Effect of Support Conditions on Static Behavior of 1400m main span and 700m side span Cable-stayed Bridge

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Abstract- Bridging a very long span across river, stream and sea is the field of cable-supported structures. The dominance of its statical systems and use of high-strength tensile elements enables bridges to advance to the borderline of the technically feasible. The cable supported bridges are divided in to various forms according different elements provision. The cable supported bridges are self anchored or earth anchored, depending on the supporting conditions and the back stays anchorage. The stiffening girder will generally be able to transmit tensile as well as compressive forces in contrast of the cable system. The static behavior of 1400m main span cable-stayed bridge with different support conditions like earth anchored, self anchored and partially earth anchored is studied. The bridge models with different support conditions are analysed in Sap 2000 software. The static behavior of 1400m main span cable-stayed bridge with different support conditions are presented in the form of Axial force and Bending moment in the bridge deck.

Keywords – Cable Supported Bridges, Support condition, Static analysis, Sap:2000

I. INTRODUCTION

As the modern day demands put forward greater challenges for the construction of longer spans or taller structures, the better solution is possible by using high strength steel cable systems as cable supported bridges like suspended-stayed or hybrid, roofs supported on cables, trusses, nets, antennae and cooling towers supported by cable systems. (Krishna P., 2001) To provide bridge with the long span, the use of high strength steel cables as tension resistance structural elements is essential. The structural systems generally used to achieve longer span are as listed below.

1. Suspension bridge system,
2. Cable-stayed bridge system,
3. Hybrid cable-stayed suspension system

Here Cable-stayed bridge system is considered to study the behavior of the bridge with different boundary conditions. In cable-stayed bridge inclined cables support the bridge deck directly with relatively taut cables, which, compared to the classical suspension bridge, provide relatively inflexible supports at several points along the span. The nearly linear geometry of the cables produces a bridge with greater stiffness than the corresponding suspension bridge. The first known cable-stayed bridge was designed in 1784 by C.T. Loescher.

The bridge can be of various types according to the cable arrangement in the cable-stayed bridge. In the current study, we have selected the fan type of cable arrangement of cables in cable-stayed bridge. In the fan system, the anchor cable connecting the pylon top to the end support in the side span and plays a dominant role in the achievement of stability in the cable system. The initial tensile forces are assigned to cable-stays to utilize it effectively in any load combination. The minimum tension in the anchor cable occurs for traffic load in the side spans only.

II. STIFFENING GIRDER AND SUPPORTING CONDITIONS

The cable supported bridges are self anchored or earth anchored, depending on the supporting conditions and the back stays anchorage. The stiffening girder will generally be able to transmit tensile as well as compressive forces in contrast of the cable system where all elements have to be in tension. Thus, when the stiffening girder replaces some of the cable elements of the pure cable system, new possibilities of achieving equilibrium will exist.

Figure 1 shows three possibilities of achieving horizontal equilibrium of one girder. Three systems of equilibrium, shown in Figure 1, can be created by the choice of the supporting condition for the stiffening girder and the attachment of the anchor cable, as illustrated in Figure 2 to 4.

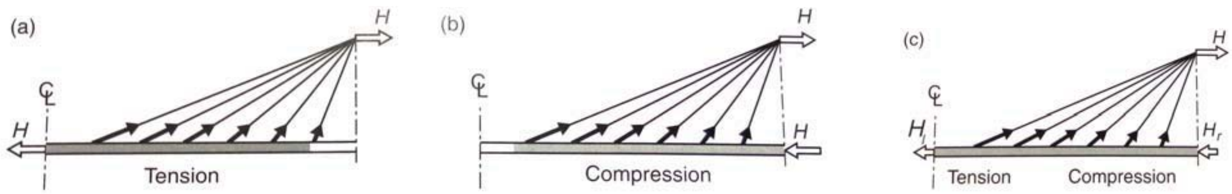

Figure 1 Three possibilities for achieving horizontal equilibrium for stiffening girder(Gimsing et.al, 2012)

As shown in Figure 1system (a) the stiffening girder is subjected at mid span to a horizontal tensile force H equal to the sum of the horizontal cable force components. This implies that the girder will be entirely in tension, and the forces of the system are consequently the same as found in the pure cable system.

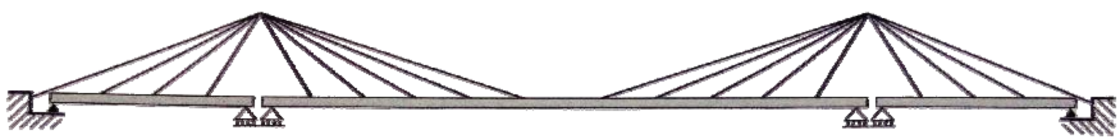

Figure 2 System A cable-stayed bridge having expansion joint at pylon and fixed bearing at the ends

As shown in Figure 2.3 in system A, the stiffening girder has expansion joints at the pylons and fixed bearings at the ends. This leads to an earth anchored system with zero normal force at the pylons and tension throughout the girder length.

In a system (b) shown in Figure 1 the stiffening girder is subjected at the pylon to a horizontal compressive force H, and the girder will therefore be entirely in compression. This leads to the self- anchored system applied in almost every cable stayed bridge built untill now.

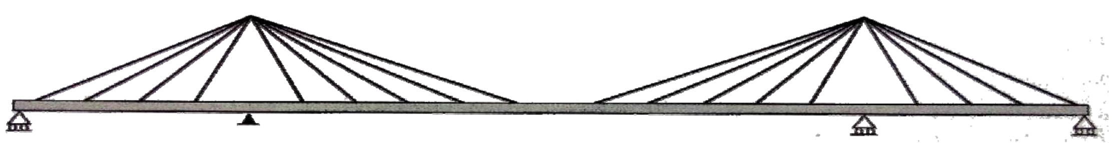

Figure 3 System B self anchored cable-stayed bridge having a continuous deck throughout its length

As shown in Figure 3 in system B the stiffening girder is continuous from one end to the other and supported by movable bearings on both end piers and one of the pylon piers. As the anchor cable furthermore is attached directly to the stiffening girder, the system becomes self-anchored with compression in the girder at the pylon and tension at the center of the span. The increase from the 185m span of the Stromsund Bridge (1955) to the Sutong Bridge (2008) with span of 1088m has been possible without deviating from the self anchored concept.

In system (c) shown in Figure 1 the stiffening girder is subjected to both a tensile force Hl at midspan and a compressive force Hr at the pylon. With Hl + Hr equal to the sum of the horizontal cable force components, the horizontal equilibrium will be fulfilled. As the midspan tension Hl has to be transferred to the soil at the ends of the stiffening girder, system (c) might be designated as a partially anchored system.

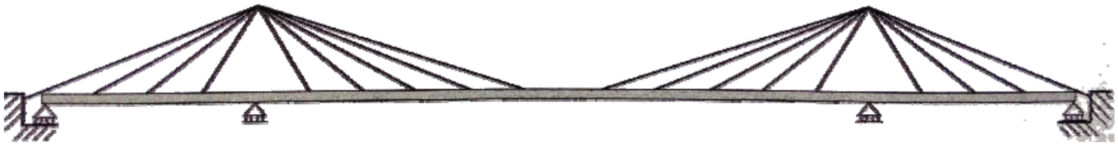

Figure 4 System C earth anchored cable-stayed bridge having a continuous deck throughout its length

As shown in Figure 4 in system C the stiffening girder is also continuous and exclusively on movable bearings, but here the anchor cable is attached to the end pier (anchor block). This implies that tension will be included at the center of the main span, whereas the side spans and the outer parts of the main span will be in compression.

A continuous stiffening girder can also be applied in an earth anchored suspension bridge. Here the main advantage to be gained is that the large angular changes occurring at the pylons under certain traffic load conditions will be eliminated. This might be of special importance in bridges carrying train load. On the other hand a continuous stiffening girder applied in a suspension bridge leads to a large negative moment in the girder at the supports on the pylons. This might lead to stresses of such a magnitude that high tensile steels will be required for the girder sections near the pylons.

In the system with a continuous stiffening girder the largest angular changes will occur at the end supports. Furthermore, special attention must be paid to the inclination of the short hangers near the ends of the side spans, where the largest longitudinal displacements due to the temperature change and asymmetric loading will occur. To reduce the angular changes a system with stiffening girder continued into short beam spans as shown in Figure 5 might be applied.

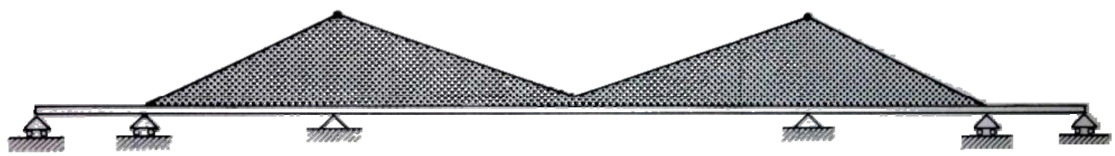

Figure 5 Cable supported bridge with stiffening girder continued into short beam spans

This principle was applied in the design from 1978 for a suspension bridge across the Great Belt in Denmark. Here short beam spans were arranged above the anchor blocks, with double supports at the ends of a multi-cable will also have the effect of reducing angular changes.

In suspension bridges and multi cable-stayed bridges where the stiffening girder is continuously supported by the cable system from one end to the other, the vertical supports of the girder at the pylons might be omitted, as shown in Figure 6.

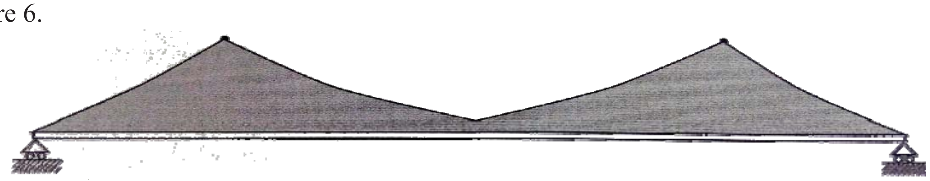

Figure 6 Cable supported bridge with the stiffening girder supported vertically on the end piers only, but laterally at the pylons as well as on the end piers

Such an arrangement generally leads to a noticeable reduction of the moments in the stiffening girder at the pylons. Laterally it will often be required to have supports at the end piers as well as at the pylons, as indicated on the plan of Figure 6. This is due to the fact that the cable system in many cases does not render a very efficient lateral support to the girder.

From all these systems of cable-stayed bridges, it is evident that the transmission of horizontal component of the cable-stay forces in cable-stayed bridge will be one of the decisive factors for the competitiveness of the long span bridge. The compression force originated in deck due to the horizontal component of cable-stays could be reduced by providing partial earth anchored system. The basic difference between self anchored and partially earth anchored system is illustrated in Figure 7.

For the partially earth anchored systems the side span to main span ratio decide the ratio between tension and compression. For a side span length of approximately one-third of main span length, the maximum axial force in the deck will be approximately halved (Gimsing et. al. 2012).

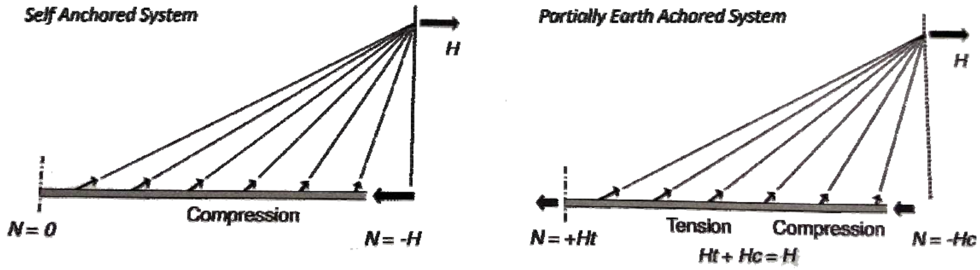

Figure 7 Horizontal equilibrium of the deck in a self anchored and a partially earth anchored cable-stayed system (Gimsing et.al, 2012)

III. CABLE-STAYED BRIDGE DATA

A. Bridge Geometrical Data:

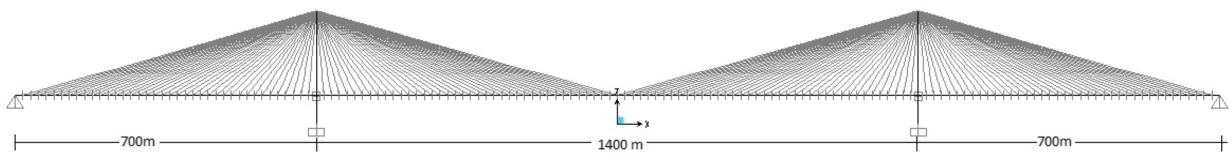

Figure 8 Cable stayed bridge with main span of 1400m and side span of 700m

As shown in the above Figure 8 cable-stayed bridge with main central span is 1400m and side span of 700m is considered in the current study. To investigate the effect of the support conditions on the static behavior of cable-stayed bridge, different support conditions are assigned in the bridge at the connection between deck-pylon and deck-abutment. The self anchored bridge, earth anchored bridge and partially earth anchored bridges can be differentiate by its supporting conditions as mentioned below.

Table 1 Constraint types of the deck

Type of bridge	Pylon1	Pylon2	Abutment	Anchorage
Self anchored bridge	**1**	**0**	**0**	**-**
Earth anchored bridge	**0**	**0**	**1**	**1**
Partially earth anchored bridge	**1**	**0**	**0**	**1**

Here, 1-indicates hinge support and 0-indicates roller support

B. Bridge members cross-sectional property Data:

The cross sectional property of the members considered to study the behavior of the cable-stayed bridge for the analysis is presented for the various members of the bridge in Table 2.

Table 2 cross-sectional properties of the girder and tower of Cable-stayed Bridge (Zhang Xin-Jun, 2007)

Members	E (Mpa)	A (m^2)	Ix (m^4)	Iy (m^4)	Iz (m^4)	M (Kg/m)	Jm ($Kg.m^2/m$)
Girder	**$2.1x10^5$**	**1.2481**	**5.034**	**1.9842**	**137.754**	**18386.5**	**$1.852x10^6$**
Stay cable	**$2.0x10^5$**	**0.008**	**0.0**	**0.0**	**0.0**	**62.5**	**0.0**
Tower C	**$3.3 x10^4$**	**30.0**	**350**	**320**	**220**	**78000**	**$5.7x10^5$**
Tower TB	**$3.3 x10^4$**	**10.0**	**150**	**70**	**70**	**26000**	**$4.7x10^5$**

Where, A - Cross section area in m^2, E - Modulus of Elasticity; J_d - torsional Constat; I_x-Vertical Bending moment of inertia; I_y - Lateral Bending moment of inertia; I_z - Vertical Bending moment of inertia; M - Mass per unit length; J_m – mass moment of inertia per unit length.

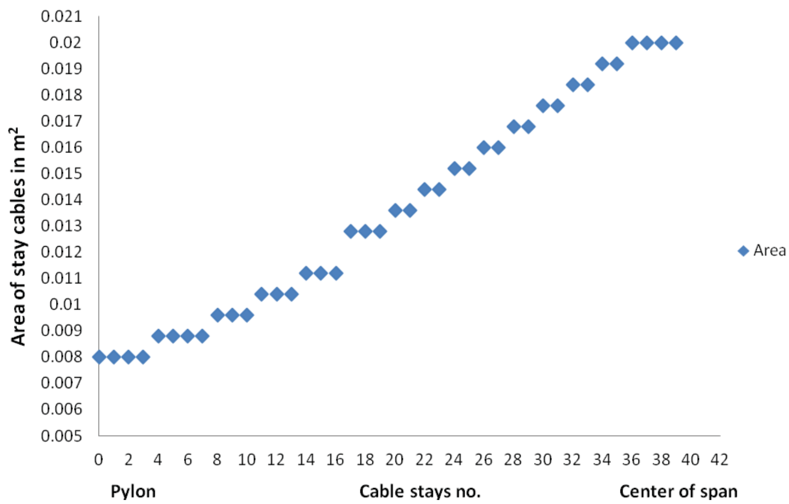

Figure 9 Area assigned to Stay Cables near pylon (cable-stays no. 0) to center of span (39)

Figure 9 presents the area of cable-stays with assigned cross sectional area in m^2 for various positions of the cables in the bridge near pylon to the center of main span.

C. Load Cases:

A load case defines how loads are to be applied to the structure, and how the structural response is to be calculated. Many types of load cases are applied. Structural elements of bridge are assigned with load cases which are shown in below Table 3.

Table 3 assigned loads to the different members

Type of the load	Value of Assigned Load	Element Assigned
Dead Load	97.980 kN/m	Deck
SIDL	50.0 kN/m	Deck
Live Load	34.650 kN/m	Deck

Nonlinear static analysis is carried out to study the behavior of the cable-stayed bridge. Here results are presented by considering support conditions of the deck.

III. Result Parameters for Parametric study

A. Effects of support conditions on static behavior of bridge

The boundary conditions to bridge deck play important role in the behaviour of the bridge. Thus the bridge is studied with self anchored, earth anchored and partially earth anchored cable system. The effect of support conditions on the behavior of the cable-stayed bridge is studied for the static stability of bridge. The behaviour of bridge can be realized by its displacement and load parameters. The static analysis of cable-stayed bridge is carried out for comparison of following result parameters with different geometrical aspects:

1. Axial force in deck throughout the length from one end to the other end.
2. Bending moment in deck under the load cases considered.

The axial force diagram of 1400m main span and 700m side span cable-stayed bridge are presented in the below Figure 10. Here, in case of self anchored cable-stayed bridge as shown in Figure 3, the bridge deck is supported by rollers at the abutments and one of the pylon while, at the other pylon deck is supported by hinged support. In case of earth anchored bridge as shown in Figure 2, the deck is supported by rollers at both the pylons and at the abutments the deck is supported by hinged supports.

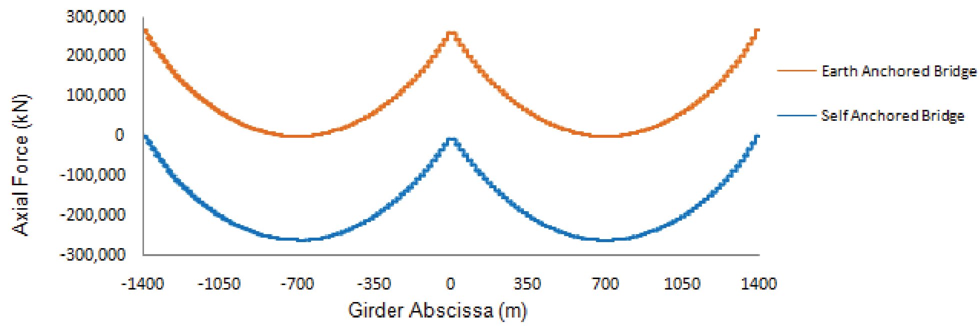

Figure 10 Axial Force Diagram of 1400 m central span and 700m side span self anchored and earth anchored cable-stayed bridge

From the above Figure 10, it is found that in the self anchored cable-stayed bridge there is no axial force at the abutments due to provision of roller supports at the abutments. The maximum axial compressive force is also found at the pylon due to provision of hinged at pylon.

From the above figure it is also found that axial force in the earth anchored cable-stayed bridge at the pylon is found minimum due to provision of roller support at the pylon. In earth anchored bridge the maximum axial force is found at the abutments and at the centre of main span. The bending moment diagram of the 1400m main span and 700m side span cable-stayed bridge is presented in the below Figure 11, which shows that the bending moment in the self anchored cable-stayed bridge is higher.

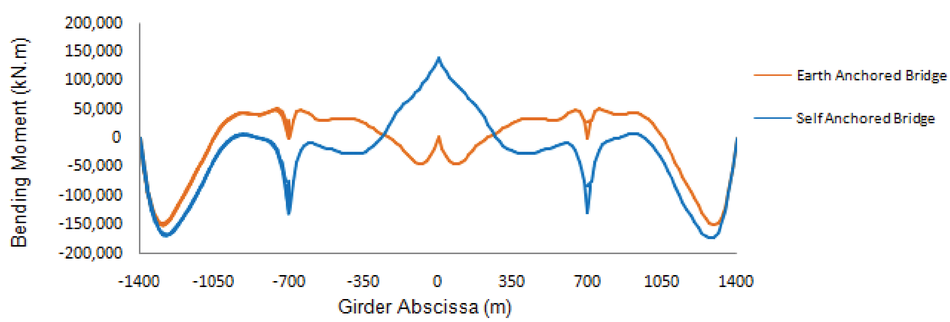

Figure 11 Bending Moment Diagram of 1400 m central span and 700m side span self anchored and earth anchored cable-stayed bridge

IV.CONCLUSION

The following are the conclusions, from the nonlinear static analysis of cable-stayed bridge with 1400m central span and 700m side span. The bridges are also studied with earth anchored and self anchored support conditions:

- Due to stressed cable-stays at the centre of the main span, the axial tensile force in the deck is found maximum in 1400m main span and 700m side span earth anchored cable-stayed bridge.
- The compressive force in the deck is found maximum in a cable-stayed bridge (CSB) with side span length of 700m.
- The axial force in deck is compressive in self anchored cable-stayed bridge while in case of earth anchored bridge the deck is subjected to axial tensile force.
- The axial force in main cables and axial force in the deck is reduced significantly and thus the material cost can be saved significantly in cable-stayed suspension hybrid bridge.

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