Analysis of Long Span Suspension Bridge under Wind Load and Moving Load

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Abstract – *Nowadays suspension bridges are becoming much more common. In the present case suspension bridges are considered for study. SAP2000 software is used for the modelling and analysis. The bridges are varied based on viz 400m, 500m and 600m in span. The suspension bridge is 22m wide as common. The models are analysed for moving load for Class AA tracked and the wind analysis is carried out for Indian Standard code and ASCE code. The results are tabulated and comparison is made using following parameters viz modal time period, frequency, deck deflection, Axial forces in cables and many.*

The results are extracted, and conclusions are drawn such from the modal analysis it can be concluded that, time period and frequency is dependent on over all span of the structure. And frequency is found to be high in case of short span bridges. Due to long span, the time period in mode 1 is found to be high in case of bridge compared to buildings. From moving load analysis, it can be concluded that, deformation of the deck varies from pylon to mid span due to variation of length of the suspender. From cable force results it can be concluded that, suspender will have less tensile force compared to sag cables, this is because, all the tensile forces in sag cables are transferred to pylon in the form of compressive forces. From the wind load analysis, it can be concluded that, the wind load will govern perpendicular to the direction of the bridge span.

***Key Words*: Suspension Bridge, Cables, Moving load, Wind load, SAP 2000 etc**…

1. INTRODUCTION

The principle of carrying a load by suspending it to a rope or cable has been utilized since ancient times. But it was not until 1823 that the first permanent cable supported bridge was built in Geneva. Even though the span of the structures erected at the time was of modest dimensions, it was the start of a big impressive leap in bridge design. Cable suspended bridges are innovative structures that are both old and new in concept when engineering started experimenting with the use of cables in bridge, they met little success due to the fact that the statics were not fully understood and that unsuitable materials were used. Nowadays, in the new technical age with a well-developed infrastructure, computer communication information is easily available, cable supported bridges are becoming much more common Existing cable supported bridges provide useful data regarding design, fabrication erection and maintenance of new systems. As bridges are being well built, experience on the subject is being gained, and longer spans are being reached.

1.1 Suspension Bridge:

A suspension bridge is composed of a roadway (sometimes called a deck) suspended by steel cables. The four towers hold up the steel cables which in turn hold up the roadway This type of bridge is used where a wide gap /distance is to be crossed and typical examples are the Golden Gate Suspension Bridge in San Francisco, the Akashi Kaikyo Suspension Bridge in Japan.

1.2 Objectives

The objectives of the study are listed below.

- To model and analyse the suspension bridge for three different spans using SAP 2000.
- To understand the behaviour of a suspension bridge subjected to wind and moving loads.
- To study the effect of increase in span on the response characteristics of different spans.
- To explore and understand the variation of key results like pylon deflection, axial stresses in pylon, forces in cables, deck deflection, due to static loads and wind loads.
- To determine the best suitable configuration for specific span length based on the results obtained in wind and moving load analysis.

1.3 Methodology

The methodology adopted are as given below

- Initially the bridge models for 3 different spans 400m, 500m and 600m is modelled using SAP2000.
- Further the models are loaded with vehicular and self-weight.
- And then Wind analysis for 2 different codes such as IS and ASCE codes are studied.
- The three models are analysed using moving loads to find the maximum deck deflection.

- Also, key responses of the systems observed and their limits with respect to code provisions are quantified and the results are discussed.

2. MODELLING

This chapter includes the modelling of bridge structure. This bridge is modelled with concrete structural elements. The models are further studied different spans and pylon height, here are the types of model shown for the easy assessment.

Modal types:

M1-Suspension Bridge1-Span 400m.

M2-Suspension Bridge2- Span 500m.

M3-Suspension Bridge3-Span 600m.

The material property is an important aspect to to be defined while modelling a structure. Both the steel and concrete are having some property, which has to be specified as below.

Young's Modulus (Steel), Es = 2,10,000Mpa

Young's Modulus (Concrete), Ec = 38730Mpa

Characteristic compressive strength of concrete, fck = 60Mpa

Yield stress for steel, fy = 345Mpa

LONG SPAN BRIDGE DATA:

Left span length: 150 Number of division: 15

Middle span length: 600 Number of division: 60

Right span length: 150 Number of division: 15

Deck width: 22m Minimum middle Sag:20

Column height H1:50 Column height H2:125

Fig 1 shows 3D View of Suspension Bridge.

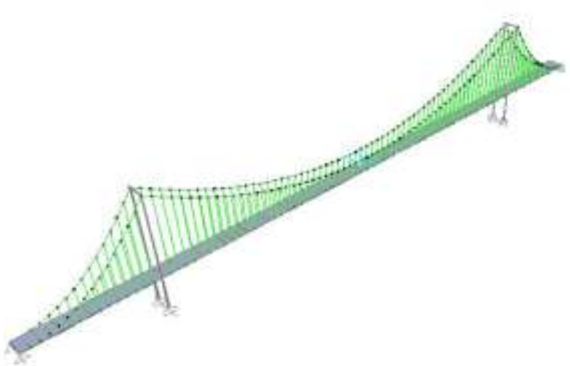

Fig.1 3 D View of suspension Bridge

3. ANALYSIS

SAP2000 software is used for analysis of suspension bridge. All material properties are defined as specified. Load Patterns such as dead load, moving load, Wind load along X and Y direction, and their combinations are assigned as per IRC. Analysis of cable bridge for moving load and wind load are carried out for obtaining deflection, axial forces in cables, pylon displacement and pylon forces.

4. RESULTS AND DISCUSSIONS

In this section, results obtained for modal analysis, moving load analysis and wind load analysis has been carried out. Key responses from all type of analysis has been presented in the form of tables and graphs.

Table 1 Mode vs. Time Period /Frequency

	Modal Analysis - Time Period (Seconds) & Frequecy(Hz.)		
Mode	**Span 400 m**	**Span 500 m**	**Span 600 m**
1	20.47Sec	20.88Sec	21.29Sec
	0.049Hz	0.048Hz	0.047Hz
2	20.33	20.74	20.67
	0.049	0.048	0.048
3	14.69	16.67	18.59
	0.068	0.06	0.054
4	11.47	12.98	14.7
	0.087	0.077	0.068
5	9.06	11.09	12.91
	0.11	0.09	0.077
6	8.65	9.78	10.52
	0.116	0.102	0.095
7	8.53	8.37	9.24
	0.117	0.119	0.108
8	8.21	8.34	8.36
	0.122	0.12	0.12
9	7.09	8.3	8.35
	0.141	0.121	0.12
10	5.63	6.67	7.52
	0.177	0.15	0.133
11	5.31	6	6.64
	0.188	0.167	0.151
12	4.8	5.12	5.7
	0.208	0.195	0.175

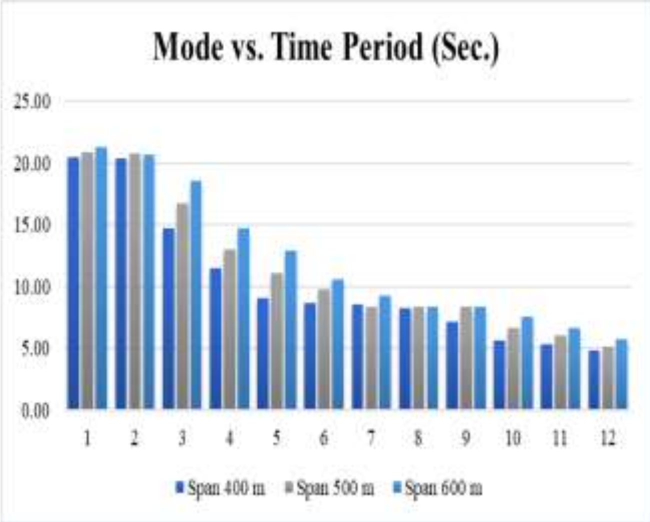

Fig. 2 Mode vs. Time Period

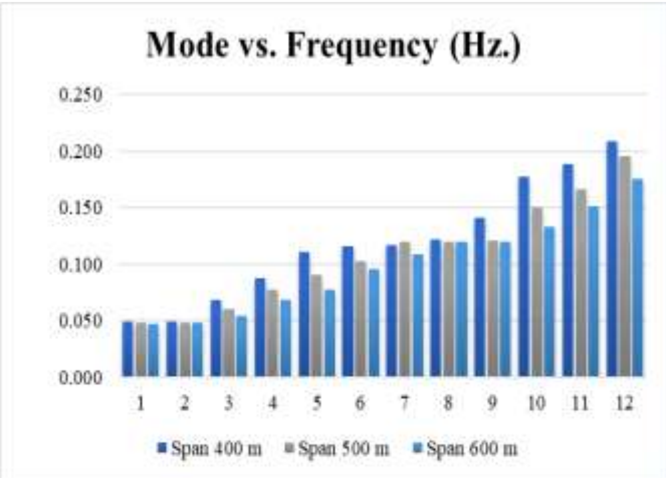

Fig. 3 Mode vs. Frequency

From Table 1 it can be observed that, time period is more in Mode 1 and has a reducing trend in higher modes for bridges of all spans. In Mode 1, suspension bridge with span of 600 m is having higher time period comparatively to 400 m and 500 m i.e., 4% and 1.96% respectively. In higher mode, the percentage increase is found to be significant in 600 m span i.e., 18.75% in (Mode 12) with respect to 400 m.

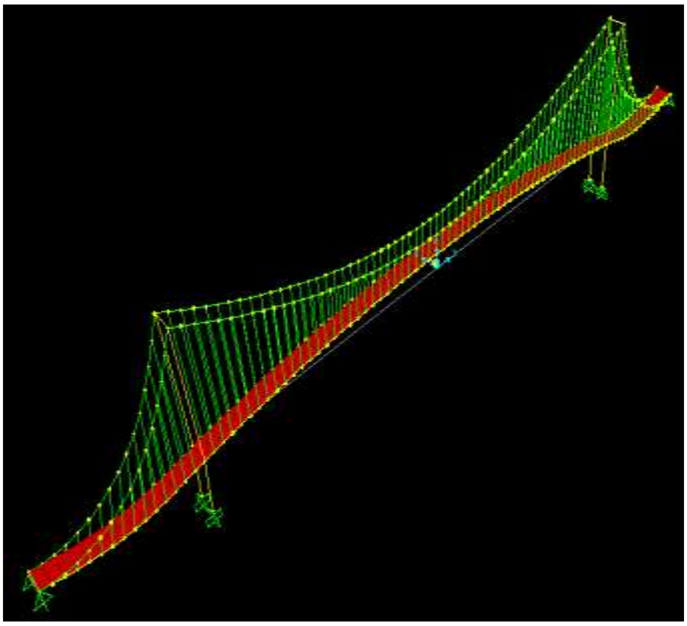

Fig. 4 Deformed Shape at Mode 1 (3D)

From Table 1 and Fig. 4 it is clear that, maximum frequency is found to be bridge with 400 m span for all modes and it found that in Mode 12, the difference in frequencies with respect to 500 and 600 m is found to be 6.25% and 15.8% less respectively. Fig. 5 and Fig. 6 shows the deformed shape of the suspension bridge in mode 1 in 3D and Plan respectively which indicates the translation type of displacement.

4.1 Moving Load Analysis

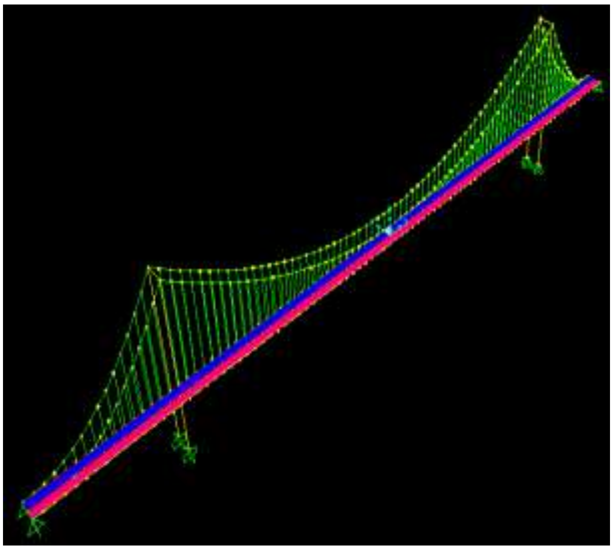

Fig. 5 3D Picture of 600 m Suspension Bridge with 2 lane Road

Moving load analysis has been carried for IRC_AA Tracked wheel load. The width of each lane is considered as 7.5 m. The Fig. 5 and two lanes modeled on bridge deck in 3D and Plan respectively. In this section, key responses like, deck deflection, cable forces in suspenders and sag cables are presented.

4.2 Deck Deflection

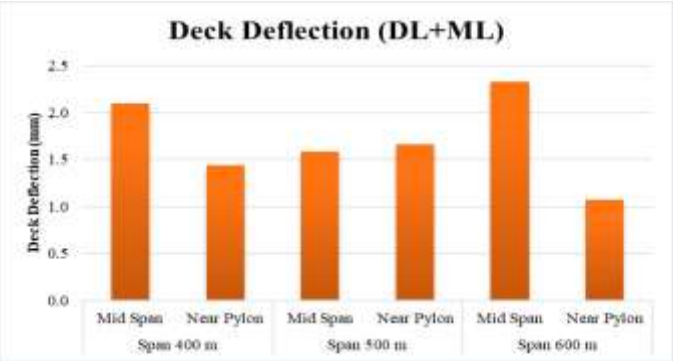

Fig. 6 Deck Deflection due to Moving Loads

Deck deflection is measured at two locations, one at the midspan and second near the pylon end. it is observed that, maximum deflection is found in mid span of 600 m suspension bridge which is 2.3 m. Near pylon, 1.7 m deflection is found for 500 m span suspension bridge. Therefore, with the increase in span, the maximum percentage of deflection is found to increase up to 43% and 9.5 % in comparison with 500 m and 400 m span suspension bridge respectively. Figure 6 show the variation of deck deflection of all the bridges at midspan and near the pylon. And typical deformation of suspension bridge due to moving loads.

4.3 Axial Forces Cables

Maximum axial forces in vertical suspenders and sag cables is presented in Table 2 and respectively.

Table 2 Axial Forces in Suspenders

	Moving Load - Axial Load in Suspenders (kN) & Axial Load in Sag cables (kN)					
	Span 400 m		Span 500 m		Span 600 m	
	Mid Span	Near Pylon	Mid Span	Near Pylon	Mid Span	Near Pylon
Axial Force in suspenders	32623	36703	23760	39534	4587	33016
Axial Force in sag cables	170984	191556	227890	236485	266094	287304

From the Table 2 it is observed that, maximum cable force is found to be in 500 m span bridge i.e., 39534 kN and minimum force at midspan of 600 m bridge which is found to be only 4587 kN. There is an increase in 7.1% and decrease in 10.04% of axial forces in suspender located near the pylon is observed in bridge of 500 m and 600 m respectively in comparison with 400 m span bridge. The variation in suspenders is indicated in the form of graph in Fig. 7.

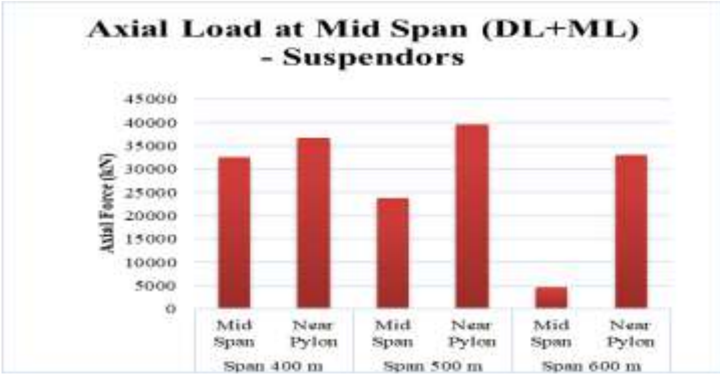

Fig. 7 Axial Forces in Suspenders

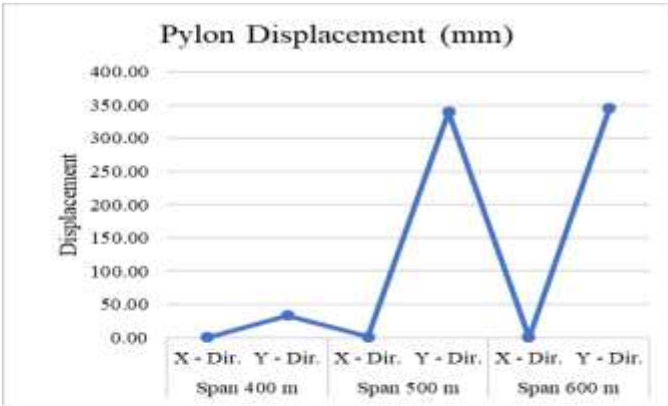

Fig.8 Pylon Displacement (ASCE 7 - 02)

4.4 Pylon displacement

Table 3 Pylon Displacement (ASCE 7 - 02)

Wind Load - Pylon Displacement (ASCE 7 - 02)					
Span 400 m		Span 500 m		Span 600 m	
X - Dir.	Y - Dir.	X - Dir.	Y - Dir.	X - Dir.	Y - Dir.
0.48	33.10	1.18	339.60	0.51	346.00

Pylon displacements is found to be significantly increased with the increase in span from 400 to 500 m. Also, for all spans of the bridges it can be observed that, displacements are higher along Y direction than in X direction. Maximum pylon displacement is found to be in 600 m span of about only 2% increase. The values and variation of the pylon deflection is shown in Table 3 and Fig. 9 respectively.

The variation of Pylon displacements and variation simlar to ASCE code is represented Fig. 9 as per IS 875 Part 3. Simiar, observations are made in this code, but the maximum pylon displacement is found to be 519 mm.

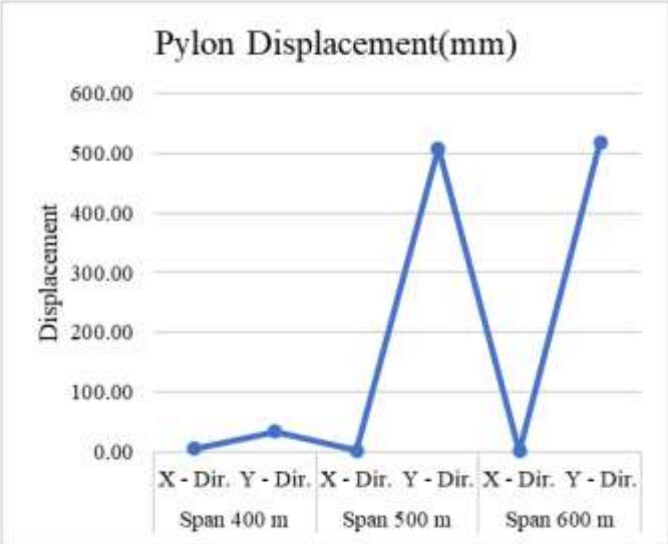

Fig. 9 Pylon Displacement (IS 875 – Part 3)

Table 4 Wind Load - Pylon Reaction

Reaction on pylon is calculated as per codal provisions and presented in table 4.

Wind Load - Pylon Reaction (DL+WY) (kN)					
Span 400 m		**Span 500 m**		**Span 600 m**	
ASCE 7 - 02	**IS 875 - Part 3**	**ASCE 7 - 02**	**IS 875 - Part 3**	**ASCE 7 – 02**	**IS 875 - Part 3**
171889	300903	347904	345552	395856	394655

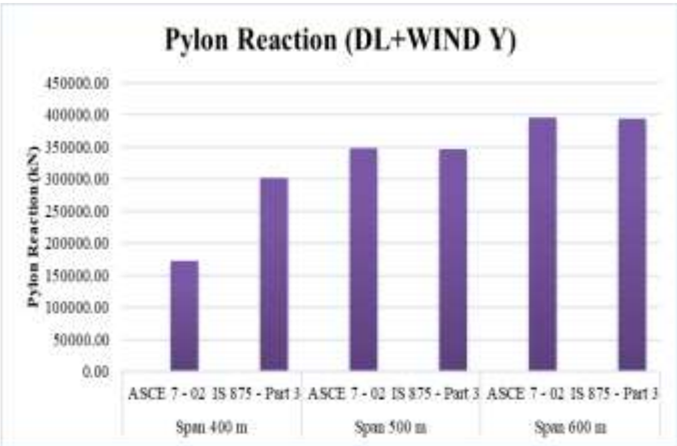

Fig. 10 Wind Load - Pylon Reaction

In this section pylon reaction and moments are extracted and present in Table six respectively for dead load and wind load along Y. It is clear from the results that, maximum pylon force and moment is found to be in span 600 m ASCE 7 – 02 code. And also it is observed that, there is no significant variation of pylon forces between two codes.

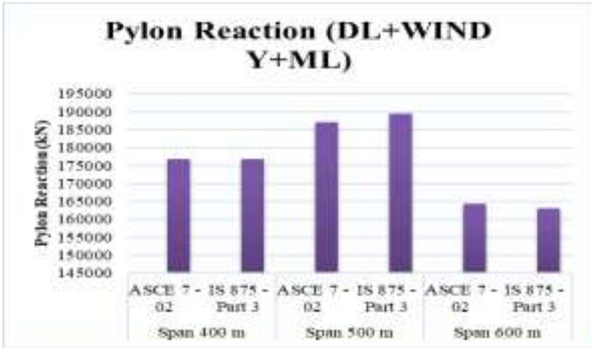

Fig. 11 Pylon Reactions (DL+MOVING LOAD + WIND LOAD)

Fig. 11 represents the pylon reactions for the combinations of dead load, moving load and wind load. From the results it can be observed that, there is significant reduction in pylon reaction (upto 50%) due to additional moving load on the suspension bridge.

5. CONCLUSIONS

Based on the results and discussions following conclusions are listed below.

- From the modal analysis it can be concluded that, time period and frequency is dependent on over all span of the structure. And frequency is found to be high in case of short span bridges. Due to long span, the time period in mode 1 is found to be high in case of bridge compared to buildings.
- From moving load analysis it can be concluded that, deformation of the deck varies from pylon to mid sap due to variation of length of the suspender.
- From cable force results it can be concluded that, suspender will have less tensile force compared to sag cables, this is because, all the tensile forces in sag cables are transferred to pylon in the form of compressive forces.
- From the wind load analysis it can be concluded that, the wind load will govern perpendicular to the direction of the bridge span.
- Compare to ASCE code IS code shown an increased response with respect pylon deflection, but all other response are found to be similar.
- From the results of combination of moving load along with dead load and wind loads, it can be concluded that, moving load will act as count action to wind loads, thereby reducing the pylon reactions and moments developed due to wind loads.

5.1 Scope of Future Work

- The present study can be extended with the incorporation of dampers to reduce the vibrations and overall deformations.
- The present study can be done for different shapes of pylon and different heights.
- Soil structure interaction can be studied.

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