

# The Analysis on San Francisco Golden Gate Bridge

Ziwen Yan

Experimental HS Attached to Beijing Normal University, Beijing 100032, China.

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## Abstract

The aim of this paper is to analyze the Golden Gate Bridge in terms of the general components, the effect of wind, earthquake, temperature, load transfer, material use, as well as the construction time line and sequence. Adequate amount of figures and drawings are provided in order to demonstrate feasibility of the bridge. This paper does not provide any new findings about the Golden Gate Bridge, it is just a comprehensive summary. It can serve as the intellectual foundation of the Golden Gate Bridge and pave the way for deeper questions.

## Keywords

Summary; Golden Gate Bridge; Load Transfer; Materials; Construction.

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## 1. Introduction

Since the Golden Gate Bridge was built, many people have studied it deeply. This paper is also about the Golden Gate Bridge, but provides a rather holistic summary from a more fundamental and comprehensive perspective. This paper mainly focuses on the general information, loading, materials, construction sequence and other effects to provide analysis for the Golden Gate bridge.

## 2. General Information

### 2.1 Introduction of the Golden Gate Bridge

Golden Gate Bridge is a suspension bridge crossing the opening between San Francisco and California in the United States.(Figure 1). There are several basic parts of the Golden Gate Bridge: abutments, pylons, piers, main(catenary) cables, suspender ropes, deck, truss and beam system, and the fort point arch. The Golden Gate bridge is a suspension bridge with 6 lanes which functions as motorway bridge or freeway bridge.



Figure 1: Picture of the Golden Gate bridge[1]

## 2.2 Structure Detail (All the names of structure correspond with figure 8)

### 2.2.1 Main(Catenary) Cables

When the Golden Gate Bridge was built, its 2332m long catenary cables were the longest cables ever produced. These cables were made by binding thinner wires together, using an innovative process.

### 2.2.2 Deck system

The golden gate bridge consists of a bridge deck, which is supported by a system of beams and trusses. This truss system spans between the bridge pylons and is hung from vertical cables at 15m intervals. In Addition, 4700 tons of truss members were used as additional bracing member in the deck to withstands wind loading within the bridge and also to prevent oscillations.

### 2.2.3 Suspender ropes

These vertical cables are supported by two major catenary suspension cables which pass over the pylons and into anchors at either end of the bridge. There are 250 pairs of suspension ropes with a diameter of 68.3m. Each suspender rope is 0.2552m in diameter.

### 2.2.4 Tower

The towers are 227m in height each and are constructed using structural steel. They are firmly connected to the deck through a riveted plate.

### 2.2.5 The Fort Point Arch

The curve of the arch experiences compression force. At the south end of the suspension bridge, a steel arch extends the deck over the brick fort below.

### 2.2.6 Anchorage

Each anchorage was made of three interlocking concrete blocks. It was a special design made for the site. In that area, earthquakes are common. This interlocking block design would prevent the anchorages from slipping during an earthquake. The cables on each sides end in these anchorages of the bridge. Each anchorage has 61 eye bars. These are metal rods with holes at the tips. The hole in each eye bar pokes out of the surface of the concrete. The wires of the main cables are fastened to the holes in the eye bars. This system keeps the cables from sagging under the weight of the bridge deck.

### 2.2.7 Rivets[2]

Riveting is generally used for joining sheet material. The joints transfer the load from one sheet to the other in shear movement(Figure 2). Because the rivet is being forced into its final shape, access from both sides is needed. Riveting is a common connection to consider because of its low cost. The rivets on the Golden Gate bridge were used to join together the steel pieces of the tower. Each tower has over a million rivets. The rivets are made of steel.

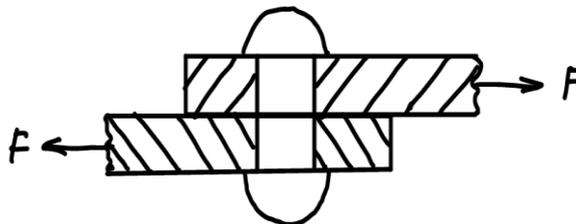


Figure 2: Shear force on the rivet

## 3. Loads

### 3.1 Live loads

The cars, trucks, and people that cross a bridge are called the live load.

### 3.2 Dead loads

The main dead load acting on the structure is self-weight. Because all other loads are not significant and can be ignored.

### 3.3 Wind loads

Wind can cause two kinds of different additional loading on a bridge. When wind blows from side to side across the bridge, it is called a static wind load. When wind blows up and down on a bridge, it is called a dynamic wind load. It can make the bridge's deck twist and buckle, or even shake the bridge apart. To prevent this, engineers used trusses in the Golden Gate's deck. The trusses make the deck stiff. A stiff deck moves less in a dynamic wind load.

The tower has several opening to allow the wind to pass through without resistance. Also the towers are joined by metal beams called struts and crossbars, which can transfer shear loads from wind.

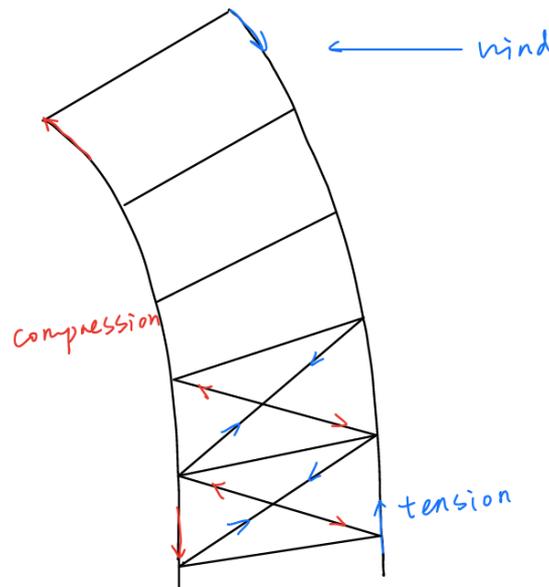


Figure 3: Forces on the crossbar

### 3.4 Earthquake

When there is an earthquake, the anchorages and the piers will move back and forth. When the anchorage is moving, the part of cables on the side span and the side deck will move left and right. But the main span only moves slightly up and down. The towers above the piers don't move much at all. If we shake the tower only, the cable connecting to the top of the tower will vibrate, but the deck is pretty much isolated from the tower. These towers are braced with 4 diagonal members at the bottom. These members connect the sides of the tower and prevent lateral oscillation. These cross members will act in tension and compression as the earthquake pushes and pulls the pylons on either side of the bridge deck. Thick cables are designed to withstand frequent earthquake.[3] When the vibration of two sides of the bridge is out of phase, the deck will experience torsion.

### 3.5 Snow load

Snow load is also very influential. Snow and ice are significant during special time of the year and this is really important to the bridge design. This is especially for long span bridges such as the Golden Gate Bridge, on which the snow is hard to be removed completely.

### 3.6 Retrofit

#### 3.6.1 Stiffening truss

The Golden Gate Bridge experienced a retrofit after the 1989 Loma Prieta earthquake. One important part of retrofit is the stiffening truss (Figure 4b). So the bridge will be less susceptible to the influence of earthquake and wind. Comparing the cross-section before and after retrofit (Figure 4), when there is no implemented bracing in the bottom of the steel truss deck, the deck can be easily twisted. The stiffening truss help improved the wind and earthquake resistance of the bridge by strengthening the torsional stiffness of the deck.

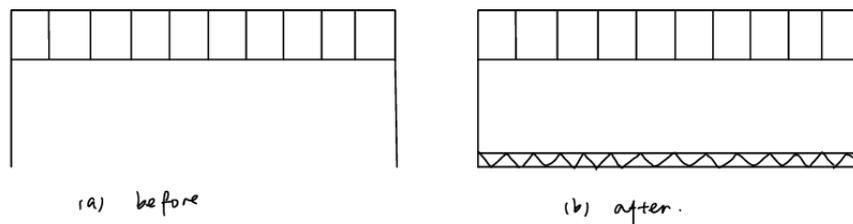


Figure 4: Cross section of the deck before and after retrofit

### 3.6.2 Orthotropic Deck

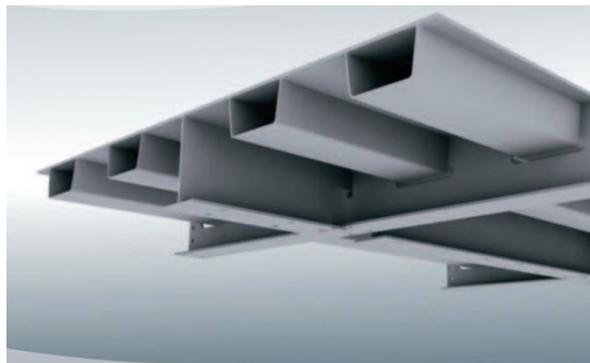


Figure 5: Cross section of an orthotropic deck[4]

The original reinforced concrete deck was replaced by new orthotropic steel plate deck. The orthotropic deck is usually comprises a structure steel deck plate which is strengthened either longitudinally or transversely, or in both directions. This design allows the deck to directly withstand vehicular loads and to contribute to the bridge structure's overall load-bearing behavior. The orthotropic deck may be integral with or supported on a grid of deck framing members such as floor beams and girders.

### 3.7 Truss and beam system

The upper part of the truss will always in compression and the lower part of the truss will always be in tension.

## 4. General load path (suppose the bridge is under uniformly distributed force and weight only)

The dead loads such as the weight of the deck and sidewalk, as well as the live loads of the bicycles, cars, and pedestrians, are all supported by the deck. The deck hands off the loads to the floor beam and bracing, then to the suspender ropes, which transfer that weight by pulling it up and also the dead weight to the two main cables. All the weight of deck and sidewalk, the traffic, the suspenders, and the main cables are transferred to the tops of two towers by the cables. (Figure 6)

The orientation of the cable causes the cable to pull down on the tower (Figure 6a). If we separate two tension forces into horizontal and vertical force, we can see that the horizontal force from the right and left canceled each other out, only vertical forces remained. So the force of the cable pulling down on the towers reach the ground through the towers and creates the reaction  $F_{ground}$ . However, when the horizontal forces didn't cancel out, the pylon will experience a bending moment (Figure 6b). This is the closer to real situation concerning the Golden Gate Bridge. Because the tower is being pushed on at the top and bottom, it is in compression. The final step of load transfer is the concrete piers and foundations. The forces go down through the steel towers and are resisted by the strength of piers, then extend into the foundations.

Continue tracing the main cable to the anchorage. Because the cable is embedded in the anchorage, it pulls on the anchorage with a large force ( $T_{cable}$  in Figure 6c). Though  $T_{cable}$  is pulling upward, the anchorage is kept from lifting off the ground by its enormous weight ( $W$ ). The ground exerts both a normal contact force ( $F_{normal}$ ) and a friction force on the anchorage, and the anchorage is kept from sliding by the friction force.

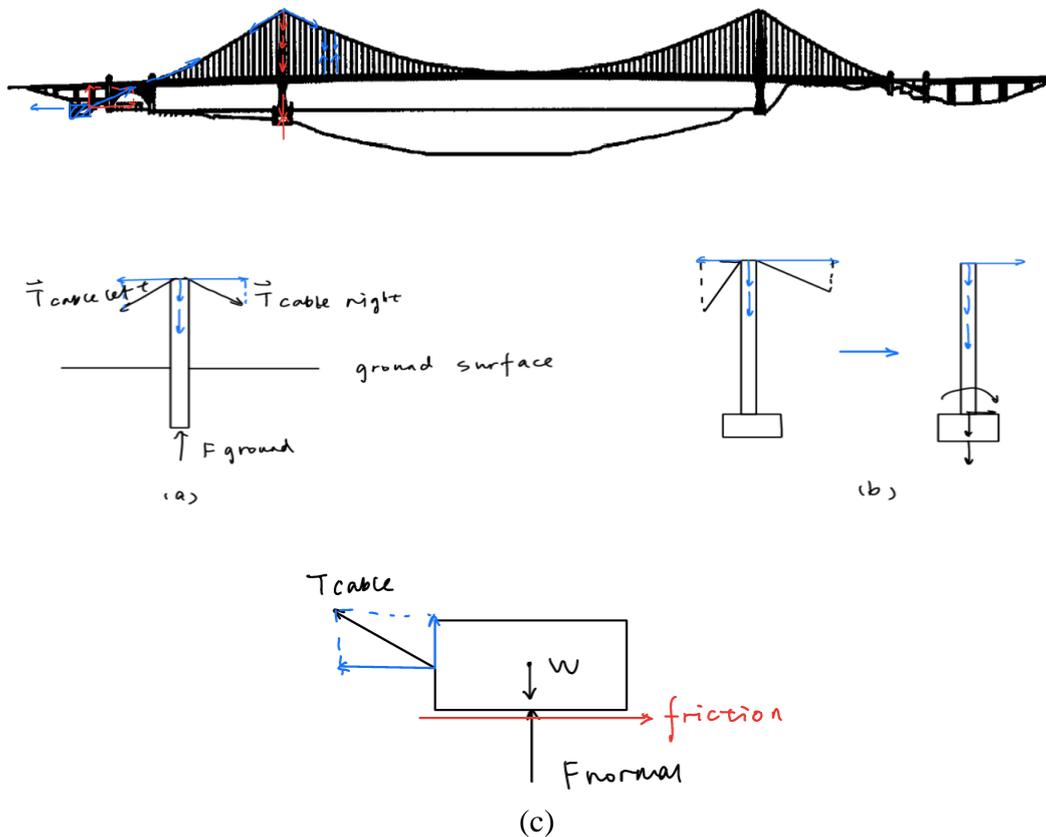


Figure 6: Load transfer and three-body diagrams of different compartments on the Golden Gate bridge

The main cable force  $T_{cable}$  is counteracted by the weight of the anchorage  $W$  and the forces that the ground exerts on the anchorage  $F_{normal}$  and friction.



(a)[5]

(b)[6]

Figure 7: Connections on the Golden Gate Bridge

(a) is the connection between suspender ropes and main cable;(b) is the connection of suspender ropes and the truss deck

The connection between suspender rope and floor beam can be considered as a pinned support. Therefore the whole deck system will not experience any kind of moment or rotation. The saddle is used to strength and immobilize the cable connections.

### 5. Uneven loading

Imagine a situation when all of the cars are stopping at one end of the bridge, then the load there will be significantly bigger. Because of the increased load, the main cable will be in huge tension and pulling up the deck on the mid-span. So the middle of the deck will go up. The tower at the other end will experience an uplift.

### 6. Material

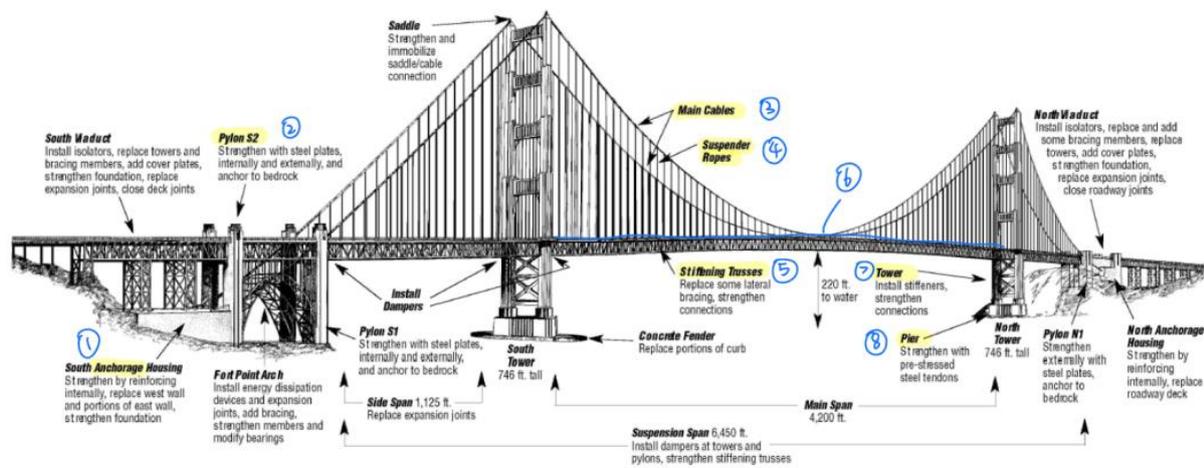


Figure 8: Labels of Table 1[7]

Table 1. Materials used in the Golden gate Bridge

	Primary Material	Other Characteristics
1. Anchorage	Concrete	connected to bedrock with steel plates, rods, and eye bars
2. Pylon	Concrete	Strengthen with steel plate
3. Main cable	galvanized steel wires	Carbon steel
4. Suspender rope	Structural steel	/
5. Truss and beam system	Structural steel	/
6. Orthotropic deck	steel	light
7. Tower	Structural steel	/
8. Pier	Concrete	Strengthen with steel bars

#### 6.1 Concrete

Concrete is used in the following places: the piers, anchorages, and pylons. The anchorage blocks are approximately 54.4 million kg heavy and contain approximately 4,400 tons of steel reinforcements. Reinforced concrete is used in piers. Reinforced concrete is a kind of concrete with steel inside so that the two materials can act together in resisting forces. The reason why there is steel reinforcement inside piers and pylons is that concrete is good under compression but not under tension. However, in many kinds of situations the piers and pylon may be subjected to tension.(e.g. when one side of the bridge has much more weight than the other, the piers may be uplifted). Steel is very good in tension. So in this case the steel can strengthen concrete from breaking due to tension.

## 6.2 Steel

The steel for the Golden Gate Bridge was fabricated by McClintic Marshall Corporation, a subsidiary of Bethlehem Steel Corporation. The cables were part of the Roebling Son's Company contract. They are produced by that company.

### 6.2.1 Cable

The two main cables are made up of 27572 galvanized steel wires. The overall diameter is 0.92m. If we take a closer look at the cross-section of the main cable, we can see that it is composed of many cross-sections of thinner wires. Carbon steel is the main material of the galvanized steel wires for the main cables. Carbon steel is very durable and strong, which can perform well under huge tension. Structural steel shall be suitable for offshore environment.

### 6.2.2 Material properties

We can use the properties of structural steel to analyze all steel elements. Young's modulus were the same, however the yield strengths were different. The yield strength of all cable elements were made to be 1100MPa. All other steel members were taken to have a yield strength of 300MPa, typical of the era.[3]

The two different types of steel has the same modulus( which means they have similar deflections), but different yield strength and ultimate strength(which means their resistance and safety is different). Because the steel used for cables are under great tension, the yield strength must be bigger so that the cable won't break easily. However, the steel used for towers and other structures are under compression, so the yield strength is smaller.

## 7. The construction Sequence of the Golden Gate Bridge[8]

### 7.1 The Anchorage

The Crews first started the construction by building the anchorages. They built a wooden mold for the base block and filled with concrete. Then there was the layer of anchor block. Crews installed steel girders to strengthen the blocks. This layer was then covered in more concrete. Finally, crews built the weight block. Its massive quantities of concrete would hold the lower two blocks in place.

### 7.2 The North Pier

The crews needed to find themselves a dry workspace in the bay. So they build a cofferdam. To create it, the crews sunk a tall metal frame filled with crushed rocks above the site where the pier would be situated. Next, they placed sheet metal around the frame, and sealed the joints to make them watertight. Water inside the frame was removed using a powerful pump. The sheet metal ensured there was no any new water getting in. With the dry working space, workers began to build the north pier. They had to go down 10 meters before reaching the foundation. They poured concrete into the pier dug, and the pier was completed, which reached 13m above the water line of the bay.

### 7.3 The South Pier

Building the south pier was more difficult. It was the first time anyone had attempted to build a bridge support in deep, open water. Work started with the construction of an oval-shaped fender, which would protect the tower from any ships in the bay that might hit it accidentally during foggy weather. To build the fender, workers placed dynamite in the floor of the bay and blast through it. Then they used high-pressure hoses to clear materials loosened by the dynamite. When the bedrock was finally reached, workers put funnels and watertight molds into place underwater. Then crews could begin to pour concrete into them to form the fender.

### 7.4 The Towers

With the piers in place, construction could begin on the towers. Workers' jobs was to rivet together the steel pieces of the tower. They worked from scaffolds to reach the growing towers easily. Each tower is made of two legs that are 27m apart. Metal beams called struts and crossbars join the legs together.

## 7.5 The Cables

By mid-1935, the towers were ready to support the two massive main cables. The cables were so large and heavy, they had to be made on site. Workers attached a steel wire as thin as a pencil to an eye bar on one anchor. They used a spinning wheel to carry the wire over both towers and down to the eye bar on the opposite shore. The spinning had to be repeated until each main cable was just over 1m in diameter and 2332m long. Gradually, workers figured out how to speed up the process. They color coded the wires and used six spinning wheels at once.

## 7.6 The Deck

To hang the deck, crews bolted pairs of suspender ropes together. This created a cradle on which the deck would sit. The deck was made of steel beams supported by trusses. Workers installed the deck in 747 sections. To spread the heavy load, crews began from each tower and worked toward the center.

## 8. Conclusion

The Golden Gate Bridge is one of the most amazing bridges in the world. It's mystery can't be thoroughly examined in only 20 pages. As a high school student, I have tried my best to analyze the bridge from the perspective of our level of knowledge. Hopefully in the future I can learn more about the Golden Gate Bridge, including other great bridges in the world, keep making scientific progress, and one day come up with more useful discoveries for the world.

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