Modal Time History Analysis Of Cable Supported Bridges Using SAP2000

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Abstract:

There has been immense increase in the desire to provide bridges with very large spans as a result of appreciable infrastructural development during past decade(s) . Cable supported bridges are mainly preferred for such large spans , comprising of Cable Stayed &/or Suspension Bridges The innovative approach adopted , thereby , enmarks the importance for variety of combinations materials and methodologies adopted for planning, execution of the Construction of the bridges with optimal cost-utility ratio. Evolution of various innovative approaches have come up Cable Stayed bridges and Suspension type of cable supported bridges for bridges of long to super long spans. So as an innovative approach , preference to Cable stayed suspension Hybrid Bridge has been given as it incorporates merits of both CSB and SB respectively.This article tries to restrict the study to evaluate the effect of innovative forms of cable system adopted on the modal time period(s) of the cable supported bridge model (studied)

For the modelling author has used SAP2000 software. The study includes the response of the bridge modelled towards innovation /variation in the cable system. A bridge similar to that of Bridge at Ling Ding Strait China is taken as a reference and models are created with variation in cable system (ranging from original cable stayed bridge to suspension type, composite bridge and cable stayed suspension hybrid bridge). The results revealed that effects selection of system of cables has a substantial impact on Modal Time

Keywords: Suspension Bridge; Cable-stayed Bridge ;Cable-Stayed-Suspension Hybrid Bridge ; Modal-Time-History-Analysis ,SAP2000

Abbreviations : CSB:Cable Stayed Brige ,SB:Suspension Bridge ,CSSHB:Cable Stayed Suspension Hybrid Bridge , MTHA : Modal Time History Analuysis

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1. INTRODUCTION:

The suspension bridge (SB), a category of cable supported bridges, is most suitable type for very long-span bridge and actually represents 20 or more of all the longest span bridges in the world.The Suspension cable is helpful in providing the constituent members longer spans flexibly. The other category, Cable Stayed Bridge (CSB) provides a better rigidity.

The schematic representation of the two categories is easily depicts the various components and the nature of forces developed amongst its constituent members.

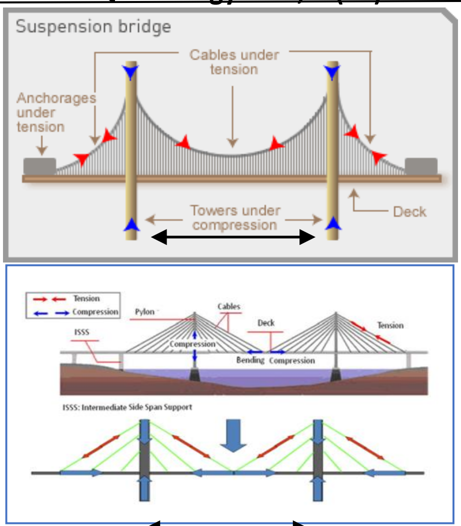

Fig 1: Schematic Diagram of force in a SB & CSB

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As evident, from Fig.1, suspension cables in suspension bridge, and cable stays in a cable stayed bridge , are in tension.Thus the load transfer mechanism sketched above shows the load of deck is carried by cables (in tension) which is transferred to the Pylon(compression) thereon to ground below.That is why structures like trusses , roof nets , ropeways , bridges which are cable supported are generally defined under the category of Tension Structures.

The Table 1 below, enlist brief details of the cable supported bridges.

2. LONG TO SUPER LONG SPANS: NEED OF THE DAY

When we talk about span, it represents clear span between Pylons.The need for long to super long spans with central main span as multiple(s) of 100 meters can be attributed to

a. Necessity for greater horizontal clearances for navigation owing to increased size ofvessels.
b. Economic Impact
c. Reduced failure of bridge due to vessel-pier collision
d. Minimised number of piers, leading to less foundation excavation,relocation

Table 1 : Some Cable Supported Bridges.

Sr	Bridge Name	Type	Country	Centre Span (>800m)	Year of Completion
1	Russky_	CSB (Steel Bridge)	Russia	1104	2012
2	Stonecutter		Hong Kong	1018	Mid 2008
3	Tatara		Japan	890	1999
4	Normandie		France	856	1994
5	Sutong	CSB (Composite Bridge)	China	1088	2008
6	Incheon		S.Korea	800	2009
7	Hutong Yangtze	CSB (Recent)	China	1092	2019
8	Qingshan Yangtze		China	938	2019
9	Jiayu Yangtze		China	920	2019
10	Chizhou Yangtze		China	828	2018
11	Akashi-Kaikyo	SB	Japan	1991	1998
12	Xihoumen		China	1650	2009
13	Great Belt East		Denmark	16245	1998
14	Gwangyang		Korea	1545	2012
15	Runyang South		China	1490	2005
16	Humber		U.K.	1410	1981
17	Tsing Ma		HongKong	1377	1997
18	Golden Gate		USA	1280	1937
19	Meckinak Strait		USA	1158	1957
20	Minami Bisan-Seto		Japan	1100	1988
21	Fateh Sukta Mehmet		Turkey	1090	1988
22	Forth Road		U.K	1005	1964
23	ShimotsuiSeto		Japan	940	1988
24	Hu Men Zhu Jiang		China	888	1997
25	Askey		Norway	850	1992

3. INNOVATIVE FORM FORCABLE SUPPORTED BRIDGE(S)

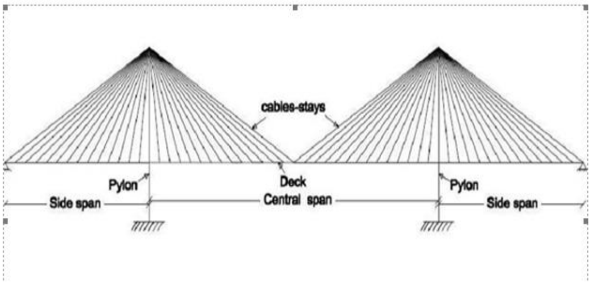
The paper has tried, in particular, to address the latest and recentforms &/or trends &/or conceptual issues with respect cable supported bridges and bridge system(s) specifically for long to super long spans.This article tries to emphasize on covering innovative forms of cable systems namely

1) Suspension bridge (SB) type of cables System
2) Cable-stayed bridge (CSB) type of cable system
3) Hybrid cable system

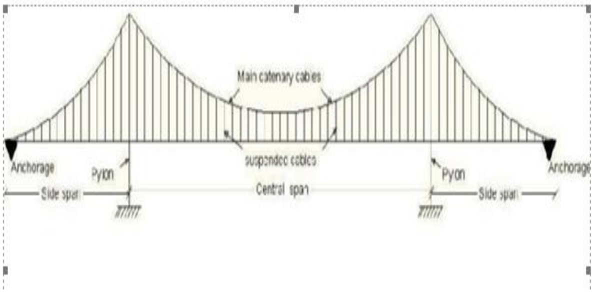
The hybridity in the cable configuration system can be further categorised in form of

a. Composite Bridge (Composite CSSB)type of
b. cable system
c. Combined Bridge (Combined CSSB)type of cable system
d. Cable Stayed Suspension Hybrid Bridge (CSSHB) type of cable system.

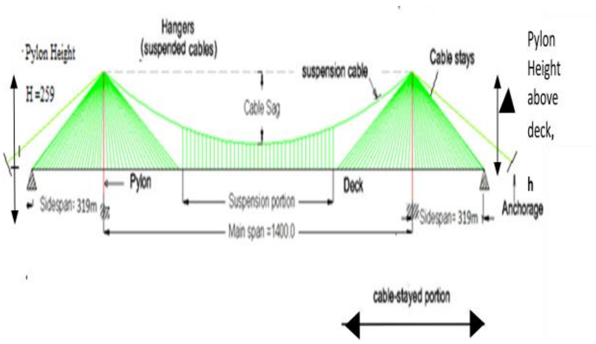
i. With no overlap (CSSHB)
ii. With partial overlap (CSSHB,overlap)



a) CSB



b) SB



c) CSSHB

Fig. 2. Cable Supported Bridges

The conventional cable supported bridges namely Cable stayed bridges and suspension bridges have their own merits and demerits which can be figured out as detailed in Fig 3 below

	Advantages	*Dis-Advantages*
Suspension	➢ Cost Effective ➢ Can Be Built High Up ➢ Span Great Lengths ➢ Has Flexibility ➢ Simple Construction	➢ Soft Ground Issues ➢ Too Flexible ➢ Cannot Support High Traffic
Cable-Stayed	➢ They are strong ➢ They take less time to build ➢ They are more economical ➢ Efficient use of materials ➢ High degree of redundancy ➢ Uncomplicated, lighter superstructure ➢ Smaller vertical deflection ➢ Low Depth to Span ratio ➢ Aesthetic good looking ➢ Low Maintenance Cost	➢ They may not be too stable ➢ They are not ideal for distances that are too far ➢ Inspection and maintenance may be more difficult

Fig. 3. Comparisonbetween CSB & SB Bridges

By combining both the system of cable supported bridges, innovative CSSHB can be formulated to ascertain achievement of followingadvantages.

1. As compared to the suspension bridge with the same span length the partly suspension portion is replaced by cable-stayed portion and suspension portion can be shortened, so the tensional forces in the main caternary cables are greatly decreased.

2. The shortened/reduced suspension portion in main span results in reduced construction costs of the main cables, massive anchors; eases out to a great extent the difficulty faced during construction in/under water, and therefore makes it possible to build in the soft soil foundation also.

3. The shortened/reduced cable stayed portion with same central main span,yields, the reduced height of tower, length of stays and the axial forces in the deck.

4. Provides better wind/flutter stability due to shortened cantilevers while erection process is underway

Thenceforth, Hybrid cable-stayed suspension bridge displays and exhibits a lucrative alternative in the case of cable supported bridge systems of long to super long spans.

4. PROBLEM FOR STUDY

Fig.4 illustrates the Problem/case for the study, which resemblesto Bridge of East channel of Lingding Strait in China .

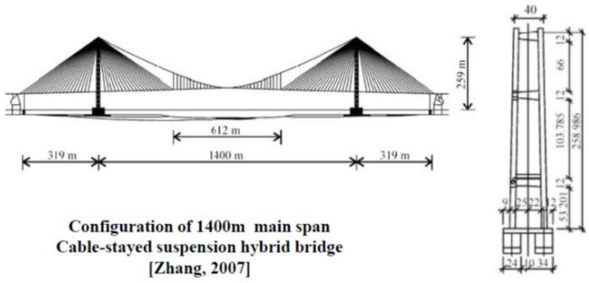


Fig. 4. Lingding Strait Bridge (China) Bridge

The bridge example, (an earth-anchored)CSSHB consists of a (main) central span of 1400 m along with two side spans of 319 m each as shown in Fig. 3 above, which was proposed in the east channel of Lingding Strait in China (Xiao 2000). The main central span consists of central suspension portion of 612 sandwichedbetween the cable-stayed portion of 788 m on either side. The two main cables are spaced laterally at 34 m, with sag to span ratio of s 1/10; hangers are placed at an interval of 18 m; whereas the cable stays are connected to the girder at an interval of 18m in the central span &The stay cables are anchored to the girder at 18 m intervals in the central span and 14 m in the side spans respectively. The deck component is a steel streamlined box steel girder 36.8 m wide, 3.8 m high. Similarly, H type Pylon Towers 259 high are used.The Specification of material and geometries incorporated are tabulated below

Table. 2. Material & C/s Properties Bridge

Members	E (Mpa)	A (m²)	J_d (m⁴)	I_y (m⁴)	I_z (m⁴)	M (Kg/m)	J_m (Kg.m²/m)
Girder	2.1×10^5	1.2481	5.034	1.9842	137.754	18386.5	1.852×10^6
Stay cable	2.0×10^5	0.008	0.0	0.0	0.0	62.5	0.0
Hanger Cable	2.0×10^5	0.0065	0.0	0.0	0.0	30.19	0.0
Main Cable in center span	2.0×10^5	0.3167	0.0	0.0	0.0	2445.80	0.0
Main Cable in Side span	2.0×10^5	0.3547	0.0	0.0	0.0	2979.5	0.0
Pylon C	3.3×10^4	30	350	320	220	78000	5.7×10^5
Pylon TB	3.3×10^4	10	150	70	70	26000	4.7×10^5

E - Modulus of Elasticity; A - Cross section area;
J_d - torsional constat; I_y -Lateral bending moment of inertia; I_z -Vertical bending M O Inertia;
M - Mass per unit length; J_m – mass moment of inertia per unit length.

Property	**Material**	
	Steel (Fe345)	**Concrete (M45)**
Modulus of Elasticity (E)	2.0×10^8 kN/m²	3.354×10^7 kN/m²
Unit Weight	76.973 kN/m³	24.993 kN/m³
Poisson's ratio (μ)	0.3	0.20
Shear Modulus (G)	1.115×10^6 kN/m²	1.397×10^7 kN/m²
Coeff. Of Thermal Expansion (α)	1.17×10^{-5}	0.55×10^{-5}

Cable No.	**Diameter (m)**	**Area (m²)**	**Cable wt. (kN/m)**
Hanger	0.0903	6.4×10^{-3}	0.493
Main Cable(SS)	0.635	0.367	28.238
Main Cable(CS)	0.672	0.3547	27.302
Stay Cable(1)	0.1009	8.00×10^{-3}	0.616
Stay Cable(2)	0.1059	8.00×10^{-3}	0.678
Stay Cable(3)	0.1106	9.61×10^{-3}	0.740
Stay Cable(4)	0.1156	10.41×10^{-3}	0.802
Stay Cable(5)	0.1194	11.20×10^{-3}	0.863
Stay Cable(6)	0.1277	12.81×10^{-3}	0.987
Stay Cable(7)	0.1316	13.61×10^{-3}	1.048
Stay Cable(8)	0.1354	14.41×10^{-3}	1.109

4.1 Bridge Structure

SAP2000 software was used for the purpose of defining material , sections- shape and type(category) to be used in the model as mentioned in Table 2; and furthermore to draw the geometry of the structural element defined; defining and assigning support(s), springs/links; defining and assigning various load cases and their combinations; finally to run analysis and interpretation of the result(s) obtained.

The various structural components defined/assigned can be summarized as :::

Deck Girder was modeled as frame element , using steel, as a steel streamlined box girder c/s ,which subjected to a DL of nearly 98 kN/m in addition to LL of approx 35 kN/m

Pylon Tower (H type) modeled ,as frame element using M45 grade of concrete with 6m x 5.0m c/s , 258.786m high, with 3 transverse beams 4m x2.5m in c/s(along its height).

Cable(s)modeled as cable element as detailed in Table 1 above , adopting Sag to Span ratio of 1:10

Supports and Links are modeled in accordance

The innovative modifications in cable system studied to study effect of cable pattern and bridges modeled as scheduled in tasks below, namely.

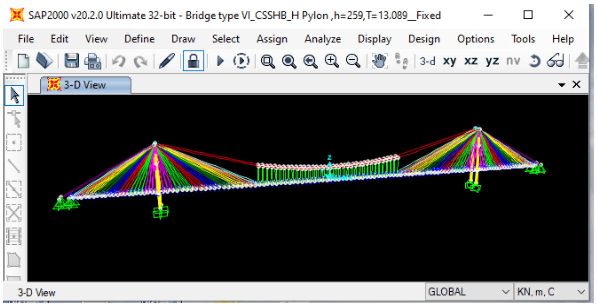
a) Type I (CSSHB) .
b) Type II (SB).
c) Type III (CSB)

The bridge(s) modeled is shown in Fig.3, subsequently.

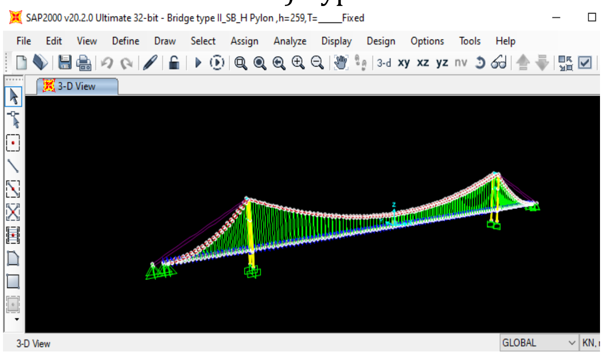
Type I (CSSHB): This is similar to Ling Ding Strait bridge explained above. The snap of the model generated using SAP2000 is illustrated in Fig 5a) subsequently

Type II (SB).: Type I is remodelled/modified completely by changing the cable system to a pure suspension bridge(i.e. without any stay cables anywhere), hereby called Type II; keeping all other parameters such as sag to span ratio , material and geometry of elements kept unchanged wrt Type I. Herein, hangers are placed at the same points where cable stays were attached to girder in the case of original CSSHB. , as clear in Fig5b)

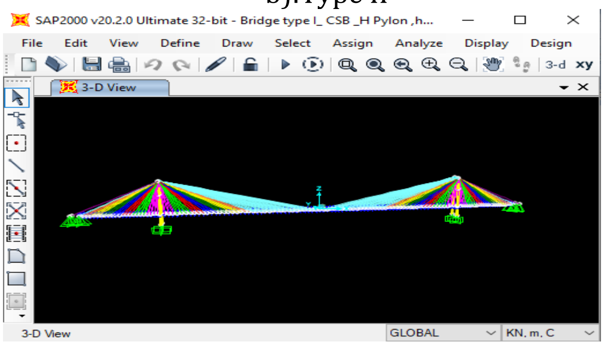
Type III(CSB).: Type I is remodelled/modified completely by changing the cable system to a pure cable stayed bridge(i.e. without any hanger cables, main suspension cable anywhere), hereby called Type III; keeping all other parameters such as sag to span ratio , material and geometry of elements kept unchanged wrt Type I. Herein, cable stays are placed at the same points where hangers were attached to girder in the case of original CSSHB. , as clear in Fig 5 c)



a):Type I



b):Type II



c):Type III

Fig. 3. Innovation: Different Cable Systems

4.2 Time History

Seismic Time History details of Bhuj Earthquake of 30 Jan 2000, recorded at Ahmedabad, having magnitude of 7.7 on Richter scale, lasting for a duration of approx 134 sec, with a PGA of nearly 1.04 m/s^2 is considered for the study (Far Field EQ)
Total No. of Accelerationrecordsconsideredin the study are 26706.

5. ANALYSIS& RESULTS

The bridge models generated were analysed for Modal Time History Analysis (MTHA), using SAP2000 software. The table below shows Time period for first 7 modes of the three types of bridge cases considered

Table. 3. Time Period : Different Bridge Configuration

Bridge Type	Time Period for Modes, T sec, for H type of Pylon (258.936m high) Sag to spa1:10						
	1	2	3	4	5	6	7
I(CSSHB)	12.94	9.45	8.82	8.49	7.88	6.63	6.55
II(SB)	12.87	10.21	8.36	8.04	7.91	6.65	6.16
III(CSB)	12.84	8.49	8.49	5.94	4.99	4.80	3.82

The comparative graphical representation of the modal time periods for different models with innovated cable systems is illustrated in Fig 6 below, depicting Time periods for each case up to7modes.

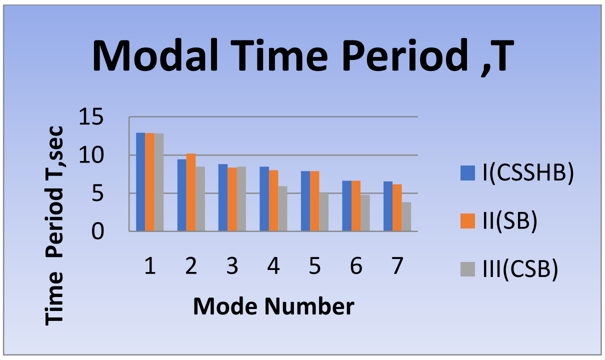


Fig. 6. Comparison: Time Period (7 Modes),for Diff. Cases

The analysis reflectsresults of seismic time history analysis, as

1) Illustrated3 (bridge types). The table demonstrates the trend observed in the deviation is almost same for all cases Type II Bridge(SB) reflects more flexibility then the Type III (CSB) .Type I (CSSHB) possesses greatest flexibility amongst the three types studied
2) Moreover, for the 3rd and 4 th mode revealed a lower Time period for all types when compared to Type I, thereby , reflecting decrease in flexibility towards those . However beyond 4th mode, there is considerable increase in rigidity for Type III as compared to Type I and II.
3) Thus, it is clearly illustrated , that CSSHB (Type I) proves out to be more advantageous compared to other types of

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conventional cable supported bridges

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