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Non-Linear Analysis of Cable Stayed Bridge

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Abstract - *This study investigates the nonlinear behavior of cable-stayed bridges. Both geometric and material nonlinearities are involved in the analysis. The geometric nonlinearities come from the stay cable sag effect, axial force-bending moment interaction, and large displacements. Material nonlinearity arises is also* considered during the analysis. The *example bridge is a cable-stayed bridge with a central span length of 110 m with different cable layouts namely, Radial, Harp and Fan type. The seismic response analyses have been conducted from the deformed equilibrium configuration due to loads. Strong earthquake records of the Bhuj earthquake of 2001 in India is used in the analysis. This earthquake records are input in the bridge longitudinal direction, vertical direction, and combined longitudinal and vertical directions to evaluate the seismic response of the bridge. The results show that among all sources of nonlinearities cable sag effect having more contribution than other two types of nonlinearities.*

Key Words*: *Cable-stayed bridge, nonlinear analysis, geometric and material nonlinearities, cable sag effect.

1. INTRODUCTION

The cable-stayed bridge, the concept of supporting a bridge girder by inclined tension stays is used from the seventh century. Due to their aesthetic appearance, efficient utilization of structural materials and other notable advantages, cable supported bridges have gained much popularity in recent decades. It is well known that the increase in the center span length of cable-stayed bridges makes nonlinear analysis unavoidable. For this special type of flexible, long span cable-supported bridge, nonlinear analysis is essential for evaluating the stresses and deformations induced not only by static loads but also by dynamic loads, such as vehicular traffic, wind, and earthquakes. When the center span length increases, a pronounced nonlinearity in the response may be expected, which will result in a considerable increase in the displacement and deformations of the bridge under strong shaking. In this case it is essential to understand the behavior from those dynamic loadings realistically.

A long span cable-stayed bridge exhibits nonlinear characteristics under any load level. These nonlinear sources may come from

- The sag effect of inclined cable stays

- The combined axial load and bending moment interaction effect of the girder and towers

- The large displacement effect

- Material Nonlinearity

Many investigations have studied the dynamic behavior and seismic responses of this highly nonlinear structure. Some researchers disregarded all sources of nonlinearities, whereas others included one or more of these sources. In fact, large member stresses may be induced under strong ground motions. The analysis is to be carried out considering nonlinear effects by using finite element based software called MIDAS 2010 for different cable layouts namely radial, harp and fan.

2. NONLINEAR ANALYSIS

Cable-stayed bridges have an inherently nonlinear behavior. This has been revealed by very early studies and shall be discussed in detail here because the nonlinearity is of greatest importance for any kind of analysis. Nonlinearities can be broadly divided in geometrical and material nonlinearities. While the latter depend on the specific structure (materials used, loads acting, design assumptions), geometric nonlinearities are present in any cable-stayed bridge.

Geometric nonlinearity originates from:

- The cable sag which governs the axial elongation and the axial tension,

- The action of compressive loads in the deck and in the towers,

- The effect of relatively large deflections of the whole structure due to its flexibility

They will be briefly explained in the following.

2.1 Major assumptions

The following assumptions are made:

- Only in-plane flexural behavior of the bridge is considered. The torsional behavior caused by eccentric loading of the bridge deck is disregarded in this study

- Bridge damping is small and therefore neglected

- When the vehicle enters the bridge, the vertical deflection and the vertical velocity of the moving vehicle are assumed to be zero.

3. PROBLEM DESCRIPTION

For the analysis purpose, we have considered three types of cable stayed bridges having same dimensions and loading conditions but different cable layouts namely Radial, harp and modified fan type of cable stayed bridge. Modelling of the bridge is done as follows

3.1 The deck

Cable Stayed Bridge is a composite member consisting of steel girders and a concrete slab. It had to be modeled such as to behave correctly in bending and torsion on one hand and to resemble the inertia effects correctly on the other hand.

The finite element model of the bridge deck is beam elements. Each of the beam elements spanning from one cable anchor location to the next. At these nodes two rigid links were placed on either side to attach the cable elements, thus achieving the proper offset of the cables.

3.2 The cables

As has already been mentioned that the modelling of the cables is a difficult issue because nonlinearities arise from the cable sag. The stiffness therefore changes with the applied load. However, in this study one linear truss element without stiffness in tension was employed for each of the cables and later it is converted to cable element.Taking into account the cable sag and thus nonlinear cable behaviour by means of an equivalent stiffness would have been extremely tedious since every cable would have had to be associated with a different force-displacement relationship because of the changing inclination and length of the cables.

A prestress was applied to all the cables in order to ensure small deformations of the deck when the self weight is applied. The bridge was modelled picking up the geometry from the design drawings. Since these show the as-built configuration the application of the self-weight to the structure has to be taken into account. In reality the cables are prestressed according to a prior calculation so that the final shape is correct.

3.3 The pylons:

Modelling of the pylons was by means of beam elements. The pylon has been connected to the deck using rigid links. This was done to transfer the entire load coming on deck to pylon safely.

The following example illustrates the cable force in the stay cables of cable-stayed bridges. The data for this is given below:

Total span length = 190m.

Bridge Height = Lower part of tower: 20 *m*,

= Upper part of tower: 40 *m*

Width of the deck = 10m.

Width of the roadway= two lane 7.5m.

Number of cables= 4 cables along main span

Spacing of cables= 20m.

Thickness of RCC Deck slab= 180mm.

Longitudinal girders (2 No.)=800mm by 1000mm.

Cross girders at 3m interval= 450mm by 800mm.

Loading : I.R.C. Class AA tracked vehicle.

Design a typical cable assuming that the cables are arranged as shown in Figure.

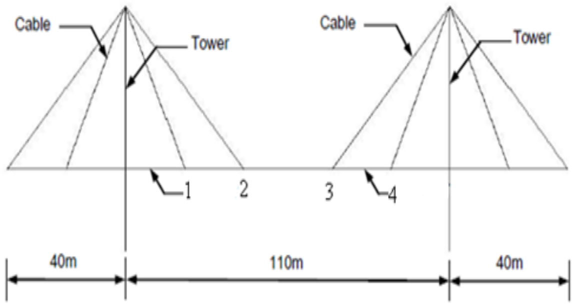

Fig -1: Radial cable stayed bridge

For a relatively simple and rapid solution of the system of linear equations by a classical method, the 'Beam-on-elastic-supports analogy' may be used. A cable supported bridge structure can be analyzed similarly to a continuous beam on elastic supports. In such an analysis, it is necessary to predetermine the sectional and geometrical properties of the cables, tower supports and beam sections. After an initial analysis, the respective cable forces are analyzed as below.

4. NONLINEAR ANALYSIS AND RESULTS:

4.1 Analysis considerations:

Cable-stayed bridges are structural systems effectively composing cables, main girders and towers. This bridge form has a beautiful appearance and easily fits in with the surrounding environment due to the fact that various structural systems can be created by changing the tower shapes and cable arrangements.

The dimensions and loadings for the three span continuous cable-stayed bridges are given in previous chapter. By keeping dimensions and loading same, we have changed only the cable arrangement of the bridge. So, three different types of cable stayed bridges namely radial, harp and fan type bridge is analyzed by using finite element based software called MIDAS2010.

Material properties for the main girders, tower-bottom, tower-top and cables are as follows.

Sr. No.	Compon-ent	E (N/mm2)	Poissons ratio	Weight density (KN/M3)
1	Girder	2.1x10e5	0.3	7.85
2	Lower tower	0.25x10e5	0.17	2.5
3	Upper tower	2.1x10e5	0.3	7.85
4	*Cable*	*1.57x10e5*	*0.3*	*7.85*

Table -1: Material properties

4.2 Geometrical nonlinear analysis result

The cable-stayed bridge deformed configurations and bending moments due to each load case were obtained through a nonlinear analysis are given below. The bending moments were evaluated in sampling sections of the deck and the towers.

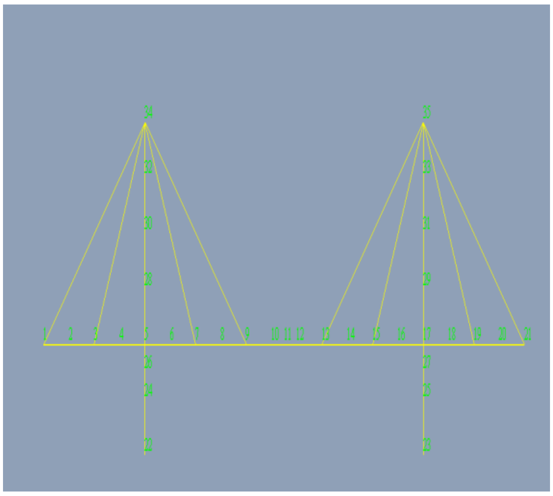

Fig -1: Node numbers

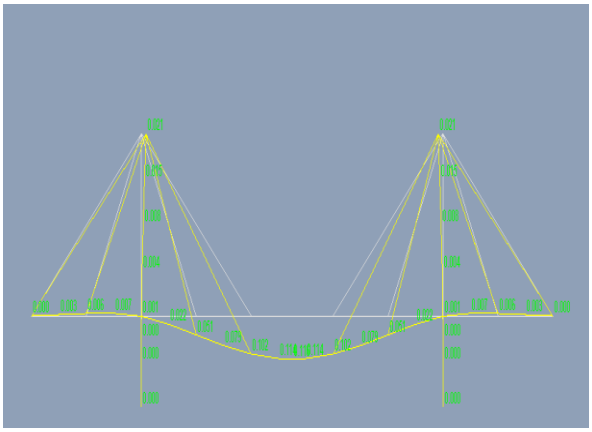

Fig -2: Deflected geometry of radial type bridge

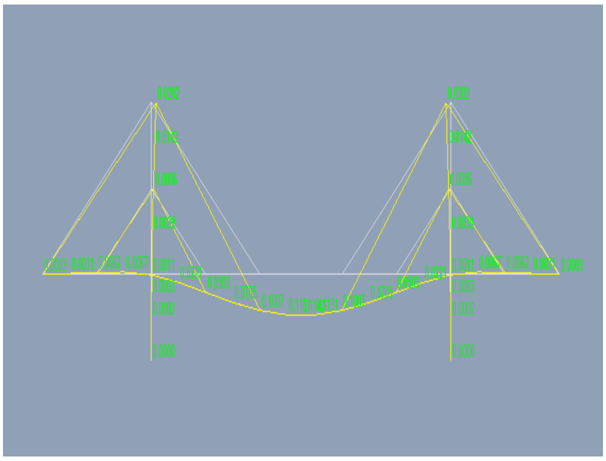

Fig -3: Deflected geometry of harp type bridge

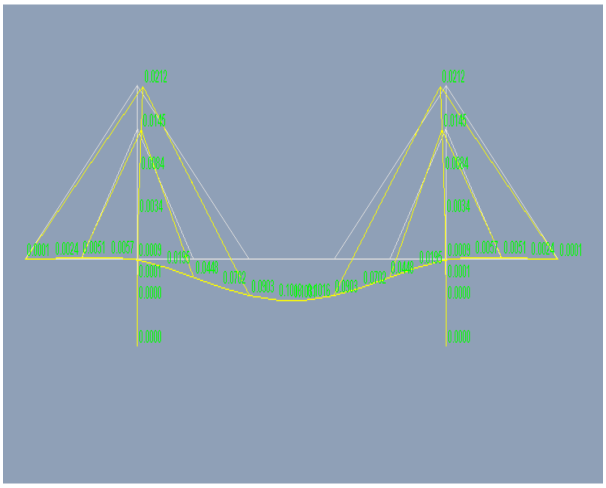

Fig-4: Deflected geometry of fan type bridge

Table -2: Displacements in meter for Bridges

NODE NUMBER	RADIAL TYPE	HARP TYPE	FAN TYPE
1	0.000	0.000	0.000
2	0.003	0.0031	0.003
3	0.006.	0.0062	0.006
4	0.007	0.0067	0.006
5	-0.002	-0.0011	-0.001
6	-0.022	-0.0221	-0.022
7	-0.052	-0.0503	-0.050
8	-0.079	-0.0785	-0.078
9	-0.102	-0.1007	-0.100
10	-0.114	-0.1131	-0.112
11	-0.116	-0.1147	-0.114
12	-0.114	-0.1131	-0.112
13	-0.102	-0.1007	-0.100
14	-0.079	-0.0785	-0.078
15	-0.052	-0.0503	-0.050
16	-0.022	-0.0221	-0.022
17	-0.002	-0.0011	-0.001
18	0.007	0.0067	0.006
19	0.006	0.0062	0.006
20	0.003	0.0031	0.003
21	0.000	0.000	0.000
22	0.000	0.000	0.000
23	-0.000	-0.000	-0.000
24	0.000	0.0002	0.0002
25	-0.000	-0.0002	-0.0002
26	0.000	0.0003	0.0003
27	-0.000	-0.0003	-0.0003
28	0.004	0.0039	0.003
29	-0.004	-0.0039	-0.003
30	0.008	0.0086	0.008
31	-0.008	-0.0086	-0.008
32	0.015	0.0142	0.014
33	-0.015	-0.0142	-0.014
34	0.021	0.0202	0.020
35	-0.021	-0.0202	-0.020

Table -3: Cable forces in KN for different type of bridges

Cable number	Radial		Harp		Fan	
	Linear	Nonlinear	Linear	Nonlinear	Linear	Nonlinear
1	2022.47	2330.5	2535.21	2979.3	2168.67	2975.2
2	2535.21	3159.2	2535.21	2856.6	2535.21	3427.7

Table 4: Cable forces in KN for different type of bridges

5. CONCLUSIONS

The effect of change in geometry, as the structure deformed under the applied loads, was incorporated in the analysis by revising the geometry of the mathematical model as Radial, Harp and Fan type. The structural properties were then recomputed using the revised geometry. The structure was considered to be subjected to a uniform deck load and a set of initial cable tensions. The results of these analysis, and similar results for other quantities such as deflection of deck or the moments in deck, show that the effect of change in geometry of the structure is small.

The effect of interaction of the bending deformations and high axial forces, in the deck and tower members, were incorporated in the analysis for different mathematical models shows that even though the longitudinal deck members and towers are subjected simultaneously to high axial forces and bending moments, the effect of the interaction of these quantities upon the overall structure is small

The final nonlinear effect to be considered is the Cable sag effect. The change in the cable stiffness was incorporated by using an equivalent cable modulus of elasticity, which combines the effect of both the deformation resulting from material strain and the deformation resulting from the change in sag in the cables, as suggested by Ernst. By using the equivalent modulus, the cables are treated as tension members.

From the table of cable forces given in previous chapter it is clear that this nonlinearity contributes more effect than other two types. Material nonlinearity also has to be considered during the analysis.

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