Seismic Analysis of Two Span Cable Stayed Bridge

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Abstract— The requirement of long span bridge is increase with development of infrastructure facility in every nation. Long span bridge could be achieved with use of high strength materials and innovative techniques for analysis of bridge. Generally, cable supported bridges comprise both suspension and cable-stayed bridge. Cable supported bridges are very flexible in behaviour. These flexible systems are susceptible to the dynamic effects of wind and earthquake loads. The cable-stayed bridge could provide more rigidity due to presence of tensed cable stays as a force resistance element. The cable bridge could assigned more span in the field of bridge. Seismic analysis of cable stayed bridge has been carried out by two different methods namely Response spectrum (RS) method and Time history method. Modelling of cable stayed bridge in SAP 2000 software is carried out and model is analysing by Response spectrum (RS) method and Time history method.

Keywords: Cable-Stayed-Bridge, Response Spectrum, Time History, SAP, Modelling

I. Introduction

Bridges are undoubtedly one of the key elements for advancement of civilization. Starting form prehistoric log bridges to present day cable stayed bridges, we have numerous types of bridges depending on total length of the gap to bridge over, type and volume of traffic, importance and expected life of bridges, condition of the soil bed, economy involved etc. Covering long spans has always been a challenge to structural engineers. With better understanding of the material properties, more control over construction techniques and introduction of high-speed computer, large Arch bridges, cable stayed bridges and suspension bridges are highly effective in covering long spans. Of these, the cable-stayed bridges have been the most effective in terms of slenderness, flexibility and economy. Due to their aesthetic appearance, efficient utilization of structural materials and other notable advantages, cable-stayed bridges have gained much popularity in recent decades.

Bridges of this type are now entering a new era with main span lengths reaching 1000 m. The girder is supported elastically at points along its length by inclined stays so that the girder can span a much longer distance without intermediate piers. The dead load and traffic load on the girders are transmitted to the towers by inclined cable stays. Due to the high level of indeterminacy, slender structure and cables, cable-stayed bridges are much more flexible as compared to other bridges like simply supported Box Girders, Slab Bridges, etc. The increased span of these flexible bridges raises concern about their behaviour under dynamic loads such as wind, earthquake and vehicular movement.

The dynamic behaviour of cable stayed bridges are complex compared to other types of bridges. Cable stayed bridges are prone to more dynamic excitations caused by wind, earthquake as compared to other types of bridges. Also dynamics of these bridges to vehicular movement is more important compared to other types of bridges. The aero dynamic behaviour of a cable stayed bridge, determines, to a great extent, the safety. It is a fact that lack of overall dynamic stability was a reason for the collapse of a number of the earliest suspension bridges, which considerably held up their development. Complexity of the cable-stayed bridge to dynamic excitation is primarily because of pre- tensioned cables holding the bridge. Several kinds of dynamic problems including dynamic instability may arise in such bridges. There has been considerable research in the past related to the wind, earthquake and vehicular movements. So far as the wind is concerned, the buffeting and aerodynamic instability caused by flutter have attracted the attention of various researchers.

Studies on the vibration of bridges for vehicular movement have also been carried out by several researchers So far as the earthquake induced vibration of cable stayed bridges are concerned, a number of studies have been carried out. They include response analysis of cable stayed bridge to both random and deterministic time history analysis for earthquake forces (Said M Allam, T K Dutta, Probir Chatterjee).

A. Need for Present Study:

Although a number of studies have been carried out on the dynamic response of bridges, different types of response analysis carried out by different methods. Analysis is carried out by sap 2000 software obtaining the response of bridges to different forms of earthquake excitations. This is extremely important for practical design of cable stayed bridge and is extremely useful for designers. Keeping this in view, the present study is undertaken.

The response of cable-stayed bridge to earthquake excitations is obtained by different methods of analysis. The future trend in the design of cable-stayed bridges to longer centre or effective spans makes non-linear analysis inevitable. This is essential not only for evaluating the stresses and deformations induced by environmental loads, such as vehicular traffic, wind and earthquakes, but also for assuring safety during construction. Since the non-linearity in the behavior of this special type of flexible, long-span bridge is of geometric type, and mainly due to large deformations, it is essential to point out that when the centre-span length increases, which will result in a considerable increase in the displacement and deformations of the bridge under strong shaking, a pronounced non-linearity in the response may be expected.

B. Objective:

1) To analyze two span cables stayed bridge.
2) Calculate the response of the bridge by response spectrum method.

3) Calculate the response of the bridge by Time history method.
4) Maximum bending moment of deck at centre.
5) Deflection at centre of deck.
6) Maximum tension in the cable.
7) Deflection at top of the pylon.

The vibration of cable stayed bridge under the passage of earthquake excitation has been a topic of considerable research for many years. With improved understanding of material behaviour and better computational facilities, problems of bridges vibrations are analysed more realistically. The cable stayed bridges being flexible are prone to considerable vibration under different types of excitation such as wind earthquake, moving load and blast. Cable supported bridges may exhibit an increased susceptibility to wind excitation. Such bridges are susceptible to aero elastic effects which include torsion divergence, vortex induced oscillation, flutter, galloping and buffeting in the presence of self-excited forces caused by wind induced vibration. There is a complex interaction in the whole structure due to earthquake excitation. Longitudinal shaking induces vertical vibration in addition to the response due to vertical vibration. Aly S. Nazmy and Ahmed M. Abdel Ghaffar (1990) presented Non-linear earthquake response analysis of long span cable stayed bridges when subjected to seismic loading is formulated.

Said M. Allam (2000) presented a response spectrum method for the seismic analysis of cable stayed bridges subjected to partially correlate stationary random ground motion under a set of important parametric variations using continuum approach.

Paolo Clemente, Mehmet Celebi (2004) showed that results of observed and analytical analysis of the dynamic response of the indiano cable stayed bridge in Florence, Italy. The observed part is based on ambient and traffic induced vibration tests, which allowed extracting the dynamic characteristics of the structure in terms of resonance, frequencies, modal shapes and damping. W. Quan, H.N. Li and X Z Liu (2008) presented seismic response of large span cable stayed bridge under multi component multi support earthquake excitations is studied. Prof. G.M Savaliya, Prof A.K Desai, Prof S.A Vasanwala presented static and dynamic analysis of cable stayed suspension hybrid bridge and validation is carried out by SAP2000 software.

C. Non-Linearity in Cable Stayed Bridge:

In spite of the fact that the behaviour of the material of the structural elements in a cable-stayed bridge is, in general, linearly elastic, the overall-load- displacement relationship for the structure is non-linear under normal design loads.'- l1 This overall non-linear behaviour originates from three primary sources. These three sources are:

1) The non-linear axial force-elongation relationship for the inclined cable stays due to the sag caused by the non-linear axial force and bending moment interaction for the tower and longitudinal girder
2) The geometry change caused by the large displacements which can occur in this type of structure under their own weight; elements; and service as well as environmental design loads.

The non-linear behaviour of the tower and girder elements due to axial force- bending moment interaction is accounted for by using the stability functions to modify both the bending and axial stiffness of the element at the end of each iteration cycle.

3) The third source of non-linearity in cable -stayed bridges, namely the overall geometry change due to large deformations, is accounted for by updating the bridge geometry by adding the incremental nodal displacements to the previous nodal coordinates at the end of each iteration cycle before re-computing the stiffness of the bridge in the deformed state.

D. Non-Linear Dynamic Analysis Procedure:

Among the many techniques available for non-linear dynamic analysis, probably the most efficient is the step- by-step integration procedure. In this approach, the response is evaluated at successive increments of time usually taken to be of equal length for computational convenience. At the beginning of each time interval, the condition of dynamic equilibrium is established. The response for an incremental time step Δt is then evaluated approximately, on the basis that the structural properties remain constant during the interval. The non-linear nature of the system is accounted for by re-evaluating the structural properties at the end of the time step, to be appropriate to the current deformed state at that time.

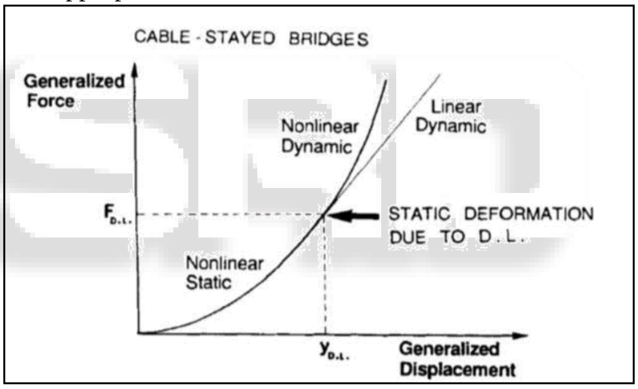

Fig. 1: (Non-linear force-displacement relationship for cable-stayed bridge)

It should be mentioned at this point that in the earthquake-response analysis, it is important to use an unconditionally stable method, because the time step size At can then be selected giving regard only to the required accuracy in the low-mode response; i.e., the time step size need not be small enough to satisfy a stability criterion. It is for this reason that the Wilson-□ method was used for the present non-linear earthquake-response analysis.

II. STRUCTURAL MODELLING

To study the effect of Elcentro earthquake three dimensional models of two span cables stayed bridges is developed in Sap 2000 v 20 and perform the Response spectrum analysis and time history analysis on the model as shown in figure 2.

Span of bridge =12 m (two span 12m each)
Height of pylon = 4.5 m
Grade of concrete = M30
Dimension of pylon = 0.4 m (bottom dia.) and 0.3m (top dia.)
Diameter of cable = 0.05 m
Width of girder = 7 m

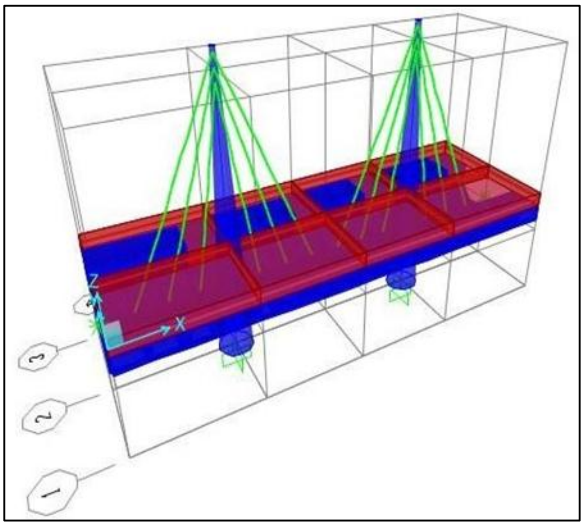

Fig. 2: (3-Dimensional View)

Vehicle Name	Load Type	Unit Load(kN/m)	Axel Load(kN)	Min. Dist. (m)
VEH1	Fixed Length	3502.54	44.481	1

Table 1: Vehicle Class and Load

Group Name	Self Mass (kN-s^2/m)	Self Weight (kN)	Total Mass X (kN-s^2/m)	Total Mass Y (kN-s^2/m)	Total Mass Z (kN-s^2/m)
Girder	4.86	47.617	4.86	4.86	4.86
Pylon	0.44	4.309	0.44	0.44	0.44
Cable	0.75	7.324	0.75	0.75	0.75

Table 2: Masses and Weight

Section	Object Type	Num Pieces	Total Length (m)	Total Weight(kN)
Tower	Frame	2	4.5	4.309
Box Girder	Frame	15	24	23.714
Cable	Cable	12	21.348	3.331
Slab	Area			16.624

Table 3: Dimensions

III. RESULT AND DISCUSSION

A. *Axial Force Diagram*

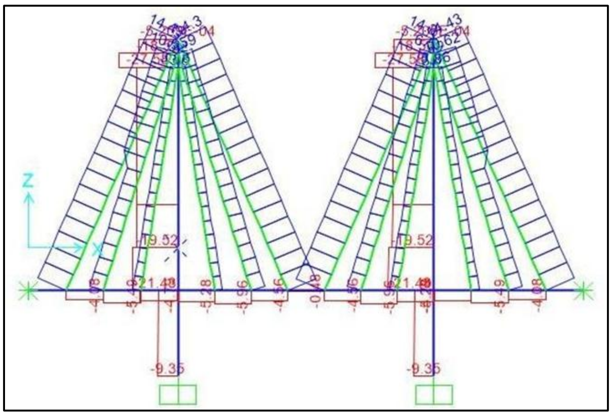

Fig. 3: (Axial Force Diagram of cable stayed bridge)

B. *Bending Moment Diagram:*

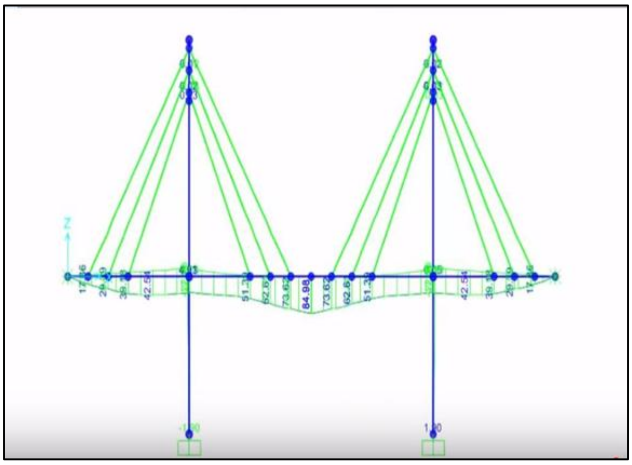

Fig. 4: (BM Diagram of cable stayed bridge)

C. *Different Mode Shape and Frequency:*

MODE	TIME PERIOD	FREQUENCY
1	0.071	13.89
2	0.065	15.35
3	0.031	31.48
4	0.03	32.5
5	0.03	33.05
6	0.021	45.58
7	0.019	50.47
8	0.014	69.93
9	0.014	70.73
10	0.012	77.25

Table 4: Time Period and Frequency at different Mode

D. *Displacement of Deck:*

NODE	DISPLACEMENT
1	0
2	0.15
3	0.324
4	0.412
5	0.456
6	0.523
7	0.62
8	0.72
9	0.824
13	0.72
14	0.62
15	0.523
16	0.456
17	0.412
19	0.324
22	0.15
23	0

Table 5: Displacement at different Node

E. *Displacement of Deck Vs Node Graph:*

(Displacement shows in Y Axis and Node shows in X Axis)

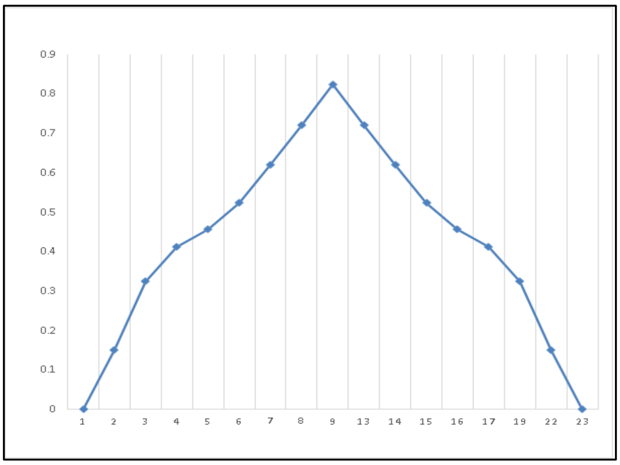

Fig. 5: (Displacement vs Node)

F. Time History Analysis:

Curve for deflection at mid span (X - Axis: Time (Sec), Y-Axis: Deflection (cm))

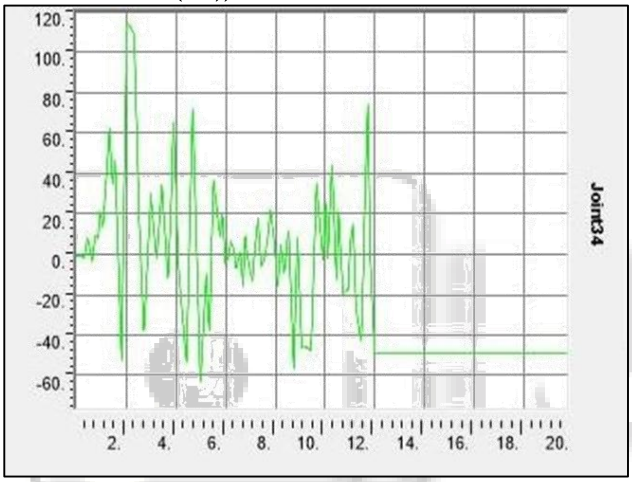

Fig. 6: (Deflection vs Time)

G. Deflection and Time Curve for Top Pylon:

(X - Axis: Time (Sec), Y- Axis: Deflection (cm))

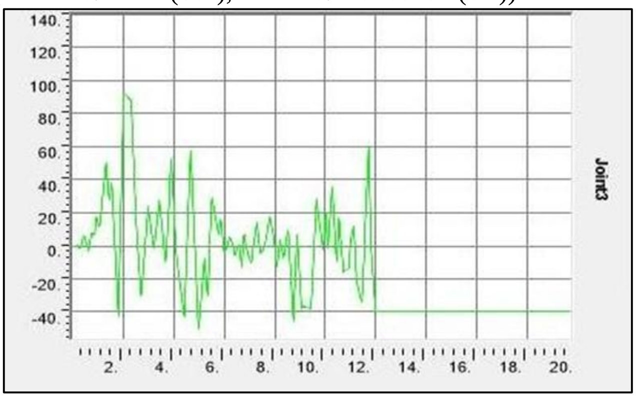

Fig. 7: (Max deflection at top of the pylon=0.92 m at T=2 sec)

H. Results:

From response spectrum analysis-
Maximum Bending moment at centre = 84.98 KN-m Maximum deflection at centre = 0.824m
Maximum deflection at top of pylon = 0.982m Maximum tension in cable = 27.58 KN

From time history analysis-
Maximum Bending moment at centre = 60.2 KN-m Maximum deflection at centre =1.15 m
Maximum deflection at top of pylon = 0.920m Maximum tension in cable = 20.4 KN

IV. CONCLUSION

It is found from the available literature that cable-stayed bridge is combining the advantages of cable-stayed bridge and suspension bridge systems. Historical development and analysis techniques related to cable-stayed bridges are discussed.

It is found from the review carried out related to development and analytical techniques that there is wide scope for the seismic analysis of cable-stayed bridge. The first five modes are the major contributory modes. It is necessary to include at least five modes in the analysis in order to obtain the most fundamental movements. It might be sufficient to consider only these modes in a preliminary analysis.

For pylon and deck, additional responses from the higher modes could be significant. A total of ten modes should be incorporated, if an accurate result is required.

V. RECOMMENDED FOR FUTURE WORK

Sap 2000 may be utilized to find out the response of cable stayed bridge subjected to filtered white noise ground excitation. Also other similar structures possessing close spaced frequencies like long pipelines and suspension bridges may be studied.

Spread-pylon cable-stayed bridge has distinct advantage like reduction of sag of cables and oscillation of cable during earthquake over traditional cable-stayed bridges. Spread-pylon also improves seismic performance of deck during strong ground motion. So the dynamic behaviour of cable stayed bridge with different structural configuration with seismic loading may be studied.

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