Effect of Cable Configuration on Modal Analysis of Cable Supported Bridges

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ABSTRACT

The infrastructural development along the globe has given rise to an urge for bridges, bridging over super-long spans. Bridges supported on Cable systems can be figured out as Cable supported bridges, in general, subcategorized as Cable Stayed Bridge (CSB) &/or Suspension Bridge (SB) type of cable systems; they generally constitute Long to super long span bridges. To have an edge, for a better cost/utility ratio, in the present scenario, the importance and hence the need for different materials and construction methodologies adopted govern the basic pointer. Primarily and predominantly, CSB's and SB's have been preferred for bridges garnering very long or, say, super long spans (herein, spans are generally in multiples of 100m). It is very much clear and understood that CSB's and SB's have their own need, merits & certain demerits too. So as an innovative thought and approach thereby, preference for Cable-Stayed-Suspension Hybrid Bridge (CSSHB) may be incorporating merits of both CSB and SB, respectively. This article tries to restrict the study to assess the consequence of Configurational Forms (Innovative) of Two Plane Cable system(s) on Modal-Time-History-Analysis (MTHA) for Cable Supported Bridge(s) model (studied) using SAP2000. This study covers a range of cable systems, such as conceptually primary cable system(s) like suspension type, cable- stay type, hybrid type in terms of the composite system (Comp CSB, hereafter), and combined (CSB+SB)type of system. The results revealed that the effects selection of a system of cables has a substantial impact on Modal Time.

Keywords: *Cable-stayed Bridge (CSB), Cable-Stayed-Suspension Hybrid Bridge(CSSHB), Modal-Time-History-Analysis (MTHA), SAP2000 Suspension Bridge (SB).*

INTRODUCTION

When cables support the deck/girder, the bridge system so formed can be termed a Cable-supported bridge(s) system. Herein, the load transfer mechanism follows the sequential flowchart: Deck, Cable System, Pylon Towers, and Ground Beneath (or else may be transferred directly to the base rocks beneath from cables via ground anchors). Broadly, thus, a Cable supported bridge system generally comprises of Deck /Girder, Cable System, Pylon Tower(s), and/or anchorages in the form of blocks or Piers.

In a broader sense, any Cable supported bridge system can be sub-categorized as Suspension type of Bridge(s) & Cable Stayed type of Bridge.

The SB, a category of Cable supported bridges, is the most suitable type for Bridge (s) spanning over spans that are very long-span and actually represent 20 or more of all the bridges covering spans considered amongst the longest around the globe. The Suspension cable is helpful in providing the constituent members longer spans flexibly.

It has been seen that cables of numerous bridges were necessitated and needed to be replaced owing to safety concerns in the last decade or two in China itself. Now it is far told truth that this process of replacement not only is too costly but impacts on the socio-economic front too as it results in pouring in investment, transportation gets disrupted during the process & as such management of maintenance work is troublesome.[11]

The other category, Cable Stayed Bridge (CSB) provides a better rigidity. As the CSB's can overcome spans>1000m too, it has made and proved themselves as a better alternative(s) to suspension bridges, practically stating. The schematic representation of the two categories easily depicts the various components and the nature of forces developed amongst its constituent members.

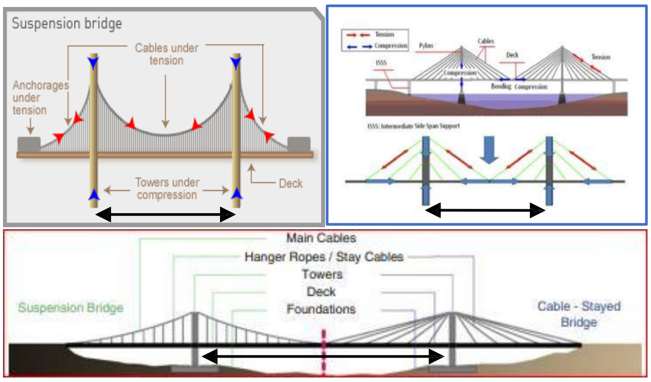

Fig. 1: *Schematic Geometric Configuration & Forces in Bridge (SB & CSB) Components.*

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

The cables are an inbuilt key governing the lock named ―Structural Safety and stability‖ for /of Cable Supported Bridges, as they are responsible and thus are major forces transmitting/transferring components. However, factually, vulnerability towards corrosion is very high, and this enhances the damage due to fatigue induced. This leads to a detrimental impact and effect on the which affect their service(s) throughout its spanned life, which may further add to problems with regard to their replacement; during the process of Bridge maintenance and its management.

LONG TO SUPER LONG SPANS: NEED OF THE DAY

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

- Increased vessel/ship size necessitates a greater clearance horizontally, too for its effective and hassle-free navigation.
- Generates considerable/noticeable impact on the Economic front too.
- Greater span imparts a Reduction in instances of bridge failure owing to the vessel-pier collision because the more

the clear span, the less will be supported/piers, and so less will be chances of pier-vessel interaction/collision.

- Greater Central clear span naturally results in less Supporting Piers, which in turn leads to less foundation excavation, relocation, execution, Maintenance and repairs during its design life.

Table 1 below enlists brief details of some of the leading Cable supported bridges of the 20th-21st century garnering long spans (>800m)

***Table 1:** Brief: Leading Cable-Supported Bridges.*

Bridge Name	**Type**	**Country**	**Center Span (>800m)**	**Year of completion**
Russky_	CSB (Steel Bridge)	Russia	1104	2012
Stonecutter		Hong Kong	1018	Mid-2008
Tatara		Japan	890	1999
Normandie		France	856	1994
Sutong	CSB (Composite Bridge)	China	1088	2008
Incheon		S.Korea	800	2009
HutongYangtze	CSB (Recent)	China	1092	2019
Qingshan Yangtze		China	938	2019
Jiayu		China	920	2019
ChizhouYangtze		China	828	2018
Akashi- Kaikyo	SB	Japan	1991	1998
Xihoumen		China	1650	2009
Great Belt East		Denmark	16245	1998
Gwangyang		Korea	1545	2012
Runyang South		China	1490	2005
Humber		U.K.	1410	1981
Tsing Ma		HongKong	1377	1997
Golden Gate		USA	1280	1937
Meckinak Strait		USA	1158	1957
Minami Bisan-Seto		Japan	1100	1988
Fateh Sukta Mehmet		Turkey	1090	1988
Forth Road		U.K	1005	1964
ShimotsuiSeto		Japan	940	1988
Hu Men Zhu Jiang		China	888	1997
Askey		Norway	850	1992

INNOVATIVE FORM FOR CABLE-SUPPORTED BRIDGE(S)

The paper has tried, in particular, to address the latest and recent forms &/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 covering innovative forms of cable systems, namely.

- Suspension bridge (SB) type of cables System
- Cable-stayed Bridge (CSB) type of cable system

- Hybrid cable system

The Hybridity is decided upon taking into due consideration the Technical, Cultural and Innovational aspects and current trends prevailing. Thus, it may be in the form of a Variety or combination of Materials used in the Stiffening Girder/Deck or any structural component &/or combination of the geometric configuration of cable system(s) adopted or considered. In this study, hybridity is categorically considered as

- Composite Bridge (Composite CSSB) type of cable system
- Combined Bridge (Combined CSSB) type of cable system
- Cable-Stayed-Suspension-Hybrid-Bridge (CSSHB)

Type of cable system

- With no overlap (CSSHB)
- With partial overlap (CSSHB, overlap)

However, it can be emphasized that both suspension and Cable-stayed bridge systems have their own merits and demerits, which are concisely illustrated in Table 2 below; owing to which concept of utilizing both systems simultaneously or in a combined way arose. This innovation was first introduced by Roebling while going for rehabilitation in Brooklyne Bridge, USA.

German Engineer Dischinger added further to this innovative approach. This innovation was also followed in various works later on, namely the Salzar bridge in Portugal, Tancarville bridge in France etc.

***Table 2:** Merits& demerits: Cable-Supported Bridges.*

Bridge System Adopted	**Advantages**	**Dis-Advantages**
Suspension (SB)	• Cost Effective • High Up — Build Possible • Over-cross Great • Span (Lengths) • Simple Construction • Flexibility may lead • to an added advantage too	• Soft Ground Issues • High Flexibility • (Too Flexible) • May not support High • Traffic may lead to problems.
Cable-Staved (CB)	• Aesthetically Pleasing • Are Strong • Have a High Degree of Redundancy • Take less Time to build • Are Most Economical • Efficient Use of materials • Uncomplicated &lighter superstructure • Comparatively • smaller vertical deflections • Low Span-Depth ratio • feasible	• They may not prove to be stable • More suitable for Over-crossing shorter spans(Not ideally recommended for spans that are too large/long) • Inspection & Maintenance may be difficult Soft Ground • Issues

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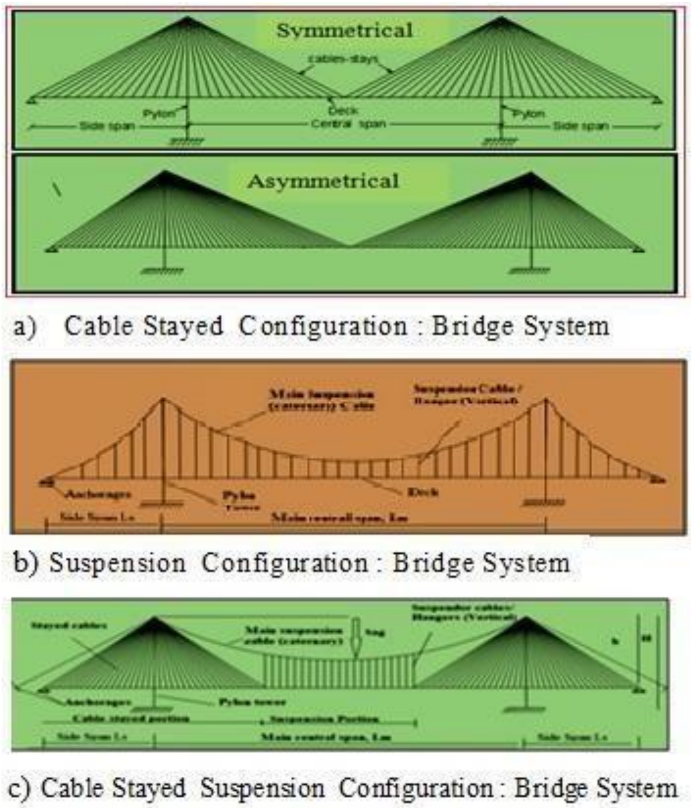


Fig. 2: *Bridge Systems: Cable-Supported Bridges.*

As clearly seen in a pictorial presentation in Figure 2 above, by a combination of both the types of cable system(s), namely CSB+SB types of Cable supported bridges, innovative CSSHB can be formulated to ascertain the achievement of the following advantages

1. The tension developed in the catenary Cable (s) gets considerably reduced owing to the shortening of the suspension portion than a suspension type of Cable supported Bridge of the same span length.
2. The construction costs show reduction owing to shortened/reduced suspension portion in the main span, especially the main cables and massive anchors; it eases out to a great extent the difficulty faced during construction in/under water, and therefore building in /on the soft soil foundation becomes feasible.
3. Simultaneously the portion of Cable-stayed portion too is shortened when compared with CSB of the same central span, and this reduction yields optimization in the form of the shortened height of the Pylon tower needed, cable stay length(s) and thereby the axial forces developed in the stiffening girder, i.e. the deck.
4. The combination of CSB and SB portions resulting in CSSHB has been proven to be providing better wind/flutter stability owing to the fact that cantilevers are far shortened while the process of erection/execution is underway.

Thenceforth, Hybrid cable-stayed suspension bridge (now onwards CSSHB) presents a better and more lucrative alternative for bridge systems that adopt Cable supported systems garnering long to super long spans.

LITERATURE

- Niels J. Gimsing and Christos T. Georgakis (2011) have emphasized and covered in detail chapters related to aerodynamics and other such topics, which are dynamic, owing to the fact that dynamic analysis has become the need of the era. They covered topics involving vibrations induced by pedestrians or&/or vehicular besides aerodynamics and Monitoring of the Bridge System.[1]

- Krishna, P. (2001), in his work, noted, covered and abstracted to summarise the stature of the various issues. He put forth& discussed notes on materials and approaches adopted for the analysis of bridges and Cable supported roofs and briefed about the prevailing trends in the conceptuality of Aerodynamics and technology adopted.[2]
- Podolny, W. (1986), in his book, discussed the general principles of CSBs, relating to all facets of construction details, methods; technical design; and the potential economies involved.[3]
- John Wilson* & Wayne Gravelle (1991), in their paper, described in detail, FEM based model developed for analyzing a CSB dynamically, taking Quincy Bay-View Bridge into its consideration.[4]
- P.H. Wang *et al.* (1993), in their research, presented a F.E.M. for the computational procedure to determine the initial shape of CSB's considering only forces of pretension induced in cable stays and the self-load of the deck[5]
- Starossek U. (1996), in his paper, proposed an alternative concept that was derived from the classical cable-stayed bridge system. He pylons, pairs of inclined pylons, rather than pylon legs, fanning out longitudinally, which were associated at the top by cross over ties. He discussed all the merits and shortcomings of such a system; to innovative concept makes the achievement of larger maximum spans economically advantageous design.[6]
- Zhang Xin-jun, SUN Bing-nan, in 2005, presented their work, considering some parameters like suspension portion length, planar arrangement of cables, subsidiary piers provided intermediately in the Side spans, Use of various forms for deck, sag etc., and submitted their subsequent effects on the bridge design.[7]
- Zhang Xin-Jun(2007), in his work, abstracted that CSSHB is a cooperative system of the CSB & SB and hence utilizes some advantages and also overcomes some of the deficiencies of both the bridge system(s). By taking the CSSHB, SB and CSB –covering 1400m as its main span as examples, the dynamic analysis along with the static performance of the system was conducted. Moreover, investigation on aerostatic and aerodynamic stability etc., by 3D nonlinear analysis was accomplished. He presented the results to show that the proposed CSSHB structurally has enhanced stiffness structural stiffness, less internal forces and improved stability towards wind, and thus is preferable in the case of super long-span bridges, as compared to the SBs and CSB's of the same span. [8]
- Zhang Xin-jun, Stern David, in 2008, submitted his investigation on ―Wind stability by analyzing a CSSHB covering 1400m as the main span, putting forth the effects of various geometrical parameters for design, namely Sag to Span ratio, the suspension to main span, ratio, the side span length- its ratio and relation with regard to main span, the layout of stay cable planes and the subsidiary piers in side spans etc. [9]
- Egon Kivi 2009; submitted his thesis on *"Structural Behaviour of CSSB"* [10]

- Bruno *et al., in* 2009, in his work presented the effect of moving vehicle(s) and their load, thereby response of the Bridge system to such Dynamics.[12]
- Aitor Baldomir *et al.* in 2010, in their research paper document, describe an optimization problem of cable cross-section of a CSB considering constraints of cable stress and deck displacement. A computer code was written to produce a model from geometrical and mechanical data, and thus solution towards optimization of the problem was presented.[13]
- Ghanshyam Savaliya *et al.*, in 2010, in their conference paper ‖ Large Span Cable Supported Bridge[14], concluded that to achieve a very long span in Cable supported bridge structures, it is required to combine both the Cable supported suspension system and cable-stayed system
- Jing Qiu *et al.*, 2011, presented their work and analysed an 1800 m CSSB to investigate the influence of various principal structural parameters; such as the rise-span ratio, the suspension-to-span ratio, the constraint condition of the stiffened girder, the number of auxiliary piers at side spans; on the static and dynamic behaviour of bridges systematically.[15]
- Tao Zhang *et al.*, in 2011, in their work illustrated the generation of the model for the finished dead stage analysis, in detail, including the boundary conditions and variations in loading. The outcomes got uncovered that the technique introduced without a doubt prompts ideal underlying execution for the cable-stayed ridge in particular and might be a useful reference for the design of other similar bridges.[16]
- Ghanshyam Savaliya *et al.* 2012, in their research, studied the behaviour of the long-span CSB having a 1400m main span and a 700m side span. He considered side span supports as the parameter to enhance the structural stability of the Bridge Bridge. The analysis of the Bridge is carried out to study the behaviour of the Bridge using Sap2000.[17]
- Bin Sun, C.S. Cai and Rucheng Xiao, in 2013, in their work on Analysis Strategy and Parametric Study of Cable-Stayed-Suspension Bridges[18], presented a systematic strategic analysis CSSBs. He established and emphasized a four-step approach for the determination of the reasonable finished dead load state, wherein focus on the optimization of the tension forces and shapes of all cables was made. A 1400 m span CSSB was considered and presented as a case study with consideration of 3 parameters under study, namely Sag to Span Ratio, Provision of cross hangers. He concluded that a suspension-to-span ratio of 0.4 - 0.6, a larger sag-to-span ratio up to 1/11.0, and two to four crossing hangers enhance structural rigidity and stability, and so can be recommended. CSSB, thus, is proven as an excellent alternative to Cable-stayed bridges and suspension bridges.
- Lonetti P., Pascuzzo A., in 2014, in their research ―Proposed, for a CSSHB, a design methodology to predict the Optimal design (pre-tensioning forces & dimensioning) of cable systems [19]‖, predicted and proposed a methodology to be adopted for evaluating post-tensioning needed in cables and thereby the c/s of cables needed optimally. The conclusion was submitted; it was concluded that ―conceptually- pure SB's or CSB's schemes result in our requirement of total steel quantity larger or lower than that associated with the HCS configuration. However, in the case of CS bridges, construction of the pylons compensates the steel quantity (reduced value) involved, which presents a larger height with respect to

conventional SB or HCS Bridge schemes‖.

- Kumudbandhu Poddar and Dr T. Rahman 2015, in their article, computationally commented and reviewed the analysis of Cable supported bridge systems inclusive of CSB, SB, CompCSB etc. He proposed as an introduction a concept of producing a new model for the CompCSB model wherein the cable-stays hangers support the deck, which has a long span, at different portions along the longitudinal direction of the Bridge.[20]
- Sevalia G. *et al.*, in 2016, submitted their doctoral work on ―Effect of Geometrical Aspects on Static & Dynamic Behaviour of CSSHB [21]‖, in which he elaborated on the effects of various geometrical aspects such as side span ratio, lateral spread of pylon tower, sag to span ratio etc. on a 1400m CSSHB
- Govardhan Polepally *et al.*, in 2020, presented their review paper and showed that the shape of the Pylon has got great influence on the seismic behaviour of cable-stayed Bridges.[22]

PROBLEM FOR STUDY

Fig.3 illustrates the Problem/case for the study, which resembles that of the Bridge of the East channel of the Lending Strait in China. The models are generated using SAP2000 software which is universally acknowledged for its versatility by structural engineers globally.

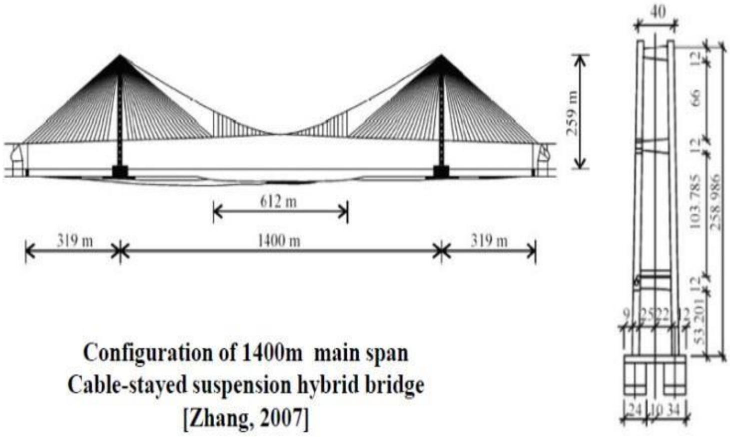


Fig. 3: *Lingding Strait Bridge (China) Bridge.*

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. 2 above, which was proposed in the east channel of Lending Strait in China (Xiao 2000). The main central span consists of a central suspension portion of 612 m sandwiched between the cable-stayed portions of 788 m on either Side. The two main cables are spaced laterally at 34 m, considering a sag-to-span ratio of 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. A 36.8 m wide and 3.8 m high steel streamlined box steel girder makes up the deck component. Similarly, H-type Pylon Towers 259 high are used. Subsequently, Table 3 and Table 4 illustrate the Specification of material and geometries incorporated

***Table 3:** Material & C/s Properties Bridge Components.*

As adopted by Zhang,2007							
Member	E (x105)	A	Jd	Iy	Iz	M	Jm
	MPa	m²	m4	m4		kg/m	Kgm²/m
Girder	2.1	1.248	5.034	1.9842	37.754	18386.5	18.5 ×106
Stays Cable	2.0	0.008	0.0	0.0	0.0	62.5	0.0
Hangers	2.0	0.0065	0.0	0.0	0.0	30.19	0.0
CS	2.0	0.3167	0.0	0.0	0.0	2445.8	0.0
SS	2.0	0.3547	0.0	0.0	0.0	2979.5	0.0
Pylon	0.33	30	350	320	220	78000	5.7 × 105
T.B	0.33	10	150	70	70	26000	4.7 × 105
E=Modulus of Elasticity				A= C/s area			
Jd= Torsional Constant				Iy & Iz = Moment of Inertias against lateral and vertical Bending			
M= mass per unit length				Jm= mass moment of inertia/unit length			
CS= main Cable in the central span				SS= main Cable in Side span			

***Table 4:** C/s Properties of Cables Adopted.*

Cable No.		**Diameter(m)**	**Area(m2)**	**Cable wt.(kN/Rmt)**
Hanger		0.0900	6.4 × 10-3	0.490
Cable- Main	SideSpan (SS)	0.635	0.367	28.238
	Central Span(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	14.40 ×10-3	1.109
Stay Cable(9)		0.1386	15.09 ×10-3	1.162
Stay Cable(10)		0.1415	15.73 ×10-3	1.211
Stay Cable(11)		0.1457	16.68 ×10-3	1.284
Stay Cable(12)		0.1471	17.00 ×10-3	1.309
Stay Cable(13)		0.1514	18.01×10-3	1.387
Stay Cable(14)		0.1556	19.02 ×10-3	1.465
Stay Cable(15)		0.1596	20.01 ×10-3	1.541

Property	**Material**	
	Steel (Fe345)	**Concrete (M45)**
Young's Modulus (*E*) kN/m2	2.0×108	3.354×107
Unit Weight(γ), kN/m3	76.973≈77	24.993≈25
Poisson's ratio (μ)	0.3	0.20
ear Modulus (G) kN/m2	1.115 ×106	1.397 × 107
Coeff. Of Thermal Expansion (α),/°/m	1.17 x 10-5	0.55 × 10-5

Bridge Components Structured
SAP2000 software was used for the purpose of defining and assigning material, sections- shape and type(category) to be used in the model as mentioned in Tale 1; and furthermore to draw the geometry of the structural element defined; defining and assigning support(s), springs/links; assigning after defining assigning various load cases and their various combinations; ultimately to run analysis followed by result(s) interpretation

The various structural components defined/assigned can be summarized as

Deck girder
It is Modelled in SAP2000 as a frame (spine) element, using steel as material, with steel streamlined box girder c/s. The deck is supposed to withstand a DL nearing 98 kN/beside a LL to the tune of 35 kN/m.

Pylon Tower
A H type/shaped frame Pylon tower made of M45 grade of concrete, modelled as a frame element in the software. The Pylon legs are 6m x 5.0m in c/s, with a height of 258.786m. It has three transverse beams along its height

Transverse beams
3 transverse beams 4m×2.5m in c/s(along its height), made of M45 concrete and modelled as frame element

Main cable(s)
Main Cables of Fe345 grade steel, modelled as cable element, to be adopted as Main suspension &/or Main cable for CSB in side span and central span, respectively, as detailed in Table 1 above.

Stay cable(s)
Using steel of Fe345 grade as material, modelled as cable element as detailed in Table 1 above. The bridge model is similar to Ling Ding Strait Bridge, i.e. Bridge type I (CSSHB) has to stay cables of 8 sizes (Cable stays 1 to 8). However, subsequently, in other Types, stays of 11 sizes have been adopted, as shown in Figure 4.

Sag to span ratio
Sag of 140m illustrates a sag-to-span ratio of 1:10

Supports and Links
These are modelled as massless and in accordance with the model to be generated. As far as the models generated t, generalized condition for support(s) link(s) between Girder - Pylon & Girder-, Abutment can be illustrated as is retrained against displacement longitudinally and against rotation in the transverse direction. Whereas the base support of the pylon leg is considered fixed. (Restrained against displacement as well as rotation in all three directions). The various cases considered for different cable configurations have been categorically figured out in Figure 4 subsequently. It reflects the six cases considered for the study.

Innovative Cable Configuration Studied
The imaginative alterations in the cable system concentrated on concentrate on impact of cable system and scaffolds displayed as booked in the undertakings beneath, in particular

- Type 1 (CSSHB)
- Type 2 (SB)
- Type 3 (CSB)
- Type 4(Composite CSSB 1)
- Type 5 (Composite CSSB 2)
- Type 6 (Combined CSSB)

The Bridge (s) modelled is shown in Figure 5, subsequently.

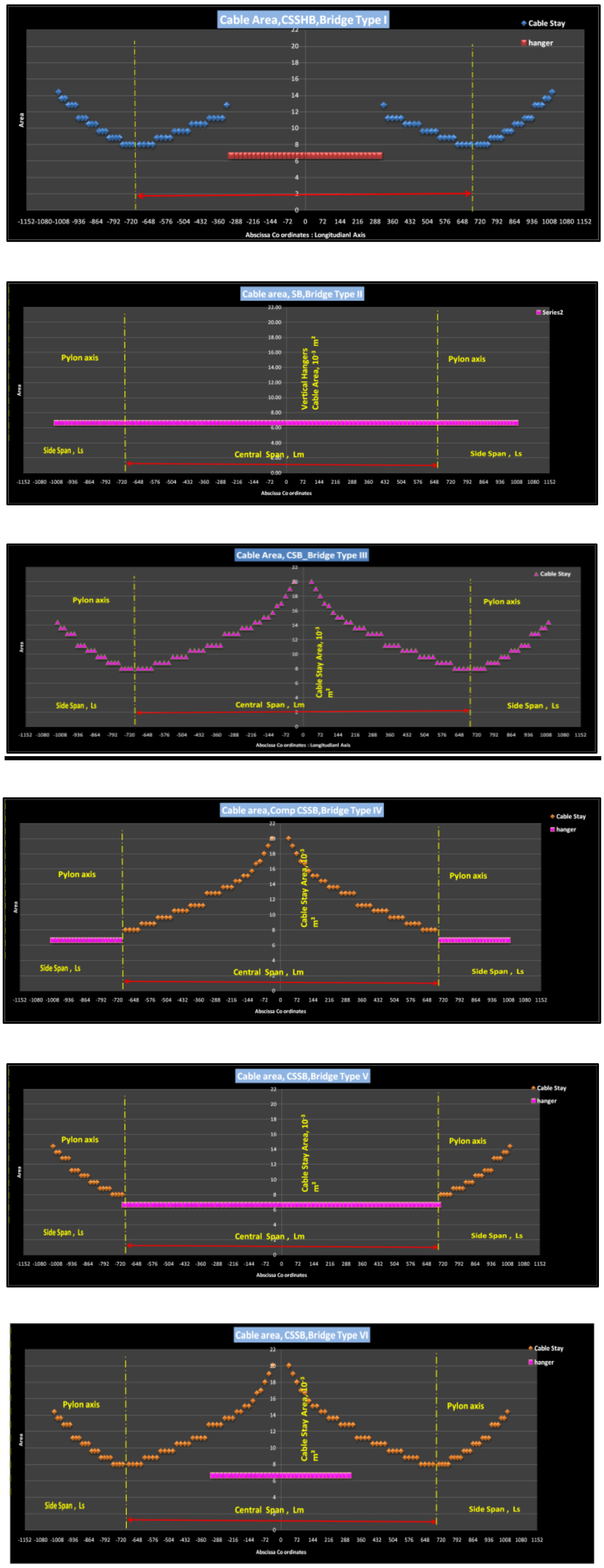


Fig. 4*: C/s Area of Cables along Bridge span::Bridge Type 1 to 6.*

Type 1(CSSHB)

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

Type 2 (SB)

Type 1 is remodelled/modified completely by changing the cable system to a pure suspension bridge (i.e. without any stay cables anywhere), hereby called Type 2, keeping all other parameters such as sag-to-span ratio, material and geometry of elements kept unchanged wrt Type I. Herein, place of providing hangers are exactly at the same location where cable stays were connected to girder in the case of original CSSHB. , as clear in Fig 5(b)

Type 3 (CSB)

Type 1 is remodelled/modified completely), Type 2 by changing the cable system to a pure cable-stayed Bridge (i.e. without any hanger cables, main suspension cable anywhere), hereby called Type 3; keeping all other parameters such as sag-to-span ratio, material and geometry of elements kept unchanged wrt Type 1. Herein, cable stays are placed at the same points where the connection of hangers to the girder is made exactly where they were in the case of the original CSSHB, as clear in Fig 5 c)

Type 4(Composite CSSB 1)

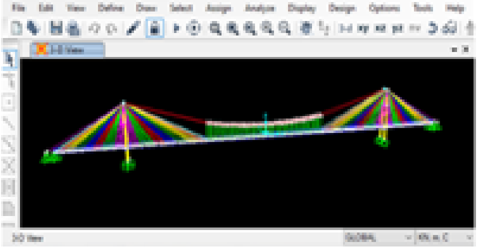
This re- innovated Bridge with an innovated/ modified cable system, hereafter called Type (CompCSB Bridge--CSSB1). In this, the central span c); Type 3 resembles the central span of Type 3, whereas Side spans resemble side spans of Type 2; thus, the central span is innovatively CSB and the side spans are modified to as SBtype as shown in Fig 5 d). Keeping all other specifications the same, herein, placement of hangers has been done at exactly the same location where cable stays were connected to the girder in the Side spans in the case of Type 1, and the cable stays are placed exactly at the same place where hangers were attached to the deck in Type II in the central span

Type 5(CompCSB--CSSB 2)

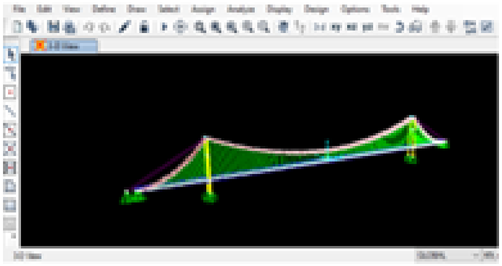
This re- innovated Bridge with an innovated/ modified cable system, hereafter called Type 5 (CompCSB--CSSB2). In this, the central span resembles the central span of Type 2, whereas Side spans resemble side spans of Type 3; thus, the central span is innovatively SB and the side spans are modified to CSB type as shown in Fig 5 e). Keeping all other specifications the same, herein, hangers are placed at the same points where cable stays were attached to the girder in the central spans in the case of Type 1 and the cable stays are placed exactly at the same pointedly place where hangers were connected to girder or deck in Type 2 in the side span

Type 6 (Combine CSSB)

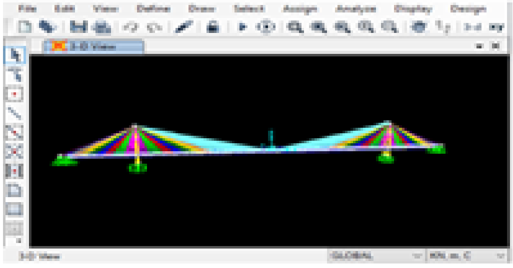
This innovation has been formulated by combing the cable system of Type 2 and Type, hence referred to as Type 5 (Combine Bridge CSSB) hereafter. In this, the central span is a combination of CB and SB, whereas the side spans are CB type, as shown in Fig 5 f).



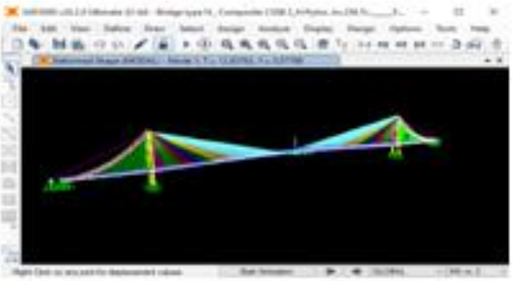
(a):::Type1



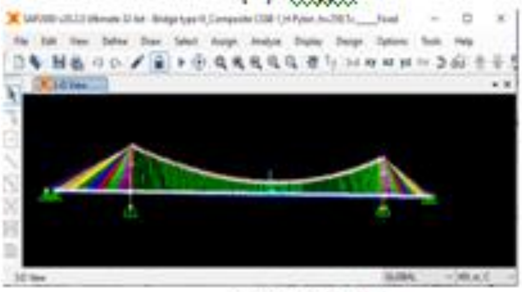
(b):::Type 2



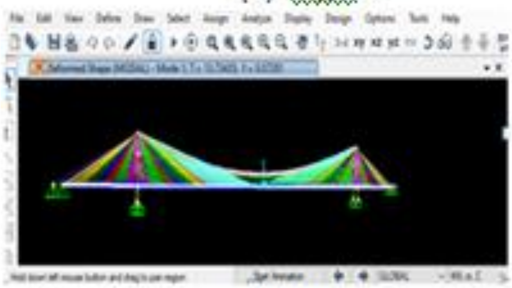
(c):::Type 3



(d):::Type 4



(e):::Type 5

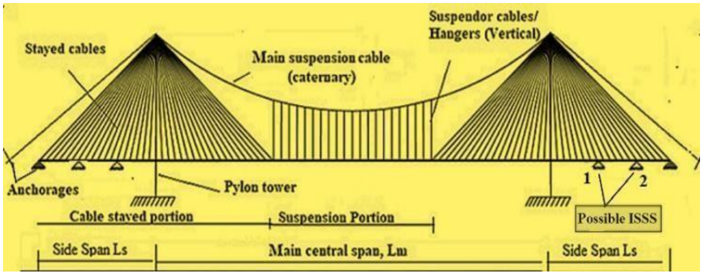


(f):::Type 6

Fig. 5: *Innovation: Different Cable Systems.*

Other Cases: Studied

Keeping all other parameters and specifications are kept unchanged. In addition, model(s) were analyzed by providing one intermediate side span support(abbreviated as ISSS, hereon) at the mid-span of Side spans for Type 1 Bridge to ascertain the effect of Intermediate Side Span Support(s) provided; for BiStayed and Unstayed cases, as depicted in Fig 6 below.



Possible ISSS Cases

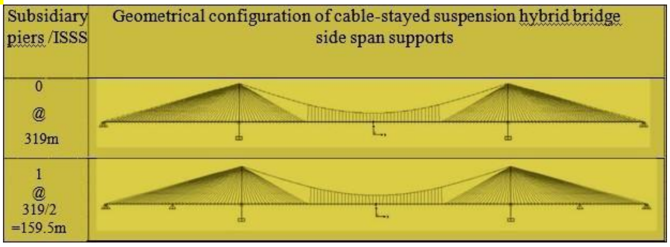


***Fig. 6:** Intermediate Side span Support Case Considered.*

Time History

Seismic Time History details of the Bhuj Earthquake of 30 Jan 2000, recorded at Ahmedabad, having a magnitude of 7.7 on the Ritcher scale, lasting for a duration of approx. 134 sec, with a PGA of nearly 1.04 m/s² is considered for the study (Far Field EQ)

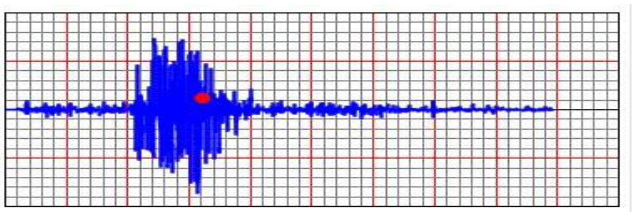


***Fig. 7:** Time History of the Bhuj Earthquake.*

As the recording station used Ahmedabad, it reflects far field EQ data (approx 400 km Southeast of Bhuj). Figure 7 shows the acceleration data graph of the recordings

ANALYSIS & RESULTS

The bridge models generated were analyzed for Modal Time History Analysis (MTHA),

The comparative graphical representation of the modal time periods for different models with innovated cable systems is illustrated in Figure 4 below, depicting Time periods for each case, upto7 modes

Bridge Type	**Time Period for Mode, T sec for H, type Pylon (sag to span ratio of 1:10 ; h=258.986m)**						
	1	2	3	4	5	6	7
Type 1	13.09	9.496	8.597	8.29	7.988	6.89	6.313
Type 2	12.87	10.209	8.363	8.038	7.91	6.654	6.164
Type 3	12.84	9.451	8.823	8.491	7.878	6.633	6.552
Type 4	12.88	8.488	8.295	5.942	4.991	4.802	3.82
Type 5	12.84	10.198	8.329	8.001	7.892	6.654	6.107
Type 6	13.74	8.557	8.364	5.991	5.296	5.276	5.248

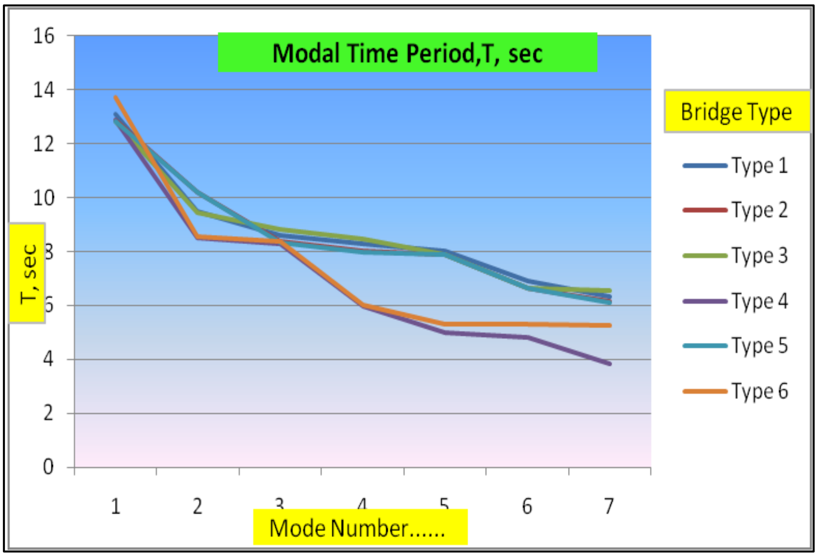
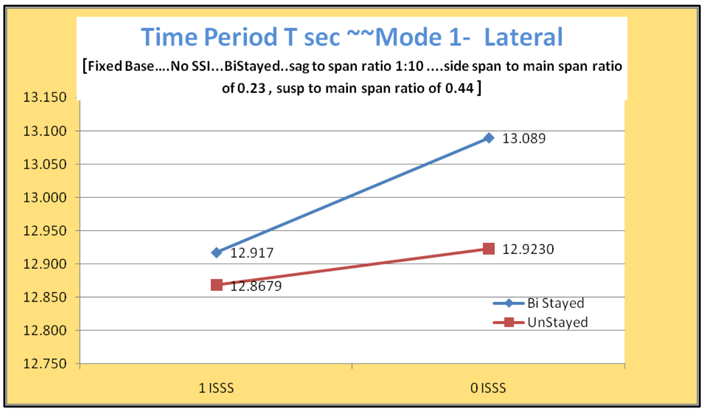


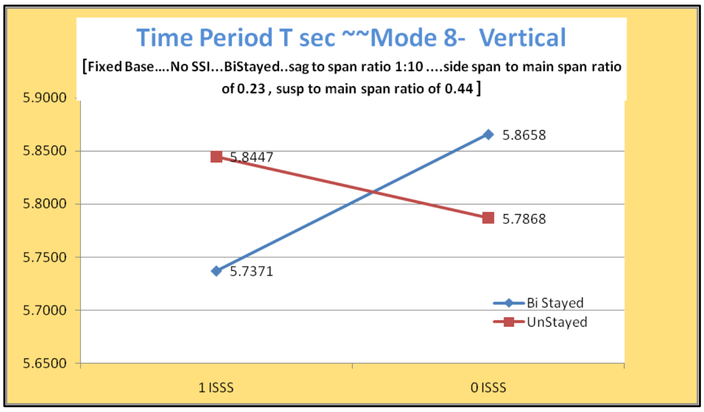
Fig. 7: *Comparison: Time Period (7 Modes), for Diff.*

Type of Bridge (Innovated)

Bridge Type	Pylon top Displacement, δ mm	Axial Force in Main Cable,SS, kN
Type 1	704	130083
Type 2	846	147188
Type 3	286	85606
Type 4	837	146051
Type 5	344	90527
Type 6	900	160173

Table 5: *Comparison: Pylon Top Deflection &Axial Force in Main Cable (SS) for Diff. Type of Bridge (innovated).*





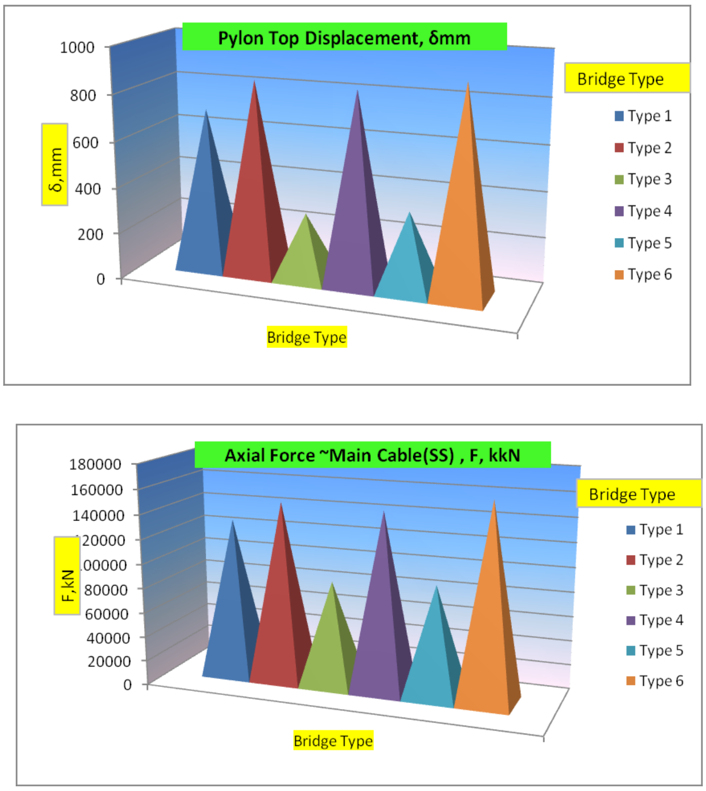


Fig. 8: *Comparison: Pylon Top Deflection &Axial Forcein Main Cable (SS) for Diff. Type of Bridge (innovated).*

Table 6: *Comparison: Time Period for Diff. ISSS.*

Linear Spread α°=0		BiStayed, 1 ISSS	BiStayed, 0 ISSS	Unstayed, 0 ISSS	Unstayed, 1 ISSS
Time period for mode (Fixed based Nossi) Sag to Span ratio 1:10	1	12.917	13.089	12.8679	12.9230
	2	9.566	9.587	9.5675	9.5778
	3	8.154	8.371	7.9157	8.1321
	4	7.783	8.093	7.5646	7.5682
	5	7.507	7.539	7.4817	7.4837
	6	6.843	6.848	6.8480	6.8439
	7	6.130	6.139	6.1352	6.1307
	8	5.7371	5.8658	5.8447	5.7868
	9	5.034	5.107	5.0253	5.0357
	10	5.024	5.024	5.0217	5.0231

The analysis reflects results time history analysis, as

- Illustrated in The table and Figures above, demonstrates the change in time period. The trend observed in the deviation is almost same for all cases Type 6 Bridge gives max modal time period(1st mode) thereby flexibility (up by approx. 4.96% as compared to Type 1.Similarly comparing Time Period for type 6 with Type I1 for the 7th mode reveals an increase in rigidity by approx. 16.87%
- Moreover, for the 4th and 5th mode revealed a lower Time period for all types when compared to Type 1, thereby, reflecting decrease in flexibility towards those (in other words enhanced rigidity towards higher modes) .
- Owing to structural rigidity, Pylon top displacement(deflection) is found minimum in case of Type 3 (CSB),which is conceptually fine; whereas the deflection is on higher Side in bridge types which have suspension portion partly or wholly or along major span i.e. Type 1,2,4,&6.Deflection in type 3 is as low as 59.37 % when compared with Type 1
- The axial force exerted in type 1(CSSHB) is less by 13.15% when compared with type 2(SB). But the axial force increases by 14.34% for type 6 (Combined CSB+SB) in comparison to type 1
- Moreover, illustrated in Fig 9, the provision of intermediate side span supports(ISSS) enhances the stiffness of the bridge system, more peculiarly, predominating and effective in the vertical direction.
- When compared to a bridge system with no intermediate side span support (i.e. ISSS=0); the provision of even one ISSS enhances the stiffness of the system optimally.

DECLARATIONS

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Availability of data and material: Data used in the present research and material are available upon request.

Conflicts of interest/Competing interests: On behalf of all authors, the corresponding author states that there is no conflict of interest.

CONCLUSION

Cable configuration plays an important role in response of a cable supported bridge system Even though, the Pylon top displacement though is least in cable stayed Type of bridge, Cable stayed suspension hybrid bridge is advantageous and should be preferred over conventional cable supported bridges, owing to the fact that it does provide rigidity to the structure, as well as appreciable decrease in cable axial force. Staying in the Bridge system also adds to the structural rigidity and resilience. Provision of Intermediate Side Support adds to the stability of the the bridge system. Even 1 intermediate side span support provides more rigidity in the vertical direction in the deck, due to reduced flexure, axial forces and deflection.

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