Suspension bridge

From Academic Kids

This article concerns modern suspended deck suspension bridges, commonly called suspension bridges. For information concerning an earlier type (still in use for some pedestrian crossings) see simple suspension bridge.

A suspended-deck **suspension bridge** is a modern vehicle-carrying bridge that uses towers to support the main load bearing cables or chains. This type of bridge is the only practical type usable for very long spans, where topography prohibits or it is hazardous to maritime traffic to add temporary or permanent central supports. This kind of bridge is particularly pleasing to the visual senses, with one beautiful example of the type being the Golden Gate Bridge at the entrance to San Francisco Bay.

Golden Gate Bridge, California, USA

The suspension cables must be securely anchored at each end of the bridge, since any load applied to the bridge is transformed into a tension in these main cables. The main cables continue beyond the pillars to deck–level supports, and further continue to connections with anchors in the ground (An exception is the Royal Albert Bridge (1859) where the anchors are replaced by an arch between the columns.) The roadway is supported by vertical suspender cables or rods. In some circumstances the towers may sit on a bluff or canyon edge where the road may proceed directly to the main span, otherwise the bridge will usually have two smaller spans, running between either pair of pillars and the highway, which may be supported by suspender cables or may use a truss bridge to make this connection. In the latter case there will be very little arc in the outboard main cables. Without special design this type is generally not suited for regional rail applications as the bridge will flex under the concentrated load of a locomotive.

The design was developed in the early 19th century. Early examples include the Menai and Conwy Suspension Bridges (both opened in 1826) in north Wales and the first Hammersmith Bridge (1827) in west London. Since then, suspension bridges have been built all over the world.

Contents

Advantages over other bridge types

- 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.
- Neither temporary central supports nor access from beneath is required for construction, allowing it to span a deep rift or busy or turbulent waterway.
- Being relatively flexible it can flex under severe wind and seismic conditions, where a more rigid bridge would have to be made much stronger and so also heavier.

Disadvantages over other bridge types

- Lacking stiffness the bridge may become unusable in turbulent and strong wind conditions and so require temporary closure to traffic.
- Being flexible in response to concentrated loads the structure is generally not used for regional rail crossings, which concentrate the maximum "live" loading at the location of the locomotives.
- 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.

Structural analysis

The main forces in a suspension bridge are tension in the main cables and compression in the pillars. Since almost all the force on the pillars is vertically downwards and they are also stabilized by the main cables, they can be made quite slender.

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Suspension_bridge-panoramic.jpg
The slender lines of the Severn Bridge, near Bristol, England

Assuming a fairly negligible cable weight compared to the deck and vehicles being supported, a suspension bridge's main cables will form a parabola (very similar to a catenary, the form the unloaded cables take before the deck is added). This can be seen from the constant gradient increase with linear (deck) distance, this increase in gradient at each connection with the deck providing a net upward support force. Combined with the relatively simple constraints placed upon the actual deck, this makes the suspension bridge much simpler to design and analyse than a cable stayed design, where the deck is in compression.

Suspension types

The suspension in older bridges may be made from chain or linked bars, but modern bridge cables are made from multiple strands of wire. This is for greater redundancy; a few flawed strands in the hundreds used pose very little threat, whereas a single bad link or eyebar can eliminate the safety margin or bring down the structure outright.

Deck structure types

Most suspension bridges have used open truss structures to support the roadbed (particularly owing to the unfavorable effects of using plate girders, discovered accidentally). Recent developments in bridge aerodynamics have allowed the re-introduction of plate structures. In the illustration to the right, note the very sharp entry edge and sloping undergirders in the suspension bridge shown. This enables this type of construction to be used without the danger of vortex shedding and consequent aeroelastic effects such as those that destroyed the Tacoma Narrows Bridge.

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RedSuspensionBridge.jpg
A plate deck suspension bridge over the Yangtze River (Chang Jiang) in China

Construction sequence

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Little_Belt_Bridge_(1970)_(Wide_view_-_01).jpeg
New Little Belt suspension bridge, 1970 Denmark

- Where the towers are founded on underwater piers, caissons are sunk and any soft bottom is excavated for a foundation. If the bedrock is too deep to be be exposed by excavation or the sinking of a caisson, pilings are driven to the bedrock or into overlying hard soil, or a large concrete pad to distribute the weight over less resistant soil may be constructed. The foundation piers are then extended to above water level.
- Where the towers are founded on dry land, deep foundations or pilings are used.
- From the tower foundation, towers of multiple columns are erected using concrete, stonework, or steel structures. At some elevation there must be a passage for the deck, with the columns extending high above this level.
- Smooth open cable paths called saddles are anchored atop the towers. These allow for slight movements of the cable as the loads change during construction. The top of these saddles may be closed with an additional part after completion of the bridge.
- Anchorages are constructed to resist the tension of the cables. These are usually anchored in good quality rock. The anchorage structure will have multiple protruding open eyebolts enclosed within a secure space.
- A temporary suspended walkway supported by wire rope follows the curve of the cables to be constructed, mathematically described as a catenary arc.
- Another set of wire ropes are suspended above the walkway and are used to support a traveler that has wheels riding atop these cables. There will be one set of wire ropes and a traveler for each cable to be "spun"
- Pulling cables attached to winches are capable of pulling the traveler from one anchorage to the other, traveling in arcs to the tops of the two towers.
- High strength wire, typically less than 1cm in diameter, is pulled in a loop by pulleys on the traveler, with one end affixed at an anchorage. Workers stationed along the walkway attach the passing cable to a bundle with a temporary binding. When the traveler reaches the opposite anchorage the loop is placed over an anchor eyebolt.
- The traveler is returned to the start point to pick up another loop or it is used to carry a new loop from this side.
- As loops are placed, corrosion proofing may be applied.
- In this way a complete sub-cable is created linking the eye-bolt (or a set of eye bolts) from one anchorage to the other. The sub-cables will have a hexagonal cross section and are held together with the temporary bindings.
- Multiple adjacent sub-cables are placed adjacent to each other. While these are on a hexagonal grid, the general form for the larger cable is circular.
- The entire cable is then compressed by a traveling hydraulic press into a closely packed cylinder and tightly wrapped with additional wire to form the final circular cross section.
- Saddles to carry the suspender cables are clamped to the main cables, each with an apropriate shape to conform to the ultimate slope of the main cables. Each saddle is an equal horizontal distance from the next, with spacing appropriate to the design of the deck.
- Suspender cables engineered and cut to precise lengths and carrying swedged ends are looped over the saddles. In some bridges, where the towers are close to or on the shore, the suspender cables may be applied only to the central span.
- Special lifting hosts attached to the suspenders or from the main cables are used to lift prefabricated sections of bridge deck to the proper level, provided that the local conditions allow the sections to be carried below the bridge by barge or other means, otherwise a traveling cantilever my be used to extend the deck one section at a time. During the construction the finished portions of the deck will appear to pitch upward rather sharply, as there is no downward force in the center of the span. Upon completion of the deck the added load will pull the main cables into an arc mathematically described as a parabola, while the arc of the deck will be as the designer intended - usually a gentle upward arc for added clearance if over a shipping channel, or flat in other cases such as a span over a canyon,
- With completion of the primary structure various details such as lighting, handrails, finish painting and paving are added.

The largest suspension bridges in the world

(by total length of suspension)

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Akashi-kaikyo_bridge2.from_jp_wp.akadruid.jpg
The Akashi-Kaikyo Bridge between Akashi and Awaji island, Japan

1. Akashi-Kaikyo Bridge (Japan) 3,909 meters
2. Kurushima-Kaikyo Bridge (Japan) 3,260 meters (suspended sections are not all contiguous)
3. San Francisco-Oakland Bay Bridge (USA) 2,822 meters (two bridges with common anchorage)

4. Great Belt Bridge (Denmark) 2,719 meters
5. Mackinac Bridge (USA) 2,625 meters

(by length of centre span)

1. Akashi-Kaikyo Bridge (Japan) 1,991 metres - 1998
2. Great Belt Bridge (Denmark) 1,624 metres - 1998
3. Runyang Bridge (China) 1,490 metres - 2005
4. Humber Bridge (England) 1,410 metres - 1981 (The largest from 1981 until 1998.)
5. Jiangyin Suspension Bridge (China) 1,385 metres - 1997
6. Tsing Ma Bridge (Hong Kong) 1,377 metres - 1997 (with road and metro)
7. Verrazano Narrows Bridge (USA) 1,298 metres - 1964 (The largest from 1964 until 1981.)
8. Golden Gate Bridge (USA) 1,280 metres - 1937 (The largest from 1937 until 1964.)
9. Höga Kusten Bridge (Sweden) - 1,210 metres - 1997
10. Mackinac Bridge (USA) 1,158 metres - 1958
11. Minami Bisan-Seto Bridge (Japan) 1,118 metres - 1988
12. Second Bosporus Bridge (Turkey) 1,090 metres - 1988
13. First Bosporus Bridge (Turkey) 1,074 metres - 1973
14. George Washington Bridge (USA) 1,067 metres - 1931 (The largest from 1931 until 1937.)
15. Third Kurushima-Kaikyo Bridge (Japan) 1,030 metres - 1999

main article: List of largest suspension bridges


Tsing Ma Bridge, Hong Kong

The Strait of Messina Bridge, with a center span of 3,300 m, is planned to connect Italy and Sicily but construction has not yet begun. Bridges have also been suggested for the Strait of Gibraltar and the Sunda Strait with longest spans of several kilometres. The suspension cables for these longest bridges are suspended from the ends of cable-stayed struts extending diagonally from tall pylons.

The length of these bridges can also be compared by the entire length of the bridge. For example, the Mackinac Bridge (USA) is 8,038 meters (26,372 feet) from shore to shore.

Other famous suspension bridges

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Western portion of the San Francisco-Oakland Bay Bridge

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Clifton Suspension Bridge (England)

- Union Bridge (England/Scotland) 137 metres - 1820. The oldest in the world.
- Menai Suspension Bridge (north Wales) 176 metres - 1826
- Conwy Suspension Bridge (north Wales) 1826
- Wheeling Suspension Bridge (USA) 308 metres - 1849. The largest suspension bridge from 1849 until 1883
- Clifton Suspension Bridge (England) 214 metres - 1864
- Brooklyn Bridge (USA) 486 metres - 1883. The largest suspension bridge from 1883 until 1903.
- Williamsburg Bridge (USA) 488 metres - 1903. The largest suspension bridge from 1903 until 1924.
- Bear Mountain Bridge (USA) 497 metres - 1924. The largest suspension bridge from 1924 to 1926. The first suspension bridge to have a concrete deck. The construction methods pioneered in building it would make possible several much larger projects to follow.
- Benjamin Franklin Bridge (USA) 533 metres - 1926. The largest suspension bridge from 1926 until 1929.

- Ambassador Bridge (Michigan-Ontario, USA-Canada) 564 metres -1929. The largest suspension bridge from 1929 to 1931.
- Royal Gorge Bridge (USA) 1929 The highest (384 metres) suspension bridge in the world.
- San Francisco-Oakland Bay Bridge (California, USA) 704 metres -1936 The western portion is two complete two tower bridges end-to-end with a central anchorage, required to avoid dynamic interactions between three main spans between the four towers. Until recently, this was the longest steel high-level bridge in the world. [1] (*http://www.sfmuseum.org/hist9/mcgloin.html*) The eastern portion, currently being replaced, may be a self-anchored suspension bridge if the current design is not changed.
- Tacoma Narrows Bridge, (USA) 853 metres - 1940 The Tacoma Narrows are prone to sustained and moderately strong winds, with which the bridge had a tendency to resonate, leading to its collapse only months after completion. Replaced using the same towers but a different deck structure.

See also

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- rope bridge - which have many features in common with a suspension bridge and predates them by at least three hundred years. However in a rope bridge the deck itself is suspended from the anchored piers and the guardrails are non-structural.
- cable-stayed bridge - again, superficially similar to a suspension bridge, but cables from the towers directly support the roadway, rather than the road being suspended from cables connecting two towers.

External links

- Structurae: Suspension Bridges (*http://www.structurae.net/en/structures/stype/s1001.cfm*)
- American Society of Civil Engineers (*http://www.asce.org/history/hp_bridges.html*) History and Heritage of Civil Engineering - Bridges

da:Hængebro de:Hängebrücke fr:Pont suspendu ja:吊り橋 ru:Висячий мост nl:Hangbrug sv:Hängbro zh:悬索桥

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