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A Review and Analysis of Suspension Bridge Structures

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Abstract: ***The requirement of long span bridge is increase with development of infrastructure facility in every nation. Long span bridge could be achieved with use of high strength materials and innovative techniques for analysis of bridge. Generally, cable supported bridges comprise both suspension and cable-stayed bridge. Cable supported bridges are very flexible in behavior. These flexible systems are susceptible to the dynamic effects of wind and earthquake loads. The cable-stayed bridge could provide more rigidity due to presence of tensed cable stays as a force resistance element. The suspension bridge could assigned more span in the field of bridge. So, combination of above two structural system the innovative form of cable-stayed suspension hybrid bridge could be the better option to provide more span. Here, attempt is made to analyze long span cable-stayed suspension hybrid bridge.***

Keywords: dynamic load, suspension bridge, eigen value, seismic loads, cable layout

1. Introduction

Since the completion of the Stromsund Bridge in Sweden in 1955, the cable-stayed bridge has evolved into the most popular bridge type for long-span bridges. The variety of forms and shapes of cablestayed bridges intrigues even the most-demanding architects as well as common citizens. Engineers found them technically innovative and challenging. For spans up to about 1000 m, cable-stayed bridges are more economical.

The concept of a cable-stayed bridge is simple. A bridge carries mainly vertical loads acting on the girder, Figure 1. The stay cables provide intermediate supports for the girder so that it can span a long distance. The basic structural form of a cable-stayed bridge is a series of overlapping triangles comprising the pylon, or the tower, the cables, and the girder. All these members are under predominantly axial forces, with the cables under tension and both the pylon and the girder under compression. Axially loaded members are generally more efficient than flexural members. This contributes to the economy of a cable-stayed bridge.

At the last count, there are about 600 cable-stayed bridges in the world and the number is increasing rapidly. The span length has also increased significantly [2,7]. Some milestones: the Stromsund Bridge in Sweden, completed in 1955 with a main span of 183 m is usually recognized as the world's first major cable-stayed bridge; the Knie Bridge (320 m) and Neuenkamp Bridge (350 m) in Germany, Figure 2 , were the longest spans in the early 1970s, until the Annacis Island-Alex Fraser Bridge (465 m) was completed in the mid 1980s. The 602-m-span Yangpu Bridge was a large step forward in 1994 but was surpassed within about half a year by the Normandie Bridge (856 m), Figure 3. The Tatara Bridge, with a center span of 890 m, is the world record today. Several spans in the range of 600 m are under construction. Longer spans are being planned.

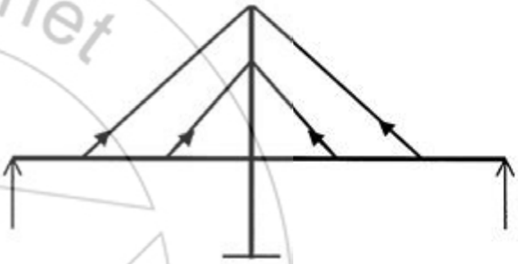

Figure 1: Concept of a cable-stayed bridge.

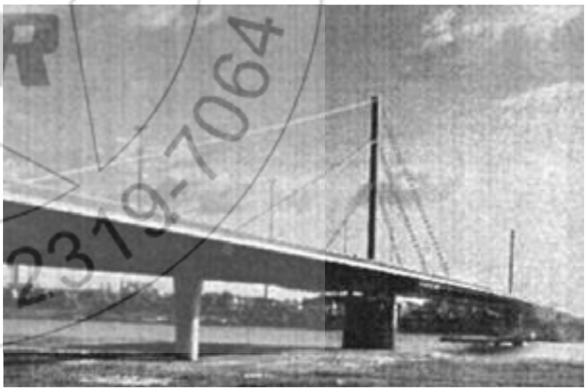

Figure 2: Neuenkamp Bridge

Figure 3: Normandie Bridge

2. Configuration

2.1 General Layout

At the early stage, the idea of a cable-stayed bridge was to use cable suspension to replace the piers as intermediate supports for the girder so that it could span a longer distance. Therefore, early cablestayed bridges placed cables far apart from each other based on the maximum strength of the girder. This resulted in rather stiff girders that had to span the large spacing between cables, in addition to resisting the global forces.

The behavior of a cable-stayed girder can be approximately simulated by an elastically supported girder. The bending moment in the girder under a specific load can be thought of as consisting of a local component and a global component. The local bending moment between the cables is proportional to the square of the spacing. The global bending moment of an elastically supported girder is approximately [5]

$$M = a * p * (I\ k) \qquad (1)$$

where a is a coefficient depending on the type of load p, I is the moment of inertia of the girder, and k is the elastic support constant derived from the cable stiffness. The global moment decreases as the stiffness of girder, I, decreases.

Considering that the function of the cables is to carry the loads on the bridge girder, which remains the same, the total quantity of cables required for a bridge is practically the same independent of the number of cables, or cable spacing, Figure 4. But if the cable spacing is smaller, the local bending moment of the girder between the cables is also smaller.

A reduction of the local bending moment allows the girder to be more flexible.A more flexible girder attracts in turn less global moment. Consequently, a very flexible girder can be used with closely spaced cables in many modern cable-stayed bridges.

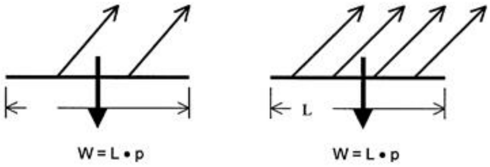

Figure 4: Cable forces in relation to load on girder

3. Permanent Load Condition

A cable-stayed bridge is a highly redundant, or statically indeterminate structure. In the design of such a structure, the treatment of the permanent load condition is very important. This load condition includes all structural dead load and superimposed dead load acting on the structure, all pre stressing effects as well as all secondary moments and forces. It is the load condition when all permanent loads act on the structure.

Because the designer has the liberty to assign a desired value to every unknown in a statically indeterminate structure, the bending moments and forces under permanent load condition can be determined solely by the requirements of equilibrium, $\Sigma H = 0$, $\Sigma V = 0$, and $\Sigma M = 0$. The stiffness of the structure has no effect in this calculation. There are an infinite number of possible combinations of permanent load conditions for any cable-stayed bridge. The designer can select the one that is most advantageous for the design when other loads are considered.

Once the permanent load condition is established by the designer, the construction has to reproduce this final condition. Construction stage analysis, which checks the stresses and stability of the structure in every construction stage, starts from this selected final condition backwards. However, if the structure is of concrete or composite, creep and shrinkage effect must be calculated in a forward calculation starting from the beginning of the construction. In such cases, the calculation is a combination of forward and backward operations.

The construction stage analysis also provides the required camber of the structure during construction.

4. Live Load

Live-load stresses are mostly determined by evaluation of influence lines. However, the stress at a given location in a cable-stayed bridge is usually a combination of several force components. The stress, f, of a point at the bottom flange, for example, can be expressed as:

$$f = (1+A) * P + (y\ I) * M + c * K \qquad (2)$$

where A is the cross-sectional area, I is the moment of inertia, y is the distance from the neutral axis, and c is a stress influence coefficient due to the cable force K anchored at the vicinity. P is the axial force and M is the bending moment. The above equation can be rewritten as

$$f = a1 * P + a2 * M + a3 * K$$

where the constants a1, a2, and a3 depend on the effective width, location of the point, and other global and local geometric configurations. Under live load, the terms P, M, and K are individual influence lines. Thus, f is a combined influence line obtained by adding up the three terms multiplied by the corresponding constants a1, a2, and a3, respectively.

In lieu of the combined influence lines, some designs substitute P, M, and K with extreme values, i.e., maximum and minimum of each. Such a calculation is usually conservative but fails to present the actual picture of the stress distribution in the structure.

5. Dynamic Loads

The girder of a cable-stayed bridge is usually supported at the towers and the end piers. Depending on the type of bearing or supports used, the dynamic behavior of the structure can be quite different. If very soft supports are used, the girder acts like a pendulum. Its fundamental frequency will be very low. Stiffening up the supports and bearings can increase the frequency significantly.

Seismic and aerodynamics are the two major dynamic loads to be considered in the design of cable-stayed bridges. However, they often have contradictory demands on the structure. For aerodynamic stability a stiffer structure is preferred. But for seismic design, except if the bridge is founded on very soft soil, a more flexible bridge will have less response. Some compromise between these two demands is required.

Because the way these two dynamic loads excite the structure is different, special mechanical devices can be used to assist the structure to adjust to both load conditions. Aerodynamic responses build up slowly. For this type of load the forces in the connections required to minimize the vibration buildup are relatively small. Earthquakes happen suddenly. The response will be especially sudden if the seismic motion also contains large flings. Consequently, a device that connects the girder and the tower, which can break at a certain predetermined force will help in both events. Under aerodynamic actions, it will suppress the onset of the vibrations as the connection makes the structure stiffer. Under seismic load, the connection breaks at the predetermined load and the structure becomes more flexible. This reduces the fundamental frequency of the bridge.

Most cable-stayed bridges are relatively flexible with long fundamental periods in the range of 3.0 s or longer. Their seismic responses are usually not very significant in the longitudinal direction. In the transverse direction, the towers are similar to a high rise building. Their responses are also manageable. Experience shows that, except in extremely high seismic areas, earthquake load seldom controls the design. On the other hand, because most cable-stayed bridges are categorized as major structures, they are usually required to be designed for more severe earthquake loads than regular structures.

6. Conclusion

Cable-stayed bridges are beautiful structures. Their popular appeal to engineers and non engineers alike has been universal. In a pure technical sense this bridge type fills the gap of efficient span range between conventional girder bridges and the very long span suspension bridges. Through these two different modelling structure designs which the half of combining harp and fan cable stays design and the whole combining harp and fan cable stays design, I found some important structural concepts for cable-stayed bridge structure design as described below:

1) Tower material of cable-stayed bridge design is one important factor to keep a high level stability for the structural body.
2) It is quite significant for cable-stayed bridge design to estimate connection between cable stayed and tower with deck.
3) The towers are bent significantly as they are subjected to large bending in the bridge structure. It needs additional cable acting the force on the opposite directions to balance the forces generated by the existing cables on the tower.
4) There has an effective function for cable-stayed bridge to analysis load distribution flow, especially, understanding and research cable design on the bridge or other cantilever structures.

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