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COMPARISON BETWEEN THE BEHAVIOUR OF THE DIFFERENT SHAPES OF PYLON IN THE LINEAR STATIC ANALYSIS OF CABLE STAYED BRIDGE USING SAP2000

Hussain Hararwala[1], Savita Maru[2]

[1,2] Department of Civil Engineering, Govt. Engineering College, Ujjain - 456001, India
e-mail: hussainh13@gmail.com, savitamaru@yahoo.com

ABSTRACT: This paper deals with the linear static analysis of Cable Stayed Bridges with different shapes of pylons under its own weight. The cable stayed bridge is one of the modern bridges which were built for the longer spans. Therefore, there is a need of study on the behaviour of the pylons before implementing it in actual practice. For this study, the different shapes of Pylons have been compared with the bridge span dimension and other parameters are kept unvarying. The different shapes of Pylons considered for Cable Stayed Bridge are A type, H type, inverted Y type, Single pylon, Diamond shaped, Pyramid Shaped, U-Shaped & Hexagonal Shaped. The height of the pylon remains same for all the models of Cable Stayed Bridge with different shapes of Pylons. The modelling of bridge has been prepared using SAP 2000 software. For this study, the arrangement of cable stay has been taken as semi fan type as well as fan type. The study reveals the following points regarding to the behaviour of Pylons such as the Axial Force in Pylon, Bending Moment in Pylon, and Shear Force in Pylon & Deflection at the top of Pylon. This study will be helpful for make an appropriate choice for the shape of Pylon used for Cable Stayed Bridge in particular conditions.

KEYWORDS: Cable Stayed Bridge, Pylons, Semi Fan & Fan Type Arrangement of Cable Stays, Dead Load, Linear Static Analysis, SAP 2000.

1 INTRODUCTION

1.1 General

Many constructions of cable stayed bridges have been auspiciously completed around over the world from last two decades of the 20th century. Due to their highly substantial display & incomparably appropriated structural materials, cable stayed bridges have been taken as one of the most popular type of bridges in last decades. With the increase in the length of span of bridges, the modern cable stayed bridges are more sufficient & extensible strong enough to the wind forces as compare to ever. A typical cable stayed bridge consists of deck with one or two pylons uplifted by the piers or the walls in the middle of the span. The cables are connected at some angle to the girder to provide additional supports. The vertical loads on the deck are carried by the cable stays which are in tension. The tensile forces in the stay cables influence horizontal compression in the deck. The Pylon transfers the forces developed in the cables to the foundation through vertical compression. The design of the bridge is figure out such that the static horizontal forces resulting from dead load are almost balanced to minimize the height of the pylon. Cable stayed-bridges have a low centre of gravity, which makes them capable in opposing the effects of earthquakes. Cable stayed bridges provide outstanding architectural display due to their small diameter of cables and exclusive upper part of structure. It can be constructed by cantilevering action from the tower i.e. the cables act both as temporary and permanent supports to the bridge deck. The advantage of cable-stayed bridges is that it can be built with any number of towers.

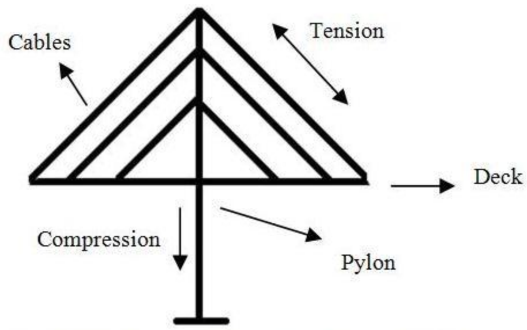


Figure 1. An illustration of typical cable stayed bridge

In last few years, several cable-stayed bridges have been constructed with different shapes of pylons such as H-shaped, A-shaped, Diamond shaped, Inverted Y-shaped etc. as shown in figure below which results in a great interest to determine the behaviour of different shapes of pylon used for cable stayed bridges. Therefore, the behaviour of the bridge can be computed by performing the analysis using finite element programmes.

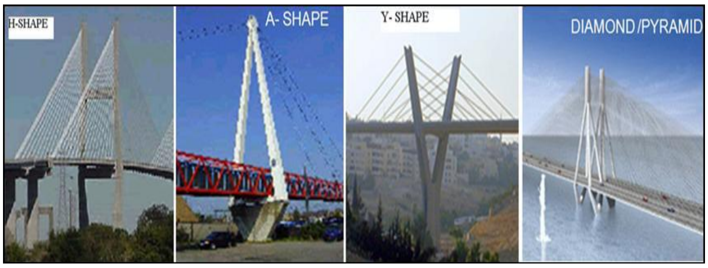


Figure 2. Different tower/pylons available for cable stayed bridge

The purpose of the pylon in the Cable Stayed Bridge is to support the cable system and transfer forces to the foundations. They are loaded with high compressions and bending moments that depend on the stay cable formation and the deck-pylon support conditions. Pylons can be made of steel or concrete, being the latter generally more economic considering similar stiffness conditions. Thus, the behaviour of the pylons will be conditioned by several aspects, and in addition to the previous idea, the geometric shape of the pylons which depends on the applied loads, cable-stay system and aesthetic conditions, is a very important aspect. The behaviour of the different shapes of the Pylon was studied by the computational analysis using software SAP 2000. SAP is finite element based program and is recognized by international community for the research purpose. SAP program will generate the various results like joint displacements, joint forces, joint reactions, base reactions, deck force, forces in cables and pylons, moments in deck & pylons, mode shapes etc.

1.2 Components of cable stayed bridge

Different components of cable supported bridge like deck, pylon, and cable-stays are discussed below:

1.2.1 Bridge deck

The deck or road bed is the roadway surface of a cable-stayed bridge. The deck can be made of different materials such as steel, concrete or composite steel-concrete. The choice of material for the bridge deck determines the overall cost of the construction of cable stayed bridges. The weight of the deck has significant impact on the required stay cables, pylons, and foundations. As the composite steel-concrete deck is composed of structural edged girders. These girders are attached by transverse steel beams. The precast reinforced concrete deck is supported by these main girders. This type of composite steel-concrete deck has more advantages as follow:

- The own weight of a composite deck is less than a concrete deck.
- The light steel girders can be erected before applying the heavy concrete slab.
- The stay cables have more resistance against rotation anchoring to the outside steel main girders.
- The redistribution of compression forces due to shrinkage and creep onto the steel girders is minimized by using the precast slab.

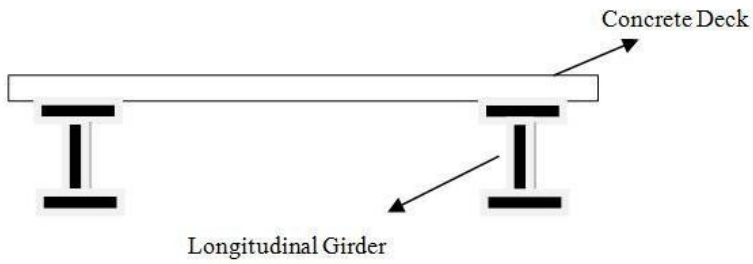


Figure 3. Typical Section of Concrete Deck

1.2.2 Pylon

Pylons of cable stayed bridges are aimed to support the weight and live load acting on the structure. There are several different shapes of pylons for cable stayed bridges such as Diamond shaped pylon, Diamond shaped pylon, and Inverted-Y shaped pylon, A-frame pylon, H-shaped pylon and Single pylon. They are chosen based on the structure of the cable stayed bridge (for different cable arrangements), aesthetics, length, and other environmental parameters.
On the basis of materials, the Pylons can be classified into two categories:

a) Steel Pylon
b) Concrete Pylon

a) Steel Pylons: Early cable-stay pylon designs were predominantly constructed as steel boxes, and bridges took the form of a steel portal frame, which was intended to provide transverse restraint to the stay system. However, this restraint is largely unnecessary as sufficient transverse restraint can be provided within the stay system itself.

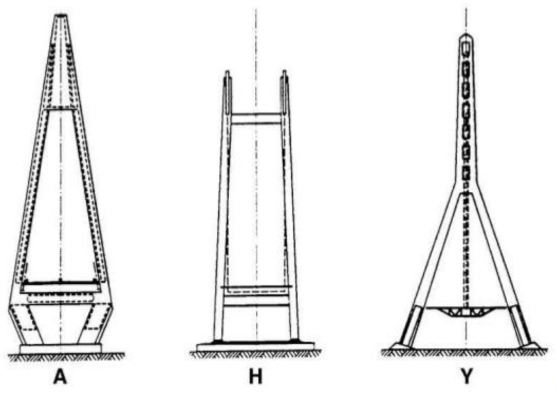


Figure 4. Different shapes of pylons used for cable stayed bridges

b) Concrete Pylons: Concrete is very efficient when supporting loads in axial compression. Advances in concrete construction and modern formwork technology have made the use of concrete increasingly competitive for pylon construction, despite the much greater self-weight when compared with a steel alternative. Concrete has proved particularly adaptable to the more complex forms of pylon.

1.2.3 Cables

Cables are one of the main parts of a cable-stayed bridge. They transfer the dead weight of the deck to the pylons. These cables are usually post-tensioned based on the weight of the deck. The cables post-tensioned forces are selected in a way to minimize both the vertical deflection of the deck and lateral deflection of the pylons. There are four major types of stay cables including, parallel-bar, parallel-wire, standard, and locked-coil cables. The choice of these cables depends mainly on the mechanical properties, structural properties and economical criteria.

Different types of cable-stayed bridges are discussed based on the arrangement of stay cables including fan, and semi-fan as depicted.

a. Fan arrangement

In this pattern, all the stay cables are attached to a single point at top of each pylon. The relatively steep slope of the stay cables results in smaller cable cross section in comparison to the harp type. Moreover, the horizontal cable forces in the deck in this arrangement are less than the harp type (Bernard et al., 1988). However, by increasing the number of the stay cables, the weights of the anchorages increase and attaching the stay cables to anchorage becomes difficult. Therefore, the fan patterns are suitable only for moderate spans with a limited number of stay cables.

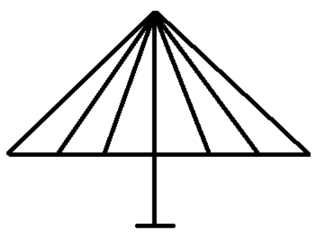


Figure 5. Fan arrangement of cable stays

b. Semi Fan arrangement

Several modern cable-stayed bridges have been built around the world using semi-fan arrangement due to its efficiency. In this system, the cables are distributed over the upper part of the pylon, which are more steeply inclined close to the pylon. The world largest cable-stayed bridge (Sutong Bridge in Jiangsu, China) was designed as a semi-fan arrangement using A-shape pylons. The semi-fan arrangement has better appearance in comparison to the fan arrangement.

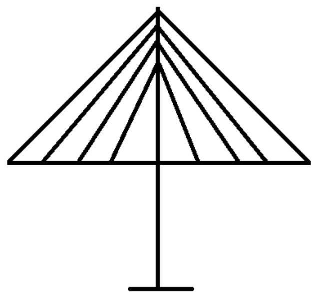


Figure 6. Semi Fan arrangement of cable stays

1.3 Preliminary design

The cable-stayed bridge, incorporating multiple stays, is a highly redundant structure where the deck acts as a continuous beam with a number of elastic supports with varying stiffness. The deck and pylon of the cable-stayed bridge are both in compression and therefore bending moments in these elements will be increased, due to second-order effects, arising from the deflection of the structure (the P Delta effect). With most cable-stay structures these secondary moments will not exceed 10% but the application of these moments will be non-linear. This means that the use of influence lines, which rely on the principles of linear superposition, can only be used as an approximate method of determining the stay loads. According to ICE manual for Cable Stayed Bridge, the following points needs to be considered before designing the Cable Stayed Bridge. They are as follows:

- Back Span to Main Span Ratio - When establishing the conceptual arrangement of the bridge it is important that the ratio between the back span and the main span be less than 0.5 in order to give a clear visual emphasis to the main span. This ratio is equally as important structurally as it influences the uplift forces at the anchor pier and the range of load within the back stay cables supporting the top of the pylon. The back stay cables have the largest stress amplitude and may therefore be critical when considering the fatigue endurance of the stays. Live load located within the main span will increase the anchor forces within the back stays and live load within the back span will decrease the anchor forces. Where there are no intermediate piers supporting the back span and there are no physical constraints imposed by the terrain, the foundations or any other requirements dictating the location of the abutment pier, this ratio can be determined by the balance of the live load moments in the main span. Leonhardt and Zellner (1980) have determined the back span to main span ratio with respect to these parameters. For a highway structure where the live loading is typically 0.25 of the dead load the theoretical ratio is 0.38. However, this calculation ignores the bending stiffness of the deck. When this stiffness is taken into consideration the optimum length of the back span is more likely to be between 0.4 and 0.45 of the main span.

- Stay Spacing - The spacing of the stay anchors along the deck should be compatible with the capacity of the longitudinal girders and limit the stay size so that the breaking load is less than 25-30 MN. The capacity of the longitudinal girders is likely to be critical when considering the case of an accidental severance of a stay (stay out condition). The spacing should also be small enough so that the deck may be erected by the free cantilevering method without the need for auxiliary stays or supports. These requirements will effectively limit the spacing within the range 5–15 m. The heavier concrete construction will require the smaller stay spacing while the larger stay spacing is more suitable for steel or steel composite construction.
- Deck Stiffness - The deflection of the longitudinal girders is primarily determined by the stay layout. It is reasonable therefore that the depth of the longitudinal girders should be kept to a minimum, subject to sufficient area and stiffness being provided to carry the large compressive forces without buckling. When checking the longitudinal girders for the stay out condition the PTI Recommendations (2001) stipulate that the structure should provide for the replacement of any individual stay with a controlled reduction of the live load during any stay exchange. The structure must also be capable of withstanding the accidental loss of any individual stay without structural instability occurring.
- Pylon Height - The height of the pylon will determine the overall stiffness of the structure. As the stay angle (α) increases, the required stay size will decrease and the height of the pylon will increase. However, the deflection of the deck will increase as each stay becomes longer. Both the weight of the stay and the deflection of the deck become a minimum when the expression $1/(\sin\alpha \times \cos\alpha)$ is also a minimum. Therefore the most efficient stay is that with a stay inclination of 45 degree. In practice the efficiency of the stay is not significantly impaired when the stay inclination is varied within reasonable limits, which may be taken as 25–65 degrees. The stay inclined at 25 degrees will be the outer stay connecting the anchor pier and the deck panel adjacent to the centre of the main span to the top of the pylon. The stay inclined at 65 degrees will be that located nearest the pylon. This implies an optimum ratio of pylon height above the deck (H) to main span (L) is between 0.2 and 0.25.
- Deck Form - The selection of the deck form will usually be based on an economic evaluation of the possible alternatives. The primary factors

influencing the choice of deck will be the length of the main span and deck width. Other factors such as the cost of foundations, the local availability of materials or labour skills and the competitive conditions at the time of tendering may also have influence over the costs. A study by Svensson (1995) has undertaken an economic comparison of the various types of deck sections within the span range 200–1000 m. The study concluded that a concrete deck section is the most economic deck section within the span range 200–400m and the composite deck above 400 m. However, the difference in cost is marginal close to the division between the two deck forms, and local factors are often decisive in the final choice. The study also does not consider the influence of any variation in the width of deck. The use of concrete construction in wide decks where there are six or more traffic lanes requires substantial crossbeams and the additional weight of these will penalise those spans near the upper end of the economic range.

Non-linear material properties will also influence the design. Apart from the behaviour of the stays under load, all concrete and concrete and steel composite decks will be subject to the effects of creep and shrinkage during both construction and the service life of the completed structure. It can therefore be seen that a preliminary design by manual calculation should be considered as the first stage in an interactive design process, providing a basis for a more rigorous analysis.

2 STUDY UNDERTAKEN

It was always key point of research for choice of strength and durability of the structure and economical structural system. The pylons or towers play an important role in the strength and durability of cable stayed bridge. Hence it is very necessary to determine the study of behaviour of different shapes of pylon before implementing it in actual practice which gives an idea for the adequate strength of cable stayed bridge in a particular condition. On the other hand, for economical system, different types of materials can be used for pylons either it can be of concrete or of steel. For designers or structural engineers, these particular studies are very essential for predetermination of behaviour of cable stayed bridge under different conditions.

The specific objective of this study is that it gives an initial idea to the designer or structural engineer that which shape of pylon should be taken into account for the adequate strength and durability of cable stayed bridge having main span of 350 m. For better enhancement, the following points are taken into consideration:

a. The arrangement of cable stays i.e. semi fan arrangement as well as fan arrangement.
b. The different cross sections of pylons i.e. rectangular & circular.

This thesis will provide the comparison between the different shapes of pylons of different materials. Thus from the results obtained, one can easily identify the most suitable shape of pylon and the material used for pylon for better strength and durability and for economical structural system.

The modelling & analysis of the Cable Stayed Bridge will have been carried out by the software SAP 2000. In the analysis of the bridge the most important part is modelling. Different components of bridges like deck, pylon, cables etc must be modelled as per the actual forces they are subjected. The dimension of bridge which was taken in consideration here was situated at river Ravi in Jammu Kashmir, India. The various shapes of pylon have been considered for the analysis are Diamond shaped, A-shaped, H-shaped, Inverted Y-shaped, single pylon shaped, Pyramid Shaped, U-Shaped & H-Shaped. There are different types of cable-stayed bridges which are distinguished on the basis of the arrangement of stay cables; they are called as harp arrangement, fan arrangement, and semi-fan arrangement. In this analysis, the considerations of the fan & semi fan arrangement of cables have been taken, & the analyses will be computed for concrete pylons as well as for steel pylons. The pylons which have been modelled for analysis purpose having their section rectangular as well as circular. Different elements of cable supported bridge like deck, pylon, and cable-stays are discussed below:

a) Bridge deck: Deck is modelled as an area section with varying depths at side span and main span for balancing the member.
b) Pylon: Pylon and pylon beam is modelled as a frame section where the pylon with the vertical orientation and pylon beam with horizontal orientation.
c) Cables: Cables of the cable stayed bridge are modelled as cable element. The cable elements act as axial load transfer element only. For particular this analysis, the spacing between cables which are attached at pylons kept as 2 m. for semi fan type pylons used in each Cable Stayed Bridge. The cable is modelled as a straight guyed structure.

The modelling of cable stayed bridge in SAP is prepared as per following procedure:

- MODELLING PROCEDURE ON SAP

  a) Draw the geometry of the bridge either by inserting coordinates.
  b) Define the materials and sections for the members
  c) Define the loading values to be applied on the structures.
  d) Now assign the defined section as the members.
  e) After assigning everything, set the analysis to be carried out and press run analysis.

SAP program will generate the various results like joint displacements, joint

forces, joint reactions, base reactions, deck force, axial forces in cables and pylons, bending moment in pylon, shear force in pylon, mode shapes etc.
The details of Cable Stayed Bridge i.e. Span configuration, Details of Deck & Pylon are given below. The details for all the components of Cable Stayed Bridge which remains same for all the shapes of Pylon in Cable Stayed Bridge are shown in Table 2.1. The details of cross sectional properties of various components of bridge shall be mentioned in Table 2.2 while the different shapes and dimensions of pylons will be discussed in Table 2.3.

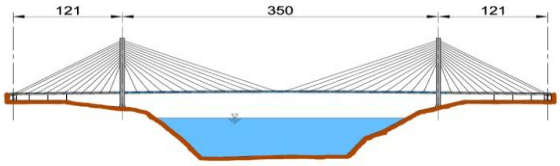


Figure 7. Typical bridge span configuration

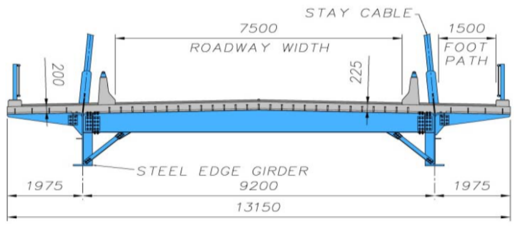


Figure 8. Main span typical section

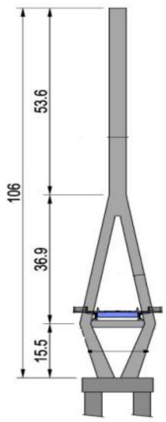


Figure 9. Pylon geometry

Table 2.1 Details of the components of cable stayed bridge

S. No.	Component	Material	Shape	Dimension (in m.)
1.	Cable	Steel	Circular	0.40
2.	Deck at Side Span	Concrete	Rectangular	Depth- 0.300 Length- 121
	Deck at Main Span	Concrete	Rectangular	Depth- 0.225 Length- 350
3.	Side Span End Cross Beams	Steel	I-Section	1 x 0.5 T_f= 0.15 T_w= 0.15
4.	Main Span End Cross Beams	Steel	I-Section	0.9 x 0.5 T_f= 0.15 T_w= 0.15
5.	Side Span Girders	Steel	I-Section	0.7 x 0.3 T_f= 0.1 T_w= 0.1
6.	Main Span Girders	Steel	I-Section	0.6 x 0.2 T_f= 0.1 T_w= 0.1
7.	Pylon Beam	Concrete	Rectangular	Depth- 3 Width- 3.5

Table 2.2 Details of cross sectional properties of various components

S. No.	Component	Cross Sectional Area (m^2)	Moment of Inertia (m^4)	Shear Area (m^2)	Torsion Constant
1.	Cable	0.125	6.36×10^{-3}	0.2545	0.0127
2.	End Cross Beams	.225	0.0317	0.15	1.59×10^{-3}
3.	Intermediate Cross Beams	0.1	5.58×10^{-3}	0.07	2.7×10^{-4}
4.	Girders	0.045	1.03×10^{-3}	0.025	3.356×10^{-5}
5.	Pylon Beam	10.5	1.7747	3.667	2.6979

Table 2.3 Details of dimensions and other parameters for different shape of Pylons

S. No.	Pylon Shape	Material	Shape	Dimension (in m.)
1.	'Diamond' Shape	Concrete	Hollow Rectangular Hollow Circular	
2.	'H' Shape	Concrete	Hollow Rectangular Hollow Circular	
3.	'Inverted Y' Shape	Concrete	Hollow Rectangular Hollow Circular	
4.	'A' Shape	Concrete	Hollow Rectangular Hollow Circular	(2.5 x 3.5) – (0.5 x 0.4) $\frac{\pi}{4}(3.34)^2$ - $\frac{\pi}{4}(0.5)^2$
5.	'Double Diamond' Shape	Concrete	Hollow Rectangular Hollow Circular	
6.	'Single Pylon' Shape	Concrete	Hollow Rectangular Hollow Circular	
7.	Hexagonal Shape	Concrete	Hollow Rectangular Hollow Circular	
8.	'U' Shape	Concrete	Hollow Rectangular Hollow Circular	

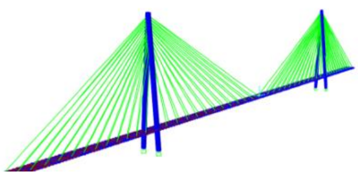
Any structure is analysed with static method or dynamic method. Selection of an appropriate analysis method depends on a number of factors. These factors are purpose of analysis, importance of structure, methods available for analysis, type of bridge or structure and soil conditions. For the final analysis the most common approach is to model either a half or the entire structure as a space frame. The pylon, deck and the stays will usually be represented within the space frame model by 'bar' elements. The stays can be represented with a small inertia and a modified modulus of elasticity that will mimic the sag behaviour of the stay. In addition to carrying out the analysis of the completed structure the model can be used in the stage-by-stage erection analysis.

There are several computer packages commercially available that incorporate the facility to consider the non-linear behaviour of a structure and are suitable for the analysis of the cable-stayed bridge.

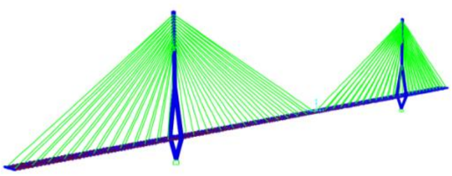
Static elastic analysis is done for all the structures. For ordinary structures static analysis is sufficient, but for important structures particularly for bridges dynamic analysis should be carried out. Also structures have irregular configuration and varying subsurface condition is analysed by dynamic analysis.

The Cable Stayed Bridge must be analyzed and designed for the loadings which are subjected to it. Here, only dead load has been considered which is subjected to it for the purpose of comparatively analysis of the bridge. In the analysis, the dead load consists of the self weight of the structural forms such as pylon, deck, footways etc as well as the self weight of the cables. The dead load has been defined as in the form of gravity load which acts in the direction normal to gravity. For the purpose of analysis, the M25 grade of concrete has been used for deck, pylons and footways while Fe415 grade of steel has been used for the cables and for steel pylons. The properties of M25 grade of concrete and Fe415 of steel has been already predefined in the software which automatically calculates the dead load of the structure after assigning the properties to members.

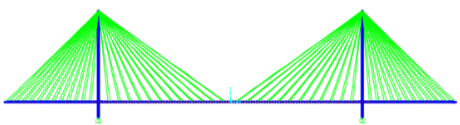
The various 3D models have been prepared of Cable Stayed Bridge with different shapes of pylons which are mentioned above in the table using SAP2000. Some of the models which have been prepared for the purpose of analysis are shown below:



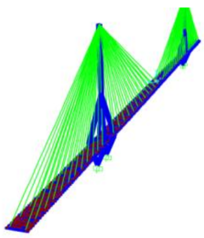
'A' Semi Fan Shaped



Diamond Semi Fan Shaped



Single Pylon Fan Shaped



Pyramid Shaped

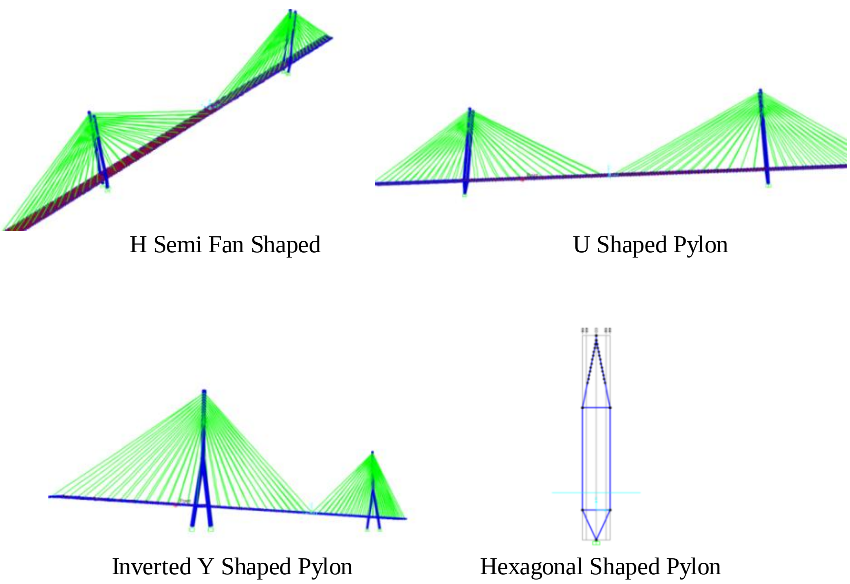


Figure 10. Different 3D models of Cable Stayed Bridge with different types of Pylons

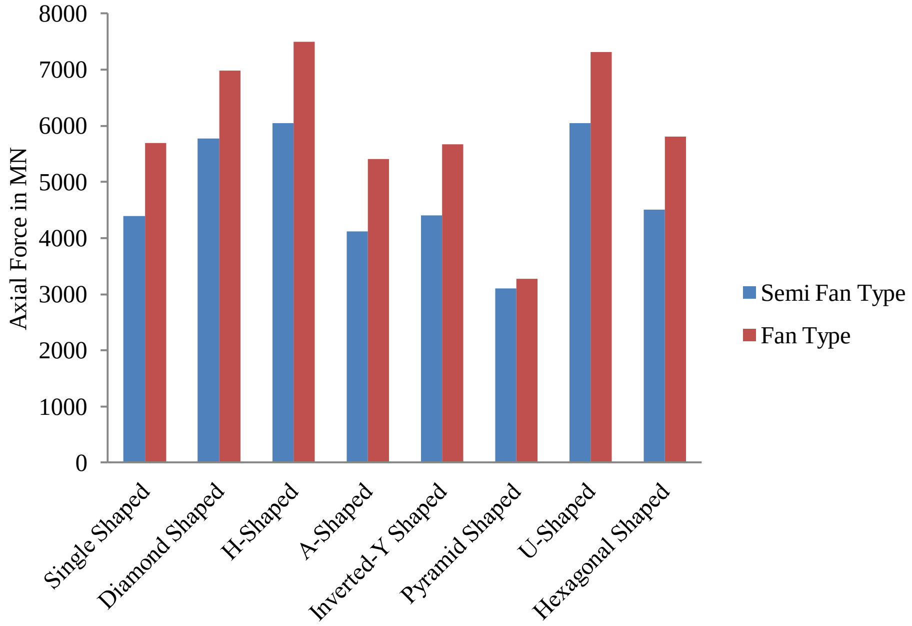
3 RESULTS

The detailed analysis has been done for the various shapes of Pylons and outputs have been carried out in the tabular form and have been plotted. The results which have been plotted give an idea about the comparison between different shapes of Pylons. The output part contains Axial Force in Pylon, Shear Force in Pylon, and Bending Moment & Deflection in Pylon.

Comparison of Axial Force, Bending Moment & Shear Force for different shapes of Pylon:

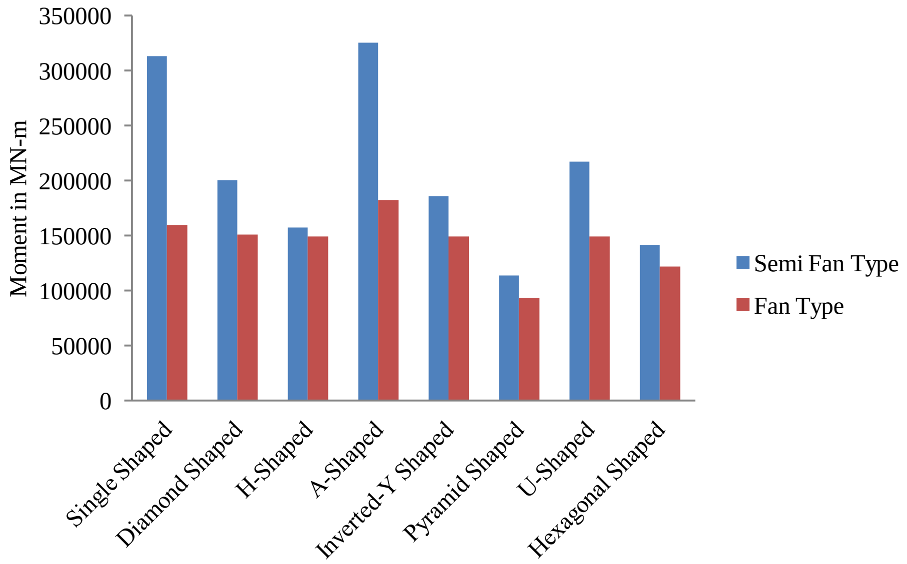
- Rectangular Concrete Pylon:

a) <u>For Axial Force:</u>



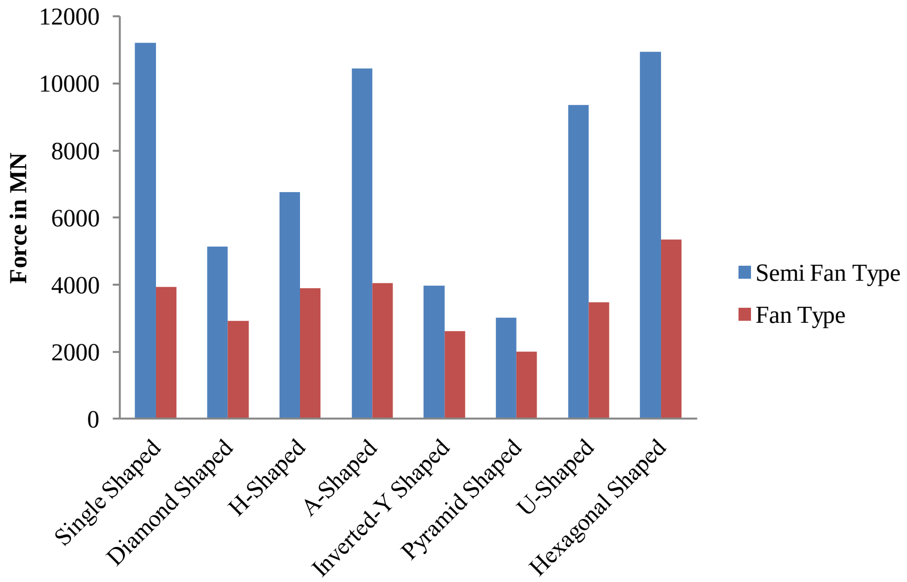
Graph 3.1. Comparison of axial forces for different shapes of rectangular concrete pylons

b) <u>For Bending Moment:</u>



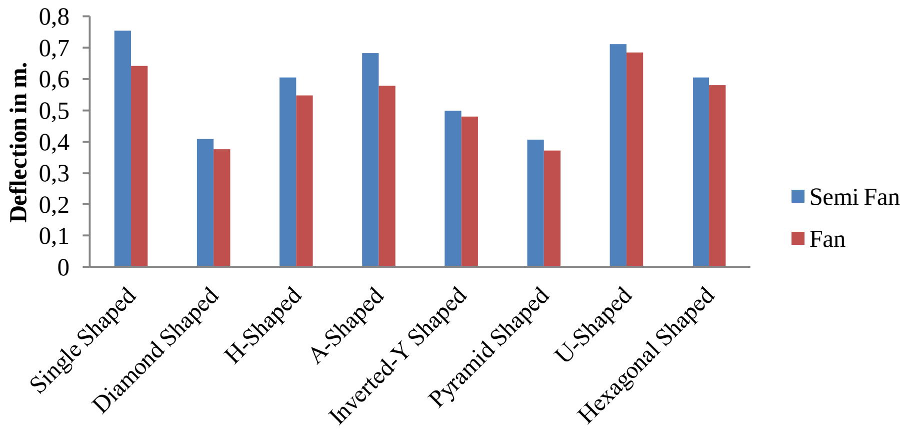
Graph 3.2. Comparison of bending moments for different shapes of rectangular concrete pylons

c) For Shear Force:



Graph 3.3. Comparison of shear force for different shapes of rectangular concrete pylons

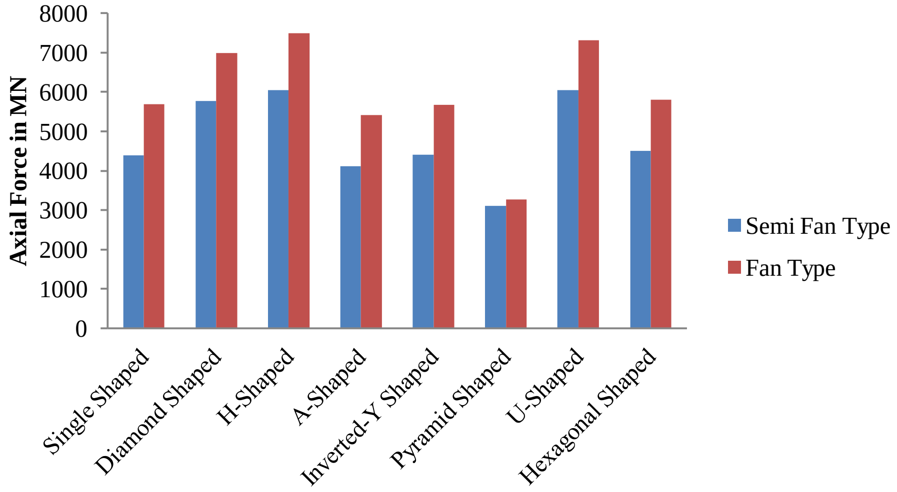
d) For Deflection at the top of Pylon:



Graph 3.4. Comparison of deflections for different shapes of rectangular concrete pylons

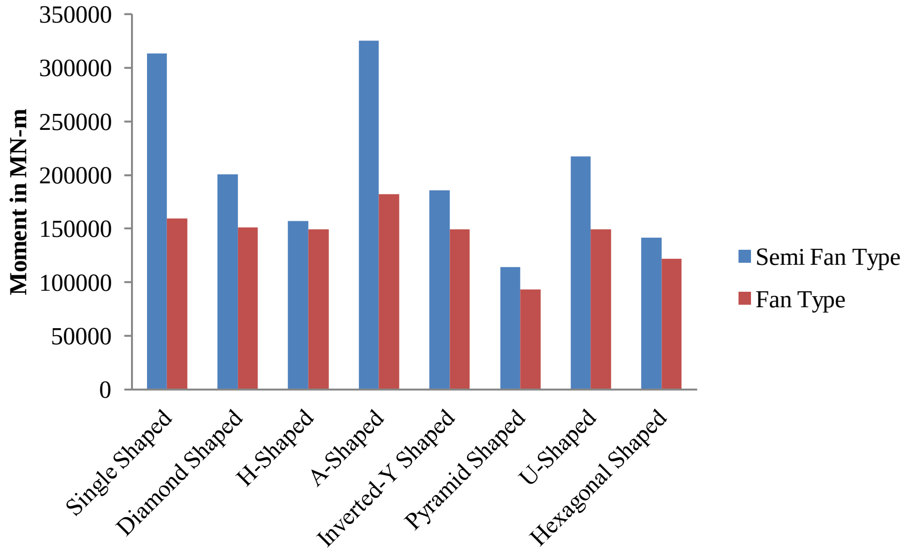
- Circular Concrete Pylon:

  a) <u>For Axial Force:</u>



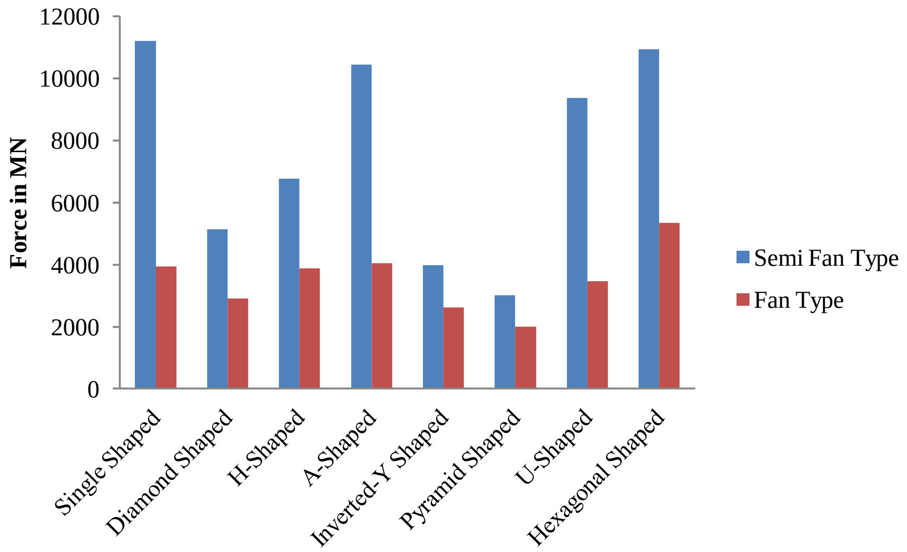
Graph 3.5. Comparison of axial forces for different shapes of circular concrete pylons

  b) <u>For Bending Moment:</u>



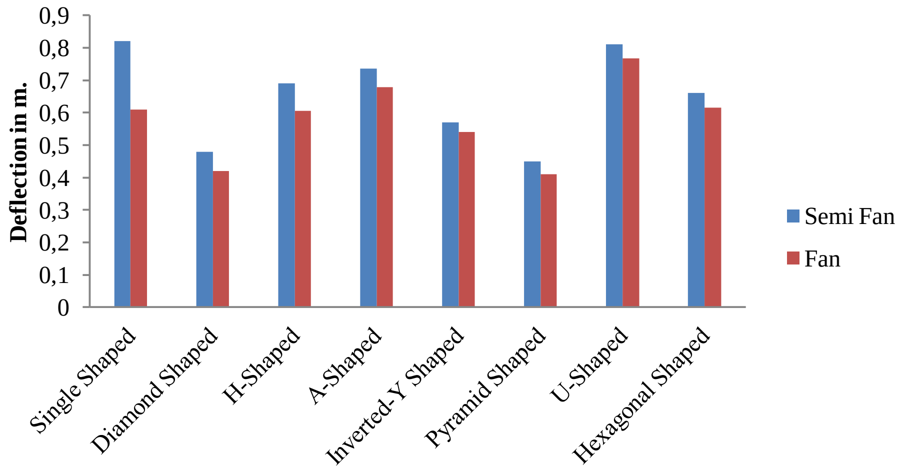
Graph 3.6. Comparison of bending moments for different shapes of circular concrete pylons

c) <u>For Shear Force:</u>



Graph 3.7. Comparison of shear force for different shapes of circular concrete pylons

d) <u>For Deflection at the top of Pylon:</u>



Graph 3.8. Comparison of deflections for different shapes of circular concrete pylons

4 CONCLUSIONS

The following points are concluded from the study undertaken:

a) For the Cable Stayed Bridge having main span of 350 m, the behaviour of different shapes of Pylons have been studied. For the purpose of comparison between different shapes of Pylons, the single shaped Pylon has been considered as a conventional shape of Pylon for the cable stayed bridge & being compared with other shapes of Pylons

- Comparison of Single Shaped Pylon with Diamond Shaped Pylon:

The values of axial forces in diamond shaped pylon having semi fan arrangement are 31% higher than the values in single shaped Pylon while the pylon having fan arrangement are 22% higher values than conventional shaped pylon.
The values of Shear force in diamond shaped Pylon are 54% less than single shaped pylon while in fan arrangement the value is 26% less.
The values of bending moment in diamond shaped pylon are 36% less than single shaped pylon while in fan arrangement the value is 5% less.
The value of deflection at the top of diamond shaped pylon is 45% less than single shaped pylon while in fan arrangement the value is 41% less.

- Comparison of Single Shaped Pylon with H-Shaped Pylon:

The values of axial forces in H-shaped pylon having semi fan arrangement are 37% higher than the values in single shaped Pylon while the pylon having fan arrangement are 31% higher values than conventional shaped pylon.
The values of Shear force in H-shaped Pylon are 39% less than single shaped pylon while in fan arrangement the value is 1% less.
The values of bending moment in H-shaped pylon are 49% less than single shaped pylon while in fan arrangement the value is 6% less.
The value of deflection at the top of H-shaped pylon is 19% less than single shaped pylon while in fan arrangement the value is 14% less.

Since H-Shaped pylon having twin towers so in this condition it does not prove economical also. If the height of Pylon is more, & the forces and moments in one of the tower of H-shaped Pylon are less than the values of pylon having single tower than it proves economical.

- Comparison of Single Shaped Pylon with A-Shaped Pylon:

The values of axial forces in A-shaped pylon having semi fan arrangement are 6% lesser than the values in single shaped Pylon while the pylon having fan arrangement are 5% lesser values than conventional shaped pylon.
The values of Shear force in A-shaped Pylon are 6% less than single shaped pylon while in fan arrangement the value is 2% higher than single shaped pylon.
The values of bending moment in A-shaped pylon are 3% higher than single shaped pylon while in fan arrangement the value is 14% high.

The value of deflection at the top of A-shaped pylon is 9% less than single shaped pylon while in fan arrangement the value is 9% less.

Similarly A-Shaped Pylon also not proves economical for such condition because it is also having two towers from the top at the either side of the deck & it also needs excessive space for the proper clearance of deck.

- Comparison of Single Shaped Pylon with Inverted-Y Shaped Pylon:

The values of axial forces in Inverted-Y shaped pylon having semi fan arrangement are 2% higher than the values in single shaped Pylon while the pylon having fan arrangement are 3% higher values than conventional shaped pylon.
The values of Shear force in Inverted-Y shaped Pylon are 64% less than single shaped pylon while in fan arrangement the value is 33% less.
The values of bending moment in Inverted-Y shaped pylon are 40% less than single shaped pylon while in fan arrangement the value is 66% less.
The value of deflection at the top of Inverted-Y shaped pylon is 34% less than single shaped pylon while in fan arrangement the value is 25% less.

This Shape of Pylon also needs an excessive space for the proper clearance of deck, therefore in such conditions it does not prove economical.

- Comparison of Single Shaped Pylon with Pyramid Shaped Pylon:

The values of axial forces in Pyramid shaped pylon having semi fan arrangement are 29% lesser than the values in single shaped Pylon while the pylon having fan arrangement are 42% lesser values than conventional shaped pylon.
The values of Shear force in Pyramid shaped Pylon are 73% less than single shaped pylon while in fan arrangement the value is 48% less.
The values of bending moment in Pyramid shaped pylon are 63% less than single shaped pylon while in fan arrangement the value is 41% less.
The value of deflection at the top of Pyramid shaped pylon is 46% less than single shaped pylon while in fan arrangement the value is 42% less.

This shape has been introduced by connecting the twin diamonds and tying them together at deck level a strong truss was created which transmits the transverse wind loads to the foundations. Hence for such conditions, it provides more strength & a better aesthetical appearance.

- Comparison of Single Shaped Pylon with U-Shaped Pylon:

The values of axial forces in U-shaped pylon having semi fan arrangement are 37% higher than the values in single shaped Pylon while the pylon having fan arrangement are 28% higher values than conventional shaped pylon.
The values of Shear force in U-shaped Pylon are 16% less than single shaped pylon while in fan arrangement the value is 11% less.
The values of bending moment in U-shaped pylon are 30% less than single shaped pylon while in fan arrangement the value is 6% less.

The value of deflection at the top of U-shaped pylon is 5% less than single shaped pylon while in fan arrangement the value is 6% less.

- Comparison of Single Shaped Pylon with Hexagonal Shaped Pylon:

The values of axial forces in Hexagonal shaped pylon having semi fan arrangement are 2% higher than the values in single shaped Pylon while the pylon having fan arrangement are 2% higher values than conventional shaped pylon.
The values of Shear force in hexagonal shaped Pylon are 2% less than single shaped pylon while in fan arrangement the value is 35% less.
The values of bending moment in hexagonal shaped pylon are 54% less than single shaped pylon while in fan arrangement the value is 23% less.
The value of deflection at the top of hexagonal shaped pylon is 19% less than single shaped pylon while in fan arrangement the value is 9% less.

From the results, it has been concluded that the Pyramid Shaped Pylon having the minimum value of axial forces, bending moment, shear force & deflection in such conditions for Cable Stayed Bridge.

b) The fan arrangement of cables gives the 5% higher values of axial force, 22% lesser values of Bending moment, 49% lesser values of Shear force & 9% lesser value of deflection than the value of axial force, bending moment, shear force & deflection in semi fan type arrangement. But when the fan arrangement considered for long spans, the size of the cables increased, which proves uneconomically large and difficult to adapt within the fan configuration. The anchorages were also substantial and more complex and the deck needed to be further become stronger at the ending point. Therefore when lot of cable stays were required then the semi fan layout must be opted. For much better results the spacing of cable stays which were tied at pylon should be kept at minimum.
c) The cross section of Pylon must be kept rectangular as the stresses in circular sections are greater than rectangular. And also for ease in construction of complex forms of Pylons such as Diamond shaped, Pyramid Shaped, A-shaped, Inverted-Y shaped rectangular pylon proves economical and can easily be constructed.
d) The moments, forces & deflections developed in Hexagonal Shaped Pylon and U-shaped Pylon are not as much higher than other suitable shapes of pylons. Hence both shapes can be implemented in actual practice after the proper experimental verification on such shapes in severe conditions.

These conclusions are based on the results of models which were prepared and analyzed using SAP2000 software.

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