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INVESTIGATION FOR SEISMIC BEHAVIOUR OF CABLE STAYED BRIDGE

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ABSTRACT: Now a day, construction of cable stayed bridges is increases exponentially; this is because of the distinctive and beautiful aesthetic quality of the structure. Two crucial parameters are examined in the presented manuscript. First, the shape of pylon and their respective performances for H-shape, A-shape, and Y shapes pylons and second, the impact of altering the deck width and span for different shapes of pylons. Both the above cases are analyzed after being exposed to static load, dynamic load as well as for earthquake load (time history analysis for El Centro). This investigation is being carried out by use of the Finite Element Method through MIDAS package. This computational tool conducts a sensitivity analysis of cable bridges. Fan type arrangements of the cables are to be considered in this paper. In the manuscript it is examined that the static loading has a key role in the design and analysis of cable stayed bridges. The best initial pre-stress forces in cables are determined using the unknown load factor approach. The displacement, reactions, stresses, cables force, shear force, bending moments resulting from various loading scenarios, mode shapes, displacements resulting from El Centro time history, and relative displacements resulting from various damping coefficients are among the response quantities of interest. As the damping coefficient increases there is a change in relative displacement of the bridge which is to be recorded in this paper. And finally, we concluded that the most efficient shape for different load cases are H-shape pylon followed by Y-shape pylons and then A-shapes pylon. The worst effects are in inverse Y-D and A-D designs because rigidity have been decreased in this specimen's models.

KEYWORDS: Cable bridge; Finite Element method; Load factors; Pylon, Damping coefficient.

1 INTRODUCTION

The bridge is a construction meant to support moveable loads being moved from one side to the other. Bridges consist of superstructure, substructure and bearings. In bridge superstructure consists of deck (girder), towers, and cables. The interdependence of these subsystems confers structural efficiency of cable bridges. This kind of bridge has more than one pylon, which connects bridge deck to towers with the help of cables. Cable stayed bridges currently extend over distance greater than 200m, like the Anji Khad Bridge of 473m in Jammu and Kashmir India and the Sudarshan Setu Bridge of 2320m in Gujarat India.

Basically, bridges are designed from top to bottom, but built from bottom to top. Structural engineers should also consider both the type and amount of load that the bridge must have to bear, as well as how the deck distributes that stress from superstructure to substructure. Due to their pleasing appearance and financial benefits, cable-stayed bridges have been widely used in recent years all over the world. As a result, there is much in-depth research on cable-stayed bridges going on. Every element of the cable stayed bride has their special meaning. In a cable-stayed bridge, cables play a crucial role in the transfer of loads from superstructure to substructure through bearings. Since the cable supports the upcoming loads and weight of the deck, it needs to be extremely strong and shielded from any outside influences.

For spans, that are bigger than cantilever bridges but smaller than suspension bridges, the” cable stayed bridge” is the best option in between that. With the aid of cables, the towers receive the load that the deck is expected to bear; the cables are subject to tension and compression forces on the towers. An important factor in the analysis of cable-stayed bridges is cable arrangement and the shape of pylons. The cable that connects the towers is secured at both ends by anchors. A cable's anchoring system gives it the strength to bear the weight placed on it; many kinds of anchorage systems are available for bridge construction like relay device (grouped anchorage) and relay device (distributed anchorage). The two main forces that every member of the bridge will encounter are tension and compression. Tension members will try to stretch their constituent parts or members while compression members try to compress the constituent parts or members.

This work examines the seismic analysis of cable-stayed bridges under static, dynamic, and earthquake load (time history for El Centro) with different pylon patterns. Pylons are primarily used to support cable systems and transfer forces to the foundation. This study analyzes the H-shaped, Inverted Y type, and A-shaped pylon patterns. 1940 ground motion was recorded for the El Centro time history function study.

Fig.1 shows the Schematic diagram of cable stayed bridge in which there is a pylon, deck (girder), and the cables. The cables hold up the deck and are fastened to both the deck and the pylon. The bridge's footing or foundation is located beneath the pylon.

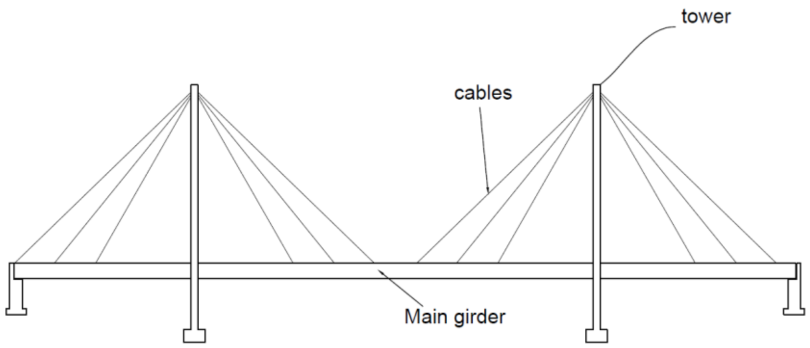


Figure 1. Schematic diagram of bridges along with its main components

Table 1. Materials properties adopted for modeling

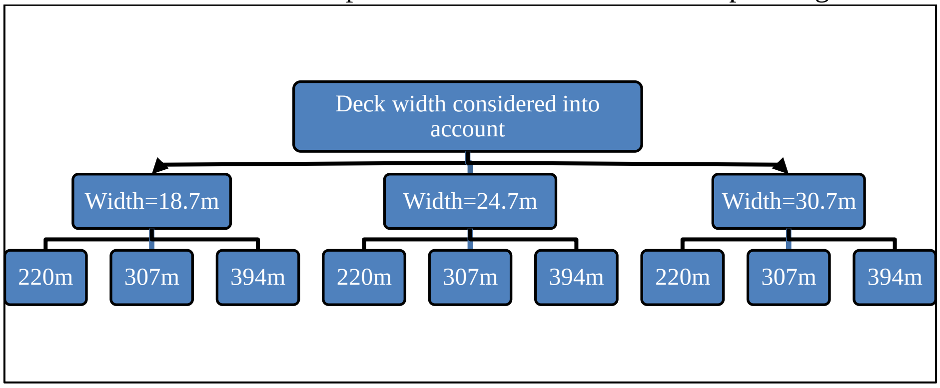
S.No	Components	Materials	Weight (kN/m^3)	Poisson ration	Elastic modulus (Giga Pa)	Stress (Mega Pa)
1.	Tower	Reinforced concrete	25.00	0.250	35.00	65.00 (compressive)
2.	Slab	Reinforced concrete	25.00	0.250	25.00	35.00 (compressive)
3.	Girder	Steel	77.09	0.30	199.00	250.00/450.00 (yield/ultimate)
4.	cable	Steel	77.09	0.30	198.00	1860.00 (ultimate)

Cable stayed bridge consists of pylon, slab, girder (deck) and cables. All the components have some specific function. The load which is coming on the girder is first transferred on cables and so cables are always in tension, after that cables' forces are transfer to pylon and so pylon is always in compression, after that the force are transfer to the footing/foundation. The properties of the different components of the cables bridges which have a significant function in the life of cable stayed bridge shows in Table 1.

Table 2 shows the detailed scope of deck width and the span which has to be considered in this paper. Three different span widths with different span length for H-shape, A-shape, Y-shape bridge is to be modeled in this research.

A cable-stayed bridge with varying geometric features is examined in various seismic scenarios. The outcomes are then compared in order to determine which pylon shape performs best under seismic load and which performs worst. MIDAS CIVIL was utilized for the numerical study of user static and seismic stresses in 3D finite element models[1]. For seismic analysis, the pyramid, straight H, inverted-Y, inclined-H and delta pylon designs are the most appropriate. Non-dynamic analysis of a cable-stayed bridge comprising of different shapes of pylons. diamond shape, inverted Y shape perform best while H-shaped pylons exhibit extremely steady dynamic response characteristics [2].

Table 2. Detailed scope for the deck width and main span length



To look at the limitations and effectiveness of the use of rubber and lead as a passive energy dissipation device and to manage seismic behaviors. Passive control system performs better in the case of short span bridge, and the best position for the placement of bearings is deck tower connection and abutment[3]. To calculate the entire bridge's flexibility under seismic loading as a function of the flexible structural system. Using SAP 2000, a 3D finite element model of the bridge's general dynamic equation of motion under seismic stimulation is created. And concluded that the displacement of towers generally decreased as delay times increased[4].

The comparison is made between a nonlinear and a linear earthquake-response study. And also Consideration is given to both synchronous and non-synchronous support motions caused by seismic excitations of flexible structures[5]. This analysis includes many causes of nonlinearity for such bridges. The analysis employs an iterative tangent stiffness approach to capture the nonlinear seismic response. They concluded that there is minimal variation in the outcomes of the linear and non-linear dynamic studies. When substantial ground shaking is applied to long-span cable-stayed bridges, the reaction of the structure must be calculated using a geometrically nonlinear dynamic analysis[6]. The aim of this research is to provide new defection limit criteria based on analysis and long-term measurement data for long span steel cable bridges. For steel suspension and steel cable-stayed bridges, structural analysis was done. MIDAS CIVIL RM Bridge V8i is used for modeling. For the purpose of monitoring the structural health, GNSS monitoring devices were deployed[7].

Some of the researchers have estimated that the impact of the angle of the earthquake's incidence as well as the multi-support excitations caused by time-lag propagation or the non-synchronous excitations. They use construction stage for the analysis[8]. And they concluded that the change in cable forces due to peak ground acceleration and the nature of earthquake is always least effective.

The impact on the cable's axial forces, deck deflection, natural frequency, the structure's mode shape, and the cable-stayed bridge's seismic reaction are all studied. Cable-stayed bridge, static and dynamic analysis is done with the help of Midas civil software. The deck's deflection and fundamental frequency increases as the corrosion increases[9].

Some of the studies examine the effectiveness as well as accuracy of the push-over analysis, then delves into the seismic reactions to different cable-stayed bridges and concludes with a discussion of various retrofitting options. Push over analysis is used to analyze cable stayed bridges under seismic activity[10]. They came to the conclusion that the 3D extension of modal pushover analysis significantly improves the original approach's accuracy in the study of large cable-stayed bridges. Except for H-shaped towers, structural damage is reduced with an increase in the primary span[11]. Efficiency of dampers decreases for span lengths greater than 400 meters. Analysis of the seismic reaction has been carried out, from the equilibrium configuration that is distorted because of dead loads, and they propose a new type of seismic damage index known as the maximum equivalent plastic strain ratio. Finite element analysis, which is nonlinear, is to be used and concluded that long span cable bridge, in response analyses need to take the dead load into account. Even with significant inputs from the earthquake record, the seismic response behavior is mostly unaffected by geometric nonlinearity[12]. It is not always the case that the earthquake having highest “PGA” value prompts the highest maximum Responses. Seismic reactions are generally diminished by the elastic-plastic effects. Additionally, the “largest PGA” value earthquake record does not provide the most plastic-elastic damage[13].

1.1 Linear vs. non-linear analysis

The governing equations for structural issues can be solved on paper to forecast the behavior of a structure. This is only possible for basic structures, though in practice this is seldom simple. Most of the time, structural issues are too complicated to investigate simply, and studying simple structures is a very time-consuming procedure. Finite element analysis enables engineers to model complex structures like bridges high rising buildings by assuming certain assumptions that can predict their behaviors with a certain level of accuracy. This paper deals with a structure in linearly static (Response spectrum) analysis and linear dynamic (time history) analysis. A brief difference between linear and Non-linear analysis is shown in Table 3.

There are few of the points which are to be assuming in the analysis is as follow:

- There is a pin connection between the cable girder and tower.
- The structure will remain in the linear elastic zone.
- Before beginning a research project, it is expected that the cross-girder nodes

on the deck will need to be displaced by 10 mm in both positive and negative vertical orientations in order to get preliminary forces in the cable.

- It is assumed that the stiffness of the cross-girder is taken to be zero and that its definition is limited to a nodal load in order to streamline the comparison and minimize transverse deformation.

Table 3. Linear verses non-linear model

Structural model / **Seismic loading**	**Linear model** (Material follows Hook's law) (i.e. E,A,I,L,G,K is constant)	**Non-linear model** (Material doesn't follow Hook's law) i.e. E,I,K is not constant)
Static case	Response spectrum analysis procedure (RSA) Equivalent lateral force procedure (ELF)	Several pushover analysis methods or non-linear static procedure (NSPs).
Dynamic case	Response spectrum analysis procedure (RSA) Linear response history analysis procedure or time history analysis (linear RHA). Modal response history analysis procedure (modal RHA)	Nonlinear modal response history analysis or fast nonlinear analysis (FNA). Linear response history analysis procedure or time history analysis (Non-linear RHA).

2 MODELLING STRATEGY

Software based on finite elements is used to study three-dimensional fan-type cable bridges. The software offers highly specialized features for modeling cable-stayed bridges. Total lengths of the cable stayed bridge are 437m, 611m, 785m. It has three continuous spans. Deck widths considered in this analysis are 18.7m, 24.7m, 30.7m.and the deck and the pylon edge are clearly separated by one meter. Two towers, totaling ninety meters in height, held up the building with the help of two fan-shaped cable planes. The first cable has a spacing of 7 meters, and there are 2 meters between each of the other cables in the span and on the pylon.

A fan type cables arrangement on the deck of the cable stayed bridge is shown in shown in *Fig 2*. The distance between the cables is 14.50meters and the first cable is at a distance of 7.00meters.

The majority of the pylon shapes used in the design and construction of both new and old cable-stayed bridges are displayed in this study. The performance of H Shape, A shape, Y Shape towers are analyzed under different loading conditions. Although the pylon's cable distances are constant, its legs may converge, diverge, or remain constant depending on the circumstances. Detailed of the pylon shapes is shown in below figure.

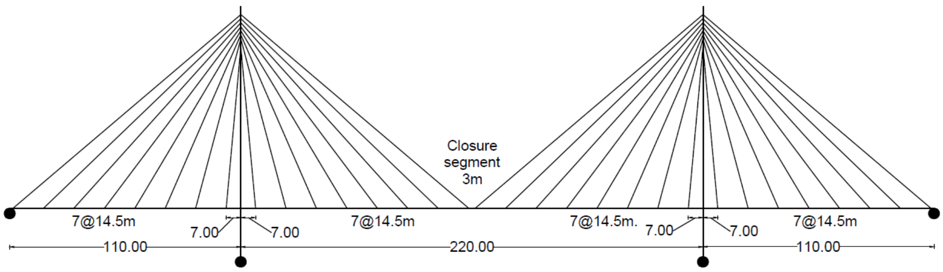


Figure 2. Systematic arrangement of cable stayed bridges in fan type. (All the dimensions are in meters)

The deck consists of a composite steel girder and the concrete deck and held up by the stringer that runs between them and the main girder. The transverse direction of the stringer connects the primary girders together. Typical cross-sectional diagram of the concrete deck with main girder and stringer given in *Fig 4.* in which the deck width is 18.7meters and thickness is 0.25meters, and the dimension of the girder beam and stringers beams is given in below *Fig 3.*

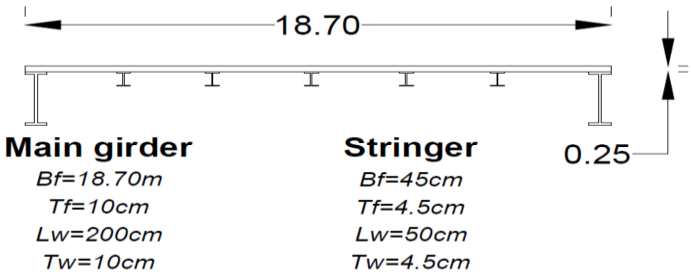


Figure 3. Detail cross section of concrete deck

Cross-sectional view H-shape, Y-shape, A-shape pylons are shown *Fig 4, Fig 5, Fig 6*. respectively. With width=18.70meters and span=220.00meters. Each of the cross-sectional dimensions is shown in Table.4. And the thickness of the slab is 0.25meters.

In this paper two cases are considered for analysis, i.e. linear static analysis, and linear dynamic analysis. In linear static case response spectrum analysis is done and in linear dynamic case time history analysis is done. Static loads considered in this study are self-weight, barrier load of 5N/mm on each side of the deck.

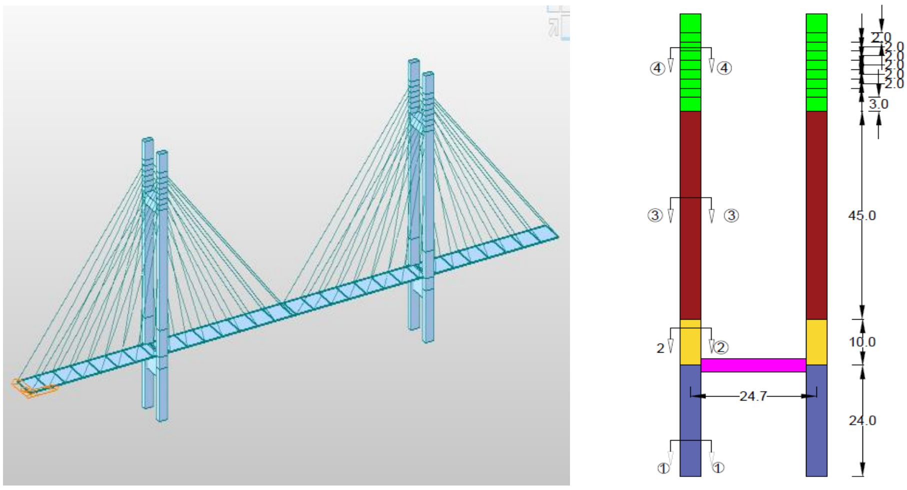


*Figure 4***.** Sketch of H-shape cable bridge

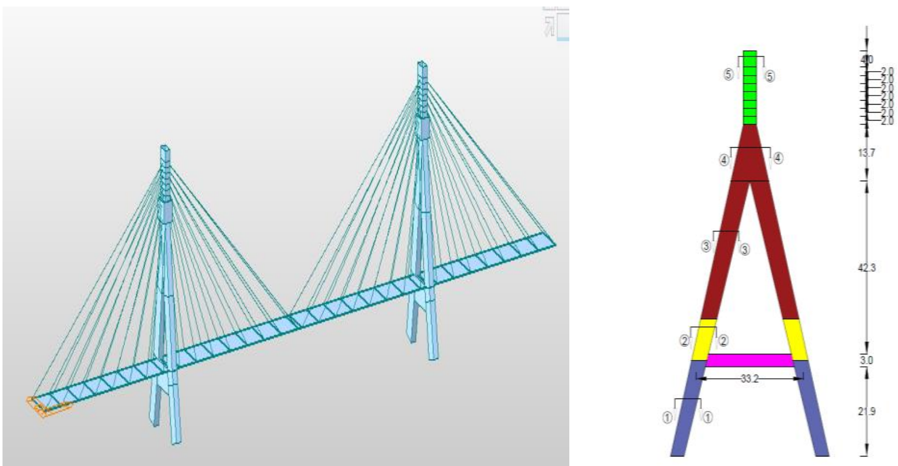


*Figure 5***.** Sketch of Y-shape cable bridge

Dynamic loads considered are response spectrum as per IS1893-2002, seismic zone considered is zone 3 (zone factor is 0.16) and soil type is medium soil with damping coefficient as 2%, importance factor as 1 and response reduction factor is taken as 3. The damping method used for the analysis is modal method and linear interpolation is use. In time history load cases we considered end time as 50sec with increment of 0.01sec. We considered time history type as transient. Time history function is El Centro site, of amplitude scale as 1 and time scale factor as 1.

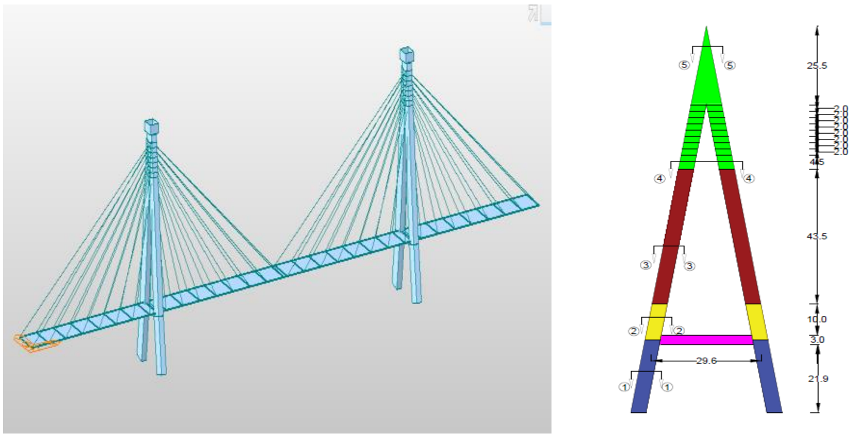


Figure 6. **S**ketch of A-shape cable bridge

Table 4. Pylon cross-sections dimensions

Section number	Dimension			
	B		H	
1-1	7.0m		4.0m	
	B	H	C	D
2-2	7.00m	4.00m	0.500	0.500
3-3	7.00m	4.00m	2.00m	5.00m
4-4	8.00m	7.00m	1.00m	1.00m
5-5	4.00m	7.00m	1.00m	1.00m
				

An arrangement of cable for different main span of bridge i.e. 220.00meters, 307.00meters, 394.00meters. The area of the cables is also shown in the below figures. The cross-sectional areas of the cables increase as we go from near the pylon to away from the pylon.

The notation and the segmental areas of the bridge are given in *Fig 7, Fig 8, and Fig 9.*

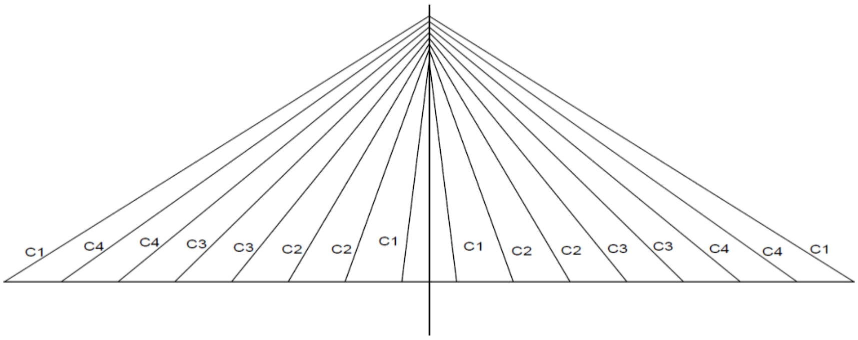


Figure 7. Arrangements of cable and there naming for the main span=220.00m. Where Cable 1=0.007058m2, cable2=0.008172m2, cable3=0.008824m2, cable4=0.009504m2.

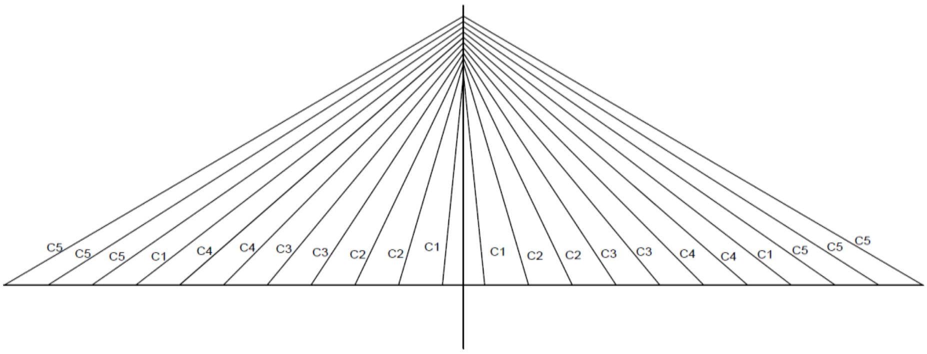


Figure 8. Arrangements of cable and there naming for the main span=307m. Where Cable 1=0.005026m2, cable2=0.00666m2, cable3=0.0095m2, cable4=0.001m2, cable5=0.0113m2.

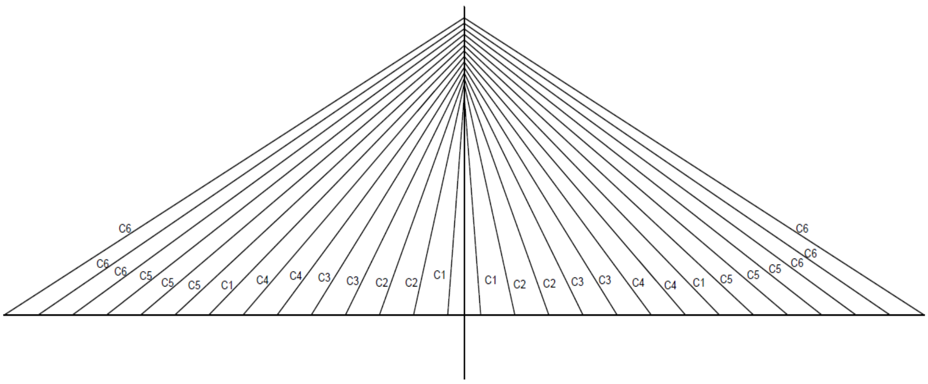


Figure 9. Arrangements of cable and there naming for the main span=394.00m. Where Cable 1=0.005026m^2, cable2=0.00636m^2, cable3=0.00785m^2, cable4=0.0095m^2, cable5=0.01056m^2, cable6=0.0113m^2.

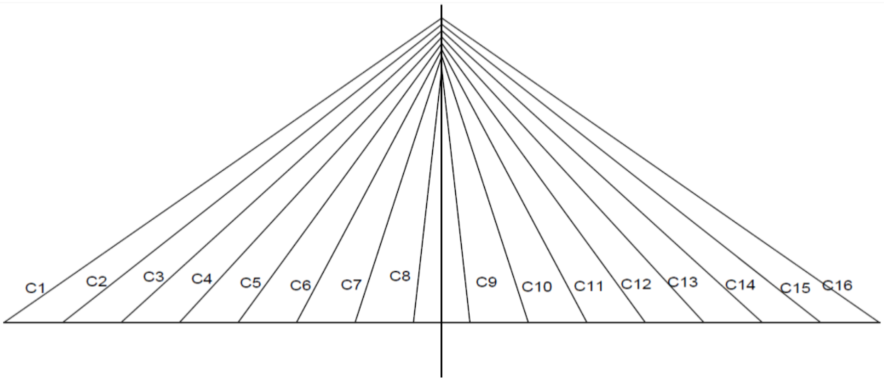


Figure 10. Stay cables arrangements.

3 RESULTS AND DISCUSSION

On different shapes of pylon linear static and linear dynamic analysis is to be analyzed and finally concluded that best shape in accordance with seismic analysis is Y-shape, followed by H-shape and then A-shape. To determine the cable bridge's natural frequencies, Eigen value analysis is applied. Typically, linear Eigen value analysis provides the foundation for modal analysis. A time history analysis is conducted while taking the El-Centro earthquake's specifics into account. The dead load frequently accounts for the majority of the bridge load in cable stayed bridge design. The analysis of the Cable Bridge depends heavily on the deadload. For their length, cable stayed bridges have geometric nonlinearities that translate into nonlinear load deflection behavior under all loading scenarios. *Fig 11.* shows that the deflected shape of the bridge for dead load.

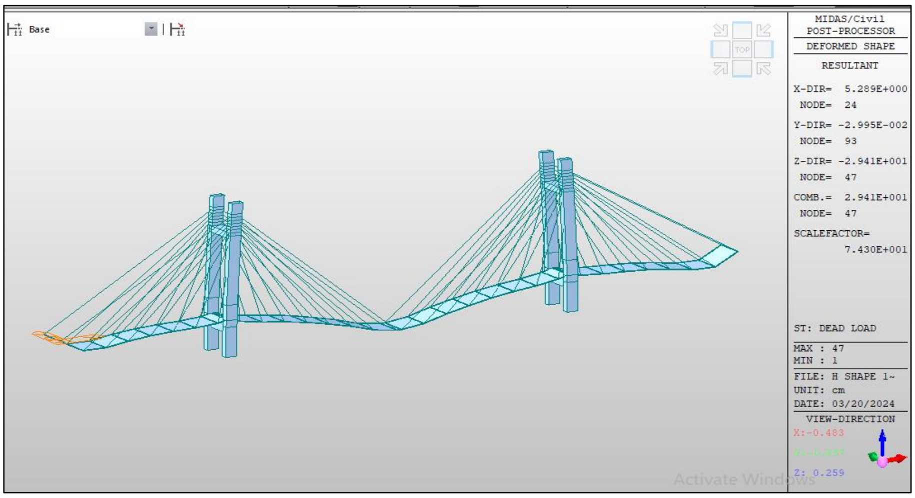


Figure 11. Deck deflection due to dead load

Above *Fig 12.* shows that, as the width increases keeping the span constant (220m) than the minimum deflection for the static case is in H-shape and maximum deflection is in A-shape pylon. The *Fig 12.* concluded that the deflection due to dead load and attachments loads play a significant role in deflection. Same results are also obtained from width 24.70m and 30.70m and for different main span length. In all the cases, static load case plays a significant role in the design and analysis of cable bridges. As the span increases the deflection due to static load cases also increases.

The same result is to be obtained from width 24.70m and 30.70m and for different main span length. In all the cases, static load case plays a significant role in the design and analysis of cable stayed bridge. As the span increases the deflection due to static load cases also increases.

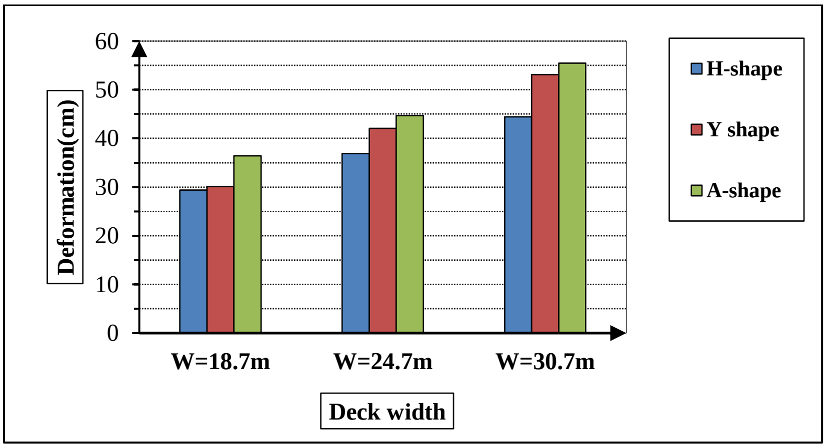


Figure 12. Comparison of deflected shape of bridge due to dead load

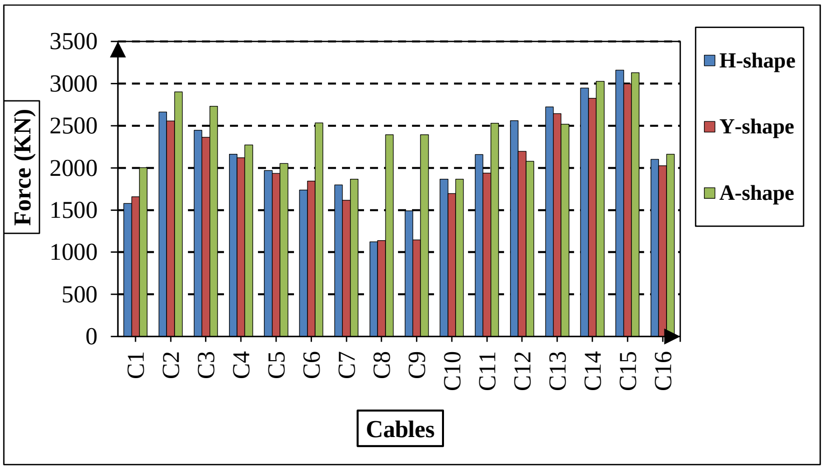


Figure 13. Comparison of cable forces

With the help of unknown load factors method, cable forces are to be found for the worst load combination and summarized in *Fig 13.*

Forces in cables due to worst load combination (i.e. D.L+ Prestress load + response spectrum in X-direction) are maximum in the case of A-shape pylon, and almost same in the case of H-shape and Y-shape. Above fig.13 concluded that keeping same width and span length of the bridge H-shape and Y-shape generated less force which is good for the cables so that the forces come on the cables is less and hence life of the cables increases drastically.

Stresses are maximum in the case of Y-shape and minimum in the case of A-shape pylon as shown in *Fig 14*. And concluded that keeping the width and the span as constant, stress developed in Y-shape pylon is maximum and hence Y-shape pylon has high resistance against the external upcoming loads. The above conclusion is derived from H-shape cable stayed bridge with deck=18.7m and main span=220.00m, and the same conclusion is draw from the other shapes of towers like A-shape, Y-shape with different span and different span length.

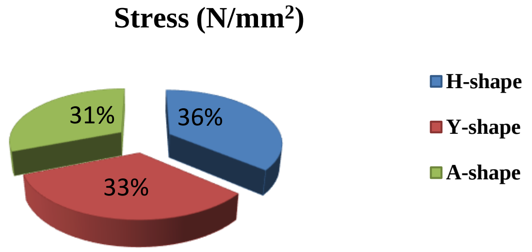


Figure 14. Comparison of developed stress due to worst load combination

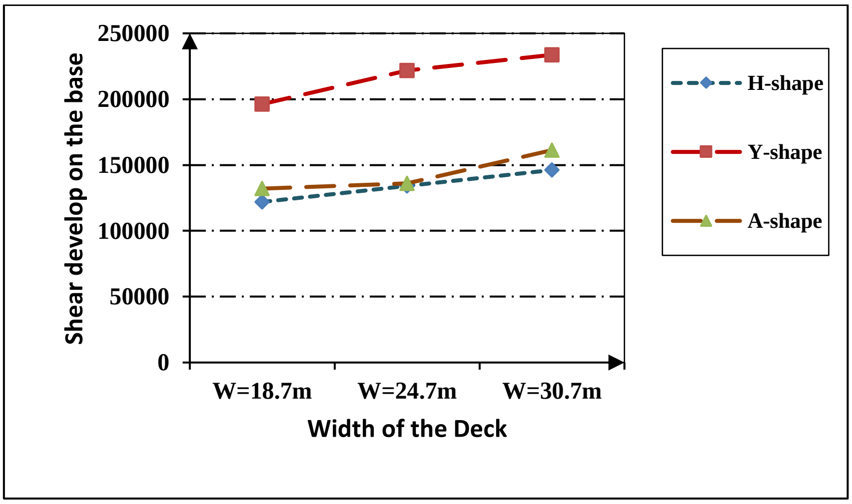


Figure 15. Comparison of shear force at the base

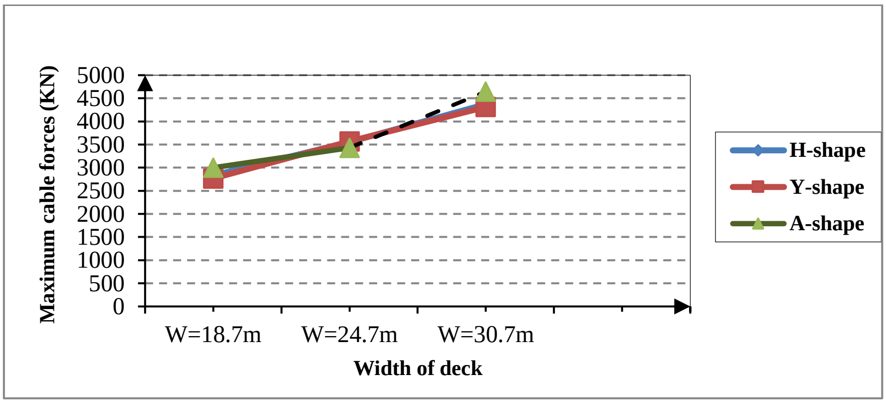


Figure 16. Comparison of maximum developed forces in the cables

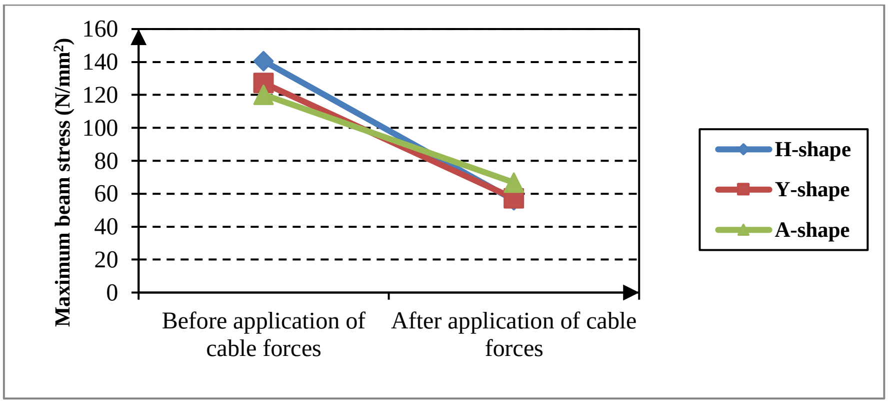


Figure 17. Comparison of stress developed in beam before and after development of cable forces

Fig 15. Shows that, as the width of the deck changes from 18.7m to 30.7m keeping the main span as 220.00m and same applied load, then higher response in Y-shape, H-shape and A-shape pylons show approx. equivalent to each other. So, we can conclude that, as the deck width increases, shear force generated at the base also increases. Thus, the deck width and shear force at the base are precisely proportional.

Fig 16. Shows that as the deck width increases keeping the span as 220.00m than the maximum cable forces are in the case of A-shape pylon, and approx. equivalent forces generated in the cable in the case of H-shape and Y-shape pylons. We can conclude that, by keeping other factors constant the cable forces increase as the deck width increases.

Fig 17. shows that the stress develops on the beam elements due to static load cases decreases drastically after the applications of cable forces. Means that the cable forces play a significant role in designing cable stayed bridges.

We can conclude that the rate of decrease of stress before and after application of cable forces is more in H-shape pylon and less in A-shape pylon.

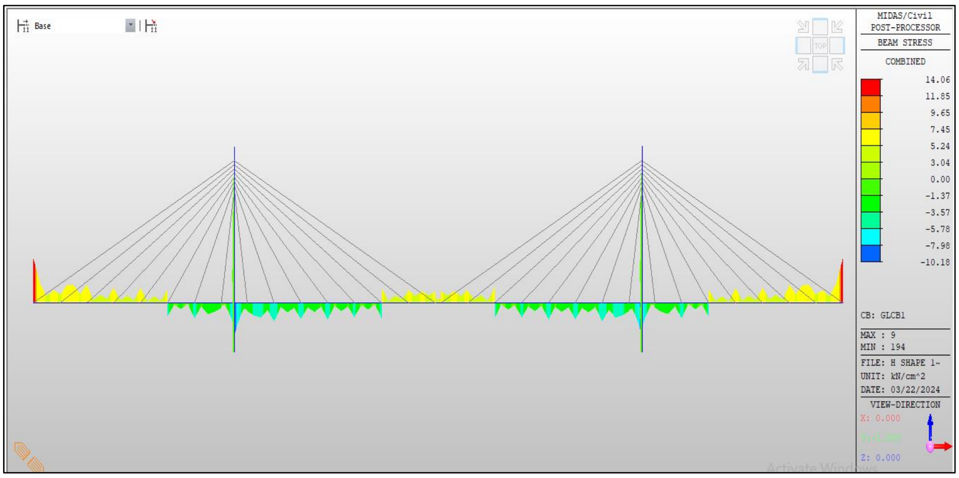


Figure 18. Stress developed due to worst load combination in span=220.00m

Stress value for H-shape pylon with width=18.70m. and by observation we can conclude that as the span increases keeping the other factors as constant the peak stress on the elements increases as shown in *Fig 18*, *Fig 19*, *Fig 20*. The same trends are also followed for A-shape and Y-shape pylons.

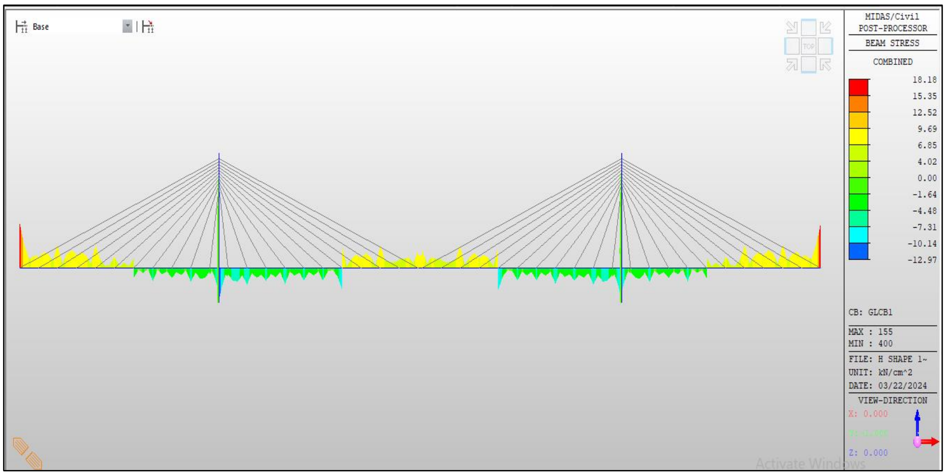


Figure 19. Stress developed due to worst load combination in span=307.00m

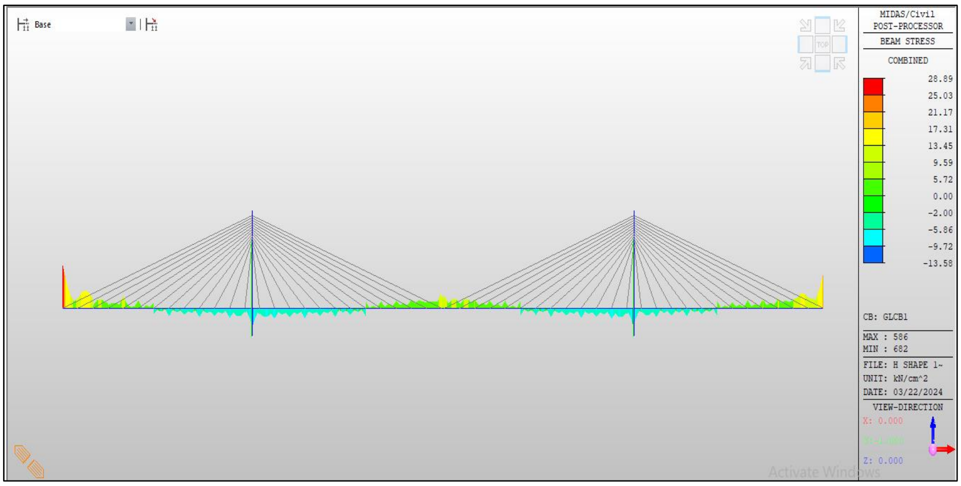


Figure 20. Stress developed due to worst load combination in span=394.00m

3.1 Mode shapes

Modes shapes for the H-shape, A-shape, and Y-shape pylon for the response spectrum as per IS1893-2002 are shown in table-5. As our frequency increases the time period decreases. And the shortest time period is observed in the case of A-shape, means that the earthquake comes within less time period. And hence distorted shape is worst in the case of A-shape pylon, which is shown in *Fig 21*, *Fig 22*, and *Fig 23*.

Table 5. Vibration modes shapes

Shape of pylon	Mode	Frequency (Hz)	Time period (sec.)
H-shape	Mode 1	0.3612	2.768
	Mode 2	0.3614	2.767
	Mode 3	0.4839	2.066
	Mode 4	0.4950	2.021
	Mode 5	0.5328	1.876
	Mode 6	0.5681	1.761
Y-shape	Mode 1	0.2124	4.707
	Mode 2	0.2451	4.078
	Mode 3	0.4107	2.434
	Mode 4	0.4299	2.326
	Mode 5	0.4455	2.244
	Mode 6	0.4459	2.242
A-shape	Mode 1	0.3089	3.237
	Mode 2	0.3768	2.653
	Mode 3	0.4318	2.315
	Mode 4	1.0942	0.913
	Mode 5	1.1199	0.892
	Mode 6	1.1373	0.879

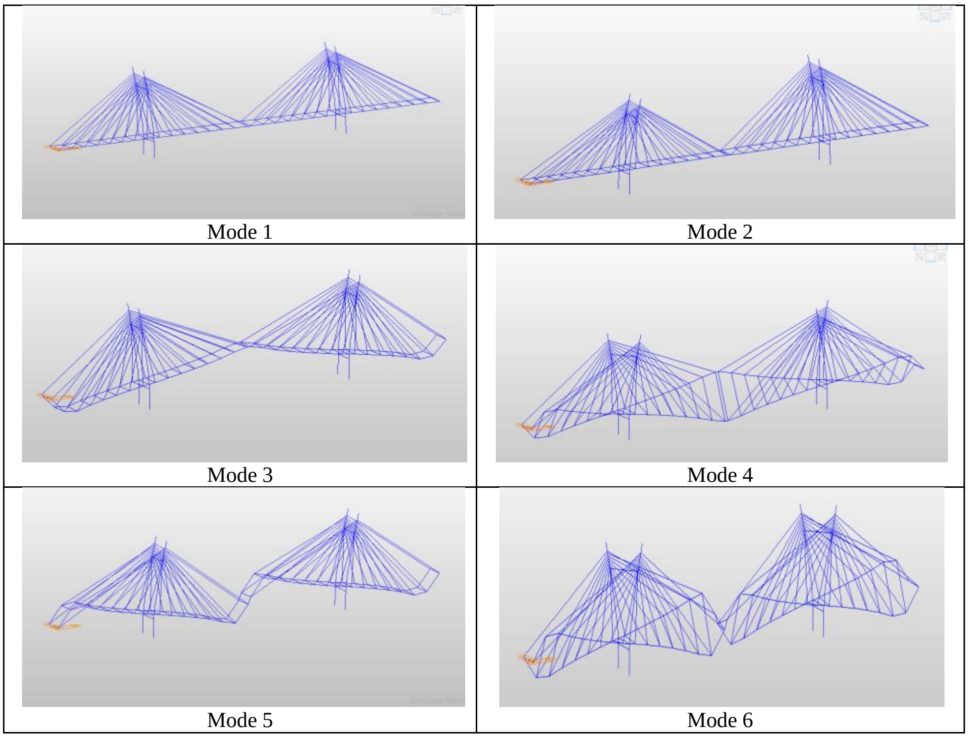
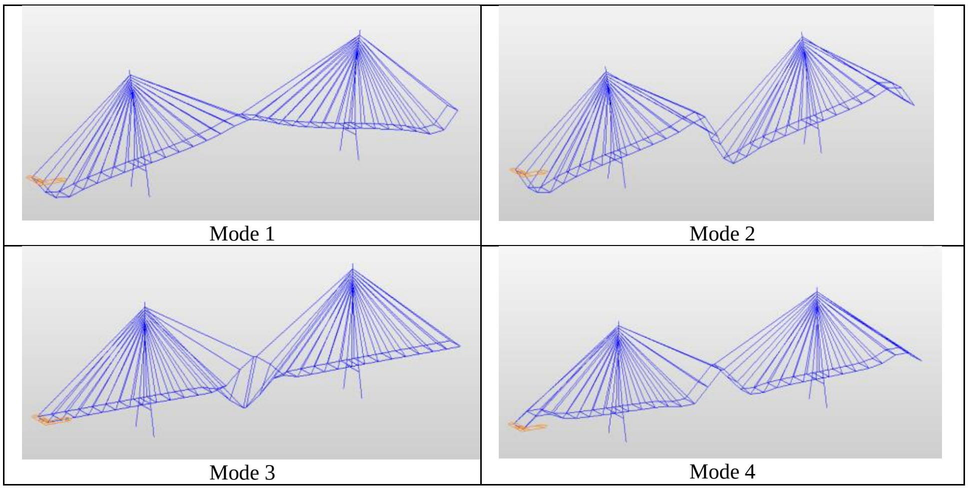


Figure 21. Mode shapes for H-shape pylon



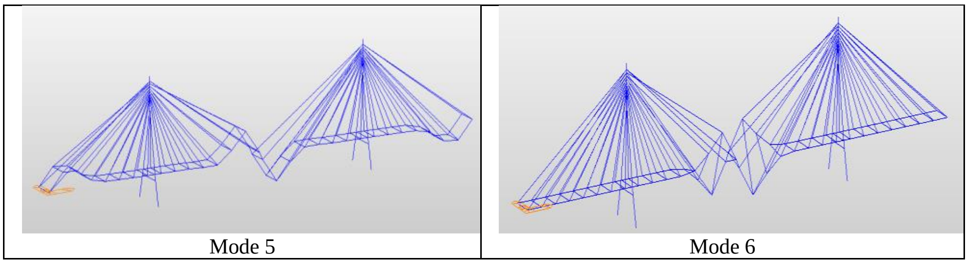


Figure 22. Mode shapes for Y-shape pylon

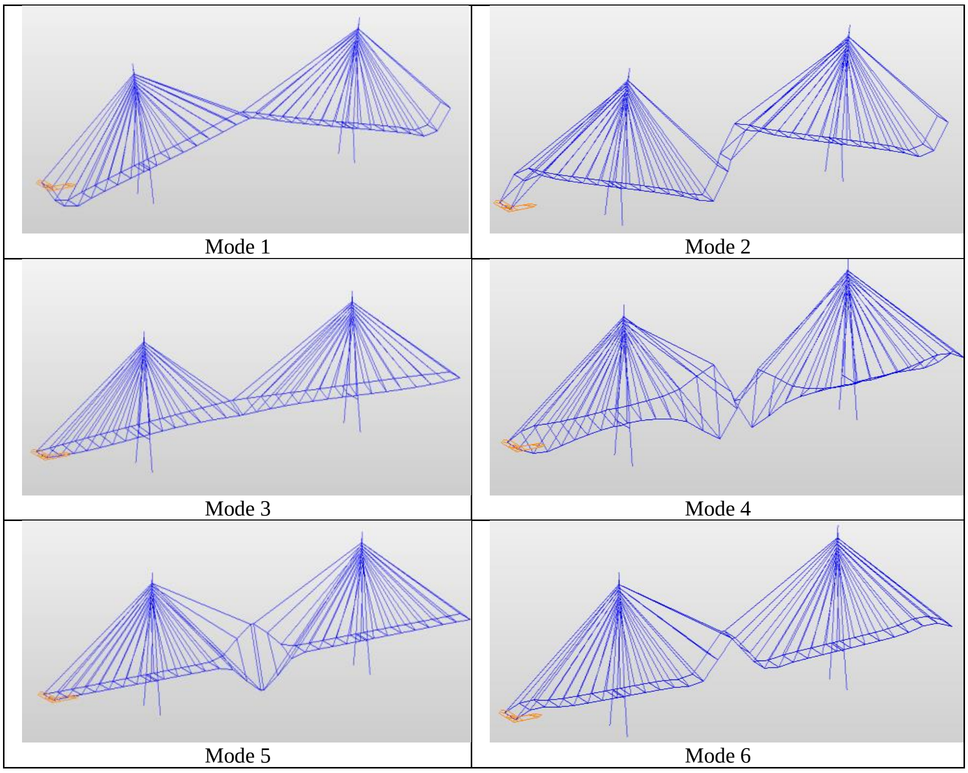


Figure 23. Mode shape for A-shape pylon

3.2 Time history analysis

Additionally, a time history analysis of the cable stayed bridge model was done. The investigation made use of earthquake data from El Centro. End time is considered as 50sec and increment is 0.01sec, and step number of increments for output is 1. For the analysis of time history, modal damping method is used and damping ratio for all the modes is 2%.

We considered some of the cases with different damping coefficient like 0, 0.01, 0.02, and 0.05. As the damping coefficient increases at constant time, we can easily conclude that relative displacement decreases as shown in *Fig 24.*

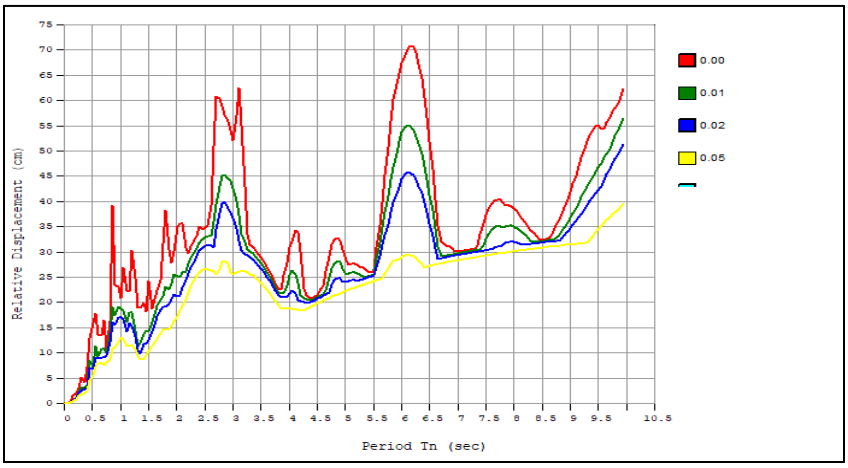


Figure 24. Relative displacement verses time graph for different damping coefficient

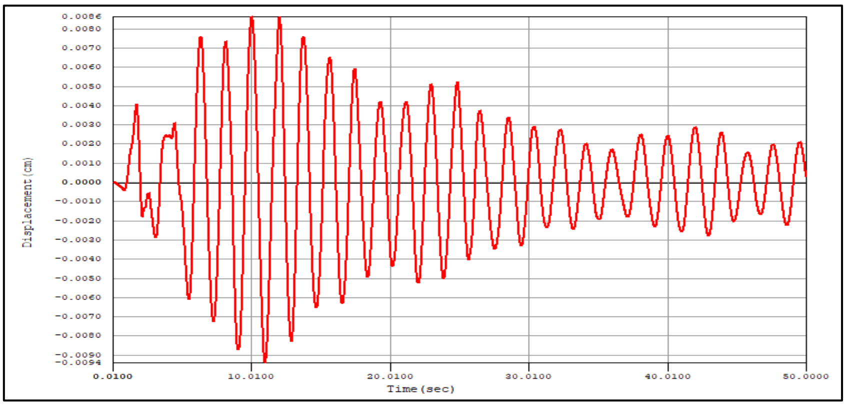


Figure 25. Displacement of cable anchored point (node 47)

Fig 25. and *Fig 26*. The displacement against time history graph under typical conditions at the tower's top and anchorage point is displayed. The graph shows that the maximum displacement on node 47 is 0.00863cm at time duration of approx. at 10sec at node 47 and maximum displacement at 0.1617cm at time duration of approx. 11sec. The below graph shows that as the time increases, the intensity of the earthquake decreases and hence displacement decreases gradually.

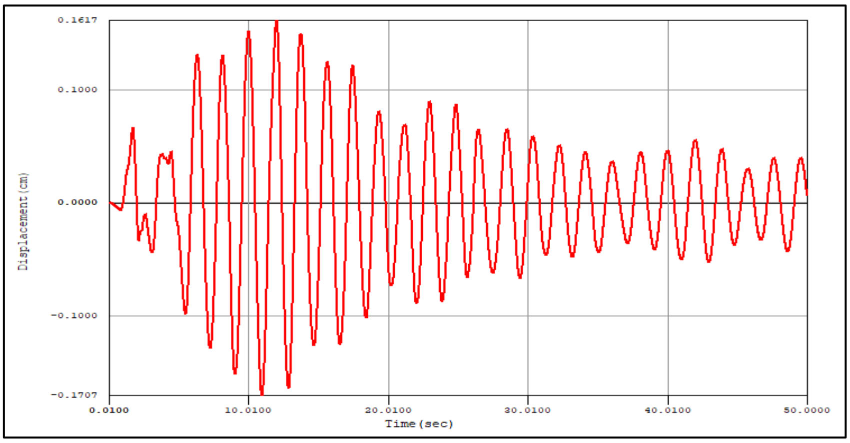


Figure 26. Displacement of cable anchored point (node 23)

4 CONCLUSION

The primary topic of this study was a frequently built three-span cable-stayed bridge with the width=18.7m, 24.7m, 30.7m and a main span of 220.00m, 307m, 394m is analyzed. The premise of this analysis is that a cable-stayed bridge with a concrete deck and composite steel girders for both the main span and side span is to be examined, but if this condition changes, then the result may differ. When there are increases in complexity in structure than there is an increase the risk of dynamic behaviors.

The main conclusions derived from his parametric investigation are as summarized below:

- Static load plays a significant role in the design and analysis of the cable stayed bridge.
- As the width of the deck increases than the deflection due to dead load, shear force at the base, cable forces in the cables also increases.
- Cable forces is maximum in the case of A-shape pylon and for H-shape and Y-shape pylon it shows equivalent to each other which shows that tension in A-shape pylon bridge is maximum, which decrease its life.
- Stresses developed in the bridge decreased drastically after the application of cable forces.
- As the span increases, the maximum stresses developed on the elements also increases.
- As we go from Mode 1 to Mode 6 the time period decreases which shows that the frequency of coming the vibration increases and hence the deformation also increases.
- As the damping coefficient increases the relative displacement of the bridge decreases.
- From the time history analysis, we can conclude that as time increases the

intensity of the earthquake decreases and hence the displacements decrease gradually.

- From the above discussion, we can conclude that the best shapes of pylons are H-shape followed by Y-shape and then A-shape. Inverted Y-shape and A-D shape pylon shows the worst shape for the seismic point of view because of due to decreases in stiffness which is due to pylon legs are convergent in nature.

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