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The Aesthetic Engineering Miracle that Defied Nature

Lying just 12 miles from the San Andreas Fault line, a beautiful 3 mile long and 1 mile wide strait connects the San Francisco Bay to the Pacific Ocean. This river mouth became an important ocean gateway to the port cities of the bay and an obstacle that separates San Francisco from Marin County. By the end of World War I, San Francisco was well on its way to become a thriving city. With its population booming, the ferry system was reaching its limit and many began calling for a bridge to span the Golden Gate Strait. Three U.S. engineers were sent data about the strait and consulted about the feasibility of a bridge. Two proposals were drawn up: one by Francis C. McMath, budgeted at \$60 million, and the other by Joseph B. Strauss, costing \$17 million.¹ Despite having no formal engineering training, Strauss's proposal was favored and he was named the chief engineer of the Golden Gate Bridge project. However, his proposal was not without flaws. Other engineers released reports criticizing the stability and its ability to survive nature's beating. Nevertheless, Strauss was able to use that to his advantage and brought two notable critics to become consulting engineers for him. With a total engineering force of around one hundred people, Strauss and his team was able to design an American icon that succeeded in creating both an engineering and architectural triumph. Not only was the bridge an engineering achievement that defeated nature, but it was also able to blend in the beauty of art to create a monument equally great in its utility and its aesthetics.

¹ Witcher, T.R. "An Icon at 80: The Golden Gate Bridge." *Civil Engineering Magazine* Archive 87, no. 6 (2017): 42–45. <https://doi.org/10.1061/ciegag.0001205>.

Despite the strong tides and winds, incessant threat of earthquakes, and the length of the strait, Strauss was able to design a functioning bridge that defied nature. Strauss's original proposal consisted of a bridge (see figure 1), that combined both a cantilever bridge and a suspension bridge to "reduce the length of cable required and at the same time increase the overall stiffness of the structure".²



Fig. 1. Early design of Golden Gate Bridge by Strauss
Golden Gate Bridge, Highway & Transportation District. *Golden Gate Bridge First Design*.

The final design retained many key features from Strauss's original proposal, from its long draping suspension cables to having two main towers. However, this original proposal was unable to address the challenges presented due to the nature of the strait. Critics found that the "pier foundations supporting the bridge would be difficult to construct and that the stiff steel superstructure would parallel the nearby San Andreas fault and would not provide appropriate lateral stability. Allowances for the dead weight of the bridge were also inadequate".³ After

² Petroski, Henry, *Engineers of Dreams: Great Bridge Builders and the Spanning of America*. New York City: Vintage Books, 1996

³ MacDonald, Donald, and Ira Nadel, *Golden Gate Bridge: History and Design of an Icon*. Chronicle Books, 2008, 30.

getting critics Leon S. Moisseiff and O.H. Ammann to become consulting engineers,⁴ they designed the more graceful full suspension bridge that still stands today. With the constant threat of severe weather and the bridge being only 12 miles east from the San Andreas fault, the bridge had to be designed to be able to move and sway with nature. The bridge's deck is able "to move 7 feet in either direction vertically" and "12 feet horizontally".⁵ The rest of the bridge consists of six parts (roadway, approaches, towers, piers, center span, and cables) rather than just one so that each part is able to move individually and absorb any kinetic energy. The bridge has now withstood the test of storms, high winds, and even earthquakes such as the Loma Prieta earthquake of 1989.⁶ Additionally, the design also had to take in account the stress caused by human traffic. The live load for the towers, cables, and stiffening trusses had to be able to hold wind stresses and the stress from pedestrians and cars. The "roadway slab and stringers were designed to carry 24 ton trucks having wheels spaced six feet gauge and axles nine feet center to center" along with the floor beams being designed for "roadway load of six 24-ton trucks".⁷ Since the road would have to be thicker to carry more and heavier vehicles, the live load had to be carefully balanced with the dead load. Designing the Golden Gate Bridge was an engineering feat that took years to plan and calculate how one bridge could span the entirety of the strait while surviving nature's assaults.

After designing such an incredible bridge, the next test was to actually build it. Before the construction of the main bridge could even begin, the foundation of the piers on both ends had to be set first. On the San Francisco pier end, tides constantly swept with "a velocity of 6.5 knots

4 Witcher, T.R. "An Icon at 80: The Golden Gate Bridge." *Civil Engineering Magazine* Archive 87, no. 6 (2017): 42–45. <https://doi.org/10.1061/ciegag.0001205>.

5 MacDonald and Nadel, *Golden Gate Bridge: History and Design of an Icon*, 14

6 Vincent, George S. *Golden Gate Bridge Vibration Studies*. American Society of Civil Engineers, Structural Division, 1958.

7 Strauss, Joseph Baermann. *The Golden Gate Bridge: Report of the Chief Engineer to the Board of Directors of the Golden Gate Bridge and Highway District*. San Francisco: Golden Gate Bridge and Highway District, 1938, 89.

and where there is no protection from the full force of heavy seas and ocean storms”.⁸ Thus, not only did construction have to deal with “founding a pier in deep water on a rock ledge devoid of overburden, but also had to deal with strong tidal currents daily, and occasionally the battering of heavy seas incidental to ocean exposure”.⁹ Strauss decided the best course of action would be to first build a massive concrete fender wall with a “thickness of 30 ft. up to elevation -45”, then above that elevation the wall would vary from 27.5 ft. to 10 ft thick.¹⁰ After the piers were constructed, the next most dangerous part would be the underwater construction of the towers. To build the south tower, located more than 1,100 feet from the San Francisco shoreline, divers had to descend over 100 feet, place dynamite charges, and remove loose material down to bedrock levels using high pressure hoses.¹¹ The excavation required a new method of underwater blasting, “which involved blasting with small pilot bombs until a sufficient depth of rock had been loosened so that a large bomb containing some 200 pounds of high explosive could be driven into the hole well below the adjoining rock surface”.¹² After the explosion, loose rocks were collected using manganese reinforced buckets. Since portable air tanks for diving had not yet been invented at the time, the diver’s life completely depended on air being pumped through a long hose (see figure 2). In addition to this, the divers were used to guide and secure beams and steel forms into position while practically blind in the dark and murky waters.

8 Strauss, *The Golden Gate Bridge: Report of the Chief Engineer to the Board of Directors of the Golden Gate Bridge and Highway District.*, 134.

9 Strauss, *The Golden Gate Bridge: Report of the Chief Engineer to the Board of Directors of the Golden Gate Bridge and Highway District.*, 134.

10 Strauss, *The Golden Gate Bridge: Report of the Chief Engineer to the Board of Directors of the Golden Gate Bridge and Highway District.*, 134.

11 *Golden Gate Bridge Exhibit*. Golden Gate Bridge, Highway and Transportation District. San Francisco, Exhibit Area 4.

12 Strauss, *The Golden Gate Bridge: Report of the Chief Engineer to the Board of Directors of the Golden Gate Bridge and Highway District.*, 136.



Fig. 2. Diver holding an air hose ready to be lowered into water at the Golden Gate
Huggins, Ted. *Diver, Golden Gate Bridge construction*. 1933-34.

After the towers were constructed, they were ready to support the two main cables that run all the way across the strait. With each cable weighing over 12,000 tons, they could not simply be carried across and lifted to the tops of the towers. To solve this issue, they used a method known as cable spinning where they pulled many smaller wires from one shore and over the towers to the other shore. Then the individual wires were grouped together into strands and once again compacted into the final cable (see figure 3). In the end, each cable consists of 27,572 smaller wires. At the time, this formation of these cables only took “six months and nine days, setting records for speed and efficiency”.¹³

¹³ *Golden Gate Bridge Exhibit*. Golden Gate Bridge, Highway and Transportation District. San Francisco, Exhibit Area 4.



Fig. 3. The Golden Gate Bridge with only suspension cables and towers
Dondero, George. Photo of the Golden Gate Bridge during construction. 1935.

Finally, using 250 pairs of suspender ropes connected from the deck to the main cables, the roadway deck could be hung in place. During the deck's construction, Strauss became the first in bridge construction to require helmet, goggles, and respirators along with the construction of a safety net (see figure 4). The net not only saved the lives of nineteen workers who fell but also gave everyone a sense of security, allowing them to work faster and more efficiently.¹⁴ This prioritization of safety set a precedent for future construction processes.

¹⁴ Strauss, *The Golden Gate Bridge: Report of the Chief Engineer to the Board of Directors of the Golden Gate Bridge and Highway District.*, 134.



Fig. 4. Strauss's safety net
Golden Gate Bridge, Highway & Transportation District. *Golden Gate Bridge Construction Safety Net*.

The Golden Gate Bridge was able to incorporate many artistic elements to create an elegant attraction in addition to its functionality. During the designing phase of the bridge, architect John Eberson was consulted and played a key role in why the bridge looks the way it does now. Eberson had previously specialized in “using Art Deco’s swooping lines to create elaborate Italianate and Moorish interiors in theaters and movie houses”.¹⁵ Although this would become Eberson’s first time designing a bridge, the towers and anchorage of the Golden Gate Bridge held similarities to skyscrapers and buildings. The first major contribution is the tower designs. Eberson sought to create a more “open space and a light look” for the towers along with indenting it as the height grew to emphasize their “monumentality, height, and grace”.¹⁶ Eberson

¹⁵ MacDonald and Nadel, *Golden Gate Bridge: History and Design of an Icon*, 38

¹⁶ MacDonald and Nadel, *Golden Gate Bridge: History and Design of an Icon*, 38

drew inspiration from the Mayan pyramids with its progressive setbacks along with its decrease in the scale of detail as the height increased. Fascia plates cover the bracing in the towers and its detail decreases as it goes further up the tower (see figure 5). This technique pairs with the stepped design to further enhance the aesthetic appeal while creating a soaring and elongated effect for the towers.

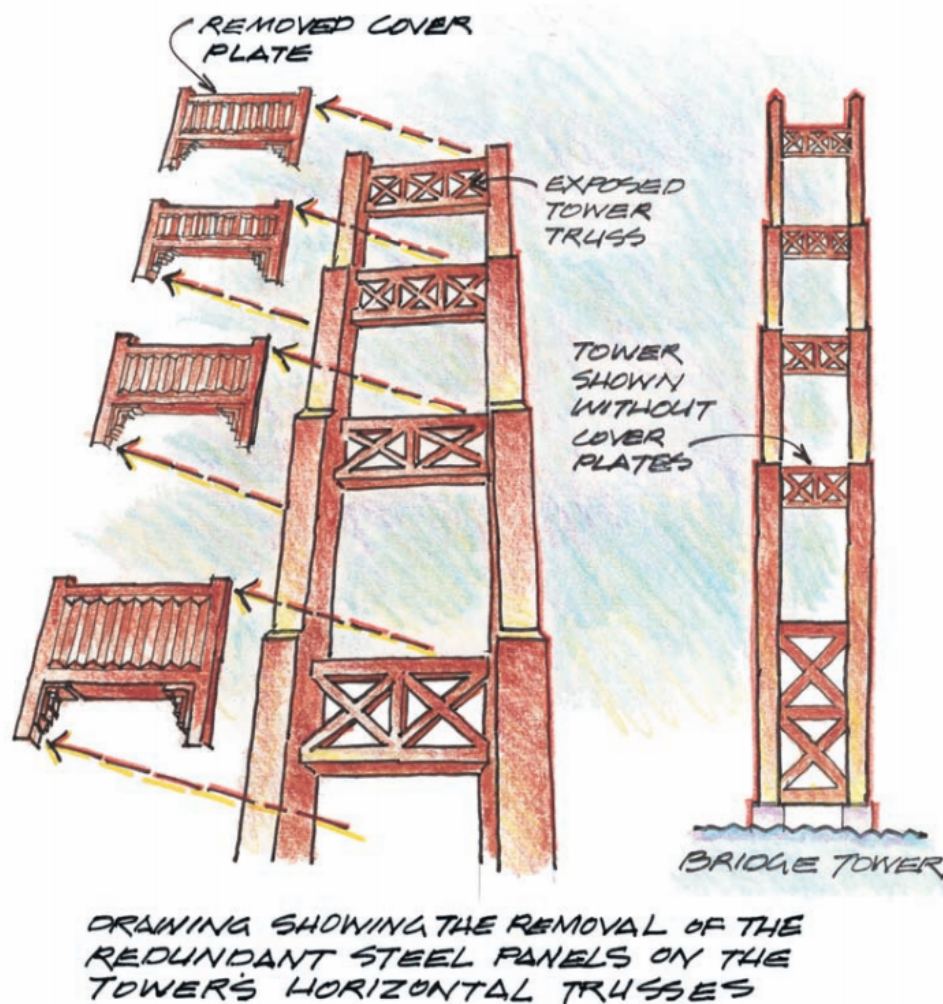


Fig. 5. Setbacks and decrease in detail with height in the towers
MacDonald, Donald. Illustration of the design behind Golden Gate towers.

The design of the Golden Gate Bridge is also a huge example of Art Deco. Certain components such as the “simplified geometric patterns, bold outlines, a stepped-back vertical style, and

motifs like chevrons” show elements of the movement.¹⁷ The vertical fluting and holes in the towers provide a great sense of depth along with reducing the visual weight of the bridge and bulkiness.

The Golden Gate Bridge is now a world famous bridge that spans the Golden Gate strait with a length of 1.7 miles long and 90 feet wide. At the time of its public opening, it was both the longest and tallest suspension bridge in the world. The strait provided many challenges, such as strong winds and high tides, proximity to the San Andreas Fault, and the length of the strait, so much so that many thought the bridge was impossible to build. However, through persistence and engineering prowess, the bridge was completed and opened on May 27, 1937. Not only was the bridge standing, but it also incorporated many architectural aspects to truly make it a beautiful landmark that is visited by millions every year.

¹⁷ MacDonald and Nadel, *Golden Gate Bridge: History and Design of an Icon*, 16

Bibliography

Golden Gate Bridge Exhibit. Golden Gate Bridge, Highway and Transportation District. San Francisco.

Petroski, Henry, *Engineers of Dreams: Great Bridge Builders and the Spanning of America*. New York City: Vintage Books, 1996

Strauss, Joseph Baermann. *The Golden Gate Bridge: Report of the Chief Engineer to the Board of Directors of the Golden Gate Bridge and Highway District*. San Francisco: Golden Gate Bridge and Highway District, 1938.

MacDonald, Donald, and Ira Nadel. *Golden Gate Bridge: History and Design of an Icon*. Chronicle Books, 2008.

O'Rourke, Tim. "Chronicle Covers: When the Golden Gate Bridge Wowed the World." San Francisco Chronicle, San Francisco Chronicle, 7 May 2019, www.sfchronicle.com/chronicle_vault/article/Chronicle-Covers-When-the-Golden-Gate-Bridge-7754315.php.

Vincent, George S. *Golden Gate Bridge Vibration Studies*. American Society of Civil Engineers, Structural Division, 1958.

Witcher, T.R. "An Icon at 80: The Golden Gate Bridge." *Civil Engineering Magazine Archive* 87, no. 6 (2017): 42–45. <https://doi.org/10.1061/ciegag.0001205>.