. The literature review reveals that steel arch bridges has been the topic of research for several decades but many things are yet to be unveiled especially the design requirements for different types of hangers in steel arch bridge and behavior of arches with different geometric profiles with varying rise/span ratio. The aim of the present project is to analyze the stresses and deflections in medium span steel arch bridges using 3D finite element analysis with parabolic geometric profile. Analysis part is expected to reveal the most critical points and sections, optimum rise to span ratio for each type of bridge, the reactions at bridge supports, bridge deflections when bridges are subjected to self and traffic loading. Modal analysis gives the 1st ten natural frequency of bridge.

CHAPTER-3

METHODOLOGY

3.1 Methodology Flow chart: SAP2000



3.2 Description of the components

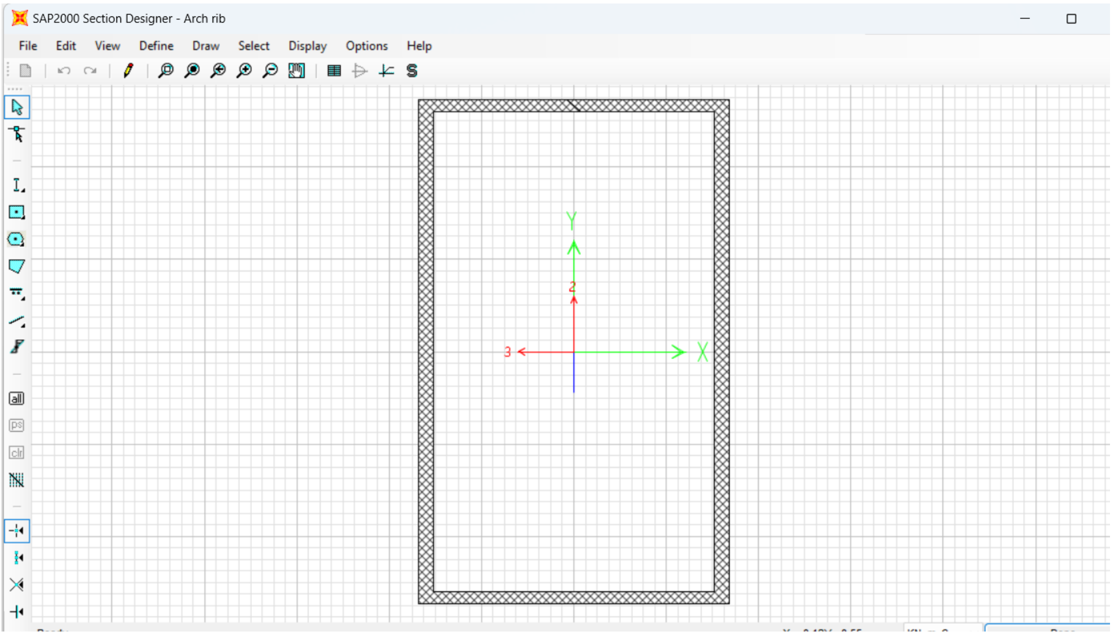


Fig 3.1 Arch Rib

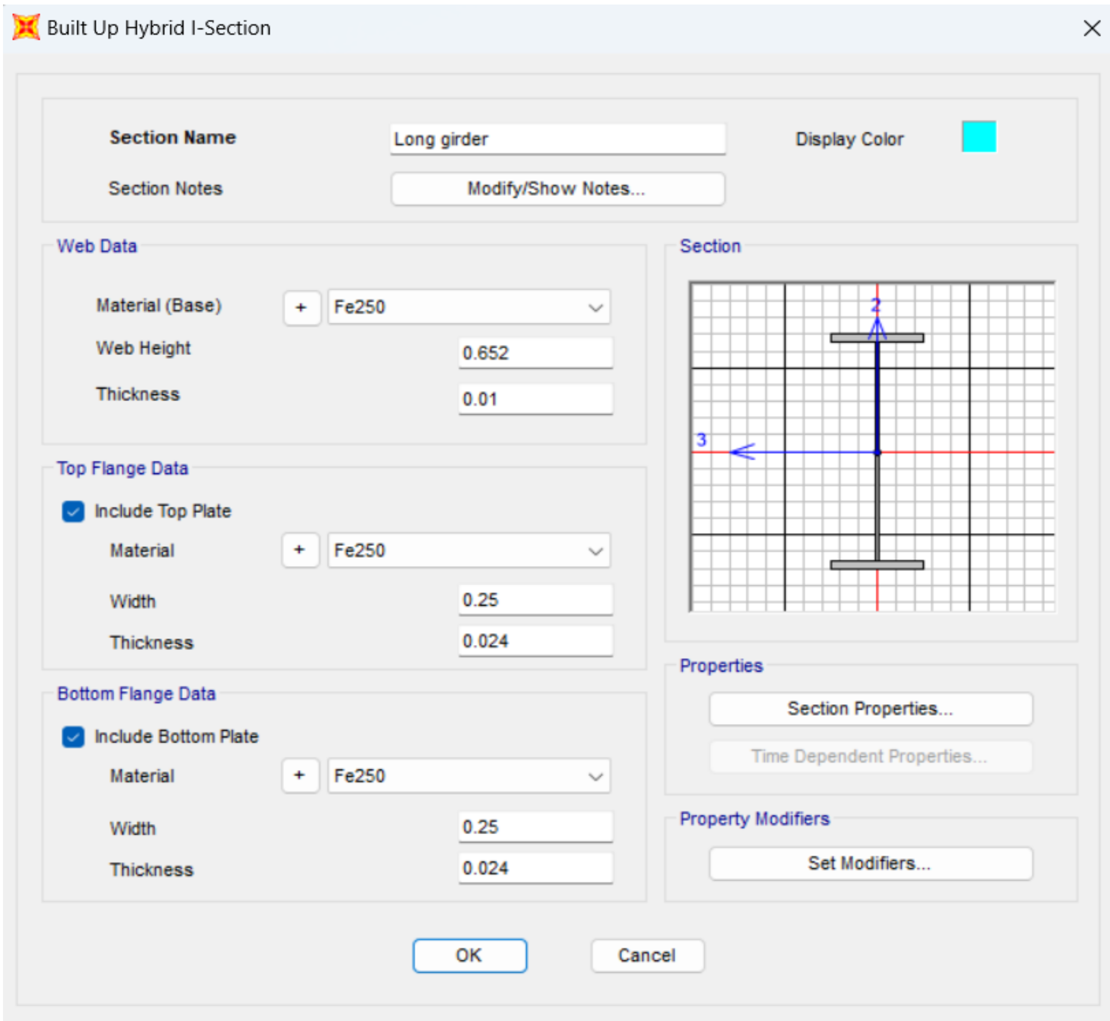


Fig 3.2 Longitudinal Girder

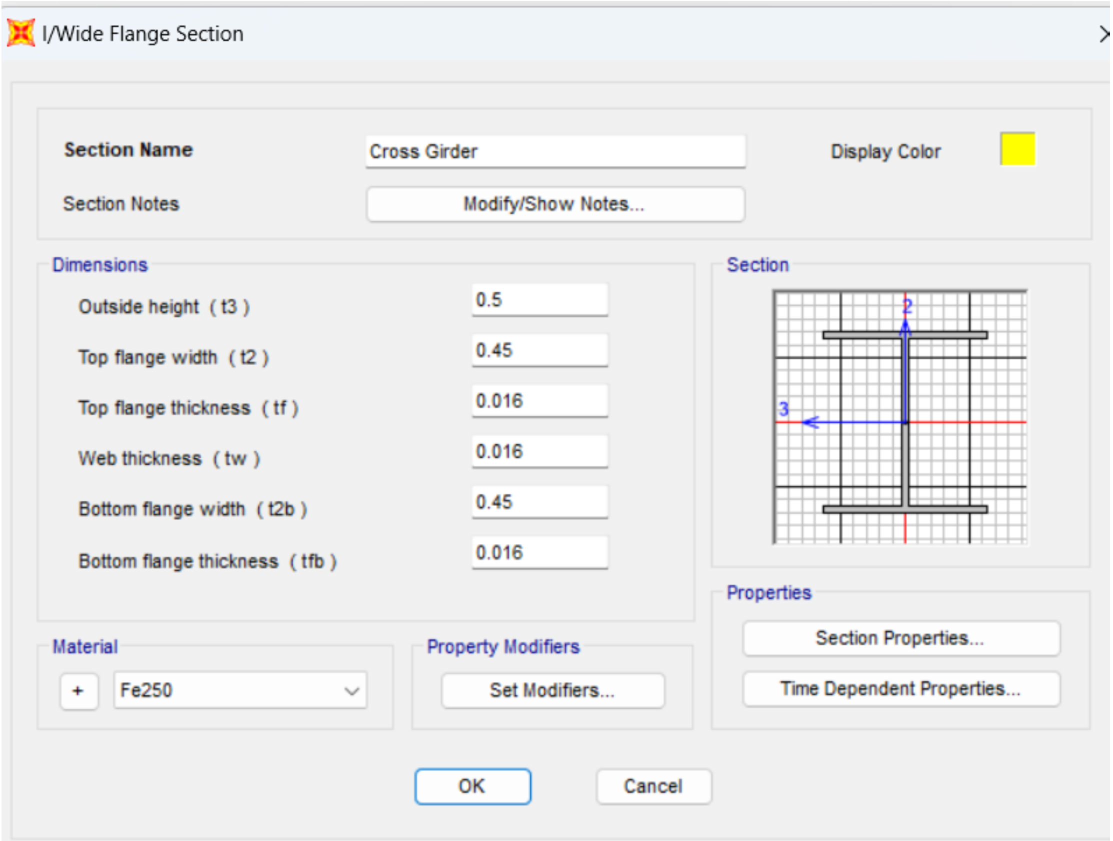


Fig-3.3 Cross Girder

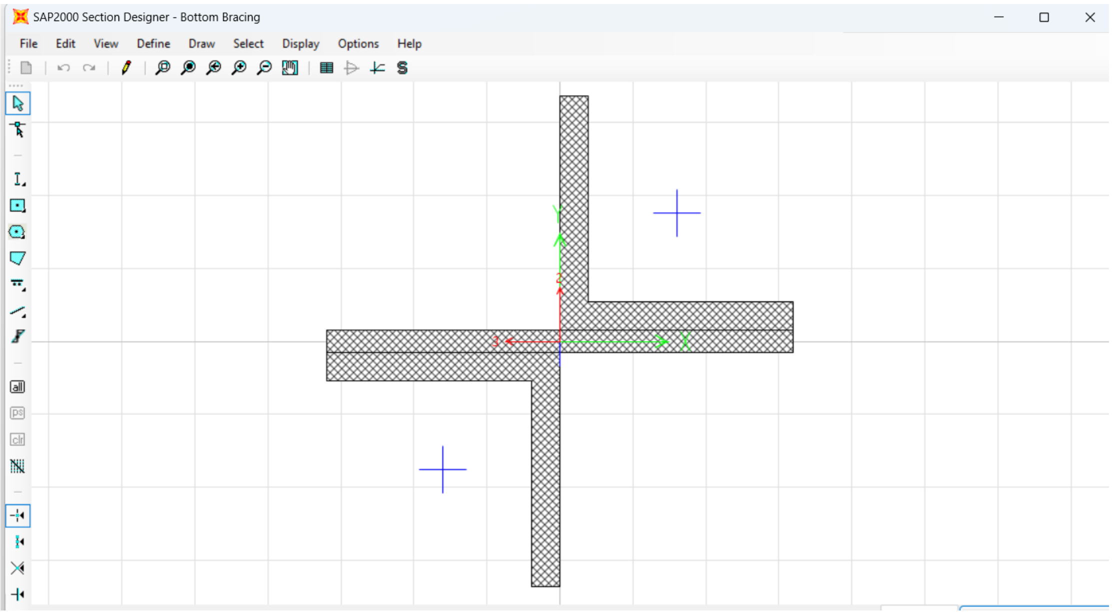


Fig-3.4 Bottom Bracing

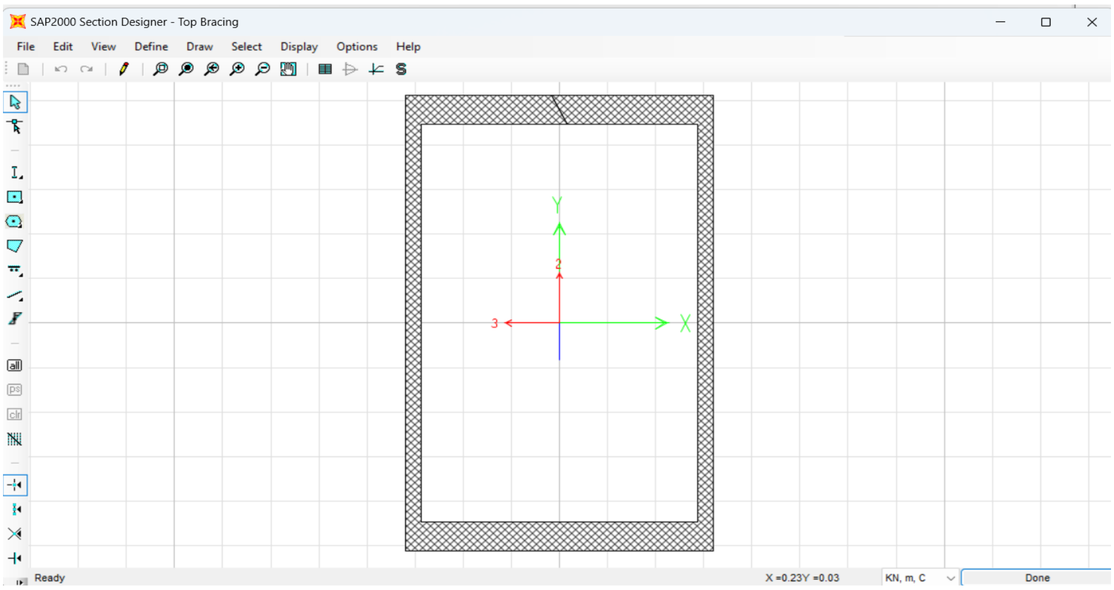


Fig-3.5 Top Bracing

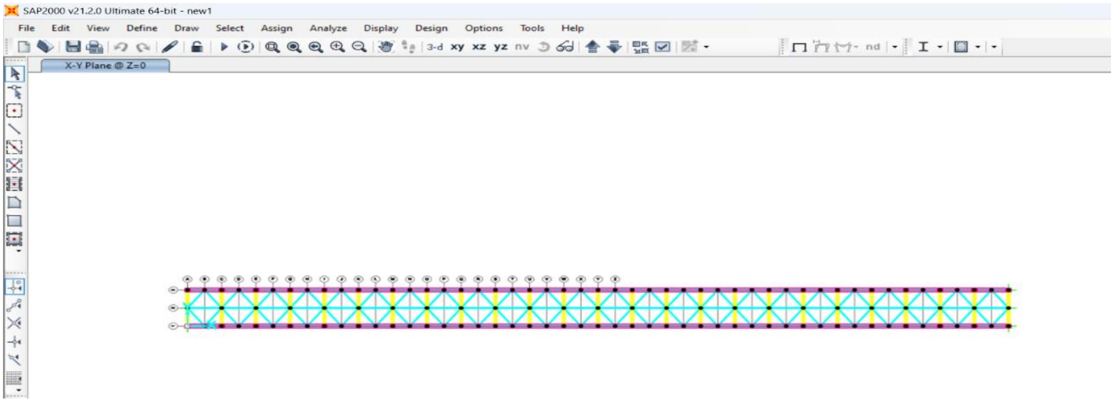


Fig-3.6 Plan at Deck level

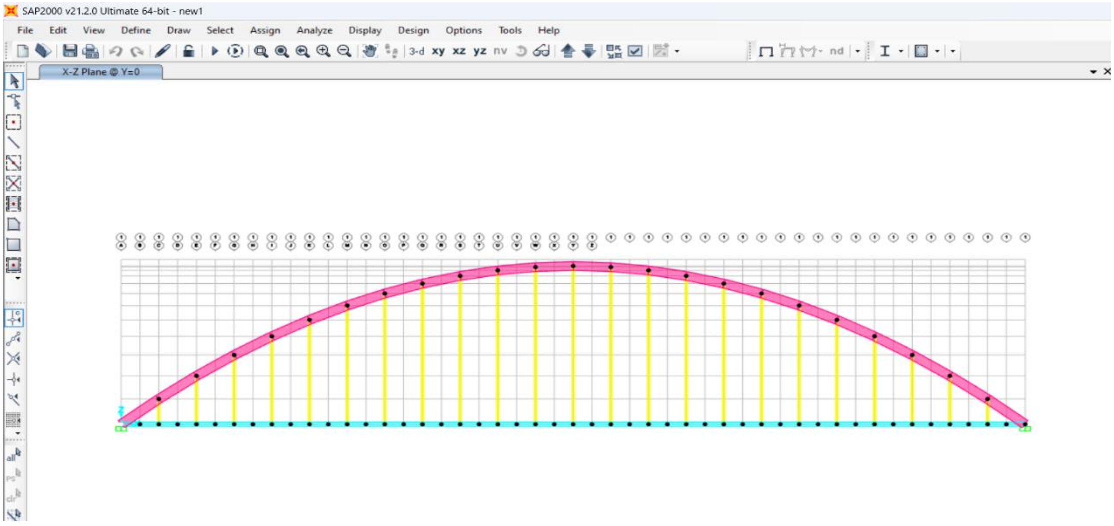


Fig-3.7 Parabolic Arch

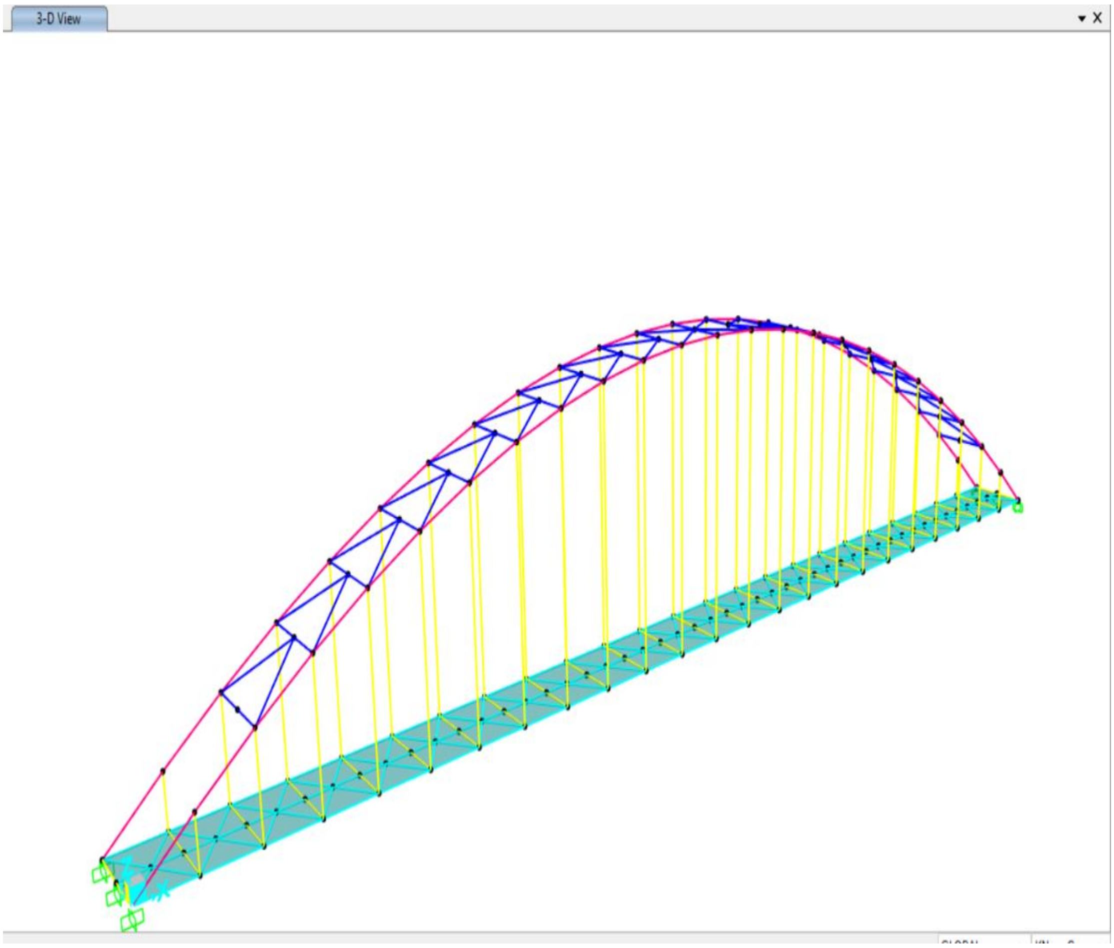


Fig-3.8 3-D Model View

The arch rib is composed of welded plates forming box section. Section contains of flange width of 760mm and thickness of 32mm, Web's height is 1300mm and thickness of web is 40mm. Longitudinal Stringers are Built up I sections with flange dimensions of 250mm x 24mm and web dimensions is 652mm x 10mm. Cross Beams are I section with flange dimension 450mm x 16mm and web dimensions is 468mm x 16mm. Cross beams are provided at 5m c/c Spacing. Bottom lateral bracing is provided to prevent the lateral buckling of longitudinal and cross girders and to keep them in position. Star shaped bracing is provided in each panel of 5m. It is made up of two angular sections ISA100×100×12 joined to a plate 200 mm wide and 10 mm thick. Top Bracing is box section with dimension of flanges are 200mm x 20mm and dimension of webs are 280mm x 10mm. Top lateral bracing resist the wind load and to prevent the arch ribs from lateral buckling. Two arch ribs are connected at the top by bracing to prevent buckling. Hangers are of hollow box sections with flange dimensions of 300 mm× 16 mm and web dimensions of 348 mm× 10 mm. Hangers are provided at every 5m and connected to cross beams and arch rib at bottom and top respectively.

3.2.1 Isotropic and Other Properties of Steel Data

Sl. No	Property	Value
1	Modulus Of Elasticity, E	2.100e+08
2	Poisson Ratio, *v*	0.3
3	Shear Modulus, G	80769231
4	Minimum Yield Stress, Fy	250000
5	Minimum Tensile Stress, Fu	410000
6	Expected Yield Stress, Fye	275000
7	Expected Tensile Stress, Fue	451000
8	Weight per unit volume	76.9729 (KN, M,C)
9	Mass per unit volume	7.849

Table-3.1 Steel Section Properties

3.3 Applied Loads

The self-weight, superimposed dead load and live load have been considered to obtain stresses and deflection.

3.3.1 Dead Load

The dead load applied on the modal is determined by the SAP2000 program itself based on the material properties the model also includes self-weight.

3.3.2 Live Load

Indian standard live load of **Class 70R** has been considered in the analysis. This loading, according to bridge design standard adopted in India is the severest loading. It consists of a wheel load train comprising a truck with trailers of specified axle spacing and loads. The heavy-duty truck with two trailers transmits loads from 7 axle varying from a minimum of 78.5KN to a maximum of 166.71KN.

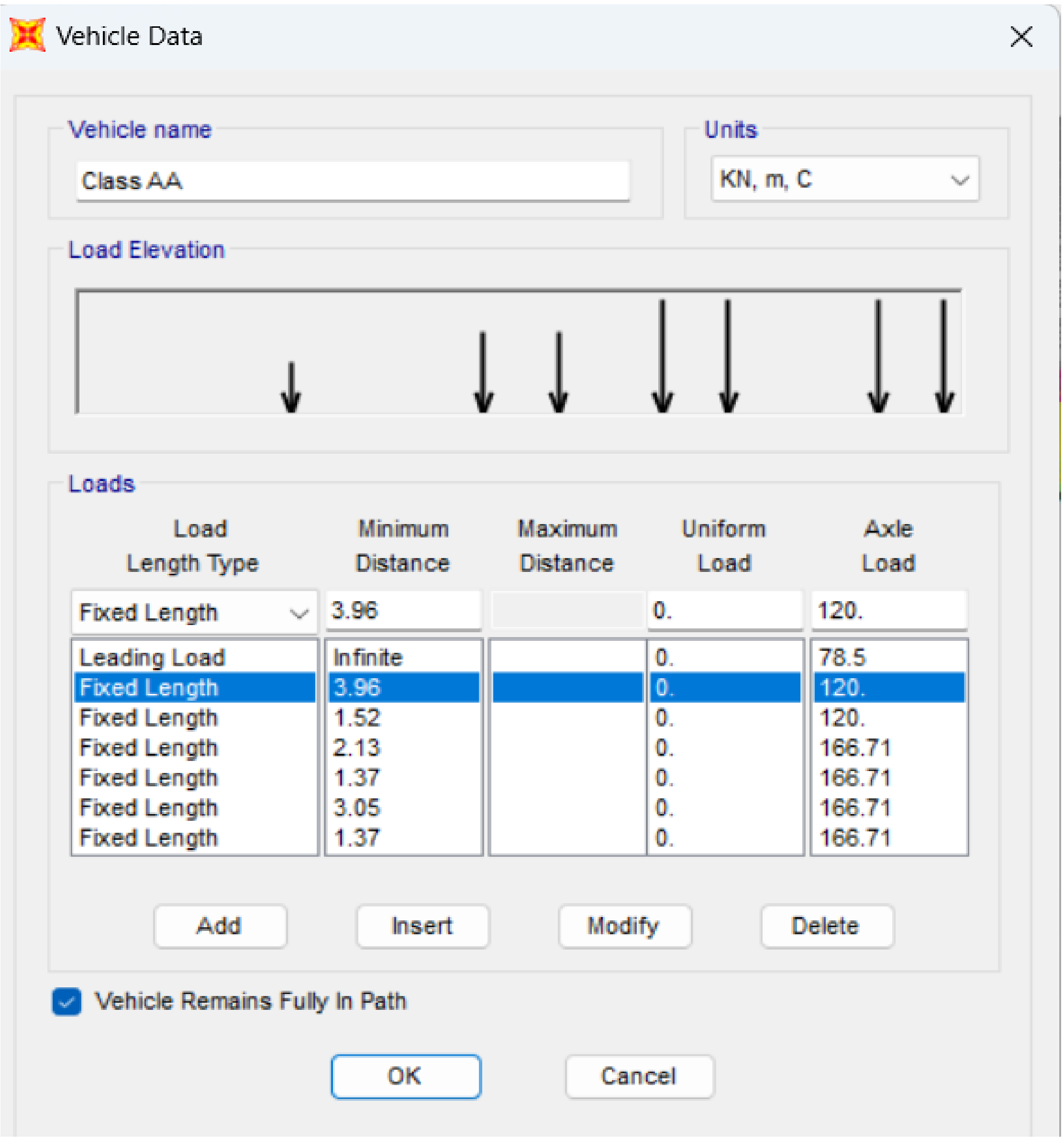


Fig-3.9 Class 70R Load

4.1 Results and Discussions-:

4.1.1 Deflection Curve for Rise/Span=1/5:

Distance from left end(x) in m	Deflection of Joints in mm
Start=0	0.0
5	11.94
10	39.28
15	72.00
20	102.43
25	125.13
30	137.25
35	138.18
40	129.07
45	112.49
50	92.79
55	76.02
Mid=60	69.11

Table 4.1 Deflection Value for h/L=1/5

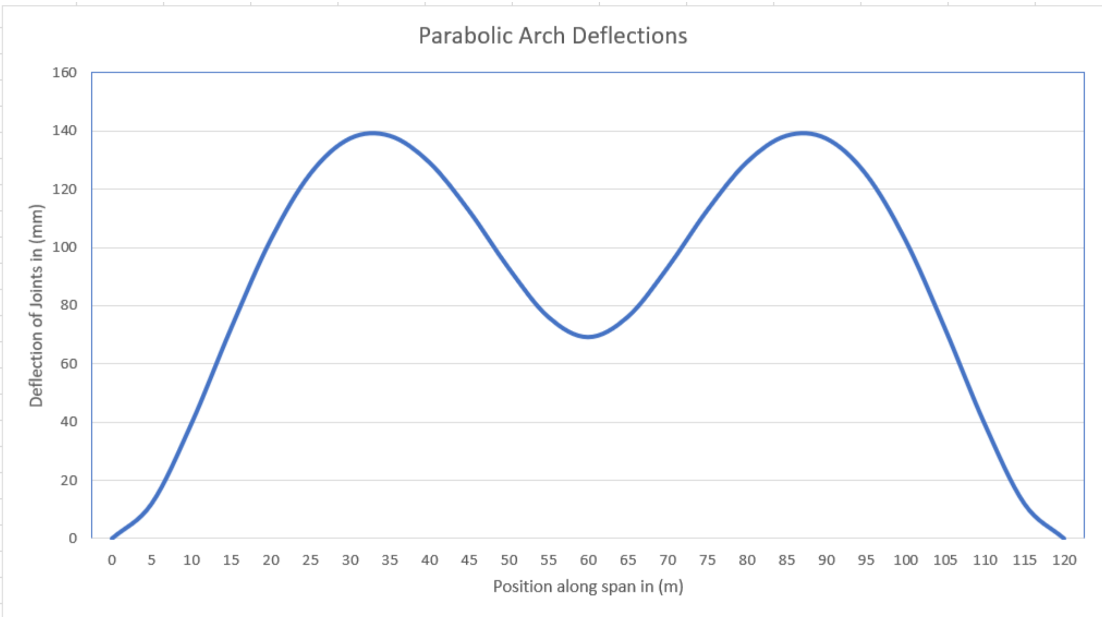


Fig 4.1 Deflection Curve for h/L=0.2

From the table 4.1 and fig 4.1 it can we clearly seen that deflection is increasing along the span till approximately mid of middle span and follows a parabolic path and then decreases till middle of span. Due to the arch action, bending moment of the arch rib is always reduced and the reduction becomes more significant towards crown as horizontal thrust at support causes maximum opposing effect. This may attribute to less deflection when the resultant live load reaches mid span. Given arch bridge is a symmetrical structure so deflection curve will be also symmetrical about mid span. From the figure 4.3 The maximum deflection for rise to span ratio of 0.2 is 138.18mm which is less than the maximum permissible allowable deflection limit of span/800 which is equal to 150mm. So, deflection is within the allowable limit and rise to span ratio of 0.2 is safe.

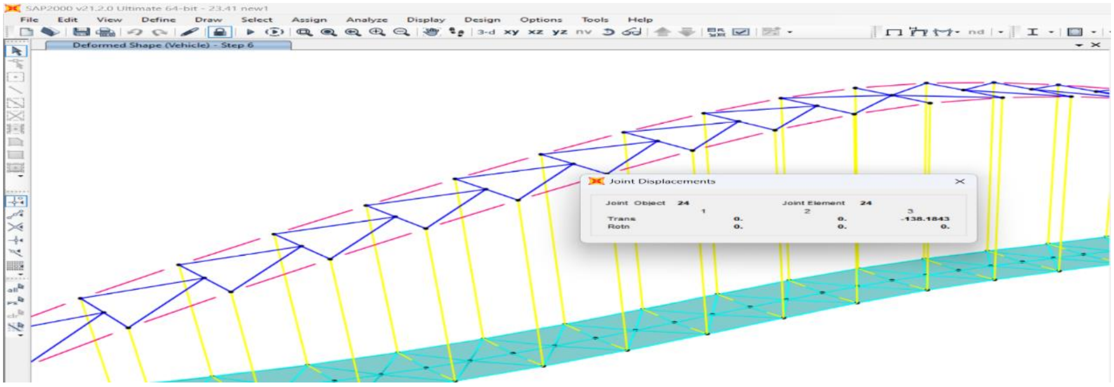


Fig 4.2 Maximum Deflection for h/L=0.2

4.1.2 Deflection Curve for Rise/Span=1/6:

Distance from left end(x) in m	Deflection of Joints in mm
Start=0	0.0
5	11.45
10	37.82
15	69.61
20	99.43
25	122.01
30	134.42
35	135.94
40	127.61
45	111.89
50	92.97
55	76.78
Mid=60	70.10

Table 4.2 Deflection Value for h/L=1/6

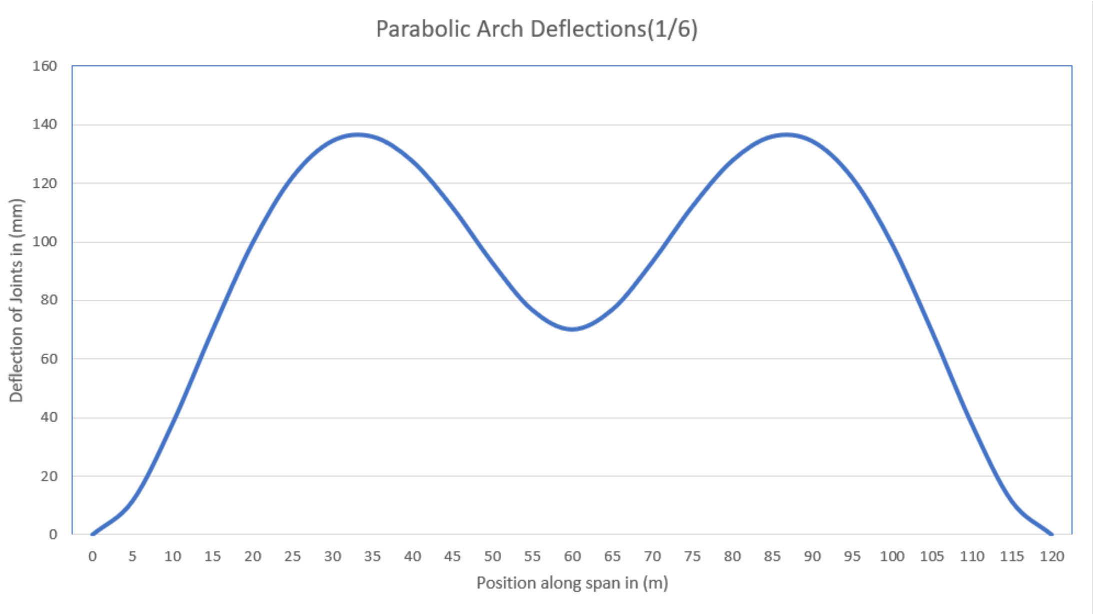


Fig 4.3 Deflection Curve for h/L=0.167

If we compare table 4.2 and fig 4.3 with table 4.1 and fig 4.1 respectively, we can say that deflection curve is similar for both the rise to span ratio but the peak of curve is different. In this case maximum peak and minimum peak is slightly less than that of 0.2 rise to span ratio. From the figure 4.4 The maximum deflection for rise to span ratio of 0.167 is 135.94mm which is less than the maximum permissible allowable deflection limit of span/800 which is equal to 150mm. So, deflection is within the allowable limit and rise to span ratio of 0.167 is also safe and slightly better than rise to span ratio of 0.2.

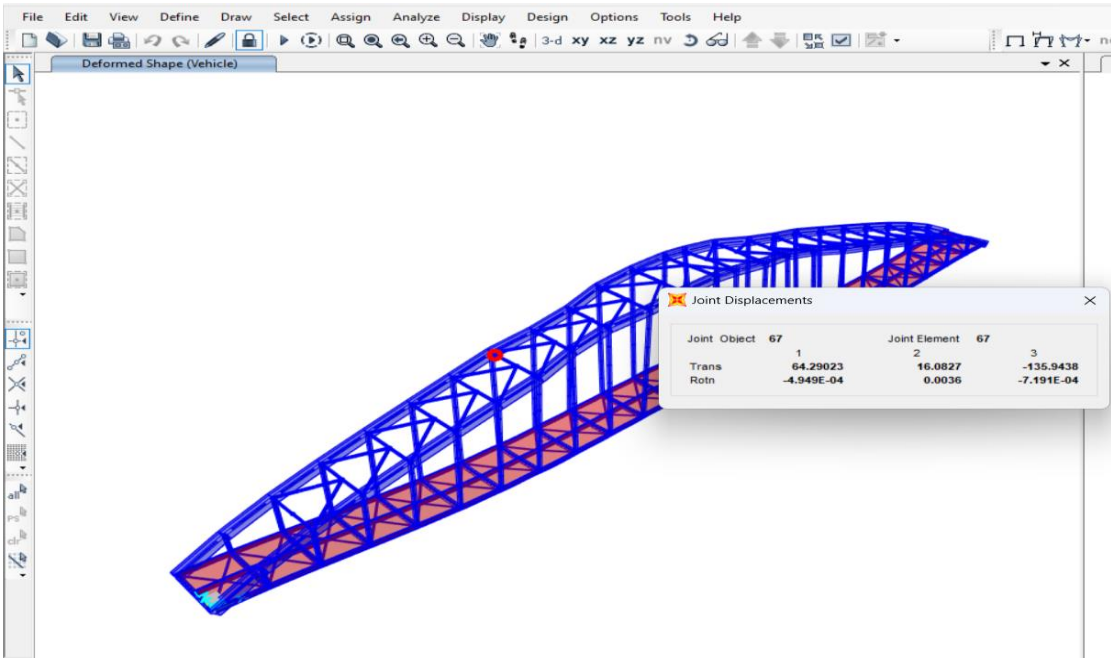


Fig 4.4 Maximum Deflection for h/L=0.167

4.1.3 Deflection Curve for Rise/Span=1/7:

Distance from left end(x) in m	Deflection of Joints in mm
Start=0	0.0
5	9.97
10	33.32
15	61.90
20	89.04
25	110.02
30	122.00
35	124.12
40	117.12
45	103.18
50	86.50
55	72.45
Mid=60	66.81

Table 4.3 Deflection Value for h/L=1/7

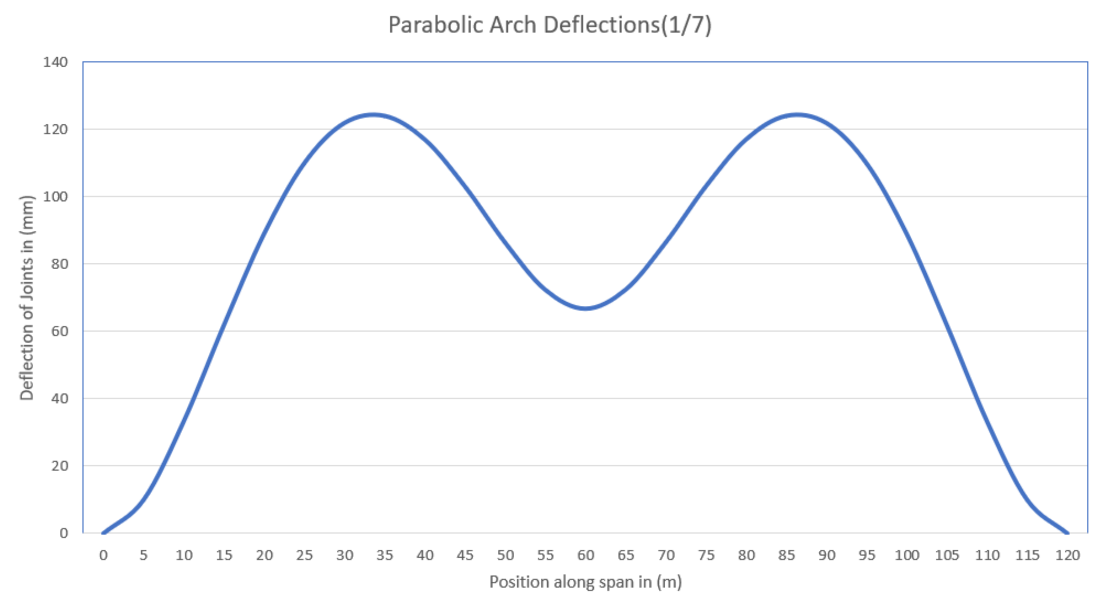


Fig 4.5 Deflection Curve for h/L=0.143

In the case of rise to span ratio of 0.143, From the table 4.3 and fig 4.5 it can be clearly seen that deflection curve is similar in all the above cases but in this case maximum peak of the curve decreased by a value of 14mm which indicates that this rise to span

Ratio is better than rise to span ratio of 0.2 and 0.167. If we compare maximum deflection of 124.13 mm as shown in fig 4.6 with IS Code guidelines then this deflection is also less than 150 mm so this rise to span ratio of 0.143 is safe and better.

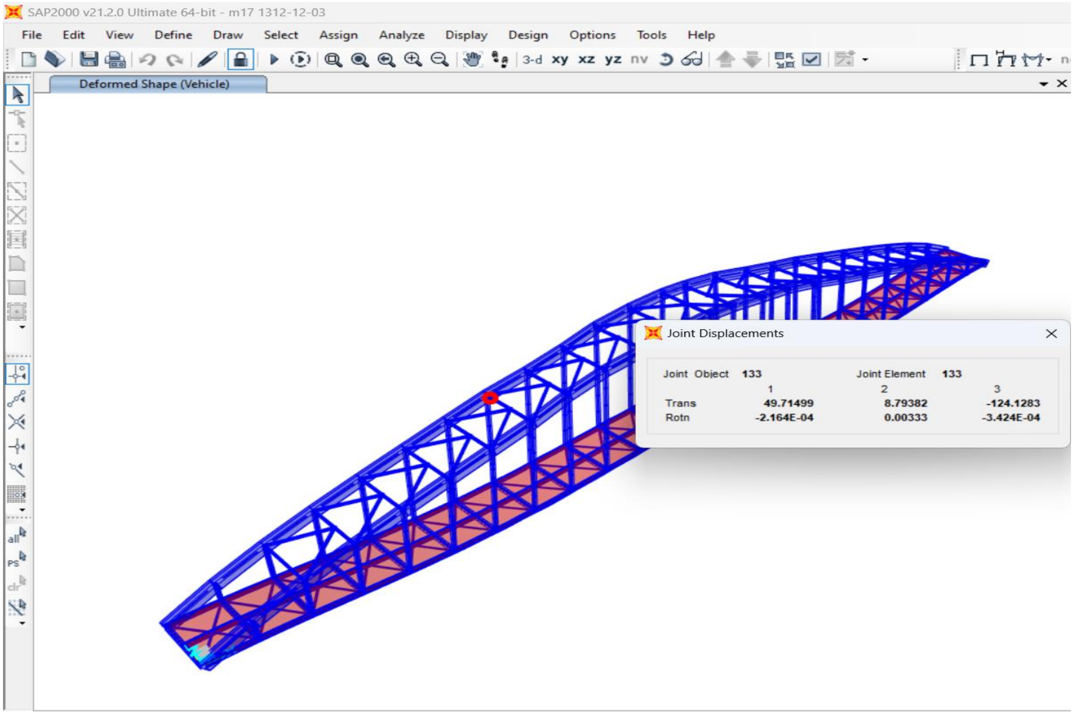


Fig 4.6 Maximum Deflection for h/L=0.143

4.1.4 Deflection Curve for Rise/Span=1/8:

Distance from left end(x) in m	Deflection of Joints in mm
Start=0	0.0
5	11.37
10	37.66
15	69.69
20	99.98
25	123.38
30	136.75
35	139.30
40	132.02
45	117.28
50	99.09
55	83.18
Mid=60	76.47

Table 4.4 Deflection Value for h/L=1/8

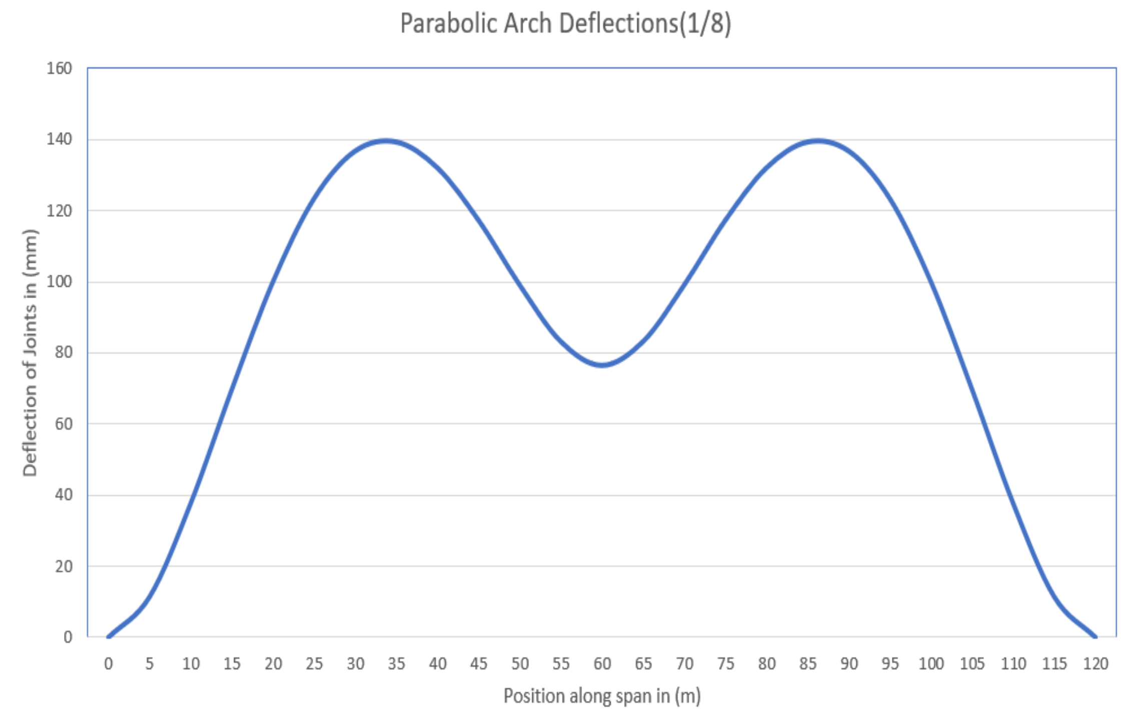


Fig 4.7 Deflection Curve for h/L=0.125

If we further decrease the rise to span ratio then we can see in the table 4.4 and fig 4.7 the maximum peak of the curve reached to 140mm which is more than all other three cases. So rise to span ratio of 0.125 is not a good choice as its performance is less than that of rise to ratio of 0.2 which was showing maximum deflection of 138.18mm (Maximum of 138.18 mm,135.94 mm and 124.12 mm). In the case of rise to span ratio of 0.125 maximum deflection is 140mm which is also less than maximum permissible limit of 150mm but this is not a preferred structure.

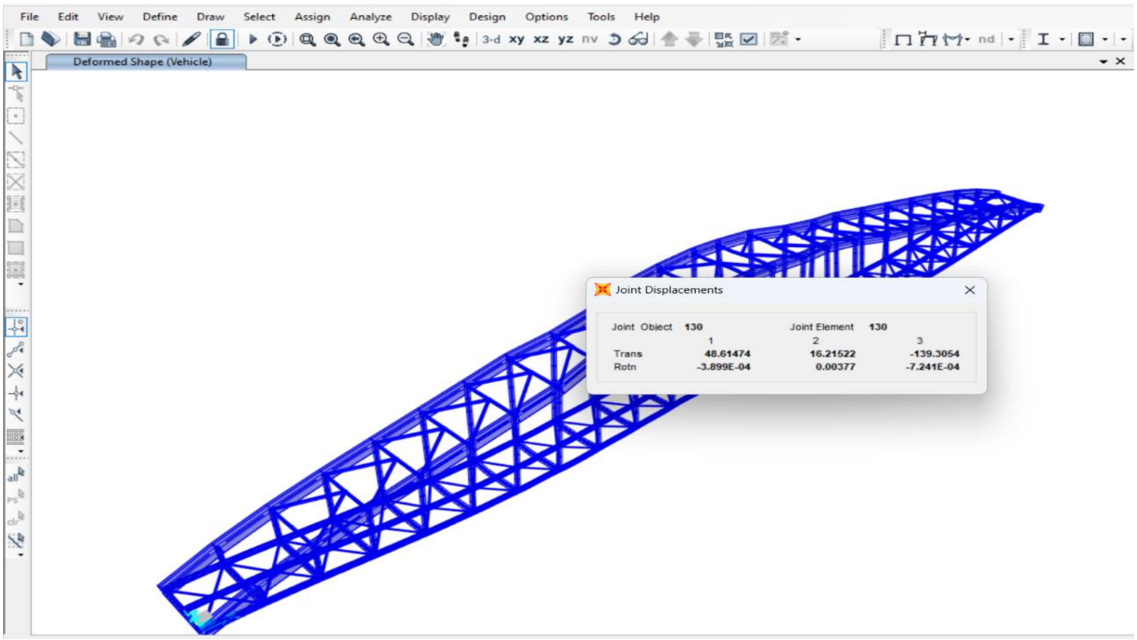


Fig 4.8 Maximum Deflection for h/L=0.125

4.1.5 Deflection Curve for Rise/Span=1/5 With Radial Hanger Arrangement:

Distance from left end(x) in m	Deflection of Joints in mm
Start=0	0.0
5	3.676
10	7.771
15	10.506
20	12.484
25	14.00
30	15.14
35	15.892
40	16.502
45	17.021
50	17.426
55	17.637
Mid=60	17.698

Table 4.5 Deflection Value for h/L=1/5 with radial hanger

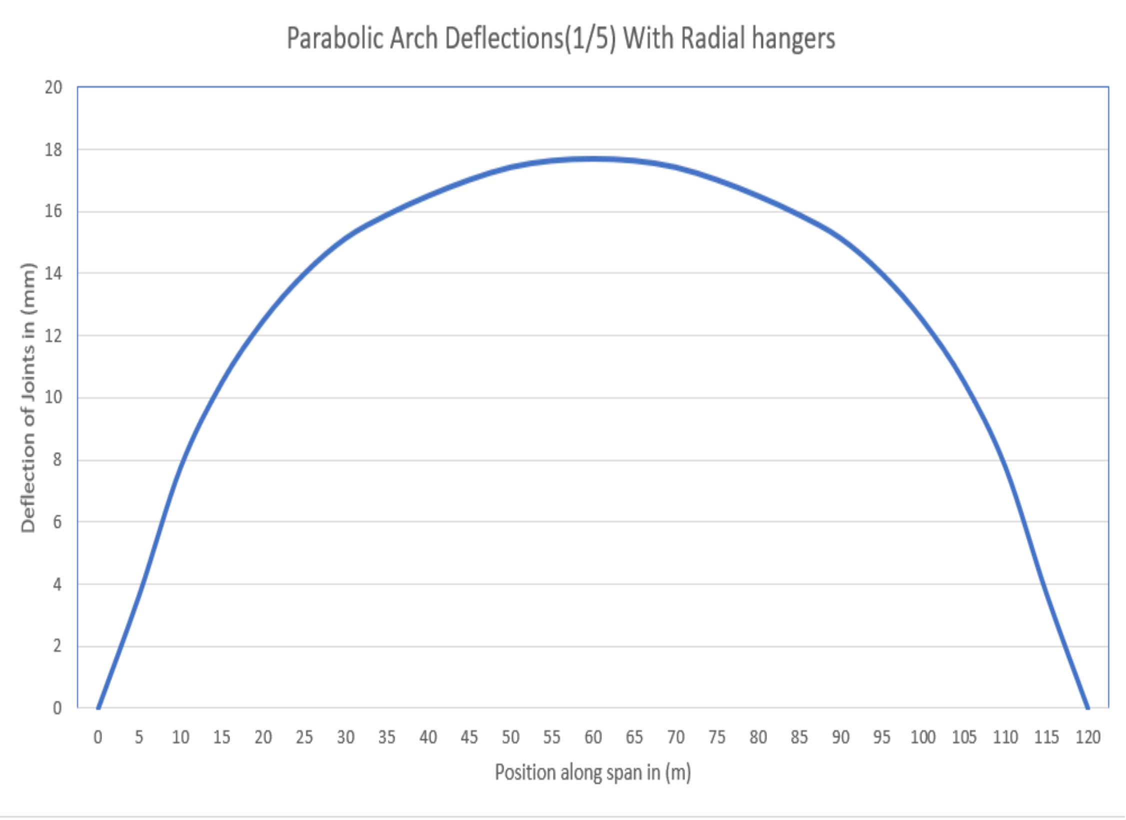


Fig 4.9 Deflection Curve for h/L=0.2 with radial hangers

In case of radial hanger arrangement, we can see in Fig 4.9 that deflection curve is not similar to that of vertical hanger arrangement. In this case deflection value is increasing till mid of the span. Since in radial arrangements of hangers, live load transfer to arch rib occurs in an inclined pattern, arch action could not play its complete role, therefore displaying maximum deflection at the crown and bridge structure is symmetrical so right and left of mid span has same deflection value so deflection curve is also symmetric.

If we compare the deflection value of radial hanger arrangement with vertical hanger arrangement then we can see that there is very less deflection in case of radial hanger arrangement. The maximum deflection value of radial hanger is 17.698 mm which is approximately 1/8 times of maximum deflection of vertical hanger arrangement with rise to span ratio of 0.2. So, we can say that radial hanger arrangement will perform much better than vertical hanger arrangement with same rise to span ratio.

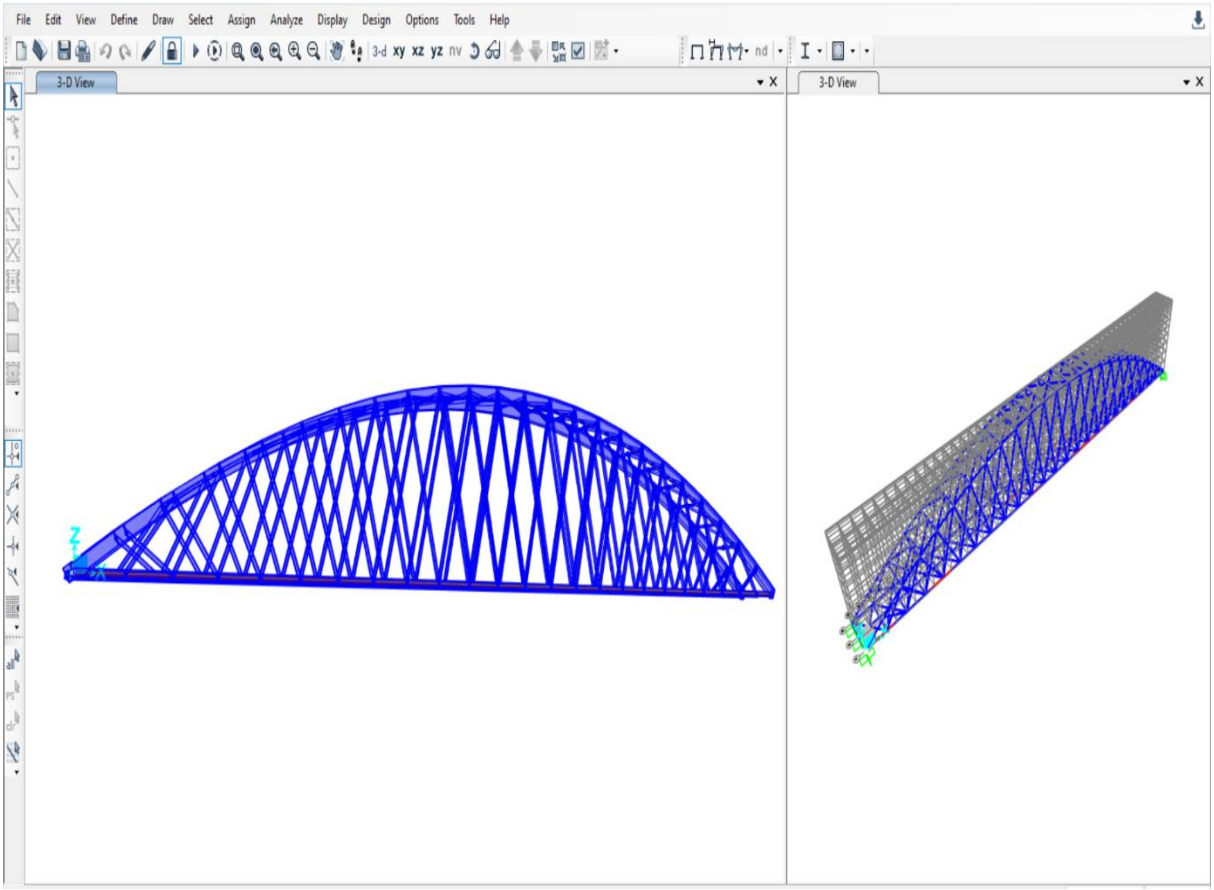


Fig 4.10 Radial hanger arrangement 3-D View

4.1.6 1st 12 Natural Frequency for each rise to span ratio:

Mode	For L/5 Freq (in Hz)	For L/6 Freq (in Hz)	For L/7 Freq (in Hz)	For L/8 Freq (in Hz)	Radial Hanger(L/5) Freq (in Hz)
F1	0.813	0.854	0.665	1.229	1.397
F2	1.030	1.156	1.178	1.325	1.764
F3	1.514	1.559	1.371	1.912	2.867
F4	1.702	1.717	1.975	2.089	3.743
F5	1.803	1.902	2.159	2.216	4.434
F6	2.350	2.436	2.368	2.735	4.492
F7	2.692	2.798	2.506	3.995	4.559
F8	3.314	3.466	2.518	4.062	5.306
F9	3.674	3.544	3.297	4.345	6.225
F10	4.546	4.409	3.353	4.706	6.775
F11	4.560	4.450	3.549	4.750	8.052
F12	4.590	4.457	3.997	5.010	8.155

Table 4.6 Natural frequency Corresponding to each rise to span ratio

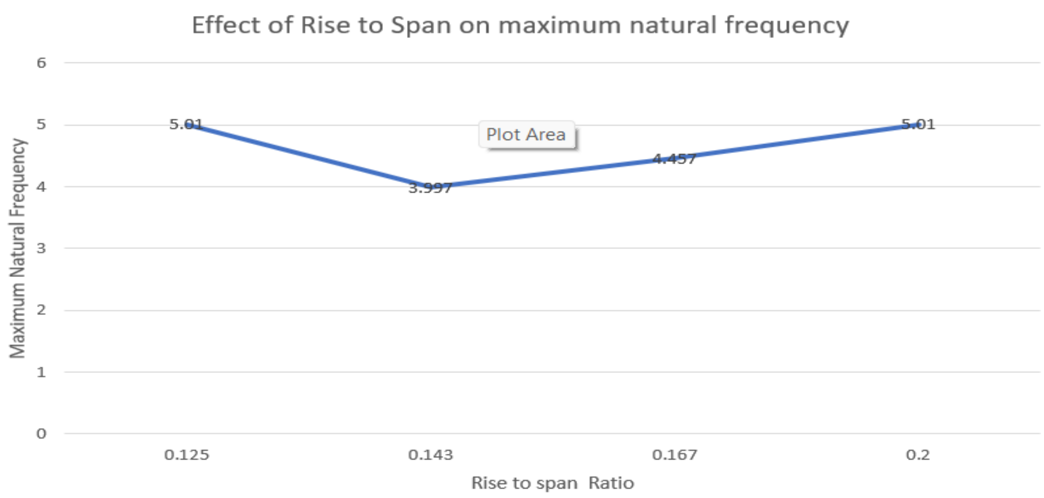


Fig 4.11 Effect of rise to span ratio on natural frequency of Bridge

From the fig 4.11 we can say that as we are decreasing the rise to span ratio natural frequency decreases till rise to span ratio of 1/7 and after that it starts increasing. Also, in table 4.6 we can see that in the case of radial hanger arrangement natural frequency is more than vertical hanger arrangement.

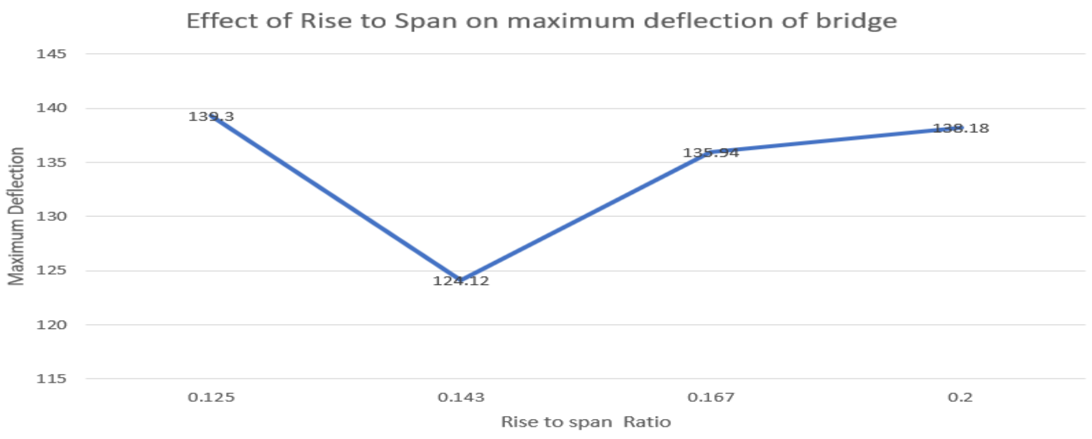


Fig 4.11 Effect of rise to span ratio

From the fig 4.11 we can clearly see that as we are decreasing the rise to span ratio till 1/7 maximum deflection is also decreasing but after further decrease in rise to span ratio maximum deflection start increasing. So, we can say that optimum rise to span ratio for parabolic arch bridge with vertical hanger arrangement is 1/7. Furthermore, if we compare maximum transverse deflection in accordance with IS code for each rise to span ratio with span length/800 i.e. ($\frac{120}{800}$ =150mm) then we can see that deflection is within the allowable permissible limit, so bridge is safe.

Now, in case of radial hanger arrangement the maximum deflection decreases to 17.698 mm which is approximately 1/8 times of maximum deflection of vertical hanger arrangement. So, we can say that radial hanger arrangement will perform better than vertical arrangement.

CHAPTER 5

CONCLUSIONS-:

In the present project, Modelling and 3D finite element analysis of a steel arch bridge has been done to examine the static response and 1st ten natural frequency of the arch bridge for different rise to span ratio and for two different hanger arrangement i.e., vertical hanger and radial hanger. Following are the major conclusions arrived at the study:

- The curve of deformation is different for vertical hangers and radial hangers, Vertical hangers show maximum deflection at middle of the mid span but radial hangers show maximum deflection at mid span.
- Out of four rise to span ratios optimum rise to span ratio is 0.143, It shows least deflection among all other cases.
- Radial arrangement of hangers shows much less deflection than vertical arrangement of hangers.
- Natural frequency is maximum for rise to span ratio of 0.125 among all span to rise ratio with vertical arrangement of hangers.
- Natural frequency of radial hanger arrangement is more than vertical hanger arrangement.

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