ISSN (Online) 2456-1290

**International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)**
**Vol 3, Issue 1, January 2018**

# Analysis and Design of Suspension Cable Bridge: A Review

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***Abstract:*** **-- A suspension bridge is a type of bridge where the deck is hung below the suspension cable in vertical suspenders. The main forces are tension in cable and compression in the towers. The cable is anchored at each end of the bridge to maintain tension in this cable. Single steel wires have a 2.54 mm thick can support over half a ton without breaking. The central sag of the cable is varies from 1/10 to 1/15 of the span. The main disadvantage of aerodynamic profile may be required to prevent the bridge deck vibrating under high wind. The suspension bridge is generally not used for heavy rail traffic where high concentrated live load occurs, which adds dangerous stress to the structure. In suspension cable bridge the types of load such as dead load, live load, wind load and design parameter are determined and analyzed by using software sap2000 for different condition. In the following paper same important papers are discussed below.**

***Index Terms*—** **Suspension bridge, Bridge deck, Dynamic load, Wind load, Live load.**

## I. INTRODUCTION

A bridge where deck is hung below the suspended cable in vertical direction is known as Suspension bridge. The cable is anchored at each end of the bridge to maintain tension in cable. The cable is flexible all through, therefore it cannot resist any moment and can adopt any shape under the load that's way the bending moment at every point of the cable is taken zero. A Single steel wire has a 2.54 mm thick can support over half a ton without breaking. The central sag of the cable is varies from 1/10 to 1/15 of the span. The main disadvantage of aerodynamic profile may be required to prevent the bridge deck vibrating under high wind. Suspension bridge is generally not used for heavy rail traffic where high concentrated live load occurs, which adds dangerous stress to the structure. Light, and strong, suspension bridges can span distances from 600 to 2100 meter for longer than any other kind of bridge. The suspension bridge is ideal for covering busy waterways.

Components of Suspension Cable Bridge:

The suspension bridge is mainly divided into superstructure and substructure. In the superstructure bridge deck, cable, tower (above the deck), hangers, lateral basin are included,

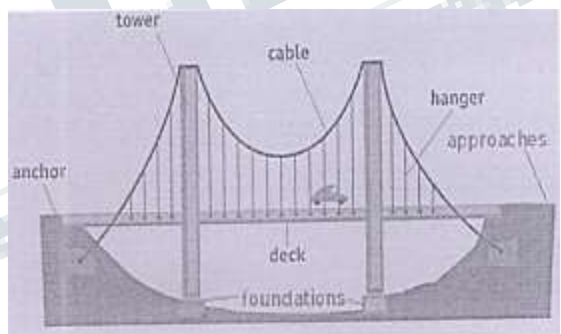


***Figure 1 Suspension Cable Bridge***

**Superstructure:**

Cable – the most central design element to a suspension bridge is the cables. These incredibly strong steel strands are affixed to one anchor then threaded over the towers and attached to the anchor on the other sides.

Tower – towers are the members that support the cables and carry the loads on the bridge span to the foundation below.

Hangers – These are the vertical suspenders cables which support the roadway.

Deck – A bridge deck is the roadway or pedestrian walkway.

**Substructure:**

Anchorages – Is the ends of the bridges cables are protected. They are massive concrete blocks strongly attached to strong rock foundation.

 

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Tower Foundation – with the weight of the bridge resting on cables which in turn rest on the towers, Suspension bridge towers must have a solid foundation

Forces in Suspension Bridge:

The main forces are tension in cable and compression in the towers.

***Figure 2 Forces in Suspension Cable Bridge***

**Structural analysis –Loads:**

Dead Load – the weight of the bridge itself like any other structure, a bridge has a tendency to collapse simply because of the gravitational forces acting on the materials of which the bridge is made.

Live Load – the traffic that moves across the bridge as well as normal surroundings factors such as changes in temperature, precipitation and winds.

Dynamic Load – the environment factors that go beyond normal weather conditions, factors such as sudden gusts of winds and earthquake.

## II. LITERATURE REVIEW

**C. Neeladharan et al. (April 2017)**

[1] In this paper Suspension Bridge are design for dead load, live load and other occasional loads. All loading and unloading conditions in analysis and design are provided as per IRC codal specifications.

Figure 3 Overall View of Suspension bridge In sap 2000

It conclude that a suspension bridge having a specification 1000 m span and single line road of intensity 20 numbers of vehicle each vehicle loaded wih 350 KN (heavy loading class AA- track load) is analyzed by sap 2000.

***Figure 4 Bending Moment for load combination***

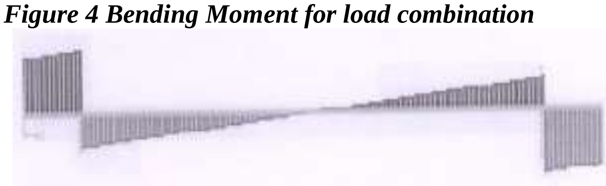

***Figure 5 Shear force for dead load***

The output of the software presents results including moments, axial loads, shear force and displacements. The maximum bending moment and shear force values are analyzed by software and compared with manual design of suspension Cable Bridge.

**Alay Panchal et al. (February 2017)**

[2] The paper presents a literature is on cable-suspension bridges to understand the complex behavior. The paper shows Significance of suspension bridge & type, multiple types loading such as dynamic load, wind load, live load effect, and design parameters. Comparative study of analysis & design of long–span suspension bridge using software sap-2000, Midas civil, ansys with different hanger's configuration has been included.

It is concluded that to improve the aerodynamic stability of structure, use some modified hangers in such a way that they act like bracing. Some computer program or efficient numerical method should develop which gives an accurate result with the time saving function.

**Kotiya Tejal et al. (April 2017)**

[3] The main purpose of this report is to understand the basic concept of the suspension bridge & dynamic analysis of suspension bridge under moving load. It is introduce sap 2000 software for bridge analysis with modeling of 2D bridge, first is cable are supported at different level and second is suspension bridge with three hinged stiffening girders. The study of the suspension bridge is carried out with the different span of the bridge with different methods. The software validations are included in this report by using SAP 2000 software.

It is concluded that, with using different girders there is a different behavior of bridge in different critical load case.

In various Study the suspension bridge under moving load are consider 1train or 2 train in opposite direction but in this paper 1 train, 2 train with highway loading that's way it converted in critical loading as per this critical load the behavior of bridge under highest moving load.

**Surya Antony et al. (June 2015)**

[4] In this paper compares the responses of linear and non-linear vibrations on continuum suspension bridge models. A continuum model with vertical vibration alone is then taken up for the study and the equation of motion is formulated. The governing differential equations were rendered dimensionless to identify the key parameters that control the dynamic response. The resulting eigen value problem was solved using MATLAB to obtain the modal characteristics of the structure. Finite element modeling and analysis on an example problem is performed in MIDAS Civil to find out the effect of hanger spacing on the modal characteristics. The natural frequencies of hangers were determined to study if they participate in the vibration or not.

It was concluded that increase in tower height and additional pre-stressing of main cable is found to increase the natural frequency. The natural frequency found to reduce with increase in side span length. Hanger spacing have a very less effect in the vibrational characteristics.

**Li Dongdong et al. (April 2014)**

[5] It shows the relationship between the elastic support stiffness and the transverse difference between two ends is obtained according to numerous analyses on a suspension bridge. The suspender forces of Qingcaobei Yangtze River Bridge are respectively calculated using traditional method and the method in this paper.

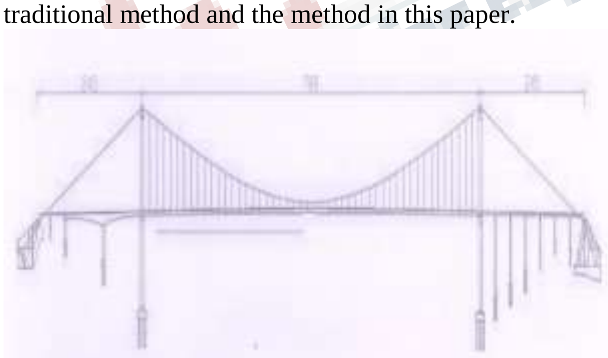

*Figure 6 General arrangement diagram of Qingcaobei Yangtze river bridge (Unit: m)*

It is conclude that [I] the model regarding the suspenders as a tensioned beam pinned at one end and elastically supported at the other end fits the real stress states well.

[II] According to the analysis, it was obtained that the k-Δ curve is a conic curve, in which the elastic support stiffness k increase faster than Δ. The elastic support stiffness k can be approximately taken as a constant the initial value of k-Δcurve to simplify the calculation process and guarantee the computational accuracy.

[III] The method proposed in this paper can meet the precision of suspenders with different lengths, especially to the short suspenders, whose calculation deviation can be controlled in the engineering allowance.

**Tatjana Grigorjeva et al. (2013)**

[6] It is performed numerical experiment by revised engineering method and by FEM under symmetrical load and asymmetrical load. The analysis and design of suspension bridges with the rigid cables successfully resist the action of symmetrical and asymmetrical load and retain its original form but with flexible cables are rather complex.

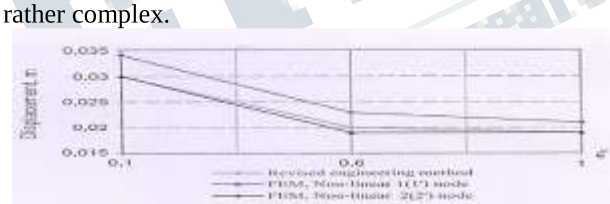

*Figure 7 Displacement of rigid cable and stiffening girder*

*Figur 8 Bending moments of rigid cable (a) and stiffening girder (b)*

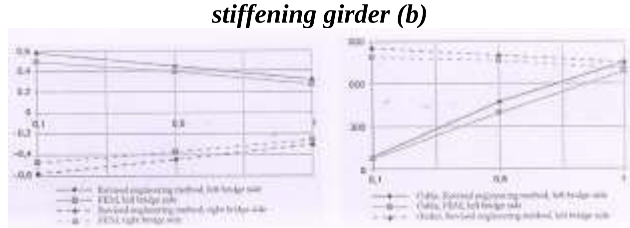

*Figure 9 Displacement of rigid cable and stiffening girder (a) and rigid cable and stiffening girder bending moments (b)*

It is concluded that revised engineering method gives possibility to assess the suspension bridge erection process then the displacement in the middle of bridge span under the action of dead load is zero. Numerical experimentation is performed and compared the results and it shows that the accuracy of revised engineering method is sufficient for conceptual suspension bridge design.

**Serap Altın et al. (March 2012)**
[7] It performed the earthquake analysis of suspension bridges, where the effects of large deflections are taken .The first part of the study deals with an iteration scheme for the nonlinear static analysis of suspension bridges by means of tangent stiffness matrices. At any equilibrium step, the vibrations are assumed to take place tangent to the curve representing the force-deflection characteristics of the structure. The bridge is idealized as a three dimensional lumped mass system and subjected to three orthogonal components of earthquake ground motion producing horizontal, vertical and torsional oscillations. By this means a realistic appraisal is achieved for tensional response as well as other types of vibration. The modal response spectrum technique is applied to evaluate the seismic loading for the combination of these vibrations It is concluded that the concept of tangent stiffness matrix, used in conjunction with the standard model superposition method, provides a systematic approach to the nonlinear dynamic analysis of suspension bridges. The general procedures described in this paper may supply useful information in the study of the aerodynamics of suspension bridges.

**Majid Barghian et al. (March 2011)**
[8] take Soti Ghat Bridge-a pedestrian suspension bridge in Nepal as a case study and has attempted to present a new model to remove the defects of both vertical and inclined hangers and proposed one modified hangers. The change in hangers reduces the tensile forces of inclined hangers significantly and decreases fluctuations in hanger forces therefore, it decreases fracture due to fatigue in hangers. The axial force of towers in the modified model shows improvement considerably comparing with the two other hanger systems. The maximum vertical displacements of the deck for modified hanger system are approximately between the maximum vertical displacements of the deck for two other hanger systems.

**Algirdas Juozapaitis et al. (Jun 2011)**
[9] The paper presents analytical expressions for the calculation of internal forces and displacements of suspension bridges with a rigid cable.

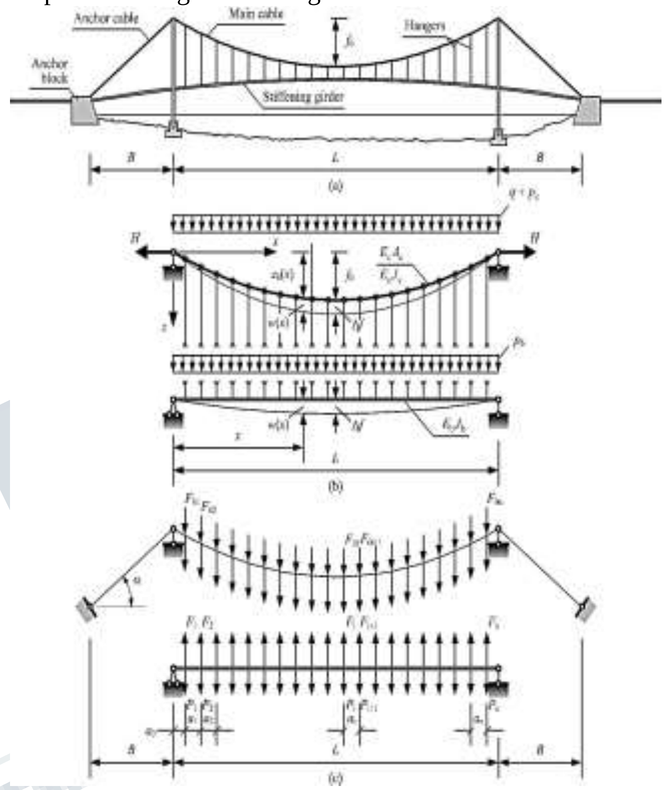


*Figure 10 Calculation model for a suspension bridge*

The paper has analysed classical suspension bridges that consist of a flexible cable and a stiffening girder, as well as modern bridge structures with rigid cable that is used for stabilization of the displacements of kinematic origin. The paper was also present a discrete calculation model for classical suspension bridges. The model considers the effect of hangers and concentrated forces on displacement and action-effects of the bridge. The equilibrium condition of such bridges and the iterative calculation are discussed.

**D. Richards (April 2010)**
[10] It performed critical analysis of the Clifton Suspension Bridge. The paper shows the design aspects including aesthetics, structure, construction, loading & maintenance.

ISSN (Online) 2456-1290

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*Table I Key Statistics*

| | |
|---|---|
| Deck Length | 214 m |
| Loaded Length | 194 m |
| Overall Width | 9.5 m |
| Tower Height | 26.2 m |
| Height of Saddles | 21.3 m |
| Clearance above water | 76 m |
| Height of piers | 26.2 m |
| Dip of Chains | 21.3 m |

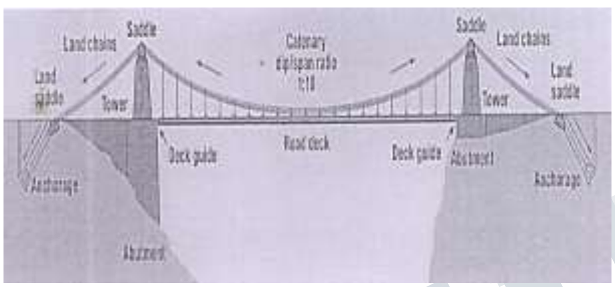


***Figure 11 Clifton Suspension Bridge***

It is concluded that bridge design has been able to withstand the test of time along with accommodating modern day usage requirements. Clifton Suspension bridge will certainly be conserved for as long as viably possible.

**Tatjana Grigorjeva et al. (May 2010)**

[11] The object of this paper to study a method for analyzing and determining the internal forces in the main cables and stiffening girder under static loading to provide recommendations for designing suspension bridges with stiffened cables. Simple formulas are presented for determining displacements, internal forces and stresses in the main cable and stiffening girder. Finite element modeling was performed. An example of a pedestrian suspension bridge is appended.

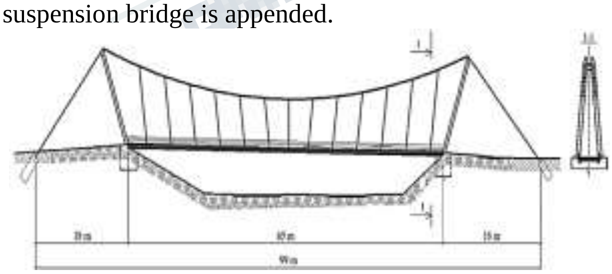

***Figure 12 General layout of a pedestrian suspension bridge***

By this analysis, suspension bridges may be designed for proper behavior and strength without using a more complicated deflection theory based on differential equations and hyperbolic or exponential functions. It has been shown that compared with common types of steel suspension bridges, the system with rigid cables provide certain advantages such as considerable reduction system deformability, simpler detailing and corrosion protection, saving of materials.

**Wai Tak Yim (April 2007)**

[12] It performed the analyses of the Akashi-kaikyo Bridge. This analysis procedure will generally include the considerations of aesthetics, loading, strength, serviceability, construction, temperature, creep, wind, durability, susceptibility to intentional damage, and possible future changes which the bridge might have to undergo.

***Figure 13 Akashi-Kaikyo Bridge model under seismic vibration***

All aspects above will be critically examined in the context of how the design and/or construction of the bridge could have been improved.

**Hirai et al.**

[13] It is perform the deals with the lateral vibration of a suspension bridges and elastic stability under lateral forces, both theoretically and experimentally. In consequence, it is suggested that the seismic design of a suspension bridge superstructure having a long span should be made under the condition of a given lateral displacement and the lateral buckling behavior of stiffening frame is to be checked.

The outline of the lateral vibration and the lateral stability of suspension bridges were discussed, but the paper presents only the basic ideas or suggestion for the above subjects, and there remain a lot of problems to investigate. As far as the seismic design of a suspension bridge in its lateral direction is concerned, the dynamic behavior of the structure must be taken into consideration.

## III. CONCLUSION

- The result including bending moments, shear forces at each node at every point within the element can easily obtained from software output.
- May be better able to withstand earthquake movements than heavier and more rigid bridges.
- The main disadvantage of aerodynamic profile may be necessary to prevent the bridge deck vibrating under high wind.
- Suspension bridge is generally not used for heavy rail traffic where high concentrated live load occurs, which adds dangerous stress to the structure.
- To improve the aerodynamic stability of structure, use some modified hangers in such a way that they act like bracing.
- Hanger spacing have a very less effect in the vibrational characteristics.
- Compared with common types of steel suspension bridges, the system with rigid cables provides certain advantages such as considerable reduction system deformability, simpler detailing and corrosion protection, saving of materials.

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