Study on Structural Responses of Long-Span Suspension Bridge with External Anchoarge System Under Unusual Winds

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Abstract*—Myanmar is a coastline country and over one-third of its boundary line contacts with the Bay of Bengal and the Andaman Sea. So, our country suffers many unusual storms which come from these bay and sea in every year. Because of these storms, many lives and infrastructures are destroyed to a large extent. And so, a lot of structures in coastline areas are necessary to design which can withstand these unusual winds. Therefore, this study emphasizes on the structural responses of long-span suspension bridge under three different unusual wind speeds. The proposed bridge is modeled with external anchorage system and the specifications used in the proposed bridge is used with American Association of State Highway and Transportation Officials (AASHTO), Bridge Rules of Government of India and Japan Road Association (JRA). The proposed bridge is analyzed and designed with Modeling, Integrated Design and Analysis Software (MIDAS). Static analysis is used on the proposed models to get the displacement, axial force, torsion, shear, moment and support reaction due to static load. Moving load analysis, also called influence line analysis, is used for the vehicle loading; HS 25 and Modified Meter Gauge Train. This study is mainly emphasized on the responses of the proposed structure for wind speeds of 110 mph, 130 mph and 155 mph which is based on the categories of Saffir-Simpson Hurricane Wind Scale. By conducting this study, it is expected to fulfill the knowledge of the anchorage system of the suspension bridge and can investigate the responses under unusual wind speeds.

Keywords*—*long-span suspension bridge; AASHTO; Bridge Rules; JRA; MIDAS; Saffir-Simpson

I. INTRODUCTION

Suspension bridges capture the imagination of people everywhere. With their tall towers, slender cables, and tremendous spans, they appear as ethereal giants stretching out to join together opposite shores. Sometimes they are short and stocky and seem to be guardians and protectors of their domain. Other times, they are so long and slender that they seem to be fragile and easily moved. Whatever their visual image, people react to them and remember how they felt when they first saw them. With cables constructed from very high strength steel loaded in direct tension as their primary load carrying members, suspension bridges are ideally suited to longer spans, and this is therefore the primary application for this type of structure. Today, the suspension bridge is most suitable type for very long-span bridge and actually represents 20 or more of all the longest span bridges in the world. A suspension bridge consists of cables, traffic carrying deck structure or stiffening girder, towers and anchorages. The function of a suspension bridge is that parabolic-shaped main cables suspended from the tops of the two towers support the traffic carrying deck which exists on the stiffening girder by hanging the suspenders and transfer their loading by direct tension force to the supporting towers and anchorages. Loading of suspension bridge may be come from its own weight, traffic live load and other environmental loads such as temperature, wind and earthquake loads, etc. Among the environmental loads, in the analysis and design of suspension bridge, aerodynamic and seismic performance for the stability of the bridge must be considered. This study focus on the structural response of the long-span suspension bridge and wind performance of the proposed bridge with external-anchored types is investigated.

II. STRUCTURAL COMPONENTS AND METHODOLOGY

A. *Structural Components*

For the vast majority of suspension bridges, it can be divided into four main components.

- The deck (or stiffening girder): The deck is the structural element subjected to the major part of the external load on a cable supported bridge. This is because the total traffic load is applied directly to the deck, and in most cases both the dead load and the wind area are larger for the deck than for the cable system. Immediately the deck must be able to transfer the load locally whereas it will receive strong decisive assistance from the cable system in the global transmission of the (vertical) load to the supporting points at the main piers. In modern practice, the stiffening truss will be made as a space truss comprising four chords connected by four diagonal bracings: two vertical and two horizontal. On the other hand, stiffening trusses is made up of vertical main trusses along the longitudinal direction, transverse trusses at the cross-section, floor beams and stringers and horizontal lateral bracing at the horizontal direction.
- The cable system: The suspension system comprises a parabolic main cable and vertical hanger cables connecting the deck to the main cable. A group of parallel-wire bundled cables support stiffening girders/trusses by hanger

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ropes and transfer loads to towers. The basic element for all cables to be found in modern suspension bridges is the steel wire characterized by a considerably larger tensile strength than that of ordinary structural steel. In most cases, the steel wire is of cylindrical shape with a diameter between 3 and 7 mm. Typically, a wire with a diameter of 5–5.5 mm is used in the main cables of suspension bridges. In the transverse direction of the bridge, a number of different solutions for the arrangement of the cable systems can be found such as one vertical cable plane, inclined cable planes, two vertical cable planes, two vertical cable planes between three separate traffic areas, more than two vertical cable planes.

- The pylons (or towers): In principle, the pylon is a tower structure, but in contrast to a free-standing tower, where the moment induced by the horizontal loading (drag) from wind dominates the design, the most decisive load on a regular pylon will be the axial force originating from the vertical components of the forces in the cables attached to the pylon. These intermediate vertical structures support main cables and then transfer bridge loads to foundations. The pylons or towers of a suspension may be made up of concrete, steel or composite material.
- The anchor blocks (or anchor piers): The anchored system in a suspension bridge can be divided into self anchored and external anchored systems (earth anchored systems). In the self-anchored system, the horizontal component of the cable force in the anchor cable is transferred as compression in the deck, whereas the vertical component is taken by the anchor pier. In the earth anchored systems, both the vertical and the horizontal components of the cable force are transferred to the anchor block. In principle, both earth anchoring and self-anchoring can be applied in suspension bridges.

B. Methodology

In this study, the proposed bridge is modeled with external anchored type and analyzed and designed by using Modeling, Integrated Design and Analysis Software (MIDAS) with American Association of State Highway and Transportation Officials (AASHTO) Standard, Bridge Rules of Government of India and Japan Road Association (JRA). As the general, linear responses, moving load responses and other design considerations constitute the essence of the study on the structural responses of the bridges. In longer spans, the deflections may be substantial, so the design of the proposed structure should be emphasizes on the deflection of the bridge and checked with the JRA limitations. Moreover, the final design members of the proposed bridge are checked with AASHTO specifications.

III. Design Specifications and Modeling

To be developed the accurate methodologies that can cause a thorough understanding and a realistic prediction of the structural responses of a bridge, it is very important that the proposed bridge must be modelled within the range of the tentative design specifications. Therefore, this paper is taken into account the tentative design specifications and the proposed design is modelled within these structural limits. In deciding the overall configuration of the bridge, the following specifications must be taken into account.

A. Design Specificaitons

The side span length should preferably not exceed around 40% of the main span in order to provide an effective restraint to the tower top. However, the side span should not be less than 25% to 30% of the main span length to avoid an excessively high imbalance of cable tension at the towers. For conceptual designs, the height of suspension bridge towers above the deck depend on the sag-to-span ratio which can vary from about 1:8 to 1:12. Stiffening-truss depths vary from 1/60 to 1/170 the span. According to these specifications, in the proposed bridge, side span length is 40% of main span length. Sag-to-span ration of 1:11.4 is used in this bridge. The minimum depth of the stiffening truss of the proposed bridge models is 1/120 of the span.

B. Modeling

According to the design specifications, the design data used in proposed suspension bridge are shown in Table I. The following material properties are used in the external anchorage model of the proposed bridge.

For cable,

- Modulus of Elasticity = 29731 ksi (2.05 x 10^8 kN/m^2)
- Tensile strength = 242.15 ksi (1670 MPa)
- Poisson ratio, v = 0.3
- Thermal coefficient = 1.2 x 10^{-5} per °C
- Weight density = 84 kN/m^3

TABLE I. Design Data used in Proposed Bridge

Name	Description
Bridge type	Suspension bridge
Total length	2160 m
Span arrangement	3-spans arrangement
Main span	1200 m
Side span	480 m (each)
Pylon height	180 m
Pylon type	Truss type
Main cable plane	Two vertical planes
Number of hangers in main span	60@20 m
Number of hangers in side span	24@20 m
Main cable diameter	1.5 m
Hanger diameter	0.5 m
Girder type	Warren truss type
Girder height	10 m
Girder width	30 m, 4 m for each lane and 1 m for sidewalk
Anchorage Type	External anchorage
Traffic Lane	HS 25, six lanes
	Modified Meter Gauge Train, one lane

The following section properties of the members of the proposed bridge model are the trial and final sections of the members as shown in Table II.

For structural steel, according to ASTM, A 572-50 steel,

- Modulus of Elasticity = 2.00 x 10^8 kN/m^2
- Tensile Strength, f_u = 65 ksi (4.48 x 10^5 kN/m^2)
- Yield Strength, f_y = 50 ksi (3.45 x 10^5 kN/m^2)
- Poisson ratio, v = 0.3
- Thermal coefficient = 1.17x 10^{-5} per °C
- Weight density = 77.09 kN/m^3

For concrete,

- Modulus of Elasticity = 3150 ksi (2.51 x 10^7 kN/m^2)
- Concrete Strength, f_c' = 4 ksi (2.75 x 10^4 kN/m^2)
- Poisson ratio, v = 0.2
- Thermal coefficient = 1.17x 10^{-5} per °C
- Weight density = 23.56 kN/m^3

The following Fig. 1 is the finite element model and Fig. 2 is the 3D view and node number of support conditions of the proposed long-span suspension bridge with external anchorage system.

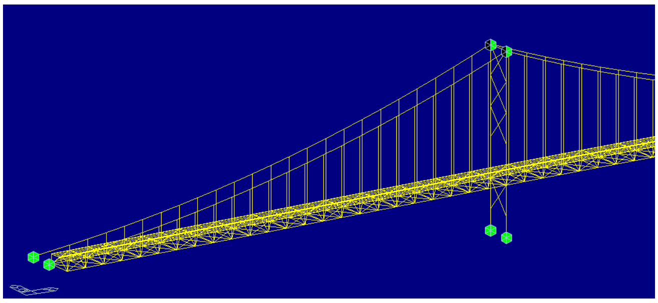

Fig. 1. Finite element model of the proposed long-span suspension bridge with external anchorage system

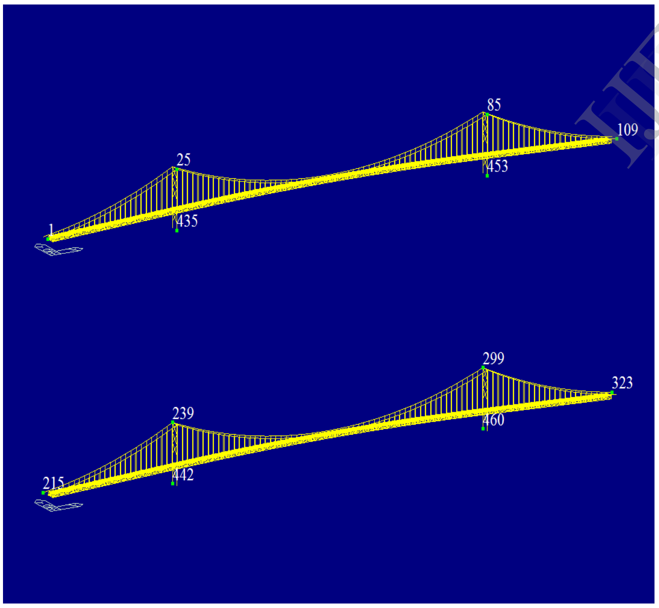

Fig. 2. 3D view and node number of support conditions of the proposed long-span suspension bridge with external anchorage system

TABLE II. SECTION PROPERTIES OF PROPOSED MODEL

Member		Trial Section	Final Section
Main Cable		1 m dia	1 m dia
Hanger		0.25 m dia	0.25 m dia
Girder	Vertical member	W 12 x 190	W 12 x 190
	Vertical main truss	W 12 x 190	W 12 x 190
	Traverse truss	W 12 x 190	W 12 x 190
	Floor beam	W 14 x 211	W 27 x 281
	Stringer	W 14 x 211	W 14 x 211
	Lower horizontal girder	W 14 x 211	W 14 x 211
	Horizontal lateral bracing	W 10 x 68	W 10 x 68
Tower	Vertical member	1.5 m x 1.0 m	2.5 m x 2.0 m
	Bracing	1.5 m x 1.0 m	2.5 m x 2.0 m

IV. DESIGN LOADS AND ALLOWABLE LIMITATIONS

The applied loads on the proposed bridge models are self weight, dead load of structural members, sidewalks, traffic loads, thermal force, wind load and seismic load.

Under these load conditions, various responses are appeared in the proposed structure. The structural responses due to these loads should be checked with the respective allowable limitations.

A. *Design Loads*

The applied loads on the proposed bridge models are dead load due to self weight and structural materials, live load due to sidewalks and traffic loads, thermal force, wind load and seismic load.

1) Dead Load: In the dead load due to self weight and structural materials, the following loads are considered.

a) For cables: unit weight = 84 kN/m^3

b) For girder and tower: unit weight = 77.09 kN/m^3

c) For concrete slab: unit weight = 23.56 kN/m^3

d) For Railway rail: unit weight = 0.44 kN/m

e) For Guardrail: unit weight = 2.92 kN/m

f) For Asphalt: 2 in thick = 0.86 kN/m^2

2) Live Load: In the live load of the proposed bridge models,

a) For Sidewalk loading: P = 1.52 kN/m^2

b) For highway loading: HS 25

c) For railway loading: Modified Meter Gauge Train

3) Thermal Load: The range of temperature change in this structure is considered as follows.

a) For axial elongation: temperature change = 16°F

b) From top to bottom: temperature differential = 10°F *c) From side to side:* temperature differential = 10°F

4) Pretension Load: The pretension forces of main cables and hangers can be attained from the reaction of the equilibrium deck system.

a) For hanger: Pretension = 2200 kN

b) For main cable: Pretension = 12880 kN

5) Wind Load: In wind load consideration, three kinds of wind speeds according to Saffir-Simpson Hurricane Wind Scale as displayed in Table III. These wind speeds are the maximum limit of hurricane category 2 (110 mph), category 3 (130 mph) and category 4 (155 mph).

From these wind speeds, design wind speeds for different structural members can be calculated in Table IV by using (1).

$$V = k_1 V_{10} \tag{1}$$

In which,

V = Design wind speed (m/s)

k_1 = Modified coefficient according to the change of wind height

V_{10} = basic wind speed appearing once in a hundred years

From the design wind speeds, wind load for different structural members can be calculated in Table V by using (2).

$$P = \frac{1}{2} \rho V^2 C_d G A_n \tag{2}$$

In which,

P = Wind load (N/m)

TABLE III. SAFFIR-SIMPSON HURRICANE WIND SCALE

Scale Number (Category)	Sustained Wind (mph)
1	74 - 95
2	96 - 110
T	111 - 130
4	131 - 155
5	> 155

TABLE IV. DESIGN WIND SPEED, V

Structural Component		k_1	V_{10} (m/s)	V (m/s)
For 110 mph	Girder	0.36	49.17	17.7
	Tower (windward)	2.489	49.17	122.38
	Tower (leeward)	2.489	49.17	122.38
For 130 mph	Girder	0.36	58.12	20.92
	Tower (windward)	2.489	58.12	144.66
	Tower (leeward)	2.489	58.12	144.66
For 155 mph	Girder	0.36	69.29	24.94
	Tower (windward)	2.489	69.29	172.46
	Tower (leeward)	2.489	69.29	172.46

TABLE V. WIND LOAD, P

Structural Component		Factor	ρ (kg/m^3)	V^2	C_d	G	A_n (m^2/m)	P (kN/m)
For 110 mph	Girder	0.5	1.2	18^2	1.8	1.31	10	4
	Tower (wind-ward)	0.5	1.2	122^2	1.6	1.31	2.5	47
	Tower (lee-ward)	0.5	1.2	122^2	0.8	1.31	2.5	24
For 130 mph	Girder	0.5	1.2	21^2	1.8	1.31	10	6
	Tower (wind-ward)	0.5	1.2	145^2	1.6	1.31	2.5	66
	Tower (lee-ward)	0.5	1.2	145^2	0.8	1.31	2.5	33
For 155 mph	Girder	0.5	1.2	25^2	1.8	1.31	10	9
	Tower (wind-ward)	0.5	1.2	172^2	1.6	1.31	2.5	94
	Tower (lee-ward)	0.5	1.2	172^2	0.8	1.31	2.5	47

ρ = Air density (kg/m^3) = 1.2 kg/m^3

V = Design wind speed (m/s)

C_d = Drag force coefficient

G = Gust response factor = 1.31

A_n = Effective project area (m^2/m)

B. *Allowable Limitations*

The deflection of main girders, floor beams and stringers of a steel bridge due to the live load (excluding impact) shall be less than the value given in Table VI.

In Table VI,

L = Span (m)

According to AASHTO-LRFD, combined stresses of bending and shear must be as in (3).

TABLE VI. ALLOWABLE DEFLECTION

Structural type of bridge / Type of girder			Simply supported girder and continuous girder	Cantilever span of cantilever girder
Plate girder bridge	Plate girder bridge with reinforced concrete slabs	L ≤ 10	L/ 2000	L / 1200
		10 < L ≤ 40	L / (20000/L)	L / (12000/L)
		40 < L	L / 500	L / 300
	Plate girder bridge with other types of floor deck		L / 500	L / 300
Suspension bridge			L / 350	
Cable Stayed bridge			L / 400	
Other types of bridge			L / 600	L / 400

$$\left(\frac{f_b}{F_b}\right)^2 + \left(\frac{f_v}{F_v}\right)^2 \leq 1.2 \qquad (3)$$

In which,

F_b = 0.55 F_y = Allowable bending stress
f_b = M / Z = Maximum bending stress
M = Maximum moment
Z = Section modulus
F_v = 0.33 F_y = Allowable shear stress
f_v = V / A_w= Maximum shear stress
V = Maximum shear
A_w = Area of web

V. ANALYSIS RESULTS OF PROPOSED BRIDGE

In the analysis results of the proposed bridge, this study mainly focus on the displacement and structural forces such as axial, shear, torsion, moment of girder members of the proposed suspension bridge due to self weight, moving load analysis and wind load and checking of deflections and girder member sizes.

A. *Analysis Results due to Self Weight*

The following figures are the displacements and structural forces of girder members along the bridge length. Fig. 3 is the displacement about X-axis along the bridge length and Fig. 4 is the displacement about Y-axis and Fig. 5 is the displacement about Z-axis. Fig. 6 shows axial force along the bridge length, Fig. 7 and Fig. 8 show shear about Y-axis and Z-axis along the bridge length, Fig. 9 shows torsion along the bridge length, Fig. 10 and Fig. 11 show moment about Y-axis and Z-axis along the bridge length.

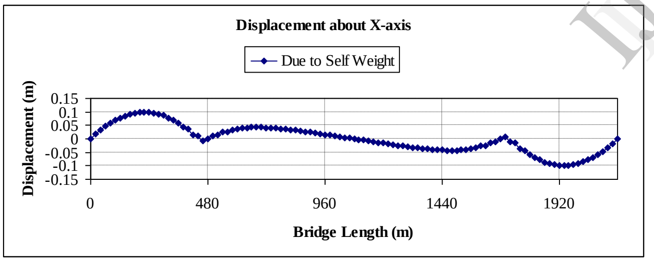

Fig. 3. Girder displacement about X-axis of external anchorage model

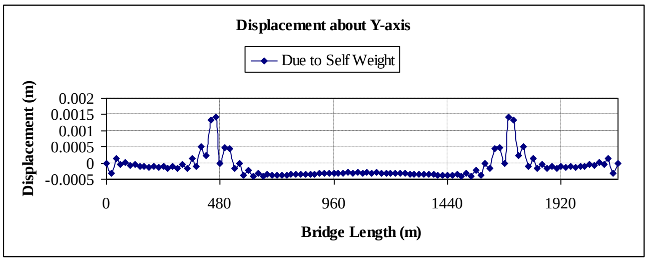

Fig. 4. Girder displacement about Y-axis of external anchorage model

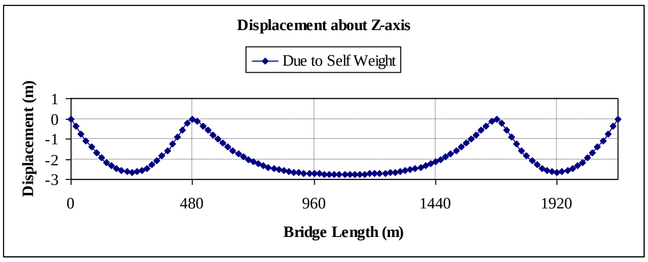

Fig. 5. Girder displacement about Z-axis of external anchorage model

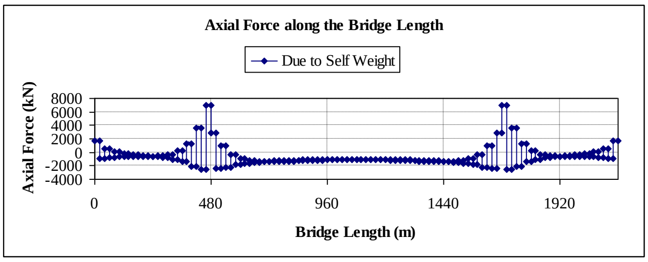

Fig. 6. Axial force of external anchorage system

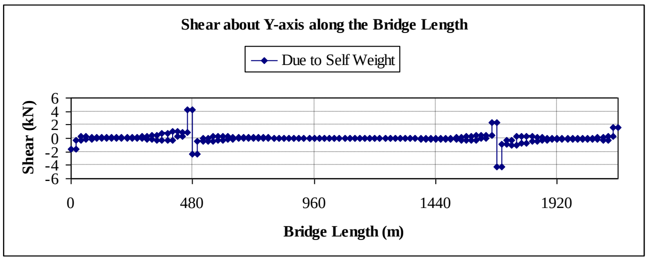

Fig. 7. Shear about Y-axis of external anchorage system

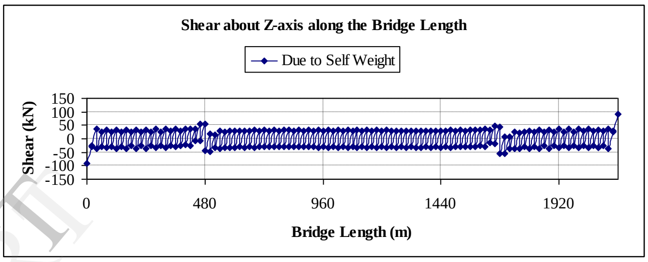

Fig. 8. Shear about Z-axis of external anchorage system

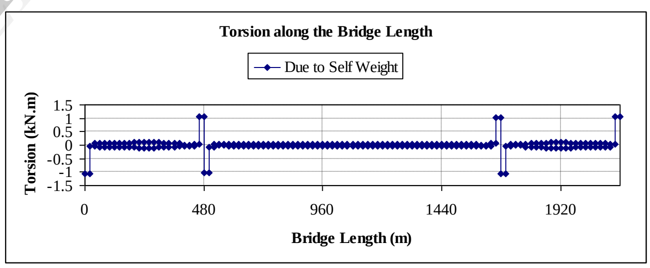

Fig. 9. Torsion along the bridge length of external anchorage system

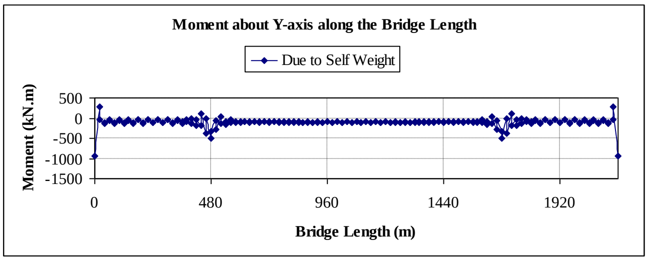

Fig. 10. Moment about Y-axis of external anchorage system

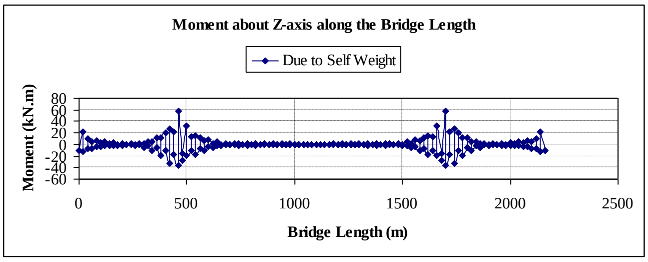

Fig. 11. Moment about Z-axis of external anchorage system

B. Analysis Results due to Moving Load Analysis

The following figures are the displacements and structural forces of girder members due to moving load analysis. In this study, moving load analysis is based on influence line analysis. Fig. 12 displays the displacement about X-axis, Fig. 13 displays the displacement about Y-axis, and Fig. 14 displays the displays the displacement about Z-axis along the bridge length. Axial forces, shear about Y-axis, shear about Z-axis, torsion, moment about Y-axis, moment about Z-axis due to moving load analysis are shown in Fig. 15, Fig. 16, Fig. 17, Fig. 18, Fig. 19 and Fig. 20, respectively.

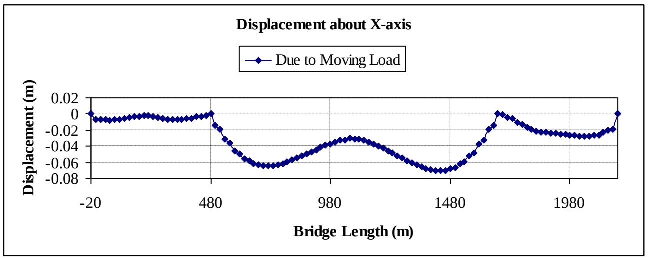

Fig. 12. Girder displacement about X-axis of external anchorage model

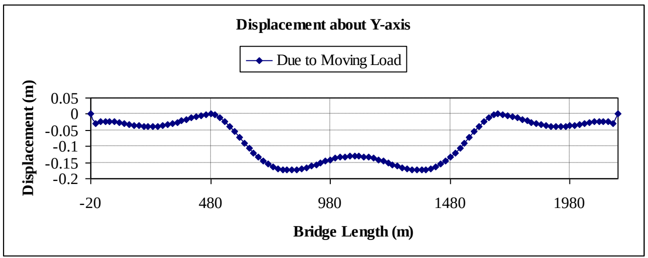

Fig. 13. Girder displacement about Y-axis of external anchorage model

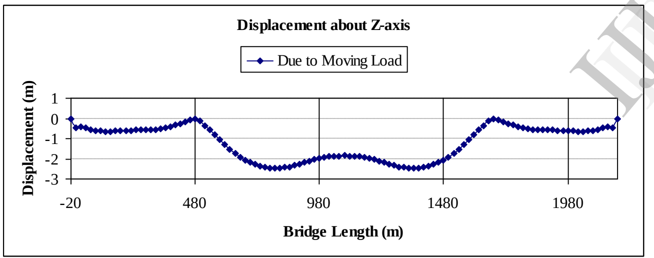

Fig. 14. Girder displacement about Z-axis of external anchorage model

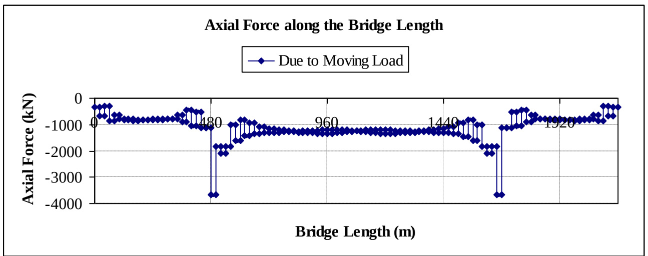

Fig. 15. Axial force of external anchorage system

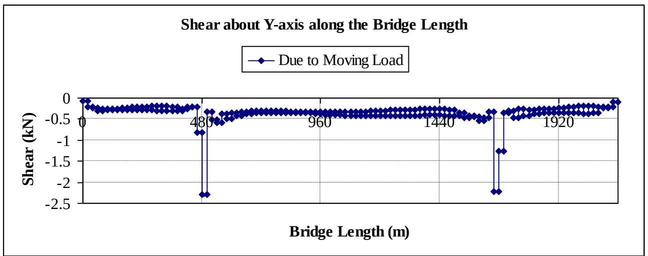

Fig. 16. Shear about Y-axis of external anchorage system

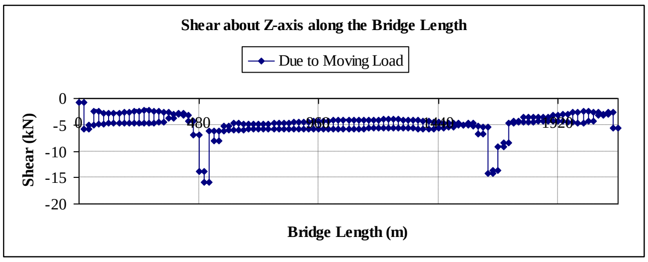

Fig. 17. Shear about Z-axis of external anchorage system

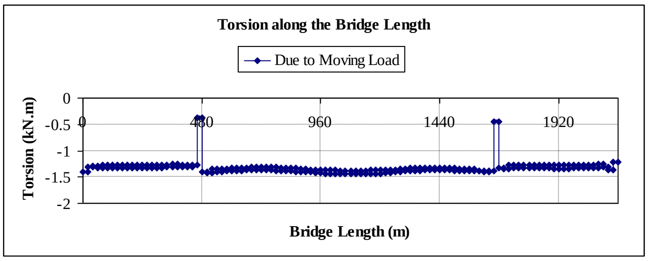

Fig. 18. Torsion along the bridge length of external anchorage system

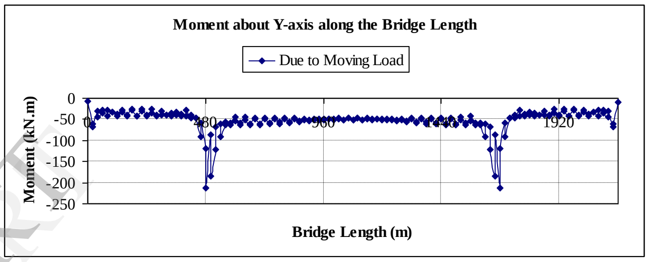

Fig. 19. Moment about Y-axis of external anchorage system

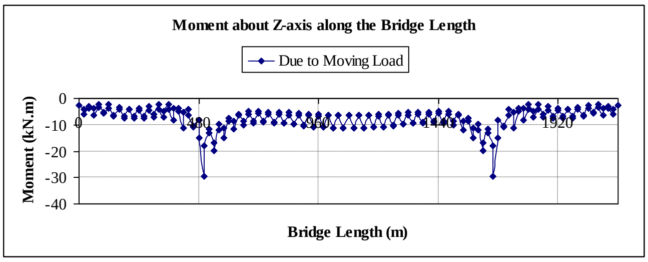

Fig. 20. Moment about Z-axis of external anchorage system

C. Analysis Results due to Unusual Wind Speeds

In consideration of unusual winds, the maximum wind limits of hurricane wind categories 2, 3 and 4 i.e. 110 mph, 130 mph and 155 mph are taken into account. The following figures are the displacements due to these unusual wind speeds. Fig. 21 is the girder displacement about X-axis, Fig. 22 is the girder displacement about Y-axis, Fig. 23 is the girder displacement about Z-axis along the bridge length of external anchorage model due to wind speeds of 110 mph, 130 mph, and 155 mph. The following figures are the structural responses of girder members of proposed suspension bridge. Axial forces, shear about Y-axis, shear about Z-axis, torsion, moment about Y-axis, moment about Z-axis along the bridge length of the proposed long-span suspension bridge due to unusual wind speeds of 110 mph, 130 mph and 155 mph are shown in Fig. 24, Fig. 25, Fig. 26, Fig. 27, Fig. 28 and Fig. 29, respectively.

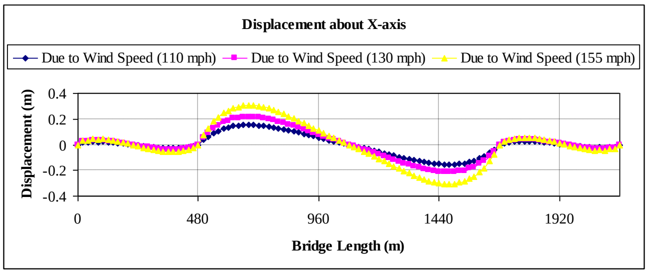

Fig. 21. Girder displacement about X-axis of external anchorage model

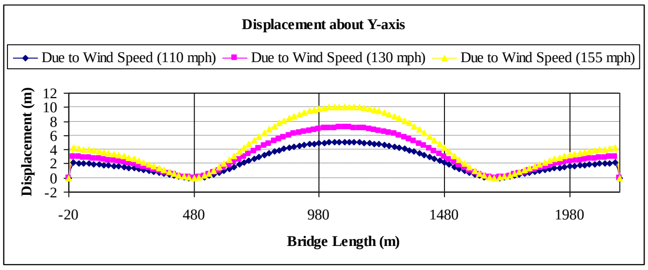

Fig. 22. Girder displacement about Y-axis of external anchorage model

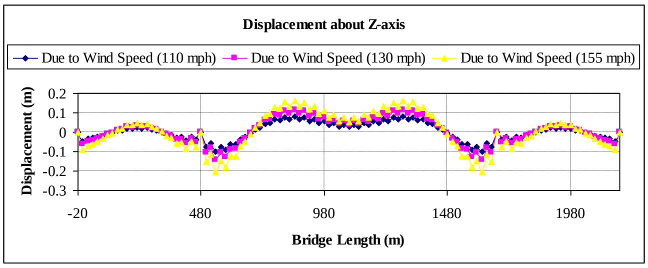

Fig. 23. Girder displacement about Z-axis of external anchorage model

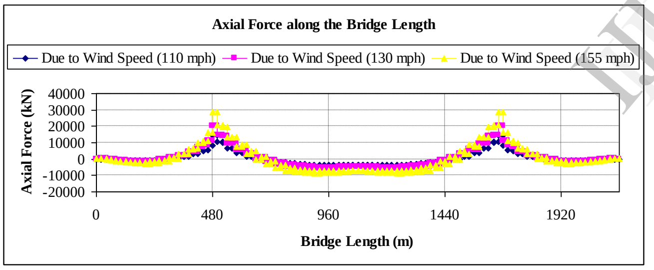

Fig. 24. Axial force of external anchorage system

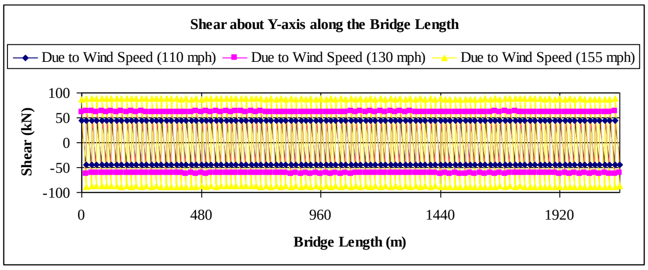

Fig. 25. Shear about Y-axis of external anchorage system

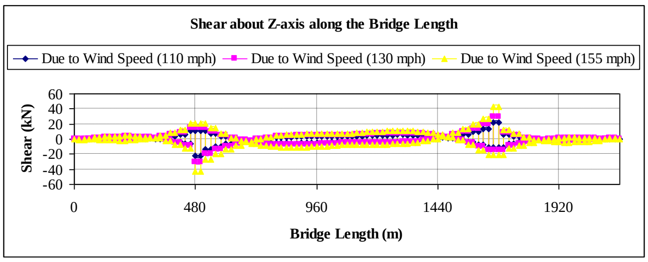

Fig. 26. Shear about Z-axis of external anchorage system

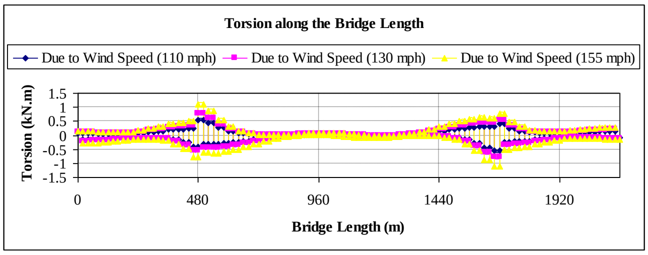

Fig. 27. Torsion along the bridge length of external anchorage system

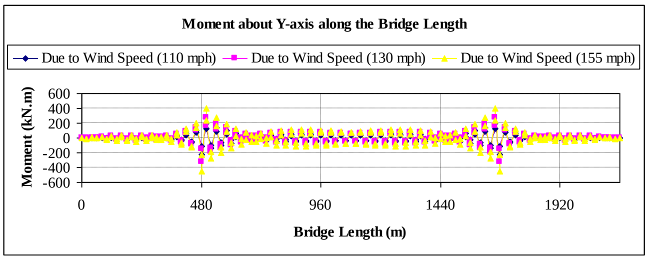

Fig. 28. Moment about Y-axis of external anchorage system

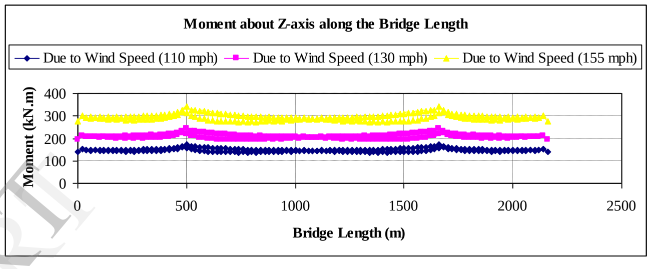

Fig. 29. Moment about Z-axis of external anchorage system

VI. CHECKING WITH ALLOWABLE LIMITS

In the checking with allowable limits, deflection of girder members under moving load condition and the combined stresses of girder members are taken into account.

A. Checking of Deflection

By using Table VI,

Allowable deflection of proposed bridge = 1200/350

= 3.43 m

For proposed external anchorage bridge model,

Maximum deflection due to moving load = 2.468 m

Maximum deflection due to self weight for proposed external anchorage bridge model is and it is lies within the allowable limit of 3.43 m. So, it can be said that the proposed external anchorage bridge is in the satisfactory condition.

B. Checking of Combined Stresses

In the combined stresses checking, the checking of final design girder members is carried out with the maximum value of bending and shear. In Table VII, combined stresses of bending and shear are in the allowable limit. So, the members of proposed external anchorage model are in the tables are satisfied sections.

TABLE VII. CHECKING OF COMBINED STRESSES OF EXTERNAL ANCHORAGE MODEL

Member	Section	$\left(\frac{f_b}{F_b}\right)^2+\left(\frac{f_v}{F_v}\right)^2$	Factor
Vertical Member	W 12 × 190	0.5	1.2
Vertical Main Truss	W 12 × 190	0.4	1.2
Transverse Truss	W 12 × 190	0.45	1.2
Floor Beam	W 27 × 281	0.48	1.2
Stringer	W 14 × 211	0.73	1.2
Lower Horizontal Girder	W 14 × 211	0.67	1.2
Horizontal Lateral Bracing	W 10 × 68	0.34	1.2

VII. CONCLUSION

Suspension bridges are widely built and used all over the world. This kind of bridge is the only practical type usable for very long span, where topography prohibits or it is hazardous to maritime traffic to add temporary or permanent central supports. Comparing with other kinds of bridge, suspension bridge is particularly pleasing to the visual senses. Moreover, it can be built high over water to allow the passage of very tall ships and it can span longer than any other kinds of bridge.

Only self weight condition under linear static analysis of proposed model, the maximum displacement about X-axis is 0.109239 m at mid point of side span, the maximum displacement about Y-axis is 0.001316 m at a 20 m distance from the tower in the side span and the maximum displacement about Z-axis can be seen at mid point of main span and its value is 2.75192 m. In girder forces, maximum axial force is 6528.81 kN at tower, the maximum shear about Y-axis is 4.11 kN at the tower, the maximum shear about Z-axis is 54.76 kN at 460 m near tower, the maximum torsion occurs at tower of and the value is 1.07 kN.m, the maximum moment about Y-axis occurs at tower and the value is 480.38 kN.m, the maximum moment about Z-axis occur at a distance 20 m from the tower in the side span and the value is 55.49 kN.m.

In moving load analysis, the deflection is zero at tower and at external anchorage point and the maximum deflection is 2.468 m at 1340 m in the main span. In girder forces, the maximum axial force is 3665.63 kN at tower, the maximum shear about Y-axis occurs at tower and this value is 2.3 kN, the maximum shear about Z-axis is 15.89 kN at 520 m, the maximum torsion is 1.44 kN.m at mid point of main span, the maximum moment about Y-axis is 211.92 kN.m occurred at tower, the maximum moment about Z-axis is 29.64 kN at 20 m in the main span from the tower.

Under unusual wind conditions, the maximum X-axis displacements due to 110 mph, 130 mph and 155 mph are 0.15454 m, 0.215943 m, and 0.307016 m occurred at 700 m from the ends of the bridge, the maximum Y-axis displacements due to 110 mph, 130 mph and 155 mph are 5.082164 m, 7.101356 m, and 10.096082 m occurred at mid point of the bridge, and the maximum Z-axis displacements are 0.102377 m for 110 mph, 0.143162 m for 130 mph and 0.203775 m for 155 mph at 540 m. In girder forces due to wind loads, the maximum axial forces are 14509.17 kN at 110 mph, 20274.64 kN at 130 mph, 28826.19 kN at 155 mph, the maximum shear about Y-axis at 20 m from girder ends are 44.97 kN at 110 mph, 62.84 kN at 130 mph, 89.34 kN at 155 mph, the maximum shear about Z-axis significantly occurred at tower are 21.46 kN at 110 mph, 30 kN at 130 mph, 42.67 kN at 155 mph, the maximum torsion occurred at tower and these values are 0.56 kN.m at 110 mph, 0.79 kN.m at 130 mph, 1.12 kN.m at 155 mph, the maximum moment about Y-axis occurred at tower are 228.51 kN.m at 110 mph, 319.43 kN.m at 130 mph, 454.43 kN.m at 155 mph, and the maximum moments at 20 m from tower in Figure 5.18 are 172.73 kN.m at 110 mph, 241.37 kN.m at 130 mph, 343.15 kN.m at 155 mph.

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