Comparative Study on the Effect of Different Shapes of Pylon in the Static Analysis of Cable Stayed Bridge using SAP2000

Aniruddha Sharma[1] Dr J N Vyas[2]
[1]P.G. Student [2]Professor
[1,2]Department of Civil Engineering
[1,2]Mahakal Institute of Technology and Management, Ujjain (M.P.) 456006, India

Abstract— This paper deals with the linear static analysis of Cable Stayed Bridges with different shapes of pylons under its own weight, vehicular load and wind load. 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 and Diamond 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. 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 Type Arrangement of Cable Stays, Vehicular Load, Linear Static Analysis, SAP 2000

I. INTRODUCTION

A. 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.

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.

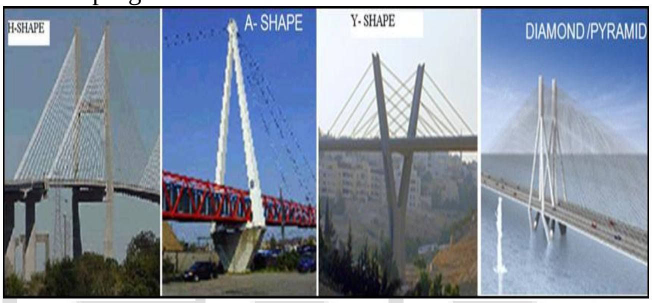


Fig. 1: Different tower/Pylons available for cable stayed bridge

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.

B. Components of Cable Stayed Bridge

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

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.

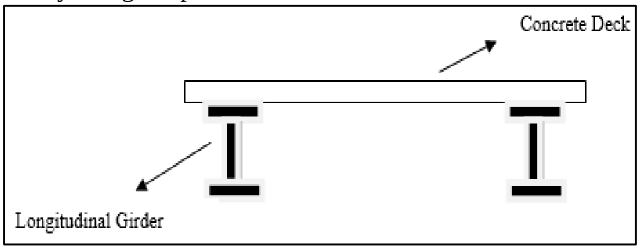


Fig. 2: Typical Section of Concrete Deck

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.

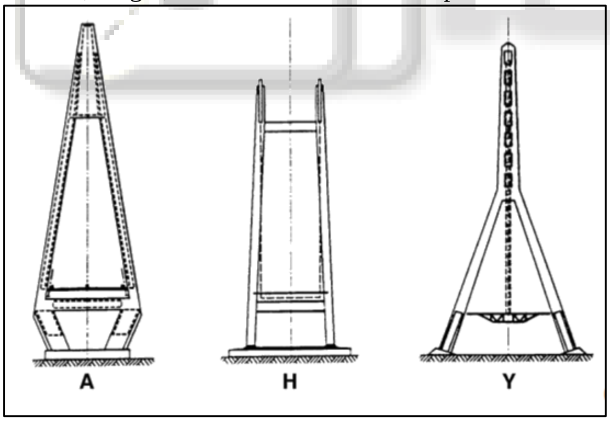


Fig. 3: Different shapes of Pylons used for Cable Stayed Bridges

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.

II. 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. 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 long span. For better enhancement, the following points are taken into consideration:

1) The arrangement of cable stays - semi fan arrangement.
2) The cross sections of pylons - rectangular.

This thesis will provide the comparison between the different shapes of pylons. Thus from the results obtained, one can easily identify the most suitable shape of 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 Single Shaped, Diamond shaped, A-shaped, H-shaped and Inverted Y-shaped. In this analysis, the considerations of the semi fan arrangement of cables have been taken, & the analyses will be computed for concrete pylons. The pylons which have been modelled for analysis purpose having their section rectangular. Different elements of cable supported bridge like deck, pylon, and cable-stays are discussed below:

1) Bridge deck: Deck is modelled as an area section with varying depths at side span and main span for balancing the member.
2) Pylon: Pylon and pylon beam is modelled as a frame section where the pylon with the vertical orientation and pylon beam with horizontal orientation.
3) 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.

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 2.1: Details of the components of cable stayed bridge

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 x 10^{-3}	0.2545	0.0127
2.	End Cross Beams	.225	0.0317	0.15	1.59 x 10^{-3}
3.	Intermediate Cross Beams	0.1	5.58 x 10^{-3}	0.07	2.7 x 10^{-4}
4.	Girders	0.045	1.03 x 10^{-3}	0.025	3.356 x 10^{-5}
5.	Pylon Beam	10.5	1.7747	3.667	2.6979

Table 2.2: Details of cross sectional properties of various components

S. No.	Pylon Shape	Material	Shape	Dimension (in m.)
1.	'Diamond' Shape	Concrete	Hollow Rectangular	(2.5 x 3.5) – (0.5 x 0.4)
2.	'H' Shape	Concrete	Hollow Rectangular	
3.	'Inverted Y' Shape	Concrete	Hollow Rectangular	
4.	'A' Shape	Concrete	Hollow Rectangular	
5.	'Single Pylon' Shape	Concrete	Hollow Rectangular	

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

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.

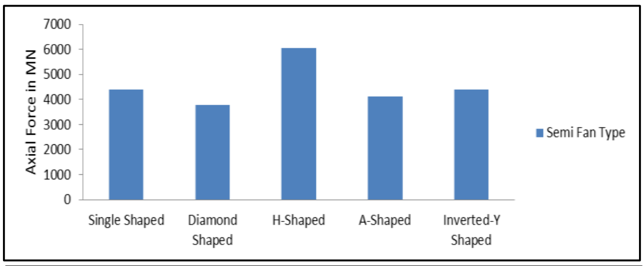
Static elastic analysis is done for all the structures. For ordinary structures static analysis is sufficient, but for important structures particularly for bridges dynamic analysis should be carried out. Also structures have irregular configuration and varying subsurface condition is analysed by dynamic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

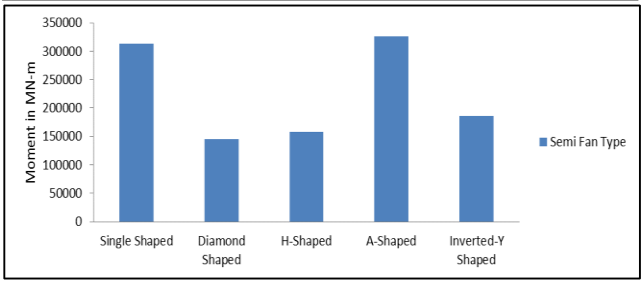
The Cable Stayed Bridge must be analyzed and designed for the loadings which are subjected to it. Here, only dead load has been considered which is subjected to it for the purpose of comparatively analysis of the bridge. In the analysis, the dead load consists of the self-weight of the structural forms 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 M30 grade of concrete has been used for deck, pylons and footways while Fe500 grade of steel has been used for the cables. The properties of M30 grade of concrete and Fe500 of steel has been already predefined in the software which automatically calculates the dead load of the structure after assigning the properties to members.

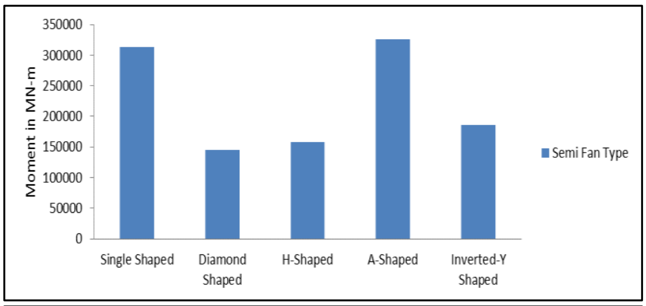
III. RESULTS

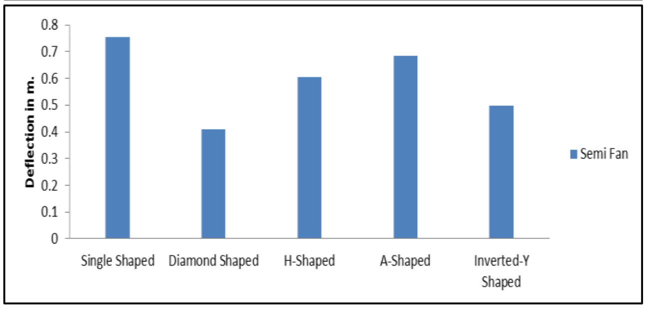
The detailed analysis has been done for the various shapes of Pylons and outputs have been carried out in the tabular form and have been plotted. The results which have been plotted give an idea about the comparison between different shapes of Pylons. The output part contains Axial Force in Pylon, Shear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

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









IV. CONCLUSIONS

The following points are concluded from the study undertaken:

– For the Cable Stayed Bridge having main span of 350 m, the behavior 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

A. 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.
– The values of Shear force in diamond shaped Pylon are 54% less than single shaped pylon.
– The values of bending moment in diamond shaped pylon are 36% less than single shaped pylon.
– The value of deflection at the top of diamond shaped pylon is 45% less than single shaped pylon.

B. 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.
– The values of Shear force in H-shaped Pylon are 39% less than single shaped pylon.
– The values of bending moment in H-shaped pylon are 49% less than single shaped pylon.
– The value of deflection at the top of H-shaped pylon is 19% less than single shaped pylon.
– 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.

C. 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.
– The values of Shear force in A-shaped Pylon are 6% less than single shaped pylon.
– The values of bending moment in A-shaped pylon are 3% higher than single shaped pylon.
– The value of deflection at the top of A-shaped pylon is 9% less than single shaped pylon.
– 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.

D. 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.
– The values of Shear force in Inverted-Y shaped Pylon are 64% less than single shaped pylon.
– The values of bending moment in Inverted-Y shaped pylon are 40% less than single shaped pylon.
– The value of deflection at the top of Inverted-Y shaped pylon is 34% less than single shaped pylon.

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

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

REFERENCES

[1] Airong CHEN, Qingzhong YOU, Xigang ZHANG, Rujin MA, Zhiyong ZHOU (2005), "The Study of Aerodynamic Problems of a Super Long Span Cable Stayed Bridge."
[2] Atul K. Desai 2013, "Siesmic Time History Analysis for Cable Stayed Bridges considering different geometrical configuration for near field earthquakes", Volume 7
[3] A.M.S. Freire[a], J.H.O. Negrao[b], A.V. Lopes[b] (2006), "The Geometrical Nonlinearities on the Static Analysis of Highly Flexible Steel Cable Stayed Bridges."
[4] Bruno D., Grimaldi A., "Non Linear Behaviour of Long Span Cable Stayed Bridges", Meccanica, Vol 20 1985.
[5] Chatterjee, Datta and Surana (1994), "A Continuum Approach for Analyzing the Dynamic Response of Cable Stayed Bridges."
[6] CSI Bridge Key Manual, Computers and Structures.
[7] Domenico Bruno, Fabrizio Greco, Paolo Lonetti 2013, "Static and Dynamic NonLinear Modelling of Long Span Cable Stayed Bridges", IJBE VOLUME 1.
[8] Dr. N D Shah, Dr. J A Desai & Dr. H.S. Patil 2011, "Effect of Pylon Shape on Analysis of Cable Stayed Bridge", ISSN: 0976-7916 Volume-2 JERs.
[9] J. Farquhar, Mott Macdonald, "ICE Manual 13 Cable Stayed Bridges" Institute of Civil Engineers 2008.
[10] Fleming & Egeseli (1980) [21, 22], "Comparison between Linear and Non Linear Dynamic Analysis

Results for a Cable Stayed Bridge Subjected to Seismic and Wind Forces."
[11] Fleming J.F., "Nonlinear Static Analysis of Cable Stayed Bridges", Computers & Structures 1979.
[12] Ghanshyam M. Savaliya[1], Atul K Desai[2] and Sandip A Vasanwala[3] (2012), "The Effects of Side Span Supports on the Behaviour of Long Span Cable Stayed Bridge.
[13] Midas Civil Tutorials, "Modelling & Analysis of Cable Stayed Bridges".
[14] N D Shah & Dr. J A Desai 2010, "Nonlinear Aerostatic Analysis of Self Anchored & Bi-stayed Cable Stayed Bridges using sap 2000", ISSN: 0975-6744 Volume 1, Issue 1.
[15] Olfat Sarhang Zadeh 2012, "Comparison between three types of Cable Stayed Bridges using Structural Optimisation", M.E. thesis, School of Graduate and Postdoctoral Studies,The University of Western Ontario London, Ontario, Canada.
[16] Prof. Dr. Ing. Wang, Pao-Hsii (2009), "Structural Behaviour of Cable Stayed Bridges Including the Interaction of Cable Stays and the Bridge."
[17] Roland (2000), "The Effect of Cables due to Deterioration in Cable Stayed Bridge."
[18] SAP Tutorials, "Modelling & Analysis of Cable Stayed Bridges."
[19] SAP2000. "Structural Analysis Programme" Integrated finite element analysis and design of structures. Computers and Structures.
[20] Seong-Ho Kim[1], Joo-Taek Park[2] and Kyoung-Jae Lee[3] (2009), "The Study of Aerodynamic Stabilizing for Tangential and Curved Cable Stayed Bridge Under Construction."
[21] Siddharth G. Shah, Desai.J.A & Solanki.C.H 2010, "Effect of Pylon Shape on seismic response of Cable stayed bridge with soil structure interaction", ISSN: 0976-4399 Volume 1, Issue 3.
[22] Simoes and Negrao (2000) had employed "Optimization in the Cost of the Deck in Cable-Stayed Bridges."
[23] Starossek U. (1996), ―Cable Stayed Bridge Concept of Longer Spans, Journal of Bridge Engg., Aug, Vol-1, 99-103.
[24] Sung Et Al (2006), "Optimum Post Tensioning Forces in Cables of Cable Stayed Bridge in Various Conditions of Loads."
[25] Vikas A C[1], Prashanth M H[1], Indrani Gogoi[2], Channappa T M[1] (2013), "The Effect of Cable Degradation."
[26] Wilson J. C. and Gravelle W. (1991) "Modelling Of A Cable-Stayed Bridge For Dynamic Analysis" Earthquake Engineering And Structural Dynamics, Volume 20, Issue 1.
[27] Xu Xie, Xiaozhang and Yonggang Shen (2014), "Static and Dynamic Characteristics of a Long Span Cable Stayed Bridge which is made up of CFRP (Carbon Fibre Reinforced Plastic) Cables."