

A Thesis on  
**ANALYTICAL STUDY OF TIED ARCH BRIDGE**

Submitted in partial fulfillment of the requirements for the award of the degree of

**MASTER OF TECHNOLOGY**

**STRUCTURAL ENGINEERING**

SUBMITTED BY

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**2020-2021**

## **DECLARATION**

I declare that the research thesis entitled “**ANALYTICAL STUDY OF TIED ARCH BRIDGE**” is the bonafide research work carried out by me, under the guidance of **Tabish Izhar (Assistant Professor)**. Department of Civil Engineering, Integral University, Lucknow. Further I declare that this has not previously formed the basis of award of any degree, diploma, associate-ship or other similar degrees or diplomas, and has not been submitted anywhere else.

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## **CERTIFICATE**

*Certified that the thesis entitled “Analytical study of Tied Arch Bridge” is being submitted by **Mr Altamash Ali (Roll no1901431003)** in partial fulfillment of the requirement for the award of degree of Master of Technology (**Structural Engineering**) of Integral University, Lucknow, is a record of candidate’s own work carried out by him/her under my supervision and guidance.*

*The results presented in this thesis have not been submitted to any other university or institute for the award of any other 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. As of today most bridges in this range of span uses in countries like United States, Japan, China and Australia are tied-arch and truss bridges. The aim of this project is to discuss about angle arrangement between Arch rib to deck plane of Tied Arch Bridge and choose the Suitable angle. On the bases of pervious research paper data we conclude that. The behaviour of Tied Arch Bridge is not observed on Continious function of hangers angle so weCompare the different sections for different Rib angle and span has not been illustrated. In the project With help of CSI Software SAP2000 for modeling this arch bridge we take 100m long span which is 14m wide 2 way lane each lane is 7m wide. To investigate the structural behavior of tied arch bridge by varying arch angle when the bridge is subjected to static and vehicle loading. For study total Maximum & Minimum member forces, study total Deflection , Moments. also study self-weight of the bridge at different angle. Economical point of view which is more good as per analysis results. In this study we only use steel sections on the bases of IS 800, IS.1161:2014 code for designing the Arch bridge.

# **CHAPTER -1**

## **INTRODUCTION**

### **1.1 Background**

Human always searched for a way to transport their products from one place to another over the years. Previous means of transportations with horses and camels were hard and took tremendously long time to cross over valleys, rivers or other obstructions; this was done by moving along the valleys and rivers to find suitable crossing points which were time consuming. After many years passed, population growth resulted in higher demand of products, such as, agricultural products, and also usage of more advanced and heavier vehicles, such as, cart. All this made transportation process even harder. This resulted in the idea of creating a passage over rivers and valleys to have a much quicker access in order to fulfill the requirements of increasing population. Today these passages are known as “bridges”.

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. As of today most bridges in this range of span uses in countries like United States, Japan, China and Australia are tied-arch and truss bridges.

Bridge is a structure that provides passage over obstacles such as valleys, rough terrain or bodies of water by spanning those obstacles with natural or manmade materials. They first begun be used in ancient times when first modern civilizations started rising in the Mesopotamia. From that point on, knowledge, engineering, and manufacture of new bridge building materials spread beyond their borders, enabling slow but steady adoption of bridges all across the world.

In the beginning bridges were very simple structures that were built from easily accessible natural resources- wooden logs, stone and dirt. Because of that, they had ability only to span very close distances, and their structural integrity was not high because mortar was not yet

invented and rain slowly but constantly dissolved dirt fillings of the bridge. Bridges are many types like Beam Bridge, cantilever bridge, truss bridge, arch bridge, tied arch bridge, suspension bridge, and cable stayed bridges.

## **1.2 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. Tied 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. The main structural components of tied 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. Because of a number of hangers loads are transferred efficiently with any intermediate supports. Support conditions in arches are fixed and pinned type.

### **1.3 Types of Arch Bridge**

1. Deck arch bridge
2. Through-arch bridge
3. Fixed arch bridge
4. Tied arch bridge

#### **Deck Arch Bridge**

It is that transfer the weight of the bridge and its loads partially into a horizontal thrust restrained by the abutments at either side.



Fig. 1.1- Chenab Railway Bridge Katra, Jammu-Kashmir, India

## **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- The Bayonne Bridge, New York

## **Fixed Arch Bridge**

It is depicted and implies no rotation possible at the supports. A fixed arch is indeterminate to the third degree.



Fig. 1.3- Godavari Arch Bridge at Godavari River

## **Tied Arch Bridge**

It is one where the reactive horizontal force acting on the arch ribs are supplied by a tension tie at deck level of a through arch.



Fig. 1.4 - The Fort Pitt Bridge, Pennsylvania

### **1.4 Advantage of Tied Arch Bridge**

They have excellent strength.

They get stronger as years pass

They can be made of any kind of material.

Arch bridges have several benefits in terms of aesthetic value and structural integrity, but it also has its drawbacks in the form of cost, time, and labor. Because of this, engineers and other experts should carefully the pros and cons of arch bridges and decide if they're the right choice for a certain project.

- Arch bridges may be used for both railway and highway bridges.
- The behaviour of all types of arch bridges is broadly similar but is influenced by the relative bending stiffnesses of the arch and the main horizontal girder.

- The horizontal thrust from the arch may be carried by the abutments (a pure arch) or by the horizontal girder (a tied arch).
- Either bracing or portal frame action is necessary to stabilize the arches and resist wind loading; many structures use a combination of both structural solutions.

## 1.5 Theory and Formula for Tied Arch Bridge

Prior to examining the analysis of the arch bridge, the specific bridge arrangement will be presented. The present day tied arch derives from centuries of arch bridge construction. Over the years arch bridges have three forms, closed spandrel, open spandrel and through arches. Closed spandrel arch bridges carry the roadway or weight above the arch, which is made of masonry blocks or concrete, which in turn transfer the load via compression to the foundations. The region between the roadway and arch is closed with fill material. Open spandrel also carry the roadway or weight above the arch but are distinct in transferring load via a finite number of columns that, in turn, transfer the load to the arch which then transfers the load to the foundation via compression in the arch. In each of these cases, the foundations are necessarily massive to resist the thrust of the arch at the ends. The third form places the roadway under the arch, suspended by cables from the arch. The third form still required large foundations to resist the arch thrust and gravity loads. Finally in the late 19th century a tension tie girder connecting the ends of the arch rib and thus resisting the arch. Tied arch bridges can consist of a single span or be configured as continuous span systems. The single span bridges are almost always through arches with the tie girder at the deck level. This paper is focused on the single span tied arch with some occasional references to other tied systems.

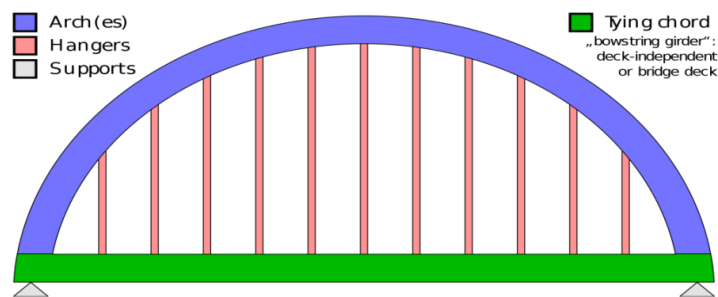


Fig: 1.5 Tied Arch Bridge

## 1.6 Tied Arch Structural Behaviour

This section will focus on the structural action of tied arch bridges providing the reader with a general overview of the structural behavior of these bridges. Figure 4 portrays the member, loading and displaced shape for the tied arch bridge. The uniform load acts on the concrete roadway deck that is ultimately transferred to the arch hangers. Tied Arch Structural Arrangement The loading places the hangers in tension and displaces the arch rib downward. The arch rib is restrained at each end, which as for the two hinged arch, produced an axial shortening and develops a compressive thrust in the arch rib. Finally, as the arch rib exerts an outward thrust on the supports, the arch tie pulls the supports into equilibrium loading the tie in tension. From the standpoint of external statics the single span tied arch behaves in a determinant manner and reacts on the supporting substructure as if it were a simply supported beam.

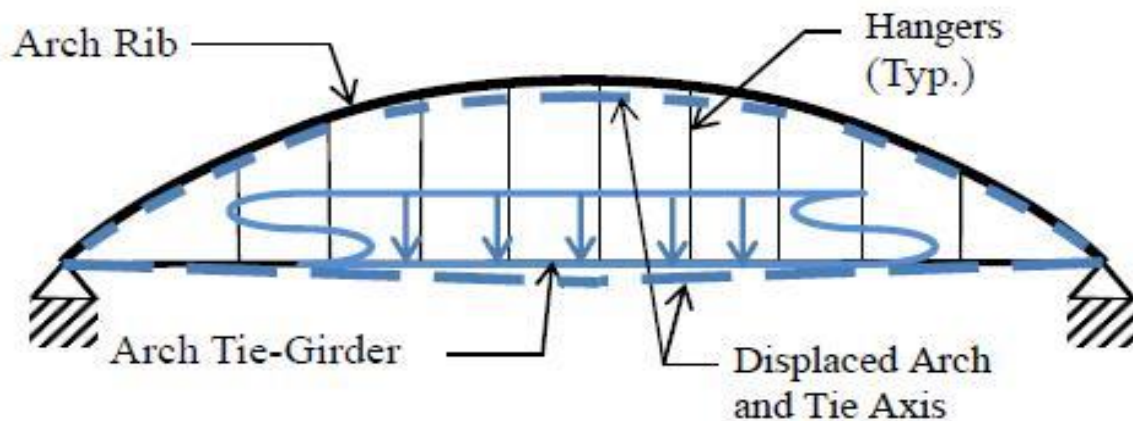


Fig:1.6 Tied Arch Structural Arrangement

Internally, however, the system is indeterminate with the behavior being dependent on the ratio of the tie stiffness to the rib stiffness. In the classic bowstring arch the tie is predominantly a tension member with minimal bending stiffness. In this system the vertical loads are carried almost exclusively by the arch rib. The resulting proportions of the rib and lateral bracing are similar to what they would be if the system were in fact a “true” arch using a compression thrust block instead of a tension tie.

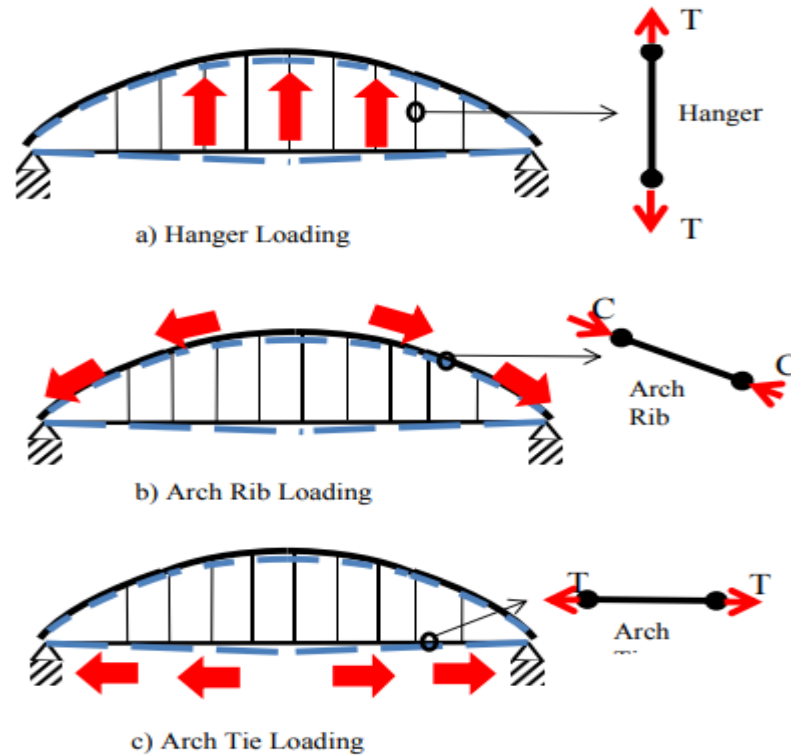


Fig:1.7 Tied Arch Structural Action

## 1.7 Arch Rib

This compression member is typically a welded box girder erected in sections spliced together. For shorter spans it's not uncommon for the rib to be a curved rolled I-section or for concrete the rib is typically has a rectangular cross section.

## 1.8 Tie-Girder

This element connects the ends of the arch and is either a welded box girder or an I-section such as plate girder. Tied arch bridges can be categorized into two main categories depending on the action in the tie-girder. Structures with a 16 relatively flexible tie-girder are termed a “bowstring” arch as the tie-girder carries mainly axial tension and has a small cross-section, hence the bowstring moniker. Tied arch bridges having a stiffer, larger tie-girder are defined as a Langer girder system. In this system, the tie-girder carries significant flexural demand. This has the benefit of nearly eliminating flexural demands on the arch rib so that it is very

nearly in pure compression. This element is singularly most responsible for the tied arch being categorized as fracture critical. The composition of more contemporary tie-girders is discussed further in this proposal.

## 1.9 Hangers

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 the “Network” system. The Langer system is further characterized as a bridge arrangement that has a relatively small arch rib cross-section in contrast to the much larger cross-section for the arch tie-girder. The majority of the recent tied arch bridges are Langer tied arches. For this project, all bridges have vertical hangers with a Langer girder arrangement. The hangers or vertical suspenders are typically located every 30 to 40 feet for long spans and are typically composed of bridge rope. The hanger spacing for Nielson or Network hangers is smaller and so reduces the flexural demand on the tie-girder while providing additional stiffness in-plane and out-of-plane. Not all hangers are rope hangers; in some variations on the tied arch such as the trussed tied arch, it’s common for the hangers to be I-sections. Sets of four or two typically comprise the hanger when using bridge rope. It’s common practice for the bridge rope to have a factor of safety of 4 as a minimum.

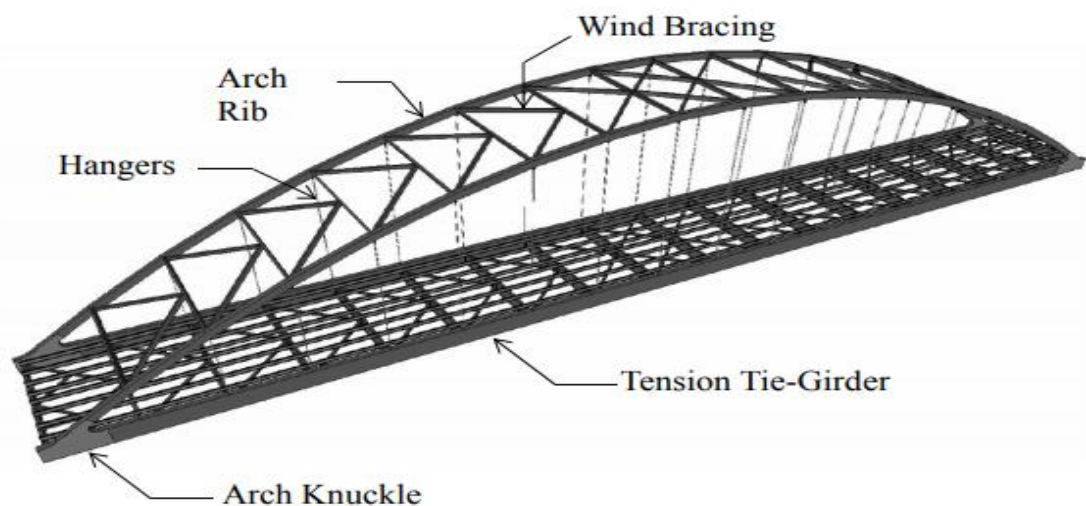


Figure:1.8 Members used in Tied Arch Bridge

## 1.10 Bridge Geometry

Arch bridge geometry is generally two types, one is semicircular and other one is parabolic. In most of the cases parabolic arch shape is used because of less height is required for long span. Equation of parabolic arch is given below;

Height can be given by the arc equation in x-y plane

$$y = f [1 - ((2x/L) - 1)^2]$$

Where,  $f$  = crown of the arch,

$L$  = span of the bridge.

As per IRC code, arch ribs fabricated with segmental chords, the panel length should not exceed 1/15 of the span. Spacing of the main girder should be greater than  $L/20$ .

## 1.11 Scope of Study

Over the years bridges have become important elements of infrastructure. Many designs have been evolved to suit the different requirements of span length, materials, environmental conditions, economics and aesthetics.

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. A brief survey indicates that, most of the bridges built in United States are arch bridge and truss bridges in the above mentioned range of span. States like, Alabama, Alaska, New York, Ohio, Pennsylvania and California are using steel truss bridges for span range of 45 to 260 meters and steel arched bridges 8 for span range of 98 to 380 m. The longest bridge spans in United States are 518 meters and 366 meters for arch and truss bridge respectively. Despite all these developments in bridge construction industry, bridge failure under variety of circumstances is one of the major worry of bridge designers and engineers. A bridge failure could be a disaster; lives of hundreds of people who pass through these bridges every day could be at risk.

In order to design a bridge three important factors should be considered: 1. Stability, which provides a safe passage for passengers, 2. Economy: which represent the efficiency of a bridge and finally, the aesthetic appeal of bridge structure. Once all these three factors overlapped together on would have optimum design. The purpose of this thesis is to evaluate tied-arch and bridges with medium spans while they are subjected to self and traffic loading. Therefore tied-arch bridges with spans of 100m spans are analyzed with the change of angle between Arch and Deck. Later the bridges are compared according to the most important analysis outcome such as, support reaction, deflection, bending moment and economy in order to identify the optimum bridge. Analysis part is expected to reveal the most critical points and sections, the reactions at bridge supports, bridge deflections when bridges are subjected to self and traffic loading.

## **1.12 SAP2000 Software**

**SAP2000** is general-purpose civil-engineering software ideal for the analysis and design of any type of structural system. Basic and advanced systems, ranging from 2D to 3D, of simple geometry to complex, may be modeled, analyzed, designed, and optimized using a practical and intuitive object-based modeling environment that simplifies and streamlines the engineering process. The SAPFire® Analysis Engine integral to SAP2000 drives a sophisticated finite-element analysis procedure. An additional suite of advanced analysis features are available to users engaging state-of-the-art practice with nonlinear and dynamic consideration. Created by engineers for effective engineering, SAP2000 is the ideal software tool for users of any experience level, designing any structural system.

Integrated modeling templates, code-based loading assignments, advanced analysis options, design-optimization procedures, and customizable output reports all coordinate across a powerful platform to make SAP2000 especially useful for practicing professionals. SAP2000 is also an excellent medium for education.

SAP2000 is general-purpose civil-engineering software ideal for the analysis and design of any type of structural system. Basic and advanced systems, ranging from 2D to 3D, of simple geometry to complex, may be modeled, analyzed, designed, and optimized using a practical

and intuitive object-based modeling environment that simplifies and streamlines the engineering process.

## CHAPTER -2

### LITERATURE REVIEW

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#### 2.1 Literature of Research Paper

##### Alex Rong (2004)

The aim of this paper was to examine the structural configuration and behavior of the bridge. A model of Rainbow Bridge was test for deflection. He concluded that was given in table.

	<b>Lateral Reaction</b>	<b>Axial Force</b>	<b>Shear Force</b>	<b>Bending Moment</b>	<b>Deflection</b>	<b>Member Length</b>
<b>Simple Beam</b>	0.0KN	0.0KN	4.4KN	34.2KN-m	1.9m	15.24m
<b>Two-Hinged Arch</b>	13.0KN	13.6KN	3.3KN	7.2KN-m	0.04m	15.96m
<b>Three-Hinged Arch</b>	16.4KN	16.7KN	3.0KN	8.0KN-m	0.17m	7.98m
<b>Rainbow Truss</b>	13.9KN	10.0KN	2.3KN	6.1KN-m	0.15m	5.29m

Table: 2.1 Results of Deflection at Different Types of Bridges

**Dongzhou Huang (2005)** He investigated the dynamic and impact behavior of arch bridges with rough decks caused by vehicles movement and took AASTHO Specification. The results show that impact factors of bending moment and axial force was not exceeding 0.4 and 0.25.

### **Carlo Pellegrino, Giovanni Cupani and Claudio Modena.(2009)**

In this study the arrangement of the hangers in tied arch bridges is one of the key issues in optimizing the design of this typology of bridges. Bending moments in the arch and the tie and axial forces in the hangers are usually the parameters on which attention is focused. In this context, this paper mainly deals with the reduction of fatigue stressing in hangers of road arch bridges. The analysis is carried out by varying the vehicular load position along the deck; Various hanger arrangements are considered: vertical, fan and network arrangement with inclined hangers having multiple intersections. One of the main results is that, on the one hand, vertical and fan arrangements are better than network ones if the fatigue in the hangers is considered as the only parameter, and, on the other hand, network arrangements are globally the best if the bending moments in the arch and the tie and the absolute values of the axial forces in hangers are also considered. Therefore, the work also focuses on decreasing the fatigue stressing of vertical, fan and network arrangements without increasing the bending moments in the arch and the tie. The results suggest that a slight modification of the radial arrangement near the arch springing points, namely using steeper hangers, leads to a smaller force variation in the hangers without increasing the bending moments in the arch and the tie.

### **Wen-Liang Qiu et. al. (2010)**

This paper presents a stability investigation of a special-shape arch bridge with a span of 180 m arch rib being subjected to massive axial force, bending moment, torque, and shear stress. This variable along there is axis. Pinned arch bridges the total weight of steel used is not more than 2% of minimum total weight. For fixed end arch bridge the total weight is not more than 5% for span up to 150 m and not more than 10% for span between 180 m to 240 m.

### **H.J. Kang ,, Y.Y. Zhao and H.P. Zhu Y.X. Jin (2012)**

To understand the mechanical characteristics of cable-arch Bridge, in the present work, a model cable-arch bridge was constructed, and its static behavior was investigated using the finite element method and experimental test. The analytical and experimental results were compared, and qualitatively good agreement has been exhibited. The results show that the cables and wind bracing have a significant influence on the mechanical behavior of the cable-arch bridge. Compared with arch bridges, the cable-arch bridge has a larger ultimate bearing capacity, a better in-plane and out-of-plane stability, and a superior capacity to resist various

live loads. Such a cable-arch bridge should have a bright future in the development of long-span bridges.

**Cristopher D. Moen, Elaine E. Shapiro and Julia Hart.(2013)**

A structural study examines the oldest remaining metal bridge in the Commonwealth of Virginia, a wrought-iron bowstring arch truss, designed and manufactured by the King Iron Bridge Company. Finite-element analysis is used to evaluate the interaction between the arch and truss, and the results are compared with field measurements from a live-load test. The study reveals that diagonal truss elements decrease arch bending by distributing concentrated vertical loads along the arch toward the abutments in a way consistent with that of modern network arch bridges. When the truss diagonals are absent, the vertical bridge-deck deflection is doubled. Under slung portal frames provide lateral stiffness to the arch, an innovation that accommodates a shallow arch profile conducive to transportation and erection.

**Hans De Backer, Amelie Outtier and Philippe Van Bogaert.(2014)**

This paper presents two practical calculation methods to design for the buckling behavior of slender steel arch bridges. The first one follows the calculation method of the Euro code, but proposes some augmented empirical formulas for the buckling length of the arches. This allows for a better representation of the out-of-plane stiffness of the arch cross section and of the wind bracings between both arches. In addition a second method is proposed, based on the use of simplified finite element models to determine the relative slenderness of the structure. Both methods are validated using results from very detailed three dimensional finite element models. Finite element models of several tied-arch bridges have been created. These models include variations of the bridge length, dimensions of the arch cross-section, boundary condition, and load type. The conclusion of these calculations is that for both of the proposed methods a higher buckling curve can be used than proposed by the code, thus resulting in a more slender bridge design.

**MIHAI VLAD, and VLADIMIR MARUSCEAC.(2015)**

One of the main features of the arch bridge is the transmission of external forces to arch ends. When arches are situated under the deck, these external forces are transmitted directly to the land, imposing land with high load capacity and high costs of foundations. 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 is to investigate 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.

### **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.

### **Jaegyun Park et. al.(2016)**

They measured the effect of high performance steel for bridges (HSB), which was developed in Korea. A basic design was performed first, using SM520 only, which is conventional rolled steel. They concluded that the allowable stress increased the overall areas of steel members decreased and the weight of the structure decreased.

### **Jacques Berthelley.(2017)**

FEM techniques are used to evaluate the stress concentration factor that has to be taken into account for the fatigue design. For bridges, many fatigue details are classified in the Euro code 3 ( part 9 ) from tests. But some details that cannot be found in the Euro code, and can however be studied and evaluated by computation. Several examples of tied arch bridges are presented. The article presents also an example where the fatigue class of the detail regarding longitudinal stresses is evaluated to FE-modelization.

### **Jielian Zheng and Jianjun Wang .(2017)**

In this study main focus is on construction of concrete-filled steel tube (CFST) arch bridges and concrete arch bridges with a CFST skeleton. The span of these bridges has been increasing

rapidly, which is rare in the history of bridge development. In this study, the current status, development, and major innovative technologies of CFST arch bridges and concrete arch bridges with a CFST skeleton in China are elaborated. This paper covers the key construction technologies of CFST arch bridges, such as the design, manufacture, and installation of steel tube arch trusses, the preparation and pouring of in-tube concrete, and the construction of the world's longest CFST arch bridge—the First Hejiang Yangtze River Bridge. The main construction technologies of reinforced concrete arch bridges are also presented, which include cable-stayed fastening-hanging cantilever assembly, adjusting the load by means of stay cables, surrounding the concrete for arch rib pouring.

**Paolo Lonetti, Arturo Pascuzzo & Stefano Aiello. (2018)**

The main aim of the paper is to propose comparisons with data arising from existing codes by using a very detailed finite element model. Parametric analyses and new design methodologies are developed to identify instability strength and the influence of the bracing system on the bridge behavior. In both analyses, a procedure based on “zero displacement method” is carried out to correctly identify the initial status of the structure in presence of dead and permanent loads.

**Xijuan Jiang, Lei Wang and Hongbin 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.

**Kazuhiro Miyach et. al.(2020)**

In this article, the ultimate strength of tied-arch bridges, causes of hanger rope breakage and simulation of chain-reaction failure of hangers are studied for tied-arch bridges. Non-linear finite element method analysis has clarified that this bridge model has sufficient ultimate strength. The hanger arrangement significantly affect the ultimate strength. When a hanger

breaks, the dead load and the heavy lorry load impulsively work on the new bridge form without the broken hangers. This impact load is assumed to be 2.0 times the static load and elastic-plastic analysis is conducted.

## 2.2 Inferences

### Hanger Arrangement

Arrangement of hangers-  $\varphi = 0^\circ$  (fan arrangement),  $\varphi = 15^\circ$ ,  $\varphi = 30^\circ$  and  $\varphi = 45^\circ$  The results show that it is possible to decrease by about 20% the average axial force. variation occurring in all the hangers of the whole suspension system.

### Buckling Behaviour

Two practical calculation method to design for the buckling behaviour of slender steel bridge span of 50 and 200 m and light wind bracings.

The result of this calculation is that for both methods a higher buckling curve can be used than proposed by the code, thus.

### Bridge Span

Yitong River Bridge -three spans - 51 m, 158 m and 51 m, with a total length of 260 m.

Prester Bridge	single span	136m
Wahrew arch bridge	single span	118m
Albert Canal Bridge	single span	117m
Ijzerlaan Bridge	single span	59m
Kapelse Steenweg Bridge	single span	60m

### Performance Comparison

The cable-stayed bridge has 30.5 % higher costs than the tied-arch. The tied-arch bridge for permanent load has remarkable advantage.

## **Bracing Patterns**

X-shaped and K-shaped configurations represent the best solutions to improve the out-of-plane instability performances.

The simplified approaches involves notable underestimations thus resulting too conservative and inappropriate to be employed for the buckling assessment of network arch bridges.

## **Design with High Performance Steel**

87.9 and 86.4% material cost and steel weight were reduced of conventional design using SM520 steel only high performance steel (HSB800 ) effective for the main girder and arch rib.

## **2.3 Objective**

To investigate the following for Tied Arch Bridge of span 100m by varying rib angle at 25,30,35,40 and 45 degree Angle :

- a.** To investigate the structural behavior of tied arch bridge by varying arch angle when the bridge is subjected to static and vehicle loading.
- b.** To study total maximum & minimum member forces.
- c.** To study total deflection.
- d.** To study self-weight of the bridge at different angle.

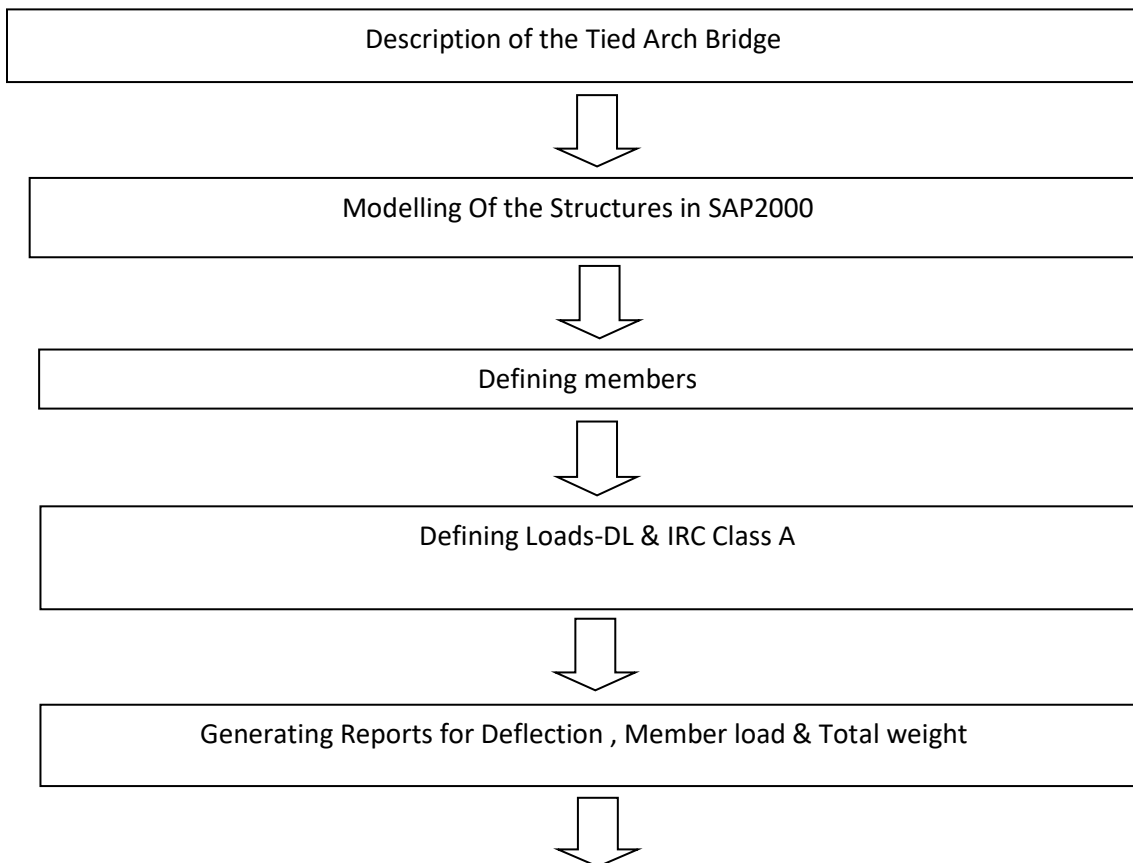
## CHAPTER-3

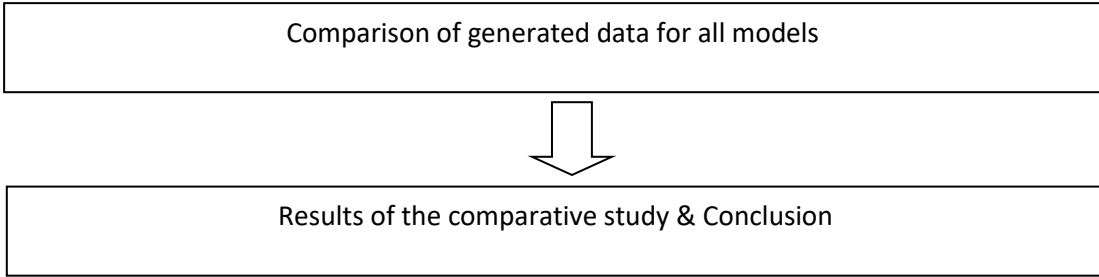
### ANALYTICAL STUDY

#### 3.1 Methodology

In designing and analyzing the performance of Tied Arch Bridge. It is especially important that an effective modeling technique be involved because of the complexity of the real structural behavior and the difficulties of full –scale measurement. During the whole process of analysis and design structural member dimensions will seems to vary being of difference in load transfer mechanism. The analysis has been done both for Self load and Live load (Vehicle load).

#### 3.2 Methodology Flow Chart





### 3.3 Description of Tied Arch Bridge

1. Size of The Deck is 100m long
2. Bridge is Two way and each side has 7m wide
3. Distance between cable is 5m
4. X -bracing is applied with the distance of 5m
5. Loads-Dead load as per member & Class A Load.
6. Sections used : Deck Longitudinal girder-ISMB 600, Cross girder-ISMB 400, Hanger-28mm cable, Arch Rib – ISNB300H, Bracing- ISNB150H.
7. 5 numbers of model are consider in this analysis each model has different angle between the Arch rib and deck plane.

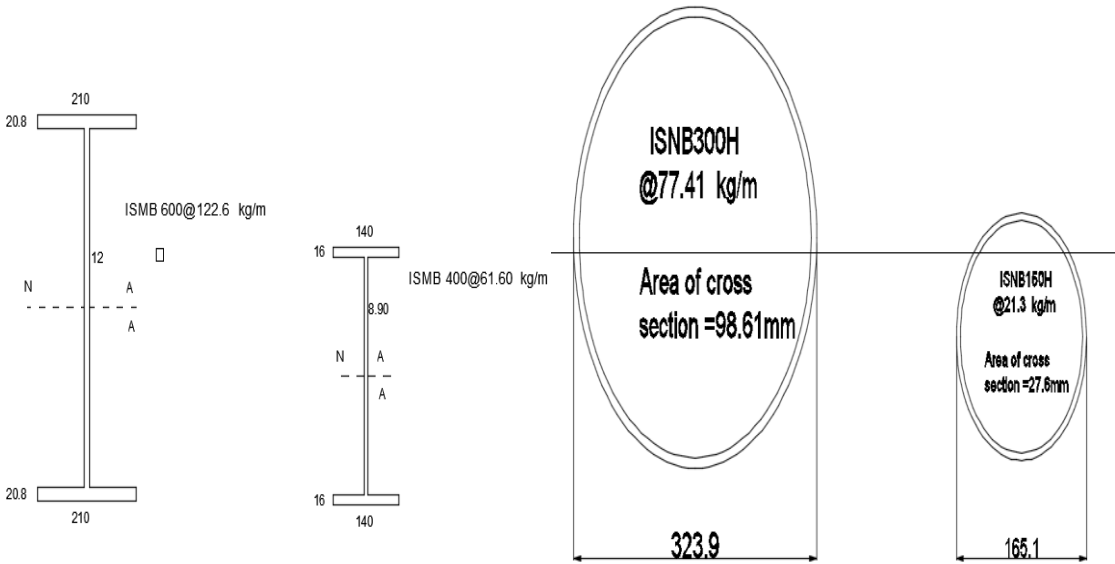


Fig: 3.1 Steel Sections

### 3.4 Modelling of the Structures in SAP2000

First we set the grids and units and also chose Indian Standard code 800 for section in the software. Then select frame section for the materials like ISMB 600, ISMB 400, ISNB300H , ISNB150H, cable and start making deck according to girders. Arch ribs is modelling by curve frame and hanger is model by cable section. after complete the modelling assign path for the vehicle load then define load pattern Dead load, Vehicle load, and run the analysis for the results.

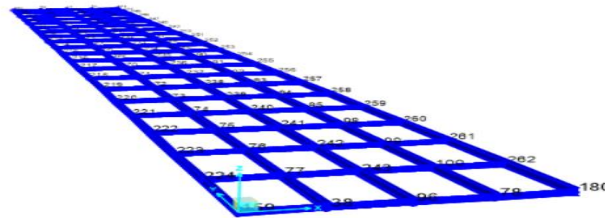


Fig: 3.2 3D view of Longitudinal & Cross Girder Deck.

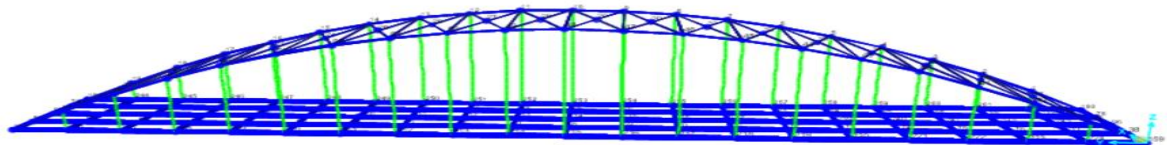


Fig: 3.3 3D view of Tied Arch Bridge.

### 3.5 Defining Members and its Properties

S.NO.	Parameter	Values
1	Bridge Type	Tied ARCH Bridge
2	Size of Deck Longitudinal girder length in z direction	100m
3	Size of Deck Cross girder length in x direction	14m
4	Grid Spacing in z direction	5m
5	Grid Spacing in x direction	3.5m
6	Spacing between hanger	5m
7	Spacing between Bracing (X shape)	5m
8	Number of grid in z direction	20
9	Number of grid in x direction	4
10	Number of lane	2
	<b>Section used in Tied Arch Bridge</b>	
11	STEEL SECTION for Deck in x Direction	ISMB 400,(61.60kg/m
	Sectional area	85.1cm <sup>2</sup>
12	STEEL SECTION for Deck in z Direction	ISMB 600,(122.6kg/m)
	Sectional area	156.21cm <sup>2</sup>
13	STEEL SECTION for Arch Rib	ISNB300H(77.41kg/m)
	Sectional area	98.61cm <sup>2</sup>
14	STEEL SECTION for Bracing	ISNB150H(21.30kg/m)
	STEEL SECTION for Hanger	28MM (3.207kg/m)
15	<b>Loads types</b>	As per IS 800-2007 & IRC 6
16	Dead Load	Self-weight
17	Vehicle Live Load	Live load
18	Wind Load	1.5KN/m <sup>2</sup> (Clause 4.1,

		Table 2)
19	Weight per unit volume	76.9729 KN, m, C
20	Mass per unit volume	7.849
	<b>Isotropic Property data</b>	
21	Modulus Of Elasticity, E	2.100E+08
22	PioSSION ,	0.3
23	Coefficient Of Thermal Expansion, A	1.170E-05
24	Shear Modulus, G	80769231
	<b>Other Properties For Steel Materials</b>	
25	Minimum Yield Stress, Fy	345000
26	Minimum Tensile Stress, Fu	450000.
27	Expected Yield Stress, Fye	379500.
28	Expected Tensile Stress, Fue	495000.

Table 3.1 Parameters of Tied Arch Bridge

For the above table describe parameter like Bridge type, Size of Deck, Grid Spacing, Spacing between Bracing, material section properties, load type , isotropical properties, like Modulus Of Elasticity, E, PioSSION U, Coefficient Of Thermal Expansion, A, Shear Modulus, G, minimum and maximum yield stresses and tensile stresses.

### 3.6 Applied Loads

The loads that are applied on the model so as for the model verification are determined according to the IS 800-2007 , IRC 6 code

#### 3.6.1 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. Dead load carried by a girder or

member shall consist of the portion of the weight of the super-structure which is supported wholly or in part by the girder or member including its own weight.

The unit weights of materials shall be used in determining loads.

### 3.6.2 Live Load

#### 3.6.2.1 IRC Class A 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 8 axle varying from a minimum of 27 KN to a maximum of 114 KN.

The Class A loading is a 554 KN train of wheeled vehicles on 8 axles.

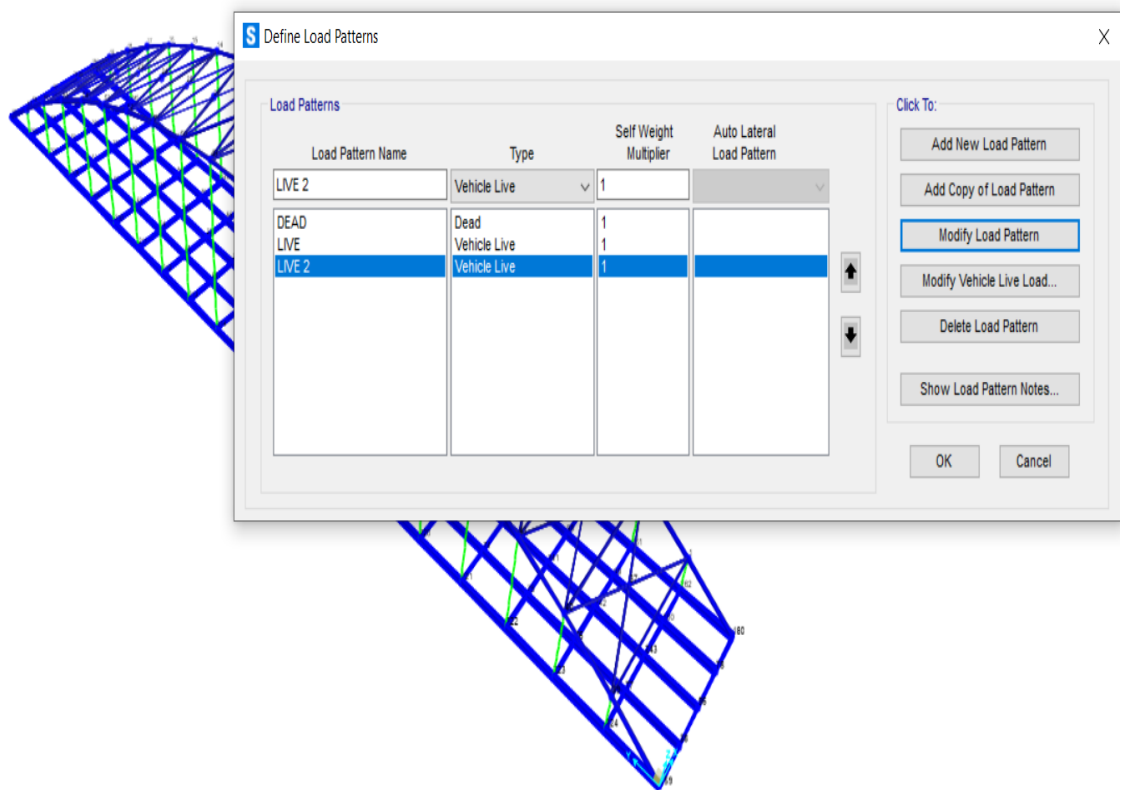


Fig: 3.4 Defining Load Pattern in Tied Arch Bridge.

# CHAPTER-4

## RESULTS AND DISCUSSION

### 4.1 Analysis of Models

#### 4.1.1\_Model no 1 at 25° Angle

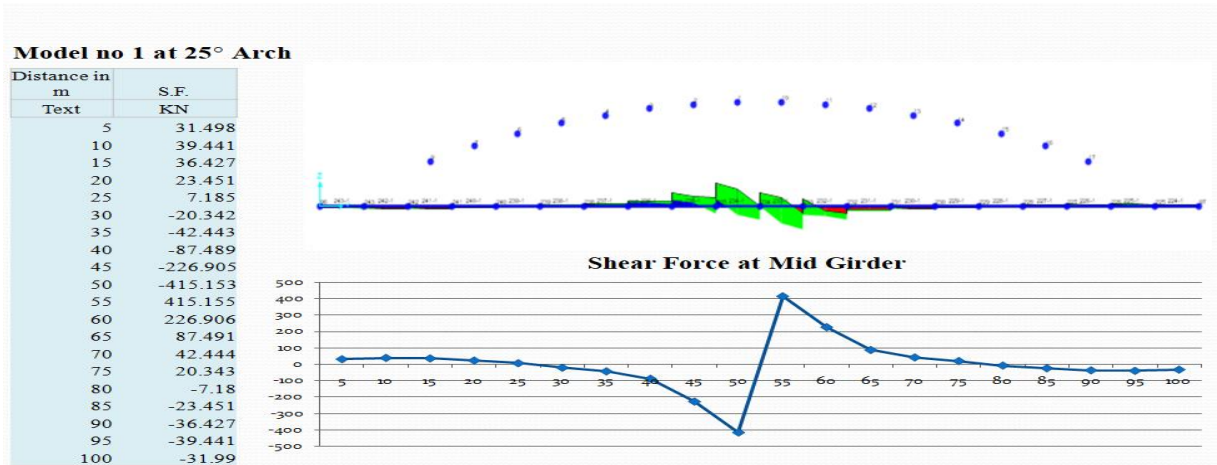


Fig: 4.1 Graph Representing Shear Force at Mid Section of the Bridge.

the bridge is modeled using commercial software SAP2000V 18.0.1. Ultimate. A 3D computer model shown that the analysis of model 1 in at 30° angle between arch rib to deck we find that the shear force start increasing gradually at the distance 35m and reach it the maximum shear force value of 415.1KN at a distance of 50m as shown in fig:4.1

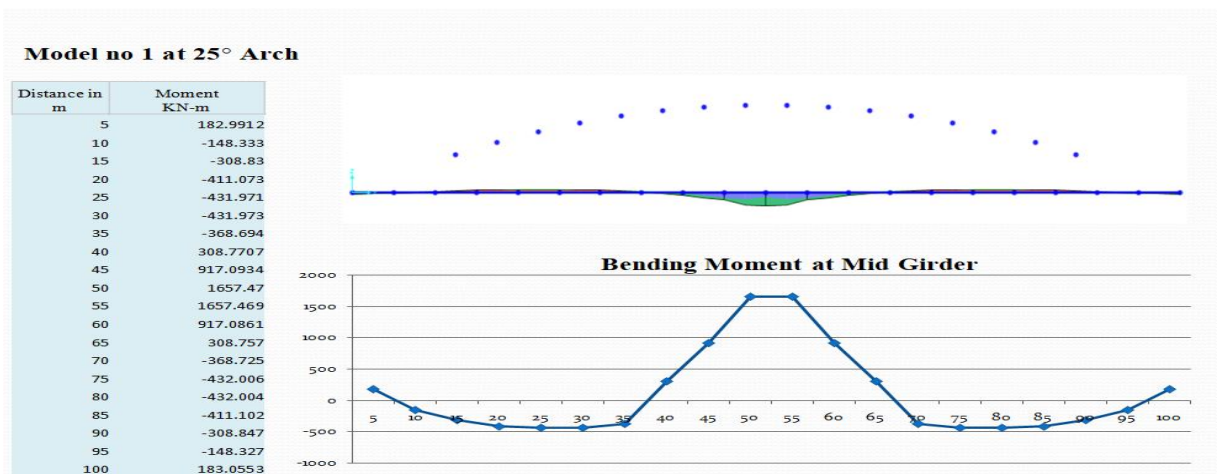


Fig: 4.2 Graph Showing Bending Moment at Mid Section of the Bridge.

At the distance of 10m bending moment is start increasing at the 35m distance when negative bending moment is -368.8KN-m then sudden steep inclination in the curve and reach maximum value of 1657.4KN-m and remain constant at 50m to 55m distance of span as shown in fig: 4.2

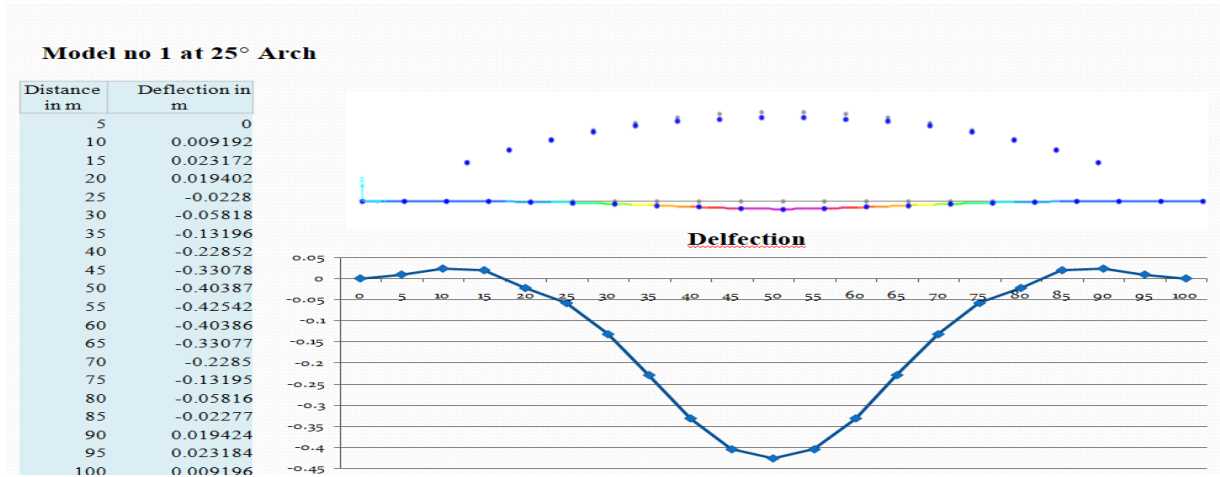


Fig: 4.3 Graph Representing Deflection and Deformed Diagram at Mid Section of the Bridge.

deflection start increase at distance of 20m and reach maximum value 0.42m at distance of 55m graph deformed diagram shown the maximum value occur at different points by using SAP2000 along with various performance level values is as shown in fig: 4.3

#### 4.1.2\_ Model no 2 at 30° Angle

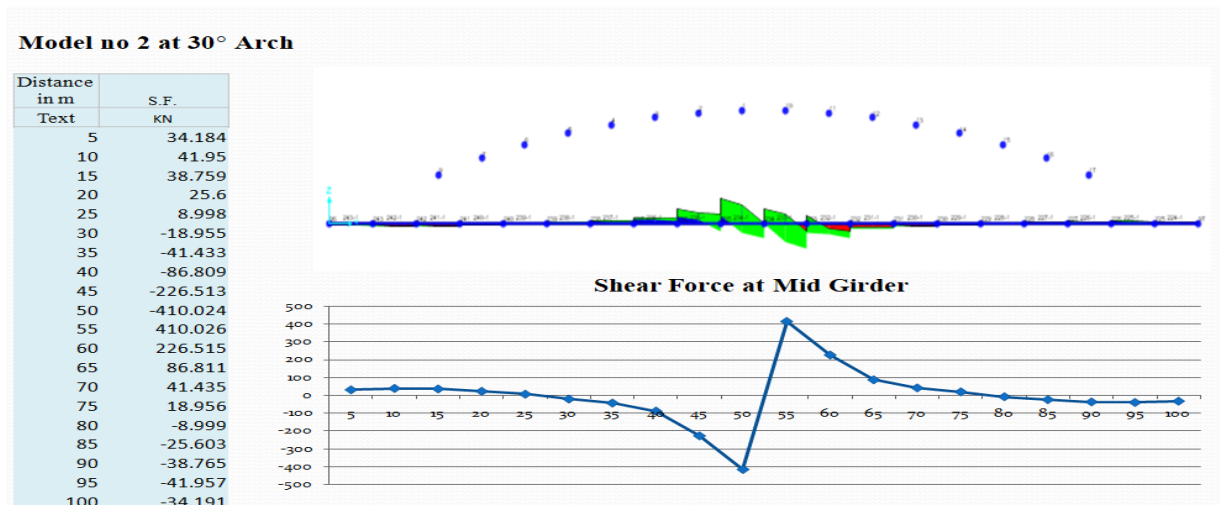


Fig: 4.4 Graph Representing Shear Force at Mid Section of the Bridge.

the bridge is modeled using commercial software SAP2000V 18.0.1. Ultimate. A 3D computer model shown that the analysis of model 1 in at 30° angle between arch rib to deck we find that the shear force start increasing gradually at the distance 35m and reach it the maximum shear force value of 410.02KN at a distance of 50m as shown in Fig 4.4

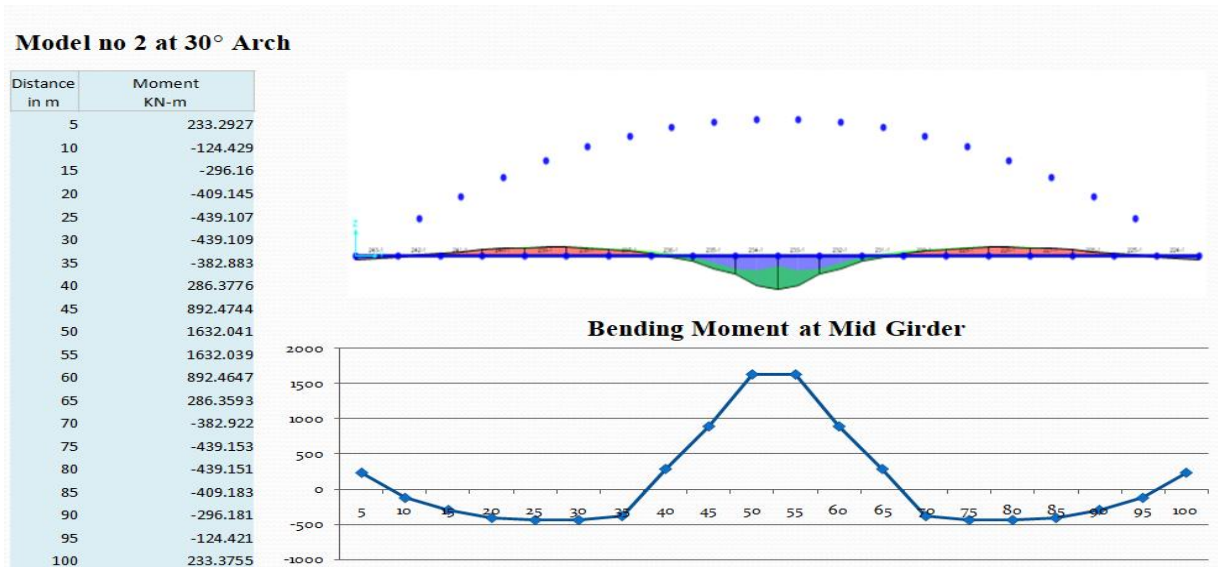


Fig: 4.5 Graph Representing Bending Moment at Mid Section of the Bridge.

At the distance of 10m bending moment is start increasing at the 35m distance when negative bending moment is -382.8KN-m then sudden steep inclination in the curve and reach maximum value of 1632.04KN-m and remain constant at 50m to 55m distance of span as shown in fig: 4.5

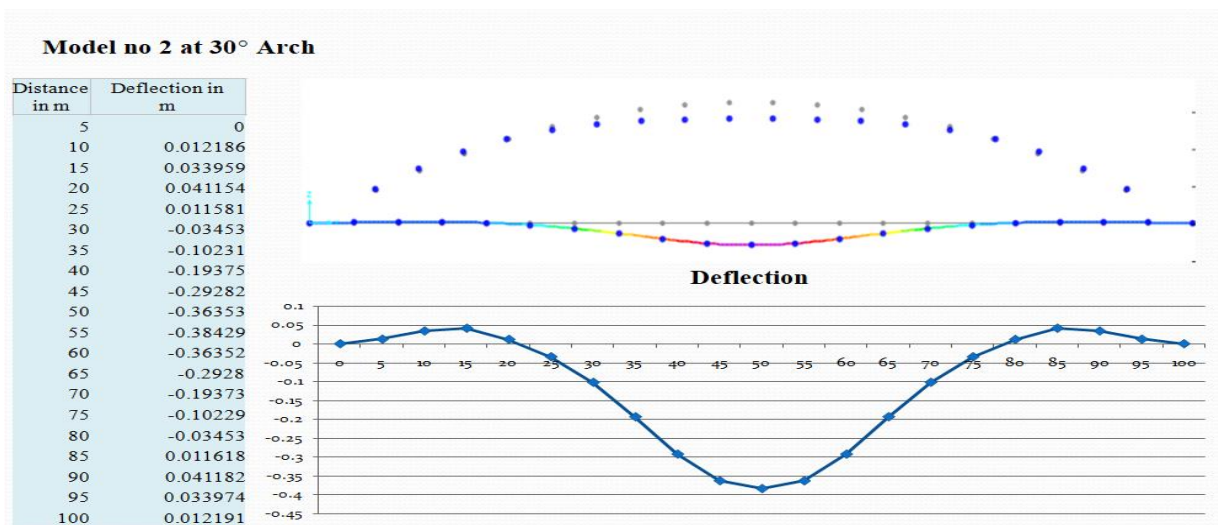


Fig: 4.6 Graph Representing Deflection and Deformed Diagram at Mid Section of the Bridge.

deflection start increase at distance of 20m and reach maximum value 0.38m at distance of 55m graph deformed digram shown the maximum value occur at different points by using SAP2000 along with variour performance level values is as shown in fig: 4.6

### 4.1.3\_ Model no 3 at 35° Angle

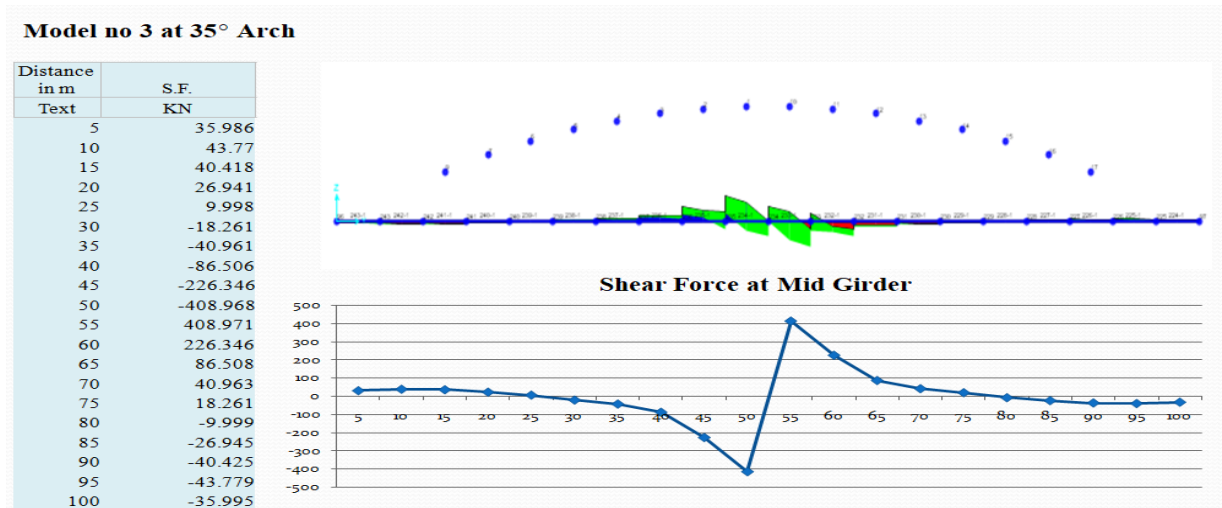


Fig: 4.7 Graph Representing Shear Force at Mid Section of the Bridge.

the bridge is modeled using commercial software SAP2000V 18.0.1. Ultimate. A 3D computer model shown that the analysis of model 1 in at 30° angle between arch rib to deck we find that the shear force start increasing gradually at the distance 35m and reach it the maximum shear force value of 408.9KN at a distance of 50m as shown in fig:4.7

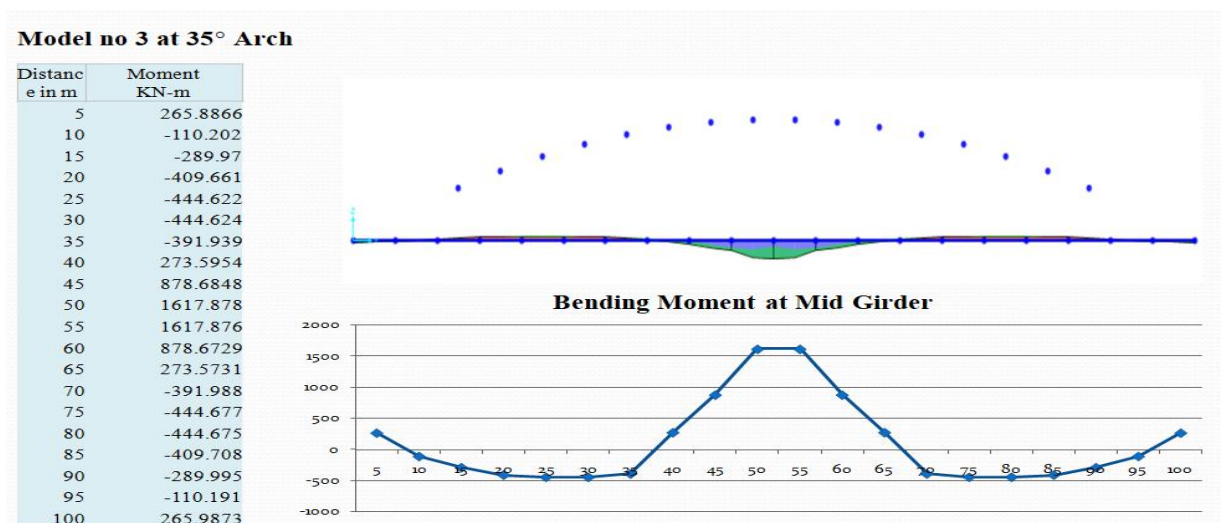


Fig: 4.8 Graph Representing Bending Moment at Mid Section of the Bridge.

At the distance of 10m bending moment is start increasing at the 35m distance when negative bending moment is -391.9KN-m then sudden steep inclination in the curve and reach maximum value of 1617.08KN-m and remain constant at 50m to 55m distance of span as shown in fig: 4.8

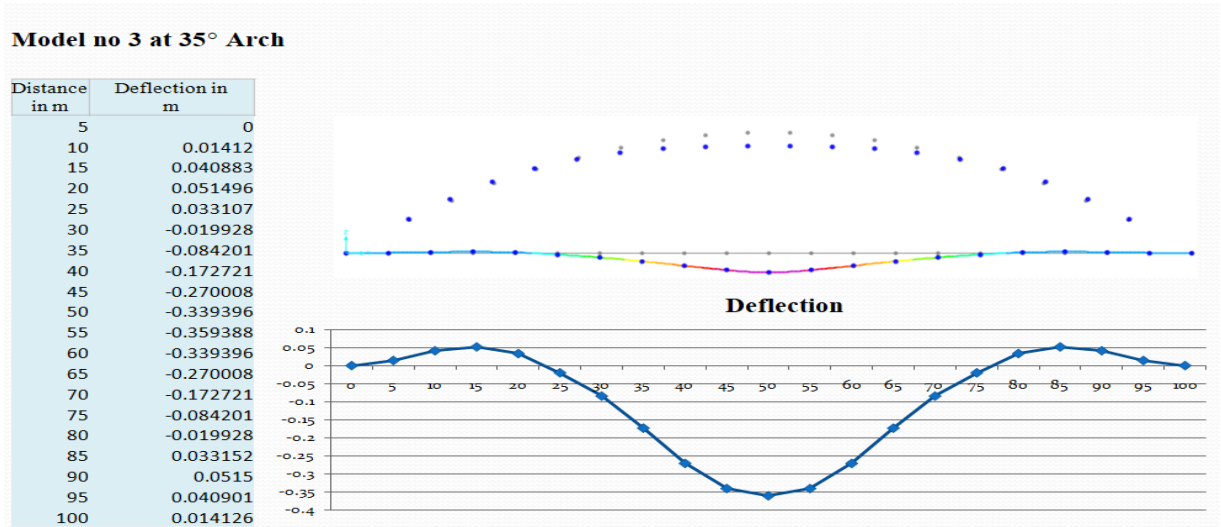


Fig: 4.9 Graph Representing Deflection and Deformed Diagram at Mid Section of the Bridge.

deflection start increase at distance of 20m and reach maximum value 0.35m at distance of 55m graph deformed diagram shown the maximum value occur at different points by using SAP2000 along with various performance level values is as shown in fig: 4.9

#### 4.1.4\_ Model no 4 at 40° Angle

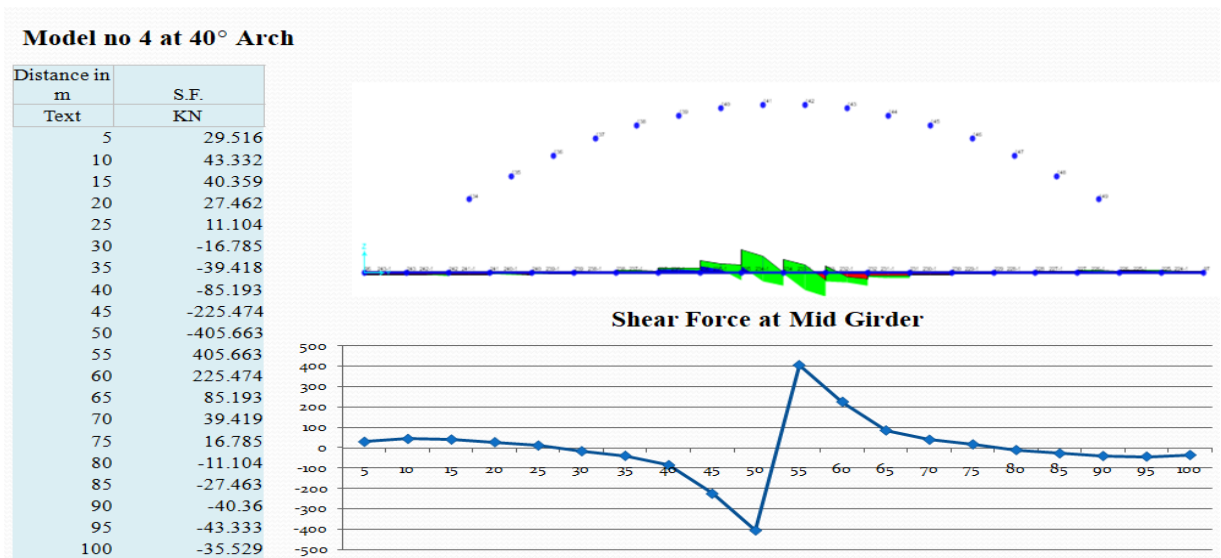


Fig: 4.10 Graph Representing Shear Force at Mid Section of the Bridge.

the bridge is modeled using commercial software SAP2000V 18.0.1. Ultimate. A 3D computer model shown that the analysis of model 1 in at 30° angle between arch rib to deck we find that the shear force start increasing gradually at the distance 35m and reach it the maximum shear force value of 405.6KN at a distance of 50m as shown in fig:4.10

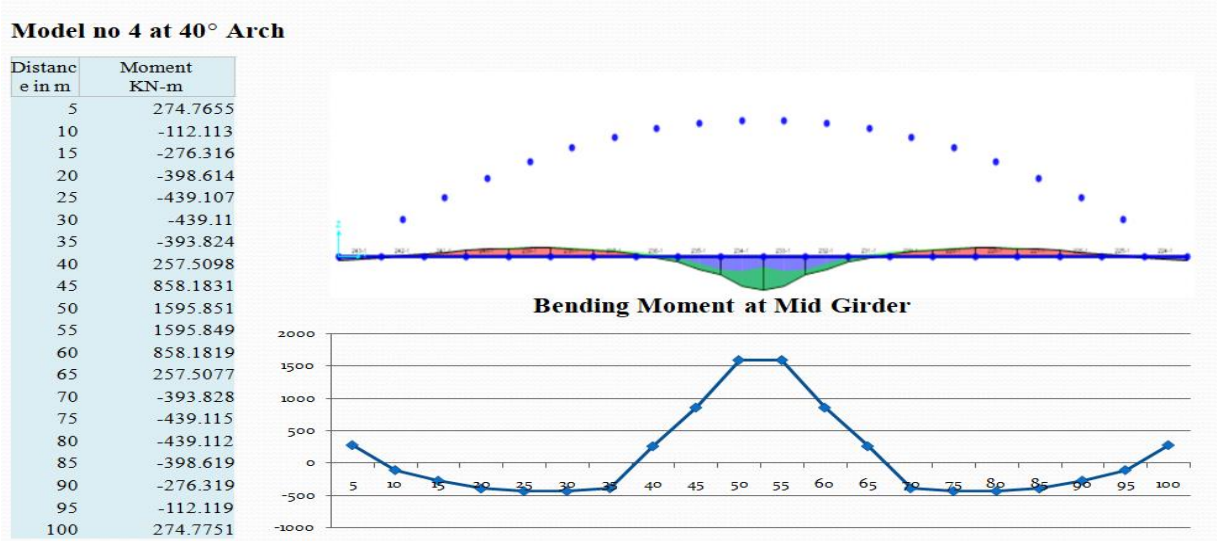


Fig: 4.11 Graph Representing Bending Moment at Mid Section of the Bridge.

At the distance of 10m bending moment is start increasing at the 35m distance when negative bending moment is -393.8KN-m then sudden steep inclination in the curve and reach maximum value of 1595.8KN-m and remain constant at 50m to 55m distance of span as shown in fig: 4.11

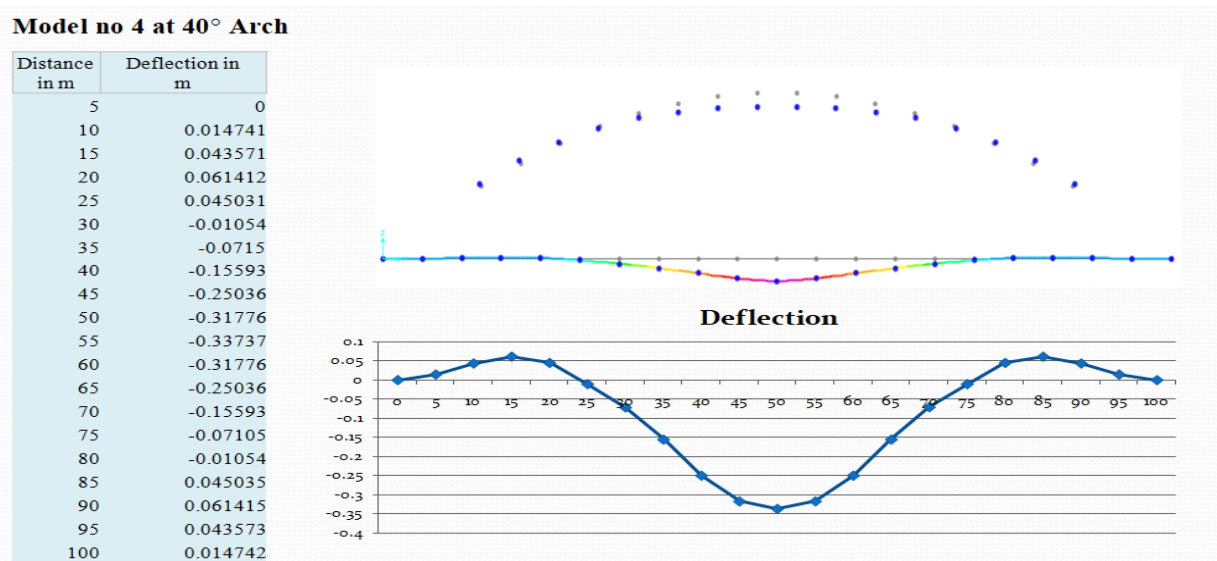


Fig: 4.12 Graph Representing Deflection and Deformed Diagram at Mid Section of the Bridge.

deflection start increase at distance of 20m and reach maximum value 0.33m at distance of 55m graph deformed digram shown the maximum value occur at different points by using SAP2000 along with variour performance level values is as shown in fig: 4.12

#### 4.1.5\_ Model no 5 at 45° Angle

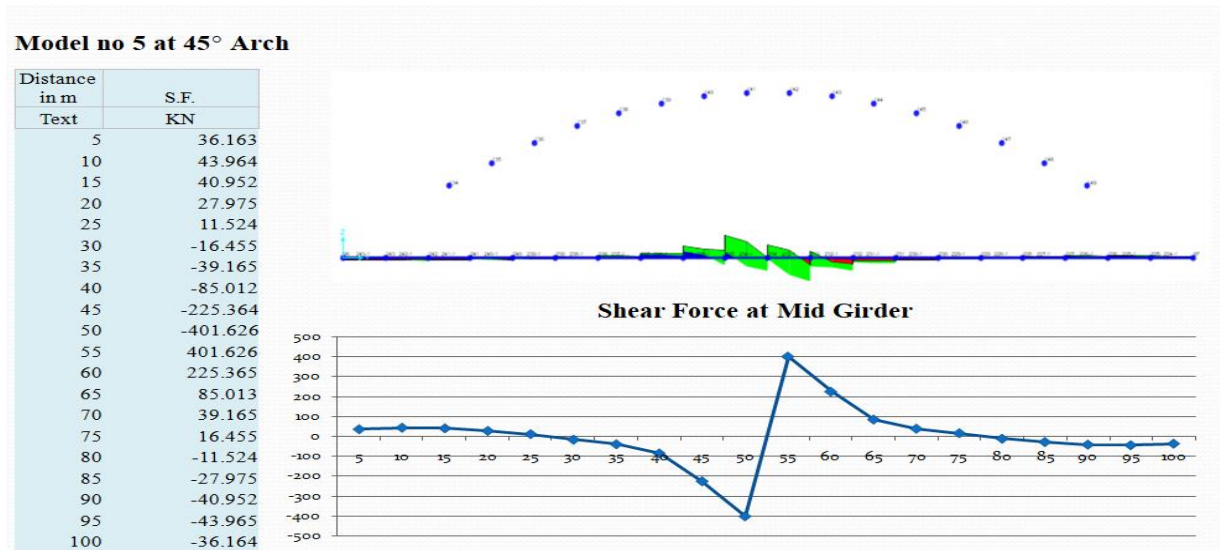


Fig: 4.13 Graph Representing Shear Force at Mid Section of the Bridge.

the bridge is modeled using commercial software SAP2000V 18.0.1. Ultimate. A 3D computer model shown that the analysis of model 1 in at 30° angle between arch rib to deck we find that the shear force start increasing gradually at the distance 35m and reach it the maximum shear force value of 401.6KN at a distance of 50m as shown in fig:4.13

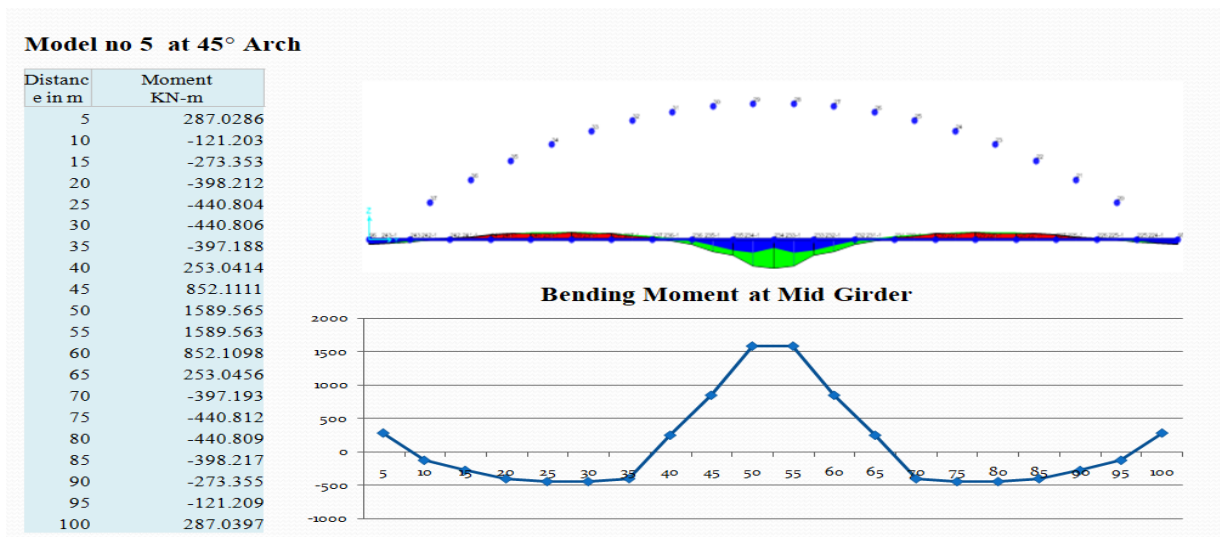


Fig: 4.14 Graph Representing Bending Moment at Mid Section of the Bridges.

At the distance of 10m bending moment is start increasing at the 35m distance when negative bending moment is -397.1KN-m then sudden steep inclination in the curve and reach maximum value of 1589.5KN-m and remain constant at 50m to 55m distance of span as shown in fig: 4.14

**Model no 5 at 45° Arch**

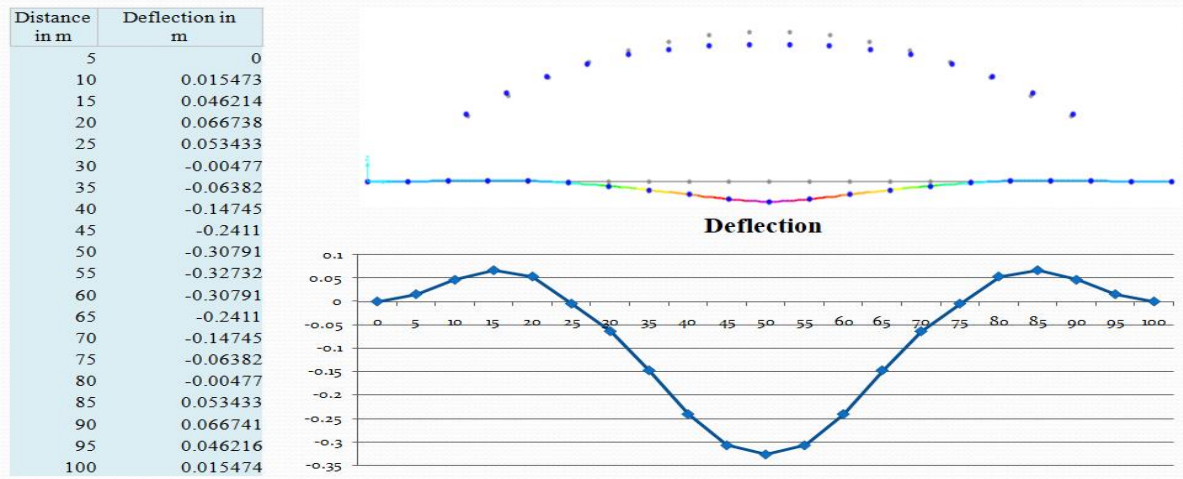


Fig: 4.15 Graph Representing Deflection and Deformed Diagram at Mid Section of the Bridge.

deflection start increase at distance of 20m and reach maximum value 0.32m at distance of 55m graph deformed diagram shown the maximum value occur at different points by using SAP2000 along with various performance level values is as shown in fig: 4.15

## 4.2 Weight Difference

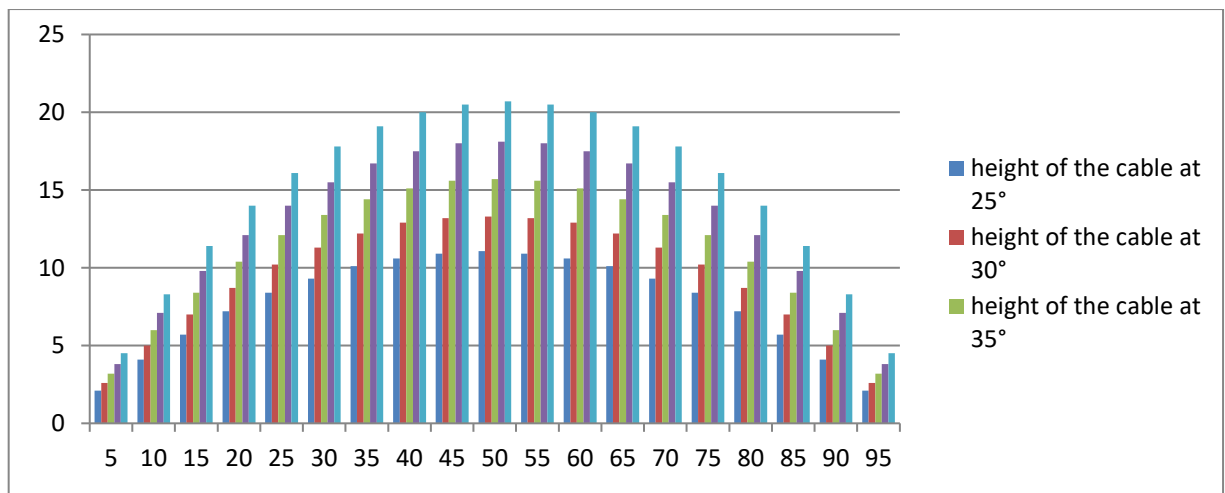


Fig: 4.16 Graph Representing Weight Difference of Steel Cable and Arch Rib 25° to 45° Angle.

Height difference between 25° to 45° degree for archs rib is **11.08m < 13.3m < 15.7m < 18.1m < 20.7m** at the centre of the span segment 50 in the Fig4.16. Graph also represent the of change in height at each segments.

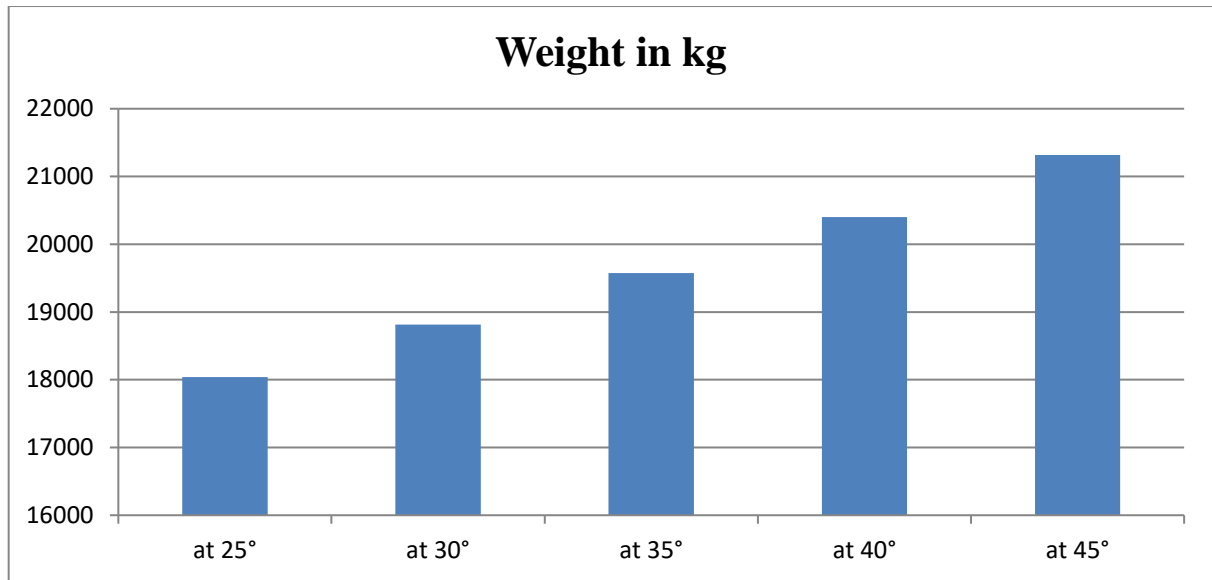


Fig: 4.17 – Graph Representing Weight of Arch Rib at Different Angle.

Weight difference of 25°, 30°, 35°, 40°, and 45° angle arch ribs **18037.65kg < 18814.18kg < 19575.73kg < 20398.54kg < 21316.02kg** as shown in fig:4.17

## Conclusions

For the analysis of 25°, 30°, 35°, 40°, and 45° angle arch ribs with the deck span is 100m with 14m wide span applying the self load and IRC Class A load and run the analysis on SAP2000 software.

for 25° angle graph show the shear force maximum value at centre is 415KN & minimum value is at corner is 31.99KN, maximum moment at centre is 1657.47KN-m & minimum moment at corner is 182.33KN-m, deflection is 0.42m at the centre.

for 30° angle graph show the shear force maximum value at centre is 410.024KN & minimum value is at corner is 34.19KN, maximum moment at centre is 1632.47KN-m & minimum moment at corner is 233.37KN-m, deflection is 0.38m at the centre.

for 35° angle graph show the shear force maximum value at centre is 408.971KN & minimum value is at corner is 35.986KN, maximum moment at centre is 1617.87KN-m & minimum moment at corner is 265.88KN-m, deflection is 0.35m at the centre.

for 40° angle graph show the shear force maximum value at centre is 405.663KN & minimum value is at corner is 29.516KN, maximum moment at centre is 1595.857KN-m & minimum moment at corner is 274.76KN-m, deflection is 0.33m at the centre.

for 45° angle graph show the shear force maximum value at centre is 401.626KN & minimum value is at corner is 36.16KN, maximum moment at centre is 1589.57KN-m & minimum moment at corner is 287.02KN-m, deflection is 0.32m at the centre.

Following results indicated that -

Shear forces is increase is 401.626KN to 415KN

Bending moments, is increase 1589.57KN-m to 1657.47KN-m

Deflection is increase is 0.35m to 0.42m

Weight of arch ribs is 15894.2kg to 17196.2kg also the hanger weight is 2250kg to 4320kg.

With the increase of angle of an arch rib shear force, bending moment, deflection is decrease. From this analysis we conclude that model 4 and model 5 is more effective results in this study because of its deflection is minimum as compare to model 1, model 2, and model 3. Increase in deflection leads to less vibration in the deck of the bridge due to moving loading. The higher value of the bending moment in main girder gives higher value of the plastic section modulus that leads to increase in section. As per the estimation of steel Tied arch bridge most of the components is same except Arch Ribs angle and Hanger cable. Because of increase the angle in arch Rib as well as length of the rib is also increase. At the reviewing of all model results. The angle between  $35^\circ$  to  $40^\circ$  is good for overall performance like resisting of bending moments, shear forces, deflection as well as weight of bridge.

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- IS 1786: 2008 High Strength Deformed Steel Bars ans Wires.
- IRC.6: 2000 Vehicle loads.
- SAP 2000 Refer Guide by CADD Centre.

# Appendix-A

## SAP2000 Analysis Report

### 1. Model Geometry

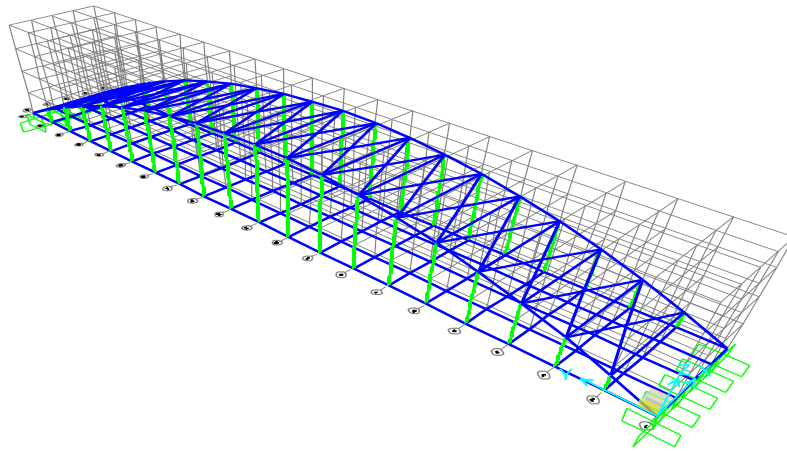


Fig1: Finite Element Model

#### 1.1 Joint Restraints

Table 1: Joint Restraints Assignments

Joint	U1	U2	U3	R1	R2	R3
38	Yes	Yes	Yes	Yes	Yes	Yes
58	Yes	Yes	Yes	Yes	Yes	Yes
78	Yes	Yes	Yes	Yes	Yes	Yes
79	Yes	Yes	Yes	Yes	Yes	Yes
96	Yes	Yes	Yes	Yes	Yes	Yes
97	Yes	Yes	Yes	Yes	Yes	Yes
159	Yes	Yes	Yes	Yes	Yes	Yes
160	Yes	Yes	Yes	Yes	Yes	Yes
180	Yes	Yes	Yes	Yes	Yes	Yes
181	Yes	Yes	Yes	Yes	Yes	Yes

## 1.2 Element connectivity

**Table 2: Connectivity –Frame**

Frame	Joint I	Joint J	Length m
1	57	19	14.
2	180	1	5.82855
3	1	2	5.67297
4	2	3	5.531
5	3	4	5.40372
6	4	5	5.29219
7	5	6	5.19741
8	6	7	5.12033
9	7	8	5.06175
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13	11	12	5.02232
14	12	13	5.06175
15	13	14	5.12033
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20	18	19	5.67297
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366	95	259	3.5
367	241	98	3.5
368	98	260	3.5
369	242	99	3.5
370	99	261	3.5
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372	100	262	3.5
373	96	78	3.5

374	78	180	3.5
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### 1.3 Frame Sections

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3	ISNB30 0H	ISNB30 0H	Default
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357	ISMB4 00	ISMB40 0	Default
358	ISMB4 00	ISMB40 0	Default
359	ISMB4 00	ISMB40 0	Default
360	ISMB4 00	ISMB40 0	Default
361	ISMB4 00	ISMB40 0	Default
362	ISMB4 00	ISMB40 0	Default
363	ISMB4 00	ISMB40 0	Default
364	ISMB4 00	ISMB40 0	Default

365	ISMB4 00	ISMB40 0	Default
366	ISMB4 00	ISMB40 0	Default
367	ISMB4 00	ISMB40 0	Default
368	ISMB4 00	ISMB40 0	Default
369	ISMB4 00	ISMB40 0	Default
370	ISMB4 00	ISMB40 0	Default
371	ISMB4 00	ISMB40 0	Default
372	ISMB4 00	ISMB40 0	Default
373	ISMB4 00	ISMB40 0	Default
374	ISMB40 0	ISMB40 0	Default t

**Table 3: Cable Section Assignments**

<b>Cable</b>	<b>CableSect</b>	<b>MatProp</b>
160	CAB1	Default
161	CAB1	Default
162	CAB1	Default
163	CAB1	Default
164	CAB1	Default
165	CAB1	Default
166	CAB1	Default
167	CAB1	Default
168	CAB1	Default
169	CAB1	Default
170	CAB1	Default
171	CAB1	Default
172	CAB1	Default
173	CAB1	Default
174	CAB1	Default
175	CAB1	Default
176	CAB1	Default

177	CAB1	Default
178	CAB1	Default
198	CAB1	Default
199	CAB1	Default
200	CAB1	Default
201	CAB1	Default
203	CAB1	Default
264	CAB1	Default
265	CAB1	Default
266	CAB1	Default
267	CAB1	Default
268	CAB1	Default
269	CAB1	Default
270	CAB1	Default
271	CAB1	Default
272	CAB1	Default
273	CAB1	Default
274	CAB1	Default

275	CAB1	Default
276	CAB1	Default

277	CAB1	Default
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## 2. Material properties

**Table 1: Material Properties 01 - Basic Mechanical Properties**

Material	Unit Weight KN/m3	UnitMass KN-s2/m4	E1	G12	U12	A1
Fe345	7.6973E+01	7.8490E+00	210000000.	80769230.77	0.3	1.1700E-05
Tendon	7.6973E+01	7.8490E+00	196500599.9			1.1700E-05

**Table 1: Material Properties 02a - Steel Data**

Material	Fy KN/m2	Fu KN/m2	FinalSlope
Fe345	345000.	450000.	-0.1

**Table 1: Material Properties 02a - Steel Data**

Material	Fy KN/m2	Fu KN/m2	FinalSlope
Tendon	168990 5.16	18615 84.63	-0.1

## 3. Section properties

### 3.1. Frames

**Table 1: Frame Section Properties 01 - General, Part 1 of 4**

SectionName	Material	Shape	t3 m	t2 m	tf m	tw m	t2b m	tfb m
ISMB400	Fe345	I/Wide Flange	0.4	0.14	0.016	0.0089	0.14	0.016
ISMB600	Fe345	I/Wide Flange	0.6	0.21	0.0208	0.012	0.21	0.0208
ISNB150H	Fe345	Pipe	0.1651			0.0054		
ISNB300H	Fe345	Pipe	0.3239			0.0063		

**Table 2: Frame Section Properties 01 - General, Part 2 of 4**

SectionName	Area m2	TorsConst m4	I33 m4	I22 m4	I23 m4	AS2 m2	AS3 m2
ISMB400	0.00784	4.688E-07	0.000205	6.221E-06	0.	0.00356	0.003733
ISMB600	0.015621	1.581E-06	0.000918	0.000027	0.	0.0072	0.00728
ISNB150H	0.00271	0.000017	8.647E-06	8.647E-06	0.	0.001426	0.001426
ISNB300H	0.00628	0.00016	0.00008	0.00008	0.	0.003238	0.003238

**Table 2: Frame Section Properties 01 - General, Part 3 of 4**

SectionName	S33 m2	S22 m3	Z33 m4	Z22 m4	R33 m4	R22 m2
ISMB400	0.001023	0.000089	0.001176	0.000089	0.161539	0.028169
ISMB600	0.00306	0.000252	0.003511	0.000253	0.242436	0.041196
ISNB150H	0.000105	0.000105	0.000105	0.000105	0.056487	0.056487
ISNB300H	0.000493	0.000493	0.000493	0.000493	0.11281	0.11281

**Table 2: Frame Section Properties 01 - General, Part 4 of 4**

SectionName	AMod	A2Mod	A3Mod	JMod	I2Mod	I3Mod	MMod	WMod
ISMB400	1.	1.	1.	1.	1.	1.	1.	1.
ISMB600	1.	1.	1.	1.	1.	1.	1.	1.
ISNB150H	1.	1.	1.	1.	1.	1.	1.	1.
ISNB300H	1.	1.	1.	1.	1.	1.	1.	1.

### 3.2. Cables

**Table 3: Cable Section Definitions, Part 1 of 2**

<b>CableSect</b>	<b>Material</b>	<b>Diameter m</b>	<b>Area m2</b>	<b>TorsConst m4</b>	<b>I m4</b>	<b>AS m2</b>
CABLE	Fe345	0.1	0.007854	9.817E-06	4.909E-06	0.007069

**Table 3: Cable Section Definitions, Part 2 of 2**

<b>CableSect</b>	<b>AMod</b>	<b>A2Mod</b>	<b>A3Mod</b>	<b>JMod</b>	<b>I2Mod</b>	<b>I3Mod</b>	<b>MMod</b>	<b>WMod</b>
CABLE	1.	1.	1.	1.	1.	1.	1.	1.

## 4. Load patterns

This section provides loading information as applied to the model.

### 4.1. Definitions

<b>LoadPat</b>	<b>DesignType</b>	<b>SelfWtMult</b>	<b>AutoLoad</b>
DEAD	Dead	1.	
LIVE	Vehicle Live	0.	
LIVE 2	Vehicle Live	0.	

## 5. Load cases

### 5.1. Definitions

**Table 5: Load Case Definitions, Part 1 of 2**

<b>Case</b>	<b>Type</b>	<b>InitialCon d</b>	<b>ModalCas e</b>	<b>BaseCas e</b>	<b>MassSourc e</b>	<b>DesActOp t</b>
DEAD	LinStatic	Zero				Prog Det
MODA L	LinModal	Zero				Prog Det
EQ-X	LinStatic	Zero				Prog Det

EQ-Y	LinStatic	Zero				Prog Det
LIVE	LinMSStatt	Zero				Prog Det
LIVE 2	LinMSStatt	Zero				Prog Det

**Table 5: Load Case Definitions, Part 2 of 2**

Case	DesignAct
DEAD	Non-Composite
MODAL	Other
LIVE	Short-Term Composite
LIVE 2	Short-Term Composite

## 5.2. Static case load assignments

Case	LoadType	LoadName	LoadSF
DEAD	Load pattern	DEAD	1.

## 6. Load combinations

**Table 7: Combination Definitions**

ComboName	ComboType	CaseName	ScaleFactor
DL+LL+LL2	Linear Add	DEAD	1.
DL+LL+LL2		LIVE	1.
DL+LL+LL2		LIVE 2	1.