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The effect of configuration of cable on overall structural configuration of pedestrian suspension bridge for larger span

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Abstract

A pedestrian suspension bridge can be placed in two ways vertical hangers and inclined hangers. The inclined hangers are subjected to more fatigue while vertical hangers are subjected to more fluctuation of forces due to critical load conditions. During critical load conditions, some of the inclined hangers are subjected to excessive stressed while some of them are subjected to a lack of stress. To improve the stability of inclined hangers a horizontal member is to add the system to eliminate the slackness in hangers. These members release some forces from over stressed hanger to slack the hanger. That system is called a modified hanger system. The system shows its validity for 100m span only. The present study analyzed the vertical, the inclined, and the modified hangers under critical loading conditions using nonlinear static analysis for the span of 150m, 200m, and 300m by taking the width and thickness of the deck constant. The result shows improvement in the stability of the hangers.

Keywords: - *Suspension bridge, hanger arrangements Modified hanger, nonlinear static analysis, overstressed hangers, slackness in hangers*

I. INTRODUCTION

A pedestrian bridge meaning a foot over the bridge which is generally a suspension bridge. A pedestrian Suspension bridge is subjected to various imposed loads like animals, humans, bicycles, motorcycles, and other such loads. The bridge is also under the effect of dynamic loads like an earthquake or wind loads. The suspension bridge is used for a large span where hangers are used to transfer force from deck to main cable and main cable transfers the force to pylon. The performance of inclined hangers is better than vertical hangers in the case of dynamic and/or lateral loading. During the majority of the period of life its span, it would under excessive tensile stress because of the combined effect of gravity load like a dead and live load. In the present study for the stability of the system a modified hanger system is introduced[1].Earlierstudyhasreveal that the suspension bridges with inclined hangers like Severn Bridge and Humber Bridge show the effect of fatigue and fracture in the early stage of their life span.

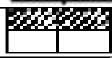
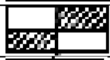
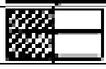
The hangers of Severn Bridge were designed for 30 years of life span, however, the hangers started to break after 8to9 years of the bridge opening. Tacoma Narrows bridge was constructed in 1940, the cause of its failure was its slander and tenderness of span which is subjected to high wind due to which hangers are subjected to the large fluctuation of forces. The bridge was of 2800ft central span and 1100ft side span. Breakage of hangers can occur suddenly and it causes strong vibration in the structural system. The effect of sudden breakage of hanger which causes strong vibration that maximum tension in cables can reach 2.22 times of its value[3]. Axial stiffness and hanger spacing have a significant effect on the sudden breakage of hangers. A suspension bridge can be of two types self-anchored suspension bridge and the normal one. Self-anchored suspension bridge with vertical hangers has slightly less overall stiffness as compared with Self anchored suspension bridge with inclined hanger pattern. But inclined hanger patterns are rarely adopted because of erection problems and fatigue in hanger[4]. In this paper, the author studied the effect of modified inclined hangers-on spans more than 100m under non-linear static analysis. The load is taken as a static live load. A foot over bridge is subjected to symmetrical and asymmetrical loading. The present study used the load patterns represented in table.1.Among which it is observed that load pattern A and load pattern D is the most critical conditions. Initial equilibrium forces in cable and hangers are calculated by the software itself. Three models were prepared such as the model with vertical hangers, the model with inclined hangers, and the model with modified hangers.

II. MATERIAL AND METHODS

A. Analytical model

Parameters of a suspension bridge are considered with three different spans such as 150m,200m, and 300m. first, vertical hangers were modeled. Vertical hangers were replaced by inclined hangers, and again inclined hangers were replaced by modified inclined hangers. A horizontal member is added between two adjacent inclined hangers so that even distribution of load in adjacent hangers is done by added horizontal cable. Parameters for three different spans with vertical and inclined hangers, given in **table 2** and **table 3**.

Table 1 live loads for applied patterns

Pattern name of the load	**Span length(m)**	**Live loads(kN/m²)**	**Load pattern**
A	**Full length**	**2.6**	
B	**Full length**	**2.6**	
C	**Half-length**	**2.7**	
D	**Half-length**	**2.7**	

B. Description of Deck

The thickness and width of the deck are kept constant for various spans like 150m, 200m, 300m. Width of the Deck is 3m and diameter of longitudinal girder 0.3m Diameter of cross beams is 10cm and plate/plane stress thickness is 2.5cm

- Crossbeams are pinned jointed with girders

C. Description of the pylon

- Pipe shaped pylon is of a diameter of 0.5m
- Pylon is braced diagonally by pylon transverse

D. Description of Cable and hanger

- The diameter of the main cable is 150mm
- The diameter of the hanger is 40mm
- The diameter of the added horizontal member is 40mm

E. Material property

- For all members, E is $2*10^{11}$ N/m^{2}accept for cables and Hangers. For main cable and hangers, fu is $1.57*10^9$N/m^2 and fy is $1.18*10^9$ N/m^2
- For all members, density is 7850 kg/m^3

III. Modelling & Analysis in software

A. Model Dimensions

- **Vertical hangers**

Table 2 Parameters for Vertical

Span(m)	H1	H2	L1	L2	L3	N1	N2	N3	S	W
150	2.5	19	45	150	45	0	80@1.875	0	15	3
200	5	30	50	200	50	0	80@2.5	0	24	3
300	7.5	45	75	300	75	0	80@3.75	0	36	3

- **Inclined hangers**

Table 3 Parameters for Inclined hangers

Span(m)	H1	H2	L1	L2	L3	N1	N2	N3	S	W
150	2.5	19	45	150	45	0	1.875,39@3.75	0	15	3
200	5	30	50	200	50	0	2.5, 39@5	0	24	3
300	7.5	45	75	300	75	0	3.75, 39@7.5	0	36	3

(units are in meter)
Where H1: height of the pier
H2: height of the tower
S : Sag
W : Width
L1: left span
L2 : center span
L3 : right span
N1 : Number of Hangers in the left span
N2 :Number of hangers in the center span
N3 : Number of Hangers in the right span

- **Added Horizontal member**
  - Height and length of added member is depends on hanger spacing(A.Mehrgan, M.Barghian [2]).
  - $0.4 \leq L \leq 2.3-0.625H$
  - $0{:}8 \leq H \leq 3{:}04$
  - Where L is length and H is height of the added member.

B. Model view with different hanger systems

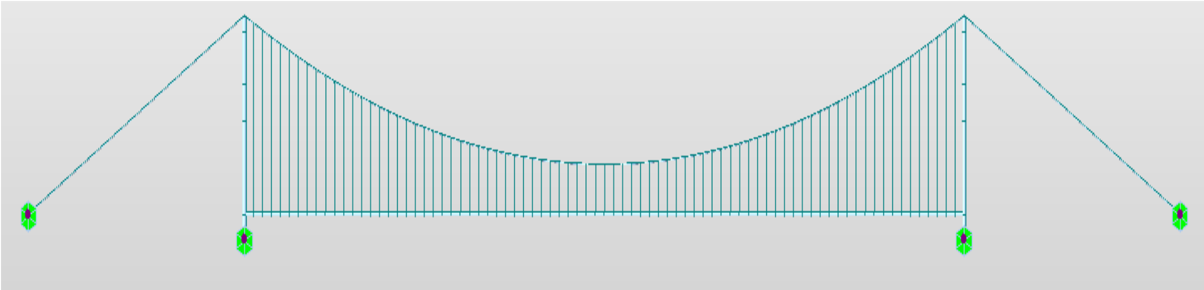


Figure.1 Vertical hanger system

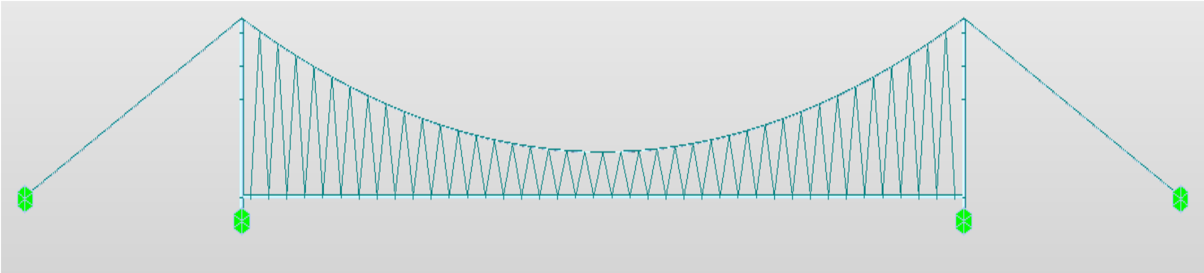


Figure.2 Inclined hanger system

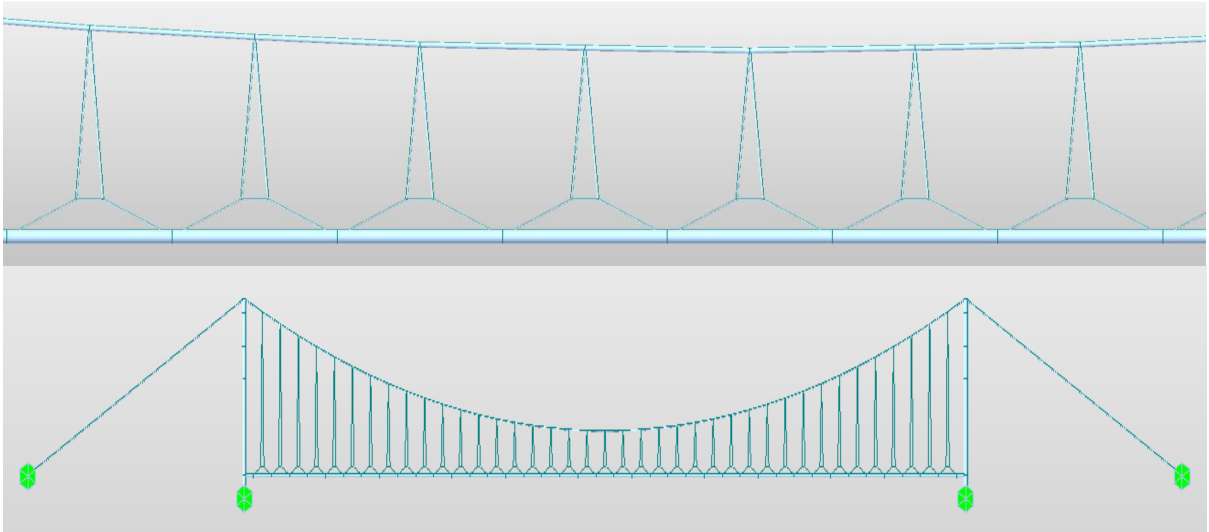


Figure.3 Modified inclined hanger system

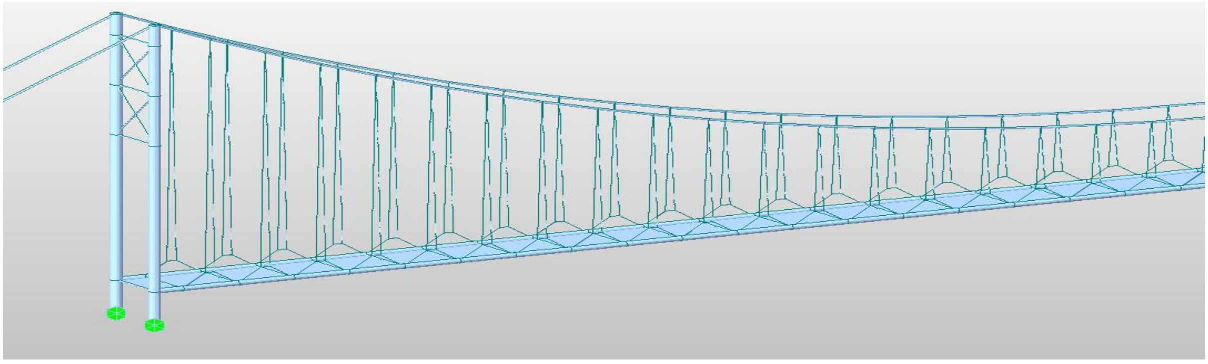


Figure.4 Isometric view

C. Result And Discussion

- **Deflected shapes due to Load pattern A and Load D**

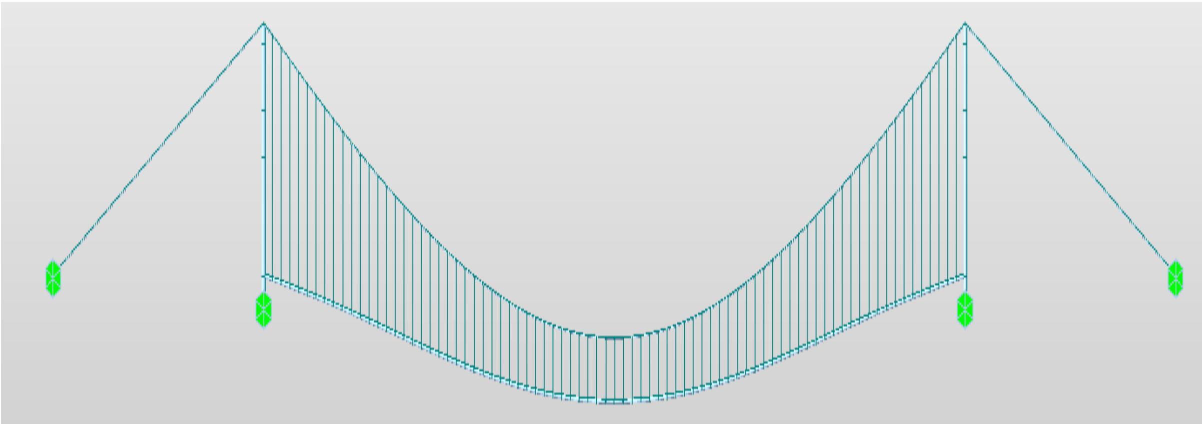


Figure.5 Deflected shape due to load A

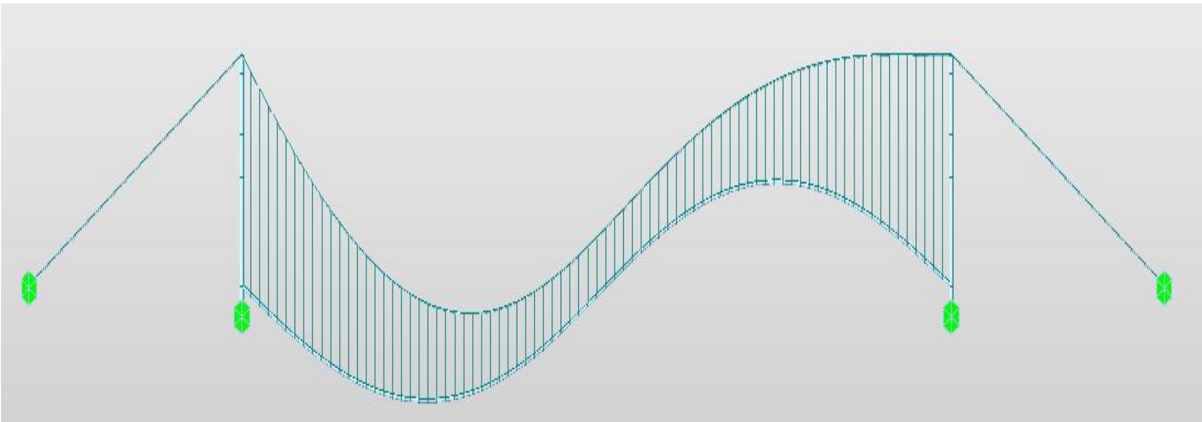


Figure.6 Deflected shape dur to load D

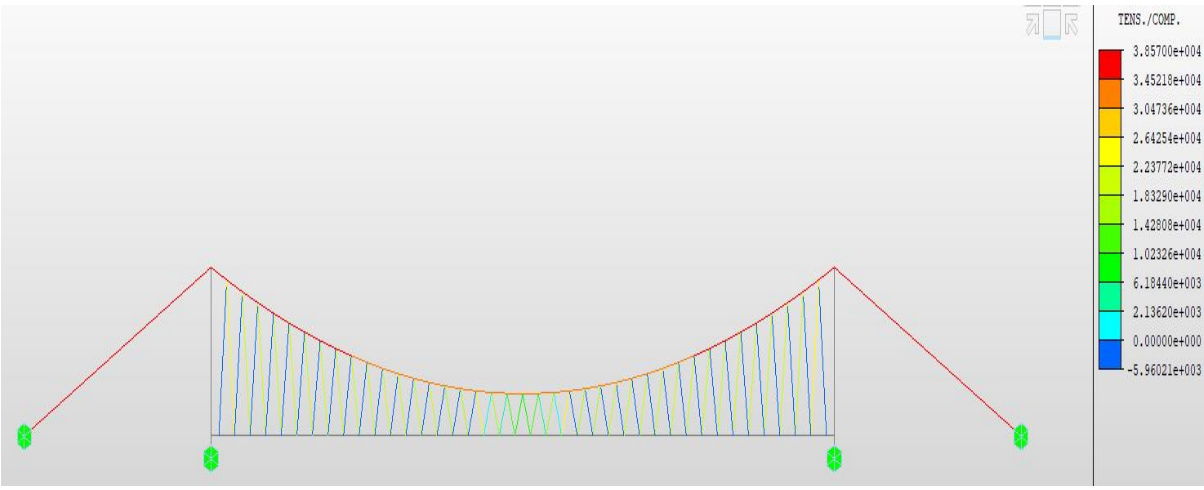


Figure.7 stresses in inclined hangers and cable due to load D

- **Figure**.5represents the vertical displacement of the deck due to applied load pattern A. Maximum vertical displacement of the deck occurred at the center of the span.
- **Figure.6**represents the vertical displacements of the deck due to load pattern D. displacements under load pattern D are the critical case. According to the **figure.6** Load applied from the left side of the span and maximum displacement occurred at a quarter of the span. Half of the span which subjected to loading is bent downward while the rest of the span bent upward. Displacement at the center of the span is zero.
- According to **figure.7,** one of two adjacent hangers is subjected to overstressing. In the case of the load pattern D, when the live load moved from left to right on the deck, some inclined hangers became slack. When live load moved from right to left on the deck, previous slacked hangers were subjected to a tensile force. By repeating this process fatigue phenomenon occurred and fracture of hangers take place.
- According to **figure.8** for the span, 150m under load Case A each vertical hanger is subjected to almost the same force 7.5kN. load case D is critical here it shows a large fluctuation of forces in vertical hangers, maximum force in vertical hangers is8 kN under load case D.
- **Figure**.**9** shows forces in the vertical hangers under load cases A and D for the span of 200m. for the load case, A maximum tensile force in the vertical hanger is 10 kN. Under load case, D maximum tensile force in vertical hangers is 10.2 kN.
- **Figure.10**represents tensile forces in vertical hangers under load case A and D for the span of 300m. maximum tensile force in vertical hangers under symmetric loading is 15 kN and maximum tensile force under asymmetric loading is 15.2 kN.
- Left sides vertical hangers are subjected to large tensile forces compared to right sides vertical hangers in the case of load pattern D. Under load case A, all vertical hangers are subjected to almost the same tensile forces.

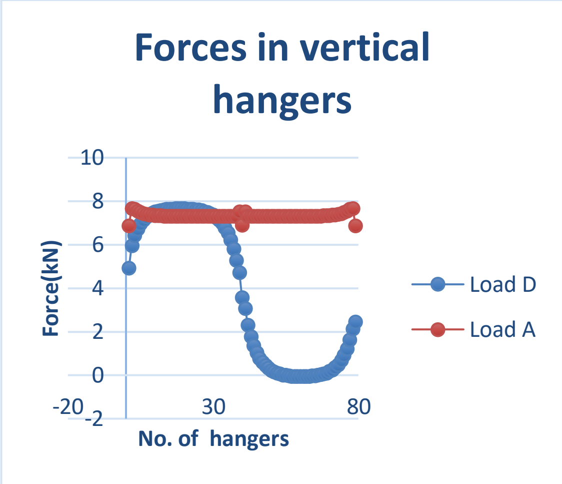


Figure.8 Hanger forces for span 150m

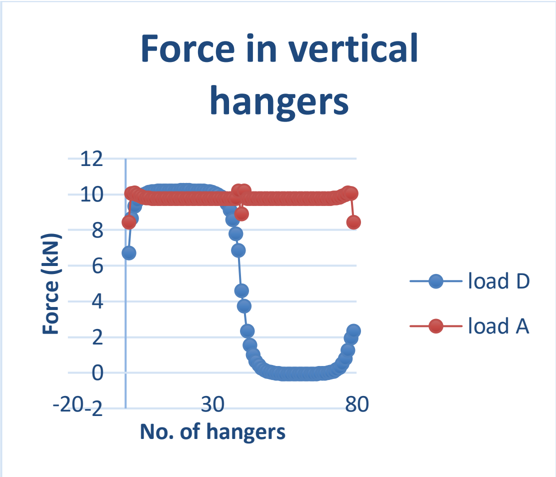


Figure.9 Hanger forces for span 200m

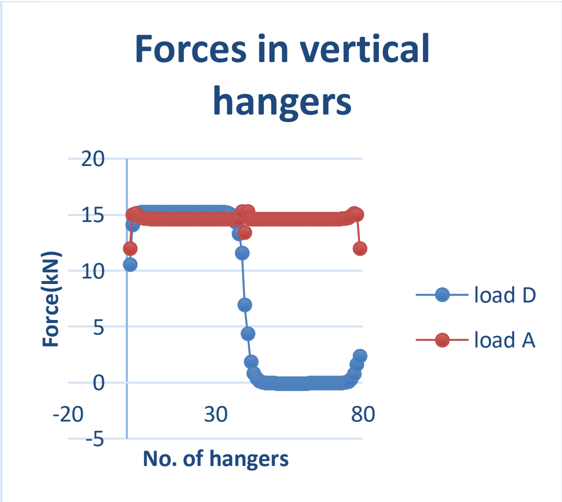


Figure.10 Hanger forces for span 300m

D. Displacements in various spans due to load pattern D

- The red curve represents the deflection pattern of vertical hangers. The blue curve shows the deflection pattern of inclined hangers. The green curve represents the deflection pattern of the modified inclined hanger system.
- As represented in **Figure.11** that the displacements due to inclined hangers, vertical hangers, and modified inclined hangers in which the maximum deflection for 150m span is due to vertical hangers -0.9m.for inclined hangers, deflection is -0.65m while for modified system deflection stays -0.7m.
- Displacements for the main span length of 200m is represented in **Figure.12**. It is observed that maximum vertical deflection for this span of the pedestrian bridge is due to the vertical hanger system which is around -1.2m. For the inclined hanger system maximum deflection stays at -0.8m and for the modified inclined hangers maximum deflection is near -1.0m.
- For 300m main spans, displacements are shown in **Figure.13**. for vertical hangers deflection is maximum compared to the other two systems. For vertical hangers, deflection stays at -1.59m. for inclined hangers deflection is -1.49m and for modified hanger system deflection is -1.48m. Here for inclined and modified inclined hangers deflection is almost the same.
- The vertical displacement of the modified inclined hanger system is between the deflection of vertical and inclined hangers for all three spans.
- As load is applied on half of the span. Half span is bent downward while the rest of the span is bent upward.
- The deck is connected to the pylon by releasing moment about Y-axis(My) and axial force about X-axis(Fx). The Displacement of the deck at the tower is almost zero.
- From all this span it is observed that as the span increases deflection due to critical load condition increases. The maximum and minimum displacements belong to the bridge with vertical and inclined hangers respectively. In the bridge with modified hangers, displacements were decreased in comparison to the bridge with vertical hangers.

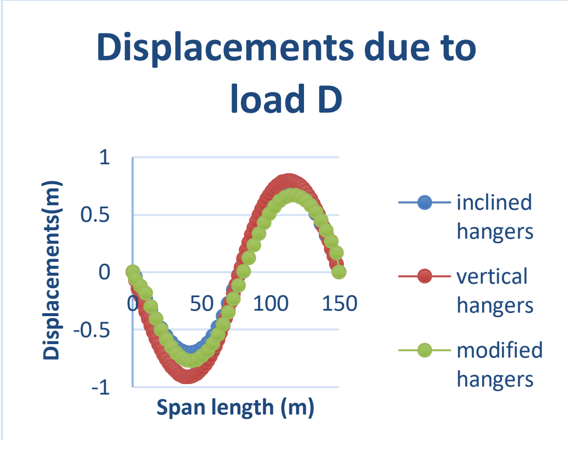


Figure.11 Displacements for 150m span under load pattern D

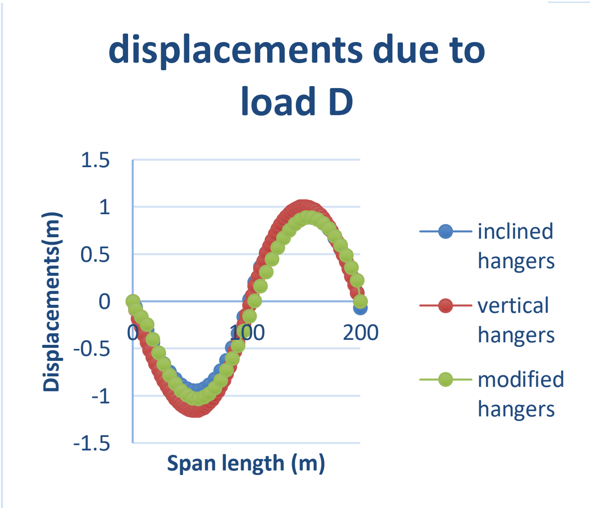


Figure.12 displacements for 200m span under load pattern D

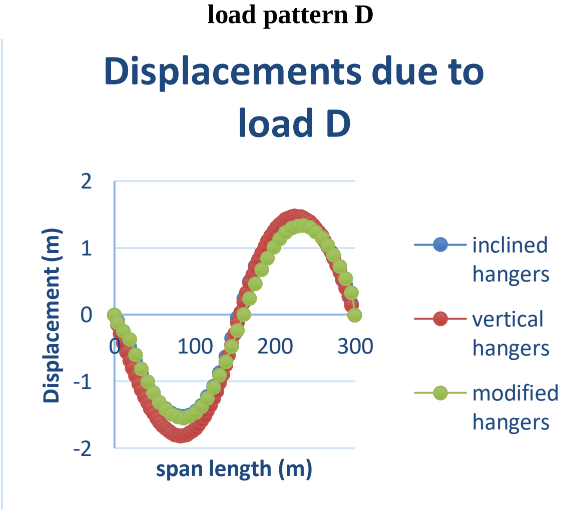


Figure.13 Deflections for 300m span under load pattern D

E. 150m span suspension bridge under load Pattern A and D

- **For load Pattern A**

1. **Cable forces**

Table 4 Cable Forces under Load pattern A

Cable forces (kN)	At tower end	Mid-span	Side span
Vertical hanger	765.28	708.39	765.56
Inclined hanger	744.86	620.22	744.36
Modified hanger	762.28	705.20	762.3

2. **Hanger forces**

Table 5 Hanger Forces under Load pattern A

Hanger forces (kN)	Maximum	Minimum	No. of slacked hangers
Vertical hangers	7.65	6.86	0
Inclined hangers	19	0	20
Upper section	10.98	2.11	0
Lower Section	18	3.47	0

- **For load Pattern D**

1. **Cable forces**

Table 6 Cable forces under Load pattern D

Cable forces(kN)	At tower end	Mid-span	Left span	Right span
Vertical hanger	437.86	363.45	413.91	380.67
Inclined hanger	484.12	344.17	459.66	349.92
Modified hanger	435.50	361.45	412.5	380

2. **Hanger forces**

Table 7 Hangers forces under Load pattern D

Hanger forces(kN)	Maximum	minimum	No. of slacked hangers
Vertical hangers	7.65	0.5	12
Inclined hangers	32.95	0	40
Upper section	8.81	0.5	0
Lower section	9.92	1	0

- according to **table 4** under symmetric loading, the force in the main cable due to vertical, inclined, and modified inclined hangers are respectively 708 kN, 620 kN,705.20kN at mid-span, and 765.56 kN, 744.36 kN, and 762.3kN on side span.
- According to **table 6** under load case D the force in the main cable due to vertical, inclined, and modified inclined hangers are respectively 363.45 kN, 344.17 kN, and 361.45kN at mid-span
- According to **table 5**number of slacked hangers under load case, A due to inclined hangers are 20. As par **table 7**number of slacked hangers under load case D due to inclined hangers are 40.
- The maximum tensile force under load case D in the inclined hanger is 32.95 kN.upper section is subjected to 9.2 kN tensile force and the lower section is subjected to 8.81 kN tensile force.
- The number of slacked hangers in the upper section and the lower section is 0.

F. 200m span suspension bridge under load Pattern A and D

- **For load pattern A**

1. Cable force

Table 8 Cable forces under Load pattern A

Cable forces(kN)	At tower end	Mid-span	Left span	Right span
Vertical hanger	877	788.40	919	919
Inclined hanger	859	693.96	901	901
Modified hanger	874	785.30	916	916

2. Hanger forces

Table 9 Hanger forces under load pattern A

Hanger forces(kN)	Maximum	minimum	No. of slacked hangers
Vertical hangers	10	8.41	0
Inclined hangers	26.15	0	16
Upper section	14	3	0
Lower section	20	4	0

- **For load pattern D**

1. Cable forces

Table 10 Cable forces under Load pattern

Cable forces(kN)	At tower end	Mid-span	Left span	Right span
Vertical hanger	523.15	402.82	507	446
Inclined hanger	553	361	537	396
Modified hanger	525	404	509	448.5

2. Hanger forces

Table 11 Hanger forces under Load pattern D

Hanger forces(kN)	Maximum	minimum	No. of slacked hangers
Vertical hangers	10.20	0	7
Inclined hangers	40.54	0	40
Upper section	12	0	1
Lower section	17	0.1	1

- according to **table 8** under symmetric loading, the force in the main cable due to vertical, inclined, and modified inclined hangers are respectively 788.4kN, 693.96kN,785.4kN at mid-span and 919kN, 901kN, and 916kN on side span.
- According to **table 10** under load case D the force in the main cable due to vertical, inclined, and modified inclined hangers are respectively 402.82kN, 361kN, and 404kN at mid-span.
- According to **table 9**number of slacked hangers under load case, A due to inclined hangers are 16. As par **table 11**number of slacked hangers under load case D due to inclined hangers are 40.
- The maximum tensile force under load case D in the inclined hanger is 40.54kN. the upper section is subjected to 12kN tensile force and the lower section is subjected to 17kN tensile force.
- The number of slacked hangers in the upper section and lower section are respectively 2 and 1.

G. 300m span suspension bridge under load Pattern A and D

- **For load pattern A**

1. **Cable forces**

Table 12 Cable forces under Load pattern A

Cable forces(kN)	At tower end	Mid-span	Left span	Right span
Vertical hanger	1302	1198	1364.86	1364.86
Inclined hanger	1277	1026	1339.40	1339.40
Modified hanger	1300	1195.3	1361.86	1361.86

2. **Hanger forces**

Table 13 Hanger forces under Load pattern A

Hanger forces(kN)	Maximum	minimum	No. of slacked hangers
Vertical hangers	15	11	0
Inclined hangers	40	0	20
Upper section	21	3	0
Lower section	30	4	0

- **For load pattern D**

1. **Cable forces**

Table 14 Cable forces under Load pattern D

Cable forces(kN)	At tower end	Mid-span	Left span	Right span
Vertical hanger	780.72	597.6	756	661
Inclined hanger	821.70	527.5	803	585
Modified hanger	782.50	599	758	662

2. **Hanger forces**

Table 15 Hanger forces under Load pattern D

Hanger forces(kN)	Maximum	minimum	No. of slacked hangers
Vertical hangers	15.24	0	7
Inclined hangers	53	0	40
Upper section	18	0	1
Lower section	26	0	1

- according to **table 12** under symmetric loading, the force in the main cable due to vertical, inclined, and modified inclined hangers are respectively 1198kN, 1026kN, 1195.3kN at mid-span, and 1364.86kN, 1339.40kN, and 1361.40kN on side span.

- According to **table 14** under load case D the force in the main cable due to vertical, inclined, and modified inclined hangers are respectively 597.6kN, 527.5kN, and 599kN at mid-span.

- According to **table 13**number of slacked hangers under load case, A due to inclined hangers are 20. As par **table 15**number of slacked hangers under load case D due to inclined hangers are 40.
- subjected to 18kN tensile force and the lower section is subjected to 26kN tensile force.

Conclusion

- The proposed modified hangers system reduce the overs stressing of inclined hangers. It transfers the force from over stressed hangers to slacked hangers.

- As shown in the results that for both load patterns main cable forces behaves differently. For all three spans, the force due to load pattern D in cable for modified inclined hangers is between the vertical hanger system and inclined hanger system. the maximum force of the main cables has decreased in the bridge with the modified hangers comparing with the bridge with inclined hangers. The forces of the main cables for the load pattern A.

- Modified inclined hangers system eliminates the disadvantages due to vertical and inclined hangers. Keeping the advantages of both. It reacts better under fatigue and lateral loads which reduce the fracture of hangers.

- The height and length of the proposed horizontal cable depend on the spacing of the hangers. For 1.25m spacing, the optimum length and height of horizontal cable are 0.4m and 0.8m. with increases spacing, length, and height of added member increases accordingly.

- For 100m span, there are no slacked hangers in vertical hangers due to load D but as the span increases, some of the vertical hangers shows minor sign of slackness.

- For all three-span in inclined hanger system under the load pattern D, the number of slacked hangers is exactly half of the total number of hangers.

- As the span increases from 150m to300m, the number of slacked hangers in vertical hangers increases.

- For a 100m span, it surely removes the slackness in hangers. As we increase the span length from 100m to 300m even modified hangers show some minor signs of slackness under load pattern D, with constant depth and width of the deck.

- A maximum tensile force under load case D in the inclined hanger is 53kN. upper section is

- The number of slacked hangers in the upper section and lower section are respectively 3 and 1.

- The maximum displacement of the modified hanger system is between displacements of vertical and inclined hangers for a 150m span. For the span of 300m, the maximum deflection of modified hangers is nearer to deflections of inclined hangers.

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