International Journal of Emerging Research in Management & Technology ISSN: 2278-9359 (Volume-6, Issue-9)

Research Article **September 2017**

Non-Linear Analysis of Cable Stayed Bridges

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Abstract-

The concept of cable-stayed bridges dates back to the seventeenth century. Due to their aesthetic appearance, efficient utilization of material, and availability of new construction technologies, cable-stayed bridges have gained much popularity in the last few decades. After successful construction of the Sutong Bridge, a number of bridges of this type have been proposed and are under construction, which calls for extensive research work in this field. Nowadays, very long span cable-stayed bridges are being built and the ambition is to further increase the span length using shallower and slender girders. In order to achieve this, accurate procedures need to be developed which can lead to a thorough understanding and a realistic prediction of the bridge's structural response under different load conditions.

In the present study, an attempt has been made to analyze the seismic response of cable stayed bridges with single pylon and two equal side spans. This study has made an effort to analyze the effect of both static and dynamic loadings on cable-stayed bridges and corresponding response of the bridge with variations in span length, pylon height and pylon shape. Comparison of static analysis results have been made for different configuration of bridges - their mode shapes, time period, frequency, pylon top deflection, maximum deck deflection; and longitudinal reaction, lateral reaction and longitudinal moment at pylon bottom. Time history analysis results have been investigated for different configuration of bridges under the effects of three earthquakes response spectrum (Bhuj, El Centro and Uttarkashi) - axial forces in stay cables, deck deflections and stress diagrams at maximum peak ground acceleration of the above mentioned earthquakes.

Keywords:

I. INTRODUCTION

During the past decade cable-stayed bridges have found wide applications in large parts of the world. Wide and successful application of cable-stayed systems has been realized only recently, with the introduction of high-strength steel, orthotropic type decks, development of welding techniques and progress in structural analysis. The variety of forms and shapes of cable-stayed bridge intrigue even the most demanding architects as well as common citizens. Engineers have found them technically innovating and challenging. Modern cable-stayed bridges are at present considered to be the most interesting development in bridge design. The increasing popularity of these contemporary bridges among bridge engineers can be attributed to its appealing aesthetics, full and efficient utilization of structural materials, increased stiffness over suspension bridges, efficient and fast mode of construction and the relatively small size of their substructure.

Cable-stayed bridge construction differs from conventional suspension bridges since in the former the girder is supported by individual inclined cable members which are attached directly to the tower, rather than by vertical hangers which are supported by one member as in the case of cable suspended bridges. One of the main difficulties an engineer encounters when faced with the problem of designing a cable-stayed bridge is the lack of experience with this type of structure, predominantly due to its nonlinear behavior under normal design loads. As accurate measurements of seismic responses are scarce in designing these bridges; the need for accurate modeling techniques has arisen. The methods available to the designer for the study of the bridge's dynamic behavior are the forced vibration test of the real structure, model testing and computer analysis. The latter approach is becoming increasingly popular since it offers the widest range of possible parametric studies.

The history of stayed beam bridges indicates that the idea of supporting a beam by inclined ropes or chains hanging from a mast or tower has been known since ancient times. The Egyptians applied the idea for their sailing ships as shown in Fig 1 Redpath and Brown in England and Frenchman Poyet, early in the nineteenth century, designed bridges with steel wire cable and steel bar stays respectively. The first concrete structure to utilize cable stays was the Tempul aqueduct with the main span of 60 m in Spain in 1925. However, the first modern cable-stayed bridge with a steel deck, designed by F. Dischinger, a German engineer, was built in Sweden in 1955, with a main span of 183 m and fan type cable configuration supported on twin column bents.

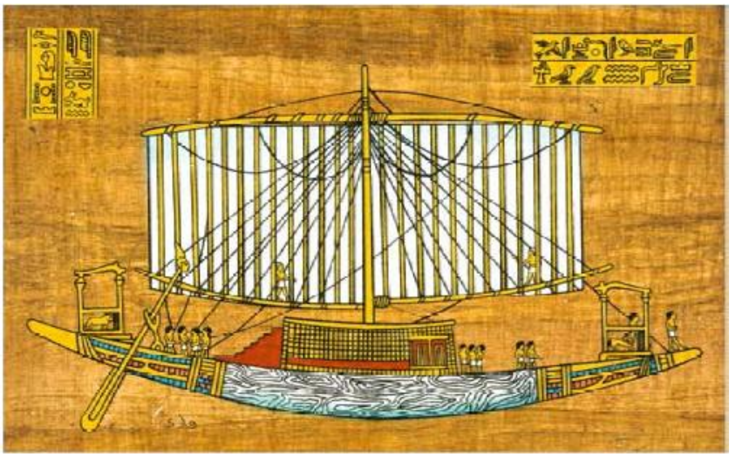

Fig. 1. Stay ropes on Egyptian sailing ships

II. ARRANGEMENT OF STAY CABLES

According to the various longitudinal arrangements, cable-stayed bridges can be divided into three basic systems – radial, harp and fan pattern (Fig.2). However, except in very long span structures, cable configuration does not have a major effect on the behavior of the bridge.

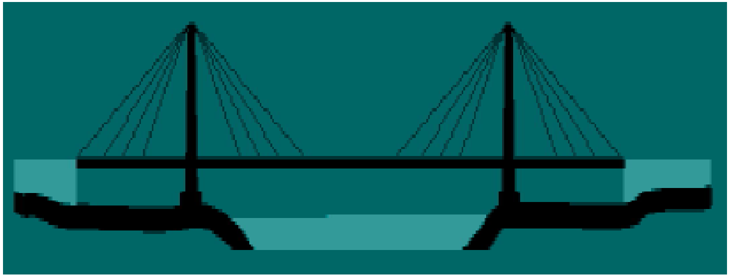

Fig2(a) Radial System

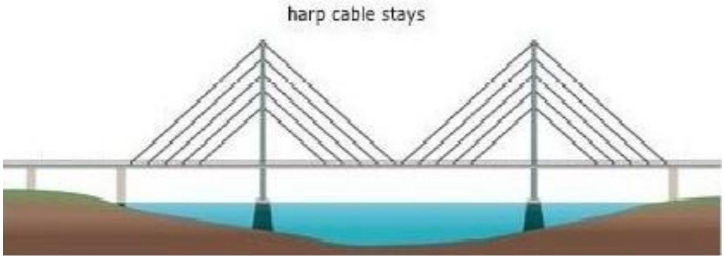

Fig2 (b) Harp System

Fig2(c) Fan System

Fig. 2 Cable Arrangement Systems

III. VALIDATION STUDY AND COMPARISON OF 2D AND 3D ANALYSIS

The 2-Dimensional Model

This model is very much the same as that used by Nazmy. The configuration of the towers and cables lie in a single plane at the centre of the deck. The cables have a harp-type configuration. The bridge has a centre span of 335.28 m (1100 feet) and two side spans of 137.16 m (450 feet) each. The pylon height above deck level is 60.96 m (200 feet) and below deck level is 15.24 m (50 feet). The towers are assumed to be fixed to the piers and rigidly connected to the deck girder at the deck level. The deck girder is simply supported at the end abutments. Figure shows the general configuration of this cable-stayed bridge model. Table shows the member properties of this bridge model.

Table Sectional dimensions of the 2D model

Section	A (m^2)	I (m^4)	E (kN/m^2)
Girder (steel)	0.319	1.131	1.655E+08
Towers (steel)	0.312	0.623	1.655E+08
Cables			
Cable No.	A (m^2)		E (kN/m^2)
15, 54, 70, 64	0.042		1.655E+08
45, 55, 71, 65	0.016		1.655E+08
46, 56, 72, 66	0.016		1.655E+08

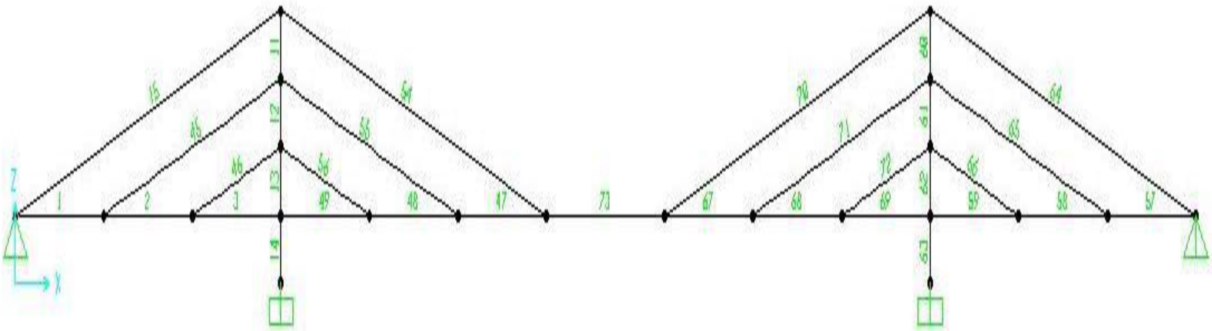

Fig. 3. Layout of 2D Model

The 3-Dimensional Model

The 3D model has similar sections as that of the 2D bridge model. The pylon is A-shaped (as shown in Figure) and the cable arrangement is harp type. The bridge has the same centre span of 335.28 m (1100 feet) and two side spans of 137.16 m (450 feet) each. The pylon height above deck level is 60.96 m (200 feet) and below deck level is 15.24 m (50 feet). A horizontal beam has been provided in the pylon at the deck level. The towers are assumed to be fixed to the piers and rigidly connected to the deck girder at the deck level. The deck girder is simply supported at the end abutments. Figure shows the general configuration of this cable-stayed bridge model. Table shows the member properties of this bridge model. Figure shows the static deformation of the model under dead load. This deformed shape is based on the non-linear analysis approach with P-Delta geometric non-linearity parameters.

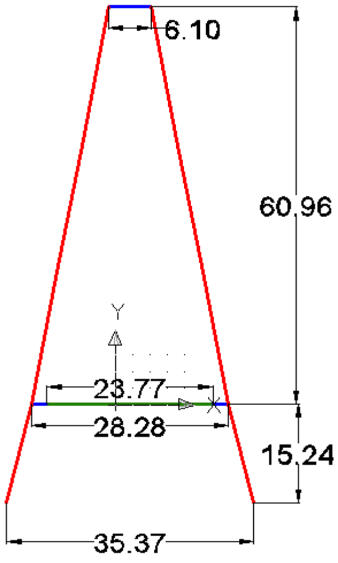

Fig. 4. Pylon Layout (All dimensions in m)

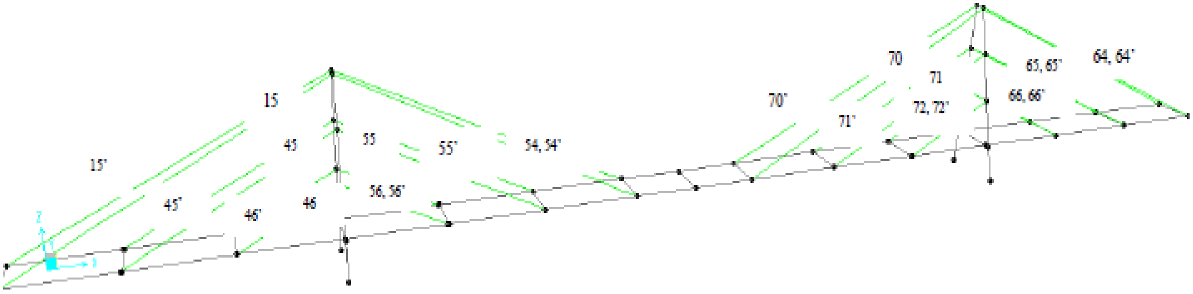

Fig. 5 Layout of 3D Model

Table Sectional dimensions of the 3D model

<table>
<tr><td>Section</td><td>A (m²)</td><td>I (m⁴)</td><td colspan="2">E (kN/m²)</td></tr>
<tr><td>Girder (steel)</td><td>0.319</td><td>1.131</td><td colspan="2">1.655E+08</td></tr>
<tr><td>Towers (steel)</td><td>0.312</td><td>0.623</td><td colspan="2">1.655E+08</td></tr>
<tr><td>Horizontal Beam (steel)</td><td>0.139</td><td>0.170</td><td colspan="2">1.655E+08</td></tr>
<tr><td colspan="5">Cables</td></tr>
<tr><td>Cable No.</td><td colspan="2">A (m²)</td><td colspan="2">E (kN/m²)</td></tr>
<tr><td>15, 54, 70, 64,15’,54’, 70’, 64’</td><td colspan="2">0.042</td><td colspan="2">1.655E+08</td></tr>
<tr><td>45, 55, 71, 65 45’, 55’, 71’, 65’</td><td colspan="2">0.016</td><td colspan="2">1.655E+08</td></tr>
<tr><td>46, 56, 72, 66 46’, 56’, 72’, 66’</td><td colspan="2">0.016</td><td colspan="2">1.655E+08</td></tr>
</table>

IV. MODELING OF CABLE STAYED BRIDGES

The effect of span length, pylon height and pylon shape on the behaviour of cable-stayed bridges have been investigated. The study was carried out for two-inclined plane system and two-vertical plane system bridges i.e. for both A-shaped pylon and H-shaped pylon. Span lengths of 100 m, 200 m, 300 m, 400 m and 500 m with pylon heights of span/2, span/3 and span/4 have been considered. The deck is designed as concrete section with steel truss as girder section. The models have been analysed for dead load (static) as well as dynamic loads under the effect of load time histories of Bhuj, El Centro and Uttarkashi earthquakes.

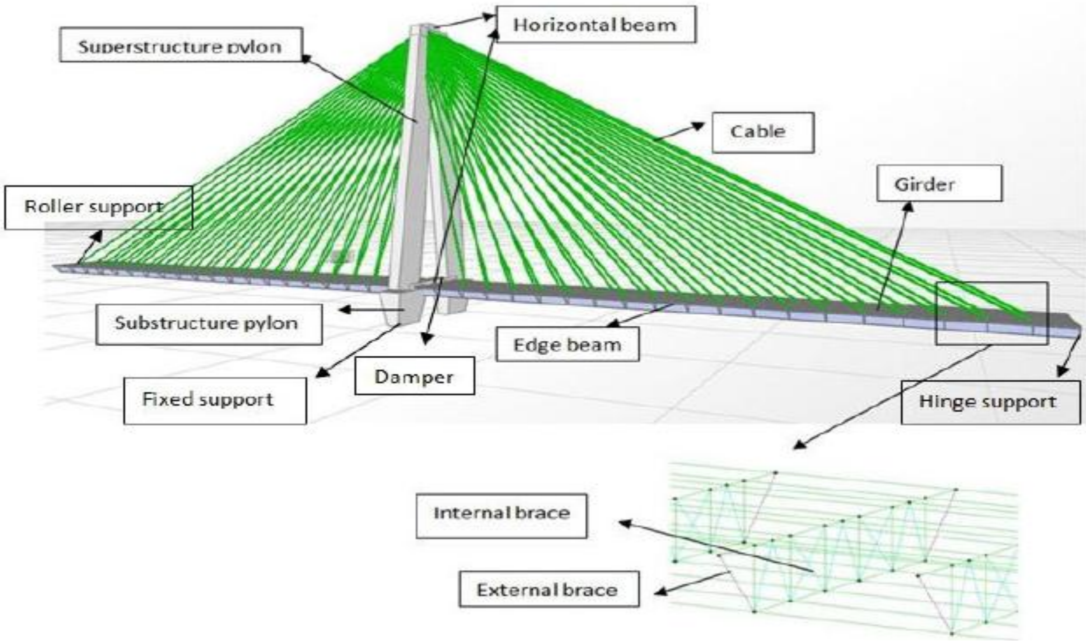

Fig. 6. Schematic diagram representing various sections of the bridge model

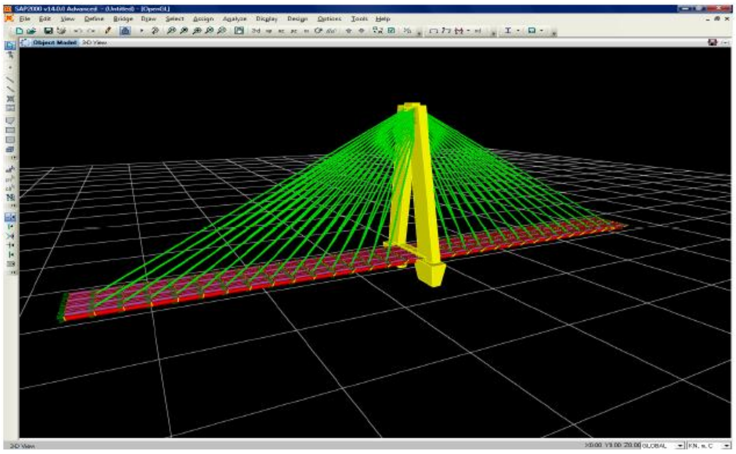

Fig. 7. The 3D CSB model in SAP 2000

V. TIME HISTORY ANALYSIS

Time history analysis can be defined as the study of the behavior of a structure as a response to acceleration, velocity or displacement of the structure during a given period of vibration. It is basically the study of the seismic response of a structure and the analysis can be linear as well as non-linear. The response of the structure can be plotted by three graphs:

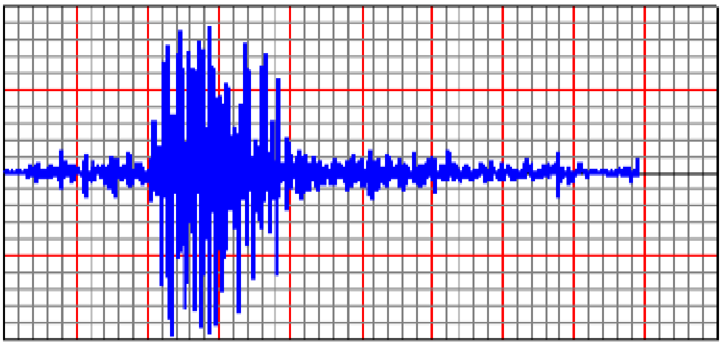

Fig.8 Peak Ground Acceleration vs Time (Bhuj)

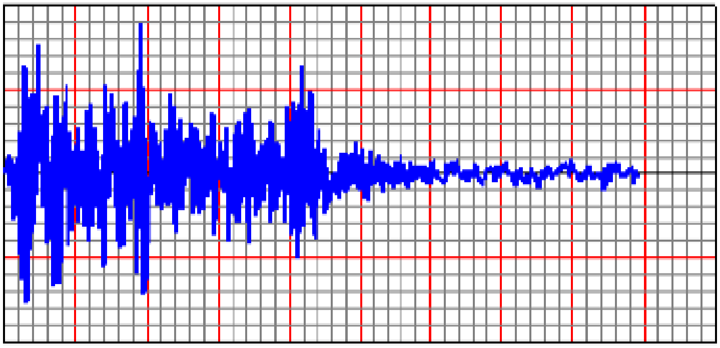

Fig.9 Peak Ground Acceleration vs Time (El Centro)

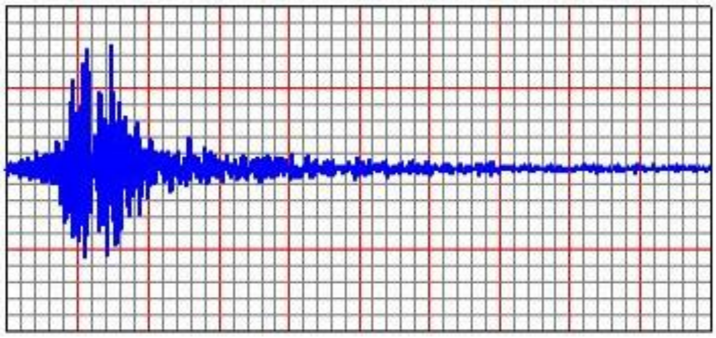

Fig 10.Peak Ground Acceleration vs Time (Uttarkashi)

VI. CONCLUSION

Looking to the increased popularity of cable-stayed bridges, it is obvious that there is a need for more comprehensive investigations of analysis and design of these contemporary bridges. In order to have a proper understanding of the seismic behaviour of these bridges, 3-D earthquake analysis has been performed considering a variety of time histories like short, medium and long duration having different PGA value and different earthquake magnitudes. Vertical excitation which is usually ignored in the seismic analysis of buildings, drastically affects the response of cable-stayed bridges, and hence the first ten major contributory modes were studied so as to obtain the most fundamental movements. Three dimensional models have been used to realistically model the complex geometry and configuration of towers and also to represent the actual dynamic behaviour of the bridge for seismic analysis.

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