# CABLE STAYED BRIDGE:

**A DISSERTATION**
**Submitted in partial fulfilment of the**
**requirements for the award of the degree**
**of**
**MASTER OF TECHNOLOGY**
**in**
**CIVIL ENGINEERING**
**(With Specialization in Structural Engineering)**

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# CANDIDATE’S DECLARATION

I hereby declare that work presented in this dissertation has been carried out by me in the Department of Civil Engineering at Indian Institute of Technology Roorkee under the supervision of **Dr. Vipul Prakash**, Professor, Department of Civil Engineering, IIT Roorkee. The matter embodied in this dissertation has not been submitted for the award of any other degree.

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# CERTIFICATE

This is to certify that the report entitled, **Cable stayed bridge** submitted by **Rajat Thenuia**, embodies the work done by him under my supervision.

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# ABSTRACT

The cable-stayed bridge is one of the relatively recent innovate bridge form. It consists of three principal components, namely, girders, tower (pylons) and cable stays. The girder is support elastically at points along its length by inclined cable-stays so that it can span a much longer distance without intermediate piers. The cables are connected to the tower to transmit the load to the foundation.

Cable stayed bridges have good stability, optimum use of structural materials, aesthetic, relatively low design and maintenance costs, and efficient structural characteristics. Therefore, this type of bridges are becoming more and more popular and are usually preferred for long span crossings compared to suspension bridges. A cable stayed bridge consists of one or more towers with cables supporting the bridge deck. In terms of cable arrangements, the most common type of cable stayed bridges are fan, harp, and semi fan bridges. Because of their large size and nonlinear structural behavior, the analysis of these types of bridges is more complicated than conventional bridges.

In the present study a simple cable-stayed has been considered for examining and comparing the forces generated in pylon and cable forces for different types of deck .Here we have considered one RCC box girder deck and the other composite truss deck.

Modern designs adopt thin and lighter decks, inducing savings in the deck, cables, piers and foundations. Field bolted splices provided fast and simple connections between almost identical modules, ensuring maximum repetition of pre-fabricated deck components and construction procedures. These concepts have been applied to the majority of composite cable stayed bridges with main-spans exceeding 200 m, built over the last twenty years by the balanced cantilever construction method.

CSI BRIDGE v20 software has been used for analysis purpose.

# CHAPTER 1

# INTRODUCTION

## 1.1 GENERAL

The cable-stayed bridge is one of the relatively recent innovate bridge form. It consists of three principal components, name, girders, tower (pylons) and cable stays. The girder is supported distance without intermediate piers. The cables are connected to the tower to transmit the load to the foundation. The increasing popularity of contemporary cable-stayed bridge among bridge engineers can be attributed to:

- The appealing aesthetics.
- The full and effective utilization of structural materials.
- The increased stiffness over suspension bridges.
- The efficient and fast mode of construction.
- The relatively small size of bridge deck elements.

Cable stayed bridge are superior to suspension bridge in the following aspects suspension bridge need a stronger anchorage at each end to hold the main cable where in cable- stayed bridges this is not predominant issue. If the ground is weak, suspension bridge create a big problem whereas cable- stayed bridge are self-anchored.

## 1.2 OBJECTIVE OF THE STUDY

For a medium to long span bridges, the dead load of the bridge is the main source of loading .In order to minimize the dead load and forces in the deck as well as cables we are comparing a RCC box girder to a composite truss deck. In cable stay bridges the anchoring of stay cables play a vital role for designing and moreover steel bridges are transparent and could be examined from outside and proper maintenance could be done at the right time which is quite difficult in concrete bridges (deck). The main advantage of truss deck is its light weight, stiffness and transparency.  In the present study a simple cable-stayed bridge of span 270 m has been considered for examining and comparing the moment, axial forces and tension forces in the cables. Here we have taken two cases, one we have considered the bridge with RCC box girder and the other one with composite truss deck.

CSI BRIDGE V20 software has been used for analysis purpose.

# CHAPTER 2

# LITERATURE

## 2.1 HISTORY

The principle of supporting a bridge deck by inclined tension members leading to towers on either side of the span has been known for centuries. However, it didn't become an interesting option until the beginning of the 19th century when wrought iron bars, and later steel wires, with a reliable tensile strength were developed. In 1823, the famous French engineer and scientist C.L. Navier published the results of a study on bridges with the deck stiffened by wrought iron chains and with a geometry as shown in fig. 1. It is interesting to note that Navier considered both a fan shaped and a harp shaped system. So the cable systems were actually up-to-date, but in contrast to present practice the backstays were assumed to be earth anchored. Navier's final conclusion was that the suspension system should be used instead of the stayed system. This conclusion was to a large extend based on observations of stayed bridges that had failed.

Some stayed bridges were built as early as the 17th and 18th centuries, and it proved very difficult to arrive at an even distribution of the load between all stays. So, imperfections during fabrication and erection could easily lead to structure where some stays were slack and others overstressed. The stays were generally attached to the girder and pylon by pinned connections that did not allow a controlled tensioning. Some bridges collapsed and the system disappeared for about two centuries. However, several unique bridges as a combination of suspension and cable-stayed bridge, so called hybrid structures, were built during the second half of the 19th century. Some examples are shown in fig. 2.Most notable bridges of the type shown in fig. 2 were designed by J.A. Roebling and built in the US. Around the turn of the 19th-20th century, the French engineer A.V. Gisclard developed an earth anchored stayed system in which not only the inclined stays but also the tension members at the deck level were made of cables. In the 1920s the system by Gisclard was developed further by substituting the horizontal cables by the deck girders and changing the earth anchored system to a self-anchored system with compression rather than tension along the deck.

In connection with the reconstruction of German bridges after the war, the Dischinger system was proposed at several occasions but never used for actual construction. One of the reasons is undoubtedly the pronounced discontinuity of the system both with respect to the structural behavior and to the appearance. Although never adopted, the proposals by Dischinger had a considerable influence on the subsequent introduction of the pure cable-stayed bridge and from the experimental results obtained by Dischinger From the re-construction of the bridges destroyed in the Second World War it was found that cable-stay bridges had a part to play in spans between girder bridges and suspension bridges. Dischingers design of the 1955 Strömsund Bridge in Sweden, see fig. 5, was the first of the modern day cable-stayed bridges. After their reappearance in the mid-1950s, cable-stayed bridges almost completely replaced the competing systems suspension bridges and arch bridges.

**Fig 2.1 Strömsund Bridge**

After the Strömsund. Bridge the next true cable-stayed bridge was the Theodor Heuss bridge across the Rhine at Düsseldorf. With a main span of 260 m and side spans of 108 m, it was considerably larger than the Strömsund Bridge. Also the bridge was more innovative by introducing the harp shaped cable system with parallel stays and a pylon composed of two freestanding posts fixed to the bridge deck structure. The cable configuration was chosen primarily for aesthetic reasons giving a more pleasant appearance.

**Fig 2.2 The Theodor Heuss Bridge.**

The second cable-stayed bridge to be erected in Germany was the Severins Bridge in Köln. This bridge featured the first application of an A-shaped pylon combined with transversally inclinedncable planes, and it was the first to be constructed as an asymmetrical two span bridge with a single pylon positioned at only one of the river banks.

**Fig 2.3 The Severins Bridge**

For the cable-stayed bridges built till the beginning of 1960s, each stay-cable was generally composed by several prefabricated strands to achieve the large cross sections required with their limited number of cables. The multi-strand arrangement in the individual stay causes complicated anchorage details in the girder and difficulties in replacement of strands. These drawbacks could be eliminated if the number of stays was increased so that each stay cable could be made of a single strand and this led to the introduction of the multi-cable system. The first two multi-cable bridges to be built were the Friedrich Ebert Bridge and the Rees Bridge both designed by H. Homberg and built across the Rhine.

**Fig 2.4 The Rees Bridge.**

## 2.2 SUSPENSION BRIDGE VERSUS CABLE STAYED BRIDGE

The cable-stayed bridge is becoming very popular, being used where previously a suspension bridge might have been chosen. The main parts for each type of bridge are given.

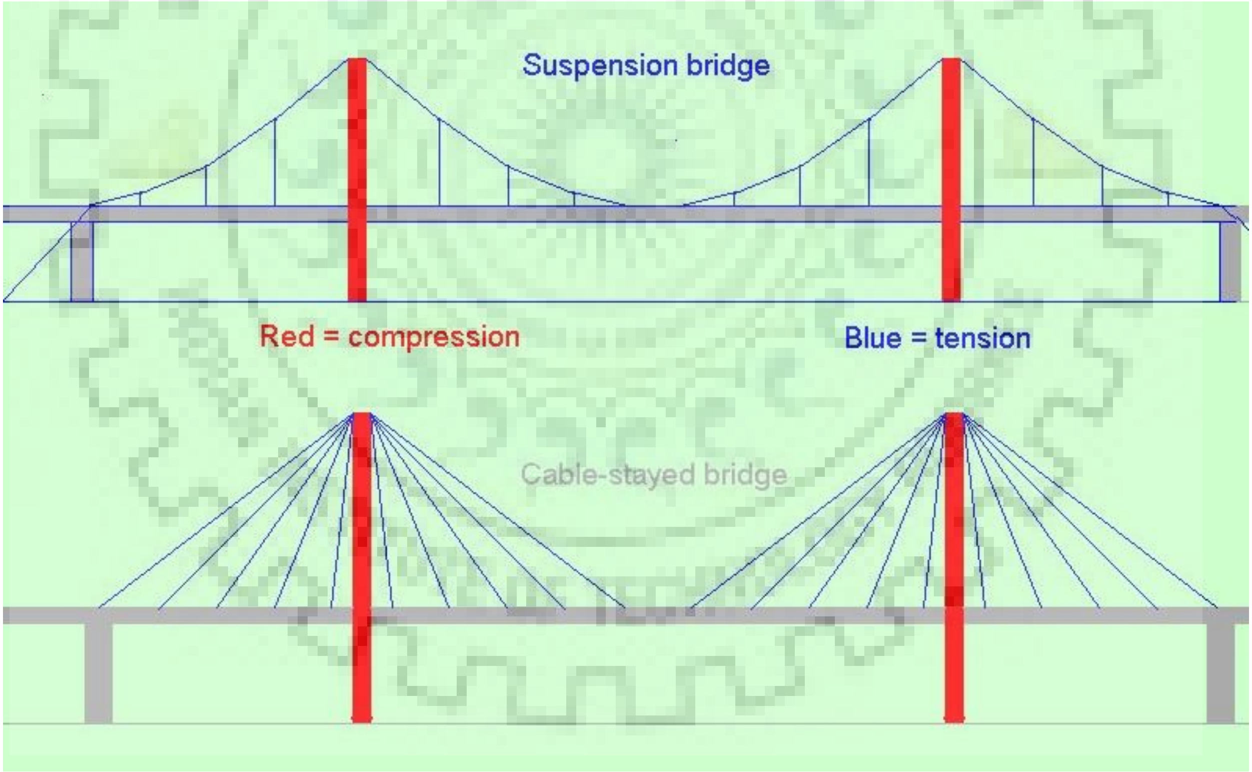


**Fig 2.5 Suspension versus cable stayed bridges**

Both types of bridges have two towers and a suspended deck structure. Whether the towers are equivalent may become apparent in the near future. There is a difference in the deck structures.

The deck of a suspension bridge merely hangs from the suspenders, and has only to resist bending and torsion caused by live loads and aerodynamic forces. The cable-stayed deck is in compression, pulled towards the towers, and has to be stiff at all stages of construction and use.

Why are the longest spans all in suspension bridges? There are two reasons:

**Firstly**, apart from the towers, which are in principle simple struts, all the highest parts of a suspension bridge are in tension. A cable, though flexible, is inherently stable against perturbations, and only needs to be thick enough to withstand the tension (static and fatigue), with a safety factor. A strut is inherently unstable, and needs to be strong enough to prevent buckling.

**Secondly**, unlike a beam, a truss, and a cable stayed bridge, a suspension bridge does not rely on internally cancelling forces to produce the required effects. The horizontal component of the tensions within it are resisted is the ground.

A great advantage of the cable-stayed bridge is that it is essentially made of cantilevers, and can be constructed by building out from the towers. Not so a suspension bridge. Once the towers have been completed, steel cables have to be strung across the entire length of the bridge. These are used to support the spinning mechanism, used since the time of Roebling and the Brooklyn Bridge, which takes thousands of strands of steel wire across the bridge.
Because the cable-stayed bridge is well balanced, the terminal piers have little to do for the bridge except hold the ends in place and balance the live loads, which may be upward or downward, depending on the positions of the loads. A suspension bridge has terminal piers too, unless the ends are joined directly to the banks of the river. The cables often pass over these piers and then down into the ground, where they are anchored, and so the piers have to redirect the tension. If the bridge is built on difficult ground, as in the case of the Humber Bridge, the anchorage can present a fearsome problem.

## 2.3 EVOLUTION OF CONCEPTUAL DESIGN

It is well recognized that in more aboriginal regions of Africa, bridge with small decks suspended by cables are used for pedestrian. The early stayed bridges used chains or bars for the stays. To arrive from these bridges to modern suspension bridges up to 1500m span several difficulties had to be encountered.

The First of them was to define where the cord was to be tied. At first cords were tied to the trees. Now a days chords or rather excellent steel cables are tied (anchored on) to artificial or natural rocks.

**Fig 2.6 Chords tied to tree**

The second rival of suspension bridge was the wind. There bridge were very much vulnerable to the wind according to span size and deck thickness. With the introduction of trellis or also known as stiffening ropes and with the increasing rigidity of the deck tower complex, it was possible to overcome this problem.

The third problem was the supporting steel cables: at first cables were made with parallel cable but rupture of any of these cables weakened the cable safety. This problem was overcome by making cables with alternately wires, so that further increasing the cable resistance as a whole, cable being strongly compressed against each other prevented rupture of one of them from affecting the full resistance of the cables.

The fourth problem was a certain brittleness, both of steel composing the cables and concrete of which towers were made. The advent of steel and high resistance manufacturing caused this problem to be overcome.

In any long span structure dead weights often predominate the live loads so that an efficient use of material offers a twofold advantage: reduction in dead weight and saving in material leading to economic construction. It known that transfer of load through direct stressing as in cables is more efficient than through flexure, Further, amongst the axially loaded members, the ideal way to proportion the members would be to have compressive force resisted by concrete and tensile forces by steel. It is, therefore natural to use efficiently the tremendous potential of high tension for long span bridge and other such structure.

During the World War II, huge devastation of bridge took place. Engineers invented and applied new methods and techniques of construction and modern method of design and analysis. Owing to the acute shortage of steel in the world in the post war period, a great emphasis was given on minimum weight design of the bridge. As a result of the orthotropic plate design theory was developed was more than 40% lightest than their prewar counterparts. Modern cables stayed bridge took all those advantage that suspension bridge could possibly offer. The first of them is that only the vertical component of the force in cables is used to support the bridge. This markedly requites cables to be as near possible to the pylon, so that better use is found of their force. Another problem lies in the fact a large number of cables are cables are needed for large spans, it is therefore essential to construct higher towers in order to attain always the largest component of the cables vertical. It is obvious that there is a physical limit to the height of the pylon, resulting among other problem: from rigidity it may yield to buckling. Also, it should be noted that the possibility very wide decks generated a possibility of great strain in the transvers direction of deck. This problem was overcome by introducing large number of cross girders.

However it is significant to note that ‘there work of art’ are exquisite copy of nature. Suspension bridge have their remote have their remotest origin in simple line while cable-stayed bridge have their origin in the human body with stretched arms marginally separated from the body.

The future applications and user of the various types of cables stayed and suspension bridges are several and will no doubt govern the intermediate and long span ranger of river and raving crossing. Highway overpasses and pedestrian bridge will be developed for reason of beauty and safety. Thus beauty and safety are combined with economy to reduce the fatalities and mortalities on the highway.

The cables system is ideal for spanning of natural obstacles of wider river, ravines or deep valley and for pedestrian and vehicular bridge, crossing wide interstate highway because there are no piers in between that will lead to obstruction. For the most parts, cables stayed bridge have been built across navigable river and channels where and navigation requirements uttered the dimension of the spans and the clearance above the main water level.

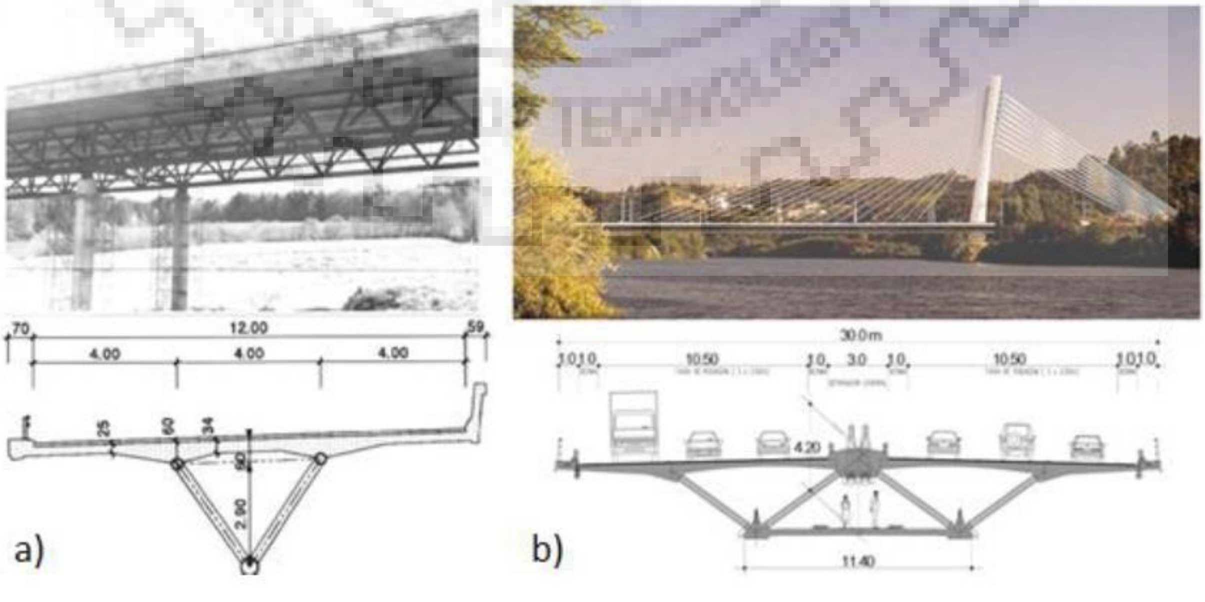
### 2.3.1 Evolution of composite decks

While some engineers were pushing the structural limits of this new type of bridges and attaining those long spans records, others were more focused on the different design possibilities allowed by this suspensions system. New tower shapes and cable arrangements have been used, mostly on smaller spans where it is easier to introduce new concepts, and aesthetically solutions have been attained. That is one of the reasons that has led cable stayed bridges to be built, even today, in smaller span ranges, where they have to compete against more conventional deck solutions.

An overall trend in bridge construction is the increased use of composite decks; these allow a faster and more effective construction phase than a concrete deck while being overall cheaper than a fully steel solution.

Truss decks have been used for a long time in suspended and girder bridges, its main advantages being the overall stiffness and transparency. An early example of a composite 3D truss deck is the Lully Viaduct in Switzerland which is now almost 20 years old (a). More recently a 3D truss with a W cross section was used in a cable stayed bridge in Portugal, the Rainha Santa Isabel Bridge (b). The W shaped cross section allows the deck width to be around 30 meters, and has enough space for the bottom slab, made of concrete, to be used as a pedestrian walkway .

This last example represents a different type of innovation in cable stayed bridges, since most new designs in the shorter span range introduce changes in the tower shape and the suspensions arrangement, while the deck types have mostly been limited to girder, box-girder or slab decks.



**Lully Viaduct** **Rainha Santa Isabel**

**Fig 2.7 Composite Decks**

## 2.4 COMPONENTS OF CABLES-STAYED BRIDGES

The main components of a cable- stayed bridge are deck, pylon (tower) and cable stay.

### 2.4.1 Deck with Girders

The most important point to be considered for choosing the deck for any cable-stayed bridge is its flexibility/ stiffness. The deck should have large stiffness to reduce number of cables stays. Also in case of large deflection it is beneficial to have a flexible deck. The optimum rigidity of the bridge depends on the spacing of cables, method of suspension and the width of the bridge. Girders of various different types are used to support the deck. The shape will depend on the governing stiffness and loading. General arrangement may be twin I girders, multiple I girders trapezoidal box girders, twin trapezoidal box girders and twin rectangular box girders.

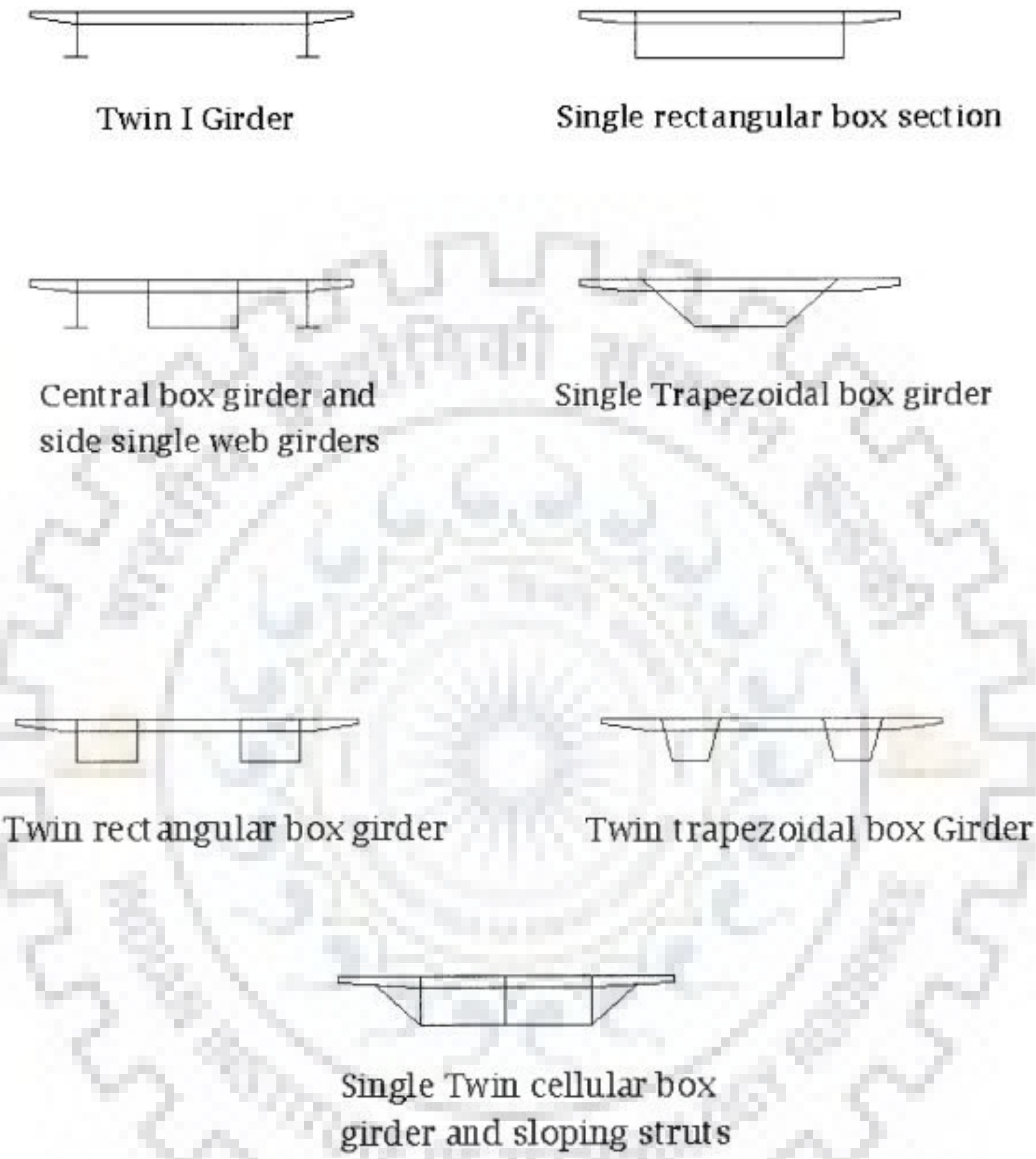


**Fig 2.8 Types of deck**

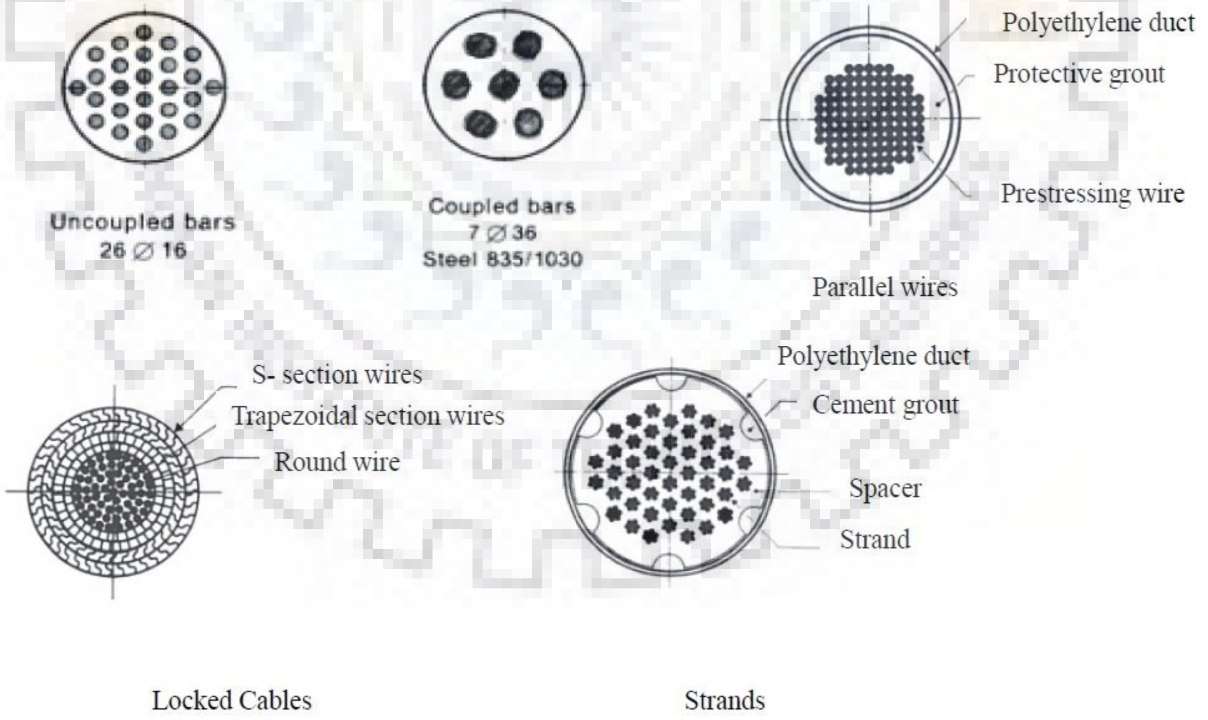
The decks can be constructed with steel, concrete or composite materials .By using steel deck it is quite possible to limits its self-weight to a value that is around 1/5th of that of concrete deck. But on the other hand the use of steel cross-section is two times more expensive. So the use of steel decks is efficient in case of longer span bridge. In composite systems, the running surface is made of concrete, and metal is used for other elements of the superstructure. Figure 2.8 shows the different types of deck.

### 2.4.2 Cable Systems

The work of the cables is to take the load from deck in the form of tensile forces and transmitting these loads to the tower. The best arrangement of wires in a cable is parallel wires and parallel strands as these have maximum elastic modulus. The choice of cables for a bridge also depends on the mechanical properties such as modulus of elasticity, durability, ultimate tensile strength etc. as well as on economic and structural criteria (design of the anchorages, erection etc.)

There are different transverse arrangements of the cables that are used. There are single plane vertical, single plane vertical lateral double plane- vertical, double plane sloping, double plane V-shape and three plane system. The choice will depend on the cross-section, loads distribution, etc.

The arrangement of wires in cables is shown in Fig 2.9.



Parallel wires

Locked Cables

Strands

**Fig 2.9 Types of cables**

## Future trends in field of cables

Cables made of CFRP have been proposed to reduce weight and diameter, as they combine very high resistance with a self-weight lower than steel. How- ever, their time dependent behaviour is still not well known, axial deformability is much higher, and CFRP stay-cables are costly compared to steel stays.

Cable forces in service are usually limited to 45% of its ultimate guaranteed resistant strength (FGUT). Few solid justifications have been given to continue using this limit, imposed to prevent the negative con- sequences of the fatigue stresses, and the local bending stresses in the anchorage of the first large-diameter stay-cables. For a characteristic combination of loads, the Eurocode 3, part 1-11 allows cable forces up to 50% of FGUT, if vibration damping devices are adopted at anchorages. In addition, during cables installation, the first strands may have installed forces up to 60% FGUT, provided after stressing the remaining strands of a cable work in the limit of 55% FGUT.

The assessment of stay-cable fatigue stresses needs also to be carried out for the service conditions (considering both the axial stresses and the bending stresses near the anchorages, due to angular deviations caused by catenary effects, wind forces and erection imper-fections). The French recommendations 21 propose a simple method valid for road bridges, limiting the cables axial stress variation to 70 MPa for the passage of the fatigue vehicle LM3 of the Eurocode 1-Part 2.

## 2.4.3 Tower (Pylon)

The tower may be single cantilever type to support a single plane arrangement of stays or may be two cantilever tower to support the double plane cable system. The pylon may be hinged or fixed at the base depending moments at the base, whereas a hinged base may does not lead to any bending moment. However, the increased rigidity of the total structure resulting from the fixed base tower may offset the diced vantage of the large bending moments. Another consideration in this regard is that a fixed base may be more practical to be externally supported until the cables are connected properly.

The pylons may be of different shapes like A,H,Y diamond delta modified A, single cantilever, portal frames twin tower etc. The A-shaped is most advantage but it will require large pylon width to accommodate below the legs of its top satisfies the necessities in a better way. A narrow diamond shapes tower is a variation of a A-type modified diamond shapes or a delta shape in also used in some bridge.

In the radiating configuring of the stays the tower should possess significant longitudinal stiffness nut in a harp types arrangement maximum amount of flexibility is required principally when the cable are attached to the pier.

Though forces in transverse in transverse direction are small in the tower in this direction also the stability should be checked. If the tower is anchored back to of fixed point it is necessary for it to be efficiently hinged about the base to prevent detrimental stresses arising from temperature variation.

The transvers configuration of tower should follow the cable plans. In order to ensure the axial compression in case of concrete bridge. The height of the pylon is governed by selection of the pylon height to span ratio, configuration of the cables general aesthetics. Figure 2.10 is showing shapes of pylon.

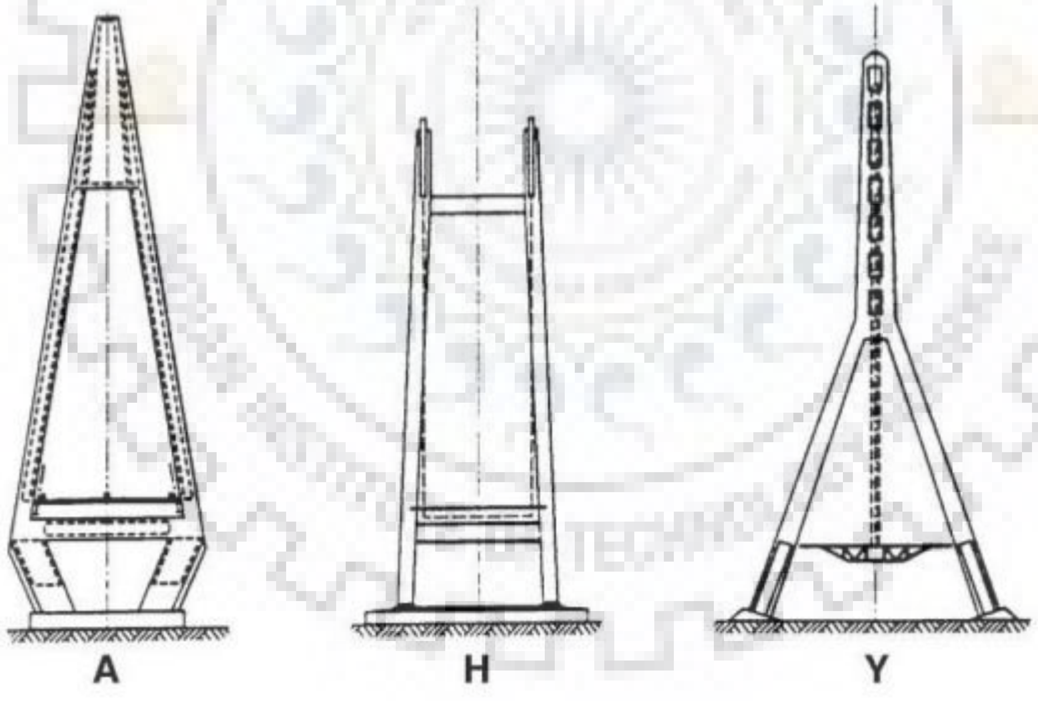


**Fig 2.10 Shapes of Tower (Pylon)**

## The Connection

- Usually the cable has a pin type joint to the Pylon.
- Have either swaged or filled sockets.
- The deck-to-cable connection is usually of the 'free' type to accommodate adjustment.
- Cable Anchorages in Pylon are usually expensive.

**Fig 2.11 The Connection**

## ANCHORAGE

In the cable-beam anchorage structure with tensile anchor plate of cable-stayed bridges, there is obvious stress concentration in the local area and the weld position of the anchor plate, which is prone to plastic failure and leads to the reduction of the bearing capacity of the anchorage zone.

Cable-beam anchorage structure with tensile anchor plate are mainly composed of anchor plate (AP), anchor padding plate (APP), anchor tube (AT) and stiffening plate (SP) . The cable force is transmitted to the AT then transmitted to the AP by the welding seam between them, and finally transmitted to the main beam through the weld between the AP and the top surface of the flange of the steel box girder. During this process, the weld joint connecting the AP and the two sides of the AT is subjected to a large cable force, and a plastic zone will appear at the root of the weld, which easily causes the AP to be damaged.

## 2.5 SPAN ARRANGEMENTS

In general the arrangement of span of cable stayed bridges are of three different types-two spans (symmetrical or asymmetrical), three span or multiple spans, In an economical cable-stayed bridge design proportions number and inclination of cables lower height and types superstructure must be assessed in association with each other.

### A) LONGITUDINAL CABLE ARRANGEMENTS

### 2.5.1 Harp pattern

Although the harp patter is not the best form the static as well economic point of view it is attractive because of its desired aesthetic advantages. The fact that the cable are parallel and cross each other at a constant in the eye of the spectator gives the structure a most satisfactory appearance. The pattern is shown in fig 2.12.

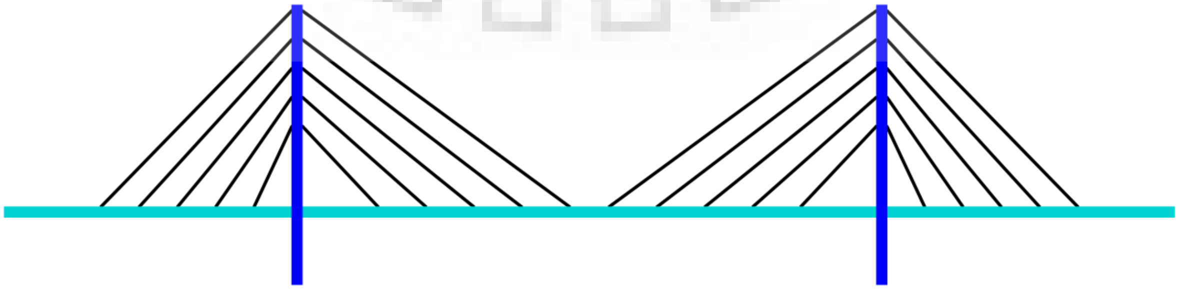


**Fig 2.12 Harp Pattern**

### 2.5.2 Fan Pattern

In the fan design, the cables all connect to or pass over the top of the towers. The fan design is structurally superior with a minimum moment applied to the towers, but, for practical reasons, the modified fan (also called the semi-fan) is preferred, especially where many cables are necessary. In the modified fan arrangement, the cables terminate near to the top of the tower but are spaced from each other sufficient to allow better termination, improved environmental protection, and good access to individual cables for maintenance. The pattern is shown in Fig 2.13.

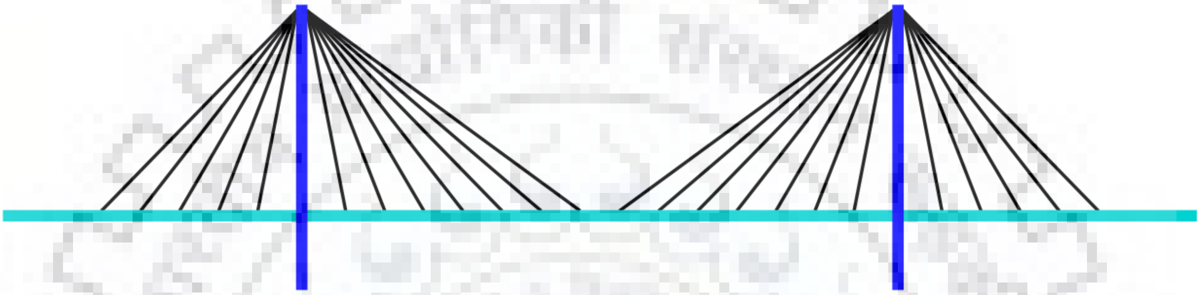


**Fig 2.13 Fan Pattern**

### 2.5.3 Star Pattern

n the star design, another relatively rare design, the cables are spaced apart on the tower, like the harp design, but connect to one point or a number of closely spaced points on the deck.The pattern is shown in the Fig 2.14.

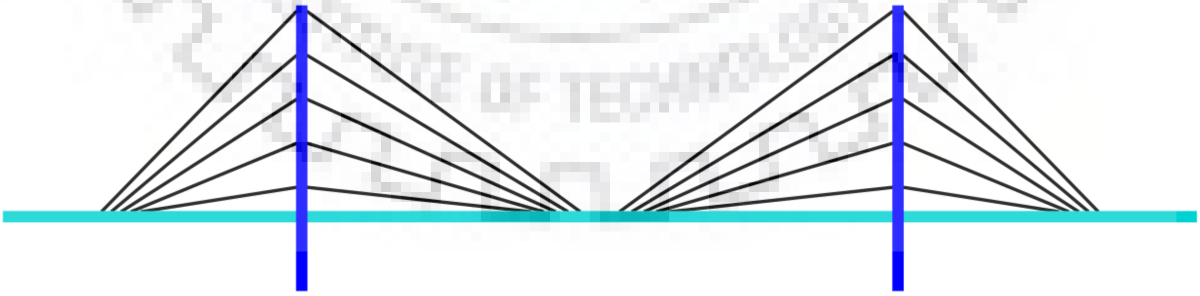


**Fig 2.14 Star Pattern**

**B) TRANSVERSE ARRANGEMENTS**

For the transverse arrangement the classification is made according to the positioning of the cables in different planes. Two basic classifications follow:

### 2.5.4 Single-plane system:

This system is composed of a single cable layout along the longitudinal axis of the superstructure. This kind of layout is governed by torsional behavior. The forces are created by unsymmetrical loading on the deck. The main girder must have adequate torsional stiffness to resist the torsion force.

### 2.5.5 Two-plane system:

If the tower is of the shape of an H-Tower, the layout is a two-plane vertical system. If only one tower is provided in the middle of the superstructure, then the layout is a two-plane, inclined system.

The transverse layout has two options for the anchorage. The anchorage is located either outside of the deck structure or inside the main girder. The spacing of the cables varies according the chosen layout and the aesthetics requirements. The current trend is to employ many cables. Increasing the number of cables reduces the required stiffness of the girders, and results in more slender superstructure sections. Consequently, the load in each cable decreases, and the construction process is simplified.

## 2.6 METHODS OF ERECTION

There are three different methods which are followed to construct a cable-stayed bridge.

1-Staging method

2-push-out method

3-cantilever method

In staging method the bridge is constructed staged from piers to deck to tower and then finally the cables are installed. It offers benefit as there is low clearance required at the underneath of the structure and temporary bents will not interfere with any traffic below the bridge.

In the push-out method the piers are erected first and then large sections of bridge decks are pushed out over the piers on sliding bearing or roller. The deck is pushed out from both abutments towards the center or sometimes, from one abutment all the way to the other abutment. Assembling the components in an erection bay at one or both end of the structure and progressively pushing the components out into the spans as they are completed can simplify construction and diminish costs.

The cantilever method is the one in which the tower is erected first and then deck will be advanced from tower with simultaneously installing cables stays. Because the deck action is like a cantilever it is called cantilever method. The main advantage of this method is that it does not hinder any traffic below it.

### Method of erection is influenced by:

- the stiffness of the pylon cable anchorage system
- viability of installing temporary supports
- maximum unsupported spans permitted by the design
- case of transporting material

## 2.7 DESIGN OF COMPOSITE CABLE-STAYED TRUSS DECKS

The design of cable-stayed bridges with composite truss decks allows superstructures to be lighter than traditional pre-stressed concrete box-girders and less deformable than steel or composite plate girder decks. By anchoring the stays at the top slab level, the stays horizontal compression component is transmitted directly to the slab, since the truss girders are relatively flexible in the longitudinal direction compared to the axial rigidity of the slab. This feature of the deck is actually important for a composite deck, since it reduces the effects of shrinkage and creep of the concrete slab, as in the longitudinal direction each lattice girder acts as a “harmonium”, allowing the deformations and reducing internal forces due to time dependent effects.

## 2.8 USE OF MASTIC ASPHALT

In order to reduce more dead weight of decks mastic asphalt can be applied over a steel plate instead of a concrete deck over the truss.

The main features of this Mastic Asphalt are:

- Durability
- Bleed prevention
- Resistant to deformation
- Self-healing vibration & shock absorbing
- Fully impermeable

## 2.9 ADVANTAGES OF COMPOSITE TRUSS DECKS OVER CONCRETE CABLES-STAYED BRIGDES

• **Decreased Weight**—One of the biggest advantages of composite (steel) is weight savings, which means lower erection costs, since the bridge pieces can be handled with lighter equipment. In addition, for the same span and load, a composite (steel) girder requires less depth than a concrete girder, which can be helpful when constrained by vertical clearance requirements.

• **Faster Erection**—Steel components are made to closer tolerances, which often translates into faster erection.

• **Lighter Foundations**—If the substructure and superstructure are designed properly, the lighter weight of composite deck (steel) will allow lighter foundations than for concrete decks.

• **Structural Efficiency**—Generally, it's easier to make spans continuous for both live and dead loads and to develop composite action with steel designs rather than with concrete ones.

### Life Cycle Costs

Life cycle performance and the long-term durability of steel bridges have been clearly documented. The long-term durability of concrete in bridges remains uncertain.

It's easier to inspect and determine the structural state of a steel bridge where all the components are visible. The long-term durability and cost effectiveness of steel bridges will be further enhanced by the use of high performance steels with weathering capabilities.

At one time or another, much has also been made of problems with fatigue in steel bridges. Critics, though, forget that many older steel bridges were designed and built before engineers had a full understanding of fatigue behavior. What is often overlooked is that these bridges have been repaired with simple bolted field splices without reduction in load capacity or service life.

Historically, decks are the most vulnerable part of a bridge. While replacement of a concrete segmental bridge deck is problematical, steel bridge decks are commonly replaced one lane at a time, permitting uninterrupted but reduced traffic flow.

## 2.10 RECENT DEVELOPMENT

The longest cable-stayed bridge in the world is Russky Bridge, Which is in Viadivostak (Russia). It is having a main span 1104 m. Following Table 2.1. Shows some the cable stayed bridge which are having span more than 500m.

**Table 2.1: Span details of some cable-stayed bridge around the world**

| **S.N** | **Bridge** | **Main Span** | **Country** |
|---|---|---|---|
| 1 | Rusky Bridge | 1104 m | Russia |
| 2 | Sutong Yangtze River Bridge | 1089 m | China |
| 3 | Stonecutters Bridge | 1018 m | China |
| 4 | Edong Yangtze River Bridge | 926 m | China |
| 5 | Tatara Bridge | 890 m | Japan |
| 6 | Normandy Bridge | 856 m | France |
| 7 | Jiujiang Yangtze River Expressway Bridge | 818 m | China |
| 8 | Jingyue Yangtze River Bridge | 816 m | China |
| 9 | Incheon Bridge | 800 m | South korea |

# CHAPTER 3

# METHOD OF ANALYSIS

## 3.1 METHODS

There are two types of method to find the construction stresses at each stage in cable stayed bridge.

1-Using Bridge Wizard

2-Using User Defined Data

**Using Bridge Wizard** – In Bridge wizard we have the options to change the main span and side span lengths but the default bridge design is with three spans having two towers. Here, we can alter the foundation settings and cables dimensions etc. but we cannot put the user defined bridge components.

**Using User Defined Data-** In user defined data we start the bridge modeling with a blank screen over which bridge can be laid out and modification could be made for the axis, reference axis. The main advantage of using it is we can provide each and every value input for the components of bridge. The various components such as deck, pylon and cables; their properties as well as dimensions can be modified to the need of the user.

### 3.2 PROCEDURE ADOPTED IN THE SOFTWARE TO CARRY OUT THE ANALYSIS

- Here, first we have to model the Pylon depending upon the cross section required. The pylon is 10m below the deck and the top of pylon goes 60m above the deck. Now provide the special joints over the pylon, these points will act as the joints through which cables are connected to the pylon and the decks. The first point is taken at 4m below the top of pylon and the other points are taken at the offset of 2m (there are 14 points on the pylon), so last cable is attached to the pylon 56m above the deck.
- After laying out the axis, here we have taken origin at the center of bridge. Here coordinates of start abutment (starting point of bridge) is taken as -135m and the coordinate of end abutment (last point of bridge) is 135m. The bridge length is taken as 270m.

- The bridge component deck is taken, here we have taken RCC box girder deck which is predefined in the software with dimensions (here we can alter the basic dimensions such as overhang, depth and width) . For comparison we have designed a composite truss deck in which we have taken a truss of double channel section (truss has width of 9m and depth of 2.4m). Over the truss we have put a concrete deck of thickness 220mm.
- After making the full bridge, now break the bridge into segments of 9m so that we have in total 30 decks with 56 cables. We have made a symmetrical bridge of 270m having deck length of 9m.
- When the bridge is made into segments, now we put the rigid joints over the segments i.e. we put rigid joints at every 9m spacing on both sides. Through these points we will attach the cables to the deck. (These joints are fixed in all directions i.e. they act as rigid links )
- Now fix the pylon at the base.
- Now put the restrains over the abutments (here we have allowed translational motion along the bridge i.e. we have fixed the motion in all other directions )
-

# CHAPTER 4

# DATA

Analysis is carried for a simple model of cable stayed bridge .Total span of the bridge is 280m. The bridge is symmetrical and the model of the bridge is shown in Fig 4.1 .The width of bridge is 8.4m and here we have taken two deck options, one with RCC Box Girder and other one with composite truss deck which are shown in Fig 4.3 and Fig 4.4 respectively.

Total height of Pylon is 70m with 60m above deck. The Pylon is a Hollow tubular steel section with bottom dia =1.4m and thickness=0.07m and top dia =0.7m and thickness=0.07m. The moment of inertia varies cubically over the length. For the following bridge, cantilever method is used for erection.

## 4.1 DIMENSIONS OF THE BRIDGE

A two span symmetrical cable stayed bridge is analyzed for a concrete deck and a composite steel truss deck. The dimensions and various loadings for the cable stayed bridge are as follows:

Bridge Type : Two span symmetrical cable stayed bridge
Bridge Length : 270m
Bridge Width : 9m
Lanes : 2 lanes

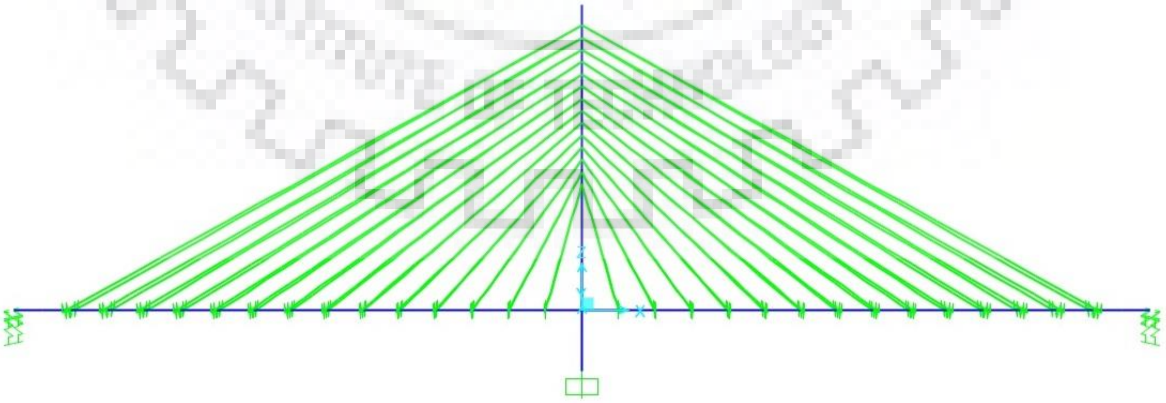


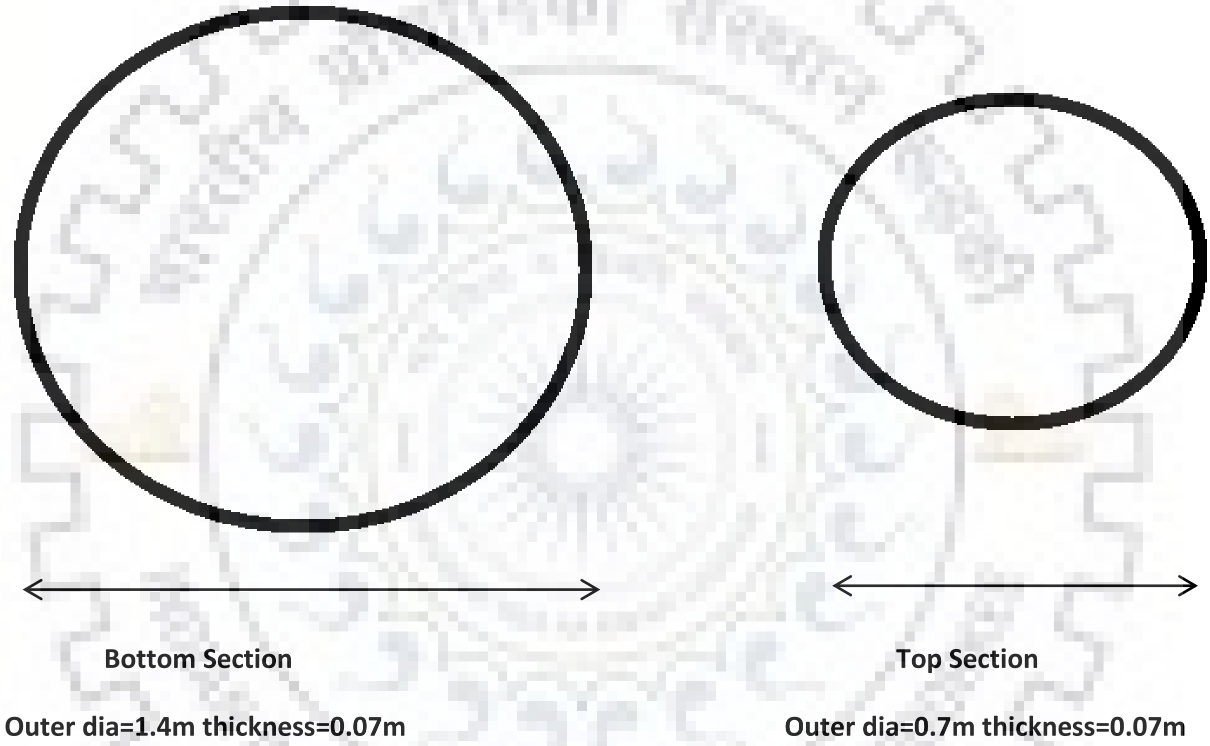
**Fig 4.1 Bridge model**

### 4.2 SECTION PROPERTIES

Following are the section properties of the sections used in the bridge**:**

#### 1) PYLON

Bottom Dia is 1.4m and thickness =.07m while top Dia is 0.7m and thickness =.07m. The moment of inertia varies cubically along the length. **$I = \pi t d^3/12$,** where thickness is 0.07m and diameter varies from 1.4m at bottom to 0.7m at top.

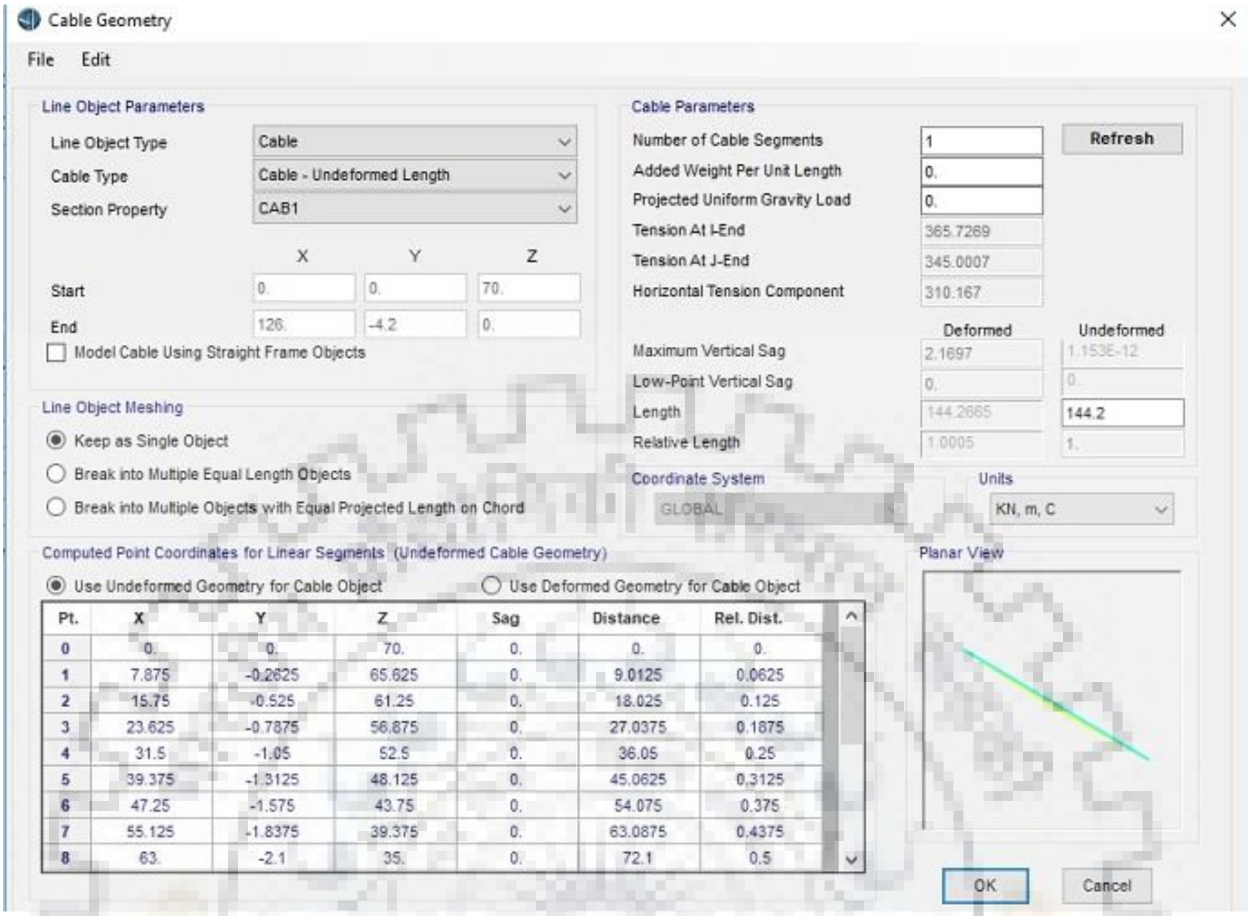


#### 2) CABLES

Area of cables is taken as 3846 mm$^2$.

Poisson ratio is taken as 0.3.

Moment of inertia along any section is taken as 0.



Line Object Parameters

| | | | |
|---|---|---|---|
| Line Object Type | Cable | | |
| Cable Type | Cable - Undeformed Length | | |
| Section Property | CAB1 | | |
| | X | Y | Z |
| Start | 0. | 0. | 70. |
| End | 126. | -4.2 | 0. |

☐ Model Cable Using Straight Frame Objects

Line Object Meshing

● Keep as Single Object
○ Break into Multiple Equal Length Objects
○ Break into Multiple Objects with Equal Projected Length on Chord

Cable Parameters

| | | |
|---|---|---|
| Number of Cable Segments | 1 | |
| Added Weight Per Unit Length | 0. | |
| Projected Uniform Gravity Load | 0. | |
| Tension At I-End | 365.7269 | |
| Tension At J-End | 345.0007 | |
| Horizontal Tension Component | 310.167 | |
| | Deformed | Undeformed |
| Maximum Vertical Sag | 2.1697 | 1.153E-12 |
| Low-Point Vertical Sag | 0. | 0. |
| Length | 144.2665 | 144.2 |
| Relative Length | 1.0005 | 1. |

Coordinate System: GLOBAL

Units: KN, m, C

Computed Point Coordinates for Linear Segments (Undeformed Cable Geometry)

● Use Undeformed Geometry for Cable Object
○ Use Deformed Geometry for Cable Object

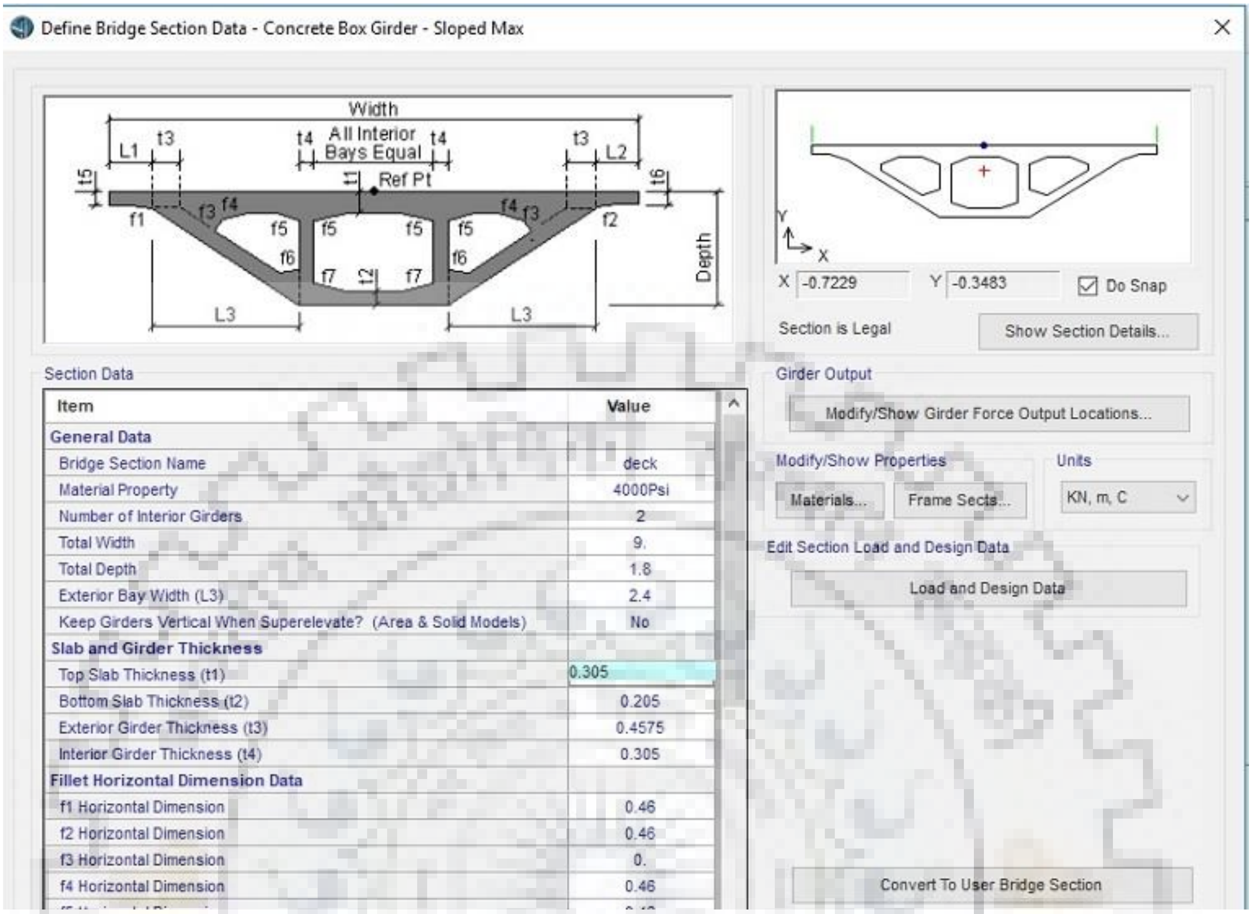
| Pt. | X | Y | Z | Sag | Distance | Rel. Dist. |
|---|---|---|---|---|---|---|
| 0 | 0. | 0. | 70. | 0. | 0. | 0. |
| 1 | 7.875 | -0.2625 | 65.625 | 0. | 9.0125 | 0.0625 |
| 2 | 15.75 | -0.525 | 61.25 | 0. | 18.025 | 0.125 |
| 3 | 23.625 | -0.7875 | 56.875 | 0. | 27.0375 | 0.1875 |
| 4 | 31.5 | -1.05 | 52.5 | 0. | 36.05 | 0.25 |
| 5 | 39.375 | -1.3125 | 48.125 | 0. | 45.0625 | 0.3125 |
| 6 | 47.25 | -1.575 | 43.75 | 0. | 54.075 | 0.375 |
| 7 | 55.125 | -1.8375 | 39.375 | 0. | 63.0875 | 0.4375 |
| 8 | 63. | -2.1 | 35. | 0. | 72.1 | 0.5 |

**Fig 4.2 Cable Geometry**

## 3) DECK

There are two sections we have considered for analysis purpose.

## -RCC BOX GIRDER


Define Bridge Section Data - Concrete Box Girder - Sloped Max

X -0.7229 Y -0.3483 ☑ Do Snap

Section is Legal

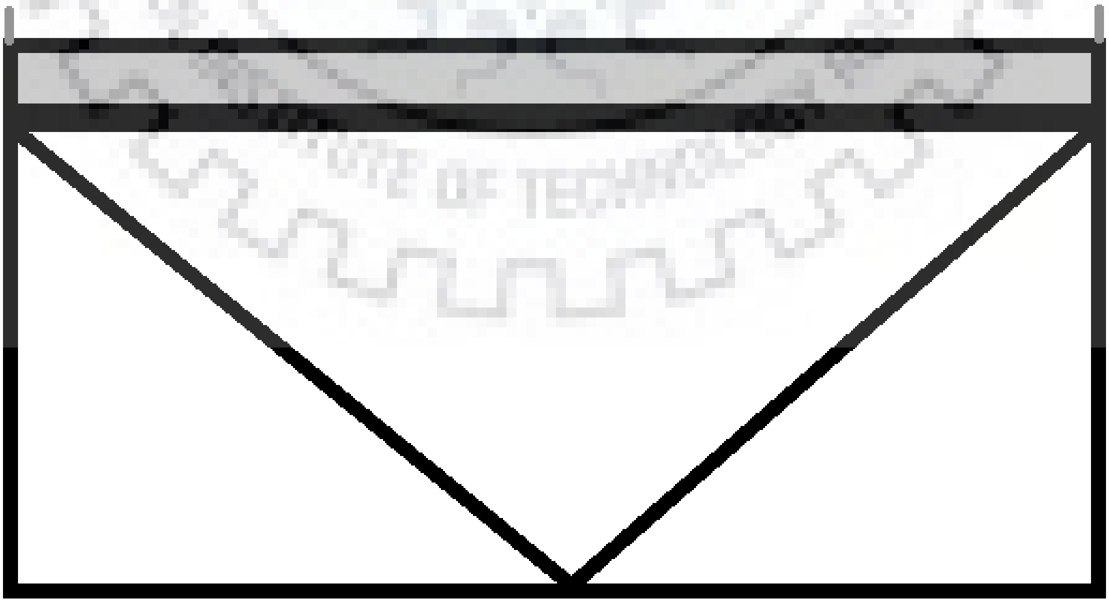
Units: KN, m, C

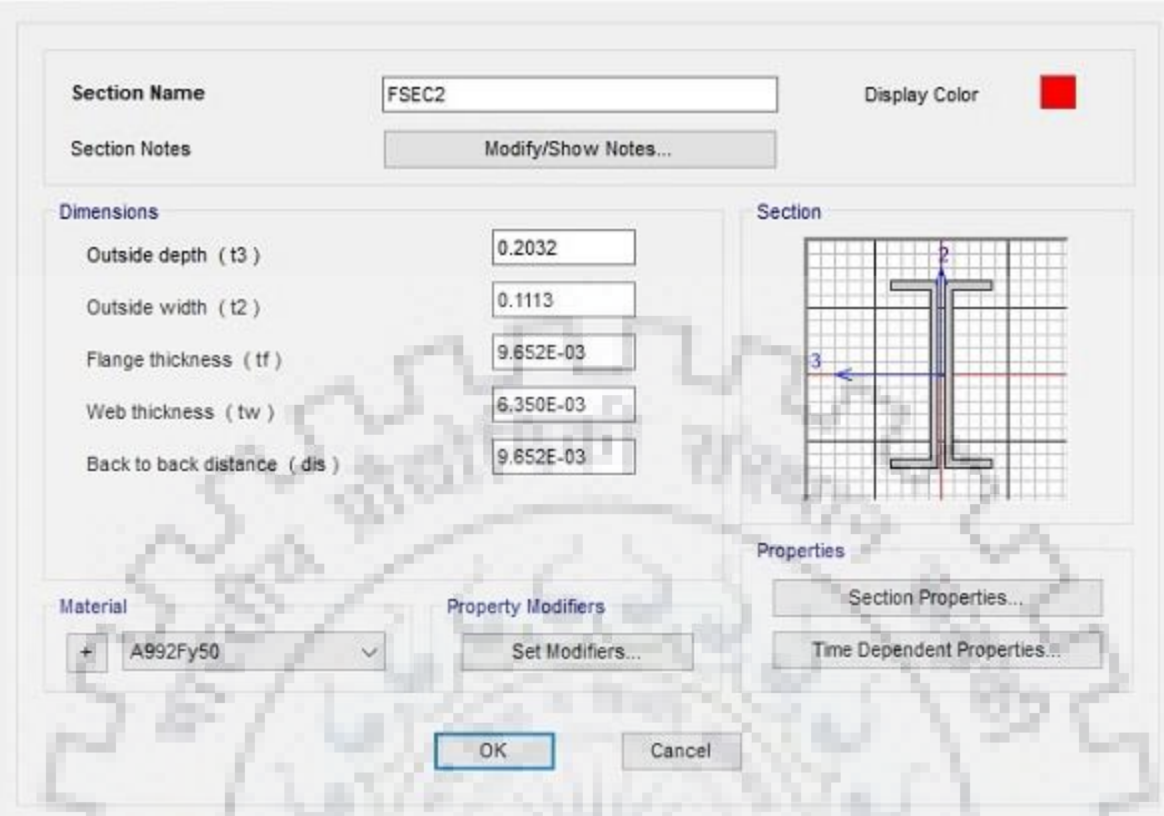
Section Data

| Item | Value |
|---|---|
| **General Data** | |
| Bridge Section Name | deck |
| Material Property | 4000Psi |
| Number of Interior Girders | 2 |
| Total Width | 9. |
| Total Depth | 1.8 |
| Exterior Bay Width (L3) | 2.4 |
| Keep Girders Vertical When Superelevate? (Area & Solid Models) | No |
| **Slab and Girder Thickness** | |
| Top Slab Thickness (t1) | 0.305 |
| Bottom Slab Thickness (t2) | 0.205 |
| Exterior Girder Thickness (t3) | 0.4575 |
| Interior Girder Thickness (t4) | 0.305 |
| **Fillet Horizontal Dimension Data** | |
| f1 Horizontal Dimension | 0.46 |
| f2 Horizontal Dimension | 0.46 |
| f3 Horizontal Dimension | 0. |
| f4 Horizontal Dimension | 0.46 |

Fig 4.3 RCC Box Girder

## -Composite Steel Truss deck





Section Name: FSEC2

Section Notes

Dimensions

Outside depth ( t3 ) 0.2032

Outside width ( t2 ) 0.1113

Flange thickness ( tf ) 9.652E-03

Web thickness ( tw ) 6.350E-03

Back to back distance ( dis ) 9.652E-03

Material: A992Fy50

**Fig 4.5 Truss Section Properties**

**CONCRETE PROPERTIES**

Here software has taken:

Symmetry type= Isotropic material

$E=2.5*10^5 N/mm^2$

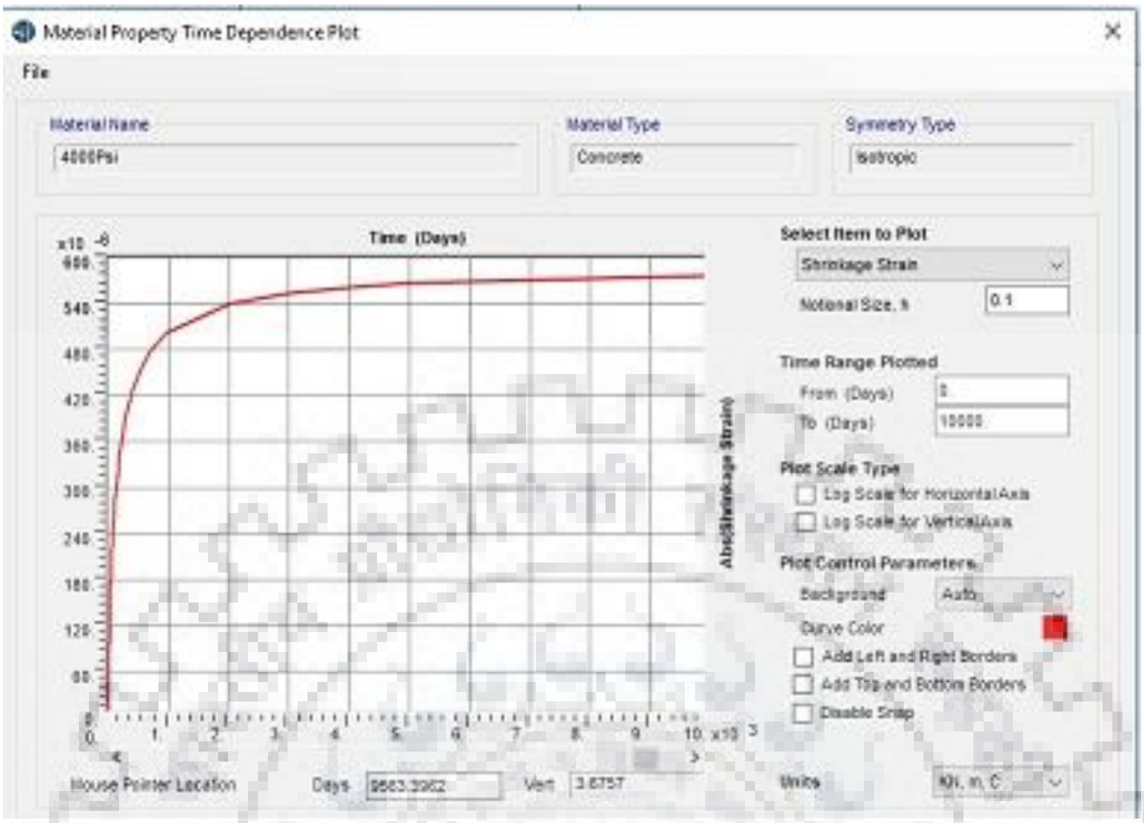
Poisson ratio=0.3

Coefficient of thermal expansion=$9.9*10^{-6}$

Weight per unit volume=23.56

Concrete compressive strength=$37.5 N/mm^2$

**Time dependent Properties of concrete**



Material Name: 4000Psi

Material Type: Concrete

Symmetry Type: Isotropic

Select Item to Plot: Shrinkage Strain

Notional Size, h: 0.1

Time Range Plotted

From (Days): 0.

To (Days): 10000.

☐ Log Scale for Horizontal Axis

☐ Log Scale for Vertical Axis

Background: Auto

Curve Color: 🟥

☐ Add Left and Right Borders

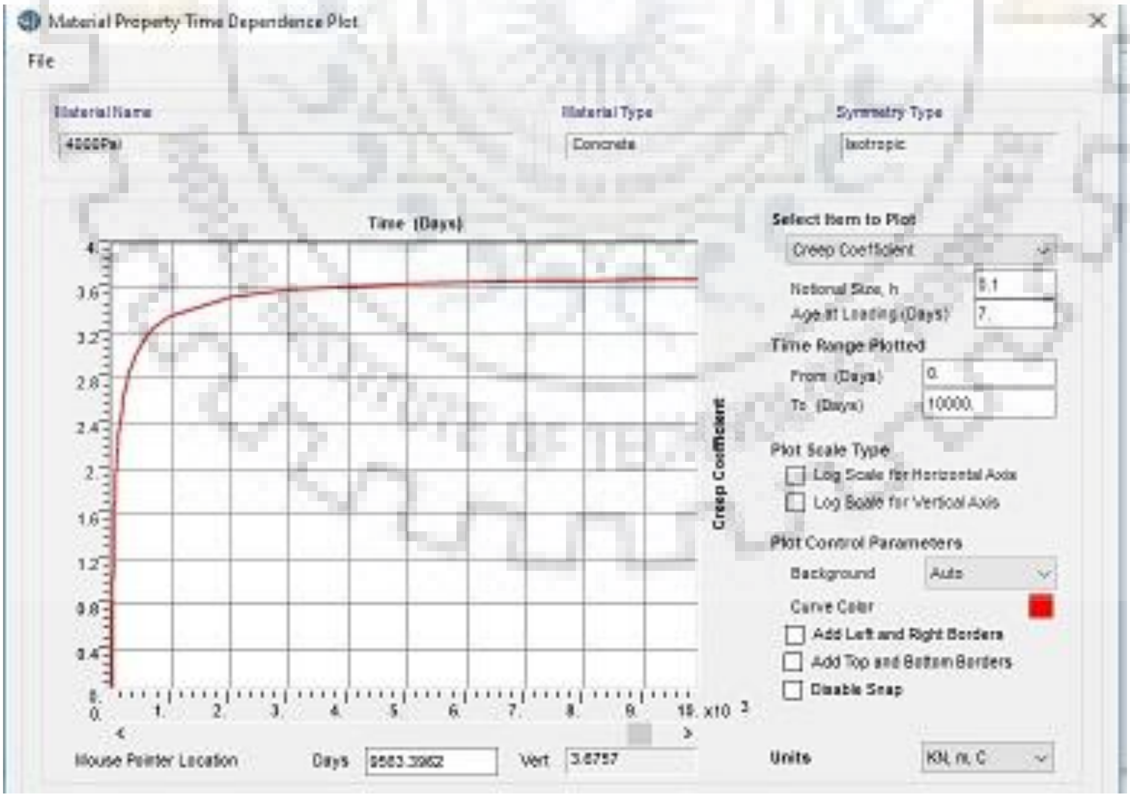
☐ Add Top and Bottom Borders

☐ Disable Snap

Mouse Pointer Location Days: 9583.3962 Vert: 3.6757

Units: KN, m, C

Fig 4.6 Shrinkage Coefficient



Material Name: 4000Psi

Material Type: Concrete

Symmetry Type: Isotropic

Select Item to Plot: Creep Coefficient

Notional Size, h: 0.1

Age at Loading (Days): 7.

Time Range Plotted

From (Days): 0.

To (Days): 10000.

☐ Log Scale for Horizontal Axis

☐ Log Scale for Vertical Axis

Background: Auto

Curve Color: 🟥

☐ Add Left and Right Borders

☐ Add Top and Bottom Borders

☐ Disable Snap

Mouse Pointer Location Days: 9583.3962 Vert: 3.6757

Units: KN, m, C

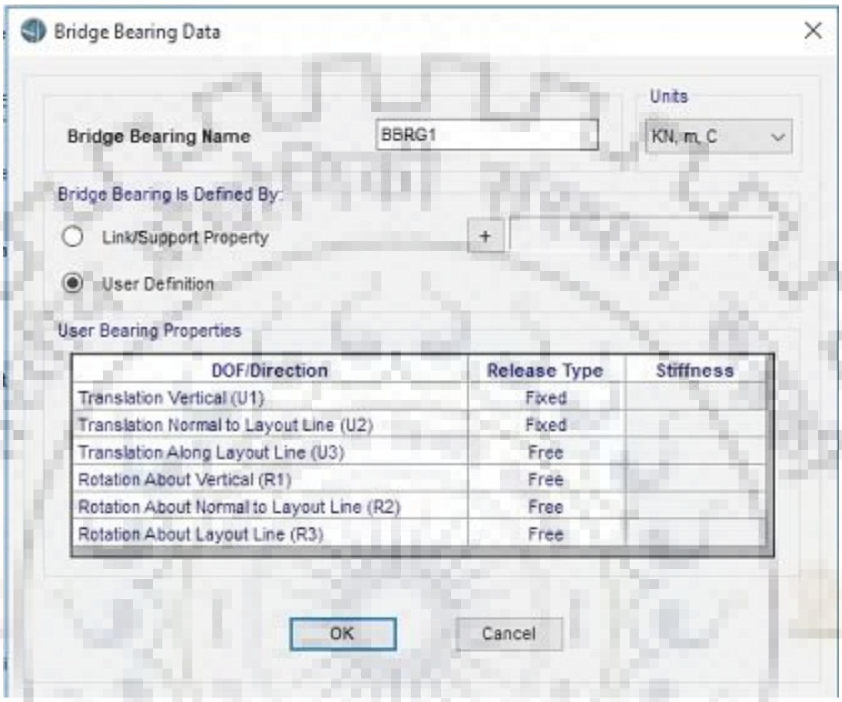
Fig 4.7 Creep Coefficient

**Bearing of abutments**

Translation vertical= Fixed

Translation normal to layout line= Fixed

Translation along the layout line= Free



Bridge Bearing Name: BBRG1

Units: KN, m, C

Bridge Bearing Is Defined By:

○ Link/Support Property

● User Definition

User Bearing Properties

| DOF/Direction | Release Type | Stiffness |
|---|---|---|
| Translation Vertical (U1) | Fixed | |
| Translation Normal to Layout Line (U2) | Fixed | |
| Translation Along Layout Line (U3) | Free | |
| Rotation About Vertical (R1) | Free | |
| Rotation About Normal to Layout Line (R2) | Free | |
| Rotation About Layout Line (R3) | Free | |

Fig 4.8 Bearing of Abutments

**4.3 LOADS**

Self-weight – automatically taken within the program as per the materials defined.

Additional dead loads – pavements, railing and parapits.

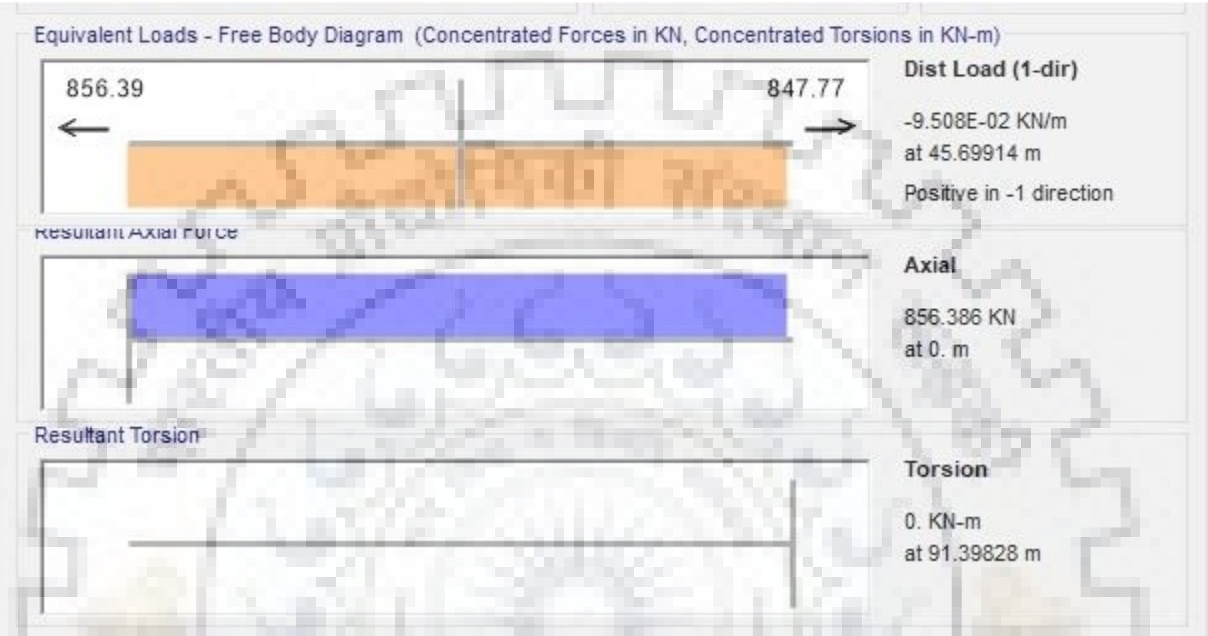
18.289KN/m

# CHAPTER 5

# RESULTS

## 5.1 CABLE FORCES COMPUTED

**Cable forces computed on bridge with RCC Box Girder deck**



Equivalent Loads - Free Body Diagram (Concentrated Forces in KN, Concentrated Torsions in KN-m)

Dist Load (1-dir)

-9.508E-02 KN/m
at 45.69914 m
Positive in -1 direction

Resultant Axial Force

Axial

856.386 KN
at 0. m

Resultant Torsion

Torsion

0. KN-m
at 91.39828 m

Fig 5.1 Load on cable1

Equivalent Loads - Free Body Diagram (Concentrated Forces in KN, Concentrated Torsions in KN-m)

Dist Load (1-dir)

-0.16 KN/m
at 18.98447 m
Positive in -1 direction

Resultant Axial Force

Axial

1204.016 KN
at 0. m

Resultant Torsion

Torsion

0. KN-m
at 37.96893 m

Fig 5.2 Load on cable3

Equivalent Loads - Free Body Diagram (Concentrated Forces in KN, Concentrated Torsions in KN-m)

Dist Load (1-dir)

-0.13 KN/m
at 26.98907 m
Positive in -1 direction

Resultant Axial Force

Axial

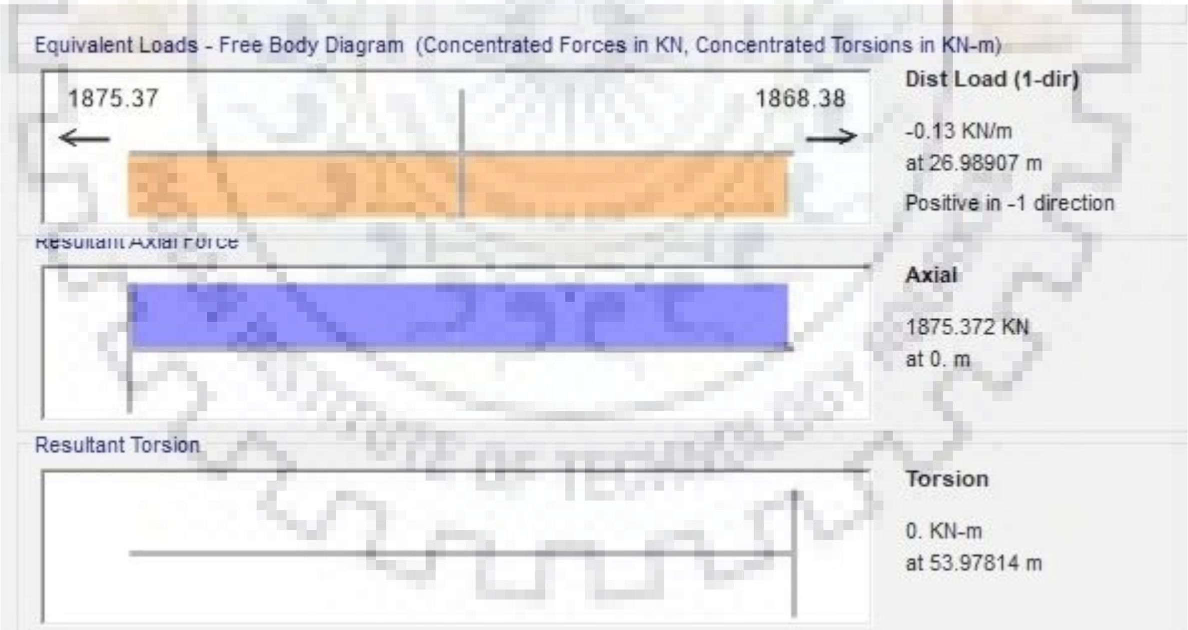
1809.91 KN
at 0. m

Resultant Torsion

Torsion

0. KN-m
at 53.97814 m

Fig 5.3 Load on cable7



Equivalent Loads - Free Body Diagram (Concentrated Forces in KN, Concentrated Torsions in KN-m)

Dist Load (1-dir)

-0.13 KN/m
at 26.98907 m
Positive in -1 direction

Resultant Axial Force

Axial

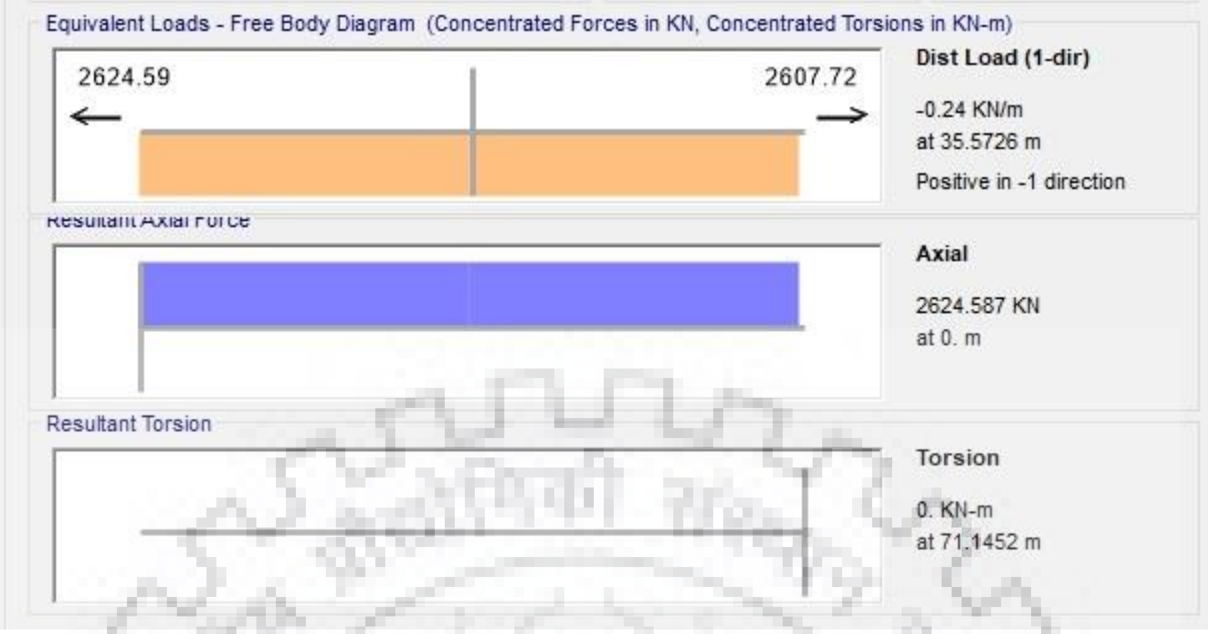
1875.372 KN
at 0. m

Resultant Torsion

Torsion

0. KN-m
at 53.97814 m

Fig 5.4 Load on cable 9



Equivalent Loads - Free Body Diagram (Concentrated Forces in KN, Concentrated Torsions in KN-m)

**Dist Load (1-dir)**

-0.24 KN/m
at 35.5726 m
Positive in -1 direction

Resultant Axial Force

**Axial**

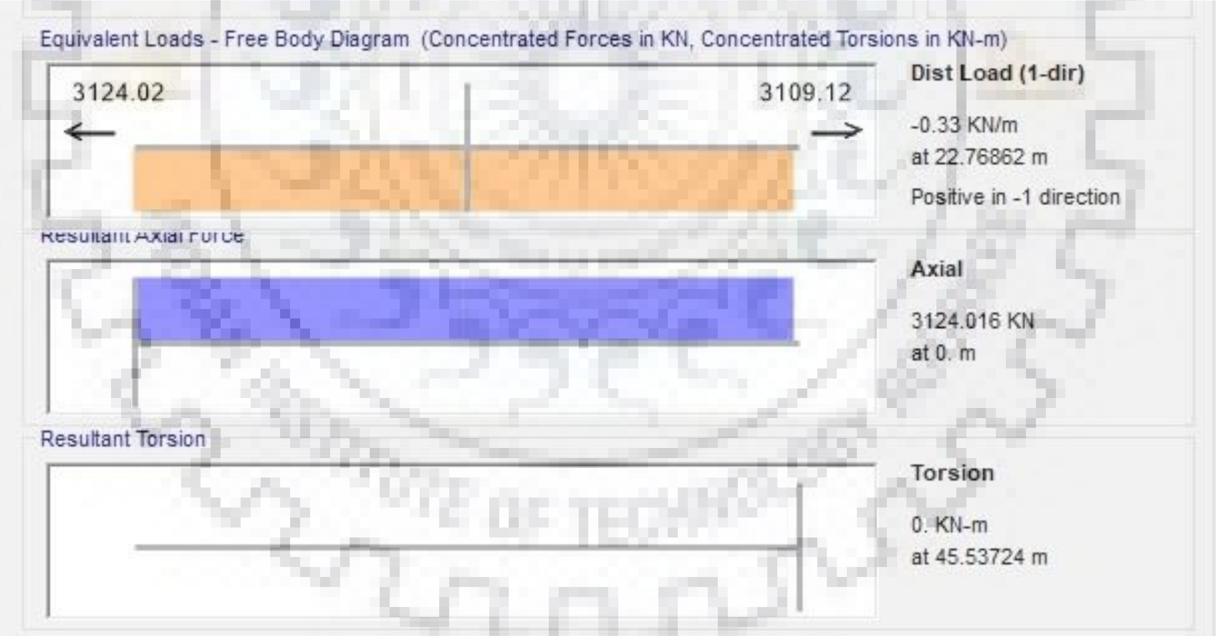
2624.587 KN
at 0. m

Resultant Torsion

**Torsion**

0. KN-m
at 71.1452 m

Fig 5.5 Load on cable 13



Equivalent Loads - Free Body Diagram (Concentrated Forces in KN, Concentrated Torsions in KN-m)

**Dist Load (1-dir)**

-0.33 KN/m
at 22.76862 m
Positive in -1 direction

Resultant Axial Force

**Axial**

3124.016 KN
at 0. m

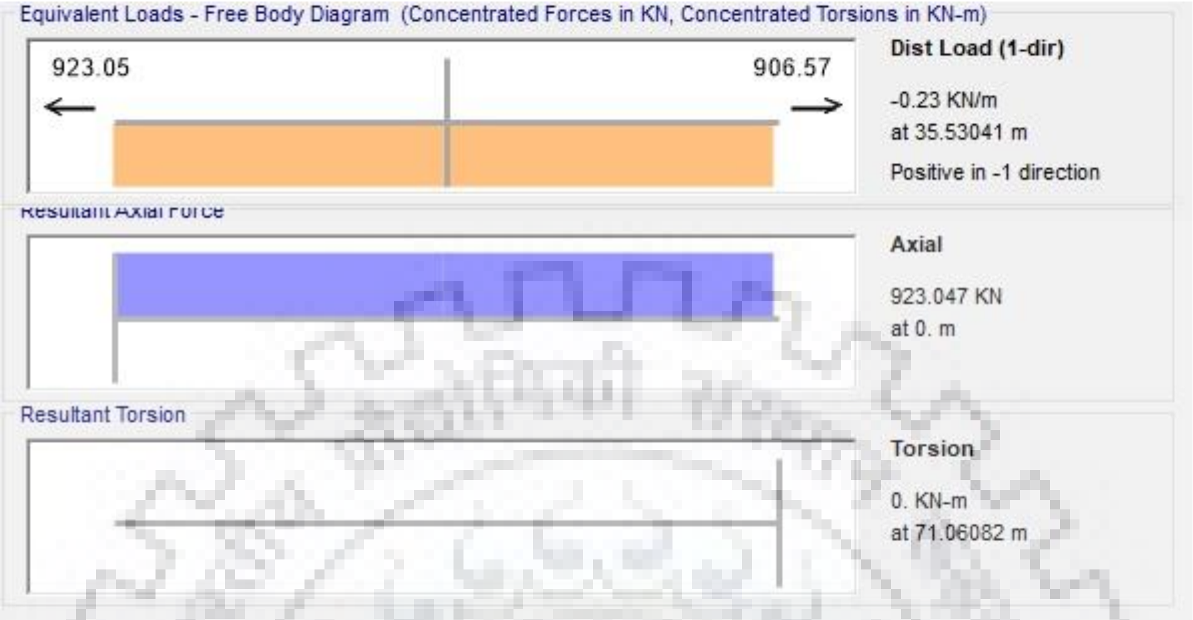
Resultant Torsion

**Torsion**

0. KN-m
at 45.53724 m

Fig 5.6 Load on cable 14

**Cable forces computed on bridge with composite truss deck**



Equivalent Loads - Free Body Diagram (Concentrated Forces in KN, Concentrated Torsions in KN-m)

923.05

906.57

Dist Load (1-dir)

-0.23 KN/m
at 35.53041 m
Positive in -1 direction

Resultant Axial Force

Axial

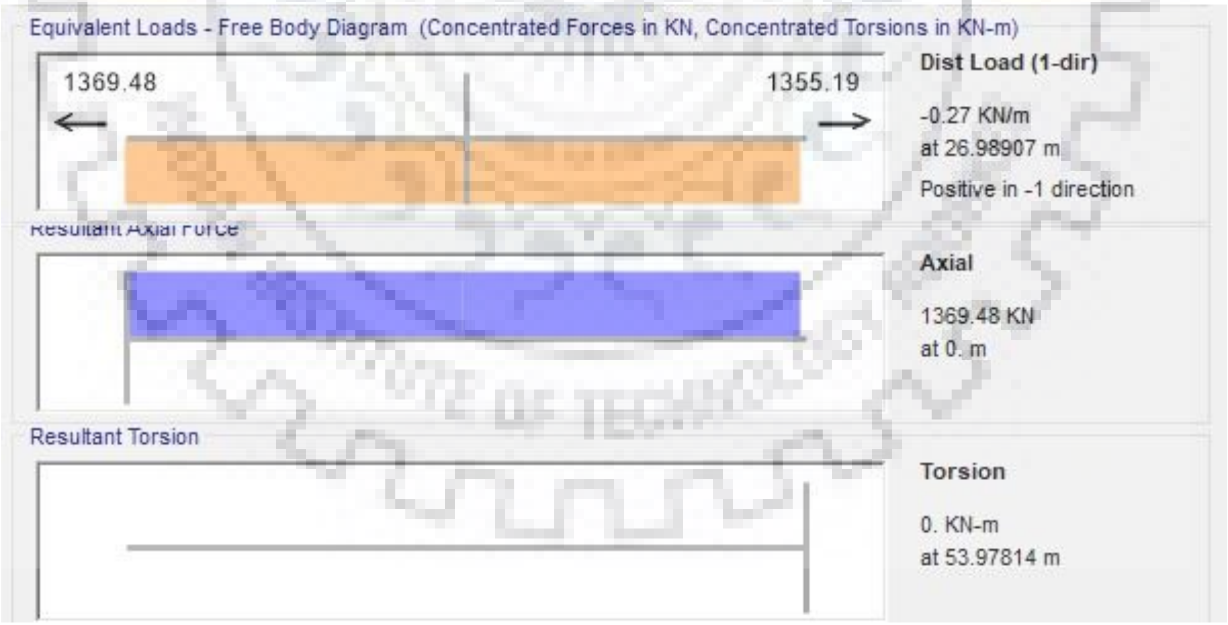
923.047 KN
at 0. m

Resultant Torsion

Torsion

0. KN-m
at 71.06082 m

Fig 5.7 Load on cable 3



Equivalent Loads - Free Body Diagram (Concentrated Forces in KN, Concentrated Torsions in KN-m)

1369.48

1355.19

Dist Load (1-dir)

-0.27 KN/m
at 26.98907 m
Positive in -1 direction

Resultant Axial Force

Axial

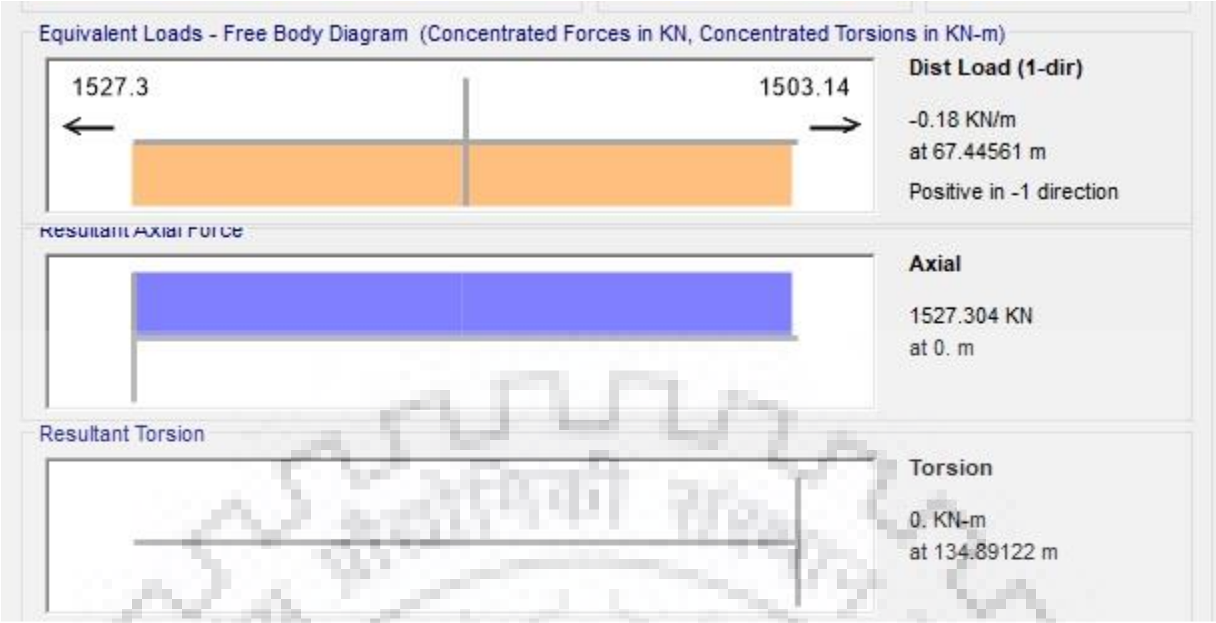
1369.48 KN
at 0. m

Resultant Torsion

Torsion

0. KN-m
at 53.97814 m

Fig 5.8 Load on Cable 7



Equivalent Loads - Free Body Diagram (Concentrated Forces in KN, Concentrated Torsions in KN-m)

**Dist Load (1-dir)**

-0.18 KN/m
at 67.44561 m
Positive in -1 direction

Resultant Axial Force

**Axial**

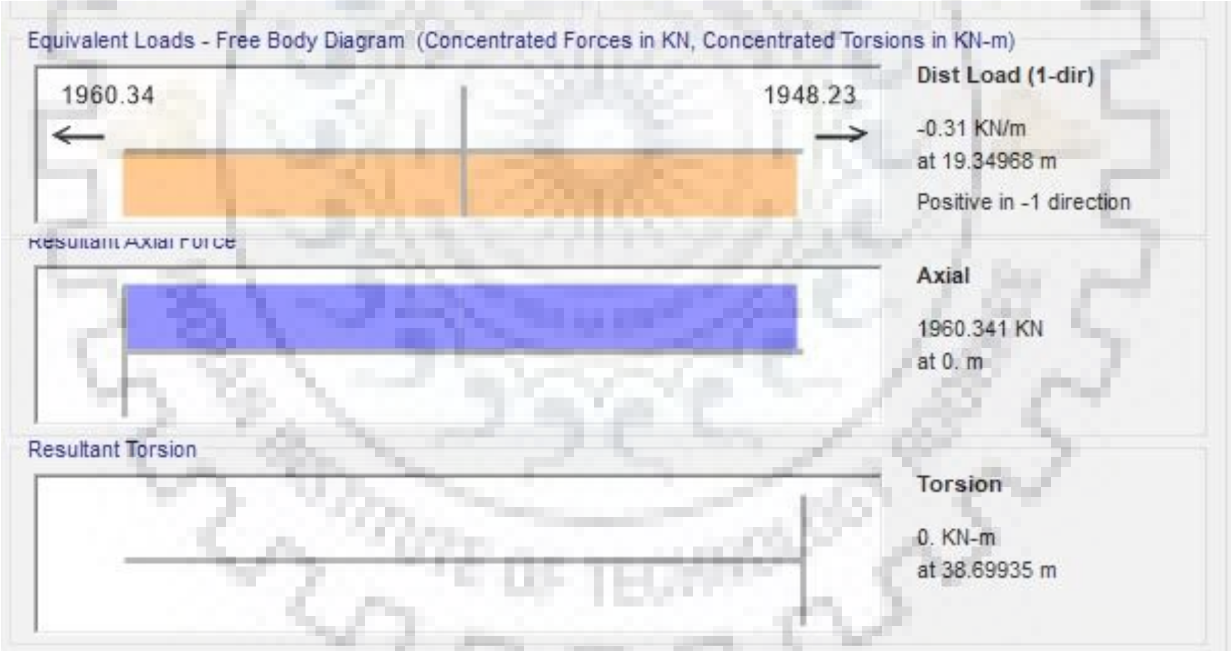
1527.304 KN
at 0. m

Resultant Torsion

**Torsion**

0. KN-m
at 134.89122 m

Fig 5.9 Load on Cable 9



Equivalent Loads - Free Body Diagram (Concentrated Forces in KN, Concentrated Torsions in KN-m)

**Dist Load (1-dir)**

-0.31 KN/m
at 19.34968 m
Positive in -1 direction

Resultant Axial Force

**Axial**

1960.341 KN
at 0. m

Resultant Torsion

**Torsion**

0. KN-m
at 38.69935 m

Fig 5.10 Load on Cable 13

## 5.2 COMPARISON OF CABLE FORCES COMPUTED

| Cable no. | Tension in RCC Box Girder (KN) | Tension in composite truss deck (KN) | PERCENTAGE DIFFERNECE |
|---|---|---|---|
| 1. | 856.39 | 658 | 23.16 |
| 2. | 972.50 | 712 | 26.78 |
| 3. | 1204.02 | 923.05 | 23.33 |
| 4. | 1311.83 | 1016.44 | 22.51 |
| 5. | 1625.28 | 1235.38 | 23.98 |
| 6. | 1641.95 | 1271.84 | 22.54 |
| 7. | 1809.91 | 1369.48 | 24.33 |
| 8. | 1811.87 | 1416 | 21.84 |
| 9. | 1875.37 | 1527.3 | 18.56 |
| 10. | 1985.48 | 1541 | 22.38 |
| 11. | 2147.81 | 1705.91 | 20.57 |
| 12. | 2256.01 | 1723.51 | 23.6 |
| 13. | 2624.59 | 1960.34 | 25.3 |
| 14. | 3124.06 | 2313.67 | 25.94 |

### 5.3 BENDING MOMENT DIAGRAMS

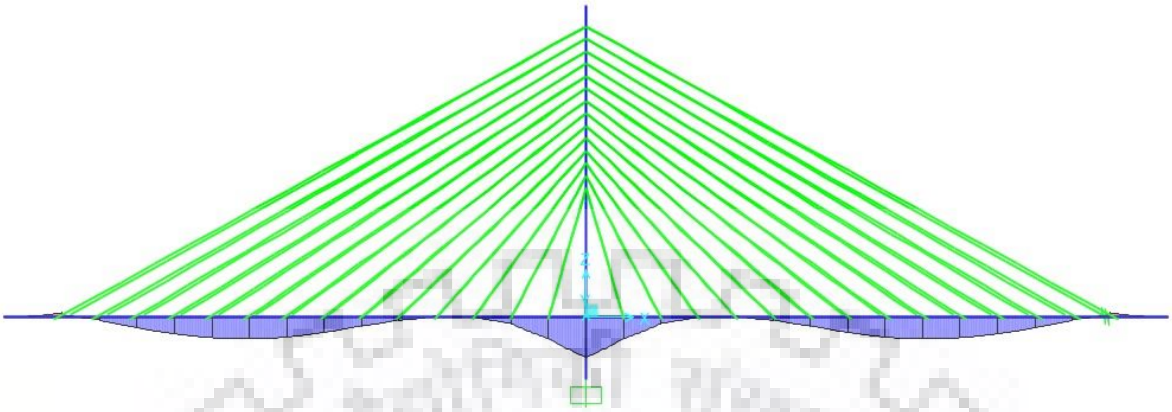


**Fig 5.11 BMD for RCC Box Girder**

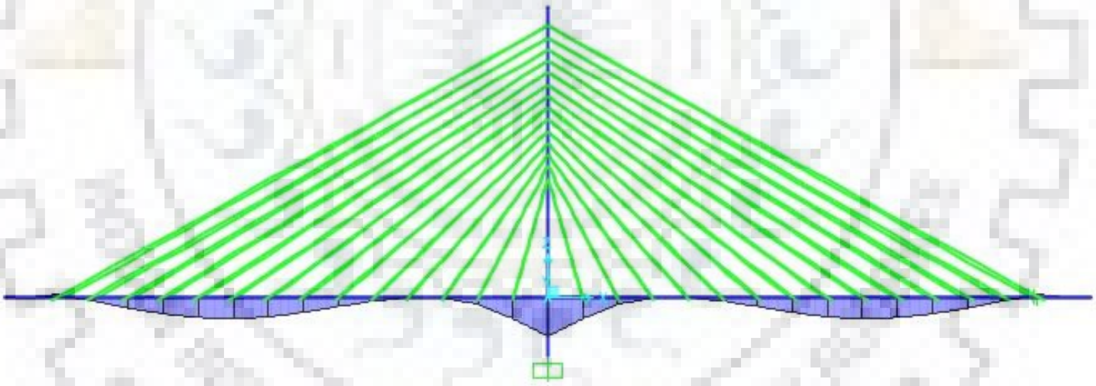


**Fig 5.12 BMD for Composite Truss Deck**

### 5.4 COMPARISON OF MAX BENDING MOMENT

Max bending Moment generated:

- For RCC Box Girder =
- For Composite Truss deck =

### 5.5 AXIAL FORCE DIAGRAMS OF PYLON

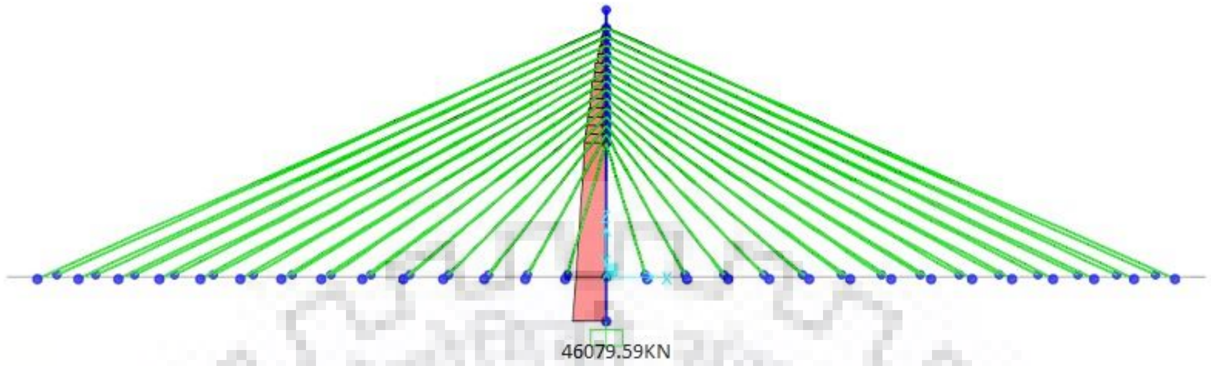


Fig 5.13 Axial Force Diagram for RCC Box Girder

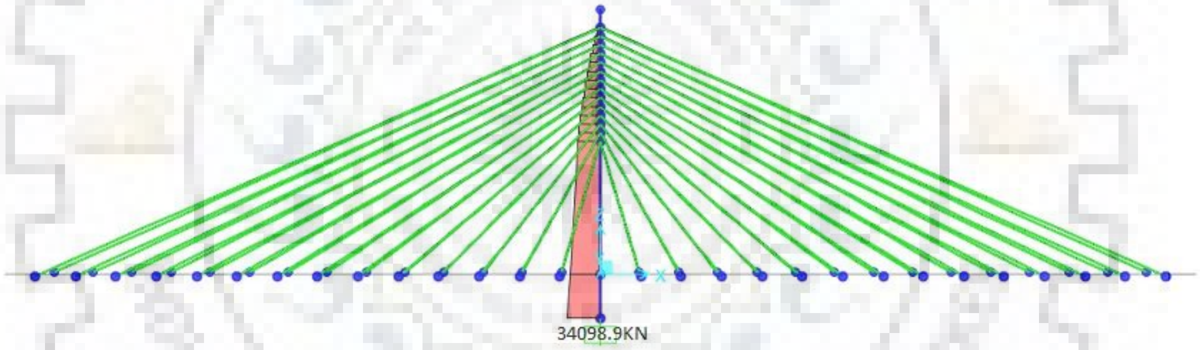


Fig 5.14 Axial Force Diagram for Composite Truss Deck

### 5.6 COMPARISON OF AXIAL FORCE

Max axial force generated in the pylon:

- For RCC Box Girder = 46079.59 KN
- For Composite Truss Girder = 34098.902 KN

# CHAPTER 6

# CONCLUSIONS

Following conclusions can be made from the present study:

1. The increase on span required lighter and more resistant deck cross-sections.
2. By adopting thin and lighter decks, we can induce savings in the deck, cables, piers and foundations.
3. Field bolted splice provides fast and simple connection between almost identical modules, ensuring maximum repetition of pre-fabricated deck components and construction procedures.
4. For cable-stayed bridge with medium spans (up to 600 m), composite steel-concrete deck may be considered as the most efficient and competitive solution.
5. The lighter decks could be made by providing a Mastic Asphalt layer over a steel plate of nominal thickness.

# CHAPTER 7

# REFERENCES

1. Niels J. Gimsing, “Cable supported bridges – concept and design”, ISBN 0 471 969397.
2. Influence of cable arrangement on the design of a cable-stayed bridge, W.P.J. Langedijk, thesis work august 2001, Delft University of Technology, The Netherlands.
3. Designing and modeling of bridge using CSI Tutorials.
4. Report IABSE Conference Seoul 2001, volume 84 “Cable-supported bridges – challenging technical limits”.
5. Gimsing, N.J, Proc. 3rd International Meeting on composite bridges, Madrid 2001.
6. M. Hassan. Optimum Design of Cable-Stayed Bridges. PhD thesis, The University of Western Ontario, 2010.
7. W. Long, MS. Troitsky, and ZA Zielinski. Optimum Design of Cable Stayed Bridges.Journal of Structural Engineering and Mechanics,
8. Svensson, H. 1999. The Development of Composite Cable-Stayed Bridges. Cable-Stayed Bridges: Past, Present and Future. IABSE Conf. Proc, Malmö.
9. Taylor, P. 1994. Composite cable-stayed bridges Intern. Conf. AIPC-FIP Proc.Vol.1. Deauville.
10. Pedro, J.J.O.; Reis, A.J. 2010. Nonlinear analysis of composite steel-concrete cable-stayed bridges. Engineering Structures.
11. Hague,S.T. 2003. Steel/concrete composite design for long span bridges. TRB 2003 annual meeting.
12. Reis, A. et al. 1999. Cable-Stayed Bridges for Urban Spaces. Cable-Stayed Bridges: Past, Present and Future. IABSE Conf. Proc., Malmö.
13. Vähäaho, J. et al. 1996.The Cable-stayed bridges in the Finnish lake and river landscape. IABSE 15th Congress Report. Copenhagen.
14. Sörensen, L.T.; Thorsen, N.E. 1999. The Øresund Bridge, Erection of the Cable-Stayed Span. Cable-Stayed Bridges: Past, Present and Future. IABSE Conf. Proc.