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(Research Article)

A Seismic Assessment of Curved Cable-Stayed Bridges

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Abstract

In bridge construction cable-stayed structure widely used in last few years for longer span. Sometime due to geometric condition of construction site in curved deck is required in cable-stayed bridges. There for this study will relates to seismic behavior of curved cable-stayed bridges provided at horizontal circular curve. In this study three different major spans of 120 m, 180 m & 240 m having different horizontal deck curvatures as θ = 0°, 10°, 30°, 45°, 60° with two different pylon shapes as A & H were considered. The assessment structure was carried out using linear time history analysis with different ground motions records in SAP2000 computer software. Various parameters such as deck deflection, deck torsion, pylon bending moment, pylon shear force are discussed. After seismic analysis of curved cable-stayed bridge it can be concluded the deck curvature shows major effect in deck torsion moment. Also A shape pylon gives better results in shear force, bending moment of pylon.

Keywords: cable-stayed bridge, curved deck, pylon shape, variation in span, time-history analysis.

1. Introduction

Generally the cable-stayed bridges are constructed having straight geometry, but sometimes due to aesthetic purpose curved geometry is preferred. Also the construction of cable-stayed bridges having curved geometry is a challenging task for civil engineers. In skew & curved deck types bridges are more attract the rotational components of earthquake. Due to geometry nonlinearity of deck, eccentricity develops between center of mass & center of stiffness for this reason deck torsion moment is increase. Therefore, curved bridges are more damage in earthquake. In cable-stayed bridge generally two nonlinearity are present first is cable sag effects and second is bending, axial combined effect in deck & pylon. It is necessary to understand the changes of dynamic behaviour as compare to straight bridge.

In cable stayed bridges, the curvature in bridge deck is not given much attention as reported in the past researches. In past effects of considering different shapes of pylon with curved span will be less attracted by researchers. The main objective of study is to understand the behavior of curved cable-stayed bridges under dynamic loading. To check the effect of curvature and find the efficient shape of pylon by time-history analysis of curved cable-stayed bridge.

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M. Bhagwat, S. Sasmal, B. Novak & A. Upadhyay(2015) focus on free vibration analysis of straight and curved geometry of deck in cable stayed bridges. A single pylon of A and H shape with equal length of two side span was considered for the study. The curvature of deck is varied by different degrees with constant radius. In modal analysis pylon and deck modes are clear and separate due to greater stiffness of A-shaped pylon. Results showed H-shaped pylon vibrate transverse mode at very low frequency due to less stiffness of H-shaped as compare to A-shaped pylon. Pylon shear force should be observed throughout the height, as the base shear force may not be the highest shear force.

Thomas Blesson B. and S.P.Thakkar(2011) gives proposed design provisions of different shapes of the pylons provided as A, H, Inverted Y, Diamond & Delta shapes by varying central span (100, 200, 300, 400). Considered Imposed load & wind load according to IRC 6:2000 for class A and 70-R wheeled vehicles. Perform linear time history analysis for the parametric study. The increase in span cable tensile force will increases due to weight of the deck. Linear and dynamic case the delta shape pylon has lesser girder axial force while diamond shapes performance batter in pylon shear force. For pylon torsion moment both pylon type H & A are gives good results while pylon bending moment A, H and inverted Y shape gives good performance.

Jiang Yi & Jianzhong Li(2021) proposed a method for cable modelling under dynamic action. In this study cable model with both methods first is conventional approach and second proposed method then compare both the structural results. Select various time-history records for nonlinear dynamic analysis of cable-stayed bridges. At low stress level conventional method not gives accurate cable force. An earthquake proposed method capable to consider the cable force variation. So proposed approach is gives good and actual response of cable.

Thomas Wilson, Suren Chen and Hussam Mahmoud (2015) are investigate about skewed and curved deck bridges under vertical component of ground motion record in nonlinear time-history analysis. Twelve number of ground motion with four different earthquake magnitude are select for analysis. Based on V/H PGA ratio and peak vertical acceleration three station data are select for each time history. Vertical ground motion was important component for skewed and curved bridges.

Raid Karoumi(1999) proposed cable modelling method. Cable modal as two-node catenary cable element, for cable supported bridges in nonlinear analysis. For model pylon and deck beam element are use, to resist bending, shear and axial force. Using iterative procedure, stiffness matrix and internal force vector for cable element are evaluated in this study. Geometric nonlinearity consider in this study. First is change in cable tension load at different levels and axial force-bending moment interaction in bridge deck and pylons. Conclude that a catenary cable element is consider geometric change of the cable at any tension level. Cable simple to formulate and gives accurate results using this method.

2. Problem definition & Bridge modelling

In this study five deck curvature i.e. 0°,10°,30°,45°,60° are consider for the parametric study of curved cable-stayed bridge. There are three long span are consider i.e. 120 m, 180 m, 240 m with two pylon shapes A & H are used shows Figure 1. Linear static analysis, Modal analysis and linear time-history analysis perform to find some important parameter like shear force, bending moment, torsion etc. of bridge structure.

2.1 Select ground motion records: For Time-history analysis total 10 numbers of ground motions data are select from PEER (pacific earthquake engineering research center) ground motion database. Select time-history based on moment magnitude is more then 6 and PGA range 0.2 to 1.2g. In time history analysis first horizontal (H1) component of acceleration is consider. Selected time-history data show in Table 1. Time-history data of shorter, medium and long duration are select for study.

2.2 Bridge modelling: In curved cable-stayed bridge there are numbers of bridge component i.e. Pylon, Deck, Cable etc. structure is modal using SAP2000 v20 computer software.

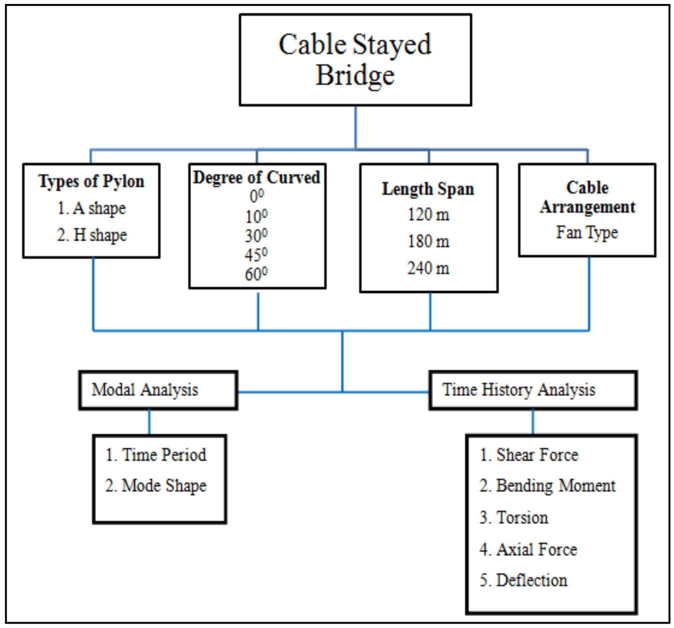

Figure 1. Problem Definition

Bridge configuration of various bridge components are described below in detailed.

2.2.1 Deck: Deck is composite section of concrete and steel, drew in section designer in SAP2000. 0.23 m thick concrete deck slab is rest in two I sections are use as main girder. There are five deck curvature i.e. 60°, 45°, 30°, 10° & 0°(Straight) consider for study. Two rigid link are use to connect cable and deck section show in Figure 2.

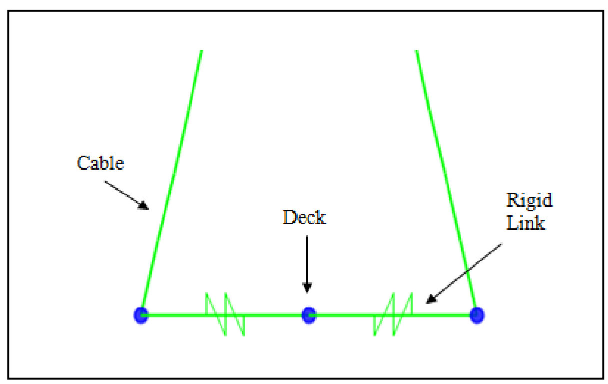

Figure 2. Deck and Link connection

2.2.2 Pylon: In cable-stayed bridge pylon is very important element, it will be use as a compression member to transfer the load directly in foundation. Here two pylon shapes are use for the study and pylon configuration show in Table 2. Both pylon shape shows in 3D view of curved cable-stayed bridge Figure 24.

Table 1. Ground motion records

Sr. no.	Event	Station	Year	M_w	PGA(g)	Duration(s)
1	Morgan Hill	Coyote Lake Dam	1984	6.19	0.713	30
2	San Fernando	Pacoima Dam Abutment	1971	6.6	1.219	42
3	Imperial Valley	El Centro Array #5	1979	6.53	0.525	39
4	Northridge	Rinaldi	1994	6.69	0.874	20
5	Kobe	KJMA	1995	6.9	0.834	150
6	Loma Prieta	Saratoga W Valley	1989	6.93	0.258	40
7	Tabas	Tabas	1978	7.35	0.854	33
8	Landers	Lucerne Valley	1992	7.28	0.725	48
9	Kocaeli	Gebze	1999	7.51	0.261	28
10	Chi	TCU052	1999	7.62	0.348	90

Note;- M_w-moment magnitude; PGA-peak ground acceleration;

Table 2. Pylon configuration

A Shape pylon	Material – Concrete Cross Section – 2m×4m Height above the deck – 40 m Height below the deck – 20 m Cross beam – 1m×2m
H Shape Pylon	Material – Concrete Cross Section – 2m×4m Height above the deck – 40 m Height below the deck – 20 m Top Cross beam – 1m×1.5m Bottom Cross beam – 1m×2m

2.2.3 Cable: In cable-stayed bridges cable is use to transfer the load as tension force only. One end of cable connect with rigid link and another end fix with pylon top. In different span length, number of cable is change i.e. 120m Span cable no. is 16, 180m Span cable no. is 20 & 240m Span cable no. is 28. Material property and diameter are same in all modal shown below Table 3.

Table 3. Cable Properties

Diameter of Cable	0.07 m
Unit Weight of Cable	76.973 kN/m^3
Modulus of Elasticity	2×10^8 kN/m^2

2.2.4 Support and Connections: In both pylon system bottom end are fix with base. One side of bridge deck is hinge support and another side is roller support with transverse direction is restraint. Deck and pylon connection is roller with use of linear bearing link between deck and cross beam. The bearing link restrains vertical & transverse directions with rotation torsion is also restrain.

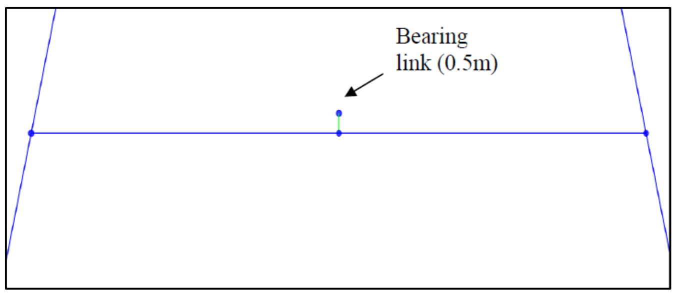

Figure 3. Bearing link

3. Parametric study of bridge

In curved cable-stayed bridge linear static analysis and modal analysis perform for parametric study of bridge. In linear static analysis check the effect of deck curvature with span variation. In modal analysis compare time period of A shape bridge system and H shape bridge system. Parametric study carried out for basic understanding of load transfer mechanics and behavior structural component in gravity load condition. Modal analysis carried out for basic information about different mode shape of curved cable-stayed bridge.

3.1 Linear static analysis: Linear static analysis carried out for dead load case to understand the behavior of curved cable-stayed bridges. In dead load case only self-weight is consider for the study. After analysis some important parameters like pylon shear force, pylon bending moment, deck torsion, deck axial force, pylon deflection and deck deflection are compare to different pylon system and deck curvature. First check the effect of different deck curvature in torsion moment of deck and shear force, bending moment of pylon. Also compare both pylon systems for further understanding of curved cable-stayed bridges. In linear static analysis, cable force behaviour are check in two different locations of deck system.

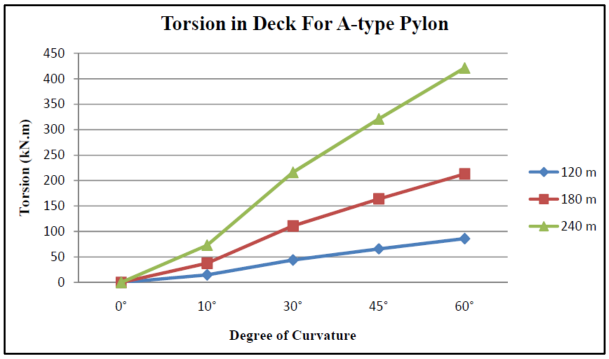

Figure 3. Deck torsion for A-shape pylon

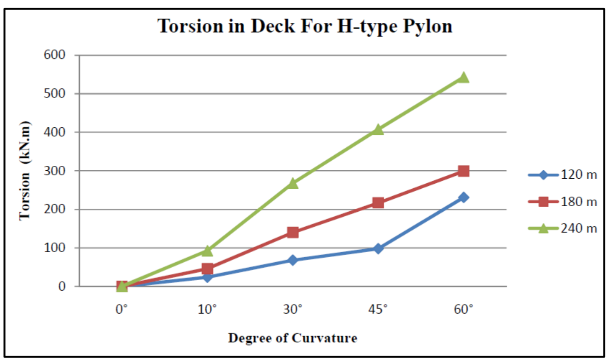

Figure 4. Deck torsion for H-shape pylon

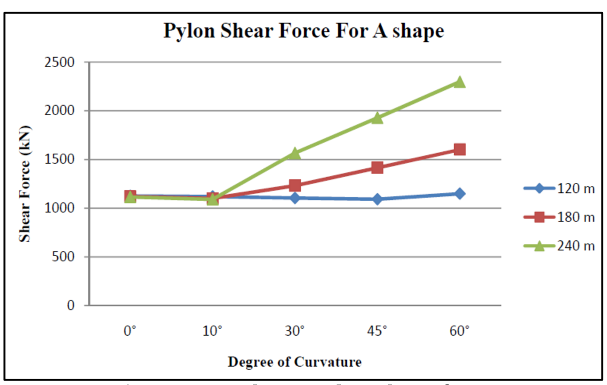

Figure 5. A shape pylon shear force

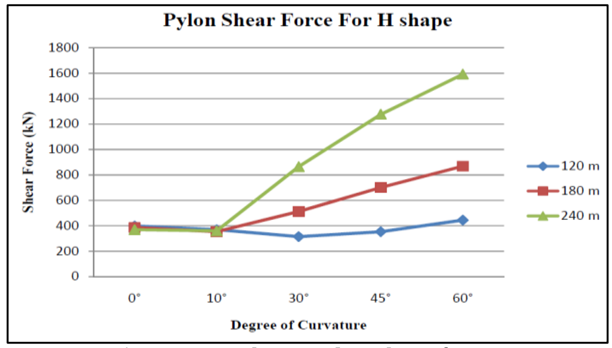

Figure 6. H shape pylon shear force

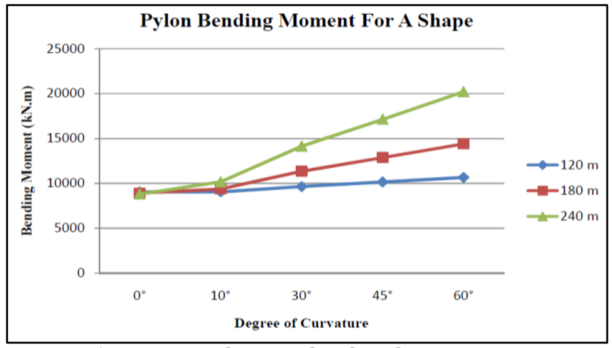

Figure 7. A shape pylon bending moment

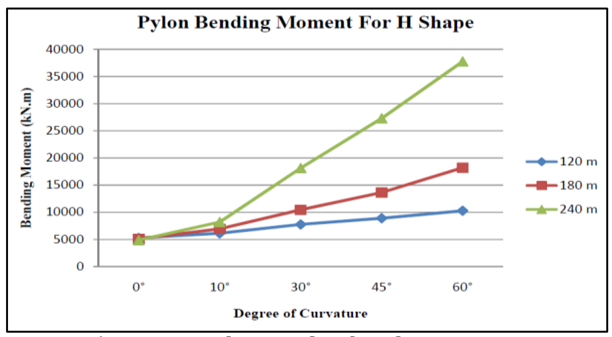

Figure 8. H shape pylon bending moment

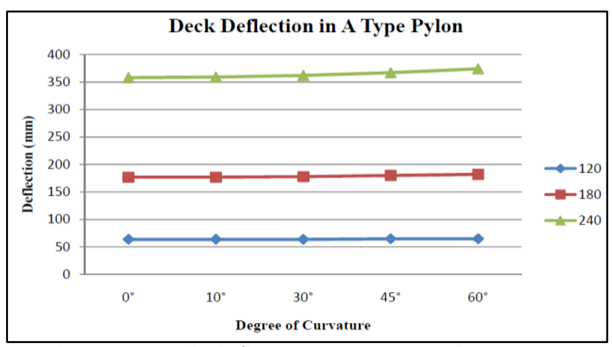

Figure 9. Deck deflection in A type pylon system

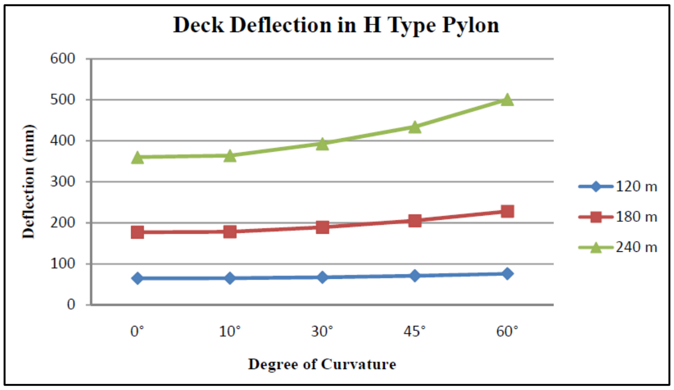

Figure 10. Deck deflection in H type pylon system

According to above result of linear static analysis, all important parameter like deck torsion, pylon shear, pylon bending moment and deck deflection are increase with degree of curvature. In 240m curved span gives maximum value and 120m curved span gives minimum value in all parameter.

3.2 Modal analysis: Modal analysis is carried out to find the time period, frequency and mode shape of different curved cable-stayed bridge modal. In SAP2000 modal analysis use Eigen vectors method and find 12 numbers of mode shape, time period & modal frequency.

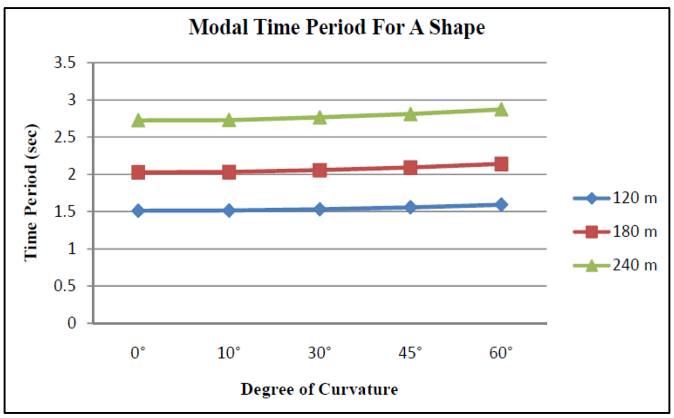

Figure 11. Modal time period of A type pylon bridges

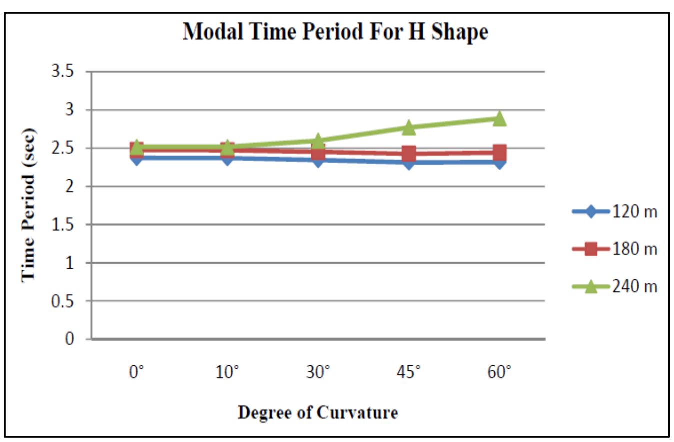

Figure 12. Modal time period of H type pylon bridges

In modal analysis A shape pylon system time period not much varies according to degree of curvature. A shape pylon system bridges give less time period as compare to H shape pylon system. Due to higher stiffness of A shape pylon. In 240m span time period is maximum and 120m span gives minimum time period value.

4. Time-history analysis

In present study linear time history analysis is perform in SAP2000. Time history apply in X direction (along the bridge) with appropriate scale factor and 5% modal damping. Find the average of ten time history result to find accurate performance of bridge. In seismic analysis check the effects of curvature in shear force, bending moment and torsion. Also compare the both A & H pylon system behaviour.

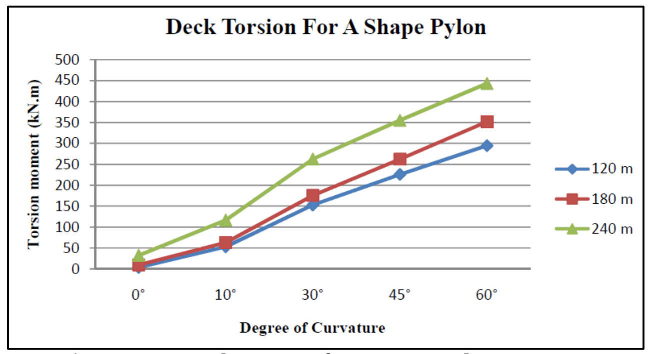

Figure 13. Deck torsion for A type pylon system

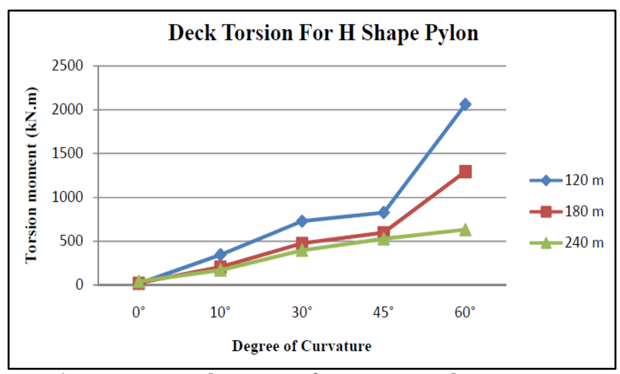

Figure 14. Deck torsion for H type pylon system

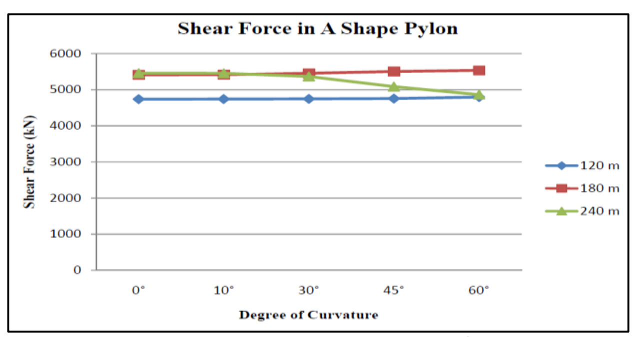

Figure 15. A shape pylon shear force

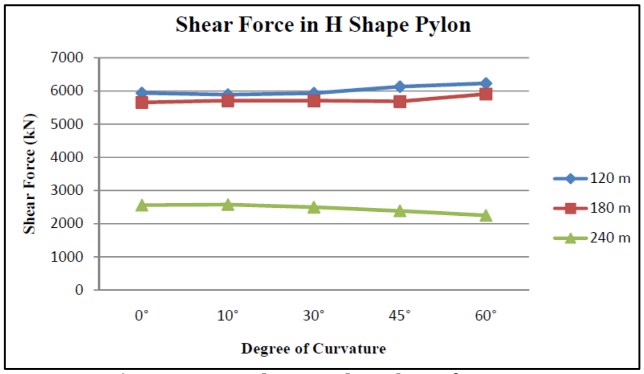

Figure 16. H shape pylon shear force

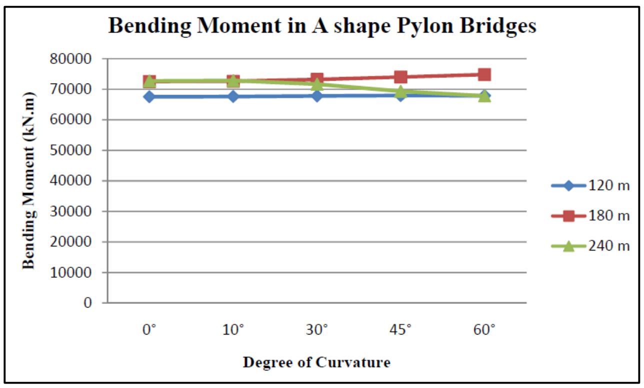

Figure 17. A shape pylon bending moment.

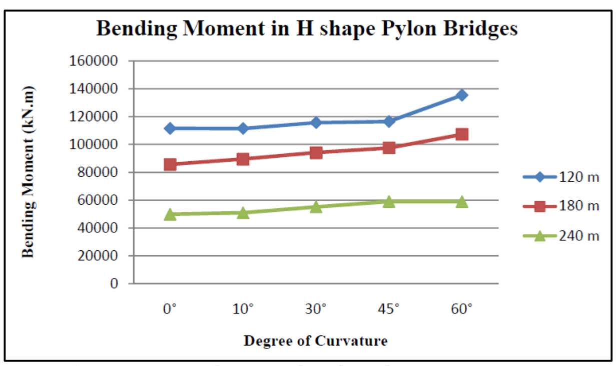

Figure 18. H shape pylon bending moment

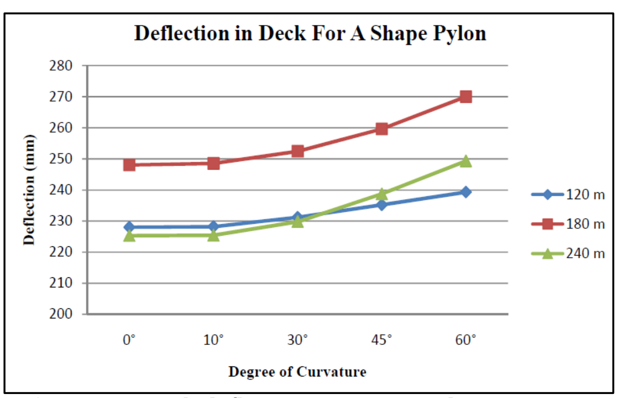

Figure 19. Deck deflection in A type pylon system

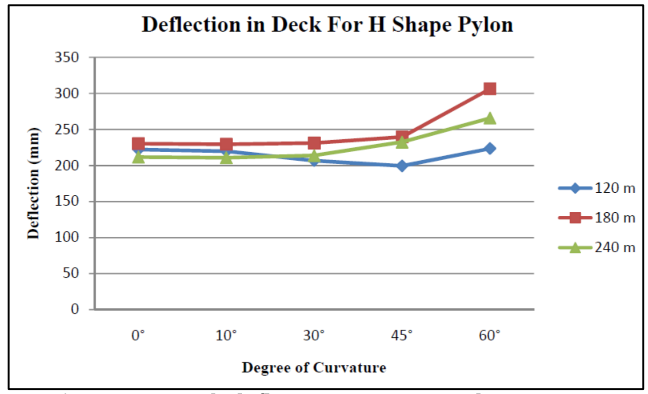

Figure 20. Deck deflection in H type pylon system

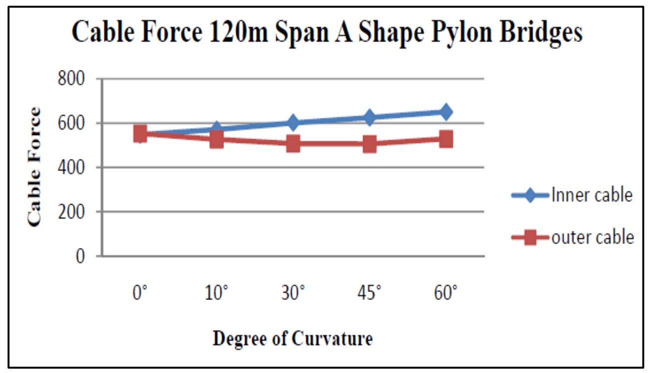

Figure 21. Cable force in120m span A type pylon bridge

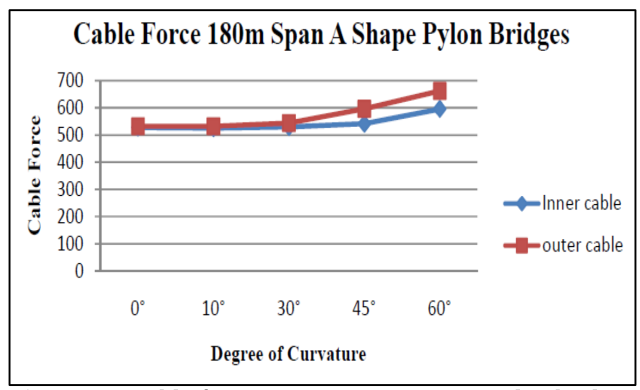

Figure 22. Cable force in 180m span A type pylon bridge

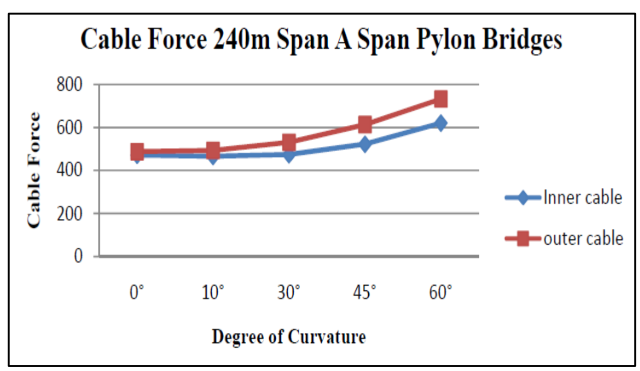

Figure 23. Cable force in 240m span A type pylon bridge

Time history analysis is carried out for seismic assessment of curved cable-stayed. After time history analysis according to above results, deck torsion increase with increasing degree of curvature. In A shape pylon system no considerable effect of deck curvature shows in shear force and bending moment. In H shape pylon system shear force and bending moment are increase with curvature. Figure 21 to 23 shows cable force in two different cable locations one is inner side of the curved deck and other is outer side of the curved deck. In 180m & 240m span bridges, outer cable gives maximum cable force. In 120m span inner cable give maximum value of cable force. Cable force of inner & outer cable is increase with increasing degree of curvature.

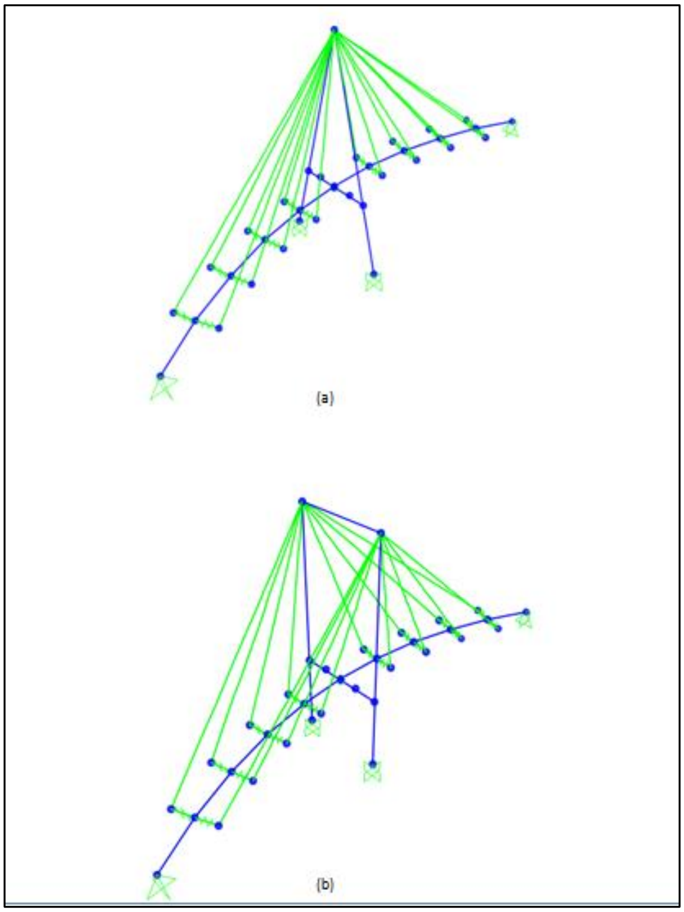

Figure 24. 3D View of 60° deck curvature bridge modal with A & H shape pylon

4. Conclusions

Based on analysis of curved cable-stayed bridges some important conclusion is obtained given below.

- In linear static analysis of curved cable-stayed bridges A shape pylon gives better performance in deck torsion and deck deflection.
- In dead load case H shape pylon is suitable for shorter span curved cable-stayed bridges i.e. 120m span.
- Pylons shear force & bending moment increase with degree of curvature in linear static analysis.
- In dead load analysis outer side cable axial force increase with degree of curvature and inner side cable axial force decrease with degree of curvature.
- In modal analysis time period increase with degree of curvature and length of span.
- Time period of A shape pylon curved cable-stayed bridges is less as compare to H shape pylon system because of A shape pylon stiffness is more.
- In seismic analysis pylon shear, pylon bending and deck torsion are important parameter to find best shape of pylon.
- In time-history analysis deck torsion is increase with increase in degree of curvature.
- No major difference has been observed in shear force & bending moment value in A shaped pylon with deck curvature.
- In dynamic analysis behavior of inner and outer cable force is different as compare to static analysis, in 120m span inner cable force is higher and in 180m & 240m span outer cable force is higher in curved cable-stayed bridges.
- A curved cable-stayed bridge structure with A shape pylon and 120m & 180m span has a better seismic performance.

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