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APPROXIMATE ANALYSIS OF CABLE-STAYED BRIDGES

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ABSTRACT:*A cable-stayed bridge is a highly statically indeterminate structure in which the stiffening girder behaves as a continuous beam supported elastically at the points of cable attachments. Except in the case of a very simple cable-stayed bridge, a computer is necessary for the solution of this type of structure. Computer programs are necessary to generate the influence diagrams for cable forces, stiffening girder, bending moments and shears, and tower and pier reactions. Programs are also required for the rapid solution of various parametric efforts and loadings that have to be taken into account in achieving a reasonably efficient design. Probably the most important problems are the determination of the optimum section of the stiffening girder section, and cable configuration and size.*

KEYWORDS:-Cable-Stayed design, Captive columns, Performance-Based Seismic Design

I. INTRODUCTION:

Bridging a gap remains a symbol of the triumph of mankind over nature. The longer and more inaccessible the chasm, greater is the adulation for the bridge structure. Cable Stayed bridges, synonymous with spans over large open space, have thus always been viewed as a tribute to human achievement. The idea of using cables to support bridge spans is by no means new, and a number of examples of this type of construction were recorded long time ago. Inclined stays were first introduced in England and widely used there in the early part of the nineteenth century. Cable-stayed bridges have become the effective alternatives in case of large span bridges.

The longitudinal behavior of the cable-stayed bridge can be understood as beam on discrete elastic supports and beam bending will be predominant. A number of techniques can be used for the analysis of the cable-stayed bridges. There are many exact methods such as the transverse matrix approach as been adopted by tang, mixed force displacement method as adopted by Smith, and recently used finite element methods used for analyzing the structure. These methods take care of both material as well as geometric non-linearity since cable-stayed bridges exhibit both types of linear behavior.

Cable-stayed bridges exhibit different sources of nonlinearity:

1. Change of geometry of stay cables under different tension load levels (sag effect),
2. Large deflection effects,
3. Combined bending moment and axial load effects,
4. Non-linear stress-strain relationship of concrete,
5. Non-linear stress-strain relationship of steel (including yielding).

II. ELEMENTS AND TYPES OF CABLE-STAYED BRIDGES:

The idea of using cables to support bridge spans is by no means new, and a number of examples of this type of construction were recorded ling time ago. Inclined stays were first introduced in England and widely used there in the early part of the nineteenth century. Cable-stayed bridges are constructed along a structural system, which comprises an orthotropic deck and continuous girders, which are supported b stays, i.e. inclined cables passing over or attached to towers located at the main piers. The application of inclined cables gave a new stimulus to the construction of large bridges. The importance of cable-stayed brides increased rapidly and within only one decade they have become so successful that they have taken their rightful place among classical bridge systems.

III. COMPARISON OF CABLE-STAYED BRIDGES WITH OTHER BRIDGES:

Comparative analysis of cable-stayed and suspension bridges indicate the structural superiority of the new systems developed even for large even for large spans. The application of inclined cables gave a new stimulus to the construction of large bridges also. The cable-stayed bridges are superior to the other bridges because of the following points:

1. The deflections of cable-stayed bridges are very small hence it is much stiffer. Thus the decks can be made lighter and more slender.

2. The quantity of steel required for erection and construction is less and thus economical.

Fig1: Side-spar cable-stayed bridge, Esplanade Riel, Winnipeg, Manitoba .

3. The deck in case of cable-stayed bridges is supported directly from the towers with stay cables providing a significantly stiffer structure.
4. It does not require large or heavy anchorage for the cables.
5. The use of the correct analysis of the structural system.
6. The use of tension members having a considerable degree of stiffness under dead load due to high pre-stress andbeyond this still having sufficient capacity to accommodate the live load.
7. The use of erection methods and methods to ensure that the design assumptions are realized in an economical manner.
8. The development of methods of structural analysis of highly statically indeterminate structures and application of electronic computers.
9. The development of orthotropic steel decks.
10. Application of high-strength steels and new methods of fabrication and erection.
11. From an aesthetic point of view cable-stayed bridges have a pleasing shape, as they clearly reveal the function ofthe cables and towers. They are pleasing in outline, clean in their anatomical conception and totally free from meaningless ornamentation.

IV. MAIN COMPONENTS OF THE CABLE-STAYED BRIDGES: -

The cable-stayed bridge is not a single arrangement but has the possibility of a multiplicity of designs. The main features of this type of bridge is that it has the girder supported not only at the abutments and piers, but also by cables radiating from the towers to the girders.

1. Towers:

The towers can be fixed or pinned at the base. For construction purpose a fixed base tower has many advantages for long span bridges. Th only advantage in a pinned base tower is a reduction in bending moments in the tower. The tower either can be made of steel or of reinforced concrete structure.

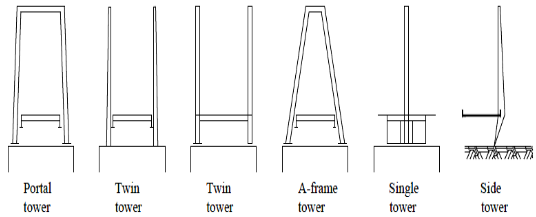

Fig. 2. Tower types

2. Cables:

The basic element for all cables to be found in modern cable-supported bridges is steel wire, which is considerably stronger than ordinary structural steel. In most cases, the steel wires of sizes of 6.4mm diameters are generally used.They are cold-drawn, stress relieved prestressing steel. Steel wire ropes are alsoavailable for the use as cable stays. But because of their low stiffness, they are not commonly used in cable-stayed bridges.

3. Girders:

Girders for cable-stayed bridges of either prestressed concrete or steel have been of various shapes and sizes. They have usually a box shape with either sloping or vertical sides. Various types of girders such as single box girder, double box girder, multiple box girders are used in cable stayed bridges.

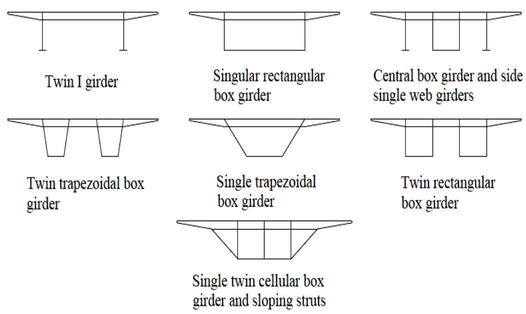

Fig.3.Types of main girder

V. TYPES OF CABLE-STAYED BRIDGE SYSTEM: -

Arrangement of stay cables in space: With respect to the positions in space, which may be adopted for the planes in which the cable stays are disposed, the system can be classified as: two-plane System and single plane system. Also it can be classified further as:

a) To vertical planes system:

In this type of arrangement two alternative layouts may be adopted: Thecable anchorages may be situated outside the deck structure, or they may be built inside the main girders.

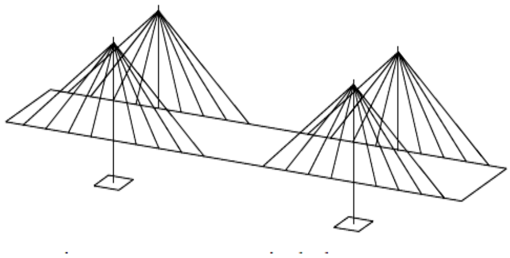

Fig4: Two vertical planes system

b) Two inclined planes system:

In this system the cables run from the edges of the bridge deck to a point above the centerline of the bridge on an A-shaped tower as shown in the adjacent figure. In this type of arrangement the anchorages required for the cables at the deck level are generally provided at the edges of the bridge structure since it would not use the useful portion of the bridge.

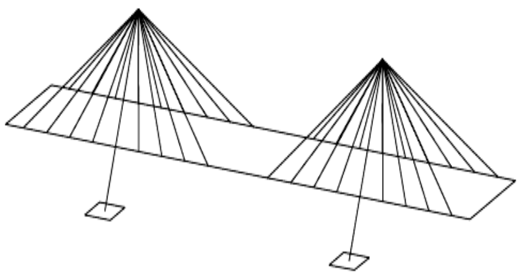

Fig5 :Two inclined planes system

c) Single plane system:

This system which was proposed by Haupt can be used if there is a median space to separate two opposite traffic lanes (functioning as a traffic divider). In this arrangement only one vertical plane of stay cables along the middle longitudinal axis of the superstructure is present. The cables are located in a single vertical strip, which is not used by any for of traffic.

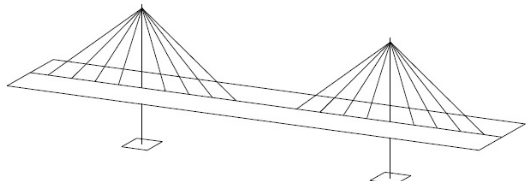

Fig6: Single plane system

d) Asymmetrical plane system:

This is the further development of the single plane system from an aesthetic point of view. In this system instead of having the plane of cable stays along the centerline of the bridge it is made eccentric from the centerline as shown in he figure.

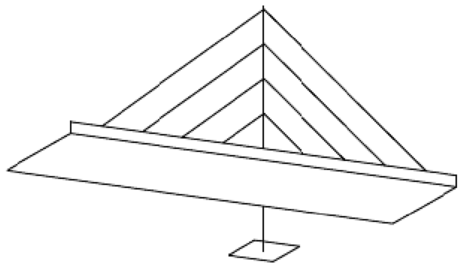

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Fig7: Asymmetrical plane system

VI. METHODS OF STRUCTURAL ANALYSIS:

A number of techniques can be used for the analysis of cable-stayed bridges.Examples include the use of a scaled-down model for testing and the use of analytical model which considers the linear and nonlinear behavior of the cable-stayed bridge when subjected to static and dynamic conditions of load.

1. Linear analysis
2. Preliminary Design
3. Nonlinear Analysis
4. Approximate structural analysis

1. Linear analysis

If the analysis of the cable-stayed bridges is based generally on the assumption that the elastic displacements of a structure are proportional to the applied loads, it is defined as linear behavior. If Hook's law is assumed to be valid, linear superposition applies also to the displacements, and, therefore, to the determination of the stresses of cable-stayed bridge systems. However, for the case of cable-stayed bridges, this assumption has proven to be approximate and, for large spans, unsafe. When the actual performance of the bridge is analyzed and the final deformed geometry is considered, then the loading moments, deflections and stresses have larger magnitude if nonlinearity is neglected.

2. Preliminary design

The design process for a cable-stayed bridge system with accepted geometrical layout may be divided into the following stages:
1. A preliminary set of sectional properties is assumed for each member of the system.
2. The sectional properties assumed is stage 1 are analyzed, applying one of the statical methods of analysis. Stresses and displacements under the given loads on the system are determined and compared with the maximum unit stresses and maximum displacement-span ratios allowed by the specifications.
3. A new set of sectional properties is chosen to satisfy the requirements of the specifications. The above stages are repeated until we obtain a specified relation between the sectional properties assumed in stage 1, and those obtained in stage 3.

3. Nonlinear Analysis:

Nonlinear performance of he cable-stayed bridges generally depends on the behavior of the cables, stiffening girders and pylons.

i. Nonlinearity of the cables:

Nonlinearity of the cables originates with an increase in the loading followed by a decrease in the cable sag which produces an elongation of the cable and corresponding axial tension. To overcome this nonlinear effect, the method of equipment modulus of elasticity was proposed to include the normal modulus and the effect of sag and tension load. The equivalent or ideal modulus of elasticity of the cable as expressed by the Ernst is,

$$E_i = \frac{E}{1+\left(\gamma^2 l^2 E / 12\sigma^3\right)}$$

Where, Ei = Equivalent modulus of elasticity for the cable.

E = modulus of elasticity of straight cable.
L = horizontal length of the cable.
γ = specific weight of the cable.
σ = tensile stress in the cable

ii. Nonlinearity of stiffened girders and pylons:

When stiffened girders and pylons are subjected to simultaneous action of compression loads and bending moments, the interaction of the loadings and the axial forces results in the nonlinear behavior. The degree of nonlinearity depends on the intensity of the compressive load compared with the buckling load and the magnitude of deflection caused by the bending action. Because of the presence of high compressive forces in the relatively slender stiffening girder and towers, the girder and the towers need to be analyzed as a beam column. The axial compression force increases the bending moment of the beam column, and the resulting relationship is nonlinear

4. Approximate structural analysis:

Approximate structural of the cable-stayed bridge system includes the computation of the following basic items:
1. Optimum inclination of the cables.
2. Height of the towers and length of the panels.
3. Cable forces.
4. Approximate weight of the stiffening girder.
5. Self weight of cables.
6. The degree of redundancy

VII. NUMBER AND SPACING OF THE CABLES

Using a small number of cables leads to large cable forces, which requirestrong and complicated anchoring devices and the strengthening of large areas of the deck for distribution of the thrust. It also requires large depth for the main girders. There is no doubt, that a large number of cables would result in less cable forces and also decrease the depth of the main girder. This shallowness in the girder depth facilitates a favorable cross-section for aerodynamic stability and simplifies erection. A large number of stay cables with such a small spacing leads to the optimum in economy and structural simplicity. The spacing should decrease from the tower to the midspan so that the cable forces do not show much variation. Such a close arrangement has the following advantages:
1. Bending strength of the stiffness girders is increased.
2. Concentrated forces at the anchorages are reduced.
3. BM between points of suspension are decreased.
4. Replacement of stay cables in case of damage or deterioration may be achieved more easily.
5. Damping capacity of the bridge is increased due to large number of staycables of different lengths and natural frequencies.

VIII. CONCLUSION:

The approximate analysis of cable stayed bridges have been discussed in brief and also the determination of the approximate cable-stay forces which they are likely to carry under working conditions have also been studied in detail. Cable-stayed bridges being highly statically indeterminate structure, a computer is necessary for the solution of this type of structure, its use being primarily in analysis rather than in design application as used for non-linear analysis. Computer programs are necessary to generate the influence diagrams for cable forces , stiffening girders, bending moments and shears, and tower and pier reactions. Same is also required for rapid solution of various parametric efforts and loadings that have to be taken into account in achieving a reasonably efficient design. The non-linear behavior of the cable-stayed bridges presents problems in the solution of the bridge systems making it rather complex than those of a structure of linear behavior.

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