

# Study on Suspension Bridge: Analysis and Construction criteria

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**Abstract:** A bridge is a structure built to span a valley, road, body of water, or other physical obstacle, for the purpose of providing passage over the obstacle. Nowadays suspension bridges are the pioneers in bridge technology. Of all the bridge types in use today, the suspension bridge allows for the longest span ranging from 2,000 to 7,000 feet. This type of bridge has cables suspended between towers & the cables support vertical suspender cables that carry the weight of the deck below. This arrangement allows the deck to be level or to arc upward for additional clearance. They are ideal for covering busy waterways. In this paper limitation, assumption analysis, how it can be constructing and loads acting on the bridge is described.

**Key words:** Loads, suspension bridge, advantages, assumption, construction, types, history.

## I. INTRODUCTION

Suspension bridge is a type of bridge that has a larger span than any other form of bridges. As it get larger span it become more flexible structure. Major bridges were still built using a truss design until 1808, when an American inventor named James Finley filed a patent on an early version of a suspension bridge. In most jurisdictions, there is a dearth of suspension bridges compared to other bridge types. A short history of suspension bridges which deals with the evolution of suspension bridge design also is included.

A suspension bridge is a type of bridge which is built by suspending the roadway from cables attached to a master cable which runs above the length of the bridge. The design of a suspension bridge is simple and straightforward, and takes advantage of several techniques to distribute the weight of the bridge safely and evenly.

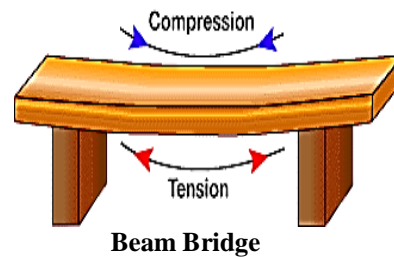
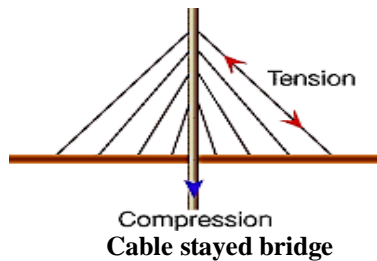
### Advantages over other bridge types

- Longer main spans are achievable than with any other type of bridge.
- May be better able to withstand earthquake movements than can heavier and more rigid bridges.
- The center span may be made very long in proportion to the amount of materials required, allowing the bridge to economically span a very wide canyon or waterway.
- It can be built high over water to allow the passage of very tall ships.

### Limitations compared to other bridge types

- Considerable stiffness or aerodynamic profiling may be required to prevent the bridge deck vibrating under high winds.
- The relatively low deck stiffness compared to other types of bridges makes it more difficult to carry heavy rail traffic where high concentrated live loads occur.
- Under severe wind loading, the towers exert a large torque force in the ground, and thus require very expensive foundation work when building on soft ground.

## Load distribution in different types of bridges



## II. HISTORY OF SUSPENSION BRIDGE

Suspension bridges date back to antiquity. However, they were not products of western technology. Their origin appears to have been in China and the South Americas. Travellers and explorers from Europe saw those structures and their reports engendered interest in the suspension principle.

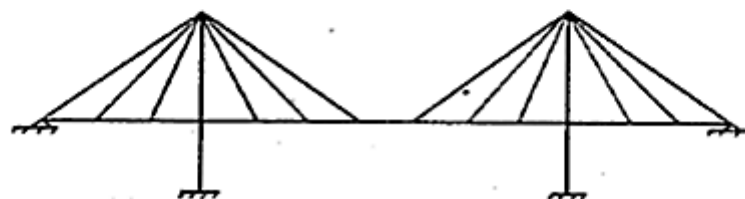
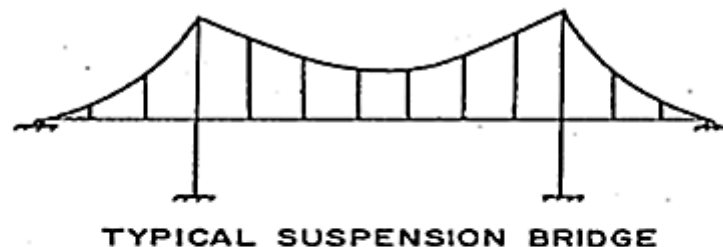
The earliest metal suspension bridges were built in China. Those bridges used iron chains suspended from ground level over gorges or rivers. The decks consisted of wooden planks placed directly on the chains. At least one of those bridges, built in the sixteenth century is still in service.

The suspension bridges observed in the South Americas were non-metallic, fibre structures used for pedestrians. Those structures were reported in the West in the mid-eighteenth century. The suspension principle was first applied in the west for temporary military bridges.

The first American suspension bridge, also a chain structure, was built by James Finley in 1801.

Finley patented the design and later built many small suspension bridges in Pennsylvania during the early 1800's. Among the many novel features of Finley's design were the use of a simple stiffening system for the deck and an intuitive, yet amazingly effective, method for determining the sag of the chains.

The first of those was Brown's Union Bridge, completed in 1823. Thomas Telford's Menai Strait Bridge, an eye bar chain structure, was the most important Civil Engineering feat of the first 50 years of the nineteenth century. The bridge, completed in 1826, had a 576-foot main span. That structure aroused worldwide interest that led to widespread employment of the suspension principle.



Overseas construction of classic suspension bridges has centred in Great Britain with the Forth Road Bridge (1964), Severn Bridge (1966), and the Humber Bridge (1980). The Japanese erected a series of cable-stayed and suspension bridges, including a 2,336-foot main-span suspension bridge between Honshu and Kyushu in 1973. A suspension bridge with a 4,635-foot main span is being planned for Hong Kong, though the construction has been temporarily deferred. The longest proposed suspension bridge will be the 10,827-foot main-span Messina Strait Bridge between Italy and Sicily.

On the European continent, the German revival of cable-stayed bridges has led to widespread employment of that type of bridge. The first cable-stayed vehicular bridge built in the US was erected in Sitka Harbor, Alaska, in 1972. A 1,222-foot main-span cable-stayed highway bridge is presently being built at Luling, Louisiana. That type of cable bridge has economic advantages over most other bridge types in spans ranging from 1,000 to 1,500 feet (10).

### III. TYPES OF SUSPENSION BRIDGE

A suspension bridge is the types of bridge, which is mainly concerned with the application of tension than compression. This bridge are usually suspended by the main cables that are anchored with the tower at both ends of the bridge. Earlier, tower were not provided in suspension bridges because they were usually constructed for short spans. But nowadays, among all the longest bridge of the world 14 bridges are suspension bridges. There are than many types of suspension bridge that exist today, described below:

- **Simple suspension bridge:**

It is oldest types of suspension bridge, usually constructed as the foot bridge. In this type of bridge, a flexible deck is provided which is supported by the cables & anchored to the earth.

- **Under spanned suspension bridge:**

In this type of suspension bridge the main cables are provided below the deck. The cables are anchored to the ground similarly as the above type. Few numbers of suspension bridge have been constructed like this due to instability of the deck.

- **Stressed ribbon bridge:**

It is the modified from the simple suspension bridge in which deck lies on the main cables but it is stiff but not flexible.

- **Suspended – deck suspension bridge:**

In this type of suspension bridge, the stiffed deck is attached to the main cables with the help of suspenders. This type is suitable for heavy traffic and light rail.

Above are most common types of suspension bridge. Some types of suspension bridge are hybrid type. This types of suspension bridges have some portion of deck similar to under - spanned suspension bridge.

### IV. ASSUMPTIONS FOR ANALYSIS

An attempt to analyze a suspension bridge and account accurately for all aspects of behaviour of all the components and materials, even if their sizes and properties were known, would be virtually impossible. Simplifying assumptions are necessary to reduce the problem to a viable size. Although a wide variety of assumptions is viable, some more valid than others, the ones adopting in forming a particular model will depend on the arrangement of the structure, its anticipated mode of behaviour, and the type of analysis. The most common assumptions are as follows:

- **Materials**

The materials of the structures and the structural components are linearly elastic. This assumption allows the superposition of actions and deflections and, hence, the use of linear methods of analysis. The development of linear methods and their solution by computer has made it possible to analyze the large complex statically indeterminate structures.

- **Participating Components:**

Only the primary structural components participate in the overall behavior. The effect of secondary structural components and non structural components are assumed to be negligible and conservative. Although this assumption is generally valid, exception occurs.

- **The Deck**

The decks are assumed to be rigid in plane. This assumption causes the horizontal plan displacements of all vertical elements at a floor level to be definable in terms of the horizontal plane rigid body rotation and translation of the floor slab. Thus the number of unknown displacements to be determined in the analysis is greatly reduced.

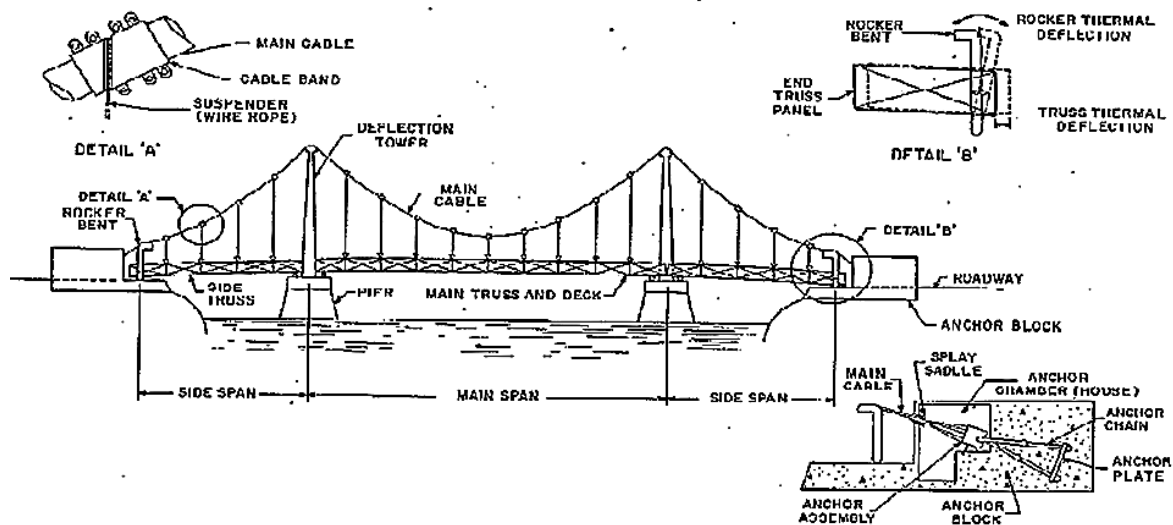
- **Negligible Stiffness**

Component stiffness of relatively small magnitude are assumed negligible. These often include, for example, the transverse bending stiffness of slabs, the minor axis stiffness cable etc. The use of this assumption should be dependent on the role of the component in the structures behaviour.

- **Negligible Deformations**

Deformations, that are relatively small and of little influence, are neglected. These include the shear and axial deformations of girder, in plane bending and shear deformation of floor slabs, and the axial deformations of tower.

## V. TYPICAL MORDEN SUSPENSION BRIDGE



The upper portion of each tower consisted of a massive buttressed Gothic arch connecting two vertical legs. The legs have a tee cross section and were spaced 30 feet apart to accommodate the truss and roadway. The inward cant of the cables, between the towers was intended by Roebling to confer compressive forces on the struts, giving the tower arches additional strength. The towers rise 75 feet above the road.

The height of the towers from the river bed to the tower peaks was 242 feet. Each tower had an internal well, 20 by 30 feet in cross section, under the roadway. At the top of the upper masonry courses, cast-iron bearing plates 11 by 8 feet were bedded to support the original cables. Each cable rested on two large cast-iron saddles. Each saddle rested on 32 rollers, which bear on the plates. When a second pair of main cables was added to the bridge in 1898, similar assemblies were encased in turrets atop the towers. The roller assemblies for the new cables rest on massive steelgirder tables mounted over the original bearing plates.

The cables were connected to land by gravity anchorages, located at the ends of the cable-supported spans. The end of each original cable was enclosed in an anchor block, 75 feet long by 12 feet wide by 25 feet high. A 25-foot wide roadway separated each pair of anchor houses. The original cables entered the anchor blocks on 36-foot centers. Each cable was separated into seven strands at splay saddles located on the faces of the anchorages. In the anchor chambers, the strands were individually looped about anchor shoes. The shoes were connected to wrought-iron eye bars by two long pins.

Table:1. Suspension bridge in the world

Ranking	Bridge	Location	Main span (m)	Completion date	Deck type
1	Akashi Kaikyo	Japan	1991	1998	Truss
2	Xihoumen	China	1650	2009	Twin-box
3	Great Belt East	Denmark	1624	1998	Box
4	Yi Sun-sin	South Korea	1545	2013	Twin-box
5	Runyang	China	1490	2005	Box
6	Nanjing Fourth Yangtze	China	1418	2013	Box
7	Humber	UK	1410	1981	Box
8	Jiangyin	China	1385	1999	Box
9	Tsing Ma	Hong Kong SAR	1377	1997	Box
10	Hardanger Fjord	Norway	1310	2013	Box

## VI. HOW SUSPENSION BRIDGE IS MADE

The suspension bridge construction is done in a sequential way:

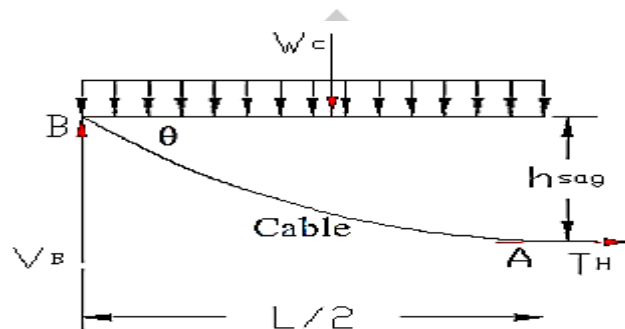
- First the towers (which anchor the main cables), then main cables and lastly deck of the bridge are made. The construction may take few months, a year or decades to complete depending on the project.
- If towers are placed in water then caissons (a concrete or steel cylinder acts as a circular dam) are used to remove water and provides water proof place for the excavation of the foundation.

- After the excavation, the concrete tower foundation is constructed. When the foundation is laid, the towers consisting of single or multiple columns, made up of high strength reinforced concrete, steel or stones, are raised. Later then anchorages are built that provide security to the ends of the cables.
- When the anchorages are completed, the main cables are stretched between the towers and are fixed at the ends in the anchorages. The cable is made up of twisted steel wires having high tensile strength. Then the suspenders (that connect deck to the main cables) are attached to the main cables.
- After the attachment of suspenders, the deck construction is started. The deck construction must proceed equally in both directions in order to balance the load conditions in towers all the time. When deck is completed, it is covered with base layer and then paved.

## VII. LOADS ON SUSPENSION BRIDGE

### • Horizontal Tension

Taking the moments about point A taken at mid-span and assuming that the supports are at equivalent heights, one can solve for the horizontal tension in the cable per the



$$T_h = \frac{W_c(L^2)}{8h}$$

Where:

$W_c$  = distributed load

$T_h$  = horizontal tension

$L$  = span in meters

$h$  = cable sag, in meters

Given the horizontal tension in the cable, solve for the slope of the cable at the towers to acquire the maximum cable tension at the height of the towers. The slope of the cable, the corresponding total tension in all cables and the tension in each cable may be calculated from the following relationships:

$$\phi = \tan^{-1} \left( \frac{4h}{L} \right);$$

$$T' = \frac{T_h}{\cos \phi};$$

$$T_c = \frac{T'}{N};$$

Where:

$\phi$  = cable deflection angle

$T'$  = cable tension, in kN

$N$  = number of cables

$T_c$  = allowable tension per cable

One must choose the number of cables based on the availability of cable and its respective breaking strength. Although each cable supplier must verify the breaking strengths of the cable, Appendix 3 may be used for academic purposes. The sum of the walkway and handrail cable design strengths must exceed the tension in the cable after accounting for allowable stress design factors. Each cable takes a load proportional to its cross sectional area and thus if cables of differing sizes are used, each cable will take a proportional load to its cross-sectional area ratio. In accordance with AASHTO (2003) standards, the following design

approach and assumptions were used throughout this report. To illustrate the design process, a 31 design example has been included through the text. By outlining pertinent assumptions and processes, modifications to the standard design may be used. One such scenario is a community's request to widen the decking from 1.0 meter width to 1.5 meters to allow for animal-pulled carts or a decrease in deck-width for low traffic crossings.

- **Pedestrian load on bridge**

To find the tension in the cable, the load on the cable must be computed. The following details the recommended design approach per American Association of State Highway and Transportation Officials article 3.16 and the supplemental "Guide Specifications for Design of Pedestrian Bridges" document. It is recommended that the reader reference applicable codes and specifications in area of intended construction prior to design.

- **Live loads**

A live load of 85 pounds per square foot is designated unless the walkway area is greater than 400 square feet. Then the live load figure is slowly reduced between 400 square feet and 850 square feet, at which time the minimum standard of 65 pounds per square foot is used. The 65 pounds per square foot minimum load limit is used to provide a measure of strength consistency with the LRFD specifications, which specify 85 pounds per square foot less a load factor indicated in the LRFD Design specification. The formula is as follows:

$$LL=85(0.25+15/\sqrt{A}) \quad 32$$

Where A is the total square feet of walkway surface area. Therefore, using a 1.0 - meter walkway cross sectional area, the following live load schedule would apply:

<b>Span (m)</b>	<b>English Unit Loading (lbs/ft<sup>2</sup>)</b>	<b>Metric unit Loading (kN/m<sup>2</sup>)</b>
<b>1-37 m</b>	<b>85 lbs/ft<sup>2</sup></b>	<b>4.07 kN/m<sup>2</sup></b>
<b>38-78 m</b>	<b>proportional reduction, from 85 to 65 lbs/ft<sup>2</sup></b>	<b>proportional reduction, from 4.07 - 3.11 kN/m<sup>2</sup></b>
<b>79 + m</b>	<b>65 lbs/ft<sup>2</sup></b>	<b>3.11 kN/m<sup>2</sup></b>

#### **Live load schedule 1.0 m deck slab width**

Furthermore, the likely case of small motor-vehicles and animal-driven carts would require both distributed and point-load analysis to find maximum loading case. As such, the conservative assumption loading of 4.07 kN/m<sup>2</sup> (85 lb/ft<sup>2</sup>) is recommended.



Total LL = 4.07 kN/m,

(Assuming 1.0 meter width)

- Dead load

	Assumptions/Conversions	Loading
<b>Suspenders</b>	8 mm diameter x 1.7 m steel rebar = $8.5 \times 10^{-5} \text{ m}^3$ per rod Unit weight steel = $490 \text{ lb/ft}^3 = 7847.3 \text{ kg/m}^3$ 0.67 kg per suspender 0.0098 kN/kg Suspender spacing 1 meter on center per side	0.007 kN/m
<b>Cross beams</b>	10 cm x 10 cm x 1.4 m Assume $600 \text{ kg/m}^3$ (Appendix 4) Cross beams 1 meter on center	0.082 kN/m
<b>Decking</b>	5 cm x 20 cm x 2 m = $0.02 \text{ m}^3$ per 2 meter member Assume $400 \text{ kg/m}^3$ (Appendix 4) 8 kg per decking panel 5 decking panels across	0.196 kN/m
<b>Cable</b>	Assume 6x19 IWRC galvanized steel cable Assume 32 mm cable (1 1/4") : $2.89 \text{ lb/ft}$ Assume 6 cables 1 lb/ft = 1.288 kg/m	0.036 kN/m

Total DL = 0.321 kN/m, assuming 1.0 meter width

## REFERENCES

- [1] Optimum Dimensions of Suspension Bridges Considering Natural Period Jewel Sarker, Dr. Tanvir Manzur
- [2] cable-suspended pedestrian bridge design for rural construction by averylouise bang B.S. university of iowa, 2007.
- [3] Introduction to cable suspension bridges By Theodore hopwood II And James h. Havens
- [4] Suspension Bridges Professor Filip C. Filippou Department of Civil and Environmental Engineering University of California, Berkeley
- [5] Responce suspension bridges W.C. yuan S.B. wang L.C fan, departement of engineering, tongji university shanghai, 200092.
- [6] Anil k. Chopra, *Dynamics of structures: theory and application to earthquake engineering* (Prentice Hall, Upper Saddle River, New Jersey, 1995).
- [7] Abdel- Ghaffar. *Dynamic Analysis of Suspension Bridge Structures*, EERL 76-01, Earthquake Engineering Research Laboratory, California Institute of Technology, Pasadena, California, 1976. Moisseiff, L. S. and Lienhard, F., Suspension bridge under the action of lateral forces, *Trans. ASCE*, 58, 1933. Brotton,
- [8] D. M., A general computer programme for the solution of suspension bridge problems, *Struct. Eng.*, 44, 1966.
- [9] Saafan, A. S., Theoretical analysis of suspension bridges, *Proc. ASCE*, 92, ST4, 1966.