Time-History Analysis of a Cable Stayed Bridge for Various Spans and Pylon Height

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Abstract - Seismic Protection is a fundamental issue when it comes to high seismic risk areas design. This protection becomes even more important when we talk about crucial structures such as bridges. Cable-stayed bridges are obviously included in this crucial group of structures. There are several seismic protection systems available and it´s important to make the right choice when one of them is needed. The right approach to this subject is to make an exhaustive comparison between the systems considered relevant in a particular case. When dealing with a cable-stayed bridge the designer should first of all understand correctly the dynamic behavior of the structure. Ground motions force the deck, the pylons and the stays to oscillate. This article provides information on time history analysis of a cable stayed bridge for various spans of the bridge and pylon height.

Key Words: **Cable-stayed bridges, Time History, Pylon shape, Peak Acceleration, Peak Deflections, deck deflections.**

1. INTRODUCTION

Cable-stayed bridges are popular since the sixteenth century and effectively utilizing till the nineteenth. A cable-stayed bridge is having a minimum one no. of tower (or a pylon), from which cables hold the bridge deck. The cables will run parallel like a fan like structure, from pylon to the deck. This is quite different from suspended type of bridge, where the cable supports the deck are suspended by main cable which is running between the towers. The cable-stayed bridges are ideal for ranges longer than cantilever bridges and shorter than suspension bridges. This is where cantilever bridges would quickly become heavier if the range were stretched, while suspension bridge cabling would not be more conservative if the range were abbreviated.

1.1 OBJECTIVES

- To model and analyses a cable stayed bridge using SAP 2000 for A shape of pylon configuration subjected to static load.
- To understand the behavior of a cable stayed bridge subjected to dynamic time history loads and moving loads.
- To study the effect of increase in span on the response of a shape pylon.
- To explore and understand the variation of key results like deformation of pylon, axial stresses in pylon, forces in cables, deck deflection, due to static loads and peak acceleration, peak displacement due to dynamic time history loads.
- To determine the suitable configuration of A Shape pylon for specific span length based on the results obtained in static and dynamic analysis.

1.2 METHODOLOGY

This Cable-Stayed bridge is modelled with concrete structural elements. The models are further studied different spans and pylon height. The cable-stayed bridge containing A-shaped pylon has been modelled as three dimensional R.C. frame. Finite element software SAP 2000 v14.0 is used for the modelling of bridge and performing finite element analysis to determine the seismic responses. Modelling, material properties, frame sections, loads applied and analysis method used in present study are described below.

Time History Analysis:

M1 – A-Type – Span 110 m – Pylon Ht. Span/3

M2 – A-Type – Span 110 m – Pylon Ht. Span/2

M3 – A-Type – Span 220 m – Pylon Ht. Span/3

M4 – A-Type – Span 220 m – Pylon Ht. Span/2

M5 – A-Type – Span 320 m – Pylon Ht. Span/3

M6 – A-Type – Span 320 m – Pylon Ht. Span/2

Moving Load Analysis:

M7 – A-Type – Span 110 m – Pylon Ht. Span/3

M8 – A-Type – Span 110 m – Pylon Ht. Span/2

M9 – A-Type – Span 220 m – Pylon Ht. Span/3

M10– A-Type – Span 220 m – Pylon Ht. Span/2

M11 – A-Type – Span 320 m – Pylon Ht. Span/3

M12 – A-Type – Span 320 m – Pylon Ht. Span/2

2. MODELLING

In the present dissertation work, Cable-stayed bridges of concrete structural elements with varying pylon height and spans.

2.1 MODEL 1 SPECIFICATION:

Type of pylon = A-shaped pylon

Span = 110m

Pylon height = 36.6m

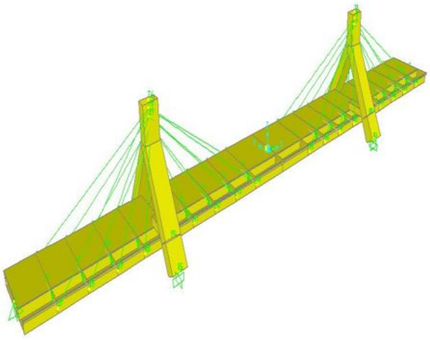

Figure 1: Model 1

2.2 MODEL 2 SPECIFICATIONS:

Type of pylon = A-shaped pylon

Span = 110m

Height of pylon = 55m

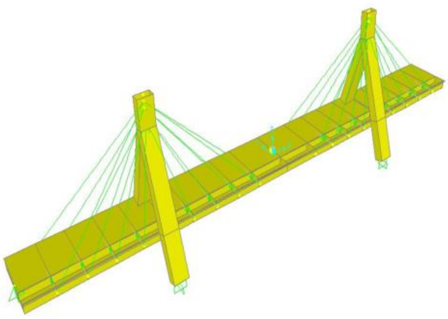

Figure 2: Model 2

2.3 MODEL 3 SPECIFICATIONS:

Type of pylon = A-shaped pylon

Span = 220m

Height of pylon = 73.3m

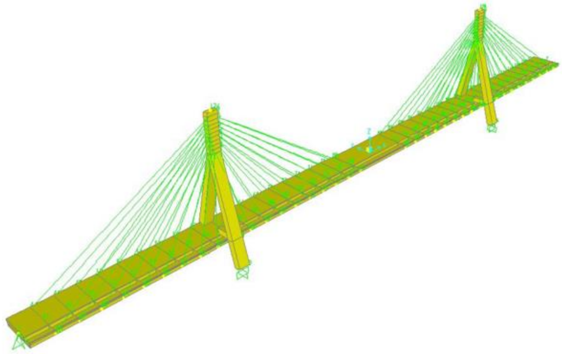

Figure 3: Model 3

2.4 MODEL 4 SPECIFICATIONS:

Type of pylon = A-shaped pylon

Span = 220m

Height of pylon = 110m

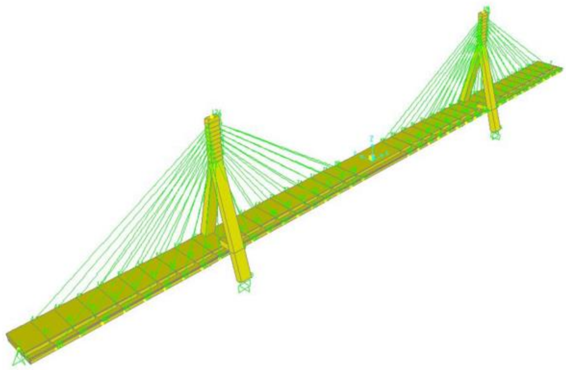

Figure 4: Model 4

2.5 MODEL 5 SPECIFICATIONS:

Type of pylon = A-shaped pylon

Span = 320m

Height of pylon = 106.6m

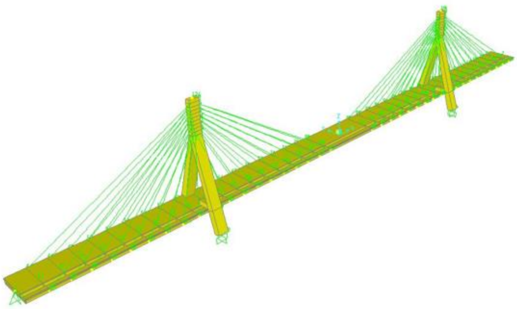

Figure 5: Model 5

2.6 MODEL 6 SPECIFICATIONS:

Type of Pylon = A-shaped pylon

Span = 320m

Height of pylon = 160m

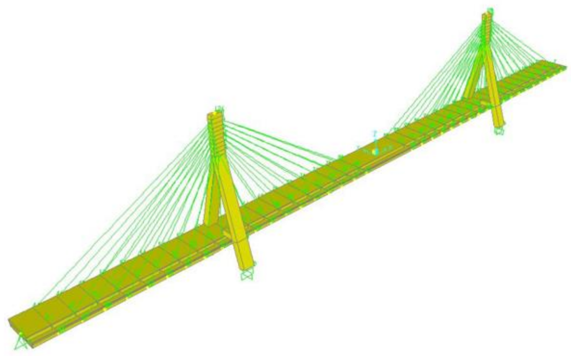

Figure 6: Model 6

3. ANALYSIS

3.1 GENERAL

Static, dynamic and moving load analysis of cable stayed bridge with A-Shape pylon has been done. In order to understand the behavior of cable stayed bridge, different spans are chosen (110, 220 m and 320 m) with two different heights of pylon (Span/2, Span/2).

3.2 TIME HISTORY ANALYSIS

"Nonlinear Dynamic Analysis It is known as Time history analysis. It is an important technique for structural seismic analysis especially when the evaluated structural response is nonlinear. To perform such an analysis, a representative earthquake time history is required for a structure being evaluated. Time history analysis is a step-by step analysis of the dynamic response of a structure to a specified loading that may vary with time. Time history analysis is used to determine the seismic response of a structure under dynamic loading of representative earthquake."

3.3 MODAL ANALYSIS

To find the vibrational characteristics of cable stayed bridge, modal analysis has been carried out and time period and frequency of the cable stayed bridge for different spans and height of the bridge is tabulated in Table 5.1 and Table 5.2 respectively. "Modal analysis uses the overall mass and stiffness of a structure to find the various periods at which it will naturally resonate. The goal of modal analysis in structural mechanics is to determine the natural mode shapes and frequencies of an object or structure during free vibration" The response in each mode of natural vibration can be computed independently with respect to the other modes. The structure can be modeled as a discrete or continuous system and depending on this ordinary differential equations or partial differential equations can be used as governing equations respectively.

4. RESULTS AND DISCUSSION

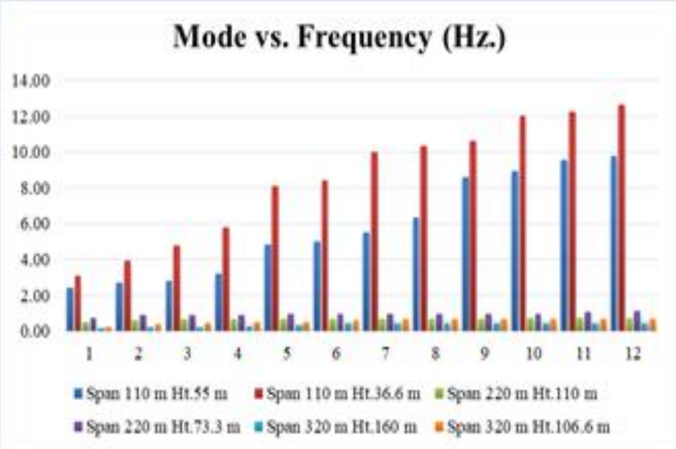

Figure 7: Mode vs. Frequency

TABLE 1: Mode vs. Frequency

	Modal Analysis - Frequency (Hz.)					
	Span 110 m		Span 220 m		Span 320 m	
Mode/Pylon Ht.	55 m	36.6 m	110 m	73.3 m	160 m	106.6 m
1	2.44	3.07	0.52	0.72	0.15	0.23
2	2.67	3.94	0.63	0.89	0.20	0.38
3	2.81	4.75	0.67	0.90	0.21	0.46
4	3.20	5.79	0.67	0.90	0.30	0.51
5	4.85	8.08	0.68	0.93	0.32	0.51
6	5.02	8.43	0.68	0.93	0.46	0.63
7	5.49	10.01	0.68	0.94	0.46	0.65
8	6.36	10.36	0.69	0.94	0.47	0.67
9	8.63	10.65	0.69	0.97	0.47	0.67
10	8.96	12.05	0.72	0.98	0.47	0.67
11	9.53	12.28	0.73	1.07	0.48	0.67
12	9.78	12.65	0.74	1.11	0.48	0.67

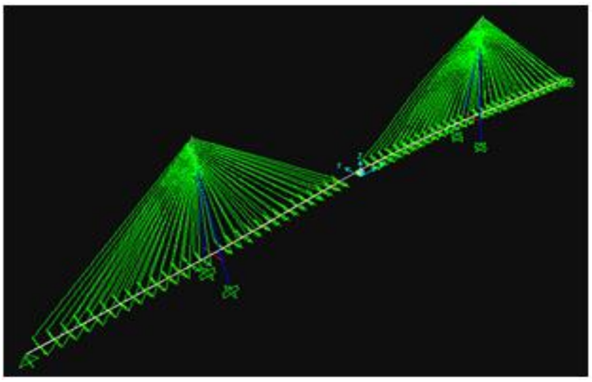

Figure 8: Deformed Shape at Mode 1 (3D)

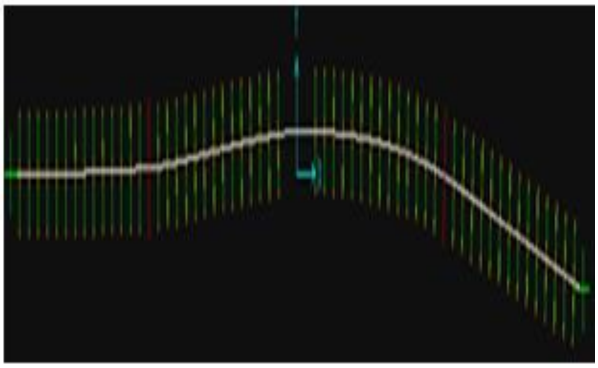

Figure 9: Deformed Shape at Mode 1 (Plan)

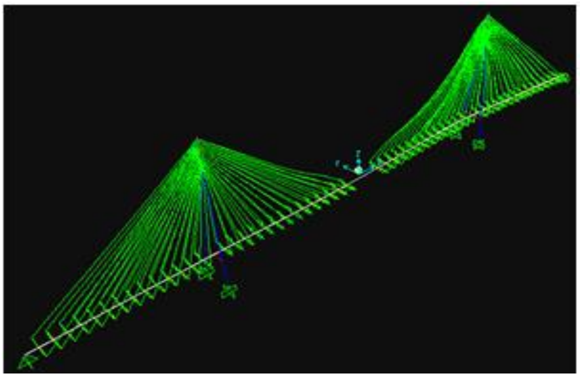

Figure 10: Deformed Shape at Mode 2 (3D)

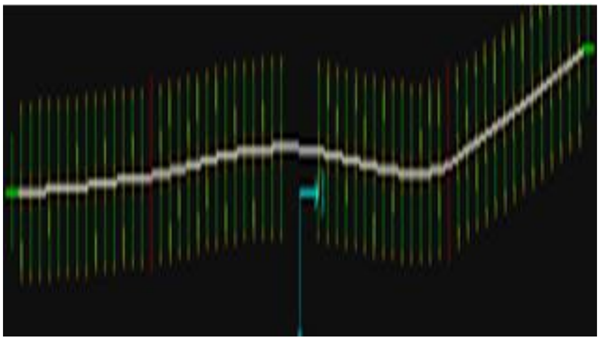

Figure 11: Deformed Shape at Mode 2 (Plan)

4.1 TIME HISTORY ANALYSIS

Time history analysis has been done for ELCENTRO dynamic input. From the analysis, peak displacements and peak acceleration has been extracted at pylon top, maximum deck deflection has been found for (DL+TH) combination. Cable forces are done for dead load of the bridge.

Table 2: Deck Deflection

Deck Deflection mm (DL+TH)					
Span 110 m		Span 220 m		Span 320 m	
Ht.55 m	Ht.36.6 m	Ht.110 m	Ht.73.3 m	Ht.160 m	Ht.106.6 m
24.59	13.91	125.00	107.00	496.00	334.00

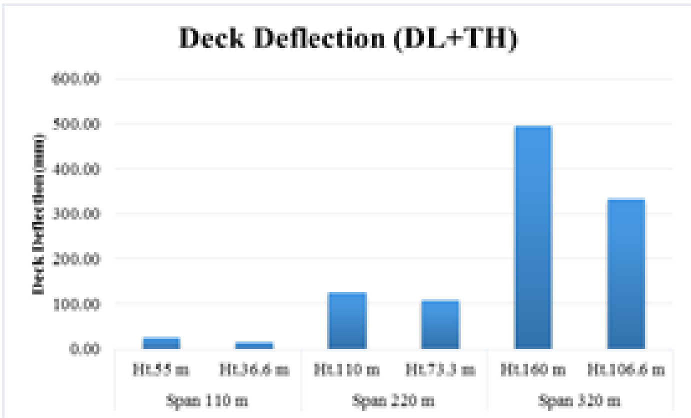

Figure 12: Deck Deflection Graph

From Table 2, it is evident that, deck deflection is maximum for 320 m span, and pylon height of 160m (496 mm) which is found to be 48% more in comparison with span/3 (106.6 m) pylon height.

Table 3: Pylon Displacement

Pylon Displacement mm (DL+TH)					
Span 110 m		Span 220 m		Span 320 m	
Ht.55 m	Ht.36.6 m	Ht.110 m	Ht.73.3 m	Ht.160 m	Ht.106.6 m
19.40	7.70	105.00	61.00	175.00	212.00

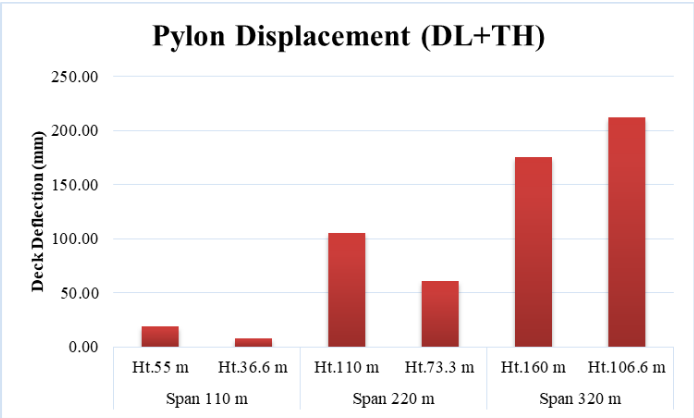

Figure 13: Pylon Displacement Graph

Pylon top deflection is found to be less for 36.6 m height and maximum for span/3 where span is 320 m. For span 220 m pylon top deflection is found to be 105 mm i.e., 40% less than that of span/2 of 320 span cable stayed bridge.

Table 4: Cable Forces

Cable forces					
Span 110 m		Span 220 m		Span 320 m	
Ht.55 m	Ht.36.6 m	Ht.110 m	Ht.73.3 m	Ht.160 m	Ht.106.6 m
27144.00	24953.00	118178.00	99837.00	484618.00	280244.00

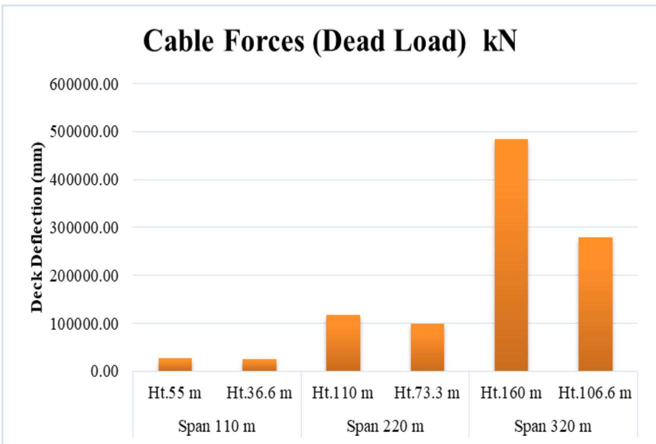

Figure 14: Cable Forces Graph

Cable forces are found to be extremely high for large span cable stayed bride and pylon height of 160 m.

4.1.1 PEAK DISPLACEMENT RESPONSES

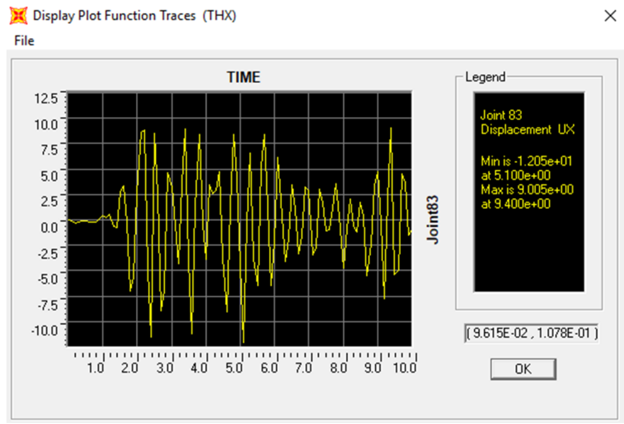

Figure 15: Peak Displacement response – Span 110 (Pylon Ht. 55 m)

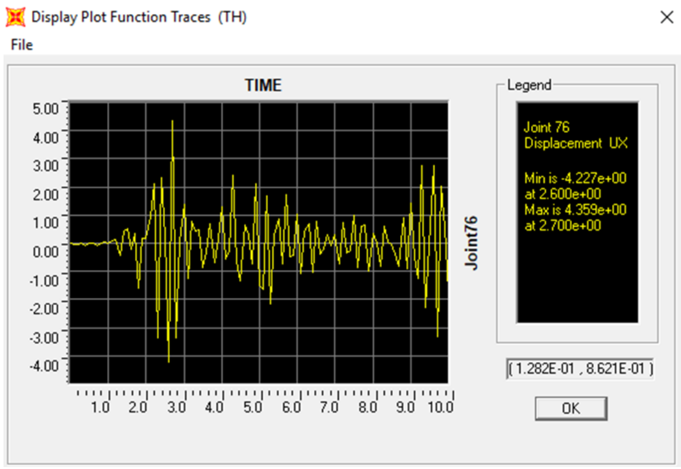

Figure 16: Peak Displacement response – Span 110 (Pylon Ht. 36.6 m)

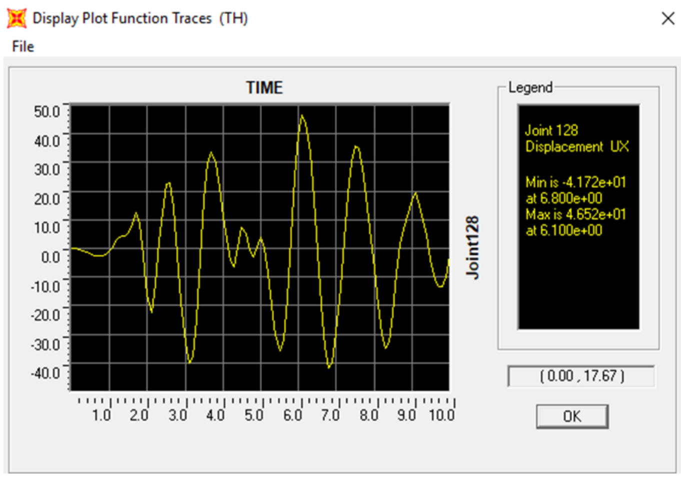

Figure 17: Peak Displacement response – Span 220 (Pylon Ht. 110 m)

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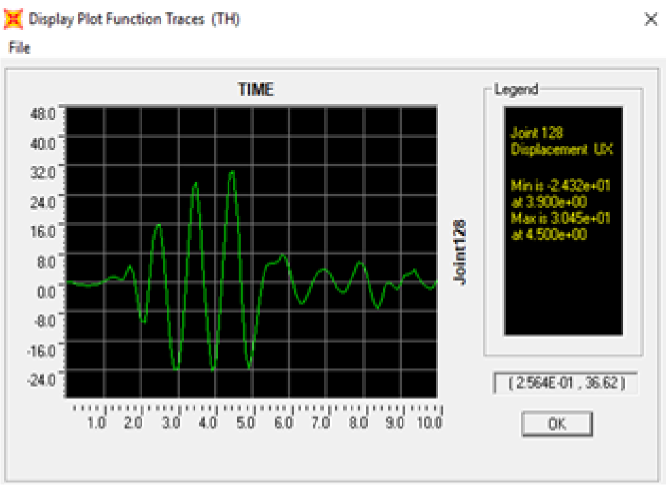

Figure 18: Peak Displacement response – Span 220 (Pylon Ht. 73.3 m)

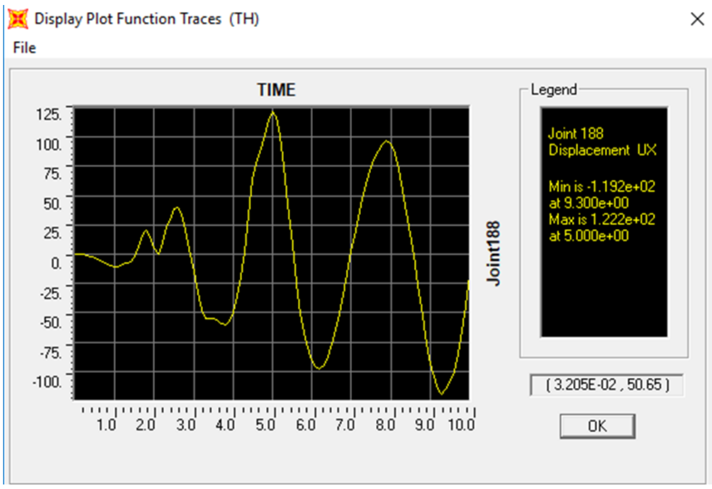

Figure 19: Peak displacement response – Span 320 (Pylon Ht. 160 m)

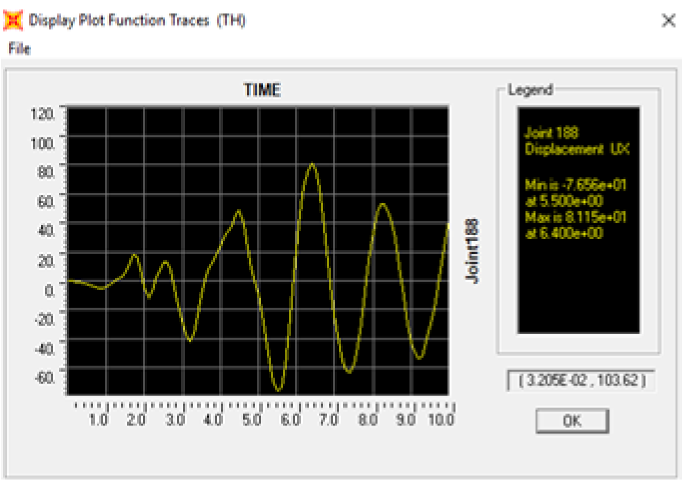

Figure 20: Peak displacement response – Span 320 (Pylon Ht. 106.6 m)

Table 4: Time History Results for peak displacements

Time History Results (Peak Displacements) mm					
Span 110 m		Span 220 m		Span 320 m	
Ht.55 m	Ht.36.6 m	Ht.110 m	Ht.73.3 m	Ht.160 m	Ht.106.6 m
12.05	4.35	46.50	30.45	122.20	81.15

Figure 15 to 20 shows the peak displacement response for different spans and for different heights of pylon and results are summarized in Table 4. From the table it is clear that, due to dynamic time history input, peak displacements is found be high in case of 320 m span cable stayed bridge for span/2 pylon height. The variation is plotted in Fig. 21. And also from time history response plots, it can be observed that, where deflection is less, the vibrations are more and for higher deflections vibrations are less pylon top portion.

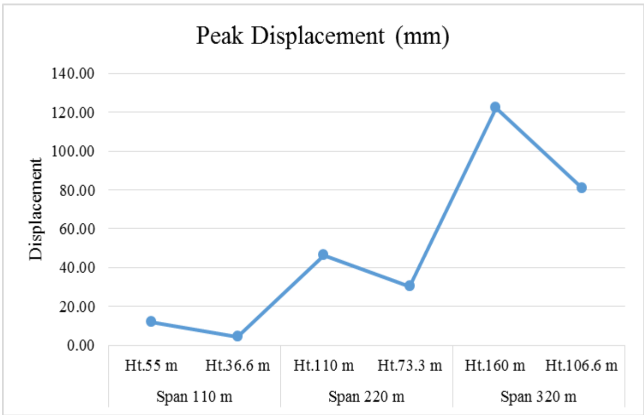

Figure 21: Peak Displacement Summary graph

4.1.2 PEAK ACCELERATION RESPONSES

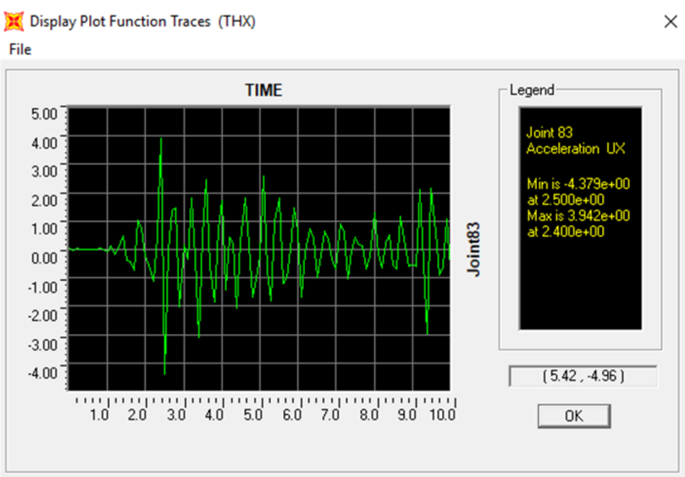

Figure 22: Peak Acceleration response – Span 110 (Pylon Ht. 55 m)

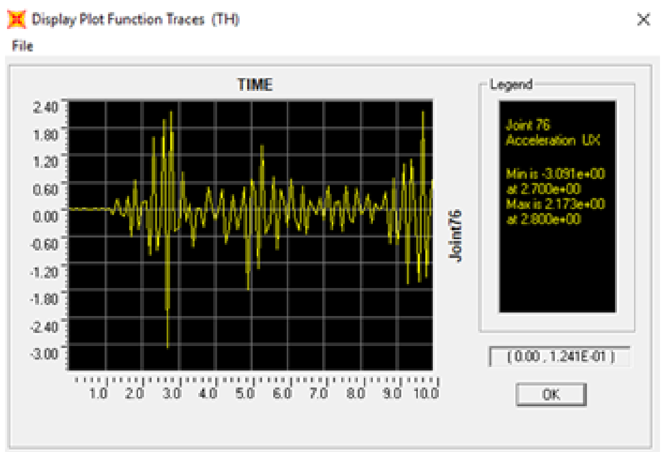

Figure 23: Peak Acceleration response – Span 110 (Pylon Ht. 36.6 m)

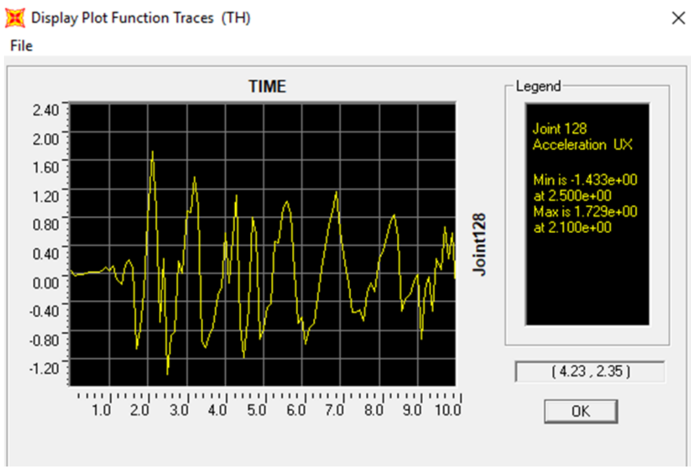

Figure 24: Peak Acceleration response – Span 220 (Pylon Ht. 110 m)

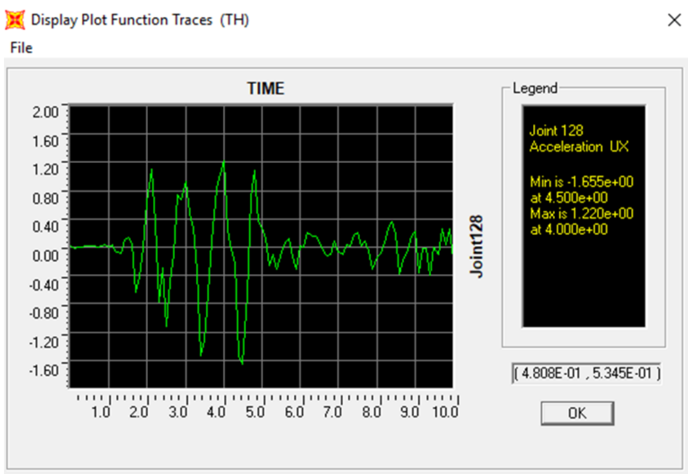

Figure 25: Peak Acceleration response – Span 220 (Pylon Ht. 73.3 m)

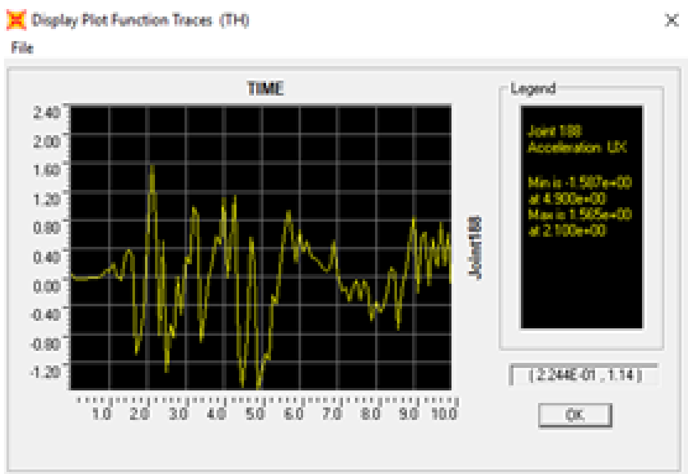

Figure 26; Peak Acceleration response – Span 320 (Pylon Ht. 160 m)

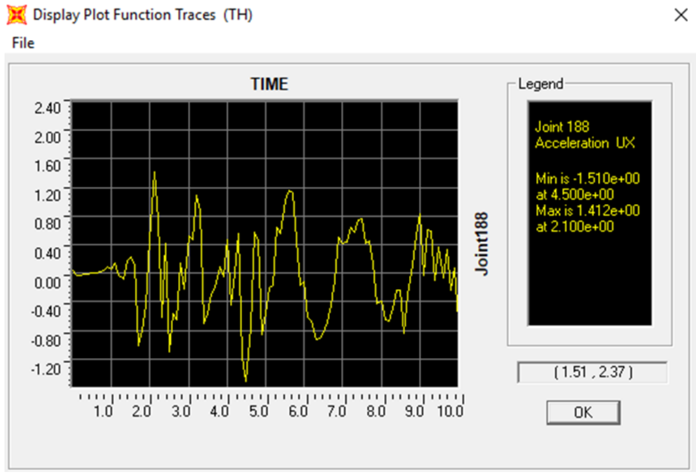

Figure 27: Peak Acceleration response – Span 320 (Pylon Ht. 106.6 m)

Table 5: Time History Results for peak acceleration

Time History Results (Peak Acceleration) N/m^2					
Span 110 m		Span 220 m		Span 320 m	
Ht.55 m	Ht.36.6 m	Ht.110 m	Ht.73.3 m	Ht.160 m	Ht.106.6 m
4.37	3.09	1.72	1.65	1.58	1.51

Acceleration is found to be high i.e., 4.37 N/m^2 in case of 55 m height pylon of span 110 m and goes on decreases with the increase in span and pylon height. Peak acceleration decrease 29% with the decrease in pylon height from span/2 to span/3. In further increase in span and pylon height peak acceleration is found to be constant as shown in Fig.28.

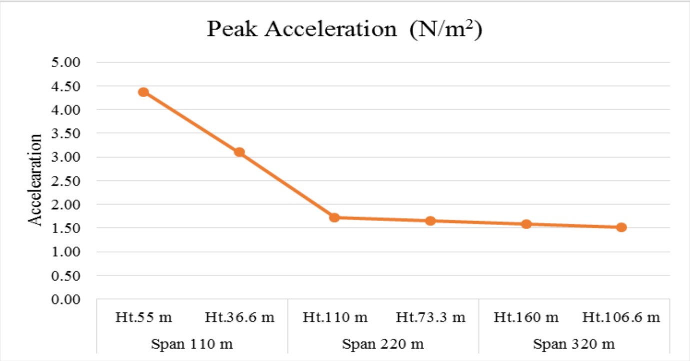

Figure28: Peak acceleration Graph

4.2 MOVING LOAD ANALYSIS

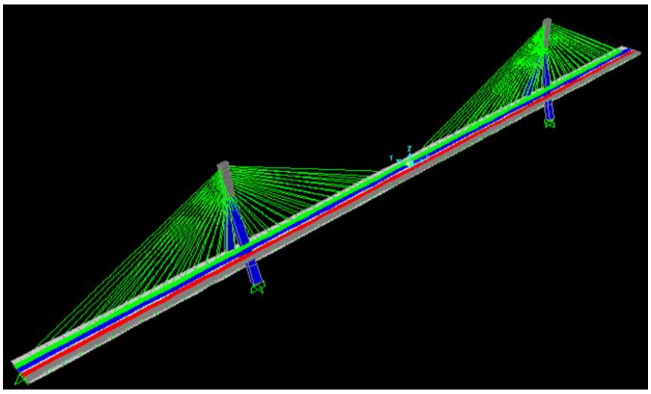

Figure 30: 3D Picture of 320 m Cable Stayed Bridge with four lane road

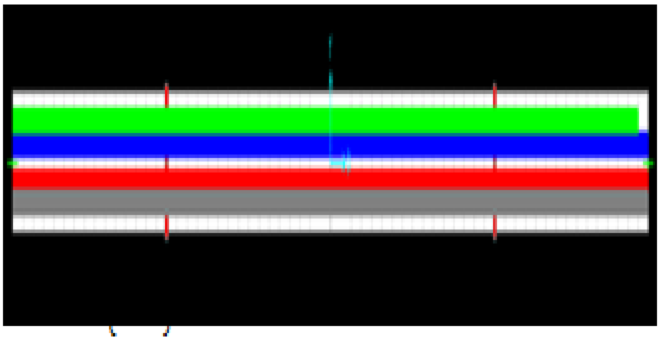

Figure 31: Picture of 320 m Cable Stayed Bridge with four lane road (Plan)

Table 6: Deck Deflection due to Moving Loads

Deflection - Moving Loads					
Span 110 m		Span 220 m		Span 320 m	
Ht.55 m	Ht.36.6 m	Ht.110 m	Ht.73.3 m	Ht.160 m	Ht.106.6 m
6.78	6.38	20.70	23.00	15.4	16.00

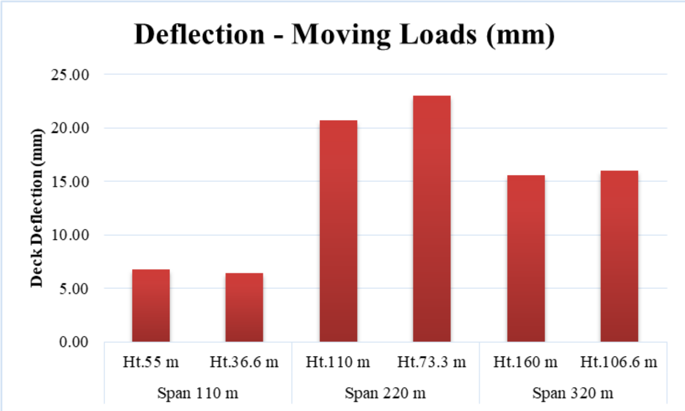

Figure 32: Deck Deflection due to Moving Loads Graph

Deck deflection due to moving loads is found to be high in case of high in case of span 220 m and pylon height of 73.3 m (Span/3) i.e., 23 mm. For large span cable stayed bridge, deck deflection is found to be less of about 30% compared to maximum deflection.

5. CONCLUSIONS

5.1 GENERAL

Based on the results and discussions following conclusions are listed below.

- From the modal analysis it can be concluded that, time period and frequency is dependent on over all span of the structure and also pylon height. And frequency is found to be high in case of short span bridges and less pylon height. Hence short span bridges are stiffer than that of long span cable stayed briges.

- From the dynamic time history analysis deck deflection is found to large in case of cable stayed bridge with large span. And specifically for span 320 m, deck flection is found to be 496 mm which is found to be higher than the limits (Span/1000).

- Pylon deflection is also found to be more in case of large span cable stayed bridge. Cable forces are found to be very high in case of large span cable stayed bridge.

- Peak acceleration is found to be high for lower span bridges and short pylons. Whereas peak deflection is found to be more in high span cable stayed bridge.

- From the present study it can be concluded that, cable stayed bridge with medium span is preferable since deflections are vibrations are within the limits.

- Also from present study it can be suggested that, more than 2 pylons can be provided for large spans, hence pylon height can be reduced and thereby reducing the deflections and cable forces.

5.2 SCOPE OF FUTURE WORK

- The present study can be extended with the incorporation of dampers to reduce the vibrations and overall deformations.
- The present study can be done for different shapes of pylon and different heights.

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