How it Works

An Illustrated Structural Analysis of the Golden Gate Bridge

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This document was created during the author's enrollment at the University of Southern California, and was intended for an academic audience with a certain level of subject familiarity. It was designed to illustrate structural principles and synergy of form and structure to 2nd year architecture students. It is intended to be explorative and intellectually provocative, not authoritative.

It is the author's desire that the information contained herein be publically available and accessible as an educational aid. Every reasonable effort has been made to conduct scholarly research and present relevant findings in a meaningful and unbiased way.

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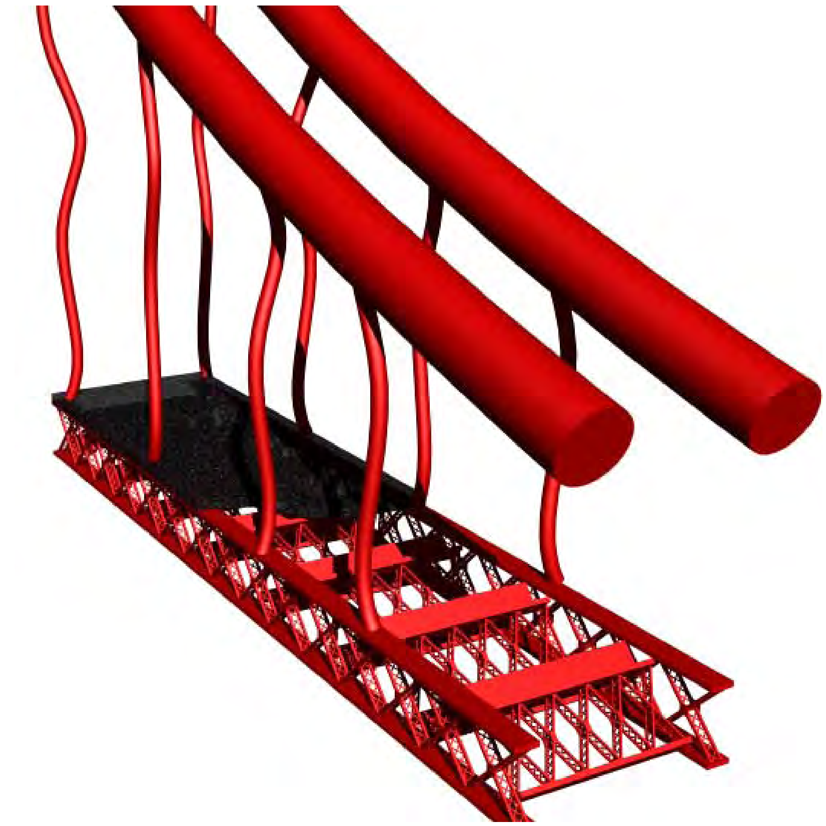
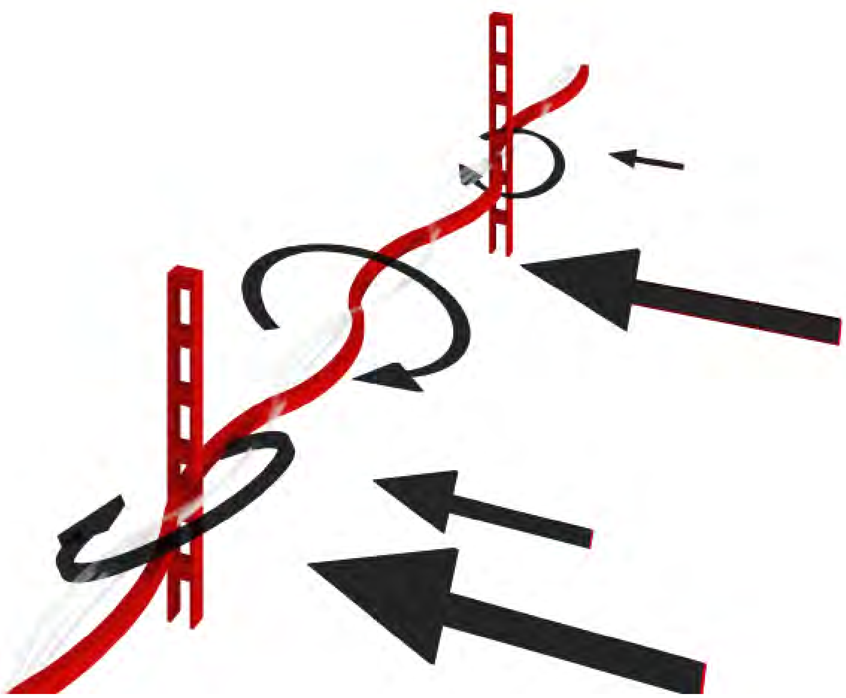
The Golden Gate Bridge is a truly incredible structure, beautifully and brilliantly executed. Though from a distance it might appear “simple” in its graceful elegance, it embodies a wealth of science and ingenuity which make it one of the most incredible engineering feats of the century—and a perfect example of the synergy of form and structure.

Basic Bridge Information
Joseph Strauss **Engineer**
Date Completed **1937**
Location **San Francisco CA**
Total length **8,981 feet**
Suspension span **6,450 feet**
Span between towers **4,200 feet**
Height above water **746 feet**
Depth of water **318 feet**
Load from cables **61,500 tons**
Weight of towers **44,400 tons**
Total weight **887,000 tons**



Strength, Stiffness, and Stability The combination of the flexible suspended cable system with the stiff/rigid truss system provides the necessary balance of stability and flexibility. It is similar in concept to that of reinforcing concrete with steel rebar to address the need for both tensile and compressive strengths in a structure, in order to maximize efficiency by exploiting each material's strengths. While the cables alone would not provide the necessary stiffness (or lateral resistance) needed for the bridge to function safely and resist being tossed about by wind, seismic loads, etc., they provide the primary vertical/spanning support for the entire structure. Similarly, while the trusses alone could never span the distance between the towers, they perform very well in the short spans between the cables, and provide a rigid framework for the road to rest upon.



Wind Load Wind resistance is a major factor in bridge building. Beyond considering wind pressure as a uniform dynamic load along the exposed face of the bridge (requiring lateral resistance/rigidity), it is also critical to consider the unevenness of gusts of wind along the 6450 foot length of the span. Not only could the wind be expected to be applied unevenly as impact point loads, but the wind currents created as the wind flows through the bridge could also result in dangerous vibrations, even destroying the bridge at certain frequencies. (Recall the Tacoma Narrows Bridge disaster.) The flexibility of the cable suspension system combined with the rigidity of the truss system work together to combat this.

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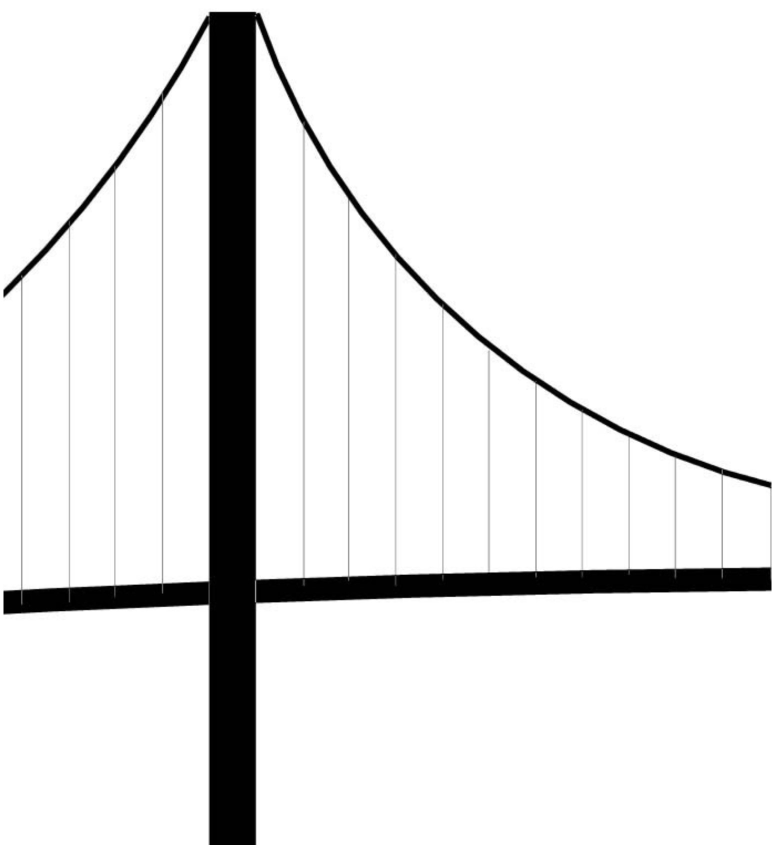
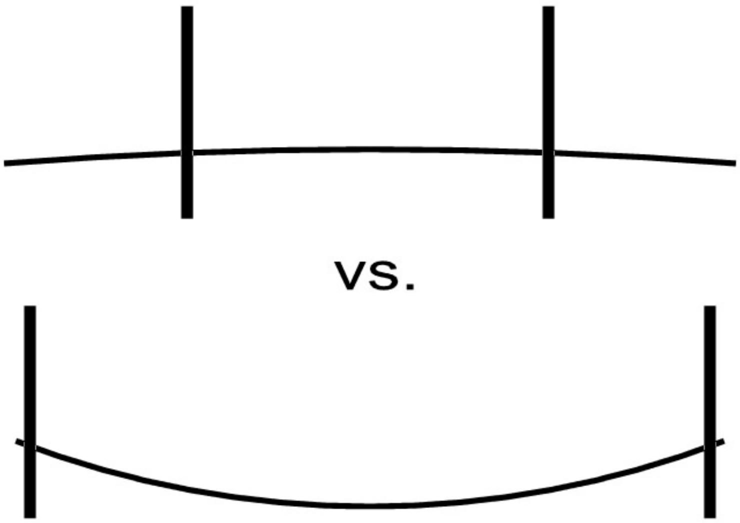
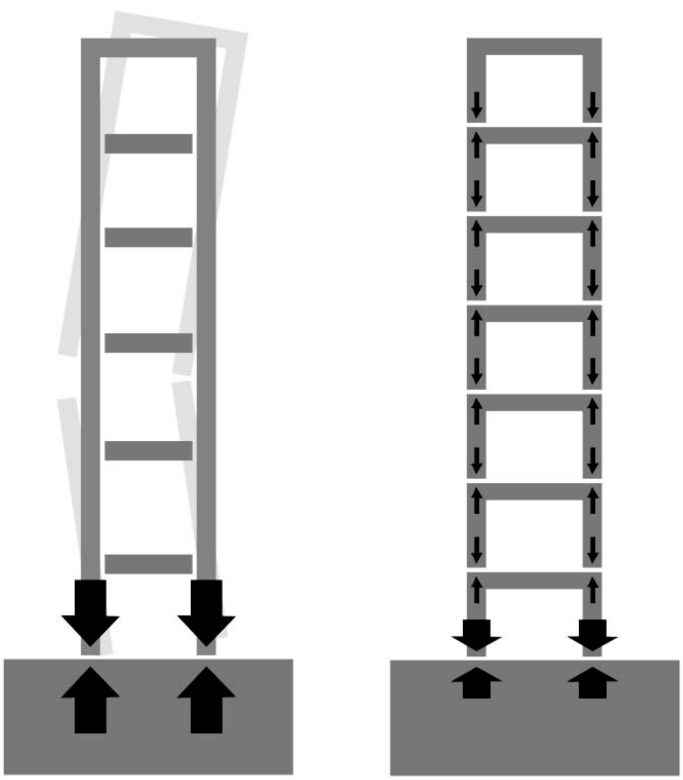
Trusses within Trusses The steel trusses exploit steel's tensile capacity and maximize its efficiency by removing bulk which does little or no work. If this were not the case, much of the steel's structural capacity would be wasted supporting itself, resulting in an extremely inefficient system. In addition, the increased mass would increase the seismic force on the structure.



Cable Suspension By using cable wires in suspension (i.e., in tension vs. in compression), the cables could be very thin and elegant as there is no threat of buckling in tension. This thinness gives the structure an elegant expression. The viewer does not see a support system struggling to bear 61,500 tons—as with arched/compression bridges—but rather is impressed with the overall expression of lightness and grace.

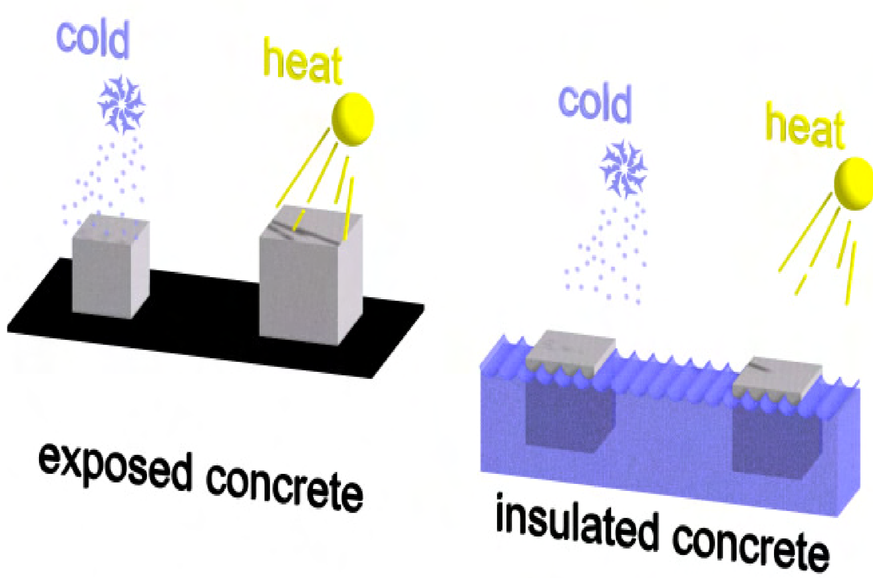


Cantilever The upward curve of the bridge greatly reduces positive bending, which is essential for such a long span of 6450 feet. This is enhanced by strategic placement of the towers. Rather than being on each end, the towers are located away from the edges so that the bridge cantilevers on either end, causing negative bending which counteracts the positive bending. This significantly reduces the amount of steel necessary in the bridge.

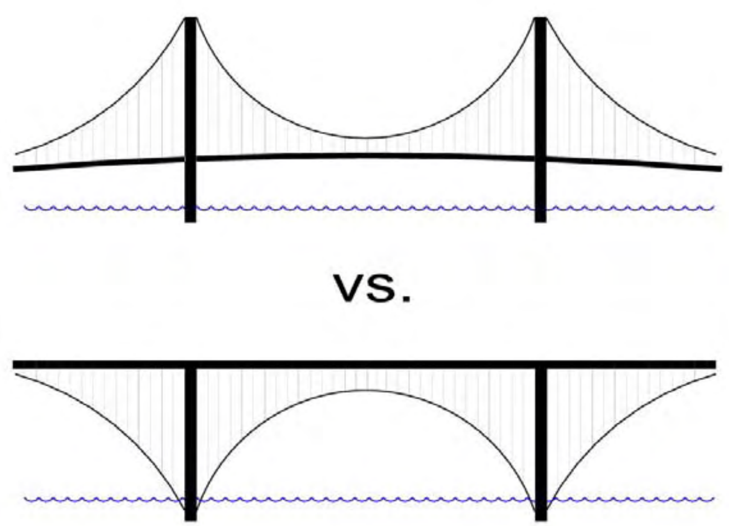


Stacked Towers The towers are composed of separate upside-down U-shaped members stacked on top of one another, as opposed to being made of two tall posts which stretch the entire height and horizontal connections. This better distributes the forces on the towers (106,000 tons) and reduces chances of buckling. It also reduces the chances of cracking/failure in unexpected places by essentially predefining (and reinforcing) the vulnerable points.

Truss vs. Beam In addition to minimizing the amount of structural material necessary, the truss—as opposed to a beam—provides for an open façade, allowing wind to flow through. This decreases the lateral wind pressure load, which is extremely important as the bridge is located in an especially vulnerable area: in the Golden Gate which has high wind currents, high in the air (where wind currents are greater than on the ground), and isolated from other buildings and natural features which might protect the bridge from the wind.



Thermal Inertia of Water The fact that the massive concrete tower footings are enveloped in water (up to 318 feet deep) is important. Water has a very high specific heat (especially when it has a solute dissolved in it, salt in this case), which means it can absorb lots of energy without a significant change in temperature. This is crucial in that it limits the expansion and contraction of the concrete footings, which occurs whenever a structure gets hot or cold. At this scale, without the insulation protection of the water, thermal stress and strain could prove detrimental to the structure.

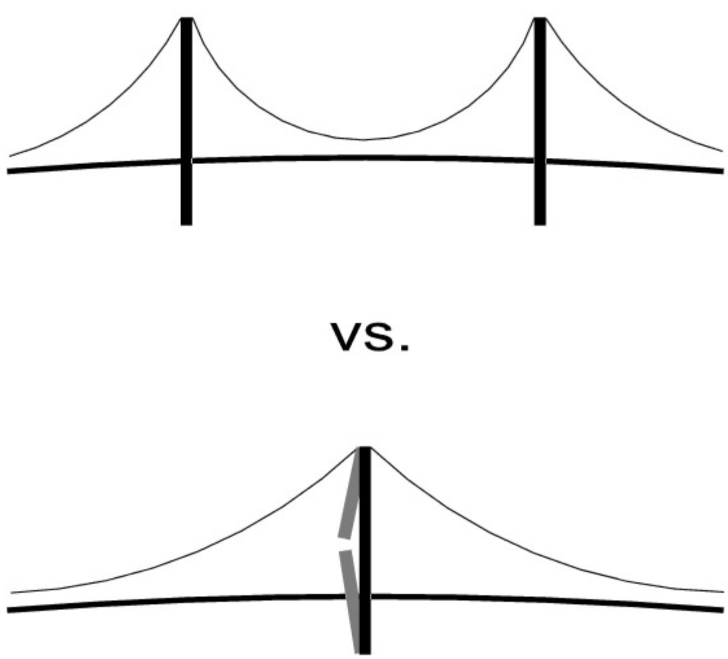


Funicular Structures Many steel bridges use arches as the key structural component, and resemble an upside-down Golden Gate bridge. Such a structure would have been much less efficient for several reasons, including:

1) Since steel is necessary to accommodate such a large span, and since it is poor in compression but excellent in tension, a cable suspension system is smart because it fully exploits steel's structural capabilities. An arched system—since it places many of the steel members in compression—is not optimal. Whereas a very thin cable can support a huge load in tension, a thick member is required in compression, specifically due to buckling.

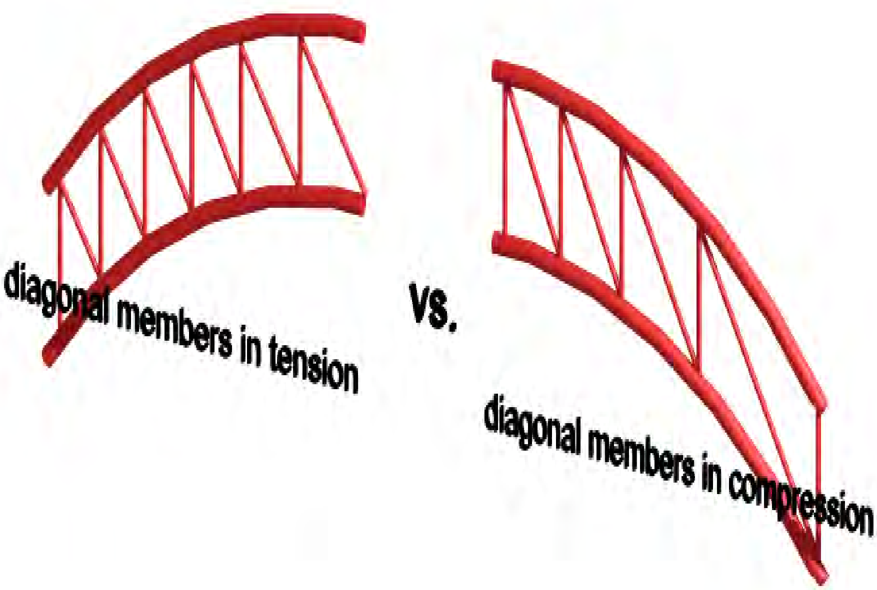
2) Synergistically speaking, the cable suspension bridge produces an overall light, flexible, graceful effect, whereas the arched bridge creates an impression of massive bearing capacity and stiffness.

3) Another synergistic aspect of cable suspension versus arched bridge is that the cable suspended bridge places the bulk of the structure above the actual bridge, thereby allowing for unhindered boat traffic, while the arched bridge blocks much of the space for boat access.

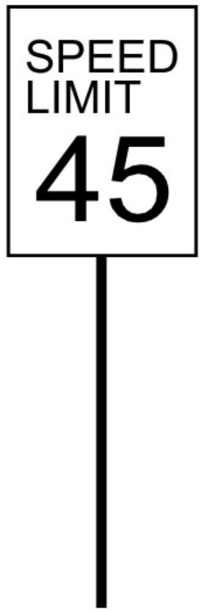


Two Towers By having two towers rather than one, the load is shared equally between the two, and is therefore halved. At the same time, there is an increase in stability and a decreased chance of buckling or collapse.

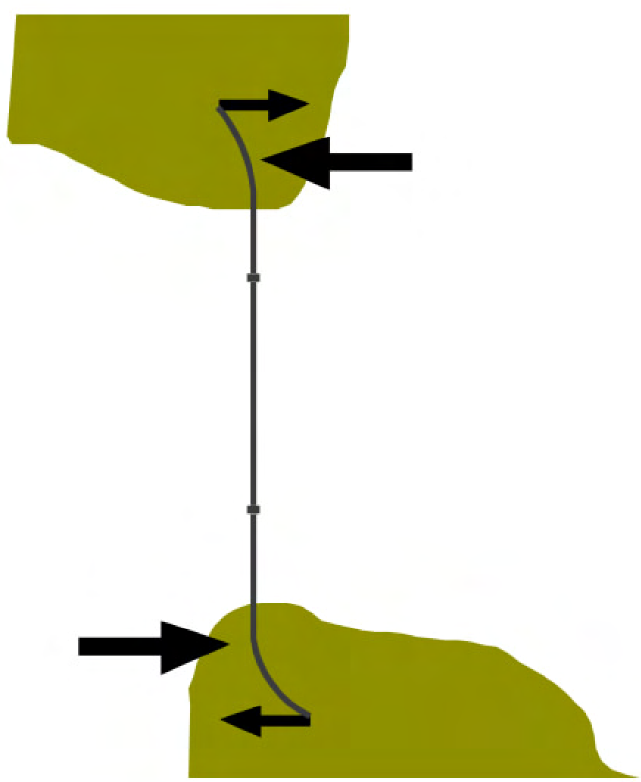
Multiple Cables While each vertical cable appears to be composed of one tendon when viewed from a distance, they are actually made up of four small cables. This results in increased flexibility, load distribution (to resist torsion), and structural integrity, in that if one cable breaks the bridge still remains intact. This is similar to using multiple thin cables rather than one thick cable for elevator pulley systems, since a single thick cable is too rigid and inflexible to wrap around a pulley, but a group of thin cables can. Aesthetically, using 4 thin cables instead of 1 thick one for the bridge allows for the cables to become even more "invisible" to the viewer's eyes.



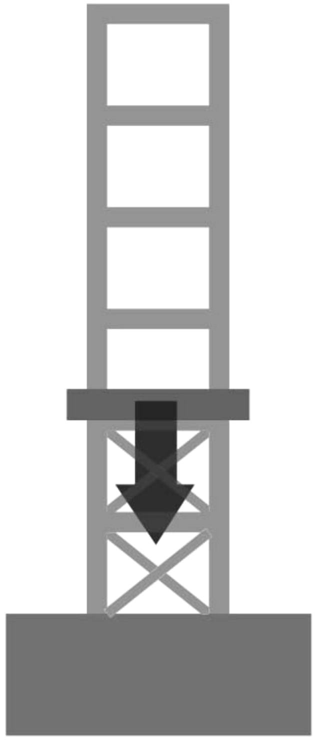
Arches The arches supporting the portion of the bridge on the land have inward sloping diagonal members, which puts them in tension, the optimum condition given that they are composed of steel. Although the nature of the arch makes for all elements to be in compression, placing the diagonal members in this way puts them in tension, and thus allows for the members to be thinner without threat of buckling.



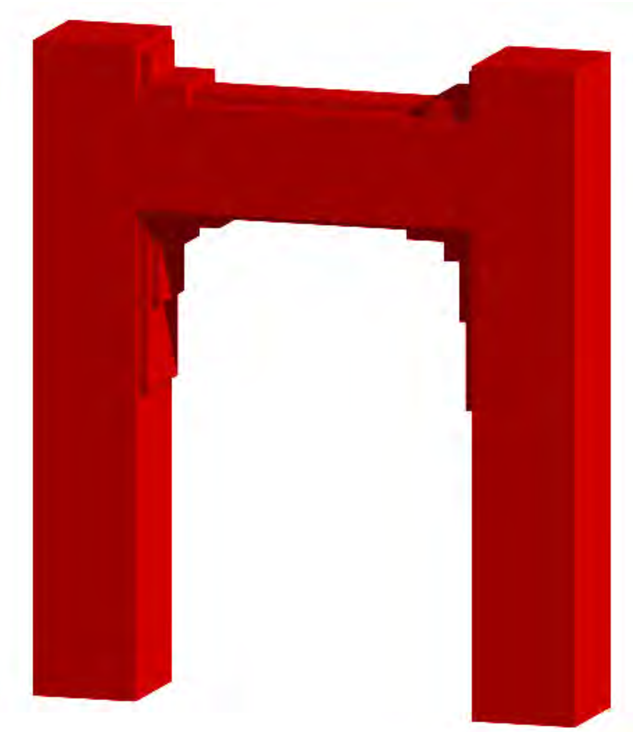
Speed Limit The fact that the speed limit is so low on the bridge (45 mph) is important. Even though most six lane highways would be 65 mph or more, due to the impulse load on the bridge when a vehicle hits a bump (such as an expansion joint), the speed must be limited. Such impulses, much greater than the normal force of a vehicle (due to the infinitely small amount of time over which the impact occurs), are very dangerous with high volumes of traffic, and can send pulsations/reverberations though the entire bridge.



Curved Ends The approaches to the bridge are curved at each end to increase lateral resistance and thereby prevent the entire structure from overturning or rotating along its axis.



X-Brace The tower has X-braced moment frames beneath the bridge to provide additional lateral resistance and compressive strength (due to the added weight of the bridge itself).



Moment Frames The towers have moment frames to resist shear and overturning. While braces could have done the job similarly, the moment frames allow for openness and a less structure-dominant, more aesthetic look. The fact that X-braces are used on the towers only under the bridge (hidden from common view) further this idea of synergy of structure.

Torque By using cantilevers, and thereby creating relatively equal distribution of loads on each side of both towers, the net horizontal force on the tower is practically eliminated, thus reducing torque about the towers at their bases.