Parametric Study of Shapes of Pylon for Cable Stayed Bridge

Thomas Blesson.B[1] , Prof. S. P. Thakkar[2]

1. **Structural Engineer , GIFT City.**

2. **Asst. Professor, Civil Engineering Department, Institute of Technology, Nirma University. email : sonal.thakkar@ nirmauni.ac.in**

Abstract- -Man's achievement in field of Structural Engineering is evident from world's largest bridge spans, tallest structures etc. In the recent years cable stayed bridges have received more attention than any other bridge mainly, in the United States, Japan and Europe as well as in third-world counties due to their ability to cover large spans. Cable-stayed can cross almost 1000m (Tatara Bridge, Japan, Normandy Bridge, France)

A study is carried out to find the dynamic and aerostatic effect on different shapes of pylons of a cable stayed bridge. The different shapes of pylons considered here are H type, A type, Inverted Y type, Diamond type and Delta type. The central span of the cable stayed bridge is also varied as 100m, 200m, 300m, 400m to study the combined effects due to shape and span. The study is carried out by taking live load according to IRC 6:2000, IRC Class A and Class 70R vehicle load along with Aerostatic wind loads was undertaken. A Dynamic analysis in the form of Linear Time-history is also carried out using El-Centro ground motion and various response quantities such as Bending-moment, Shear-force, Torsion and Axial force are represented.

*Index Terms***:** El-Centro Ground Motion, Equivalent modulus of elasticity, pylon shapes

I. INTRODUCTION

During the World War II many bridges were destroyed in Germany. The demand to build these bridges was urgent. The requirements of efficient use of materials and speedy construction made cable stayed bridges the most economical design for the replacements**.** The state of art in the design and construction has changed immensely since the first steel cable-stay bridge was built in Stromsund, Sweden in 1955. This may be viewed from the fact that the Stromsund Bridge had a span of 183m whereas Suntong Bridge on Suzhou Nantong, in China has a longest span of about 1100m was completed in the year of 2008. Such a revolution has happened due to the introduction of high strength cable and better construction techniques and analyzing tools readily available. The increase in the cable sag can lead to a substantial decrease in the stiffness of the stay and subsequent nonlinear behavior of the bridge under live load has come into focus[2],[3].

II. ANALYSIS OF CABLE STAYED BRIDGE

SAP2000 is a powerful and versatile tool for analysis and design of structures based on static and dynamic finite element analysis. Non linear analysis can also be performed in SAP2000. The analytical capabilities are just powerful representing the latest research in numerical techniques and solution algorithms. The program is structured to support wide variety of the latest national and international codes for both steel and concrete designs.

MODELING OF DECK

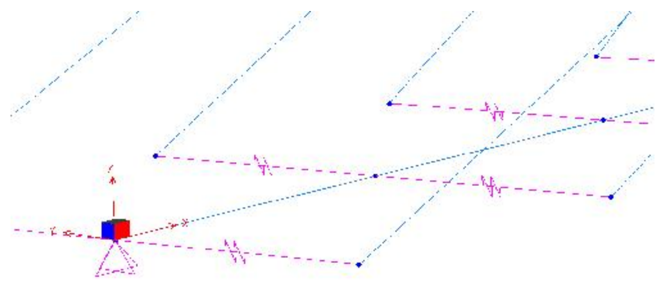


Fig. 1 Deck connected by a rigid link

A box girder of concrete has to be modeled such as to behave correctly in bending and torsion and to resemble the inertia effects correctly. As indicated in fig. 1, at nodes rigid links are used to connect with the cable in perpendicular direction to the beam element. This is done to achieve the proper offset of the cables with respect to the centre of inertia of the spine.

MODELING OF CABLES

A linear frame element is utilized for modeling of cables. The modeling of cables is a difficult issue because of nonlinearities arises from the cable sag. The stiffness thus changes when load is applied. The prestress was applied to all the cables in order to ensure a small deformation of the deck when the self weight is applied. A cable is converted in to a rod model, with its sectional area alone being considered. Converted modulus of elasticity E_{eq} is taken from the equation of H. J. Ernst,

$$E_{eq} = \frac{E}{1 + \frac{(wH)^2 AE}{12T^3}}$$

E_{eq} = Equivalent modulus of elasticity of the cable.
E = Modulus of elasticity of the straight cable
w = Weight of the cable per unit length.
A = Cable sectional area.
H = Horizontal projected length of the cable.
T = Cable initial tension.

Modeling of Pylon

Function of Pylon or tower is to support the cable system and transfer the forces to foundation. Therefore, it is subjected to high axial forces and bending moments and also depend upon support conditions. The material of construction can be concrete or steel depending upon soil condition and construction speed required. Towers are of different types to accommodate different cable arrangements, bridge site condition, design features and asthetics. They are generally H shaped, Y type, Inverted Y type, Delta type or diamond type.

Pylon modeling is done as beam elements. The pylon leg stretches at the pylon head which was divided into beam elements as long as the distance between the cable anchorage points.

Support Condition

There are different boundary conditions prevailing for the connection of the frame element to each other. Here in the study beam on elastic support analogy has been considered.

III PROBLEM DATA

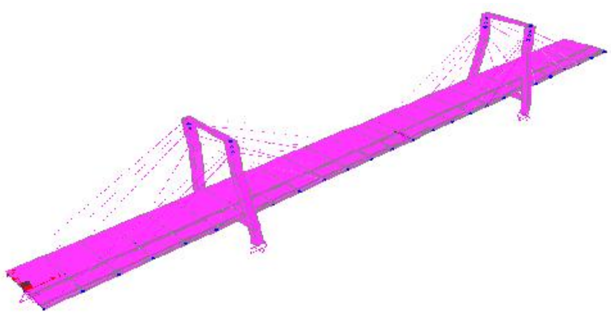


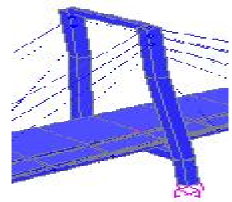
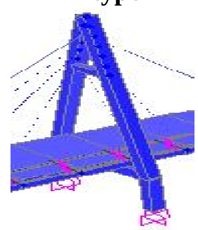
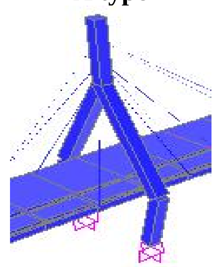
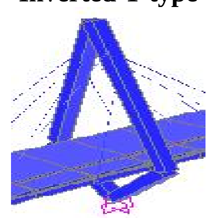
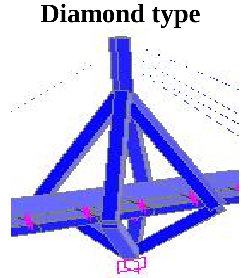
Fig. 2 Rendered view

Following data was considered, for parametric study of effect of pylon shapes. The rendered view is shown in fig. 2.

Central span 100m Side spans: 50m.
Height below deck: 10m.
Height above deck: 30m
Deck concrete box girder dimension: width: 17m, depth: 2m
Modulus of elasticity: 33541 MPa, Grade of concrete: M 45
Top cross beams: B: 1m D: 1.5m
Bottom cross beams: B: 1m D: 2m
Cable properties: Modulus of elasticity 2 x 10^5M Pa
Areas:
Cable 1 & cable 2: 0.004m^2,
Cable 3 & cable 4: 0.003m^2
Cable 5 & cable 6: 0.002m^2

Similarly the central span is varied as 200m, 300m, 400m, and the shape of pylons are taken as A type, Inverted Y type, Diamond type, Delta type as illustrated in the table.1. Time period result for H type of pylon are shown in fig. 3 for different mode shapes[1],[4],[5]

TABLE I
PARAMETRIC STUDY DATA

SHAPES	**TOTAL SPAN(m)**			
 **H type**	200	400	600	800
 **A type**	200	400	600	800
 **Inverted Y type**	200	400	600	800
 **Diamond type**	200	400	600	800
 **Delta type**	200	400	600	800

OutputCase Text	StepType Text	StepNum Unitless	Period Sec	Frequency Cyc/sec
MODAL	Mode	1	1.124403	0.88936
MODAL	Mode	2	0.981808	1.0185
MODAL	Mode	3	0.926655	1.0791
MODAL	Mode	4	0.685151	1.4595
MODAL	Mode	5	0.557803	1.7927
MODAL	Mode	6	0.491492	2.0346
MODAL	Mode	7	0.43868	2.2796
MODAL	Mode	8	0.415362	2.4075
MODAL	Mode	9	0.372808	2.6823
MODAL	Mode	10	0.324349	3.0831
MODAL	Mode	11	0.296475	3.373
MODAL	Mode	12	0.285401	3.5038

Fig. 3 Time period result

IV Moving Load Generation

Traffic lanes four lanes of traffic each 3.75m wide are generated on top of the 17.0m wide concrete box girder as seen in fig. 4.

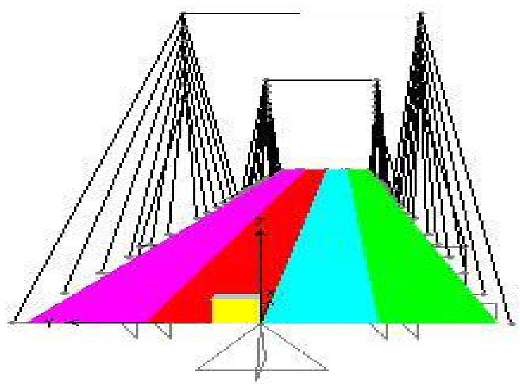


Fig. 4 Lanes as seen in SAP2000 model

Vehicles Load in Sap2000

IRC class A and class 70R wheeled vehicles are generated as the general vehicle definition form of SAP2000 as shown in fig. 5.

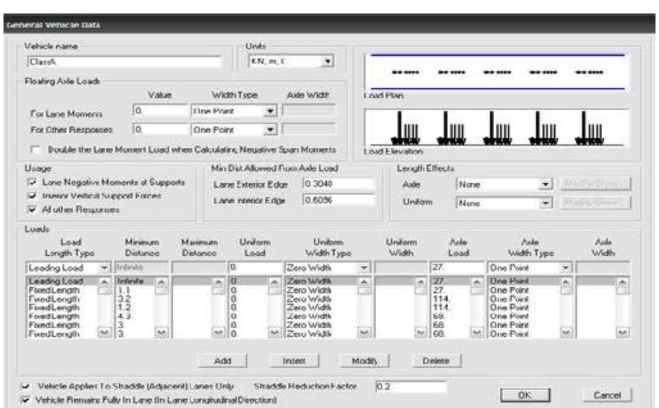


Fig. 5 Vehicle data dialogue box

Moving Load Analysis Cases

The final step in the definition of the vehicle live loading is the application of the vehicle class to the traffic lanes. A moving load case is a type of analysis case. Unlike most other analysis cases one can not apply load cases in a moving load case. Instead each Moving Load case consists of a set of assignments that specify how the classes are applied to the lanes. For example:

Moving load M_1 is for vehicle of class 70R applied to lane 1 and lane 2, while lane 3 contains vehicles of class A,

M_2 refers to class 70 R vehicle in lane 1 and 2 while class A in lane 4,

M_3 refers to class 70 R in 1 and 4 and class A in lane 2,

M_4 refers to class 70 R in 1 and 4 and class A in lane 3,

M_5 refers to class A in all the four lane.

Wind +ve : drag, lift and punching moment applied for +ve Y axis in the direction perpendicular to the bridge axis.

Wind -ve : drag, lift and punching moment applied for -ve Y axis in the direction perpendicular to the bridge axis.

TH : linear dynamic analysis performed in the form of El-Centro ground motion.

V LOAD COMBINATIONS

In the linear case following load combinations is used :

Dead + M1, Dead + M2, Dead + M3, Dead + M4, Dead + M5, Dead + Wind+ve, Dead + Wind-ve, Dead + M1 + Wind+ve, Dead + M2 + Wind+ve, Dead + M3 + Wind+ve, Dead + M4 + Wind+ve, Dead + M5 + Wind+ve, Dead + M1 + Wind-ve, Dead + M2 + Wind-ve, Dead + M3 + Wind-ve, Dead + M4 + Wind-ve, Dead + M5 + Wind-ve

In Dynamic case following load combination is used:

Dead + M1, Dead + M2, Dead + M3, Dead + M4, Dead + M5, Dead + Time History, Dead + M1 + Time History, Dead + M2 + Time History, Dead + M3 + Time History, Dead + M4 + Time History, Dead + M5 + Time History.

VI DYNAMIC ANALYSIS

Since cable stayed bridge have low structural damping, therefore increase in span lengths of these flexible structures raises many concerns about their behavior under environmental dynamic loads like wind, earthquake and vehicular traffic load.

These bridges occasionally experience extreme loads, especially during a strong earthquake or in a high wind environment and very little information is available regarding dynamic response of cable stayed bridge. To evaluate estimated earthquake loads on the cable there are two main approaches:

- ❖ Pseudo- dynamic or static approach.
- ❖ The dynamic (time-history) response analysis.

The time history function of El-Centro ground motion was taken for the study purpose as shown in fig. 6.

Time-History Analysis

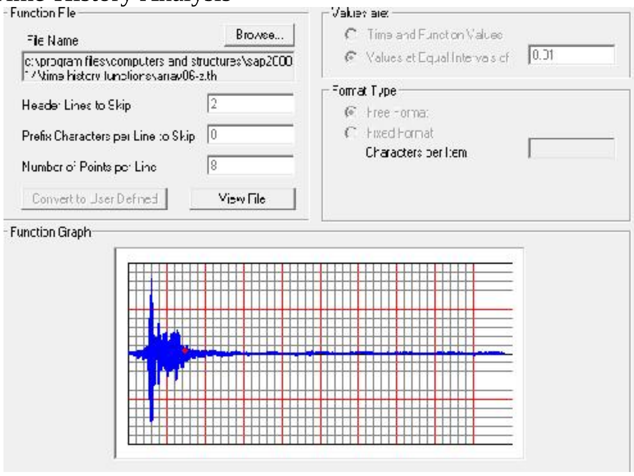


Fig. 6 El-Centro ground motion input

VII PARAMETRIC STUDIES

To find out best possible pylon configuration for given conditions, response quantities like bending moment, shear force, torsion and axial force were plotted for different configuration and different span. The study was carried out for cables, girder and pylons which form major structural component for both linear case and dynamic cases.

VIII RESULTS

Cable **:**Fig. 7 and 8 are for cables subjected to axial force in linear and dynamic case for different shape of pylons.

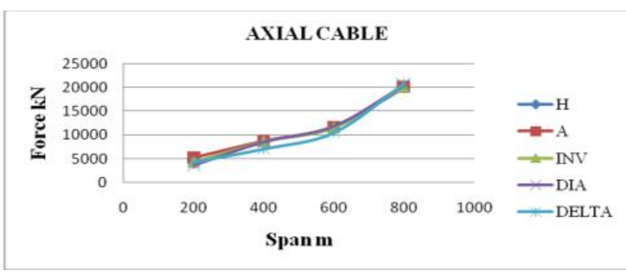


Fig. 7 Linear case

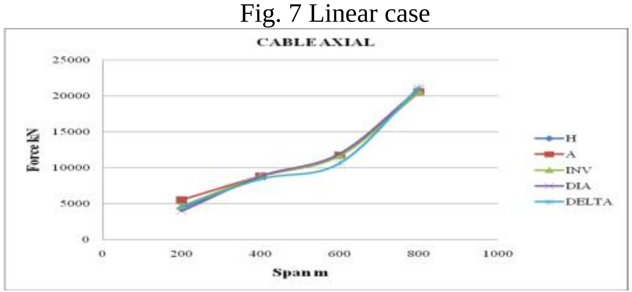


Fig. 8 Dynamic case

Girder Forces

Axial Force kN **:** Axial forces in girders, for both linear and dynamic case fig. 9 and 10 are plotted for different shape of pylons.

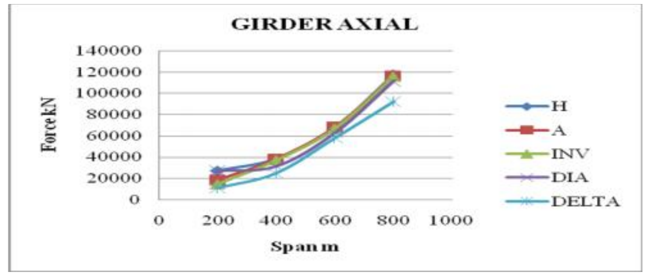


Fig. 9 Linear case

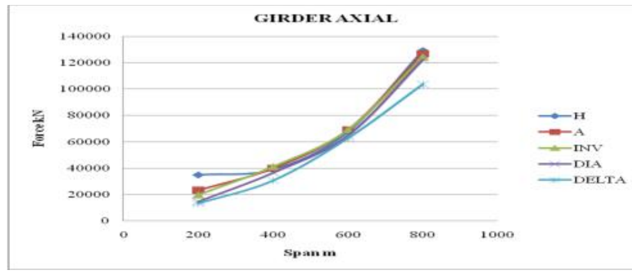


Fig. 10 Dynamic case

Shear Force kN

Shear force in linear and dynamic case in girder is represented by fig. 11 and 12 for different pylon shapes.

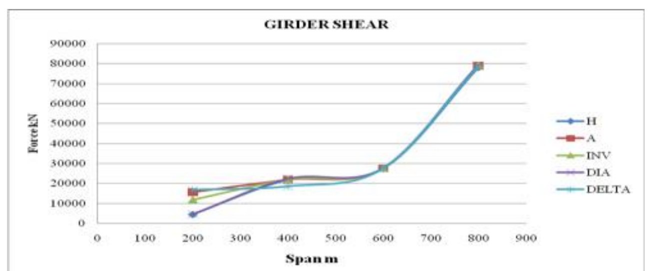


Fig. 11 Linear case

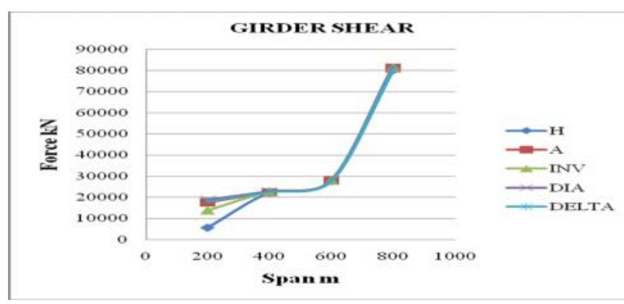


Fig. 12 Dynamic case

Torsion Force kNm

Fig. 13 and 14 shows torsion in girders for different shapes of pylon

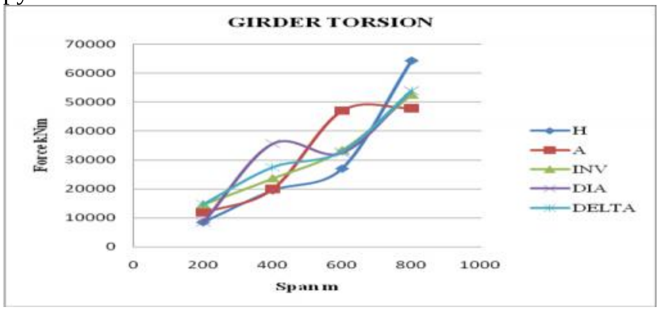


Fig. 13 Linear case

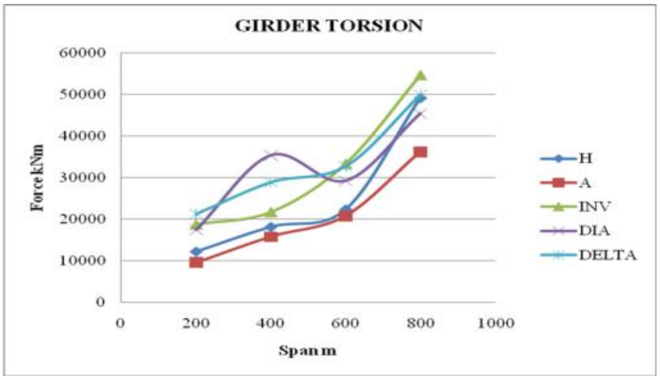


Fig. 14 Dynamic case

Moment kNm : Fig. 15 and 16 represent the graph of bending moment for linear and dynamic analysis for different pylon shapes.

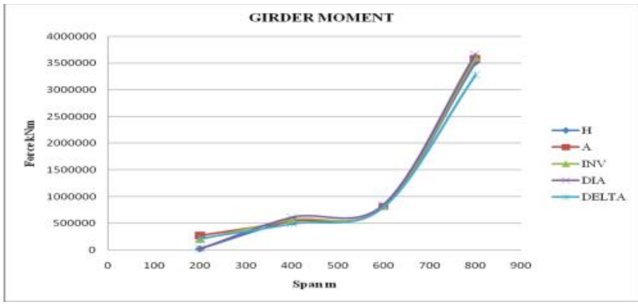


Fig. 15 Linear case

Fig. 16 Dynamic case

Pylon

Axial Force kN : is generated for linear and dynamic case in fig. 17 and 18.

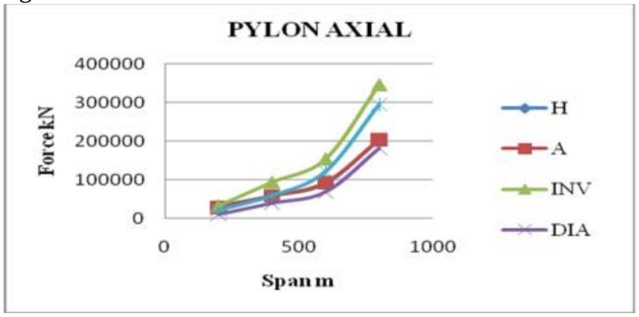


Fig. 17 Linear case

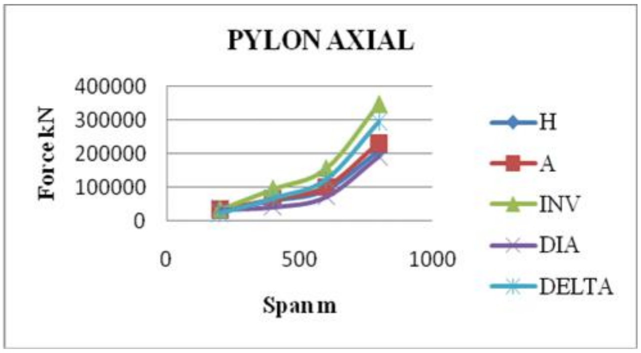


Fig. 18 Dynamic case

Shear force kN : variation of shear force for linear and dynamic case is viewed from fig. 19 and 20 for H, A , Inverted Y, diamond and delta shape of pylon.

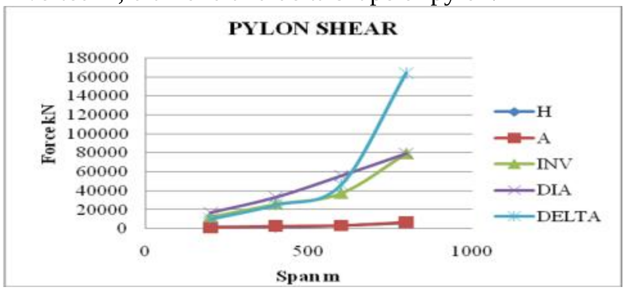


Fig. 19 Linear case

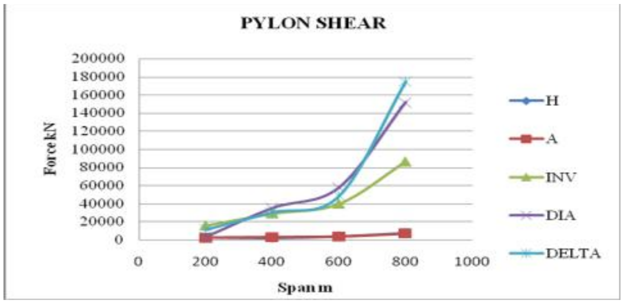


Fig. 20 Dynamic case

Torsion Force kNm : Effect of torsion on different shapes of pylon is represented in fig. 21 and 22 for both linear and dynamic case

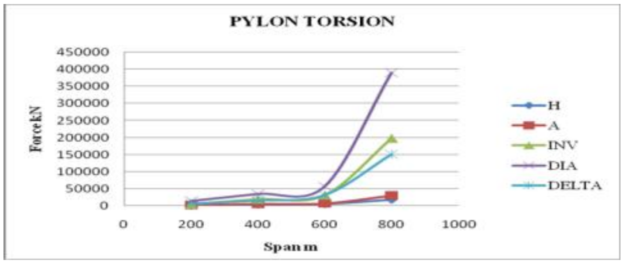


Fig. 21 Linear case

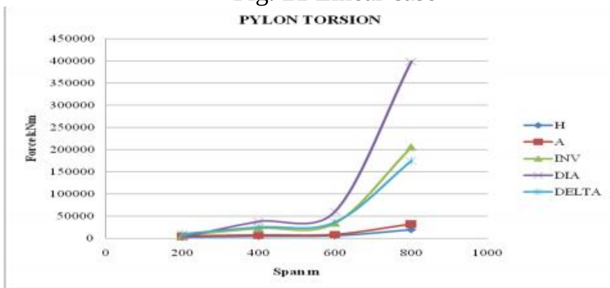


Fig. 22 Dynamic case

Moment kNm : Different pylon shapes behaviour when subjected to bending moment in linear and dynamic case is represented in fig. 23 and 24.

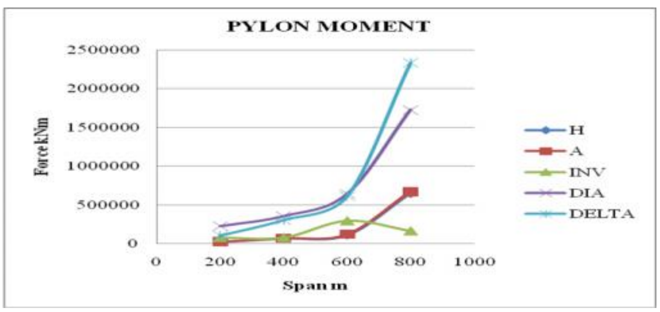


Fig. 23 Linear case

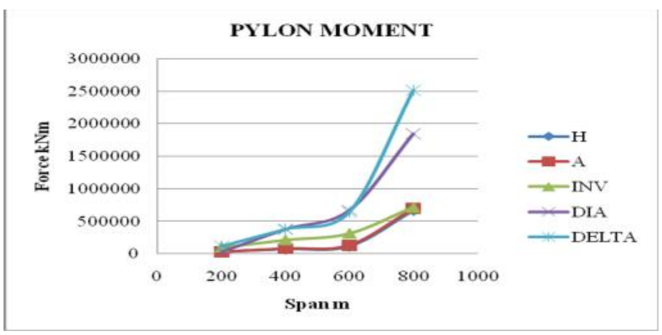


Fig. 24 Dynamic case

IX DISCUSSIONS

- The trend line patterns of cable in axial force in both linear and dynamic case for all the shapes of the pylons to the span of the cable stayed bridge remains similar as in Fig. 7 and 8.
    - As the span increases the axial tensile force in the cable increases. This is because the segment length and depth of the deck increases and so the number of cables also increases.
- In Girder axial force the trend line pattern remains same but in dynamic case the percentage increase in force is more than that of linear case as in Fig. 9 and 10.
- The delta shape of pylon has a lesser force than others in both linear and dynamic case and so its performance in girder axial force is better.
- In Girder shear the Diamond shape at lesser span performs better in both but as span increases its performance deteriorates case and the trend line pattern also remains same as in Fig 11 and 12.
- In Girder Torsion the A shape Pylon performance is better with the increase in span but the trend line do not have same pattern in both case as in Fig.13 and 14.
- In Girder moment the trend line for both cases remains similar as in Fig. 15 and 16 and the performance of all shapes also similar.
- In pylon axial force the diamond shape performance has been better with increase in span than with other shapes while the trend pattern of the graph are similar as in Fig.17 and 18.
- Pylon shear the performance of both the H type and A type pylons are far better than rest of all in both cases and also from Fig.19 and 20 the pattern remains similar.
- Pylon torsion the performance of both the A type and H type again is far better than the rest of the shapes which can been concluded form Fig. 21 and 22.
- Pylon moment the A shape, H shape and also the Inverted Y shape performance is good compared with the rest two in both cases of analysis and the trend line remains almost similar in both cases as in Fig 23 and 24.

X CONCLUSION

Thus form all the above discussion the performance of different shape are better for different response quantities so it cannot be merely concluded form this analysis which is better so a detailed cost comparison can only give the better shape suitable.

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