Mason Smetana
CEE 1335
Assignment #3

Long Span Bridge Trends

The introduction of more sophisticated mathematics and advancements in material science allowed for the design and construction of more complex bridge structures. More specifically, the overall length of bridge spans has increased due to all of these improvements. The first few bridges constructed prior to these advancements would typically be simple slabs that would span a few feet across a divide to allow for easier foot travel. Today, large bridge spans of up to 6600 ft stretch across land divides at great heights and aid in the transportation of both people and material. The more recent main bridge types include girder (beam) bridges, truss bridges, cantilever bridges, portal frame brides, arch bridges, suspension bridges, and cable-stayed bridges. There are two significant types of bridges that promoted the achievement of such long spans: suspension bridges and cable-stayed bridges. The longest suspension bridge is the Akashi Kaikyō Bridge with a main span length of 6,532.2 ft. Following this, the largest cable-stayed type bridge, the Russky Bridge, has a main span length of 3,622 ft.

Figure 1: Akashi Kaikyō Bridge – Kobe, Japan

Figure 2: Russky Bridge – Vladivostok, Russia

In order to demonstrate how these structures are able to cover such great lengths, a few key concepts must be explained. A bridge will usually consist of multiple elements that each serve individual purposes, but all work together to keep the bridge stable and give the bridge the ability to carry loads. Bridges consist of spans, which are separated by either reinforced land or columns (piers) that are connected to the foundation of the structure. Each of these elements work together to transfer forces throughout the structure. Man-Chung Tang, a Chairman of the Board T.Y. Lin International, summarizes how these elements act in a structure in his article *Evolution of Bridge Technology*, "If we observe the anatomy of all structures in the world, we find that there are basically only three types of structural elements: those that transfer the forces that act upon it by axial force, by bending or by curvature. A member in a truss is an axial force element. A beam is a bending element. And, arch ribs and suspension cables are curvature elements," (Tang, 2007). The three basic types of elements are implemented in every bridge that has ever been constructed. The way these elements are used in a structure places limitations on how long a span can be. For example, the simplest form of these bridge types, the girder bridge, carries loads across each span by placing the top of the beam in compression and the bottom of the beam in tension.

Depending on the material, the length of the spans are limited to how much bending moment or tensile/compressive forces they can observe before failure. As structural materials advanced, from a log being turned to its side all the way to the steel used in construction today, the durability of bridges improved significantly. When some of the earliest forms of concrete were discovered, during the era of the Roman Empire, the arch bridge became a very popular bridge type. It took advantage of avoiding tensional stresses that could develop in an element of the structure by distributing the loading along the arch in compression. Upon the discovery iron and steel, more complex geometrical structures were able to be constructed. A truss bridge uses various steel shapes to transfer the load in both tensile and compressive manors. Eventually during the 19th century, the wire rope was invented by German mining Engineer Wilhelm August Julius Albert. These wire ropes were then introduced to bridge designs that now hold the longest span bridges (suspension and cable-stayed bridges). Prior to these discoveries, the length of bridge spans were limited to material constraints and fundamental analysis methods. It was not until recently (i.e., the 20th century) that bridge engineers took advantage of the new materials and analysis techniques. At this point in time, more bridges had to be built to meet the demand of increasing transportation needs. Still with all of these advancements, each bridge type may have a limit on how long its span length can be.

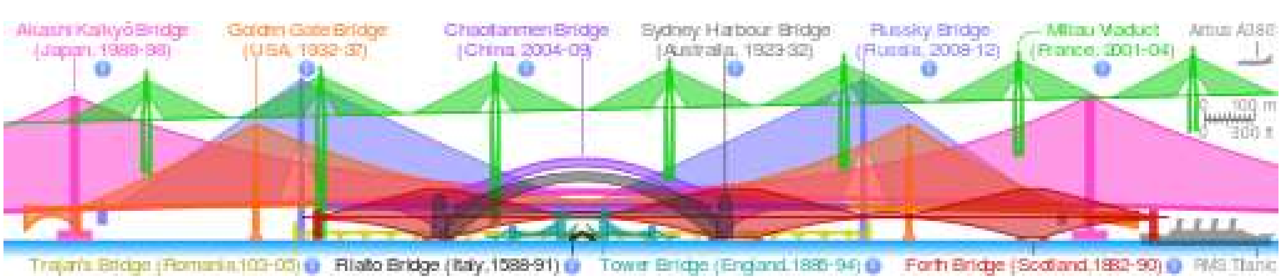
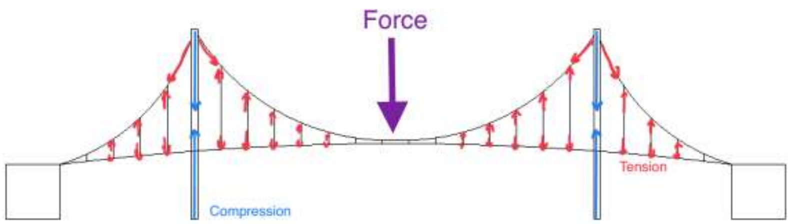
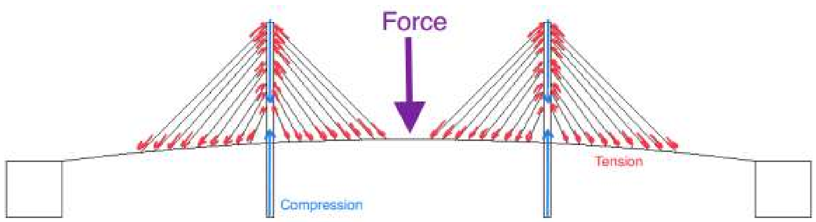


Figure 3: Comparison of Notable Bridge Structures

As seen in the visual shown in **Figure 3**, in order to span greater lengths, the recently constructed bridges are typically bridges that contain cables as part of their structure. Taking a closer look at the Akashi and Russky bridges, these structures are very similar. They contain approach spans and one large span in between two support towers. These large towers are holding the compressive load applied from the cables pulling down in either direction. The height and design of these towers play a large factor in the overall length of the span. If the towers are unable to withstand the compressive forces that develop within them, then the entire structure will fail.



Suspension Bridge Flow of Forces



Cable-Stayed Bridge Flow of Forces

The cables in between the towers are holding the bridge deck up in a tensile manor. This is because cables are usually designed to be tensile members and distribute the larger load into smaller segments. Heller and Oakley mention in their book *Salvadori's STRUCTURE IN ARCHITECTURE*, "The tensile load in a cable is thus evenly divided among the cable's strands, permitting each strand to be loaded to the same safe, allowable stress. This behavior makes cables the singularly most efficient structural form possible. All of the material of a cable can be effectively used to carry loads, and there is no possibility of buckling," (Heller & Oakley, 2017). Also, the curved nature of suspension bridges closely resembles an inverted arch bridge. The use of the cables in the suspension bridge allow for a uniformly distributed tensile loading of the gravitational forces applied to the deck. Similarly, the arch bridge effectively uniformly distributes a compressive load within its elements. In an arch bridge, the members that are in tension would instead be in compression and the compression members would then be in tension, respectively. The curvature within these cables are also known as funicular curves. According to Heller and Oakley, "the funicular curve differs from a parabola, although it has the same general configuration: It is a catenary curve…" (Heller & Oakley, 2017). Not only do these curves generally follow a parabolic curve, but the cables also naturally bend to their self-weight and alter this curve. This affect is known as catenary curve, which enables the use of a cables natural hanging tendency to support loading. Additionally, suspension bridges and cable-stayed bridge will usually contain diaphragms or other framed structures in between the bridge decks to resist bending in the deck enforced by the tension within the cables. (This is illustrated in **Figure 4**)

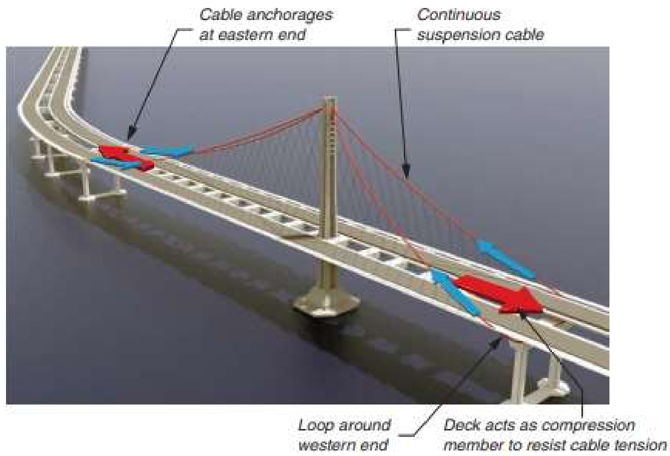


Figure 4: Additional flow of forces in cable-stayed bridge

Due to the overall tension that develops in the cables, there is no need to have additional supports underneath the deck as seen in other bridges. The cables are able to carry the weight of the deck and force the towers to develop a compressive axial force reaction. Their decks are usually reinforced by truss system (as seen in the Akashi bridge) or a girder system (as seen in the Russky bridge). Without the reinforcement of the deck, the internal forces that develop would cause the asphalt and concrete materials to fail from just their self-weight alone.

Although the aesthetic of bridges are generally appealing, they are also an integral component of how bridges support different loadings. Geometry and material are significant metrics that are carefully selected by the design engineer. A contemporary engineer is able to combine prior knowledge of existing structures and imagination in the design of a new structure. With these features in mind, an engineer must always consider the economic budget as a driving constraint in a project. The following table shows the recommended span ranges based on bridge type. This is sourced from Puckett and Barkers book, *Design of Highway Bridges*.

Bridge type	Material	Span range
Slab	Concrete	0–40 ft. (0–12 m)
Girder	Concrete	40–1000 ft. (12–300 m)
Girder	Steel	100–1000 ft. (30–300 m)
Cable-Stayed	Steel	300–3500 ft. (90–1100 m)
Truss	Steel	300–1800 ft. (90–550 m)
Arch	Concrete	300–1380 ft. (90–420 m)
Arch	Steel	800–1800 ft. (240–550 m)
Suspension	Steel	1000–6600 ft. (300–2000 m)

Figure 5: Table of Bridge Types and Span Lengths

A girder bridge design for an overpass is not only simple to construct but also may only cover a small divide of land. However, on the other side of the spectrum in a region such as Asia, the landscape is much more mountainous and surrounded by water in some locations. This may be why many of these longer spanned bridges being built in Asia. When building over a body of water, much more surveying for foundation elements will have to be used. It is much more difficult to build a series of piers across a body of water than two large towers as seen in the suspended structures. The combination of higher mountains and larger bodies of water highlights the need for longer spans in a region such as Asia. Also, a lot of the steel that is fabricated in the world is exported from China. According to worldsteel.org, China produced 928.3 million tons of steel, whereas America only produced 86.6 tons of steel in 2018. The production of such large structures will cost less if the supply is more abundant locally. Another example of this phenomena can be found in Pittsburgh Pennsylvania. In this city, there are a total of 440 bridges(a lot of which are steel). This is because many years ago Pittsburgh exported a plentiful amount of steel both locally and nationally.

It would not make sense to build a suspension bridge if the divide between two points is less than a significant distance. As the spacing increases, more spans and piers will be needed in order minimize the forces that develop within the structural members. At this point a suspension bridge or other bridges of this nature will be more effective because they will require less foundation elements for stability and distribute this loading more effectively. If the structure does not need to be complex, it will be cheaper and easier to construct. A girder bridge or truss bridge is a perfect bridge build over a highway system. Due to the generally smaller span spacing, a girder bridge comprised of either prestressed concrete girders or steel girders are easy to assemble. The best designed bridge is arguably a bridge that is ultimately the most economic and effectively uses the material properties in design. Other than these considerations, the landscape and region will also affect the overall design of the bridge.

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