PDHonline Course C577 (8 PDH)

Bridging San Francisco Bay

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Bridging San Francisco Bay

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Part 1

Inland Sea

3

Satellite view of "The Inland Sea." The entry to the bay is through the Golden Gate Strait which separates the San Francisco peninsula from Marin County (roughly three miles long by one mile wide). Collectively known as *San Francisco Bay*, it consists of three bays; *San Francisco Bay* (south), *San Pablo Bay* (north) and *Suisun Bay* (northeast). Northern California rivers deposit their fresh water into the bay creating turbulent conditions. 4

PROCLAMATION

We, Norton I, *Pei Gratia*, Emperor of the United States and Protector of Mexico, do order and direct that a suspension bridge be constructed from the improvements lately ordered by our royal decree at Oakland Point to Yerba Buena, from thence to the mountain range of Sausalito…Whereof fail not under pain of death. Given under our hand this 18th day of August, A.D. 1869 and in the 17th year of our reign, in our present Capitol, the city of Oakland.

Norton I – Emperor

RE: '49er Joshua A. Norton who amassed a fortune during the gold rush and then lost it (and his mind). However, he was the first person to propose bridging the bay between Oakland and San Francisco using Yerba Buena Island as a stepping stone. 5

Known as "Yerba Buena" (before the Gold Rush of 1849), San Francisco was a sleepy village of four hundred souls. The discovery of gold changed all that and San Francisco with its "Inland Sea" became the focus of the rush and by 1850, the population had exploded to 30K. In May of 1869, the transcontinental railroad was completed. Except for locally manufactured goods, everything else arrived by ship. With the rail heads on the east side of the Bay and San Francisco - with its excellent deep-water port on the west side, San Francisco found itself isolated on its peninsula. In effect, the Bay was like a giant mote separating San Francisco from the rest of the continent. By the early 1870s, talk of building a bridge with a rail link to Oakland (East Bay) using Yerba Buena Island was gaining momentum and many local newspapers promoted the idea. Joshua Norton, the '49er who declared himself emperor of North America, may have been an amusement to the public-at-large, but his idea for bridging the Bay was taken seriously. Unfortunately, the deep water of the bay, distances involved and cost to build such a bridge was not a practical reality in the 1870s. 6

Bay and Harbor of San Francisco, the pride of all California, not for sale to the Railroad Company

***Sacramento Daily Union*, 1871**

RE: headline celebrating the *Central Pacific Railroad's* (CPRR) defeated house bill which would have made Goat Island (Yerba Buena) its terminus. Sale of the *Daily Union* was henceforth banned on CPRR trains.

7

"The Bay Bridge Committee lately submitted its report to the Board of Supervisors, in which compromise with the Central Pacific was recommended; also the bridging of the bay at Ravenswood and the granting of railroad facilities at Mission Bay and on the water front. William C. Ralston, ex-Mayor Selby and James Otis were on this committee. A daily newspaper attempts to account for the advice of these gentlemen to the city by hinting that they were afraid of the railroad company, and therefore made their recommendations to suit its interests."

***San Francisco Real Estate Circular*, April 1872**

RE: in early 1872, a "Bay Bridge Committee" was formed for the purpose of constructing a railroad bridge across the bay

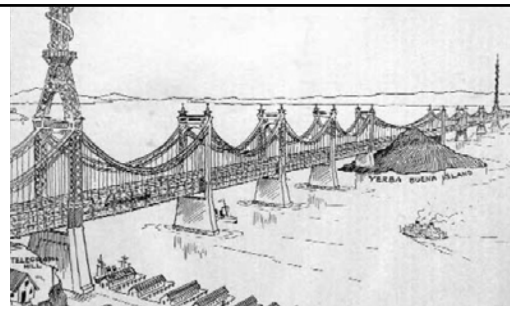
8

WHEREAS, we issued our decree ordering citizens of San Francisco and Oakland to appropriate funds for the survey of a suspension bridge from Oakland Point via Goat Island; also for a tunnel; and to ascertain which is the best project; and whereas the said citizens have hitherto neglected to notice our said decree; and whereas we are determined our authority shall be fully respected; now, therefore, we do hereby command the arrest by the army of both the Boards of City Fathers if they persist in neglecting our decrees.

Given under our royal hand and seal at San Francisco, this 17th day of September, 1872

9

Norton I - Emperor



"Ideal sketch of the proposed San Francisco Trans-Bay Suspension Bridge of three stories, as it will look when constructed between Telegraph Hill, San Francisco, and the Oakland shore, nine and one-half miles distant, with its center resting on Yerba Buena Island."

10

RE: newspaper caption (ca. 1913)

In 1920, the *Southern Pacific Railroad's* highly profitable *Golden Gate Ferry Service* began to offer vehicular ferry service across the Bay. As the 1920s progressed and car ownership increased, so too did traffic on the roads and, especially, at the ferry terminals thus highlighting the need for bridges. In 1929, the Golden Gate vehicular ferry and the Southern Pacific ferry service/s were merged to form *Southern Pacific Golden Gate Ferries*.

11

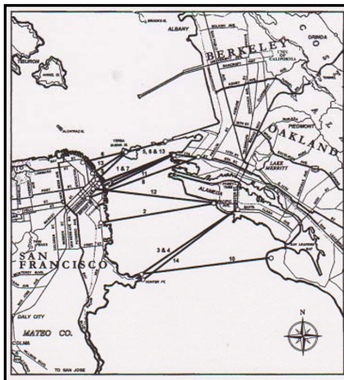
This map (ca. 1922) shows some of the many ferry routes that once crossed the "Inland Sea" that is San Francisco Bay. Many of the bridges in use today – including the *San Francisco –Oakland Bay Bridge*, were built at and/or near ferry sites because the existing infrastructure of road, rail, trolley and bus lines converged at the ferry terminal/s.

12

Ferries Plying the Waters of the Bay (ca. 1928) 13
San Francisco (foreground) / Yerba Buena Island (upper left)

In 1921, San Francisco received proposals for a private toll bridge between San Francisco and Oakland. Also that year (with funds provided by the *San Francisco Motor-Car Dealers Association*), test borings into the bay floor were conducted by consulting engineers *Ralph Modjeski* and *Vipond Davies*. In October 1921, the War Dept. rejected San Francisco's application to build a bridge across the bay to Oakland using Yerba Buena Island. Since Yerba Buena was a military reservation (a U.S. Navy Base until 1997), permission from the War Department was required to use it as the stepping stone across the bay.

14



Map of 1926 Private Proposal Alignments

***ENR* published this map (in 1926) of 17 proposals for bay crossings (by 1928 there were 38) from various sources for a private franchise. There were individual and team proposals from some of the greatest names in bridge building. Seven proposals called for "High Steel Trusses," three Cantilever and two Suspension plans were submitted, a hybrid Cantilever/Bascule, tunnels and a tunnel/bridge combination.** 15

The Ridgway Report

16

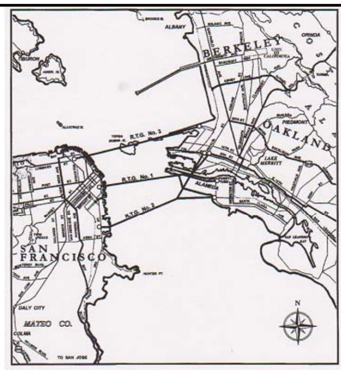
Overwhelmed by so many diverse POVs and the critical need for the War Department to be convinced that a bridge was feasible and would not interfere with navigation, city and county officials in San Francisco sanctioned a $40K independent study on the feasibility and preferred design of a trans-bay bridge by a Board of three consulting structural engineers;
- ***Robert Ridgway***
- ***Arthur N. Talbot***
- ***John Galloway***

Ridgway was the Chief Engineer of the *Board of Transportation* in NYC and served as Chairman. Galloway was a native Californian who had consulted (starting in 1892) on many civil engineering projects. Talbot was a retired professor of civil engineering at the *University of Illinois*. The three were selected for their expertise and lack of conflicting interest – none had been part of any of the private franchise applications. On May 5th 1927, a detailed, extensive report was issued which came to be known as the *Ridgway Report.* 17

Three key issues were addressed in the Ridgway Report;
- **Location**
- **Bridge Type/s**
- **Traffic Mix**

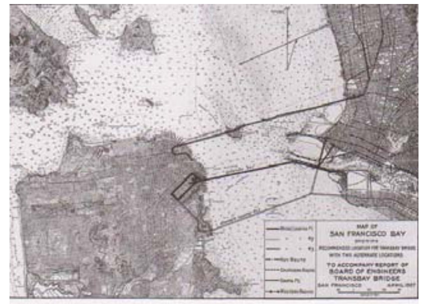
For the latter, whether or not to accommodate rail as well as vehicular traffic was the main issue. Three mixes were considered;
- **Automobiles and trucks**
- **Interurban rail**
- **Main-line rail**

The latter was dismissed from consideration since it would require longer approaches and reinforcing of the structure. However, the report was firm on accommodating both vehicular and interurban rail service. As for location, the report chose three of its own alignments. All were straight-line, linear east-west alignments with only one (R.T.G. No. 2) using Yerba Buena (Telegraph Hill to the Key System Mole). The report recommended R.T.G. No. 1 (Rincon Hill to Alameda) as its first choice, R.T.G. No. 3 (southern-most crossing) was second choice and R.T.G. No. 3 was the last choice. 18



Map of Ridgway Report Alignments

19



Map of San Francisco Bay Showing Recommended Location for Transbay Bridge with Two Alternate Locations to Accompany Report of Board of Engineers Transbay Bridge (1927)

20

As for bridge types, the report was in favor of a cantilever bridge for the shipping channels of the west bay and simple truss spans for most of the east bay with inclusion of a bascule (or other type of movable bridge) to accommodate shipping. A suspension span was considered infeasible due to "physical conditions." Two other critical issue were, however, left for others to resolve;

- **Geology of the Bay**
- **Financing**

According to the report, the two were inseparable: "*…vitally necessary information regarding foundation…must be expected to present great difficulties and extremely expensive construction…at best the building of the piers will be a difficult and hazardous undertaking.*" The report recommended three actions be taken;

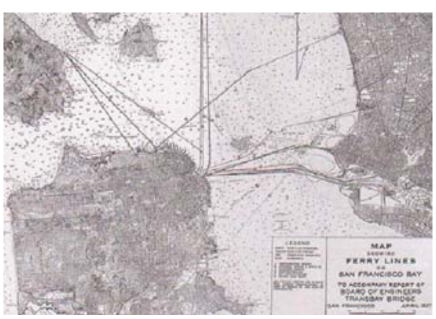
- **Adapt the Rincon Hill to Alameda Mole alignment (with a request for War Dept. approval)**
- **Conduct test borings to determine "foundation conditions"**
- **Prepare preliminary design/cost estimate for feasibility study**

21

Official though it was, the *Ridgway Report* had little status with the political and/or regulatory process required to see it through to completion, but it was an important first step. Basically, it recommended that, with a good alignment, the bridge could and should be built. Crucially, it provided a rallying point for the proponents of the bay crossing. It was taken before War Department, Congressional and State Legislature hearings as their battle cry. Six legislative and administrative hurdles were to follow;

- **Creation of the *California Toll Bridge Authority* (1929)**
- **Adoption of the Bay Bridge as a state-owned and financed structure (1930)**
- **Convening of the *Hoover-Young Commission* (1929-30)**
- **Approval of a permit by the *War Department* (1931)**
- **Approval of bridge construction bonds by the *Reconstruction Finance Corporation* (1933)**
- **Approval of the project and its financing by Congress (1933)**

22



Map Showing Ferry Lines on San Francisco Bay to Accompany Report of Board of Engineers Trans-Bay Bridge (1927)

23

San Francisco State Senator *Roy Fellom* introduced legislation (in May of 1927) mandating a study be performed by the *California Department of Public Works* investigating the feasibility of the state taking over existing private toll bridges (i.e. *Antioch, Dumbarton Bridge/s*). The study would also consider the feasibility of the state building new toll bridges (including the Bay Bridge). In June, San Francisco applied anew to the War Department for a building permit and once again (in October 1927), the application was rejected (it was based on the recommendations of the study).

24

Map of Bay Area Bridges
(ca. 1930)
With proposed location of SF-OB Bridge. "Private Toll Bridge" (at bottom) is the *Dumbarton Bridge.* The "S.P. Railroad Bridge" (upper right) is the *Martinez-Benecia Bridge* (a.k.a. *Suisun Bay Bridge*). It was a lift bridge built for the *Southern Pacific Railroad*. Also indicated is David Steinman's *Carquinez-Strait Bridge*.

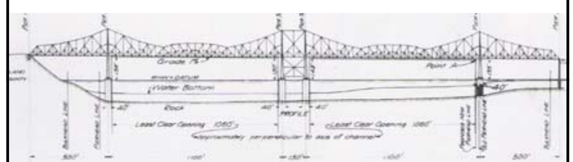
25

Dumbarton Bridge
(opened January 17th 1927)
Consisting of eight, 228-foot steel truss spans, two towers and a vertical lift span, the original bridge was 1.2 miles long

26

The towers of the lift span were 186-feet high

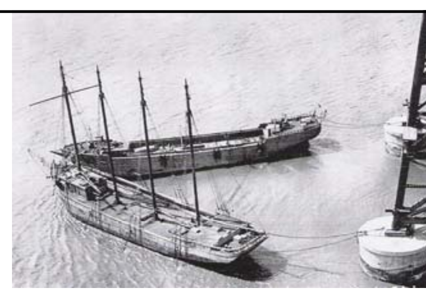
27



Carquinez-Strait Bridge
(opened May 21st 1927)
The original *Carqiunez-Strait Bridge* (cantilever) consisted of two anchor arms and a center tower. Between them were two 1,100-foot main spans (with 433-foot suspended spans each weighing 633-tons). The total length of the bridge was 4,982-feet.

28

29



The exposed center pier was of great concern as a hazard to navigation. The *C&H Sugar Refinery* and the *Matson Navigation Co.* filed suit to stop the bridge from opening on schedule. As a temporary pier fender, four derelict wooden sailing ships were anchored on either side of the pier.

30

31

May 21st 1927. Crowds gathered for the opening of the world's longest highway bridge. President Coolidge officially opened the bridge with a telegraph signal from the White House. This significant event was overshadowed by other news of that day; Charles Lindbergh's successful transatlantic flight.

32

A postcard view of the *Martinez-Benecia Bridge* for the *Southern Pacific Railroad* (opened in October 1930). With the opening of the bridge, the train ferries that had plied the Carquinez Strait between Benecia and Port Costa for fifty years made their last run the day the bridge opened. The bridge is still in use.

33

Southern Pacific's vintage *C.P. Huntington, No. 1*, becomes the first train to cross the new $12 million lift bridge across Suisun Bay. Close behind is the first modern locomotive to cross the bridge.

34

In March of 1928, Congress held hearings on a bill sponsored by U.S. Senator for California *Hiram Johnson* – over the objections of the War Department, for approval of a Bay Bridge permit. It did not pass. With the federal government (i.e. War Department) the main obstacle, on October 3rd 1928 state government and city officials met to discuss the feasibility of the state building the bridge without federal assistance. At the conclusion of the meeting, Mayor *James Rolph* of San Francisco and Governor *C.C. Young* issued a joint statement in support of California building the Bay Bridge. Also in 1928, the *California Department of Public Works* released a report recommending the state build any/all future toll bridges including, most importantly, the Bay Bridge.

35

James Rolph, Jr.
(a.k.a. "Sunny Jim")
(1869-1934)

James Rolph, Jr. served as the 30th Mayor of San Francisco for eighteen years – from 1912 to 1931. He served as the 27th governor of California from January 7th 1931 (he resigned as Mayor the same day he was sworn in as Governor) until his death in office on June 2nd 1934. In his honor, the Bay Bridge was unofficially named "The James 'Sunny Jim' Rolph Bridge."

36

Part 2

The Hoover-Young Commission

37

Though he is most remembered for being POTUS at the height of the Great Depression, Herbert Hoover was also the politician most responsible for the building of the Bay Bridge. In fact, Hoover was responsible for many large-scale public works projects that assisted greatly in combating chronic un-employment. In the case of the Bay Bridge, his pro-active stance predated both the depression and his presidency. Former Secretary of Commerce, mining engineer and native San Franciscan, Hoover attempted to act as an intermediary between California and the War Department while he was Secretary of Commerce under the Harding and Coolidge Administrations.

38

"I attempted to conciliate the military and engineering conflicts, but my authority, without the backing of the President, was insufficient. Also, opinion in the Bay cities concerning the proper and feasible route was divided, and acrimonious debate was going on. At that time there seemed to be no way of financing a project so ambitious as this."
Herbert Hoover

39

With his election as POTUS in 1928 and inauguration in early 1929, the situation changed entirely. During his campaign, he openly endorsed the Bay Bridge and promised, if elected, to fulfill his pledge. With the after-effects of the October 1929 stock market crash setting-in during his administration, the idea of a large public works project (such as a trans-bay bridge represented) had even greater appeal than before the depression. During the 1920s, two large-scale public works had been debated; the Bay Bridge and the *Central Valley Project* (CVP). Soon after his inauguration, Hoover and California Governor *Clement C. Young* formed two commissions – both known as *Hoover-Young Commissions*, to seek out means by which the California State Government and the Federal Government could work together to see these great projects through to completion. Ultimately, the Bay Bridge would be completed (in 1936) as a state project and CVP as a federal project during the 1940s and '50s. At a press conference held on August 13th 1929, Hoover announced the creation of the *Hoover-Young San Francisco Bay Bridge Commission.*

40

Clement Calhoun Young
26th Governor of California
(1869-1947)

41

"There can be no question as to the necessity of such a bridge for the economic development of these communities. In addition to the cities of San Francisco, Oakland and Alameda, the Governor of California through recent legislation has recently taken an interest in this problem. In order that we may have an exhausting investigation with a view to a final determination which I hope will be acceptable to all parties, I have consulted the Secretary of War and the Secretary of the Navy as well as Mr. Meek, the representative of Governor Young, and I shall appoint a Commission comprising two representatives from the Navy, two from the Army, and I shall ask the authorities of San Francisco to appoint another member. I shall ask the Governor to appoint one or two members and I shall appoint a leading citizen, Mr. Mark Requa if he will undertake it, in the hope that we may arrive aty a determination of the common interest."
Herbert Hoover – POTUS, August 13th 1929
RE: establishment of the *Hoover-Young San Francisco Bay Bridge Commission*

42

"…signaled to the army and navy that their representatives on the commission must be open-minded and not tied to traditional prejudices against a trans-bay bridge"

RE: an historian's perspective on the appointment of *Charles D. Marx* to the Hoover-Young Commission. Marx was a respected professor of engineering at *Stanford University* who had taught Hoover as an undergraduate (he was also a close personal friend). *Mark Requa* was to chair the commission. Also a close personal friend of Hoover, he was a prominent Republican and an engineer of considerable accomplishment. The commission included many other prominent figures, but what would prove most significant of all was the appointment of its secretary; *Charles H. Purcell*. Purcell had been appointed *Highway Engineer for the California Division of Highways* in 1928. His engineering skills and political acumen would serve him well and earn him well-deserved credit for being the man most responsible for physically building the bridge. However, without the formation of the Hoover-Young Commission, it's unlikely that the bridge would have been built in the 1930s.

43

Charles Henry Purcell (1883-1951)

44

Aside from its political role, the Hoover-Young Commission played a critical role in the bridge's creation in three significant aspects;

- **Location**
- **Geometry of the bridge (i.e. vertical and horizontal clearances)**
- **Financing**

The first meeting of the commission was held in Governor Young's office on October 7th 1929. It met again on October 8th and 9th and adjourned until July 22nd 1930. It met two more times in July 1930 and disbanded after issuing its final report on August 6th 1930. At the first meeting of the commission (10/07/29), the *Department of Public Works* was tasked with producing a series of studies. In turn, DPW assigned the study to Purcell's *Division of Highways*.

45

Resolved that the Department of Public Works of the State of California be asked to make an engineering, economic and traffic study to furnish the Commission with all data obtained for the purpose of determining the relative value of the several proposed locations for a connection between San Francisco and Alameda counties.

RE: first resolution of the Hoover-Young Commission passed on October 7th 1929 (at its first meeting). By tasking the DPW – an administrative body with minimal staff/capabilities, the commission placed the *Division of Highways* (a sub-division of the DPW) at its disposal. With a large staff and extensive transportation planning experience, it was up to the challenge of preparing the complex studies and accompanying reports. The request for these studies were well funded and put the engineers of the *Bridge Department* (of the Division of Highways) on an immediate, dedicated assignment.

46

Another significant administrative body formed specifically for the Bay Bridge project was the creation in 1929 (just prior to the convening of the Hoover-Young Commission) of the *California Toll Bridge Authority* (CTBA) by the *California State Legislature*. The *CTBA Act* appropriated $50K for engineering feasibility studies and provided the legal authority to construct the bridge. The CBTA consisted of five high-ranking officials;

- **Governor**
- **Lieutenant Governor**
- **Director of Finance**
- **Chair of the Highway Commission**
- **Director of Public Works**

With little support staff, the CBTA deferred to its sister agency; the Hoover-Young Commission. Essentially, the DPW served as support staff to both entities and DPW funding priority was directed to the Bridge Department (based in Sacramento). Eventually, a *Bay Bridge Division* of the DPW (headquartered in San Francisco) was formed around the personnel involved with the commission studies.

47

In their final report to the commission, Highway Engineer Purcell and Division of Highways Bridge Engineer *Charles Andrews* cited the 1927 Ridgway Report extensively. The Ridgway Report emphasized two critical concerns;

- **What was the condition of the bay floor?**
- **Was the bridge financially feasible?**

Purcell and Andrews, with assistance from the Bridge Department's staff, headed-up the studies. In their report, they sought to answer these two questions but they also re-opened questions concerning the bridge's alignment. Though it was not resolved when the commission's report was issued (1930), they sought to try and define what bridge types would be most appropriate for the bay crossing. However, the most critical concern for both men was the condition of the bay floor.

48

"The wide expanse of the bay across which any bridge must pass was un-prospected as far as depths to suitable foundation were concerned. This fact was noted by Messrs. Talbott, Ridgway and Galloway, in their 1927 report. No intelligent cost estimate could be arrived at until such borings were made, and even the possibility of building a bridge could not be determined on any complete line."

RE: excerpt from the *Hoover-Young San Francisco Bay Bridge Commission* final report, 1930. Since test borings were critical and were based on possible bridge alignment/s (yet to be determined), test borings could not be conducted unless/until alternative alignments were decided upon.

49

Purcell and Andrews used the three straight-line alternative alignments outlined in the 1927 Ridgway Report to narrow down the choices;

- **<u>Location No. 1</u> (the preferred alternative in the Ridgway Report) – from Rincon Hill (SF) to the Alameda Mole**
- **<u>Location No. 2</u> – from 16th Street (SF) to Alameda**
- **<u>Location No. 3</u> – from Telegraph Hill (SF) to the Key Route Mole (via Yerba Buena Island)**

Four additional alternatives were added by the Bridge Department for a total of seven(7) alignment alternatives (1A-C + 2-5).

50

Locations No. 1-A, 1-B, and 1-C.

The three Location No. 1 alternatives extended from Alameda to San Francisco. Location No. 1-A extended from the Alameda Mole (now part of NAS Alameda) to Pier 32 in San Francisco, near the corner of Beale and Brannan. The San Francisco terminus for this alignment was about 1/2 mile south of Rincon Hill. Under this alternative, traffic tubes were to connect the roadway between the Alameda Mole and the City of Oakland on the East Bay.[87] Locations 1-A, 1-B, and 1-C were relatively minor variants on the Location 1, with variations only as to the location of the east abutments. All variations of Location 1 required a very long bridge, with no intervening island anchorage, as was ultimately provided by Yerba Buena Island.

Location No. 2.

Location No. 2 extended from 16th Street in the Mission District of San Francisco to a location on the island of Alameda. It was thus located about one mile south of Location 1, on both the east and west sites. This alternative was one suggested in the Ridgway Report.

Location No. 3.

Location No. 3 was quite similar to what was actually built, differing only as to the San Francisco abutment. Location No. 3 used the Key Route Mole between Oakland and Yerba Buena Island, as does today's Bay Bridge. In San Francisco, however, the bridge touched down at Pier 22, in the vicinity of Telegraph Hill.

Location No. 4.

This emerged as the preferred alternative and was essentially what was built, with minor variations. In San Francisco, the touch down point was Rincon Hill. This alignment proceeded northeast to Yerba Buena Island and from the island to the Key Route Mole, with the eastern leg being identical to the eastern portion of Location No. 3.

Location No. 5.

This location linked Hunters Point in San Francisco with the natural mainland of Alameda. This alignment would be re-studied in the 1950s, commonly called the Southern Crossing.

[87] Alameda Island was much smaller in 1930 than it is today; much of the current island was filled to create the Naval Air Station there, just prior to World War II.

Alternative Alignments
(1A thru 5)

51

Bridge Alignment Map of the *Report of the Hoover-Young San Francisco Bay Bridge Commission* (1930)

52

Location, Location, Location

53

The results of the test borings for all seven alternate bridge alignments were both troubling and encouraging. The focal point of the conclusions was the depth to bedrock. In Location No. 1, bedrock was found at a depth of 229-feet (below mean high water). Though the depth was great, these were the best test bore results. For Location No. 2, bedrock (for a key western pier) was found at 293-feet. The engineering report concluded: *"It is very doubtful whether any safe bearing for such a pier could be obtained above elevation -293…For this reason the possibility of building a bridge on this location is doubtful and the line has been abandoned."* For Location No. 5, borings extended to 233.5-feet without contacting bedrock: *"rock elevations are beyond the reach of practical foundations."* The western span (between San Francisco and Yerba Buena) for Location Nos. 3 and 4 were more positive with bedrock found at 211-feet and 163.5-feet respectively. Alignment No. 4 would be the one built: *"Location No. 4 is the most favorable because of the lesser depths to shale…a high ridge of sandstone extends from Pier 24 across the main channel to Goat Island."*

54

With Location No. 4 determined most suitable (because of the ridge of rock discovered between San Francisco and Yerba Buena), test borings were made for the eastern span (between Yerba Buena and Oakland). The results were indeterminate. Typically, the test borings extended past 300-feet and, most often, made little or no contact with bedrock. One test bore (830-feet east of Yerba Buena) made contact with what was assumed to be bedrock at 269-feet. Another test bore (270-feet east of the island) encountered rock at 216-feet. With these disappointing results, the engineers concluded that, perhaps, it would not be feasible to take the eastern (continuous span) piers to bedrock. Rather, they would/could be founded on hard sand via piles. However, they remained optimistic that the main (cantilever) span piers could be taken to bedrock. They concluded: ***"East of Goat Island the cantilever span adjacent to the island can be founded on shale. The remaining part of the structure is composed of 300-foot viaduct spans and can be safely supported on piles driven in sandy clay."*** Ultimately, the eastern piers would be founded on hard clay rather than bedrock. 55

56

The Hoover-Young Commission Report also included a traffic study to determine: need, location, bridge design (i.e. levels/mix of traffic) and anticipated toll revenues. ***Lester Ready*** – a traffic consultant, was hired to perform the study. It focused on the commuting patterns of both auto and rail commuters traveling from their homes in the East Bay (centered in Oakland-Berkeley-Alameda) to their jobs in San Francisco. The study concluded that the bridge should begin and end at the centers of this commute (the same for both interurban and/or vehicular, as it turned out). This meant connecting downtown Oakland with downtown San Francisco (it would also maximize toll revenue). The study also considered the impact of a bridge on ferry service and/or commuters switching from the interurban to automobiles: ***"Increased vehicular traffic and deflection of passengers from interurban trains may be expected."*** The study found that Locations 3 and 4 would save a commuter thirty minutes whereas Location 5 would cause drivers to lose time. Based on the assumed volume of traffic and anticipated revenue, Ready's report suggested the bridge could support a construction cost of $72 million. 57

With the alignment issue resolved and the traffic study essentially confirming Location No. 4 as the best choice, the last issue the commission report dealt with was that of the bridge's design. The design criteria focused on two main issues;

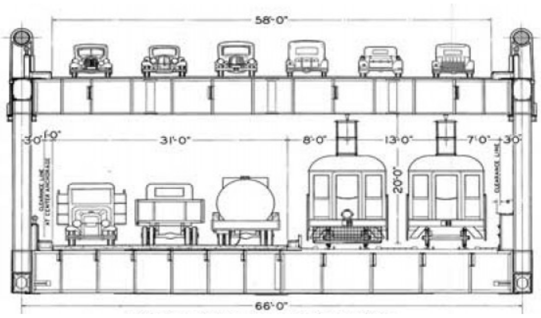
- **Capacity (for both rail lines and vehicle lanes)**
- **Horizontal clearance (distance between piers)**
- **Vertical clearance (to the underside of the road deck)**
- **Grades (for the road deck)**

Since Location No. 4 was the preferred alternative alignment, the report focused on it with little discussion of the other alternatives. A vertical clearance of 220-feet was determined as adequate for all ship traffic entering the harbor. However, it would prove much more difficult to form a consensus on horizontal clearances. The Hoover-Young studies assumed at least one 1,600-foot clear span between San Francisco and Yerba Buena and one 650-foot clear span between Yerba Buena and Oakland. Both the War Department and shipping concerns found these clearances inadequate thus greatly influencing the bridge type/s selected for both east and west spans. 58

As for grades, a design criteria for 3% and 3.5% for electric trains and vehicles respectively was assumed. Capacity included both the need for the bridge to pay for itself and anticipated traffic and was a reflection of previous economic and traffic studies: *"The structure capable of carrying the anticipated traffic should have a capacity of six lanes for highway traffic and at least two operative and one passing or emergency track for interurban trains."* The required bridge structure for Location No. 4 was broken down into six key elements;

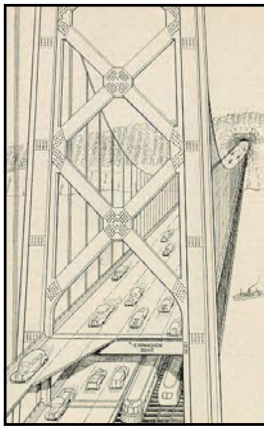
- **Arrangement of traffic lanes**
- **Bridge type/s on west bay crossing**
- **Roadway structure across Yerba Buena Island**
- **Bridge types between Yerba Buena Island and the East Bay**
- **Traffic distribution in San Francisco**
- **Traffic distribution in the East Bay**

Two alternatives were offered for traffic lane distribution. The first called for 6 lanes for cars and trucks on the upper deck and 4 rail lines on the lower deck. The second called for 6 car lanes on the upper deck, 2 truck lanes and 2 rail lines on the lower deck. 59



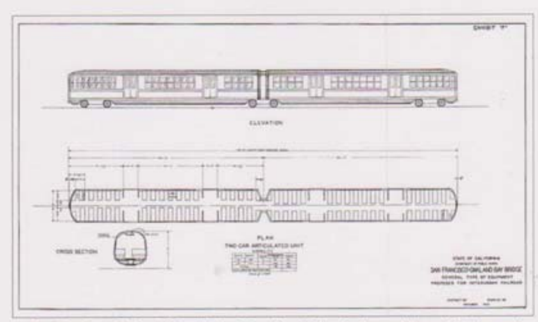
Typical Bridge Cross-Section (1933)

Note: three(3) lanes for trucks were included for the lower deck 60



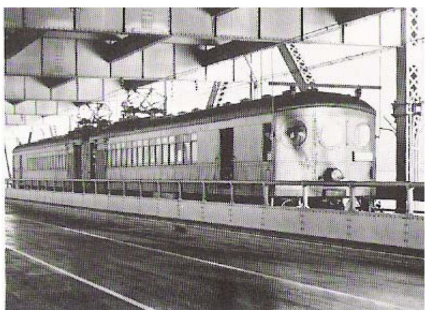
The upper deck was designed exclusively for automobile traffic with six, 9'-8" lanes (with an allowance for a 10-ton truck in any one lane. The lower deck was designed for 30-ton trucks with three lanes 10'-4" wide. A 27-foot wide space was reserved (two tracks) for 70-ton interurban rail cars.

61



San Francisco-Oakland Bay Bridge Interurban Railroad: General Type of Equipment Proposed for Interurban Railroad (1933)

62



63

For the west bay crossing, the commission report recommended four 1,700-foot cantilever spans with 600-foot anchor spans at each end. Yerba Buena was to be crossed: *"by cut, fill, and viaduct."* This would include a deep trench (about 150-feet deep) with viaducts at each end. The east bay crossing was to include one 720-foot cantilever (adjacent to the island) with twenty-one 300-foot steel deck spans to the Oakland shore. The west bay cantilevers were to be conventional through-type cantilevers whereas the east bay cantilever was to be a deck-type cantilever.

64

The commission report simply described East Bay traffic distribution as follows: *"The highway traffic is distributed by two roads to Yerba Buena Avenue and Twenty-Second Street, each passing through a subway under the Southern Pacific tracks. Railway connections are made directly into the present track systems of the Key Route and Southern Pacific railroads."* Traffic distribution in San Francisco was described in greater detail: *"Highway traffic in San Francisco is carried on Harrison Street to a plaza located between Fourth and Fifth Streets and Folsom and Bryant Streets. A ramp for truck and automobile traffic takes off the approach viaduct at First and Essex Streets and discharges traffic to the Embarcadero and waterfront. Interurban railroad traffic loops off the approach viaduct on First Street and runs over an elevated loop on First Street to Minna Street; from which it proceeds west on Minna Street to Clementina Street, then east to First Street. Four loop stations are contemplated. In the estimates given it is proposed to receive and discharge main line passengers to and from the main line railroad in Oakland at the First Street loop station…"*

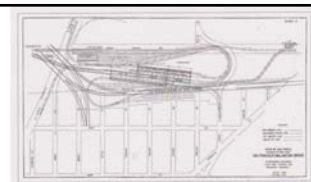
65

Map of San Francisco Metropolitan Transit District, Report on Interborough Rapid Transit, San Francisco-San Mateo (1931)

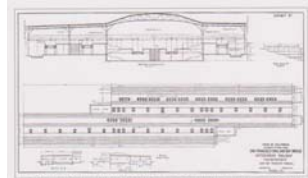
66

Suburban Lines of the Southern Pacific Co and Key System Transit Co to Accompany Report on Transbay Bridge (1927)

67

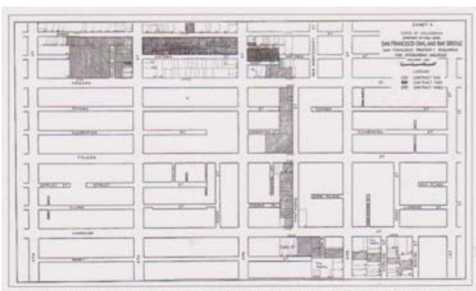


San Francisco-Oakland Bay Bridge Interurban Railroad: East Bay Tracks and Transfer Terminal (1933)



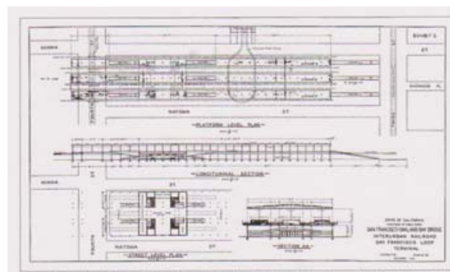
San Francisco-Oakland Bay Bridge Interurban Railroad: Plan and Section of East Bay Transfer Terminal (1933)

68



San Francisco-Oakland Bay Bridge Interurban Railroad: San Francisco Property Required for Interurban Railroad (1933)

69



San Francisco-Oakland Bay Bridge Interurban Railroad: San Francisco Loop Terminal (1933)

70

Save for the traffic mix (second alternative), the traffic plaza between Fourth and Fifth Streets and the Embarcadero off-ramp, the bridge that was actually built is very different from the one described by the commission report of 1930. In general, by the time the Hoover-Young studies were completed and the final report drafted, only the alignment (location) and traffic mix were resolved. By 1931, in the minds of political leaders and the public at-large, the overall bridge design was a done-deal. This however was not the case. Before the commission's final adjournment (August 6th 1930), it held two sessions (July 28th and 29th 1930) whereby civic and political leaders from San Francisco and the East Bay where allowed to address their concerns to the commission. In general, all were in favor of any type of bridge. Only Alameda expressed disappointment at the alignment selection with its eastern terminus being Oakland rather than Alameda (as it was under the Ridgway Report of 1927). The commission meeting on August 4th 1930 finalized the selection of Location No.4: *"The only practicable site for a high level bridge across the bay is Location 4, from Rincon Hill to Goat Island."*

71

The last hurdle to be overcome by the commission was that of the War Department (i.e. Army and Navy) who long objected, in general, to any bridge north of *Hunter Point* (this qualified Location No. 4 as objectionable). Admiral Standley spoke into the record for the Navy: *"We desire to present to the Commission for consideration certain inherent objections to a bay bridge of the type and in the position shown as Location No. 4…No bridge north of Hunter Point is free from naval objection, but a bridge on Location No. 4 , 'Rincon Hill-Goat Island' is the least objectionable from the standpoint of the national defense."* The Army's objections/statements were in tune with the Navy's, but both had to concede to the inevitable and grudgingly went along with plans for a bridge across the bay at Location No. 4.

72

The Hoover-Young Commission adapted thirteen measures, a.k.a. "conclusions." Some conclusions were contested, others were not. The longest conclusions (and most objected to by the military) were those concerning both horizontal and/or vertical clearances. Conclusion '*b*' reflects best the compromise reached with state leaders: "*Consistent with meeting the traffic needs and engineering requirements the type and location of a bay crossing should be such that it will not unreasonably obstruct future navigation or cause serious interference with or constitute a serious menace to the operation of the Navy in time of war.*" A compromise between city officials (concerned about access) and state planners (wanting maximum flexibility in design) is reflected in conclusion '*l*': "*The details of construction of the bridge structure is the function of the State of California working through the California Toll Bridge Authority. Consideration of traffic distribution on both sides of the bay is of prime importance and should be worked out in cooperation with the authorities of the municipalities in interest.*"

73

(a) To meet the present and future needs of the several communities a crossing for traffic between San Francisco and the East Bay cities is necessary.
(b) Consistent with meeting the traffic needs and engineering requirements the type and location of a bay crossing should be such that it will not unreasonably obstruct future navigation nor cause serious interference with or constitute a serious menace to the operations of the Navy in time of war.
(c) Because of the limitations, cost of construction and operation a vehicular tunnel under the bay is inadvisable.
(d) As indicated by the rock explorations the only location upon which to base a high level bridge is on a line from Rincon Hill to Goat Island.
(e) A bridge on the location designated as Location No. 4, from Rincon Hill via Goat Island thence parallel to the Key Route mole, is practicable from an engineering standpoint. It is economically feasible under a proper fiscal plan and will adequately serve the traffic.
(g) The bridge shall provide at least six lanes for vehicular traffic and in addition five lanes for interurban and heavy automobile truck traffic.
(h) The bridge between San Francisco and Goat Island shall consist of not more than four main spans, the westerly one of which shall have a horizontal clearance of not less than 1750 feet between fenders.
(i) The vertical clearance of the two center spans shall be not less than 214 feet above M.H.H.W. [mean higher high water] at the center of the spans, and this height shall be maintained for approximately 500 feet on either side of the center of the span, and minimum vertical clearance at the San Francisco pier head line shall be 180 feet above M.H.H.W.
(j) The [East Bay Crossing] shall have a minimum vertical clearance of 180 feet above M.H.H.W and a minimum horizontal clearance of 600 feet between fenders. Consideration shall be given in the final plans to a minimum clearance of 700 feet between fenders.
(k) The final design should be such that it will conform with the scenic beauty of San Francisco Bay.
(l) The details of construction of the bridge structure is the function of the State of California working through the California Toll Bridge Authority. Consideration of traffic distribution on both sides of the bay is of prime importance and should be worked out in cooperation with the authorities of the municipalities in interest.
(m) A right of way across Goat Island must be obtained from the Navy Department and be approved by Congress.

Hoover-Young Commission "Conclusions"
(a thru m)

74

The 1927 *Ridgway Report* served to commit the leaders of San Francisco and the East Bay to a "downtown-to-downtown" alignment (connecting downtown San Francisco with either downtown Alameda or Oakland). The *Hoover-Young Commission* resolved the bridge's location, traffic mix and roadway design. More importantly, it provided the consensus and conceptual agreement to build a bridge across the bay from long-time antagonists. It is arguable that without the support of Herbert Hoover and the formation of the Hoover-Young Commission, the Bay Bridge might never have been built. The critical turning point came when, as POTUS, Hoover threw his complete support and influence behind the project which was embodied in the *Hoover-Young San Francisco Bay Bridge Commission*. Indeed, many insisted that ex-President Hoover be given the honor of officially opening and dedicating the bridge (in November 1936) in recognition of his crucial role in making it a reality. For now though, the job of actually building the bridge would be left in the capable hands of the engineers.

75

Part 3

Design By Committee

76

"Though it is true that no individual engineer, no matter how great, can single-handedly do everything – from detailed calculation to supervision of construction – required to bring a major span to fruition, great bridges do appear to have had masterminds behind them, albeit masterminds with many helper minds…Among the reasons for the Bay Bridge's relative obscurity must also be counted the fact that this bridge had no single prominent and dominant dreamer like a Roebling, Lindenthal, Ammann, or Strauss serving as executive director and providing a visible personality to the project."

Henry Petroski, Author

RE: ambiguities concerning who was responsible for the design of the Bay Bridge

77

At the time the Bay Bridge opened, credit for its design was, for the most part, given to Chief Engineer C.H. Purcell. In the intervening years, Design Engineer *Glenn Woodruff* has been recognized as having played a pivotal role in the bridge's design along with other engineers (and architects) working for the *Bay Bridge Division of the California Department of Public Works.* In early 1931, the bridge division set up engineering offices at *500 Sansome Street* in San Francisco. Except for some preliminary designs generated by the Hoover-Young Commission, no design work had been done to-date. Essentially, the entire bridge would be designed in a 24-month period (between early 1931 and early 1933). Between the state engineers (working out of Sansome Street) and the private *Board of Consulting Engineers* (working in their NYC offices), the largest and most expensive bridge ever built was out to bid by the beginning of 1933 with complete specifications. The Bay Bridge Division of the DPW was a semi-autonomous agency, not part of the Division of Highways and well-removed from the CBTA (which had been created by the state to build the Bay Bridge as part of its mandate).

78

Though the Bridge Division drew upon staff from the *Division of Highways* (responsible for the design and maintenance of the state's highways and bridges), it was not responsible for any part of the design of the Bay Bridge. Both the CBTA and Bridge Division were entirely responsible for the design with the latter doing all the heavy lifting. The CBTA was a political entity which was merged into the Division of Highways after WWII. In 1931, the state legislature authorized the CBTA to build a bridge between San Francisco and Alameda County. The actual building of the bridge was charged to the DPW (it was given $650K to design the bridge). Thus, by legislative action, DPW (an "umbrella" state agency) rather than the Division of Highways would be tasked with designing and building a bay crossing. This is rather ironic considering that most of the technical reports submitted to the Hoover-Young Commission were generated by C.H. Purcell, Charles Andrew and other engineers, geologists etc. of the Division of Highways. Thus, during the H-Y Commission's term, the Division of Highways was doing the work attributed to the DPW. That would no longer do.

79

The legislative allocation of $650K (for bridge design work) to the DPW forced their hand requiring it to develop an administrative agency to design the bridge. With James "Sunny Jim" Rolph – former San Francisco Mayor (and major bridge proponent) in the Governor's mansion, the way would be smoothed to do this. Rolph appointed *Earl Lee Kelly* to head DPW and he in turn created an entirely new organization within DPW (without ties to the Division of Highways): *San Francisco-Oakland Bay Bridge Division* (a.k.a. *Bay Bridge Division*). Kelly tapped C.H. Purcell for the job of *Chief Engineer* for the Bay Bridge while he simultaneously retained his position as *Highway Engineer* for the Division of Highways through to the bridge's completion in 1936.

80

ORGANIZATIONAL LIST FOR BRIDGE DESIGN BY THE DIVISION OF HIGHWAYS, EARLY 1930'S

California Department of Public Works
Earl Lee Kelly, Director (after 1932)

California Division of Highways
C. H. Purcell, Highway Engineer

Bridge Department, Division of Highways
Charles Andrew, Bridge Engineer (on loan to Bay Bridge Division, 1931-36)
Frank Panhorst, Acting Bridge Engineer, 1931-36

ORGANIZATION LIST FOR BRIDGE DESIGN FOR BAY BRIDGE, 1932-36

California Department of Public Works
Earl Lee Kelly, Director (after 1932)

California Toll Bridge Authority
Earl Lee Kelly, Director

Bay Bridge Division of the Department of Public Works
C. H. Purcell, Chief Engineer
Charles Andrew, Bridge Engineer (on loan from the Division of Highways, 1931-36)
Glenn Woodruff, Engineer of Design

Board of Consulting Engineers for the Bay Bridge
Ralph Modjeski
Leon Moissieff
Daniel Moran
Charles Derleth, Jr.
Henry Brunnier

81

Chief Engineer

82

***Charles Henry Purcell* was born on January 27th 1883 in North Bend, Nebraska. He studied engineering at Stanford University (for one year) but had to return to Nebraska after the death of his father. In 1906, he graduated with a civil engineering degree from the *University of Nebraska*. He worked for railroad and mining companies in the western U.S., but his passion was for bridges. In 1910, Purcell accepted a position as a bridge engineer for the *Oregon State Highway Department.* This gave him the opportunity to design many of the bridges that are part of the *Columbia River Highway*. In 1917, the *U.S. Bureau of Public Roads* (today's *Federal Highway Administration*) hired Purcell as a bridge engineer and in 1919, he was appointed the *District Engineer for the Bureau of Portland*. In 1928, Purcell accepted the position as *Highway Engineer for the California Division of Highways* (this title is for the head of the agency). As mentioned, he retained this title (while serving as Chief Engineer for the Bay Bridge) and held it until he was appointed *Director of the Department of Public Works* in the mid-1940s. Purcell died on September 7th 1951 after a long and distinguished career.**

83

Bridge Engineer

84

The position of "Bridge Engineer" is, essentially the equivalent of "Chief Assistant to the Chief Engineer." For this critical job, Purcell looked to the Division of Highways choosing *Charles Andrew* who was placed "on loan" from the Division of Highways (on a full-time basis) for the duration of the Bay Bridge project. Andrew was a civil engineering graduate of the *University of Illinois* (1906). He worked under Ralph Modjeski on the *Portland and Seattle Railroad Bridge* (over the Willamette River at St. Johns, Oregon) between 1906 and 1908. It is probably due to his experience with Modjeski during this period that both Purcell and Andrew turned to him to chair the prestigious Board of Consulting Engineers for the Bay Bridge. He held several public and private sector engineering positions thereafter and from 1918 to 1920 he served under Purcell at the U.S. Bureau of Public Roads in Portland, Oregon. From 1920 to 1927, he was the Bridge Engineer for the State of Washington. In 1927, he was hired to head the California Division of Highway's Bridge Department. At first, Purcell and Andrew comprised the entire full-time staff of the newly formed Bay Bridge Division.

85

Design Engineer

86

Reluctant to rely on career civil servants to design the Bay Bridge (though they themselves were exactly that), Purcell and Andrews' first action was to request that the Bay Bridge Division be granted exemption from civil service examinations/requirements and that all appointments be made by the Chief Engineer directly based on qualifications and expertise. This allowed them to hire immediately *Glenn Woodruff* who was then working for Ralph Modjeski in NYC. Woodruff graduated from *Cornell University* in 1910 with a civil engineering degree. He worked for railroads and the *American Bridge Company* prior to WWI and served in the military during the war. After the war, he worked for railroads again and then for the prestigious consulting firm of *Robinson and Steinman*. Between 1923 and 1930, Woodruff worked on several major bridge projects including the *Delaware River Bridge* in Philadelphia and the *Huey P. Long Bridge* in New Orleans as principal engineer for Ralph Modjeski. After WWII, he formed the engineering consulting firm of *Woodruff and Simpson* contributing to major projects such as the *Mackinac Straits Bridge* in Michigan. He died in 1974.

87

Board of Consulting Engineers

88

In March 1932, the Division of Highways forced the Bay Bridge Division to transfer all its positions to civil service status and to make all new hires from prevailing civil service lists. However, by this time most of the bridge design staff was in-place. Fifty engineers, surveyors and clerical staff were hired, most coming from Northern California. Many of the earliest hires were "transfers" – from the *Bridge Department of the Division of Highways* in Sacramento. The years 1931-1933 focused on bridge design and from 1933-1936, construction prevailed requiring a whole new set of personnel experienced in construction. Again, transfers would prevail but new hires were made as well (under civil service jurisdiction). Even before the Bay Bridge Division was fully staffed, Purcell and Woodruff began to assemble a *Board of Consulting Engineers.* In contrast to the large but publicly anonymous engineering staff of the Bay Bridge Division, this board of prestigious engineers would be highly visible to the public and engender confidence in the project.

89

Though there was no legislative provision requiring a "Board of Engineers" be established, precedent and tradition had established that (for very large bridges at least) it was the responsible thing to do. Indeed, every large bridge project built between 1927 and 1937 had a "peer review" by famous engineers serving on an oversight Board. Another reason of course was the scale and cost of the bridge itself. Only Woodruff was experienced in the kind of bridge design/s the Bay Bridge would require and this, no doubt, was the main reason he was hired as Design Engineer. The Board of Engineers would not be there for show and/or a rubber stamp, they were relied upon heavily by Purcell and his staff throughout the Bay Bridge's design and construction for their knowledge and advice. In December 1930, DPW announced its intention to appoint a consulting board of engineers with superstructure expert *Ralph Modjeski* as its chairman and foundations expert *Daniel Moran* as one of its board members. Though no board member would be under contract until August 1931, consultations and correspondence began in earnest.

90

"We are in receipt of your letter of January 22nd, to which was attached a proposed layout for the bridge across the west channel between San Francisco and Goat Island…I should be very glad to have your comments on any of the subject matter of this letter."

RE: excerpt from letter C.H. Purcell sent to Ralph Modjeski (with four alternative alignments attached) in early 1931. Both Purcell and Woodruff relied heavily on Ralph Modjeski.

91

"I can assure you, however, that all major appointments in the designing organization will be made in consultation with you and that efficiency and ability will be the basis upon which such appointments will be made. We have sent a similar letter to Moran and Proctor for their signature. The contract to them designates you as the Chairman of the Consulting Board. I cannot finally advise you of the complete personnel of the Consulting Board at this time for the reason I have not fully decided the matter. I am considering Mr. Moisseiff or Mr. Robinson and two local men. The appointment of Mr. Robinson is contingent upon your anticipated conference with him when you return to New York."

RE: excerpt from a July 25th 1931 letter from Purcell to Modjeski regarding selection of board members. *Holton Robinson* (of *Robinson and Steinman*) is the "Mr. Robinson" referred to.

92

Modjeski

93

"It is that Ralph Modjeski was inherently an artist. He has not chosen oil, or dry point, or marble, or even music, in which he doubtless would have excelled, to express himself, but steel, and stone, and concrete. Using these as his chosen media, 'by a pleasing simplicity of form and reliance upon the quiet dignity of the long spans whose members gracefully express function free from superfluities,' he has made of bridge building a recognized art without in the least minimizing its importance as a science."

RE: excerpt from a 1931 tribute. He was born *Rudolphe Modrzejewski* in Cracow, Poland in 1861. His mother was a famous actress (*Madame Modjeska*) and he traveled widely with her as a child. She settled in Orange County, CA. (in 1876) and founded a Utopian colony: *Modjeska Canyon* (near Anaheim). From 1878 to 1881, he lived in Paris where he studied civil engineering at *L'ecole des Ponts et Cahaussees.* After graduating, he moved to the U.S. and worked for *George S. Morrison* – a prominent bridge designer. He worked on several major bridges and in 1893, he moved to Chicago to start his own consulting firm specializing in RR bridge design.

94

Moran

95

***Daniel Edward Moran* (and partner *Carlton Proctor*) were the most famous foundation engineers of their day. Moran was born in New Jersey in 1864. He earned a degree in civil engineering from *Columbia University* in 1884 and began working for railroads after graduating. By the early 1890s, he turned his attention to the specialized field of foundations engineering which he practiced for the remainder of his career. He specialized in *Pneumatic Caissons* and, besides numerous buildings, worked on many of the largest bridge projects of the period between the world wars including: *Benjamin Franklin Bridge* (Philadelphia), *Huey Long Bridge* (New Orleans), *Carquinez-Strait Bridge* (San Francisco) and the *George Washington* and *Triborough Bridge/s* (NYC). The *San Francisco-Oakland Bay Bridge* was Moran's last hurrah. He died in 1937.**

96

"If you remember, the question of another member of the Board of Consulting Engineers familiar with suspension bridges was being considered: one of them being Mr. Moissieff and the other, Mr. Robinson. After serious consideration of the matter, I would recommend that Mr. Moissieff be appointed rather than Mr. Robinson. One is, that Mr. Moissieff worked under me for two or three years in connection with the Delaware River Bridge and I am very familiar with his qualifications. The second reason is, that it would be practically impossible to get Mr. Robinson to act on the Board without the cooperation of Mr. Steinman. Another reason for the above might be given, in that Mr. Moissieff being employed on the Golden Gate Bridge would therefore be able to devote more time to the Trans-Bay Bridge than would Mr. Robinson. I trust that you will approve of this recommendation and make suitable arrangements."

RE: excerpt from an August 1931 letter from Modjeski to Purcell (in response to Purcell's 07/25/31 letter). Purcell took Modjeski's advice and appointed *Leon Moissieff* to the Board of Consulting Engineers (rather than Holton Robinson) five weeks later. 97

Leon S. Moissieff **was born in Latvia in 1872. In Riga, he attended the *Baltic Polytechnic Institute* but emigrated to the United States with his family. They settled in NYC where he earned a degree in civil engineering from *Columbia University* in 1895. He was so pleased with his new country he named his daughter "Liberty." He worked as a bridge designer for New York City where he became acquainted with Gustav Lindenthal and designed the superstructure of the *Manhattan Bridge* (1909). In 1915, he set-up his own bridge consulting firm specializing in suspension bridges. He was a major proponent of "Deflection Theory" and the use of steel in bridges. He consulted on several major suspension bridge projects including the *George Washington Bridge* (NYC) and the Golden Gate Bridge (San Francisco). Sadly, he died a broken man in 1943 after a long and distinguished career as a bridge engineer. The collapse of the *Tacoma-Narrows Bridge* – of which he was the principal designer, in a wind-storm on November 7th 1940 essentially ended his career.** 98

"There should be at least one local western California engineer. I feel that I have the qualifications which deserve consideration if a local man is appointed; just as I am the local member of the Board of Consulting Engineers for the Golden Gate Bridge. A local man can do much to bring together amity and understanding the heterogeneous interests of central California…"

RE: excerpt from a letter written by *Charles Derleth, Jr.* to *William Filmer* – a director of the *Golden Gate Bridge and Highway District*. Derleth – a member of the *Board of Consulting Engineers for the Golden Gate Bridge* and professor of engineering at the *University of California* (and East Bay resident) wanted Filmer to petition Governor Rolph for his appointment as one of the "local men" Modjeski intended to appoint to the Board for the Bay Bridge. It worked and Derleth was appointed to the Board along with *Henry Brunnier* – whose office was in San Francisco. 99

The New York Members of the Board

100

With the members of the Board in place, communication between the Bay Bridge Division and the Board occurred at two levels;

- **Informal correspondence between Modjeski/Moran and Purcell/Andrew/Woodruff (before and after the Board was convened)**
- **Formal actions of the entire Board (after it was convened)**

The most important informal communications occurred in early 1931 when major bridge design decisions were being made. Based in NYC, Modjeski, Moran and Moissieff – the primary members of the Board, met frequently concerning the Bay Bridge and many letters were signed by all three. As well, of the five members of the Board, the three NYC-based members were highest paid. It would be to the New York members that Purcell, Andrew and Woodruff would turn to resolve specific design and calculation tasks. Moran designed the pneumatic caissons for the deep-water pier foundations and Moissieff checked the calculations for the entire bridge. Modjeski – as Board Chairman, was removed from design tasks. Rather, he served as arbiter of design decisions both major and minor. 101

The Board met formally (in San Francisco) sixteen times between early 1932 and late 1936 (often for several days in a row). Most often, these meetings concerned critical design issues such as;

- **Bridge type for the west crossing**
- **How to sink the foundations (for the deep-water piers, both east and west)**
- **Bridge type/s for the east crossing**

102

Part 4

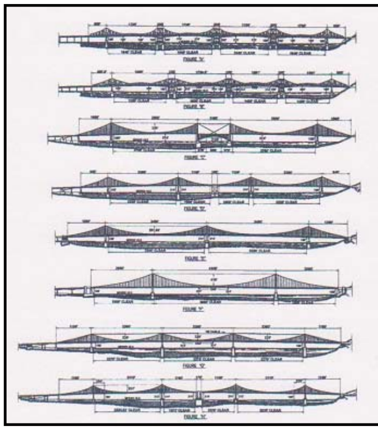
West Bay Crossing

103

Two miles separated San Francisco from Yerba Buena Island and presented the most difficult problem/s to solve – both natural and man-made. Length of span and depth to rock were the natural obstacles to be overcome, the War Department was the other. For the latter, the critical factors were vertical and horizontal clearances in the shipping/military west channel. The question was how to minimize the number of piers (while satisfying these clearance requirements) thus reducing the high cost of deep water piers. With long-span suspension bridge designer Ralph Modjeski and deep water foundations expert Daniel Moran to guide them, the task would no doubt be made easier for Purcell and his staff. Essentially, the choices narrowed down to four designs for the west bay crossing;

- **Multiple cantilever spans**
- **A double (tandem) suspension bridge with a central anchorage**
- **A continuous suspension bridge with two anchorages and more than two towers**
- **A conventional suspension bridge with two towers and two anchorages**

104



West Bay Crossing Options

A cantilever design was the basis for Hoover-Young Commission planning, including the final report's cost estimate. As well, the State of California had used a cantilever design for illustrative purposes, application for a War Department permit and RFC application (for funding). 105

"The 1931 legislature appropriated $650K for preliminary surveys and designs. The bridge department of the division of highways immediately began more detailed design studies, particularly on the possibility of a suspension-bridge layout for the west channel. This resulted from the opinion of the Hoover-Young Commission that wider horizontal clearances were desirable than could be provided by a cantilever design. The studies included a twin suspension span, including the use of a central anchorage and a continuous suspension-span layout."

RE: excerpt from a 1937 *ENR* article about the Bay Bridge (authored by Purcell, Andrew and Woodruff). In fact, nearly as soon as the Hoover-Young Commission disbanded in August 1930, Purcell and Andrew were already considering abandoning the cantilever in favor of a suspension design.

106

The *conventional suspension bridge* option was the most challenging. It would require a main-span of 4,100-feet and very long side-spans of 2K-feet (required for span and navigational clearance). In comparison to the Golden Gate Bridge (being designed/built simultaneously), the main-span was 100-feet less than the GGB's 4,200-feet, but the side-spans were nearly 2x as long (because of the distance involved). Another option was a *continuous suspension span.* Two variations on this never-before-built option were explored;

- **Three towers (with two main-spans of 3,400-feet and side-spans of 1,290-feet)**
- **Four towers (with three main-spans of 2,380-feet and side-spans of 1,140-feet)**

Considering the seismic activity of the region and high winds of the bay and the fact that a suspension bridge using multiple towers had never been built before, Purcell erred on the side of caution and dismissed it as a viable option along with the conventional suspension span option.

107

Like the continuous suspension span, the *double-suspension span* option was an unproven design with many similarities to the four-tower continuous span option studied (save for a central anchorage). The two main-spans would be 2,310-feet and the four side-spans 1,160-feet each. Only the design that was actually built was studied. In a 1937 *ENR* article, Purcell, Andrew and Woodruff explained how they came to select this design for the west bay crossing; *"Designs were worked out for both of these types (twin suspension design and continuous span), and in June, 1931 professor G.E. Beggs, Princeton University, was retained to make models of these two designs in cooperation with Professor R.E. Davis at the University of California. The model study checked the design of the department, proving the superiority of the central anchorage type. This layout was also favored at early conferences with Ralph Modjeski, chairman of the consulting board…we presented these studies to the consulting board which had been appointed, and unanimous agreement was reached on the outline of the final design."*

108

"Even during the final steps of securing approval for the cantilever layout, the engineering thinking had turned to a suspension design as the more logical answer to the problem. The advantages included lower cost, fewer construction hazards and more pleasing appearance. The length of the crossing required consideration of the following alternatives:
- *Conventional suspension type with 4,100-foot main-span*
- *Multiple-span layout*
- *Central anchorage design*

The 4,100-foot span presented strong temptations. It required fewer departures from past practice than any alternative layout, reduced the number of piers to be constructed and was a more monumental structure. On the other hand, it was open to the following objections;
- *The difficulties in building the San Francisco anchorage. An open cofferdam, 100 x 250-feet in plan, constructed to minus 120-feet would have been required*
- *While investigations indicated that it would be possible to secure the necessary stiffness with a width of 72-feet center-to-center of trusses, a large amount of stiffening-truss material would have been required to resist wind stresses*
- *It did not provide as much clearance in the main steamship lane between the pier-head line and the first pier as does the adopted design*
- *The construction west of the anchorage involved the destruction of two harbor piers*
- *The construction cost was estimated at $3 million higher than the adopted design*

RE: excerpt from 1937 *ENR* article authored by Purcell, Andrew & Woodruff

109

Brooklyn-Battery Bridge (ca. 1936)

Robert Moses proposed a twin suspension bridge with a central anchorage (superimposed on the photograph) between Battery Park and Brooklyn (akin to the west bay span of the bay Bridge). Eleanor Roosevelt led the protest of NYC's gentry against the bridge arguing that the approaches and anchorage would destroy Battery Park. With help from her husband (POTUS), it was defeated using the argument that it would entrap the Atlantic Fleet at their *Brooklyn Navy Yard* base if sabotaged. It worked and the *Brooklyn Battery Tunnel* was built instead.

110

Lower Manhattan and Battery Park
(ca. 1936)

111

"…tiled ventilated vehicular bathroom, smelling faintly of monoxide and inviting claustrophobia"
Robert Moses
RE: his opinion of tunnels

112

Brooklyn Battery Tunnel
(under construction)

113

Evidence from correspondence reveals that Modjeski, Purcell and Andrew were in favor of a twin suspension span early-on while Moran, Moissieff and Woodruff favored the conventional suspension span. None however were in favor of a continuous span of either the three and/or four tower configuration. The model study revealed that the towers (particularly the inside towers) were too flexible to resist most seismic and/or wind forces (unless joined at their tops via horizontal cables). Modjeski expressed his concerns in letters to both Purcell and Woodruff in the middle and latter part of 1931: *"If this latter type of Bridge is used (continuous suspension bridge), the most economical remedy for the elimination of the excessive deflections would be by use of tie-cables between the tops of the towers…The use of tie-cables might result in some savings in the weight of stiffening trusses and towers but would be objectionable from an aesthetic standpoint…I suppose you mean by 'tie-cables' is what are sometimes referred to as restraining cables. Personally, I am very much opposed to the use of such cables as being in the nature of a makeshift..."*

114

Moissieff too expressed his strong opinion against a continuous span in a letter to Glenn Woodruff dated November 7th 1931: *"In order to obtain the desirable rigidity would involve a cost much higher than the difference of $2 million estimated by you for the single span bridge. I, therefore, recommend that your work be concentrated on a more complete study of the single and twin spans…your figures have demonstrated the inapplicability of this type for the West Bay Crossing."* Thus, the continuous span was unanimously rejected on cost and aesthetic grounds. However, the conventional span option still had its proponents on the Board and in the Bay Bridge Division. Purcell and Modjeski appear to have decided upon a twin suspension span as early as January 1931. On January 19th 1931, Modjeski met with the War Department and sent this message to Purcell via telegram: *"Had interview with General Brown and Pillsbury. Stop. Both will gladly approve suspension design with central anchorage. Stop. Two shore spans 2,200-feet clear and two center spans about 1,050-feet clear each. Stop. Will await further instructions from you. Will send sketch from New York."*

115

Purcell received the twin suspension bridge with central anchorage scheme-sketch from Modjeski in February 1931 and acknowledged its similarities to the design developed by his staff. He agreed with Modjeski that this design was superior: *"from the standpoint of economy as well as aesthetics."* However, Moran and Moissieff disagreed with Purcell and Modjeski's conclusions. Their ally in the Bay Bridge Division and still in favor of a conventional suspension span was Glenn Woodruff. Moissieff wrote to Woodruff in November and December 1931: *"The higher cost of 7% which the single span shows is in my mind well justified by the superior structure which will result. The absolute figure of $2 million will probably be saved by your more detailed studies…I will entertain hopes that the long span will prove practical."*

116

Though Daniel Moran had been brought onto the Board of Consulting Engineers to deal with foundation issues, he and partner Carlton Proctor had a strong opinion in favor of a conventional suspension design which was expressed in a letter to the Board dated November 1931 and signed by both men: *"We would further call attention to the Board to the greater advantages, to the cities of San Francisco and Oakland, of a single span design; first, because it would provide the best possible water way for shipping and; second, because it would undoubtedly create a bridge which architecturally and spectacularly would appeal to the civic pride of both cities, and would attract and interest all of the surrounding districts…would attract so many visitors to the two cities, that in the course of years the profit to the two cities, from this source alone, would more than compensate for the relatively small difference in cost…would place an extremely large pier in the center of the channel, which would place five piers in the channel instead of two, and which would also indicate that the design was one adopted for economical reasons rather than for reasons based on harbor requirements plus architectural requirements."*

117

On January 26th 1932, the Board of Consulting Engineers met and unanimously approved the double suspension-span, rejecting the conventional single-span: *"On account of the difficulties and hazards of pier construction on the rock slopes west of Yerba Buena and on account of cost."* Ultimately, the decision on whether to use the double or single suspension-span design was that of the Bay Bridge Division, specifically in the persons of C.H. Purcell (as Chief Engineer) and Glenn Woodruff (as Design Engineer). Both designs were considered viable aesthetically, structurally and economically to build. The Board's role was no doubt influential, but advisory by nature. The fact that both the Chief Engineer and Chairman of the Board of Consulting Engineers favored the double suspension-span was, perhaps, the over-whelming factor in its being chosen.

118

119

Part 5

East Bay Crossing

120

East Bay Crossing

121

Piers

122

Naturally, the type of bridge selected affected the number of piers required (for both the west and east bay). No matter how many would be required, it was never in doubt that they would be the most difficult part of the bridge to construct. Two questions were paramount;

- **How deep should they go?**
- **How best to perform the work?**

Though test borings had been conducted for the Hoover-Young Commission studies, much was still unknown about conditions of the bay floor. Not until August 1931 when state appropriations were released could further test borings be conducted. Using the H-Y borings in the meantime, starting in January 1931 and in consultation with Modjeski and Moran, Purcell and Andrew began design studies for the span length and pier placement for the main shipping channel on the eastern side of Yerba Buena Island. Three span lengths were being considered by Purcell and Andrew;

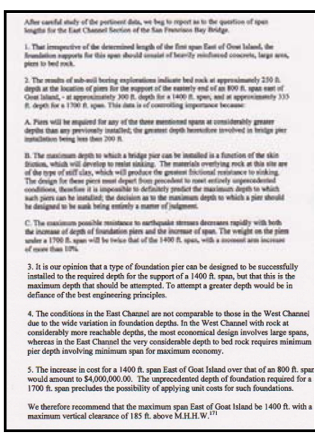
- **800-feet (less than the minimum specified by the War Dept.**
- **1,400-feet (the minimum acceptable to shipping interests)**
- **1,700-feet (length preferred by shipping interests and War Dept.)**

123

In December 1930, Purcell and Andrew forwarded the Hoover-Young Commission test bore studies of the bay floor to Modjeski and Moran. They were seeking advice – based on these limited studies, for the foundation implications of an east bay span design. Though not formally under contract, they responded with a detailed preliminary analysis in a letter dated January 10th 1931. The letter highlighted two key conclusions Moran and Modjeski had made concerning the east bay piers;

- **The first of the east bay crossing piers should be taken to bedrock**
- **The east bay main-span should not exceed 1,400-feet**

124



After careful study of the pertinent data, we beg to report as to the question of span lengths for the East Channel Section of the San Francisco Bay Bridge.

1. That irrespective of the determined length of the first span East of Goat Island, the foundation supports for this span should consist of heavily reinforced concrete, large area, piers to bed rock.

2. The results of sub-soil boring explorations indicate bed rock at approximately 250 ft. depth at the location of piers for the support of the easterly end of an 800 ft. span east of Goat Island, - at approximately 300 ft. depth for a 1400 ft. span, and at approximately 335 ft. depth for a 1700 ft. span. This data is of controlling importance because:

A. Piers will be required for any of the three mentioned spans at considerably greater depths than any previously installed; the greatest depth heretofore involved in bridge pier installation being less than 200 ft.

B. The maximum depth to which a bridge pier can be installed is a function of the skin friction, which will develop to resist sinking. The materials overlying rock at this site are of the type of stiff clay, which will produce the greatest frictional resistance to sinking. The design for these piers must depart from precedent to meet entirely unprecedented conditions, therefore it is impossible to definitely predict the maximum depth to which such piers can be installed; the decision as to the maximum depth to which a pier should be designed to be sunk being entirely a matter of judgment.

C. The maximum possible resistance to earthquake stresses decreases rapidly with both the increase of depth of foundation piers and the increase of span. The weight on the piers under a 1700 ft. span will be twice that of the 1400 ft. span, with a moment arm increase of more than 10%.

3. It is our opinion that a type of foundation pier can be designed to be successfully installed to the required depth for the support of a 1400 ft. span, but that this is the maximum depth that should be attempted. To attempt a greater depth would be in defiance of the best engineering principles.

4. The conditions in the East Channel are not comparable to those in the West Channel due to the wide variation in foundation depths. In the West Channel with rock at considerably more reachable depths, the most economical design involves large spans, whereas in the East Channel the very considerable depth to bed rock requires minimum pier depth involving minimum span for maximum economy.

5. The increase in cost for a 1400 ft. span East of Goat Island over that of an 800 ft. span would amount to $4,000,000.00. The unprecedented depth of foundation required for a 1700 ft. span precludes the possibility of applying unit costs for such foundations.

We therefore recommend that the maximum span East of Goat Island be 1400 ft. with a maximum vertical clearance of 185 ft. above M.H.H.W.[171]

Modjeski/Moran Letter
January 10th 1931

125

When the state appropriation became available to finance a comprehensive geological study via test borings, Purcell and Andrew turned to Moran for advice on how to structure the program to yield the most reliable data. On August 3rd 1931, Moran responded to the request with a four-page letter including detailed specifications for every aspect of the work; from type of cutting edge to the diameter of the samples taken and methods for storing samples for inspection. By the end of 1931 (based on preliminary test boring results), Purcell and Andrew were having serious doubts about going to bedrock with the east bay piers. Purcell wrote to Moran on November 4th 1931: "*We are just starting borings on the east channel. You will recall that there has been some discussion in regard to the pier at the east end of the 1,400-foot channel on account of extreme depth (approximately 300-feet) to rock. From all reports, the clay in this section is extremely stiff and it does not seem to me that we should assume the necessity of carrying this pier to rock. For instance, it may turn out that this clay is as good as the clay on which the two bridges at Memphis are founded.*"

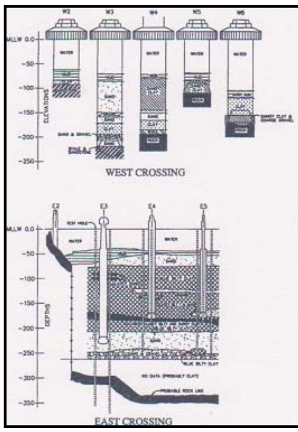
126

Preliminary Test Borings
(1931)

127

On November 9th 1931, Moran responded to Purcell with guarded optimism: *"In answer to your letter of November 4th, I beg to say that in our opinion all main piers should be carried well below the level at which artesian water is found. If the substrata below the artesian water levels are determined by test to have a low compression change, we would agree with you that these piers could be safely designed to rest on very solid clay…In our opinion it is essential to make laboratory tests on the clay-like materials encountered by the borings, and to obtain careful samples of rock."* Moran wrote to Purcell a less encouraging letter in early January 1932: *"The initial report of Prof. Davies confirms our preliminary diagnosis of the soil samples, in that the tests indicate that under moderate loads of less than six tons per square foot on the clay at the elevations from which the samples were obtained, a very considerable settlement results…Even if the sampling and testing of materials progresses rapidly it will undoubtedly be impossible for us to arrive at a decision as to proper design of the piers for the eastern section of the bridge, or as to the unit loads which can be imposed on the material by February 10th."*

128



Test Boring/s Results

129

A series of meetings were held by the "New York Members of the Consulting Board" in May 1932 concerning the east bay piers. The focus was on what methods should be used to construct the piers rather than depth. Moran had invented (he had a patent pending) and used on several previous bridges a "floating caisson" method of pier construction in deep water. By this time, all were in agreement that it was a fool's errand to attempt to reach bedrock on the eastern crossing. Most problematic of all was pier E-3. It was described: *"as a reinforced concrete crib sunk to elevation -230.0, with such dimensions that the resulting pressure does not exceed 2.5 tons per square foot in vertical loads only."* Piers E-4 and E-5 were described similarly but taken to a lesser depth of minus 180-feet. As for the balance of east bay piers: *"to be designed as pile foundations…it is the intention that during construction careful observation should be made to determine if the piles are destroying the character of the soils through which they are being driven, and if necessary, at the time of construction, either the adoption of other methods for driving the piles or a redesign of foundations to avoid piles, be considered."*

130

At a meeting of the Board (in San Francisco) on April 18th and 22nd 1932, UC Professor of Geology *Andrew Lawson* presented in-person the results of the final geological studies which he conducted. It appears that Lawson's findings put to rest any lingering thoughts of founding the east bay piers on bedrock as far as Moran and Proctor were concerned. Lawson found rock at minus 308.1 and minus 284.0 for piers E-4 thru E-6. However, Lawson was confident that the clays above the deep rock could be used as foundations for the east bay piers: *"These figures indicate that the rock surface east of Yerba Buena Island is deeper than that between the island and San Francisco, and that therefore the ancient valley, which by subsidence became San Francisco Bay, had its main drainage on the east side of the island, then a hill in the valley. It is furthermore probable that the deepest part of the rock surface is still further east, since a bore hole that was put down near Alvarado some years ago passed thru 730-feet of gravels, sands and clays before reaching bedrock. While these observations as to the character of the bedrock are interesting, the surface of the latter is too deep to be considered as a possible foundation for the piers necessary for the support of the bridge east of the island. It becomes , therefore, a matter of importance to ascertain the character, distribution and bearing strength of the bay bottom deposits which rest on the bedrock surface, since it is in these that the foundations must be found for the succession of piers that will carry the bridge over this portion of San Francisco Bay…a persistent stratum of sand or very sandy clays about 30-feet thick…adequate foundation will be found for the piers at the top of this 30-foot sand layer…"*

131

Picnic on Yerba Buena Island ca. 1890
(East Bay and Oakland beyond)

132

East Bay Piers
(under construction)

133

134

By June 1932, with the design work behind schedule and the decision taken by Purcell, under advice, not to go to bedrock for the east piers, the focus shifted to sinking the piers. This was the realm of *Moran and Proctor* which the state had contracted with to: *"advise this department as to what types of caissons and piers should be used."* For three months prior to the May 1932 Board meeting in San Francisco, Moran and Proctor were working out a pier-by-pier specification for the east bay crossing which was adopted by the Board at the May meeting. Thus began the most difficult, heroic and important aspect of constructing the Bay Bridge. With the state expressing interest in Daniel Moran's "floating cylinders" caisson, he contacted his patent attorneys seeking advice: *"anxious to have the State of California have free use of this invention for this bridge."* By the fall of 1932, the Bay Bridge Division's engineers completed design drawings for the caissons and sent them to Moran and Proctor for review/approval. Their approval entailed voluminous commentary.

135

Superstructure

136

Urban legend holds that San Francisco, being "first among equals," got the monumental tandem suspension bridge (west bay crossing) while the "lesser among equals" - Oakland and the East Bay, got a utilitarian cantilever and simple spans. This is just a legend. In reality, cost, aesthetics, safety and bay floor conditions all influenced the design of the east bay bridges. In early portrayals of a trans-bay bridge, a series of cantilevers was indicated on both the east and west sides of Yerba Buena. Consideration for a wider shipping channel and favorable bay floor conditions which would allow for heavy piers and a central anchorage were the main reasons for abandoning the cantilever design for the west bay crossing. On the contrary, every investigation of the east bay led to the conclusion that it could not support foundations for a long-span bridge. Thus, a long-span suspension bridge was never considered for the east bay. Moran and Modjeski had concluded (in early 1931) that a 1,400-foot main-span was the maximum allowable due to poor foundation conditions in the east bay. This reality would limit the choices available for a bridge with a main-span of 1,400-feet maximum.

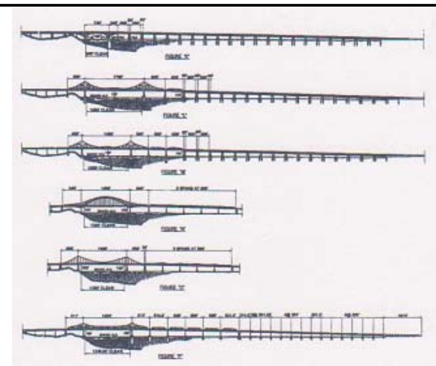
137

In a 1931 speech, Charles Andrew highlighted the suspension-span choices still being discussed but, hamstrung by east bay floor conditions, he only had this to say regarding the east bay crossing: *"Present superstructure plans east of the island contemplate a 1,400-foot cantilever just off the shore, followed by three or four 500-foot spans and a long stretch of fixed spans of shorter length to the east shore."* In January 1932, Glenn Woodruff made a speech concerning the selection of a bridge type for the east bay crossing: *"In crossing from Yerba Buena Island to the Key Route Mole, our span layouts are made quite definite by the War Department permit which requires a 1,400-foot span east of Yerba Buena then three 500-foot spans. For the remainder of this crossing the lengths of the spans will be such as to keep the cost to the minimum. Our principal design problem is, then, to find the most economical solution of the 1,400-foot span and at the same time give due consideration to the question of appearance. We have considered three possibilities as follows: 1. A self-anchored suspension. 2. Cantilever. 3. Continuous. Our studies have not reached such a point as to enable us to give a definite conclusion."*

138

An *East Bay Crossing Options* illustration appeared in the 1937 *ENR* articles authored by Purcell, Andrew and Woodruff including the three alternatives Andrew gave in his January 1932 speech plus a tied arch (similar in appearance to NYC's *Hell Gate Bridge*). The article failed to explain why a cantilever was chosen over the others (in contrast to their in-depth ENR discussion of why the double-suspension span was chosen for the west bay crossing over the other options). The discussion focused on the unstable conditions of the east bay, long distances between expansion joints and the need to reduce dead-load (i.e. using steel rather than masonry to reduce weight).

139

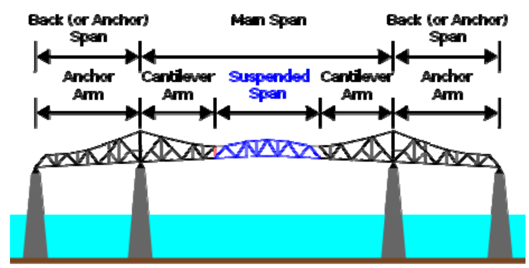


East Bay Crossing Options

140

On January 25th 1932, a report prepared by the Bay Bridge Division concerning bridge design considerations for the shipping channel of the east bay crossing was issued: *"None of these cantilever designs were satisfactory from the standpoint of appearance. The tied arch design was developed as presenting a better appearance…The estimates indicate that it compares favorably in cost with the cantilever design."* On January 27th 1932, the Board met and concurred with the report: *"the different alternative designs for the East Bay Crossing were submitted to the Board. After discussion, it was decided that if not materially more expensive, the arch design should be adopted."* On March 18th 1932, the Bay Bridge Division issued another report: *"We have made several layouts in an effort to develop a structure more pleasing in appearance than a conventional cantilever. Among our early studies we developed a design for a self-anchored suspension bridge. The appearance of the resulting structure was not satisfactory and its cost was excessive. Our next effort was the tied arch design."* The Board met again in April 1932 to reconsider the issue.

141



Cantilever Bridge Design

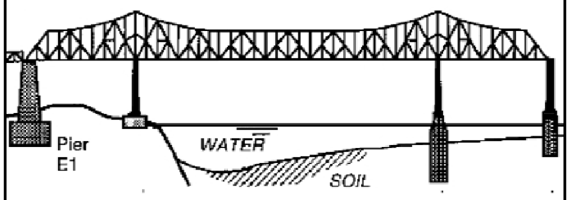
142

Demonstrating the Principle of the Cantilever
(*Firth of Forth* RR Bridge – Scotland, 1890)

143

The March 18th 1932 report went on to directly compare the costs and advantages/disadvantages of a tied arch vs. a cantilever: *"It should be noted that the same unit prices have been used in both the arch and cantilever design. It is our opinion that not less than $240K should be added for more expensive fabrication and more difficult erection of the arch span. This gives a differential of $600K in favor of the cantilever layout. We recommend that one of the cantilever layouts be chosen for the final design and that further study of the arch layout be discontinued."* Though feasible, the tied arch came in at an estimated cost of $3,608,500.00 while the cantilever came in at $3,239,000.00. However, the main concern was the erection of the arch which required intermediate falsework (to support the arch during construction and restrain the arch halves from rotating on their hinges until joined). Besides the estimated additional cost of $600K (inclusive of the additional erection costs), this would require obstructing the east bay shipping channel for an extended period of time, something the state wanted to avoid if at all possible. Thus, cost savings plus freedom of navigation favored a cantilever design.

144



East Bay Cantilever

145

146

147

Purcell Pontifex

148

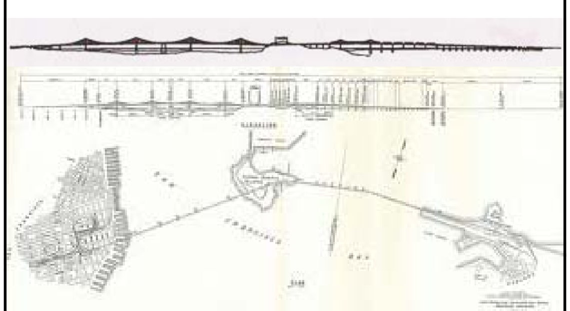
"…presented strong temptations. It required fewer departures from past practice than any alternate layout, reduced the number of piers to be constructed and was a more monumental structure."

Charles H. Purcell - Chief Engineer, SF-OB Bridge

RE: excerpt from an article in *ENR* concerning the proposed 4,100-foot suspension span which would have required a large anchorage on the San Francisco side, a large stiffening truss, destruction of piers and cost $3 million more than the adapted design;

- **Pair of double-deck suspension bridges with a main span/s of 2,310-feet arranged in tandem and sharing a common central anchorage**
- **A 540-foot tunnel through Yerba Buena Island with a bore larger than any tunnel in the world (at the time)**
- **A 1,400-foot truss bridge laid-out in a sweeping curve – third largest in the world and the longest & heaviest cantilever span in the U.S.**
- **Truss spans +500-feet long to the Oakland shore**

149



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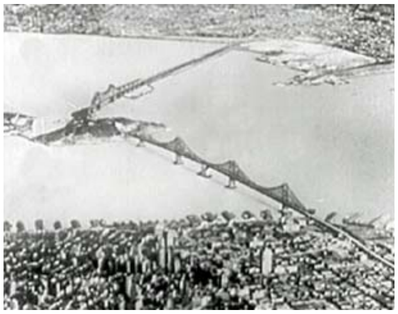


151

152

153

"The greatest bridge yet erected by the human race"
Former Pres. Herbert Hoover
RE: excerpt from his ground-breaking ceremony speech (1933). As a San Francisco native and engineer himself, he helped clear many obstacles during his term as POTUS (1929-1932)

154

Though most credit for designing the Bay Bridge was given to Chief Engineer C.H. Purcell at the time of its opening and retroactively to Design Engineer Glenn Woodruff in later years, neither is true considering the "team effort" involved and the significant role of the Board of Consulting Engineers. Key components were designed by the consultants;

- **The double suspension-span for the west bay crossing and the multiple bridge concept was Modjeski's**
- **The foundation design/s were Moran's**

Of course, they were subject to Purcell's approval, but they were the intellectual property of others. Purcell was a skilled engineer, administrator, decision-maker, organizer and political operative, no doubt, but the title given to him by the press in 1936: *Purcell Pontifex* (*Purcell the Bridge Builder*, in latin) was misleading, at best. This was not Purcell's fault, he was a dedicated civil servant who was simply doing his job as he saw fit. As Chief Engineer, the focus was on him – like it or not.

155

"Charley, some day people will erect a monument to you for building the San Francisco-Oakland Bay Bridge!"
Herbert Hoover – former POTUS, November 12th 1936
RE: excerpt from his opening day speech

156

"To our untutored mind the San Francisco-Oakland Bay Bridge has been flung across our waters by a kind of white magic. Call it engineering magic, by all means, but the science of strains and stresses, etc., etc., when applied to an undertaking as huge as this, seems to us to transcend the resources of the human brain. When we look at the bridge we are all humility, and we salute a miracle. Many laymen must feel as we do. There is the bridge before our eyes. How did it get there? We have a strong suspicion that it got there because an engineer by the name of Charles H. Purcell has been on the job."

San Francisco *Recorder* – November 1936

157

Purcell had to consider three key factors during the design process of the Bay Bridge; *Cost / Safety / Aesthetics*. Because of the after- effects of the stock market crash, it was no longer possible to sell bonds to private investors as originally conceived. Only the Hoover administration's *RFC* was willing to invest in the bridge - $70 million, and not a penny more. Without alternate sources of finance, Purcell needed to economize whenever possible. Thus, his choices for the bridge (he even rejected many of the design details for the approaches that the *Board of Consulting Architects* - a Board he had appointed) were all based on cost effectiveness. Safety was always a major concern, but it's a paradox considering the many risks taken in the design (i.e. double suspension-span, very deep west bay pier foundations and not taking the east bay piers to rock). With the Board of Consulting Architects appointed in 1933, well after the bridge design/s were established, their influence was not as great as it may have been had it existed earlier. Fortunately, most engineering Board members had excellent aesthetic sensibilities which were brought to bear in the design of the Bay Bridge.

158

"I cannot believe my eyes. I cannot believe you. It just cannot be so. It's too marvelous."

RE: SF-OB Bridge visitor to his tour guide upon seeing the western span of the Bay Bridge for the first time

159

160

161

"We can no longer escape into virgin territory; we must master our environment."

Franklin Delano Roosevelt (POTUS)

RE: *New Deal* policies creating great work projects which provided relief from the depression and unemployment (twelve million in 1933). Except for TVA, most of these projects were in the western U.S. and included the Bay Bridge.

162

Part 6

Sub-Aqueous Piers

163

It took two years to design the Bay Bridge (1931-1933) but only slightly more than three years (1933-1936) to build it. There were three reasons why the bridge was built at an accelerated pace;
• Put men back to work
• Minimize interest payments on the federal (RFC) loan
• Deliver on promises made to Bay Area political and civic leaders
The sooner the bridge opened, the sooner toll revenues would start to flow into the state (CTBA) coffers. Though many details would be worked out during the construction process, by early 1933 most plans and specifications were complete. On February 28th 1933, contract bids for the major bridge elements were solicited. However, the bids could not be opened unless/until the RFC loan was assured. Paperwork for the RFC loan was completed on April 28th 1933 and the bids were opened that same day. The initiation of construction ceremony was held on July 10th 1933 with former POTUS Herbert Hoover ceremoniously "turning the sod." From the White House, President Roosevelt set-off a remotely controlled explosion on Yerba Buena Island.

164

July 10th 1933. California Governor James Rolph, Jr. and former President Herbert Hoover pose with *Miss Bay Bridge*, *Miss Prosperity*, and young ladies representing Bay Area communities at the groundbreaking ceremony.

165

Seven contracts (Nos. 2 thru 8) were tendered for the major elements of construction. Contract No. 1 was completed in 1932 and was for the bay floor test borings during the design phase. There were minor contracts tendered beyond these seven both during construction and after the bridge opened on November 12th 1936. The major contracts for the interurban railway were not completed until January 1939. The contracts broke down as follows;
•Contract No. 2 – West Bay Substructure - $6,957,000.00
•Contract No. 3 – SF Anchorage & Approaches - $1,049,000.00
•Contract No. 4 – East Bay Substructure - $2,687,000.00
•Contract No. 5 – Yerba Buena Tunnel & Anchorage - $1,821,000.00
•Contract No. 6 – West Bay Superstructure - $9,566,000.00
•Contract No. 7 – East Bay Superstructure - $8,798,000.00
•Contract No, 8 – Oakland Approaches - $254,000.00
Contracts Nos. 3, 5 & 8 were awarded to local contractors while the major steel work contracts (Nos. 6 & 7) went to the *Columbia Steel Co.*, a subsidiary of steel fabricator *U.S. Steel Corp.* Substructure contracts (Nos. 2 & 4) went to affiliates of the *Six Companies*.

166

Contract No. 2

West Bay Substructure

167

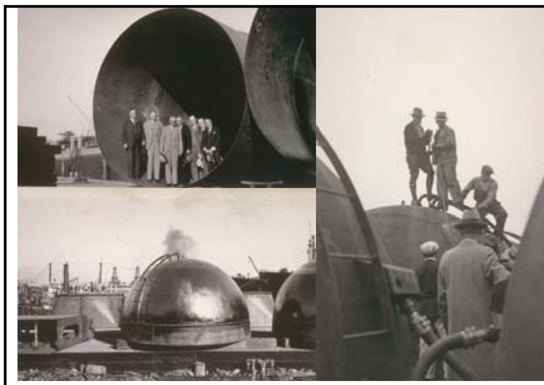
Contract No. 2 included all water piers between San Francisco and Yerba Buena Island and was, perhaps, the most difficult and challenging requiring unproven methods and technologies. West Bay piers were designated "W" (starting from San Francisco) and East Bay piers were designated "E" (starting from the western-most pier). Pier W-1 was on land thus it was not part of Contract No. 2 (Piers W-2 thru W-6) and was included under Contract No. 3 (SF Approach). At its peak in March of 1934, 968 men were employed under Contract No. 2 with about 800 men employed (average) through to completion in January of 1935. Pier W-2 was conventionally constructed using an open cofferdam while Piers W-3 thru W-6 would require Daniel Moran's "floatation cylinder" caisson method. Moran and Proctor provided the conceptual design for these pneumatic caissons while Bay Bridge Division engineers worked out the details (with Moran and Proctor providing review and oversight). Pier W-2 was located at the outer edge of an historic steamship dock: *Harbor Pier No. 24*. It was built of solid concrete to a height 40-feet above water level and supports a bridge tower.

168

Pier W-2
(under construction, 1933) 169

Pier W-2
(completed November 1933) 170

Successfully completed in November 1933, Pier W-2 was the first element of the Bay Bridge put in-place. Piers W-3 thru W-6 needed to be taken to bedrock (in the busy shipping channel) to depths never before achieved. The successful sinking of a *"domed coffer dam with pneumatic false bottom"* – as Carlton Proctor termed it, would become the subject of much interest in civil engineering journals for years to come. A "floatation caisson" consisted of a rectangular wooden frame with steel struts surrounding a series of 15-foot diameter steel cylinders. Because the piers varied in size, so too did the number of cylinders. Piers W-3 and W-6 included 28 cylinders set in four rows of seven and Pier W-5 (smallest) included 21 cylinders set in three rows of seven. Pier W-4 (largest) was for the central anchorage and included 55 cylinders set in five rows of eleven. "Spandrel Shapes" were created by the voids between the rectangular grid and the cylinders and between cylinders. Once at the site, hemispherical domes were welded atop the cylinders. Concrete was poured into the voids (to sink the caisson) while air pumped into the cylinders controlled the descent. 171



172

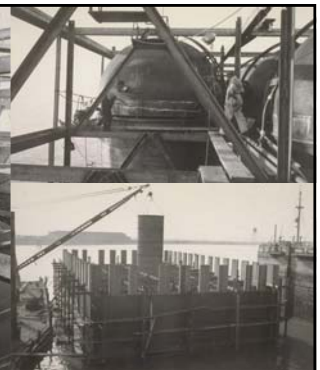
Pier W-5
(May 1934) 173

The caissons were built by the *Moore Dry Dock Company* at their San Francisco plant and towed to position. Once there, they were secured into position in two ways;
• A block and tackle system using reinforced concrete anchors
• Floating wooden fenders held in place with piles (in shallow water) or anchors (in deep water)
Sidewalls built to keep the top of the caisson above water were added as the caisson sunk. Cylinders were extended by sawing off four domes at a time, adding new lengths and then welding the dome/s atop the new lengths of cylinder. The process was repeated until the caisson "landed" on the mud floor of the bay. Proctor emphasized that landing: *"required great care and delicacy of handling."* To allow the caisson to move without listing in the strong tidal currents of the bay, anchor lines needed to be adjusted carefully. By releasing air from the domes, gravity took over and sinking occurred rapidly. Several domes were left in place until the caisson was stable on the bay floor and then they were removed. With domes removed, the cylinders now took on a new role as "dredging wells." 174

Caissons
(at Dry Dock) 175

Caisson Fender 176

Concrete Anchor 177



Cylinders & Domes 178

As the caisson descends, the sidewalls and cylinders are built-up 179

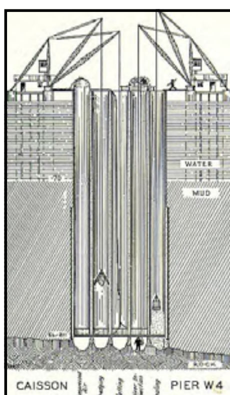


Plate No. 3—*The Moran-Purcell Caisson*

Properly landed, cranes that were secured to the temporary fender surrounding the caisson dropped clamshell buckets to the bottom of the cylinders excavating the bay bottom one bucket-full at a time. With removal of the "spoil" and the help of a cutting edge, the caisson sunk deeper below the bay floor. As this sinking progressed, additional concrete was poured in the voids, the sidewalls were built-up and the cylinders extended. The process continued until the caisson "founded" on bedrock. It was often necessary to use powerful water jets to clear away layers of firm sands. Firmly established on bedrock, the cylinders were filled with 30-foot concrete "plug/s." 180

Cranes removing "spoil" from cylinders

181

Hazards! are many and oft-times fatal in submarine diving engineering…We delight in hazard undertaking because we have the equipment, experience and men to do them. No matter how difficult, consult us first on your submarine diving, marine salvaging, wrecking, underwater construction and examination problems.

Chief Diver Bill Reed's advertisement for his Submarine Diving-Engineering business. His and other diver's work made the deep foundations of the SF-OB Bridge possible. He was paid $15,000/year plus $1.00/foot for each dive made.

182

The cylinders were "plugged" with 30-feet of concrete to make them bottom-heavy

183

Pier W-3
June 1934

184

The deep-water piers were sunk in the following order;
- **Pier W-6**
- **Pier W-4**
- **Pier W-3**
- **Pier W-5**

Pier W-3 was the deepest pier reaching bedrock at minus 220-feet but is in water only 50-feet deep. Pier W-4 went to minus 180-feet to reach bedrock and Piers W-5 and W-6 to minus 105-feet. However, Pier W-6 (near Yerba Buena Island) was sunk in the deepest water. After the pier hit bedrock (for Piers W-2, W-3, W-5 & W-6), work crews began constructing the base upon which the tower legs would rest and be secured (with deeply embedded threaded bolts and nuts). Pier W-4 is the central anchorage (no tower) and rises in concrete to the bridge deck. Just above the water line, each pier includes a *fender* which is a cantilevered concrete arm extending from the pier edges and finished in timber. It appears to exaggerate the mass of the piers but is, in reality, a slender projection. Actually, the steel tower base occupies only about one-half the area of its pier base.

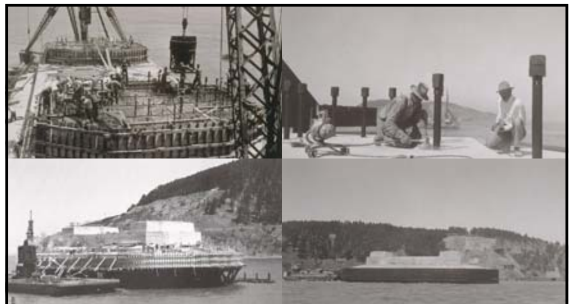
185

Piers W-3 thru W-6
(under construction - Yerba Buena beyond)
May 1934

186

Pier W-6 thru W-3
(note the cantilevered concrete "fender" of Pier W-6 in foreground)
May 1934

187



Tower Base

188

The Emergency

189

Pier W-6 is located approximately 1,160-feet off the western shore of Yerba Buena where the water depth is +30-feet deeper than any other pier. It serves as the base for the eastern-most bridge tower of the suspension-span. It was towed to position in June 1933, landed on December 11th 1933 and dredging commenced on December 19th 1933. Though not the deepest pier to bedrock, it caused the most anxiety because it was the first and most problematic. In New York, Daniel Moran followed the progress of the sinking of the caisson and upon landing, sent a telegram to Charles Andrew: *"Congratulations to you and Glenn for fine position and penetration of Six. Extend congratulations for me to Contractor. How are you for level?"* By mid-January 1934, the caisson was at minus 135-feet (30-feet below the bay bottom). On January 14th 1934, the caisson began tilting severely to the east (towards Yerba Buena). The eastern side of the caisson was about seven-feet lower than the western side due to the tilt. The tilt was caused by a stiff stratum atop a softer one which the caisson was resting on. Dredging removed the upper stratum exposing the softer stratum below which could not support the weight.

190

Pier W-6
(listing towards Yerba Buena Island)
January 14th 1934

191

Daniel Moran came to San Francisco immediately to supervise the corrective work on Pier W-6. He worked closely with the Bay Bridge Division and the contractor and it took several weeks to bring the caisson back to level. The strategy was to remove material from the high (west) side of the caisson while using re-installed domes and forced air to act as a brake on the lower (east) side. On February 23rd 1934, the caisson was nearly level when it suddenly tilted five-feet to the north. The same corrective measures were taken (in the opposite direction) and on March 3rd 1934, the caisson was level. In early February 1934, Pier W-4 (central anchorage) also tipped but correction of the tilt was complicated by the fact that the cylinders were plugged with mud making re-capping and forcing air into the cylinders ineffective as a brake. The tilt was corrected by dredging the cylinders furthest from the tilt. Ironically, Pier W-3 – the deepest of the five western water piers, went smoothly as did Pier W-5. The bridge tower piers were finished to a height 25-feet above water level while W-4 extended to 225-feet above water level. Completion of Contract No. 2 allowed Contract No. 6 to commence.

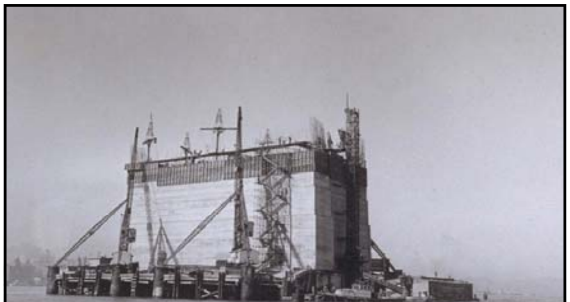
192

Pier W-4
August 1934

193

Pier W-4
September 1934

194



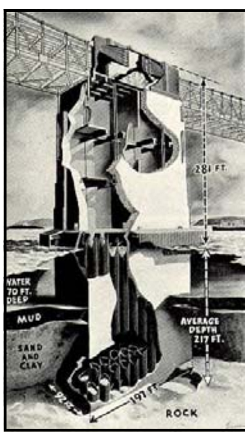
Pier W-4
November 1934

195

Moran's Island
(a.k.a. Pier W-4)

Common anchorage for the double (tandem) west bay suspension bridges. W-4 used 165K cubic-yards of concrete (more than the Empire State Building) and was the equivalent of a 40-story building covering an entire city block.

196



The Central Anchorage is a unique feature of the Bay Bridge. It serves to anchor both bridges and connect the ends of the bridge cables together via an "A-Frame" at the top of the pier. The A-Frame is a pre-fabricated, riveted steel assembly that transfers *balanced* cable forces from one cable to the other and *unbalanced* cable forces into the concrete box pier (W-4) directly below. The A-Frame was post-tensioned to the pier with eyebars, providing both strength and rigidity. Until the construction in Japan of the back-to-back *Minami Bisan-Seto* and *Kita Bisan-Seto* bridges in the 1980s, the Bay Bridge's central anchorage was unique in all the world.

197

<u>Contract No. 4</u>

East Bay Substructure

198

Contract No. 4 – for the east bay pier foundations, was, essentially, the equivalent of Contract No. 2 (west bay pier foundations). At its peak, 796 men were employed with an average of under 600. There were similarities between the two contracts in the methodology of sinking the piers, but there were significant differences in the execution since none of the east bay piers (save for Pier E-2, just off shore) were taken to bedrock (as were all of the west bay's piers) and many were supported on timber piles. Another factor is the number of piers for the east bay; twenty-two for the east bay vs. six for the west bay and of different sizes and configurations. This is due to the fact that there were several bridge types with differing load-factors whereas the west bay piers (save for W-4, the central anchorage) all supported a suspension bridge tower thus they were uniform in size and configuration. Like the west bay piers, the east bay piers are numbered sequentially from west to east, in this case starting with pier E-1 on Yerba Buena Island. Since it is on land, it was built as part of Contract No. 5 (it supports a viaduct from the tunnel and the western anchor-arm of the cantilever bridge).

199

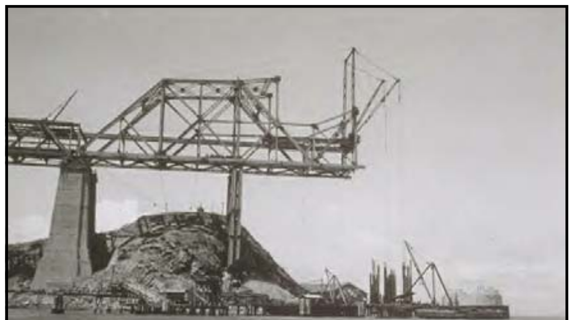
Pier E-1
July 1935

200

The piers built under Contract No. 4 break-down as follows;

- **Piers E-2 and E-3 – supports the two towers of the cantilever and are the tallest of the east bay piers and bear the greatest compressive load of all east bay piers**
- **Pier E-4 – supports the eastern anchor-arm of the cantilever and western end of the first (of five) through truss spans. Along with Pier E-1, E-4 (as support for an anchor arm) bears the greatest tensile load of the east bay piers**
- **Piers E-5 thru E-8 – supports the five through trusses**
- **Pier E-9 – supports the eastern end of the fifth (of five) through truss spans and the western end of the first (of thirteen) deck truss spans**
- **Piers E-10 thru E-23 – supports the deck truss spans to the Oakland shore. The first seven (E-10 thru E-17) support steel towers while the balance (E-18 thru E-23) are solid concrete providing direct support for the deck trusses. As compared to the through-truss and/or cantilever piers, the deck truss piers are in close proximity to one another.**

201



Pier E-1 (far left) / Pier E-2 (far right)
May 1935

202

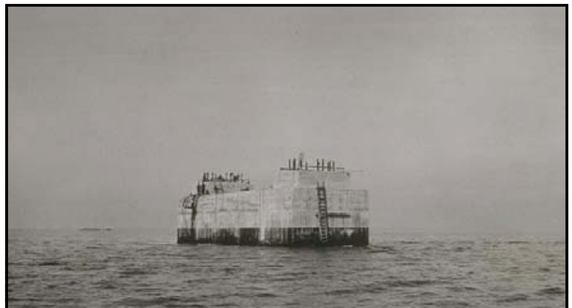
Pier E-2 under construction (September 1934). Built of solid concrete in an open cofferdam and founded on bedrock 45-feet below water level.

203

Piers E-1 thru E-5 (left to right)
May 1935

204

205

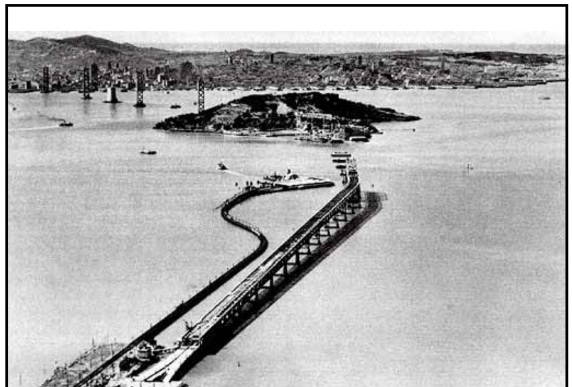


Pier E-5
March 1934

206

Typical Deck Truss Piers
(direct support - E-18 thru E-23)
1934

207



208

The three major east bay piers are E-3 thru E-5 and presented the greatest design and construction challenge in the east bay. Using a cellular pneumatic caisson (similar to the west bay piers) they were sunk to great depths. However, besides not going to bedrock, there are two important differences:

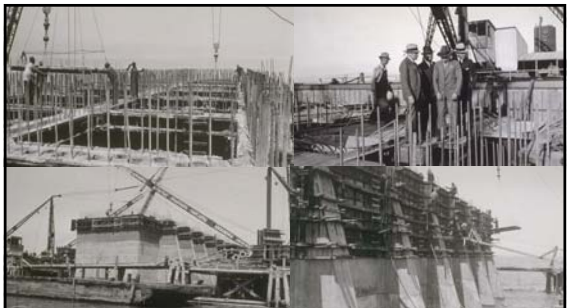
- **The cells are rectangular rather than cylindrical**
- **Since they would not be founded on rock, it was important to reduce their weight as much as possible**

The three piers were similar in design (rectangular with rectangular chambers) but of two different sizes. Pier E-3 was the largest of the three measuring 80 x 134.5-feet (w/28 chambers). Piers E-4 an E-5 both measured 60 x 90.5-feet (w/15 chambers). Sinking the caisson/s followed the same process as for the west bay piers. Once landed, the bay bottom was removed (via the excavation chambers) until the caisson reached a "suitable stratum" level. Once this level was reached, an additional fifteen-feet was excavated and concrete placed in the bottom of the excavation chambers thus creating a concrete base below the edges of the caisson.

209

Pier E-3
March/April 1934

210



Pier E-3
June/July 1934
(Daniel Moran making personal inspection - upper right)

211

Pier E-3 was sunk to minus 235-feet (plus another 15-feet for the concrete base) for an overall total depth of minus 250-feet making it the deepest pier foundation for the entire bridge (Pier W-3 went to minus 220-feet). Piers E-4 and E-5 were both taken to a depth of minus 180-feet. Pier E-3 was originally to have been sunk to minus 223.5, but the "skin friction" (resistance of the caisson's material to the mud of the bay floor) was overestimated by the state engineers and the contractor. To create cavities (for the 15-foot concrete base), the contractor used water jets in the excavation chambers to remove the mud but the caisson continued to sink another +10-feet lower than planned (to minus 235-feet). According to the Resident Engineer: *"had been overestimated by both State and Contractor's forces…the real problem was, not to cause the caissons to sink, but to stop them as desired."* Pier E-3 thus earned the title: "Deepest Bridge Pier in the World."

212

Piers E-4 and E-5
November 1933

213

Pier E-4
Late 1933 / Early 1934

214

Pier E-4
(setting anchor bolts in tower bases)
April 1934

215

Caisson E-5
(late 1933)

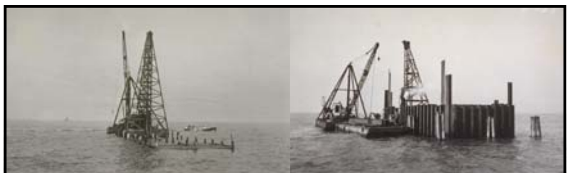
216

Pier E-5
December 1933

217

Piers E-6 thru E-23 used a very different method of construction than that of E-3 thru E-5. They were "Intermediate Pile Piers" using steel-sided cofferdams founded on piles. Pier E-9 was unique in that it supports a square, four column tower: *"it acts as longitudinal bracing for the spans approaching the cantilever and stabilizes the curve in the bridge at this point."* Interestingly, it was at Pier E-9 that the upper deck collapsed during the 1989 *Loma Prieta* earthquake. At its completion Pier E-9 was the largest pile foundation in the world.

218



Intermediate Pile Pier
(under construction)
ca. 1933

219

Tower Anchor Bolts
(atop Pier E-8)
October 1934

220

Pier E-9
July – September 1934

221

Pier E-9
October 17th 1989

222


Pier E-18
February thru April 1934

223

Pier E-19
February 1934

224

Pier E-20
February 1934

225


Pier E-21
Late 1933 / Early 1934

226


Pier E-22
Late 1933

227

Pier E-23
March 1934

228

New Army Dock
June 1934

229

Piers E-19 thru E-22
March 1934

230

Piers E-22 thru E-14
(Oakland Approach)
June 1934

231

Part 7

West Bay Construction

232

Starting at Pier W-1 (Rincon Hill, San Francisco), the west span of the Bay Bridge is composed of a double suspension-span in tandem. One is anchored in San Francisco, the other at Yerba Buena Island and both share a common anchorage at Pier W-4 (central anchorage). Overall, each suspension-span is approximately 4,700-feet long with main-spans of 2,310-feet and side-spans of 1,160-feet. Two parallel wire cables (26-inches in diameter) support a truss-stiffened double-deck roadway. Two X-Braced steel towers support the pair of main cable/s in each span. The stiffening trusses are 66-feet wide by 35-feet deep with diagonal wind-bracing below the lower level (but not the upper level). The truss chords and diagonals are box-shaped with either solid plate and/or latticed sides. All vertical members are H-shaped. The floor deck consists of reinforced concrete over longitudinal I-Beam stringers which are supported by transverse steel plate girder floor beams. The western approach is composed of 380-foot continuous deck truss spans extending from the SF anchorage to Pier W-1. The framing system for these trusses is similar to the suspension trusses.

233

Contract No. 6

West Bay Superstructure

234

It can be argued that Contract No. 2 – for the west bay piers, was more difficult and complex than Contract No. 6 – for the superstructure of the double suspension span/s from Rincon Hill in San Francisco to Yerba Buena Island, but for the viewing public that work was - for the most part, out-of-sight below the waters of the bay. Not so for the superstructure work. The most popular show in San Francisco was the erection of the towers, aerial spinning of the mighty cables and hanging of the suspended structure; all involving hundreds of daredevil workmen. Though the work was awarded to U.S. Steel subsidiary *Columbia Steel Company* (they had an office in San Francisco), they subbed out most of the work including fabrication and erection of the four steel towers and cable-spinning to the *American Bridge Company*. Other companies did supplemental work such as field painting, fabrication of light structural elements and some elements of the central anchorage. Of course, Contract No. 6 was dependent upon the successful completion of Contract No. 2, but it was also dependent on Contracts Nos. 3 and 5 – for the San Francisco and Yerba Buena anchorages respectively.

235

San Francisco Anchorage
(Contract No. 3)
March 1935

236

San Francisco Anchorage
(Contract No. 3)
May 1936

237

Yerba Buena Anchorage
(under construction)
(Contract No. 5)
June 1935

238

Yerba Buena Anchorage
Cable Bents
April 1935

239

Yerba Buena Anchorage
Cable Bents
(w/cable saddles in-place)
June 1935

240

At +$9 million, Contract No. 6 was the most expensive work of all for the Bay Bridge. It was broken-down into three components;

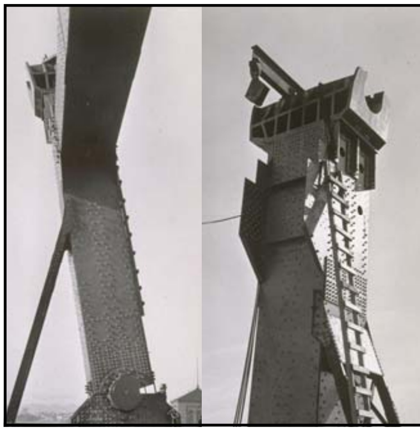
- **Erection of the four towers on Piers W-2, W-3, W-5 and W-6**
- **Aerial spinning of the main cables from San Francisco to the central anchorage and from the central anchorage to Yerba Buena**
- **Hanging of the suspended structure (i.e. stiffening trusses)**

Contract No. 6 also included steel "Bents" in San Francisco (atop Pier W-1) and Yerba Buena. Carbon. Nickel and Silicon Steel was used for all major structural components (special heat-treated eyebars were used in the trusses of the east bay crossing). All structural plate steel connections were made with rivets (typical) or bolts.

241

Steel "Bents" (A & B)
(atop Pier W-1)
December 1934

242



Cable Bent
Post & Saddle
(atop Pier W-1)
December 1934

243

Cable Bent Saddle

244

Cable Bent Rocker
Post and Bearing
(atop Pier W-1)
December 1934

245

A Tale of Four Towers

246

Except for some minor variations, essentially each of the four towers of the west bay double (tandem) suspension-span are identical, though they are not of uniform height. The base plate atop the pier rests at an elevation of 40-feet above the low water level of the bay. Outer towers (on Piers W-2 and W-6) rise to 414-feet above their base plates while inner towers (on Piers W-3 and W-4) rise to 458-feet. Because the Central Anchorage is higher than the bridge deck level, the towers closest to it required greater height. Each tower is composed of two "legs" or columns that are tied together with horizontal and diagonal bracing. Each leg forms a cross (in section) with a hollow core measuring 7 x 8-feet. Surrounding the core are steel "cells" – rectangles varying in size. Six cells are at the top and bottom and four cells are on each side of the core (thus forming a *cruciform*). The largest of these steel cells measures 3.5 x 4-feet. As the tower legs ascend, they taper and steel thickness varies from nearly three-inches to less than one-inch. Measured east-west (parallel to the cables), at the base each leg measures 30 x 20-feet and about 83-feet separates each leg from one another. 247

Setting Tower Base Plates (1934)

The legs of the steel tower are connected to the top of their concrete pier/s via steel bearing plates over milled concrete surfaces (for compression) and secured with embedded bolts and nuts (for tension). This detail allows for normal bridge tower compression loading and a ductile reserve for bending (seismic resistance). 248

Tower No. 2 "Cells"
February 1934

249

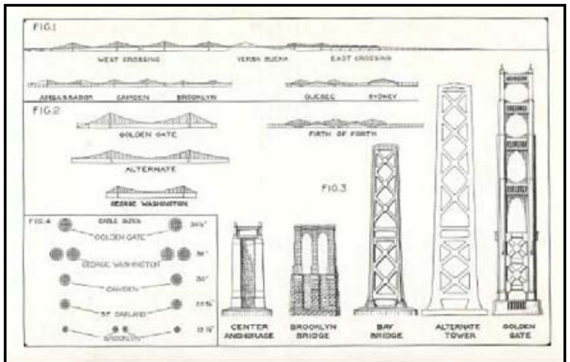
Tower No. 5 "Base Cells"
November 1934

250

Tower No. 2 (atop Pier W-2)
(stiff-leg derrick lifting pre-fabricated base cell section into position)
March 1934

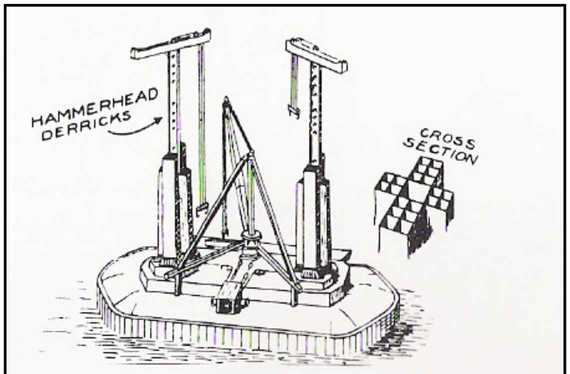
251

The purpose of the hollow core in each tower leg was to house a *Hammerhead Derrick*. The derrick served to lift tower sections into place (beyond the range of the stiff-leg derrick at the tower's base). The Hammerhead Derrick was able to rise with the tower leg it was nested in while the tower components were assembled beneath its position until the tower was complete. Typically, a *Creeper Derrick* is used to construct the towers of a suspension bridge (as was used for the Golden Gate Bridge). This type of derrick also has the ability to raise itself with the rising tower legs it sits between, but is *external* to the tower leg/s rather than *internal*. Thus, each Hammerhead Derrick can rise independently. After Columbia Steel was awarded Contract No. 6, American Bridge suggested the innovative Hammerhead Derricks be used. The structure of each tower is formed around a horizontal strut at the base of each tower with a pair of heavy diagonal X-Bracing above (to deck level). Two more horizontal struts support the upper and lower deck levels. Above the upper deck strut, a trio of heavy diagonal X-Bracing rise to meet one more horizontal strut at the top of the tower. 252



Tower Elevations
(with comparison to *Brooklyn* and *Golden Gate* Bridge/s)

253



254

Hammerhead derricks in position Tower No. 2 (left). Interior view of tower core (above). Known as *batter leg* towers, the slight incline of the tower legs allows the cables to be centered over the trusses. At truss level, the tower legs are slightly outboard of the truss centerline/s allowing better deck-space utilization. This was the first use of batter leg towers on a major suspension bridge.

255

Tower No. 2
Horizontal Base Strut in position and X-Bracing being erected (April 1934)

256

Tower Leg and Base Strut

257

Tower No. 6
October 1934

258


259

Personnel Lift

260


261

“Heater” (a.k.a. “Cook”) passing an 800-degree “white-hot” rivet (via a pneumatic tube) to the rivet gang (inside the tower leg/s)

262

Except for the tower columns, all members are “latticed” (comprised of crossing steel members). They appear solid due to the fact that solid steel plates were placed over them (where exposed to view).

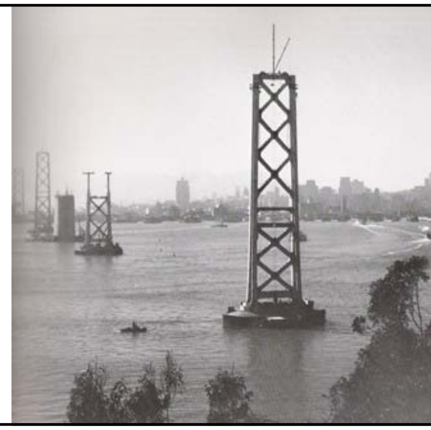
263

The American Bridge Company carefully fabricated and test-fit the tower components before sending them to the bridge site. It was a fairly simple matter of assembling the pre-fabricated sections one-by-one for each tower. To allow the Hammerhead Derricks to be re-used, the towers were built one-at-a-time. Work under Contract No. 6 began on February 26th 1934 (at Tower No. 2) and concluded on September 3rd 1936 with the installation of the hood for the central anchorage. By the time the cable-spinning operation commenced in June of 1935, all four towers were essentially complete. In all, the towers consumed 35K-tons of steel and 505K field rivets. Combined (east and west bay crossings), the Bay Bridge used 1/8th (or 13%) of the steel produced by the United States in the years it was under construction.

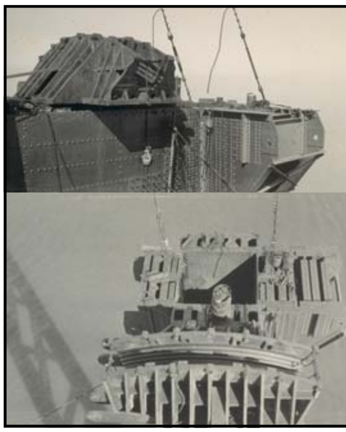
264

Tower Nos. 6-3-2 (right to left)
October 1934

265



266




Tower No. 2
Cable Saddle
June 1934

267

Central Anchorage
A-Frame Section
March 1935

268


Central Anchorage
A-Frame
1935

269

North A-Frame
Central Anchorage
May 1935

270

271

272

U.S. Pacific Fleet at anchor
(near Tower No. 3)

273

Aerial Cable Spinning

274

For all the press and interest it generated, the aerial spinning of the main cables was fairly routine. The method had been in use since the 19th century and though the technology had improved, it was still the same basic idea: spin very strong small diameter wires into one very large, very strong parallel wire cable and then hang the bridge deck from it. Though routine for the experienced bridge builder, it was also considered the most complex and dangerous part of building a suspension bridge. In this case, doubly dangerous since it involved spinning cables for two suspension bridges simultaneously. That reputation was well deserved and proved out on the Bay Bridge. Seven men died from falls during the cable spinning operation. The cable-making process includes four progressive steps;

- **Hang a "Footbridge" (a.k.a. "Catwalk") for access to the cable/s**
- **Spin the wire from one anchorage to another over two towers to create wire "Strands" which when bound together form the cable**
- **Compact (a.k.a. "squeeze") the hexagonal configuration of the cable strands into a round configuration**
- **Attach cable bands (for the suspender ropes)**

275

Footbridge

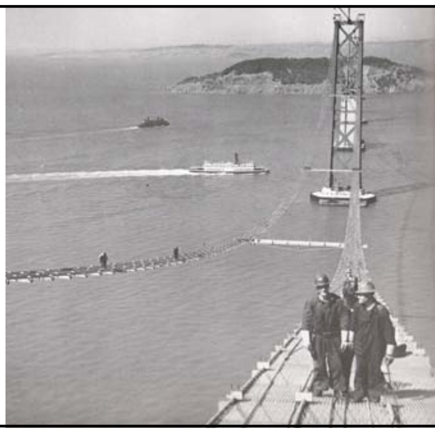
276

The footbridge/s followed the same catenary curve of the two (north and south) main cables and were hung from temporary support cables about three-feet below the actual cable. They were ten-feet wide supported by four, 2.5-inch diameter wire ropes with U.S. Steel's *Cyclone* mesh fencing acting as the floor. The mesh fencing was strong, light, cheap and allowed the wind to pass through readily. Intermediate posts on both sides of the footbridge supported a wire rope handrail.

277

North Footbridge
May 1935

278



279

North and South Footbridge/s
May/June 1935

280

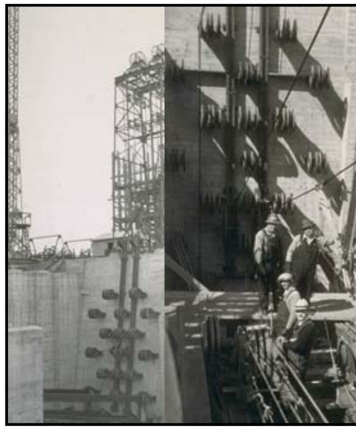
281

Cable Spinning

282

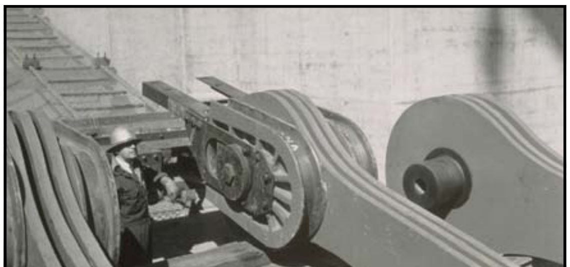
Akin to a loom, cable spinning entails spinning individual wires from one anchorage to the other until enough wires have been spun to form a *Cable Strand*. A spinning machine (at the anchorage) powers a *Traveler* (spinning wheel) that is attached to a moving cable (much like a ski lift). From the wire spools, a "dead wire" is temporarily secured to a strand shoe and the beginning end of the wire is looped around the traveler wheel (bottom wire) paying out a "live wire" (from the top of the wheel) as it traveled from one anchorage, over the two towers and then to the Central Anchorage where it was looped around another strand shoe at that anchorage. Back and forth the traveler went between anchorages until 472 (0.19-inch diameter) wires were bound together forming an individual strand. Each completed strand (via its shoe/s) are secured (with a steel pin) to an eyebar anchor deeply embedded in the anchorage/s. In this way, the tremendous "pull" of the main cable/s can be resisted best (akin to the dispersal of a tree's roots). The wire ends are secured with a "Ferrule" – a threaded coupling that joins the wire ends (also correspondingly threaded) in a vice-like apparatus.

283



Embedded Eyebars
San Francisco
Anchorage
May 1935

284

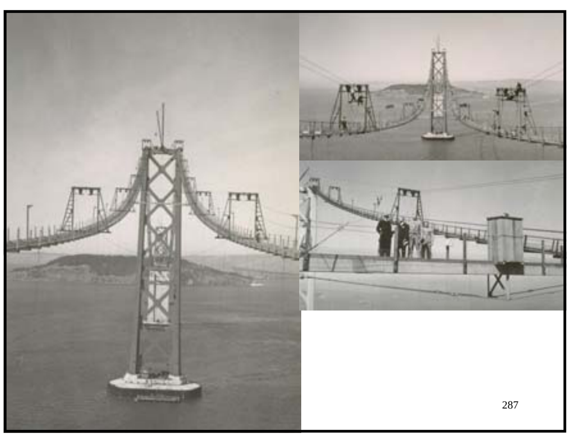


San Francisco Anchorage
Three eyebar anchors with two strand shoes secured (via steel pin)
May 1935

285

"Gallows" atop Footbridge/s
(for support of the moving cable/traveler wheel)
June 1935

286



287

North cable traveler wheel in action
The wheel had a cow bell attached to alert workmen of its approach
August 1935

288

289

South Cable Strand Separator
June 1935

290

Each main cable consisted of thirty-seven strands bound together to form the cable. An innovation used on the Bay Bridge concerned the method of spinning the strand/s. Typically, the strands would be spun *outside* of the cable saddle/s where they would ultimately rest. For the Bay Bridge, the strand/s were spun *inside* the cable saddle/s This negated the need to lift each completed strand into position in the saddle/s.

291

Cable Strands
June/July 1935

292

Central Anchorage
September 1935 (left)
July 1935 (above)

293

On the night of September 18th 1935, one of the completed strand shoes (extending from San Francisco to the Central Anchorage - Pier W-4) popped open. The reasons for the wire pulling away from the shoe are not certain, perhaps it was due to contraction caused by the lower night-time temperature. The entire strand was destroyed and was re-spun causing a two-week loss in the schedule.

294


Central Anchorage
North and South Cables (left)
North Cable (right)
October 1935

295


Main Cable/s - Central Anchorage
1935

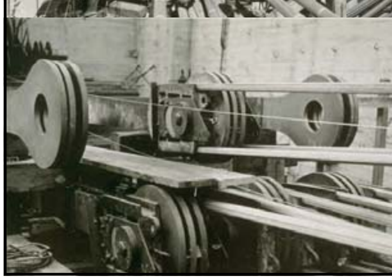
296


North Cable – Central Anchorage
February 1936

297


North Cable Shroud – Central Anchorage
September 1936

298

San Francisco Anchorage
August/September 1935

299

300



North Cable
San Francisco Anchorage
October 1935

301


Cable Splay (left)
North Cable Splay – San Francisco Anchorage (right)
November 1935

302

North and South Cables – San Francisco Anchorage
October 1935

303

North and South Cables – San Francisco Anchorage
(with protective shrouding in-place)
November 1935

304

North and South Cables – Yerba Buena Anchorage
January 1936

305

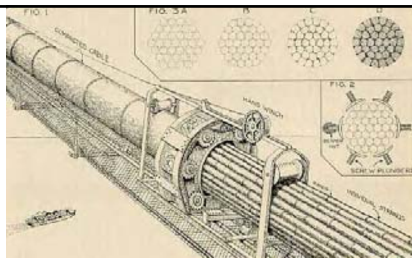
North and South Cables – Yerba Buena Anchorage
February 1936

306

307

Cable Compacting

308



After all thirty-seven strands were in-place, the next step was to compact them from a hexagonal configuration (Fig. 3A) into a round configuration (Fig. 3D) using a 7.5-ton compressed-air jack. The jack squeezed the strands together under tremendous pressure and then the cable was wrapped with a tightly bound fine galvanized wire.

309

North Cable Compactor
October 1935

310

North Cable Compacting
October 1935

311

North Cable Compacting
(between Central Anchorage and Tower No. 3)
October 1935

312



313



Wrapping the main cable/s with fine galvanized wire
1936

314

The two main cables were secured in-place by a pair of saddles (north and south) at Pier W-1's Cable Bent/s, Tower Nos. 2, 3, 5 and 6 and the Cable Bent/s at the Yerba Buena anchorage (pictured above). Each saddle was cast at a U.S. Steel subsidiary (in New Jersey) and weighed approximately 46-tons. At the time the Bay Bridge was built, the steel castings for the saddles were the largest ever made for a bridge project.

315

North Cable/Saddle – Tower No. 2
November 1935

316

South Cable/Saddle – Yerba Buena Bent
September 1936

317

South Cable/Saddle – Pier W-1 Bent
July 1936

318

Cable Bands & Suspenders

319

A cable band is a steel clamp consisting of two semi-circular halves bolted together around the main cable/s in corresponding positions. Welded to each half are slots; to secure the pair of suspender ropes which would be looped around each cable band for support of the suspended structure. There are a total of 612 cable bands.

320

January 1936

Wrapping protective seizing around wire rope suspender. Rather than using a pair of suspender ropes (typical), the shortest suspenders of the four side-spans consist of short, fabricated steel shapes able to resist both compressive and tensile forces (the suspender ropes can only resist tensile forces). Under an unbalanced live load and due to the length of the side-span/s (1,160-feet), a *stress reversal* can occur requiring compression resistance at these locations.

321

January 1936

Wire rope suspender "Pickling" process

322

January 1936

Pouring zinc socket/s for wire rope suspender end/s

323

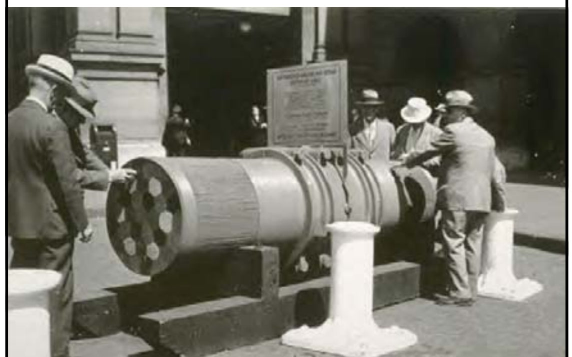
Installing North Cable Bands

November 1935

324

Checking strain in cable band bolts
December 1935

325

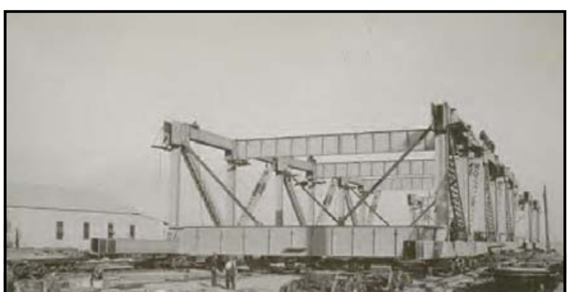


326

Suspended Structure

327

Aside from the deep-water foundations, perhaps the most difficult aspect of building the Bay Bridge was hanging the suspended structure (stiffening truss) from the main cables for the great length of the tandem suspension bridges. There was great concern among the engineers (and contractor) that the additional weight of the stiffening truss would cause great strain on the anchorages and/or throw the towers out-of-balance (akin to hanging laundry on a clothes line). To avoid this problem, a scale model of the bridge was built. Scale weights were hung from the model's cable/s to simulate the effect of hanging the stiffening truss sections and a scheme for hanging the trusses was developed. From the 612 cable bands, 2.25-inch cold-drawn wire-rope suspenders were hung in pairs around each cable band. The length of the suspender rope varied according to its position on the main cable/s. Sockets at the end/s of the suspender ropes secured the top-chord of the stiffening truss section/s to the suspenders and, in turn, to the main cable/s. Laid end to end, the suspender ropes would measure forty-three miles. 328



February 1936
Stiffening Truss sections under assembly at *Islais Creek*

329

Unit No. 144 being assembled
(at *Islais Creek*)
April 1936

330

Unit No. 1 – Stiffening Truss
December 1935

331

Lifting Struts (near the Central Anchorage)
December 1935
The pair of lifting struts were set between the main cables and its lifting cables were operated via a hoist engine on shore. A barge brought each stiffening truss section to position below the struts and it was lifted into position (supported at its four corners).

332

Lifting Struts
(in action)

333

January 1936
Lifting struts (between Pier W-1 and Tower No. 2)

334

December 1935
Stiffening Truss Unit No. 1 on barge adjoining Pier W-4. Ready to be lifted into place between Pier W-4 (Central Anchorage) and Tower No. 3. Truss units were installed from the Central Anchorage towards the inner tower/s (Nos. 3 and 5).

335

December 1935
Stiffening Truss Unit No. 1 in-place (between W-4 and Tower No.3)

336

January 1936

Suspender ropes in-place. Barge at mid-span between Tower Nos. 2 and 3 with several stiffening truss section/s in-place. Hanging of the trusses began at mid-span rather than at the tower/s as would be typical for a suspension bridge).

337

January 1936

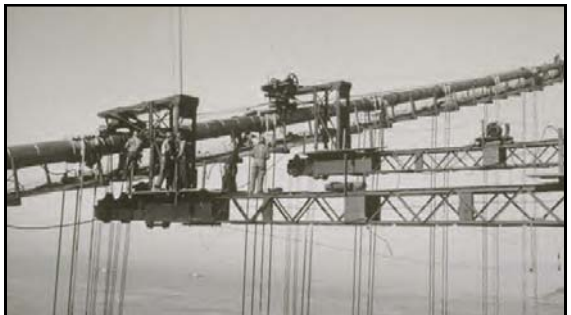
Stiffening Trusses extending from Pier W-1 towards Tower No. 2

338

January 1936

Stiffening Truss sections extending from mid-span towards Tower Nos. 2 and 3 (upper left) and from W-4 (Central Anchorage) towards Tower No. 3 (upper right)

339



January 1936

Lifting struts between Tower Nos. 2 and 3

340

January 1936

Stiffening Trusses extending from Pier W-1 towards Tower No. 2

341

February 1936

Stiffening Truss extending from Pier W-1 towards Tower No.2

342

Tower No. 3
February 1936
Right of Tower – stiffening trusses extending from mid-span (between Tower Nos. 2 and 3) to Tower No. 3
Left of Tower – trusses extending from the Central Anchorage (W-4) towards Tower No. 3

343

For most of their length, the stiffening truss spans are supported by the main cable and suspenders. However, at the towers they are supported by a system of lateral bearings and vertical links. The latter (under each truss and connected to the inside of the cruciform-shaped tower leg/s) acts like large rocker-bearings. Required for the operation of trains, the vertical links provide vertical/torsional rigidity and an allowance for large longitudinal movement. The lateral bearings consist of girder members with slots that engage pins in the tower leg/s. In the presence of large longitudinal movement of the trusses, this arrangement allows for the transfer of lateral wind loads from the trusses to the towers. Collectively, this system allows vertical, transverse and torsional loads to be resisted while allowing movement in the three other directions;

- **Longitudinal**
- **Transverse Rotation**
- **Vertical Rotation**

Allowances included 30-lbs./SF (wind loads) and 10% of the bridge's weight (acting laterally) for seismic loads (typical of the era).

344

The *Standard Oil Company of California* commissioned talented artists to create covers for several issues of their monthly publication: *The Standard Oil Bulletin,* during construction of the Bay Bridge (Feb. 1936 at left). They did the same for the Golden Gate Bridge during its construction (1933-1937).

345

March 1936
Continuous span truss sections commencing from Pier W-1 towards San Francisco Anchorage and Viaduct

346

March/April 1936

347

Central Anchorage (W-4)
March 1936
Right of W-4 – Stiffening Trusses extending between W-4 and Tower No. 3 complete
Left of W-4 – Stiffening Trusses begin to extend from W-4 towards Tower No. 5

348

Central Anchorage
March 1936

349

March 1936
Working from mid-span (between Tower Nos. 2 and 3), a stiffening truss section is lifted into place (near Tower No. 3). The special section/s adjoining the towers, W-4 and anchorages were left out until all other sections were in-place.

350

March 1936
Stiffening Truss section in place starting from mid-span between Tower Nos. 5 and 6. Truss sections being hung from Yerba Buena towards Tower No. 6 simultaneously

351

352

March 1936
A half-truss section is lifted off of a barge near Yerba Buena Island. Near the island, it was not feasible to lift full truss sections off barges as was the case in open water.

353

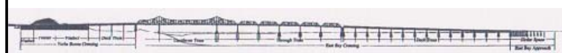
April/May 1936
Trusses extending from Y-B anchorage towards Tower No. 6

354

July 1936
All Stiffening Truss sections in-place

355

Part 8



East Bay Construction

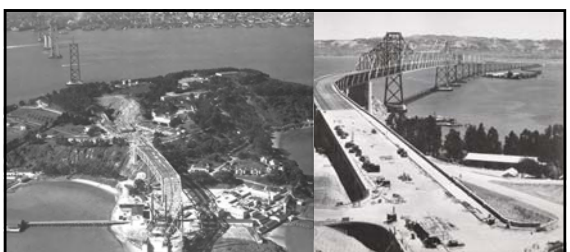
356

Four deck trusses (measuring 288-feet) connect the eastern portal of the Yerba Buena Tunnel to the cantilever bridge. This length allowed the sections to be curvilinear to accommodate the geometry of the tunnel. Measuring 1,400-feet (main-span) with anchor span/s of 510-feet, it was the longest and heaviest cantilever bridge in the U.S. when completed (1936) and was the largest component of the east bay crossing which otherwise features through and/or deck trusses. Five through trusses measuring 570-feet/each extend from the eastern-end of the cantilever and fourteen, 288-foot deck trusses extend from the eastern-most through truss to the Oakland shore. Ten, 82-foot steel girder spans and six, 41-foot concrete girder spans extend from the eastern-most deck truss to the Oakland toll plaza. A curved segment was required at Pier E-9 (juncture of through and deck trusses) to allow for clearance of the ferry terminal which was located on a spit of fill in the bay at the time the bridge was constructed. Pier E-9 is the only four-column pier and was spanned by two, 50-foot metal plates. These plates failed during the October 1989 *Loma Prieta* earthquake.

357

Yerba Buena (Steel) Viaduct

358



The steel truss spans of the Yerba Buena viaduct provide the transition from the concrete viaduct (extending from the east portal of the Yerba Buena tunnel) to the cantilever span. They are deck truss spans akin to those of the east bay crossing, straight but on a segmented-curvilinear alignment. Though part of the east bay crossing, they were included in Contract No. 5 for the Yerba Buena Tunnel and anchorage

359

Yerba Buena Steel Viaduct (Deck Trusses)
June/July 1935

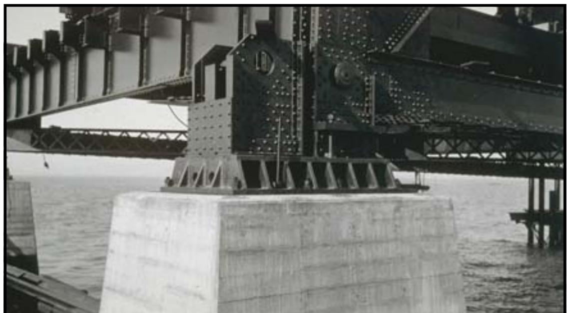
360

Pier E-9 (left)
January 1935

361

Although there is much diversity in the structural *types* of spans in the east bay, there is also much commonality in the structural *system* utilized. Each structural span carries an upper and lower deck of traffic on reinforced concrete slabs. Transverse floor beams support longitudinal stringers which support transverse purlins which support the concrete deck. Only the above-deck framing of the through trusses includes sway-bracing. As for the west bay, only the lower deck framing includes lateral bracing – the upper deck does not. At major expansion joint locations, "split bents" support the trusses allowing for thermal expansion. This negated the need for multiple rocker bearings on a single bent with its inherent instability. The large box pier (E-9) provided for a longitudinal anchor point for the multiple approach (deck truss) spans of the bridge. At a location of curvature and span length transition, its configuration allowed for direct transfer of forces from the lower chords of the trusses to the main members of the pier. The cantilever is unusual in that it uses concrete (west) and steel (east) for its piers and longitudinal anchorage is only provided at its west-end.

362



Pier E-22 – "Split Bent"
September 1934

363

Installing an Expansion Joint "Grid" on bridge deck

364

Span E-7 (Through Truss) – deck support in-place
April 1935

365

<u>Contract No.7</u>

East Bay Superstructure

366

As was the case with Contract No. 6, Contract No. 7 – for the east bay superstructure, was awarded to U.S. Steel subsidiary Columbia Steel Company. They subbed out the cantilever span to the American Bridge Company (as they did for the west bay suspension-spans) but the spans east of Pier E-4 (through and deck truss spans) was subbed out to the *McClintic-Marshall Company* (a subsidiary of Bethlehem Steel Co.). Work on Contract No. 7 could not commence until Contract No. 4 (East Bay Substructure) was complete. Compared to the suspension-spans of the west bay, the east bay superstructures were straightforward and proceeded well ahead of schedule finishing six months ahead of the west bay superstructure with completion of paving (after all steel was in-place) in April 1936. One bitter irony was that, though the work was more routine than the west bay, more workmen died constructing the east bay superstructure than anywhere else on the Bay Bridge. A fire broke out on Pier E-3 in July 1936 causing $10K worth of damage. Six men were forced to jump into the bay, but they were all rescued with no fatalities.

367

Cantilever Span

368

Pier E-1 (on Yerba Buena) is a concrete pier extending to the underside of the bottom chord of the cantilever's truss. It serves to anchor the west anchor-arm of the cantilever and also supports the east-end (of the eastern-most) Yerba Buena steel viaduct spans. Pier E-4 is an X-Braced steel tower (like E-2 and E-3) that serves to anchor the east anchor arm of the cantilever and supports one end of the first (western-most) through truss spans. Thus, Piers E-1 thru E-4 and their respective towers (save for E-1) carry the loads of the cantilever to terra firma. Like all modern cantilever bridges, it is composed of five essential elements;

- **Two Anchor Arms (508-feet/each)**
- **Two Cantilever Arms (412-feet/each)**
- **Suspended Span (576-feet)**

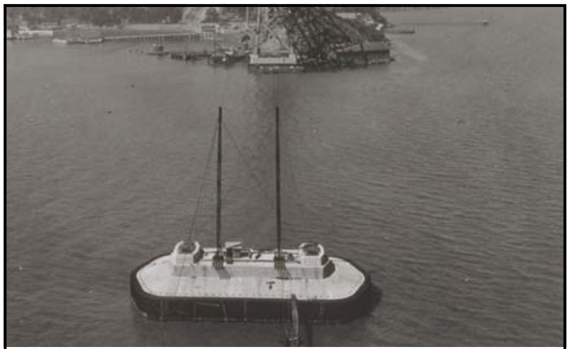
The suspended-span is unsupported from below and connects the ends of the two cantilever arms. As such, there are three spans;

- **Main Span (1,400-feet – from Pier E-2 to E-3)**
- **Two Anchor Spans (508-feet/each – between Piers E-1 and E-2 and between E-3 and E-4)**

369

The towers (a.k.a. "Bents") are structural steel "X-Braced" supports extending from the top of the concrete pier/s to the bottom chord of the trusses (on each side). Atop each leg of the tower, a "shoe" is anchored (to a steel plate) which provides a pin connection of the tower leg to the truss' bottom chord. Constructed of angles and plates riveted together, each tower leg forms a cellular cross-section akin to the west bay tower legs. The towers located on Piers E-2 and E-3 support the main-span of the cantilever and are therefore the tallest of the east bay crossing and bear the greatest dead-load of any east bay pier.

370



Pier E-3
(tower base plates in-place)
August 1935

371

At the cantilever's main supports (Piers E-2 and E-3) 18 and 24-inch diameter steel pins were used to connect five truss members to a common pre-fabricated assembly that caps the supporting steel bent (tower). This allowed for movement during construction of the cantilever without which secondary stresses would develop. Such secondary stresses were causal in the collapse of the *Quebec Bridge* (a cantilever) in 1907.

372

The main compression members at the bottom chord of the cantilever are composed of built-up, riveted steel plates while the main upper chord tension members were fabricated from high-strength heat-treated eyebars (used only at the highest points above the anchor/cantilever spans where they are in tension only).

373

Anchor arms complete and cantilever arms nearly complete. The suspension span will extend between the ends of the cantilever arms. Temporary steel towers were used to construct the anchor arm spans (as seen between Piers E-3 and E-4 in the photo above) but not the cantilever arm/s span/s and/or the suspension span. The cantilever arm/s were extended to 412-feet and the balance (576-feet) of the main span was erected using traveler derricks. They operated from the front-end/s of the truss lifting sections from barges below and building the cantilever in front of them from the east and the west until the suspended span was joined in the middle. Essentially, a cantilever is a type of through truss, albeit a specialized one.

374

375

West Anchor Arm

July 1935

Note the two temporary steel tower supports (between Pier E-1, at left and Pier E-2, at right)

376

The cantilever was constructed in three distinct stages;

- **Anchor Arms**
- **Cantilever Arms**
- **Suspension Spans**

Cantilever components were hoisted into place by a: *"traveler consisting of two guy derricks mounted side-by-side on a base that moved along the structure."* Rather than raising a pre-assembled suspension-span from barges below (as was customary for most major cantilever bridges built up to that time), the suspended-span was built out from each cantilever arm until they joined mid-span. The decision not to raise the suspended-span from below was due to rough water conditions at the site making it inadvisable. The cantilever suspension–spans were off-center and required hydraulic jacks and battering rams (for the connecting pins) to get them into final alignment: *"changing weather and tidal conditions made the closing of the gap difficult to calculate to a nicety."* C.H. Purcell considered the cantilever the second "most ticklish" job in building the Bay Bridge (sinking the west bay piers was first).

377

Carquinez-Strait Bridge

Suspended Span

Upper Left - January 1927. The 433-foot 633-ton north suspended span nearly complete

Upper Right - March 3, 1927. The north suspended span is moved into position for lifting into place between the north cantilever arm and the north tower anchor arm

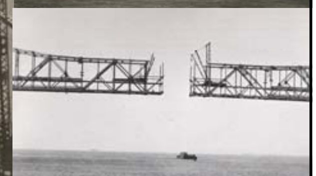
Left - To lift the suspended spans into place slowly and carefully, sandbox counter-weights were used. As the sandboxes descended, the suspended span ascended into place between the cantilever arms via lifting lugs in about thirty minutes

378

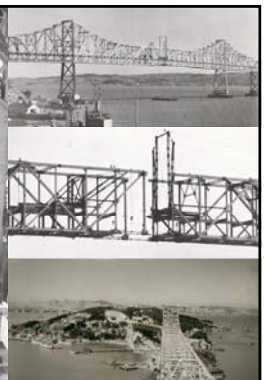


Upper Left – suspended span nearly in position
Upper Right – completed Carquinez-Strait cantilever bridge
Left – model used to study the method of lifting the suspended span/s into position between the cantilever arms 379





Left–traveler derrick (at work)
Right– closing the suspension-span gap (March 1935) 380

381

ca. March 1936

Suspension-Span Complete

When completed, the Bay Bridge cantilever was the third longest cantilever bridge in the world (after the *Firth of Forth* and *Quebec Bridge/s*). It was the longest cantilever bridge in the United States when completed and had a mid-span clearance of 185-feet; 35-feet higher than the world's longest cantilever; the *Firth of Forth Bridge* (150-feet at mid-span). 382

Through Trusses

383


Piers E-5 thru E-9 support the five through truss spans (extending from the east-end of the cantilever). At Pier E-9, the transition from through trusses to deck trusses occurs as well as a curve in the roadway. The through truss spans have an upper and lower deck within a steel (*Warren*) truss framework. Each through truss span is 504-feet long by 84-feet high and consists of twelve, 42-foot long panels. The lower deck is attached to the trusses just above the lower chord and the upper deck is attached at about one-third the height of the truss (above the lower chord). The through trusses are supported by braced steel towers secured to concrete piers. 384

Pier E-5 with X-Braced Steel Tower
August 1935

385

Through Truss Span E-8
(Pier E-9 - upper left)
March/April 1935

386

Through Truss Span E-7
March/April 1935

387

388

Through-Deck Truss Transition
(atop Pier E-9)
April 1935

389

Deck Trusses

390

The deck truss spans (a.k.a. “double-deck truss spans”) are often referred to as the “incline section” due to its slope towards the Oakland shore. They include their lower deck inside the truss framework while the upper deck rests on top of the truss framework. The deck trusses extend from Pier/s E-9 to E-23 and include fourteen spans of 288-feet each. Steel towers support the deck trusses from Piers E-9 thru E-17. East of E-17 (E-18 thru E-23), the deck trusses are supported directly by their concrete piers. Each truss is 38-feet high overall. The final segment beyond the deck trusses and toward a landing at the Oakland toll plaza includes ten, 82-foot steel plate girder spans and six, 41-foot concrete girder spans.

391

Deck Truss Span E-9
January 1935
Note the two temporary steel tower supports between Pier E-9 (left) and Pier E-10 (right). The deck trusses were constructed from the Oakland shore west (towards the through trusses)

392

Deck Truss Span E-16
November 1934
This span transitions from steel tower support (Pier E-17, at left) to direct concrete pier support (Pier E-18, at right). Note the temporary steel support at the middle of the 288-foot span.

393

Left – traveler derrick
Above – concrete (tower) pier supported deck truss spans – Oct./Nov. 1934

394

Direct (Pier) Supported Deck Truss Spans
October/November 1934

395

Deck Truss Span E-22
(near Oakland shore – Pier E-23 at right)
Note the temporary truss support as it extends westward
August 1934

396

Plate Girder Spans
(on Oakland shore)
June 1935

397

Lower Deck Concrete Girder Spans
September/October 1934

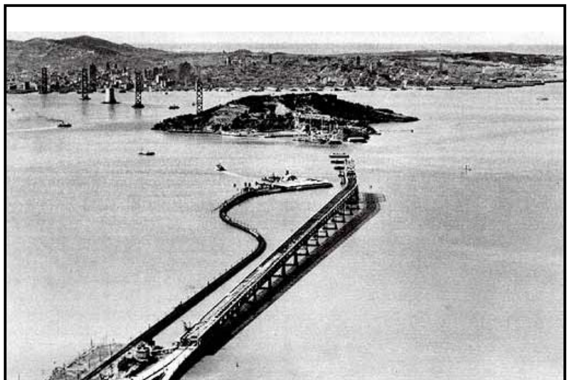
398

Lower Deck Concrete Girder Spans
November 1934 (left) / January 1935 (right

399

View from atop East Anchor Arm of continuous spans
March 1936

400



401

Oakland Approach

402

The Oakland approaches (Contract No. 8) touched down on a "mole" – a train yard island that had been built into the bay to provide mass transit rail lines with deep water access. Unlike the approaches on the SF side (located in a dense urban setting), the Oakland approaches were in a large, open area. However, the approaches were far more complex in that they needed to connect to complicated rail and highway systems on the Oakland side. Between 1936 and 1938, the California Division of Highways built a series of "connectors" to help distribute traffic from the bridge onto area streets. This included *Ashby Avenue* (Berkeley) and *Cypress* and *38th Street/s* (Oakland) and a connection to the new *East Shore Highway* via a series of elevated ramps. Due to realignments and reconfigurations starting in the 1950s, virtually all the original Oakland approaches no longer exist.

403

East Bay (Oakland) Approach
Top right – March 1934
Above – April 1934
Left – January 1935

404

Bridge Deck

405

Despite the fact that the Bay Bridge is composed of disparate structural elements (i.e. suspension, cantilever etc.), the deck system used was generic for almost all bridge elements. The requirement for two deck levels constitutes a truss between them which is similar from one end of the bridge to the other. In general, the truss system is 66-feet wide by 35-feet deep consisting on both deck levels of reinforced concrete slabs on longitudinal steel stringers which, in turn, are supported by transverse floor girders. Only the double-deck reinforced concrete decks of the San Francisco and Yerba Buena viaducts differ in their deck design.

406

West Suspension-Span deck installation
Summer 1936

407

"Batch Train" delivering concrete where/when needed

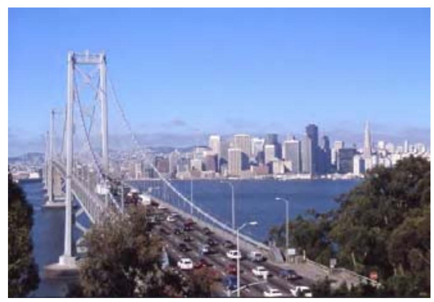
408

409

Upper Left – suspension-span upper deck (between W-2 and W-3)
Upper Right – suspension-span upper deck (Central Anchorage)
Lower Left – suspension-span lower deck (between W-5 and W-6)
Lower Right – suspension-span upper deck (Y-B Anchorage)

410

411



412

413

<u>Part 9</u>

Contract No. 3 (San Francisco: Anchorage, Pier W-1 and Viaduct)

414

Anchorage

415

“The San Francisco anchorage is of the gravity type, depending entirely upon the weight of 63,600 cubic-yards of concrete to resist the 38K-ton pull of the cables.”
C.H. Purcell – Chief Engineer, SF-OB Bridge

416

The San Francisco Anchorage is one of three anchorages (San Francisco, Yerba Buena and the Central Anchorage) for the main suspension cables of the west bay double suspension-span (the Central Anchorage atop Pier W-4 acts as a double anchorage). The western suspension-span extends from the San Francisco Anchorage to the Central Anchorage and the eastern suspension-span from the Central Anchorage to the Yerba Buena Anchorage. The San Francisco Anchorage also serves as a pier for the concrete viaduct approaches to the bridge. The method for securing the cable is essentially the same at all anchorages; eyebars embedded in a mass of concrete restrain the cable strands (via steel spools around which the strands are spun – a.k.a. “shoe/s”) which are attached to the protruding ends of the eyebars. As such, the San Francisco Anchorage consists of three elements;

- **Inclined steel girders (hold the back/s of the eyebars)**
- **Steel eyebars (embedded in massive amounts of concrete)**
- **Concrete embedment**

The San Francisco Anchorage is the best example of this system.

417

Rincon Hill San Francisco
Site of the San Francisco Anchorage
1933

418

December 1933
Eyebars in-place for installation in San Francisco Anchorage

419

January 1934
Inclined steel girders in-place at rear of San Francisco Anchorage. Each of the inclined steel girders accepted seven eyebars and there were five sets of girders (35 eyebars total) for each cable.

420

February 1934
Eyebars in-place in San Francisco Anchorage

421

February 1936
San Francisco Approach (concrete) Viaduct under construction atop the completed San Francisco Anchorage (main cables in-place). The anchorage is a gravity structure which by its shear mass, is able to resist the tremendous "pull" on the cable/s.

422

Pier W-1

423

The purpose of Pier W-1 was two-fold;

- **Support Cable Bents (A&B) atop the pier**
- **Support the eastern-end of the continuous steel spans (between the anchorage and Pier W-1)**

Pier W-1 also serves as the western terminus of the suspension-spans. Like the anchorage (to the west), it was a large-scale concrete forming and pouring operation and its construction was closely coordinated with that of the San Francisco Anchorage. It is a land pier built on reclaimed tidelands. An open cofferdam (with sheet pilings) brought the base of the pier to bedrock. It is a tall structure defined architecturally by a stepped form with deep reveals and shadow lines. Between the San Francisco Anchorage and Pier W-1, there are two smaller intermediate steel piers. They are original to the bridge and are called *Piers A and B*. From the cable bents, the main cables descend to the bottom of the San Francisco anchorage to Pier W-1's rear. As were all concrete elements on the San Francisco side, it was designed by the Board of Consulting Architects.

424

San Francisco Anchorage
April/May 1936
To the left (rear) of the anchorage is the concrete viaduct and to the right is the western end of the continuous steel spans (between the anchorage and Pier W-1). In the upper left photo (below the steel truss) is intermediate support *Pier A*. Piers A and B were closely spaced to meet existing street geometry and their steel framing allowed the two main cables to pass through to the base of the anchorage. Special plate girders (parallel to the trusses) carry the floor beam loads past the cables to common panel points.

425

Pier W-1

426


Left – Pier W-1 (April 1935)
Above (top) – June 1935 (Pier W-1 at left)
Above – August 1935 – Pier W-1 (left) supporting east-end of trusses

427

Viaduct

428

The upper deck approach to the Bay Bridge consisted of a long concrete viaduct structure beginning at *Fifth Street* (between *Harrison* and *Bryant*) extending to the rear (west-end) of the San Francisco Anchorage. An on-ramp provided access to the upper deck from *First Street* (between *Howard* and *Folsom Streets*), just west of the anchorage. Also just west of the anchorage, an off-ramp looped around and connected to *Freemont Street* (at *Harrison Street*). Two-way truck traffic access and egress (from the lower deck) was from *Harrison Street* (between *First* and *Second Streets*). Interurban trains came off the lower deck between *First* and *Second Streets* and looped through the *Transbay Transit Terminal* at *Mission Street* (between *Freemont* and *First Street*) and then back onto the bridge (to Oakland). For the most part, the original structures are made of reinforced concrete with haunched concrete girders supporting concrete slabs in turn supported on reinforced concrete multi-column bents. The foundations consisted of spread footings on rock or timber piles to rock. Mainly in the terminal ramps (elevated), steel girders/bents were used alongside adjacent concrete.

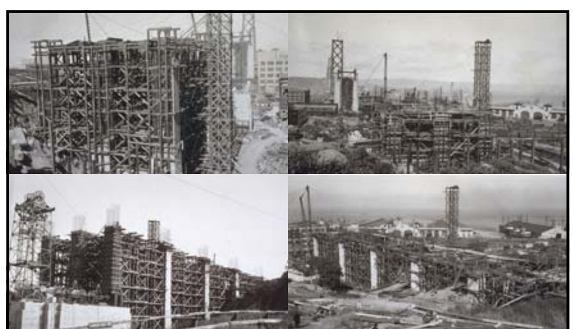
429

San Francisco Approach
ca. 1933

430

San Francisco Approach Viaduct
February 1934 (upper left) / August 1934 (lower left)
September 1934 (upper right) / October 1934 (lower right)

431



San Francisco Approach Viaduct
March 1935 (upper left) / April 1935 (upper right)
May 1935 (lower left & right)

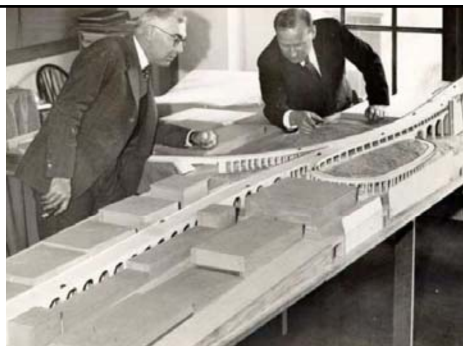
432

San Francisco Approach – Span Nos. 7 thru 18
The approach spans (and on an/off ramps) were built under Contract No. 15 (not Contract No. 3)
November 1935

433

Construction of the concrete approach/viaduct most closely approximated that of conventional roadway construction. Extending from the top of the San Francisco Anchorage to the 5^th^ *Street Plaza*, essentially it is a reinforced concrete girder bridge inclusive of a double deck viaduct at its eastern section. At Fifth Street, the upper deck approach touched down into a rectangular plaza with two diagonal street cuts; one for automobiles entering and another for exiting the bridge. Though much of the original San Francisco approach still exists, it is lost in a maze of freeway ramps, most serving State Route 101.

434



Study model for San Francisco Approaches
(C.H. Purcell at left)
(ca. 1933)

435

San Francisco Approach Viaduct
November 1935 (upper left) / January 1936 (upper right)
February 1936 (lower left & right)

436

San Francisco Approach On Ramp
(Span Nos. 38 thru 111 – Contract No. 15)
April 1936

437

San Francisco Approach Viaduct
May 1936

438

San Francisco Approach
(NG and NM Lines – Contract No. 15)
May 1936
439

San Francisco On Ramp
(Contract No. 15)
June 1936
440

441

442

Atop San Francisco Anchorage (Viaduct Pier)
(at interface with steel truss viaduct spans)
June 1936
443

July 1936
Left to right: west suspension span / Pier W-1 / Steel Viaduct Spans / San Francisco Anchorage / Concrete Approach Viaduct
444

San Francisco Approach
(Contract No. 15)
September 1936

445

Part 10

Yerba Buena

446

Yerba Buena (a.k.a. *Goat Island*) is a natural island located approximately midway between Oakland and the San Francisco peninsula. Prior to 1900, it was an Army post. In 1900, it became a station for the U.S. Navy. On the shallow shoals north of the island, the *Army Corps of Engineers* created a man-made island to host the *Golden Gate International Exposition* of 1939/40: *Treasure Island.* After the Exposition, Treasure Island was supposed to become an airport serving San Francisco and the East Bay, but WWII got in the way and it and adjoining Yerba Buena served as the *Treasure Island Naval Station* from 1940 until the closure of the station in 1998. Though Yerba Buena is roughly in-line with the bridge's points-of-origin (in SF and Oakland), a bend (in the steel viaduct) on the east-side of the island was necessary since the three origin points are not perfectly in-line. For about one-half mile (2,950-feet), the bridge crosses Yerba Buena. Between the Yerba Buena anchorage and tunnel (540-feet long), and for a short section at the east portal of the tunnel, the roadway is in a cut. The curvilinear steel truss viaduct (off the east portal cut) connects to the cantilever.

447

Yerba Buena Island

448

449

Treasure Island

Left: ca. 1937 (under construction) / Right: ca. 1939 (during the fair)

Treasure Island; site of the 1939/40 *Golden Gate International Exposition*, was built with dredged soil from the bay and the spoil from digging the Yerba Buena tunnel portion of the Bay Bridge. The island was to become *San Francisco International Airport* in 1941. However, the Navy took control of the artificial island in 1942 after America's entry into WWII and it became *Treasure Island Naval Station*.

450

451

452

453

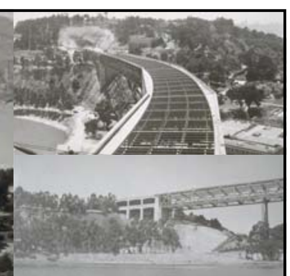
Yerba Buena Island

Left - Western Approach anchorage excavation and roadway (viaduct) cut (January 1934)
Above (top) – West Tunnel Portal excavation (February 1934)
Above – East Tunnel Portal excavation (May 1934)

454

East (Tunnel) Portal Viaduct and Cut
April/May 1935

455



Left – West Bay suspension-spans, Y-B Tunnel, east-portal viaduct and steel truss spans
Above (top) – segmented steel truss spans / east portal
Above – viaduct/truss interface

456

<u>Contract No. 5</u>

Yerba Buena: Tunnel, Anchorage & Viaduct

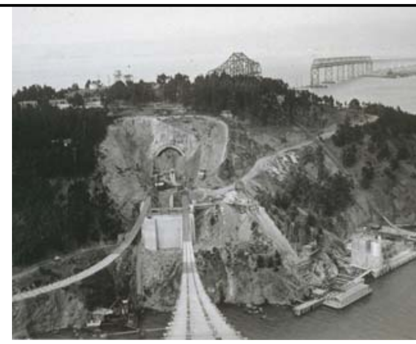
457

Tunnel

458

At the time it was built, the Yerba Buena Tunnel was the largest diameter (bore) tunnel in the world. With vertical sidewalls and an arched roof, it appears to be a segmental arch but is more often referred to as a "Horseshoe Arch." Many innovations were used in its construction including constructing the sidewalls prior to excavating the roof. The twin decks of the roadway are carried through the island via a 76-foot wide by 58-feet high (at arch crest) opening. The 35-foot tall sidewalls (supported by spread footings) act as retaining walls for the concrete arch roof which has a 21-foot rise. To resist the pressure from the earth above, the concrete arch varies from three to six-feet thick.

459



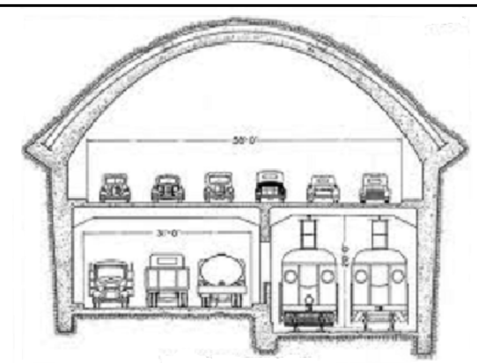
West Tunnel Portal
(as seen from the south footbridge – concrete plant at lower right)
September 1935

460

Inside the tunnel, a structural frame carried upper deck traffic while a slab-on-grade carried lower deck traffic. Originally, the upper deck framing consisted of reinforced concrete beams and slabs supported by corbels and pilasters built into the retaining walls and by a row of columns (between the lower deck's truck and interurban track lanes) slightly off-center of the tunnel. The inside walls of the tunnel were finished with tile. Rock drilling was required and the "spoil" from the tunnel excavation was used as landfill for creating Treasure Island. During construction, The Board of Consulting Architects made many changes to the tunnel's design causing delays and additional costs.

Left – North Tunnel Wall (Feb. 1935)

461



Tunnel Cross-Section

462

West Tunnel Portal
December 1935

463

Tunnel Upper Deck
(at West Portal)
January 1936

464

Steel Framing for Tunnel Vault
April 1935 (top L&R) / June 1935 (bottom L&R)

465

East Tunnel Portal
May 1935

The Yerba Buena Tunnel was excavated in sequential steps (with concrete pours following each step). A company experienced in hard rock mining performed the work. At the bottom of each sidewall, drifts were driven through blasting, drilling and mucking. For the latter, a temporary railroad track sped up the removal process. The *pioneer* (a.k.a. *pilot*) tunnels were extended until each sidewall reached 40-feet high and then concrete was poured to form the sidewalls. A pilot tunnel was excavated near the center of the arch and then the arch was excavated to allow for concrete to be poured for the barrel arch. With sidewalls and arch in place, the inner core of the tunnel was excavated and the spoil removed. Once the core spoil was removed, the concrete decks were formed and poured and the tunnel walls were lined with tile. The work proceeded without incident.

466

Left – Pilot Tunnel No. 5 (Sept. 1934)
Above (top) – Pilot Tunnels Nos. 1 and 2 - Note RR tracks for muck (May 1934)
Above – Tunnel No. 2 (July 1934)

467

Yerba Buena Tunnel
West Portal (left) / East Portal (right)
September 1935

468

On the north side of Yerba Buena Island, the Army Corps of Engineers was beginning the long process of filling the shallow shoals to create Treasure Island. As such, they were accepting any/all muck (a.k.a. *spoil*) from the nearby tunnel excavations. Trucks took the muck to a large disposal chute (left) where it slid directly into the Treasure Island work site.

469

Yerba Buena Tunnel
Oct. 1935 (top L&R) / Nov. 1935 (bottom L&R)

470

From an aesthetic point of view, the west portal of the Yerba Buena tunnel is perhaps the most interesting architectural feature of the entire bridge considering its art deco embellishments. It includes stepped concrete elements appearing as large blocks on either side of the tunnel and three segmented arch-forms at the tunnel entrance. Unfortunately, since the upper deck is now mono-directional heading west (to San Francisco), the beautiful form of the western portal can only be glimpsed briefly through the driver's rear view mirror.

471

Western Portal
(at night)

472

473

East Tunnel Portal
December 1935

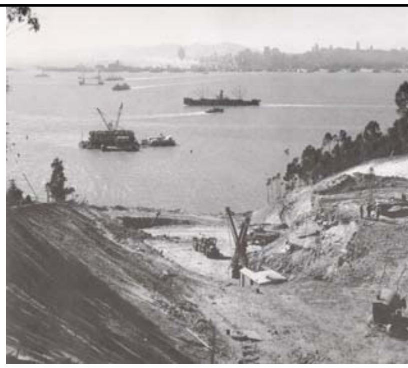
474

Anchorage

475

The Yerba Buena Anchorage is a conventional *rock anchorage* rather than a *gravity anchorage* (as in San Francisco). At Yerba Buena, the two main cables pass over inclined cable bents (leaning towards the island anchorage). Two tunnels were dug to a tapered depth (they're wider at their rear/s than at their mouth/s to accommodate steel eyebar girders) of 170-feet (to bedrock) through the hard rock of the island in order to anchor the cable strand eye-bars securely. A concrete pier (which also serves as a bridge abutment) supports the two cable bents. Chief Engineer C.H. Purcell described it as follows: *"To secure adequate anchorage, a tunnel included at an angle of 37-degrees below the horizontal was driven 170-feet into the rock for each cable. Grillage beams were placed at the bottom of each tunnel and were connected to the strand shoe by means of an eyebar chain. The cables were turned downward over a steel cable bent. The downward inclination was for the purpose of engaging an adequate mass of rock in as short a length as possible. All elements of the anchorage are enclosed in a concrete structure which is treated architecturally to match the San Francisco anchorage."*

476

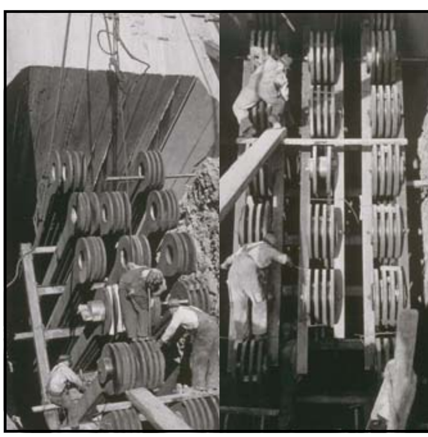


Yerba Buena Anchorage Excavation
December 1933

477

Left - North Cable Tunnel (Feb. 1934)
Above (top) – North Cable Tunnel (March 1934)
Above – South Cable Tunnel (August 1934)

478



North Cable Tunnel
October 1934

479

Yerba Buena Anchorage
Upper Left – July 1934 / Upper Right – December 1934
Lower Left – January 1935 / Lower Right – June 1936

480

Yerba Buena Anchorage
(Approach Viaduct at right)
April 1936

481

Viaducts

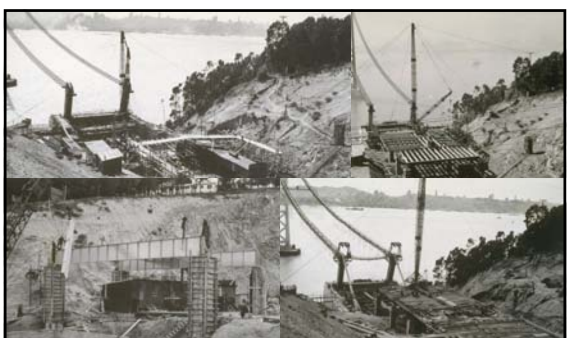
482

Both the west and east portal (concrete) viaducts are similar to the San Francisco double deck viaduct in that they are, essentially, double-deck reinforced concrete girder spans. The upper deck was supported by three column bents (situated in the middle of the lower deck) and framed with reinforced concrete columns and girders. Also (as in San Francisco), the Yerba Buena Anchorage serves as a pier to support the roadway and provides the transition from/to the west bay suspension-span/s. The concrete viaducts were built on both sides of the tunnel.

483

West Portal Viaduct

484



West Portal Viaduct
Upper Left – September 1935 / Upper Right – October 1935
Lower Left – October 1935 / Lower Right – Feb. 1936

485

West Portal Viaduct
March 1936

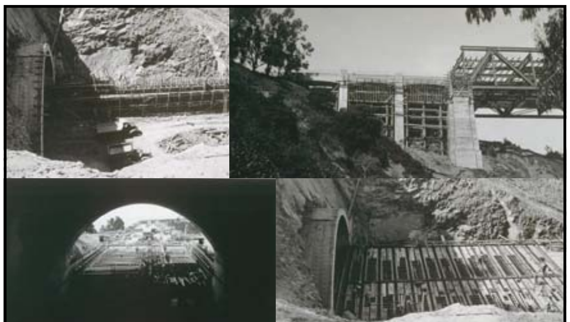
486

East Portal Viaduct

487

East Portal Viaduct
Upper Left – November 1934 / Upper Right – January 1935
Upper Left – April 1935 / Upper Right – June 1935

488

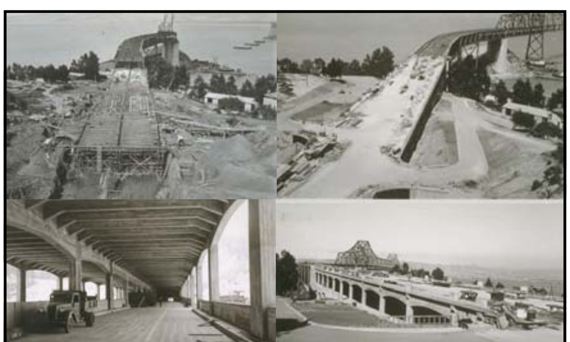


East Portal Viaduct
Upper Left/Right – August 1935
Lower Left/Right – September 1935

489

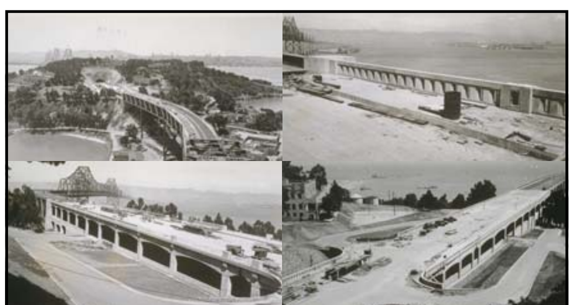
East Portal Viaduct
March 1936

490



East Portal Viaduct
April 1936

491



East Portal Viaduct
Upper Left/Right & Lower Left – May 1936
Lower Right – June 1936

492

Part 11

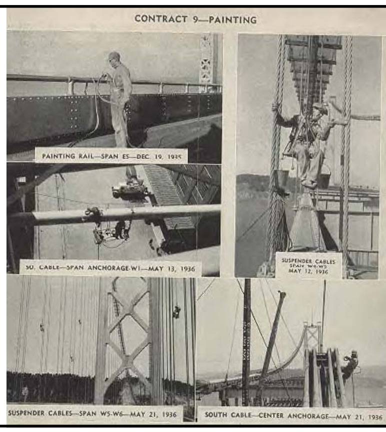
Minor Contracts

493

The “minor” contracts were only minor in the sense that they paled in comparison to the larger contracts (i.e. Contract Nos. 2 thru 8). Contract No. 9 involved painting the west bay spans of the bridge with a top coat of aluminum paint. It required approximately 105K gallons of paint and 187,254 man-hours. Contract No. 10 included constructing the Administration Building and Toll Plaza. Contract No. 11 was for electrical work. Most minor contracts (after No. 9) were completed post-1936. Other contracts broke down as follows;

- Contract No. 14 – a garage on Yerba Buena
- Contract No. 13 – tunnel lining
- Contract No. 15 – on/off ramps in San Francisco
- Contract No. 18 – feature for the GGIE on Treasure Island
- Contract No. 20 – reinforcing details
- Contract No. 21 – fire extinguishers
- Contract No. 22 – alteration to Maintenance Building
- Contract No. 23 – beautification of Rincon Hill
- Contract No. 24 – fill at Administration Building
- Contract No. 41 – distribution structure
- Contract No. 42 – Folger Avenue Underpass
- Contract No. 43 – San Pablo Avenue subway
- Contract No. 52 – anti-sabotage cables

494



495


Painting Suspender Cables
(between Tower Nos. 5 and 6)
May 1936

496

497


498

499

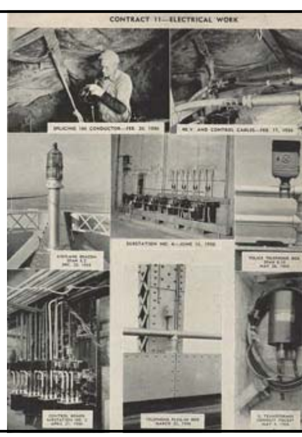
500

Administration Building and Toll Plaza
Upper Left – February 1936 / Upper Right – April 1936
Lower Left/Right – May 1936

501

Toll Plaza (left) and East Parking Area (right)
June 1936

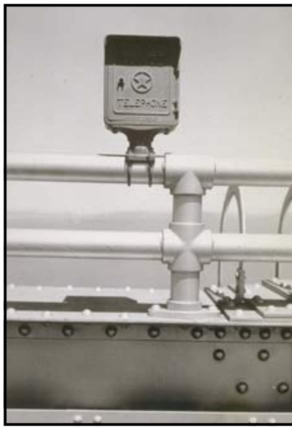
502



503

Airplane Beacon
atop Span E-5 (Cantilever)
December 1935

504



Police Telephone Box
(Span E-10)
May 1936

505

Folger Avenue Underpass (Contract No. 42)
Upper Left/Right – August 1935
Lower Left – August 1935 / Lower Right – Nov. 1935

506

The Bay Bridge opened to automobile, truck and bus service on November 12th 1936. However, the railroad elements (electric trolley service) on the Bay Bridge did not open until January 1939. There were three major contracts;
• Rail work in the East Bay
• Rail Work on the Bay Bridge
• Construction of the *Transbay Terminal Building* (in San Francisco)
Several smaller contracts were required to construct substations for the electric railroad and other related improvements. There were three main reasons why there was a long delay in starting interurban service after the bridge opened;
• Complex negotiations were required with different interurban lines: *The Key System* / *Southern Pacific Railroad* / *Sacramento Northern Line* – all of whom had operated independently and would have to use common facilities on the Bay Bridge
• Involvement/approval/oversight of the *California Railroad Commission*
• State requirement to use upgraded equipment

507

508

509

When all was said and done, besides the great engineering achievement the Bay Bridge represented at the time of its completion, it was also noteworthy having been completed under budget, ahead of schedule and without major incident. There was of course the incidents concerning Piers W-6 (tipping) and E-3 (sank deeper than expected) and the un-spooling of a cable strand during spinning and countless other incidents, but nothing happened that was calamitous; amazing considering the shear scale of the operations. However, the bridge took a terrible toll in human life with twenty-six men killed during construction operations. Credit should be given to the many contractors who performed the work. They were given much flexibility in planning, construction methods used and applying innovative alternatives (i.e. Hammerhead Derricks for erecting the bridge towers) and Chief Engineer Purcell and the Bay Bridge Division relied heavily on their expertise. Of course, the state engineers and the Board of Consulting Engineers' role was critical. Daniel Moran died in 1937 and Ralph Modjeski in 1940. The Bay Bridge was a fitting final tribute to their life's work.

510

"…is a tribute to the intelligence of the American working man, which can not be equaled by any other nation. The engineers and those connected with the construction of this great bridge have worked hard during these past three years. We now turn the structure over to the people for their use."
C.H. Purcell – Chief Engineer, SF-OB Bridge
RE: opening day (11/12/36) remarks

511

"…soundly financed and soundly built…It is not only a monument to the genius of Charles H. Purcell, the engineer in charge, it is a symbol of the unlimited capacity of modern men, working together through government, to unify, not only the physical world around us, but the hearts and goodwill of men."
Charles Henderson, RFC Representative
RE: opening day (11/12/36) remarks

512

Part 12

Bridge Opening

513

In 1915, San Francisco hosted the *Panama Pacific Exposition* to celebrate the opening of the Panama Canal. The Bay Bridge was closer to home and Bay Area residents had watched for three years the bridge's construction and by the summer of 1936, the end was in sight. For local political leaders, a celebration was the order of the day and they came up with a two-fold plan. The first celebration would be held at the time of the Bay Bridge opening in mid-November 1936. The other, more elaborate celebration would be held several years in the future (1939/40) and include a celebration of the opening of the Golden Gate Bridge (May 1937) as well. It would be held on man-made Treasure Island; a direct by-product of the creation of the Bay Bridge, and be called the *Golden Gate International Exposition*. However, for a four-day period (November 11th thru 14th), the focus was on the Bay Bridge;

- **November 11th – small group of events related to *Armistice Day***
- **November 12th – dedication ceremonies, bridge opened to traffic**
- **November 13th – parades and galas throughout the Bay Area**
- **November 14th – San Francisco parade and closing events**

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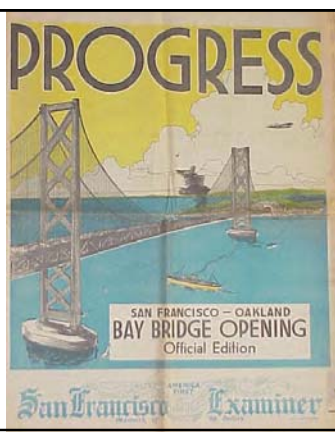

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November 12th 1936

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November 12th was the day the bridge would be dedicated and opened to traffic and was the focus of the celebratory events. At 9:00AM, a boat race from Sacramento and Stockton terminated at Pier 3 in San Francisco. At 10:00AM, a "Marine Parade" of 500 work and pleasure boats left from San Francisco, headed towards Yerba Buena and then back to San Francisco. Overhead, 250 Navy planes (from fleet carriers) flew over the bay between San Mateo and San Rafael. Two official dedication ceremonies; one in Oakland (at the Toll Plaza) and one in San Francisco were to occur at 10:40AM and 11:00AM respectively, but they were delayed for about an hour. At noon there was a yacht regatta and an air show including an "Air Parade of China Clippers" at 3:00PM. In the late afternoon there were Navy ship races and the official bridge lighting occurred at 5:30PM. In the evening, there were several Navy Balls in both San Francisco and Oakland and a Public Ball was held at the Oakland Auditorium. Large crowds were present and almost immediately, traffic on the bridge grew congested: *"The Greatest Traffic Jam in the History of San Francisco"* (SF *Chronicle*)

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"A city gone mad! San Francisco has seen many celebrations, including the exposition of 1915. But not in the memory of the oldest inhabitants has there been witnessed such a spontaneous outpouring of enthusiasm as marked the formal opening of the transbay bridge."
San Francisco *Chronicle*

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"I note that on November the twelfth at 10:00AM the bridge ceremonies take place and that Governor Merriam cuts the chain. Merriam had as much to do with this as a resident of China. The man that ought to cut that chain is Herbert Hoover."

Mark Requa – Hoover-Young Commission member

RE: excerpt from a telegram Requa sent to *Leland Cutler* (festivities planner). Cutler invited Hoover to attend the opening ceremonies despite the fact that Governor Merriam and ex-POTUS Hoover did not like one another.

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"We cannot dedicate this bridge without noting the remarkable advancement of the last three-hundred years…This bridge which we dedicate today stands as a symbol of cooperative achievement for the residents of this local community, the State and the Nation. We have learned that isolation stimulates fear while cooperation inspires confidence. Isolation never advances commerce, business, industry and culture. It curtails rather than impels a feeling of community consideration. Accordingly, we dedicate this great structure as a part of the highway system of California to the use of the people in an emblem of friendship and neighborly association."

Frank Merriam – Governor, State of California

RE: excerpt from his speech/s on November 12th 1936 closing the opening day ceremonies (he made two speeches that day, one in Oakland and the other in San Francisco)

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Bay Bridge (left) / GGIE (right) / Golden Gate Bridge (top)
ca. 1939

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The BAY BRIDGE SAFETY RECORD *is* VERY GOOD *but we want to* IMPROVE IT *and need* YOUR HELP

San Francisco-Oakland Bay Bridge Management

and the

California Highway Patrol

Request the observance of the following rules:

1. Never cross the double center line stripe.
2. Never straddle a traffic lane stripe.
3. Stay in your traffic lane except when passing.
4. When driving slowly keep in lane next to the curb.
5. Do not follow too close behind the car ahead. It may stop suddenly.
6. The red call boxes along the sides of the bridge are for your convenience and safety. Use them if your car is stalled. You will be given prompt courteous service at a nominal cost.
7. Mix equal portions of good driving and courtesy.

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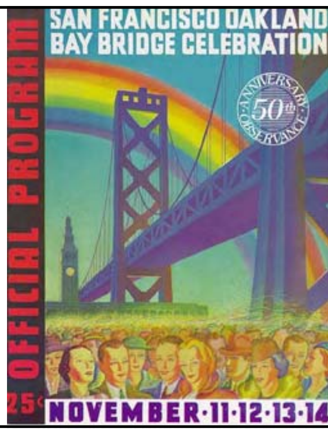

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"The day of the ferry-boats on San Francisco Bay is almost over. In their time, they have contributed their share of romance and color and movement to that colorful and romantic harbor, but the superb bridge which spans its waters will soon take over the loads of commuters who daily shuffle back and forth between their homes in the East Bay and their jobs in San Francisco. The change will be welcome to most of them. Almost at once they will forget the joys of the boat trip, the fresh salty air blowing across the decks, the cries of the gulls that wheel and dart above the rails, and the occasional glimpses at close quarters of great sleek liners heading out toward the Golden Gate. They will go speeding to San Francisco in their streamlined trains, and wish only that the bridge had been built years ago."

Lenore Glen Offord, Author

RE: excerpt from *Murder on Russian Hill*, 1938

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Part 13

A Work in Progress

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From the day it opened, the Bay Bridge became one of the heaviest used bridge structures in the world. To this day, it is the most important link in the Bay Area's arterial highway system. To accommodate growing/changing traffic needs/conditions and to maintain its structural integrity, the bridge has been extensively modified since its November 1936 opening. Though there has been incremental changes made constantly over the years, there were two main events that account for the majority of changes;

- **Removal of the interurban railroad tracks (lower deck) and reconfiguration for mono-directional, mixed traffic on each deck level between 1959 and 1963**
- **Seismic retrofitting of the west bay suspension-span/s and replacement of the entire east bay crossing in the wake of the October 1989 *Loma Prieta* earthquake**

The changes made between 1959 and 1963 most visibly affected both the San Francisco and Oakland approaches. These necessary changes allowed highway connections to be made and coincided with freeway construction in both Oakland and San Francisco.

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West Bay Suspension-Span/s Cross-Sections
(Post-1963)

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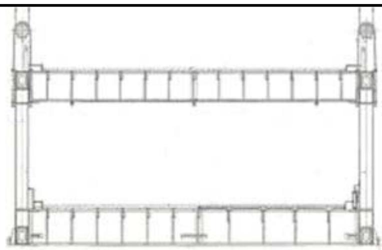

Suspended-Span Cross-Section
(Post-1963)

Remodeling of the west bay suspension-span/s concerned mainly the reinforcement of the upper deck to enable it to carry truck traffic. Pre-cut cover plates were secured to the bottom flange of the transverse floor beams to increase their carrying capacity. The lower deck was widened after the interurban rails were removed.

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The 1959-1963 changes can be broken down into three components;

- **Strengthening of the upper deck for truck traffic (it was designed solely for automobile traffic) and lowering of the upper deck in the Yerba Buena Tunnel (to allow room for trucks)**
- **Removal of the interurban rail tracks on the lower deck and replacement with traffic lanes and rebuilding of all lanes to accept mixed truck, bus and automobile traffic. This also entailed lowering of the lower deck (allowing for lowering of the tunnel's upper deck)**
- **Due to the change in traffic flow (mono-directional), the San Francisco and Oakland approaches as well as the Yerba Buena ramps were reconfigured to accept the new traffic patterns**

Complicating the latter, the work coincided with freeway construction and required close coordination. The upper deck was strengthened mainly by the addition of cover plates to the transverse floor beams and adding rolled girders under the original stringers to increase their strength. For the SF Approach, the remodeling mainly concerned the removal of the center columns supporting the upper deck and reinforcement of outer columns and floor beams.

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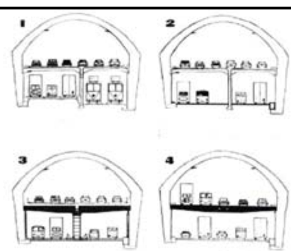

Yerba Buena Tunnel Modification
1959-1963

The off-center columns (between the interurban and traffic lanes) which supported the upper deck were removed to allow for lowering of the upper deck. Next, the lower deck was brought to a uniform (lower) grade. Then, a new (lower) upper deck (without intermediate support) was installed for the full length of the tunnel.

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Structurally, the 1959-1963 remodeling of the east bay spans was similar to that of the west bay suspension-span/s. The rolled girder shapes added below the original stringers were given an upward (at center) camber (bend) to act compositely under both live and dead loads. After the interurban rails were removed from the lower deck (to allow for widening and new traffic lanes), the heavier floor stringers were left in-place to support the new deck slab. The other major change concerned the alterations required to allow five lanes of mono-directional traffic (east-bound) to exit from the lower deck.

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Loma Prieta

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The east bay crossing suffered the worst effects of the October 1989 *Loma Prieta* earthquake. Both fifty-foot spans (upper and lower) at Pier E-9 were replaced in the wake of the earthquake. Fortunately, the collapse of the upper deck was the only structural failure resulting from the quake. East of E-9, the reinforced concrete piers have been strengthened and at the abutment area, original columns and footings have been replaced with more ductile units. In the late 1980s, major changes were made to the San Francisco and Oakland Approaches and they were damaged during the 1989 earthquake. In Oakland, the I-880 freeway (a.k.a. *Cypress Structure*) near the bridge approach was rebuilt along a new alignment requiring entirely new connections to the bridge. In San Francisco, the *Embarcadero Freeway* was severely damaged during the earthquake and was demolished. With the loss of direct freeway connections, new bridge approaches were required. As an interim safeguard; until removal and replacement of the SF Approach (as part of the seismic retrofit), tension ties were placed along the concrete cross-beams of the upper deck providing a better beam/column connection.

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The seismic retrofitting of the west bay suspension-span/s includes;
- Strengthening the towers with steel plates
- Additional lateral bracing to the upper plane of the trusses
- Strengthening the truss cross-section against sway with cover plates
- Strengthening select truss members to provide more/better axial and/or bending load capacity (pictured above)
- Strengthening anchorages and foundations
- Strengthening reinforced concrete Pier W-1

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The seismic retrofit of the Yerba Buena crossing includes the following;
- Strengthening of the tunnel components against increased seismic earth pressures
- Strengthening the west portal concrete viaduct
- Strengthening the east portal concrete viaduct

As part of the east bay crossing replacement, the segmented steel truss spans (between the east portal concrete viaduct and the cantilever) will be replaced. As well, the tunnel walls will be given additional strength and ductility via modern construction materials. Alterations for the accommodation of the new east bay span/s will also be included (pictured above).

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New East Bay Crossing

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A Signature Bridge Design

As a new Bay Area landmark, the new East Span will provide state-of-the-art technology and usher in the look of this new century. The design is modern and striking, with the profile of the new Suspension Span mirroring the lines of the existing suspension bridge between San Francisco and Yerba Buena Island and the Golden Gate Bridge.

The designers envisioned the bridge as a "white line" across the Bay. All vertical elements, including the tower, piers, and light standards have been designed to emphasize the clean modern lines of the structure and intensify the effects of light and shadow. Unique light poles and railings will be used on the bridge to unify the different structural designs of each component and create a seamless appearance. The light poles will vary in height and illumination intensity to maintain a constant level of light on the roadway.

To add to its distinctiveness, the new asymmetrical suspension span will have a longer forward span (east of the tower) than back span, which will provide a more gradual transition from the gently sloping Skyway and will give the new East Span a unique silhouette.

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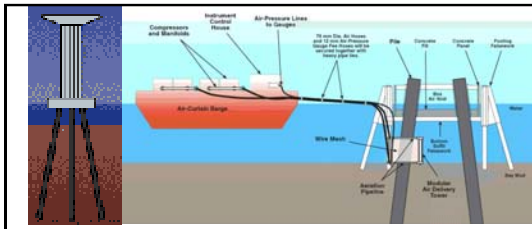

The new East Bay Span required the use of the largest hydraulic hammers and marine cranes in the world. The world's largest pre-cast concrete segments make up the Skyway deck. Approximately 200 million pounds of structural steel, 120 million pounds of reinforcing steel, 200K linear feet of piling and +/- 450K cubic yards of concrete will be used in its construction. The Skyway foundation will consist of 160 eight-foot diameter hollow steel piles in fourteen sets of piers. Each pile weighs a maximum of 365 tons and was driven into the mud of the bay up to 310-feet. In comparison, the existing east bay span consists of 85-foot long timber piles. Rather than being driven straight down (vertically), the steel piles were *battered* (driven at an angle) to maximize strength.

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