ISSN: 2278-0181
Vol. 2 Issue 7, July - 2013

Analysis Of Differently Configured Cable Supported Bridges And Its Validation

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Abstract

Plentiful attractive and spectacular bridges have been designed and built in the last few decades than at any other comparable time in the history of civilisation. A note worthy development in bridges is that of cable stayed structures, widely adopted all over the world since the 1960s because of their smartness as well as economy. Traditional suspension bridges evolved into cable stayed bridges that eliminated the need for strong anchorages of the suspension cables thereby reducing the impact on environment. The requirement of long span bridge is increasing day by day. For that purpose the behaviour of the1400m central span cable-stayed bridge and 1400m central span suspension bridge is studied in this paper. The analyses of the differently configured bridges are carried out in SAP2000. The results are presented and validated is carried out by comparing the time period of the analysed bridges with the available data in literature.

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(1) Introduction

The structures which use high strength steel cables as axial force resistant members like cable supported bridges. Cable supported roofs like stayed or supported on cables, trusses as well as nets, or air inflated, guyed masts, ropeways, antennae and cooling towers utilizing cable systems. [2] The deck of the bridge can be supported with different structural systems like suspended, cable-stayed or hybrid.

To use the cables as tension resistance structural members in bridges for provision of long span bridges, the structural systems generally used to achieve longer span are as listed below.

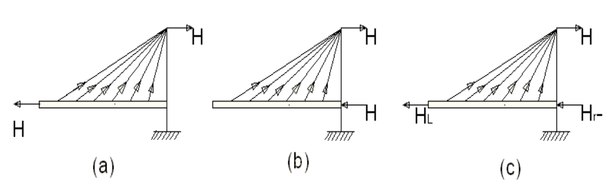
1. Cable-stayed bridges,
2. Suspension bridges,
3. Hybrid cable-stayed suspension bridges [3]

Here Cable-stayed bridge system and suspension bridge is considered to study the behavior of the bridge. Inclined cables of the cable-stayed bridge, support the bridge deck directly with relatively taut cables, which, compared to the classical suspension bridge, provide relatively inflexible supports at several points along the span. The nearly linear geometry of the cables produces a bridge with greater stiffness than the corresponding suspension bridge. The first known cable-stayed bridge was designed in 1784 by C.T. Loescher. [4]

A variety of geometrical configured cable-stays are used as per the necessity in longitudinal direction of the bridges. Here, for study the performance of the considered bridge, bridge elements and its properties are discussed below:

A. Stiffening girder

In contrast of the cable system where all elements have to be in tension, the stiffening girder will generally be able to transmit tensile as well as compressive forces. Thus, when the stiffening girder replaces some of the cable elements of the pure cable system, new possibilities of achieving equilibrium will exist.



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In system (a) the stiffening girder is subjected at midspan to a horizontal tensile force H equal to the sum of the horizontal cable force components. This implies that the girder will be entirely in tension, and the forces of the system are consequently the same as found in the pure cable system. In system (b) the stiffening girder is subjected at the pylon to a horizontal compressive force H, and the girder will therefore be entirely in compression. This leads to the self-anchored system applied in almost every cable stayed bridge built up till now. In system (c) the stiffening girder is subjected to both a tensile force H_L at midspan and a compressive force H_r at the pylon. With $H_L + H_r$ equal to the sum of the horizontal cable force components, the horizontal equilibrium will be fulfilled. As the midspan tension H_L has to be transferred to the soil at the ends of the stiffening girder, system (c) might be designated as a partially anchored system. The three systems of equilibrium can be created by the choice of the supporting conditions for the stiffening girder and the attachment of the anchor cable.

B. Supporting Conditions

Supporting conditions for the stiffening girder is assumed that the girder and the pylon pass each other without a direct connection. However, in cable stayed bridges system bearings are placed between the girder and pier below. With this system one of the bearings must be fixed longitudinally, and it is often chosen to make one of the pylon bearings fixed and the other longitudinally movable. The bearings under the pylons generally will be subjected to vertical forces of a considerable magnitude. In modern cable stayed bridges a compact neotop bearing is often used. For the movable bearing the neotop is supplemented by a sliding Teflon bearing.

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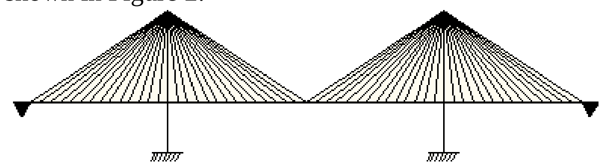
Support location	Ux	Uy	Uz	Rx	Ry	Rz
Tower	0	1	1	1	0	1
Pier	0	1	1	1	0	1
Abutment	0	1	1	1	0	1

C. Fan System in cable-stayed bridge

According to the cable arrangement of the cables in the cable-stayed bridge, the cable arrangements in the bridge can be of various types. Here we have select the fan type of cable arrangement of cables in bridge as shown in Figure 2.



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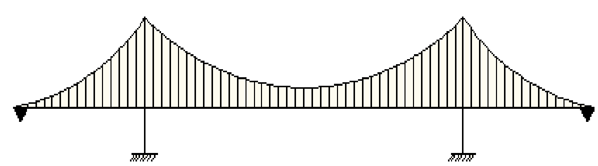
In the fan system, the anchor cable connecting the pylon top to the end support in the side span and plays a dominant role in the achievement of stability in the cable system. To utilize the anchor cable efficiently, it is required that this cable for any loading combination is subjected to a certain tension. The minimum tension in the anchor cable occurs for traffic load in the side spans only.

D. Suspension system in suspension bridge

A suspension bridge is a type of bridge in which the deck of the bridge is supported with the vertical suspenders. This vertical suspender is connected to main suspension cable. This cable is supported on the tower at the top and anchored at the end of the side span by anchorage. Here we have select the suspension cable arrangement of cables in bridge as shown in Figure 3.



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The suspension cables must be anchored at each end of the bridge rigidly, as load applied to the bridge is transformed into a tension in these main cables. The main cables continue beyond the pillars to deck-level supports, and further continue to connections with anchors in the ground.

For understanding the performance characteristics of same span length cable-stayed bridge and suspension bridge is considered for the study. Here, one bridge of 1400m central span fan type cable-stayed is considered and the second bridge having 1400m central span suspension bridge is considered for study.

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(2) Different elements of bridge modeled in SAP2000 for analysis

Different elements of cable supported bridge like deck, tower, cable-stays, main suspended cables, hangers are discussed below:

2.1 Bridge deck

Deck is model as a frame section with cross sectional properties as mentioned in the following tables for different types of bridges.

2.2 Pylon

Pylon and pylon beam is modelled as a frame section where the pylon with the vertical orientation and pylon beam with horizontal orientation.

2.3 Cables

Cables of the cable supported bridge like hangers, main suspended cables, cable-stays in cable-stayed bridge portion are modeled as cable element. The cable elements act as axial load transfer element only.

2.4 Load Cases

A load case defines how loads are to be applied to the structure, and how the structural response is to be calculated. Many types of load may act on the structure. Most broadly, load cases are classified as linear or nonlinear, depending on how the structure responds to the loading.

Load cases considered for three-dimensional nonlinear static finite element analysis are:

2.4.1 Linear load cases:

The results of linear analyses may be superposed, i.e., added together, after analysis. The following types of load cases are considered:

1. Static: Loads are applied without dynamical effects. Response-Spectrum, Statistical calculation of the response caused by acceleration loads. It requires response-spectrum functions. This is the most common type of analysis
2. Modal: Calculation of dynamic modes of the structure using eigenvector or Ritz-vector method. Eigen vectors are the mode shapes of the bridge for that time. Loads are not actually applied, although they can be used to generate Ritz vectors.

2.4.2 Nonlinear load cases:

The results of nonlinear load cases normally should not be superposed. Instead, all loads acting together on the structure should be combined directly within the specific nonlinear load case. Nonlinear load cases may be chained together to represent complex loading sequences.
The following types of nonlinear load cases are considered:

1. Nonlinear Static: Loads are applied without dynamical effects. May be used for pushover analysis.
2. Nonlinear Time-History: Time-varying loads can be applied. It requires time-history functions. The solution may be by modal superposition or direct integration methods.

2.4.3 Functions Definition

Options are available to define functions to describe how load varies as a function of period or time. The functions are needed for certain types of analysis only; they are not used for static analysis. A function is a series of digitized abscissa-ordinate data pairs.
Four types of functions are available:

1. Response-spectrum functions:
   Response-spectrum functions is Pseudo-spectral acceleration vs. period for use in response-spectrum analysis.
2. Time-history functions:
   Time history function is loading magnitude vs. time for use in time-history analysis.
3. Steady-state functions: Loading magnitude vs. frequency for use in steady-state analysis.

As many named functions as needed could be defined. Functions are not assigned to objects, but are used in the definition of load case.
Run Analysis
After materials property assigned, elements geometry modelling done, load patterns assigned, and load cases defined, the bridge model assigned for analysis.
The modelling and analysis of cable-stayed bridge as well as suspension bridge is carried out using SAP2000 software. The modelling of the bridges in SAP2000 is validated with the data available in literature. The modelling and validation of the cable-stayed bridge and suspension bridge is discussed below:

(3) Cable-stayed bridge

Modeling of 1400m main central span and 680m side spans Cable-stayed Bridge is carried out in sap 2000. Figure 4 shows a side view of the cable-stayed bridge

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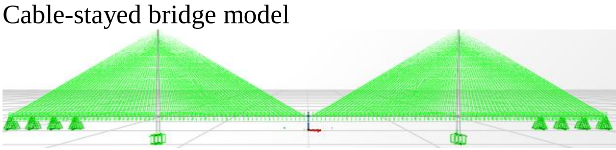
model. Here, centre and side spans are assigned to be 1,400 and 680 m respectively. For the side span, three intermediate piers are installed at the distance of 100 m in the order to increase in-plane flexural rigidity of the bridge.

Cable-stayed bridge model



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1400m central span Cable-stayed Bridge Data:
The deck shown in Figure 4,
Width of Streamlined steel box girder = 35 m,
Width of Streamlined steel box girder = 3.5 m,
Suspended by diagonal stays at intervals = 20 m,
Height of Tower from deck level = 280m,
Height of tower is one-fifth of the centre span length.
Table 2 gives cross-sectional properties of the girder and tower.

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Members	E (Mpa)	A (m^2)	Ix (m^4)	Iy (m^4)	Iz (m^4)	M (Kg/m)	Jm $(Kg.m^2/m)$
Girder	$2.1x10^5$	1.761	3.939	193.2	8.33	26340	$2.957x10^6$
Tower	$2.1x10^5$	1.760	39.67	40.32	39.27	19327	$8.574x10^6$

The cross-sectional areas of the stay cables are plotted in Fig., in which the 1st stay cable is located near the bridge end, whereas the 34th stay cable is located near the tower.

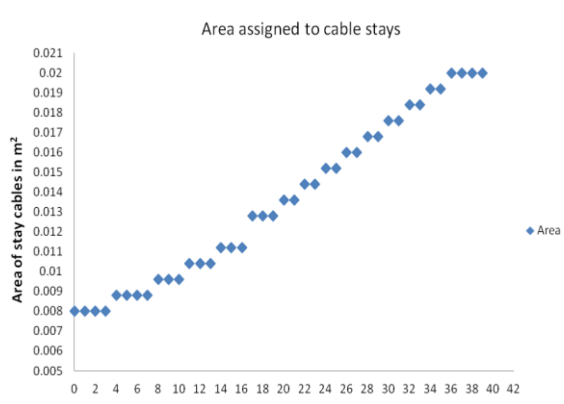

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Table 3 Modal Load Participation Ratios in Cable-stayed Bridge

Output Case	Item Type	Item	Static	Dynamic
MODAL	Acceleration	Ux	100 %	96.00 %
MODAL	Acceleration	Uy	100 %	99.58 %
MODAL	Acceleration	Uz	100 %	99.46 %

Comparison of Results of cable-stayed:

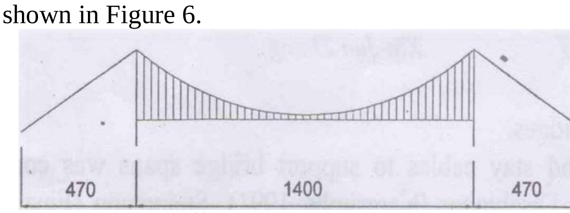
Results obtained by analysis carried out using Sap2000 V14.0.0 are compared with the available data from literature of Xin-jun Zhang.

Table 4 Natural Frequency of the sample cable-stayed bridge (Hz)

Modes	Xin-jun Zhang	Sap2000	Mode Shape
Lateral Bending	0.0558	0.0556	1-S
Vertical bending	0.1830	0.1640	1-S
Vertical bending	0.2625	0.3025	2-S
Vertical bending	0.3912	0.4452	3-S
Torsion	0.3959	0.4489	1-S

(4) Suspension bridge

Modeling of 1400m central span and 470m side spans bridge are carried out to study the behaviour of the suspension bridge.
Based on data of the Runyang Bridge, the longest suspension bridge built in China, a sample suspension bridge with the centre span of 1400 m is designed as shown in Figure 6.



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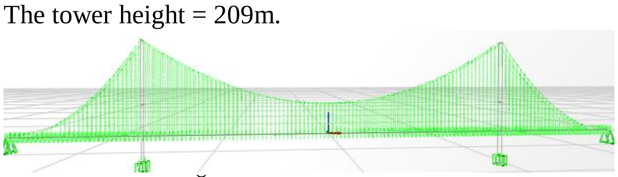
Geometrical data of Runyang suspension bridge for modal analysis
The cable's sag to span ratio = 1/10,
Distance of two main cables = 34.3 m,
The spacing of hangers = 16 m,
The width of streamlined steel box girder deck = 35.9 m,

The height of streamlined steel box girder deck = 3.0m, The tower door-shaped frame with 3 transverse beams, The tower height = 209m.



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The cross-sectional properties of the bridge are given in Table 5

Members	E (Mpa)	A (m2)	Jd (m^4)	Iy (m^4)	Iz (m^4)	M (Kg/m)	Jm ($Kg.m^2/m$)
Girder	$2.1x10^5$	1.761	3.939	193.2	8.33	26340	$2.957x10^6$
Tower	$2.1x10^5$	1.760	39.67	40.32	39.27	19327	$8.574x10^6$
Main Cable	$2.0\ x10^5$	-	-	-	-	3717	-
Hanger Cable	$2.0\ x10^5$	-	-	-	-	16.8	-

E - Modulus of Elasticity; A - Cross section area; Jd - torsional Constat; Ix-Vertical Bending moment of inertia; Iy - Lateral Bending moment of inertia; Iz - Vertical Bending moment of inertia; M - Mass per unit length; Jm – mass moment of inertia per unit length.
Define material properties
Materials Properties can be defined and modified by define material property data.

Comparison of Results of suspension bridge:

Results obtained by analysis carried out using Sap2000 v14.0.0 are compared with the available data from literature of Xin-jun Zhang.

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Modes	Xin-jun Zhang	Sap2000	Mode Shape
Lateral Bending	0.0517	0.0565	1-S
Vertical bending	0.1294	0.1115	1-S
Vertical bending	0.1849	0.1606	2-S
Vertical bending	0.2473	0.2475	3-S

(5) Discussion:

Discussion on the analysis result and its validations are as follows:
The Dynamic Analysis of the Cable-stayed bridge and suspension Bridge of 1400m main span is carried out using Sap 2000 v14.0.0 and results are compared for Validation of software.
Non-Linear Static analysis is carried out for the Static performance of the structures.
Modal analysis using the Ritz-Vector method is carried out to find out different mode shape of the structures.
From the modal analysis and nonlinear static analysis of the Cable supported bridges it is found that the dynamic properties like natural frequency and time period are matching with the values available in literature carried out with negligible variation.

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