SAN FRANCISCO OAKLAND BAY BRIDGE 1933 - 1936

Suspension Span

The California Toll Bridge Authority Act of 1935 authorized the creation of the Toll Bridge Authority, which was responsible for the design and construction of the bridge. The bridge was completed in 1936.

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Vicinity Map

The bridge is located near San Francisco and Oakland, California. It is one of the most iconic bridges in the United States and is a significant landmark.

The bridge is 820 feet (250 meters) wide and 2760 feet (840 meters) long. It is supported by 16 suspension towers and 36 main cables. The main cables are made of 1,940,000 feet (591,000 meters) of steel wire, and the total weight of the bridge is approximately 50,000 tons (45,000 metric tons).

The bridge is an important part of the San Francisco Bay Area transportation network and is a popular tourist attraction.

The bridge was designed by the California Toll Bridge Authority, with construction managed by the California Department of Transportation. The bridge was opened to the public on June 3, 1936.

The bridge is a UNESCO World Heritage Site and is recognized for its architectural and engineering significance.

The bridge is an example of the innovative use of technology and materials in the early 20th century, and it continues to be a symbol of progress and innovation.

The bridge is located in the San Francisco Bay Area, California, and is a key component of the Bay Area Rapid Transit system. It is also a major transportation route for vehicles, cyclists, and pedestrians.

The bridge is a popular destination for tourists, and visitors can enjoy the stunning views of the San Francisco Bay and the surrounding area from the bridge.

The bridge is maintained by Caltrans, the state agency responsible for the maintenance and operation of California's highways and transportation systems.
1. San Francisco Approach

2. Yerba Buena Island

3. East Bay Approach

**Symbol Key**

- Automobile Traffic: A
- Truck Traffic: T
- Military Traffic: M
- Direction of Traffic: —

**KEY PLANS**
**Triangulation Net**

Surveys required during construction called for a variety of methods. Because of the magnitude and complexity of the surveys required, and the necessity for speed and accuracy, a Department of Triangulation and Surveys was formed to establish the necessary survey data needed to locate the structures for the San Francisco-Oakland Bay Bridge. A triangulation net consisting of 11 stations was developed; two were on the west shore, three were on Yerba Buena Island, three were deep water locations and three were on the east shore. Two basic lines were established to control the accuracy of locating points by triangulation. Three base lines were set up: one along the San Francisco waterfront, one on the west side of Yerba Buena Island, and one along the Bay Route on the Oakland. A NORTHERN TRAVELING surveying tape was used to establish the dimensions along the base line. Three of these tapes were used for all surveying and were calibrated at the Bureau of Standards laboratories in Washington D.C. Each of the triangulation stations contained a theodolite, and short wave radio to communicate with all construction stations and boats. The observatory platform and instruments were protected from the warping effect of the sun's rays and the vibrations from the wind by shelter houses. The angles of the triangulation net were measured at night when the atmosphere was more uniform, contained less smoke, and heat waves were less noticeable. It was also possible to obtain greater accuracy by defining points with artificial light. The accuracy of the bridge net was 1 foot in 76,500 feet (1.45 m). This meant that the differential between the triangulation net and chained dimensions was 0.037 foot in a distance of 6.717 feet. Range poles (lining rods) were placed on the top of each triangulation station and were used on daylight locations to establish moving anchor points, construction docks, submarine cables, and canals. The range poles were 7 inches in diameter and were the largest ever used. A common datum point was established on Telegraph Hill in San Francisco so that all of the bridges sections would ultimately align. The common datum point was transferred to the Oakland side by two steps. The Telegraph Hill station was located at (30.60 feet) and then to the Albers Mill building, adjacent to the Southern Pacific Mule Station in Oakland (10.230 feet). Datum points were then transferred to various points of the construction using a transfer system established by United States Coast and Geodetic Survey.

**Cable Layout**

The layout of the cable curve (catenary) required fourteen separate control systems. Graphs and tables were prepared so that the cable could be adjusted to the correct position by setting the mid-span point at the proper elevation for any reasonable condition of temperature, span length, and change in elevation of the suphists. A five hundred foot model was constructed to evaluate these factors. The rate and extent of tower deflections, (up to 1 foot) due to a 40 degree temperature differential, was determined by observing the locations of the tower tops by a vertical collimator throughout a twenty-four hour period. The vertical collimators were also used during the cable spinning to monitor the vertical alignment of the towers. Observation platforms, located and enclosed by canvas, were erected at desired elevations on the tower and contained equipment similar to that in the triangulation net stations. The mid-span rods and range targets were illuminated for night work, and the theodolites were equipped for electrical illumination of the cross hairs. All observations were taken at night because the temperature of the wires could be more accurately measured and the rate of movement of the towers and rocking was at a minimum. Guide wire temperatures were obtained from thermometers encased in short lengths of cable wire, and strand temperatures were obtained by inserting metal encased thermometers between the wires.

**SURVEY DATA**
San Francisco Approach

The original San Francisco approach for automobiles was a long concrete viaduct structure that began at Fifth Street between Van Ness and Broadway and extended to the San Francisco anchorage. There were intermediate separate entrances and exit ramps just west of the anchorage that are not shown in these elevations. Most of the viaduct had a single level deck for automobiles. However, just west of the anchorage, the viaduct had two levels of decks. The lower deck was for truck and train traffic, which entered and exited the bridge near First Street. The anchorage was located inland in order to be constructed on unlined material and serve as a gravity anchorage.

West Bay Crossing

The West Bay Crossing consists of tandem 2,310 foot span suspension bridges connected by a massive center anchorage. The side spans are 1,150 feet long except at the west end of the western span which is 1,171 feet. The bridge originally contained an upper deck for automobiles and a lower deck for trucks and trains. A continuous steel deck truss spans between the San Francisco anchorage and pier W-1.

Yerba Buena Crossing

The Yerba Buena Crossing consists of a main tunnel with concrete portals, and viaducts linking both levels of traffic on the West Bay and East Bay Crossings. The tunnel is a fred concrete wall supported by concrete sidewalls. A curved steel deck truss extends over the east side of the island to pier E-1, which marks the beginning of the East Bay Crossing.

East Bay Crossing

The East Bay Crossing consists of a cantilever truss, five through trusses, fourteen deck trusses, and a series of girder spans at the Oakland approach. Due to the extreme depths of mud on the bay floor, none of the foundations between Yerba Buena Island and the Oakland Mole bear on bedrock. Instead they are supported on a layer of silty clay and sand several hundred feet below the bottom of the bay.

ELEVATIONS

(South Elevations Illustrated)
Suspension Bridge Spans

The main support members of the suspension bridge are parallel wire cables, 66 feet apart and 28-3/4 inches in diameter. The cables, which run the length of the bridge, are draped over towers, and secured at either end to anchorages. Suspension, hung from the main cables, support the truss stiffened-deck truss system and are attached to truss panel points along the top chord. The weight of the bridge is supported by the cables, which are in tension and the towers which are in compression. The deck systems are supported on floor beams which are anchored to the panel points of the truss.

Truss Bridges-General Notes

The Truss bridges consist of parallel trusses, 66 feet apart. Cross members and bracing tie the top and bottom chords together creating a box-like cross section. The trusses are composed of a combination of straight members arranged in a triangular pattern. They are connected so that the stresses in the individual members, due to the loads on the whole truss, are direct stresses in the form of tension or compression. The truss members are either riveted box sections made up of angles, plates, and lattice bracing, or high tensile strength weldments with pin connections. All the truss, except for the cantilever type, act as simple span beams supported by piers or towers at each end. Floor beams, connected at the truss panel points, support the deck system. The concrete slabs are supported on three systems of steel beams (transverse purlins, supported on longitudinal stringers, supported on transverse floor beams). The lower deck framing includes lateral bracing, while the upper deck floor system does not.

Cantilever Truss Spans

The cantilever bridge is composed of two arms that extend from opposite sides and a middle span which is suspended from the ends of each arm. The arms consist of an anchor arm supported by piers and the cantilever arm, which extends beyond the pier toward the middle of the span. Piers E1 and E4, at each end of the cantilever bridge, are designed to resist the uplift force of the anchor arms. Piers E2 and E3 are in compression, supporting the weight of the cantilever system.

Through Truss Spans

There are five through truss spans of 504 feet center to center of the bearing pins. The through truss spans have both upper and lower decks within the truss framework, and sway bracing incorporated in the above-deck framing. Each span centers two decks of traffic on reinforced concrete slabs.

Deck Truss Spans

There are fourteen deck truss spans of 288 feet center to center of the bearing pins. The deck truss spans have the lower deck inside the truss framework and the upper deck on top of the truss framework. There is no sway bracing incorporated in the deck truss spans. Each span centers two decks of traffic on reinforced concrete slabs; each slab is supported on three systems of steel beams (transverse purlins, supported on longitudinal stringers, supported on transverse floor beams). The lower deck framing includes lateral bracing, while the upper deck floor system does not.

BRIDGE TYPES
VIADUCTS

A viaduct is defined as a long bridge consisting of a series of short concrete or masonry spans supported on piers. Viaducts can also be a structure of steel girders and towers. The Viaducts of the San Francisco Oakland Bay Bridge occur at both, the San Francisco and the east bay approach, and also at both ends of the Yerba Buena Crossing. The original structures are mostly reinforced concrete construction, with launched concrete girders, carrying reinforced concrete slabs, supported on reinforced concrete multiple-column bents. Foundations consist of spread footings on rock or timber piles to rock. Steel girders were used at certain locations, mainly in the Terminal ramps, where the elevated roadway crosses city streets. These steel spans shared concrete bents with adjacent concrete spans, and are supported at intermediate locations by steel bents.

S.F. Viaduct - Single Deck Spans

The majority of the San Francisco approach was of single deck construction and provided automobile access to the upper deck of the bridge. The double deck viaduct occurs between Rincon Street (between Second and Third) and the San Francisco-Anchorage. The lower section was used for bus and railroad traffic. Viaducts were also built for the bridge railway system to circulate to and from the bridge in a loop through the Transbay railway terminal. The original structures were mostly of reinforced concrete construction, with launched concrete girders, carrying reinforced concrete slabs, supported on reinforced concrete column bents. Foundations consisted of timber piles or spread footings on rock. Steel girders were used at certain locations where the elevated roadway crossed over city streets. These steel spans shared concrete bents with adjacent concrete spans and were supported at intermediate locations by steel bents.

Yerba Buena Viaduct - Double Deck Spans

The viaducts on Yerba Buena Island were double deck concrete structures with portions of the lower deck sitting on grade. These viaducts extend west and east from the tunnel portals and connect to each of the bridge crossings.

East Bay Approach - Girder Spans

The viaducts of the East Bay approach were constructed of both steel and concrete. Concrete was used for the columns and lower deck system, and steel girders were used for the upper deck system.
1. Cable Suspension & Anchorage

The cable suspension system consists of two 28-3/4-inch diameter main cables, 66 feet on center. The cables pass over a cast steel saddle at the top of each tower and are anchored at each end to concrete anchorage structures. Pairs of suspenders, tensioned over a cast steel cable bend bolted to the main suspension cable, support the truss system. These ropes are anchored to each side of the top truss chord at every panel point.

2. Warren Stiffening Truss

Stiffening trusses are centered below each main cable. The majority of the truss members are boxed sections made up of steel angles, plates, and diagonal lacing riveted together.

3. Upper & Lower Decks

Upper and lower floor beams span between the two trusses at each panel point. Roadway stringers (parallel to the trusses) span between the floor beams. Originally, a six-inch concrete slab provided the roadbed for cars on the upper deck and trucks on a portion of the lower deck. It consisted of a 5-1/4-inch reinforced lightweight concrete slab with a 3/4-inch mortar cement wearing surface. There is lateral bracing installed in the lower deck system but not in the upper deck. The stringers under the rail system are in two pairs, one pair for each track to support the wooden rail ties. Lateral bracing runs between the railroad stringers. Horizontal chevron bracing, spanning between the lower floor beams, resists lateral forces. The direction of the chevrons changes at the midpoint of the span with the point of the chevron always pointing toward the nearest tower or anchorage.

4. Assembled System

SUSPENSION BRIDGE STRUCTURAL SYSTEMS
Cable Spinning Procedure

Stage 1: Laying Catwalk Cables

Stage 2: Raising Catwalk Cables

Stage 3: Installing Catwalk, Gantry and Storm Cables

Stage 4: Spinning Wheels Leaving Anchorage

Stage 5: Spinning Wheels Arriving at Anchorage

Cable Spinning Diagram

Cable Spinning Detail

Suspension Bridge Construction

November 18, 1936

March 10, 1936

Typical Truss Unit (70 tons)
1. Truss Suspension

At each suspender location (insert 1), the wires of the cable are clamped together with a cast steel cable band that is bolted together around the cable. Friction due to the clamping forces prevents the cable bands from slipping down the cables. Grooves in the cable band provide support for the suspender ropes, which are looped over the cable band to support the truss. At the lower ends of the suspender arms, the suspender ropes are connected to sockets using modern zinc-plated bolts. The sockets are then secured within steel plate anchors to support the trusses.

2. The Rocker Arms

The rocker arms exist in pairs on each tower shaft - for a total of four such links on each tower, immediately beneath the trusses. A pair of rocker arms on one tower shaft is shown in insert 2. The top of each link is connected to the tower end panel point of the truss, the bottom of each link is connected to a plate assembly that is part of the inside leg of the crotch bar cross-section of the tower shafts. These top and bottom connections are pinned, using bearing pins that are oriented in the direction of the transverse axes of the bridge. The rocker arms support the weight of the last panel of each truss, as compression links. Under imposed loads and environmental conditions - wind, earthquake, traffic, temperature change, etc. - they prevent the ends of the trusses from moving vertically relative to the tower, and also from twisting as a unit about the longitudinal (east-west) axis of the bridge. The articulated rocker arms, with bearing pivot pins at each end, allow the bridge deck to move in the longitudinal direction (both rocker arms rotate in and out together), to rotate about a transverse axis as caused by vertical loads (the rocker arms rotate only slightly, while the truss pivots about the upper bearing pin), and also to rotate about a vertical axis as caused by lateral loads (one arm rotates inward, the other arm rotates outward as the trusses bend sideways).

3. The Wind Anchorage

The wind anchorage system exists on the centerline of the tower and is connected to the tower lateral brace of the trusses and to the transverse bracing girder (not shown) that is part of the tower brace just beneath the tower roadway. These anchorage, shown in insert 3, transfer lateral loads on the trusses to the towers without allowing lateral (N-S) movement. The last panel of lower lateral brace below the tower deck projects through the last lower floor beam. A vertically oriented pin at the base of the lateral members engages a longitudinal slot between fabricated steel shapes that is connected to the lower framing. The system resists transverse lateral loads without allowing transverse movement by forcing the pins to engage the edges of the slots. The configuration of the slots allows the pin to move freely and allows relative longitudinal movement between the trusses and the towers. The ends of the slots are closed so that at the event of extreme longitudinal loads, the pins can never break free of the slots.

Suspension Tower Details

Each of the towers and anchorage of the West Bay Crossing suspension bridge provides support for the cable system, and articulated support of the trusses. The articulation allows for thermal expansion and contraction of the trusses and roadway slabs by allowing free movement in three directions - longitudinal, transverse rotation, and vertical rotation. Simultaneously, vertical, transverse, and horizontal movements are restrained at each end of the suspended trusses. This type of articulation is common to suspension bridges of the Bay Bridge era, although the particular details are unique to this structure.
Sheet Pile Cofferdam (W2 Shown)

The steel structure of the suspension bridge begins at the San Francisco anchorage and extends to the Yerba Buena Island anchorage. Piers numbered W-1 through W-6 support the span. There are two intermediate piers, A and B, between the San Francisco anchorage and pier W-1. Foundations for piers W-1 and W-2 are reinforced concrete, cast in place in open cofferdams constructed of sheet piling. Pier W-1 is built on reclaimed fill and extends 60 ft. below the water's surface. Pier W-2 is the first pier in the water and was constructed using the outer end of a steamship dock as a working platform. Bedrock was found 88 1/2 ft. to 105 ft. below the water, which was shallow enough to permit the use of sheet piling. A timber frame (56 ft. by 112 ft.) was floated into place and sunk by weighting it down. The sheet piling was driven around the timber frame to the depth of bedrock. Sand and mud were excavated to expose the bedrock. The bedrock surface was then cleaned and inspected by divers. The first portion of concrete was placed in the submerged cofferdam with dump buckets. When a seal was formed at the bottom, water was pumped out and the remainder of the concrete was poured in the dry cofferdam. Most of the wood timbers were left in place, and the sheet piling was removed.

Cellular Caisson (W6 Shown)

A new method of construction called the "Cored Cylinder Method" was developed for piers W-3, W-4, W-5, and W-6 to penetrate the extreme depths of mud and composite materials and to reach bedrock, which ranged from 10 ft. to 224 ft. below the water line. Pier W-4 was the largest pier in the world, extending from 317 ft. below the water to 281 ft. above the water. Construction of the pier began with a rectangular caisson, using steel spaces and stiffeners. To accommodate extreme water pressure, a timber shell was constructed with 10" x 12" vertical timbers faced with 4" x 12" diagonal timbers, sealed with caulking, and cemented. A steel grid with a sharp cutting edge at its base was constructed at the bottom of the caisson for support and to cut through the bay mud. The interior of the caisson contained a grid of steel cylinders 15 ft. in diameter and spaced 17 ft. center to center. Aft and starboard hemispherical domes were welded to the top of the cylinders to permit the caissons to be floated out and anchored into position. Working docks were then built on each end of pier W-3 and on each side of pier W-4. At piers W-5 and W-6, work was done from dock barges. Heavy timber floating fenders were built to protect the caissons and to block wave activity. Sinking the caisson was accomplished by pouring concrete into the spaces around the sealed cylinders. The air pressure within the cylinders, which controlled the rate of descent, ranged from 17 psig to 42 psig depending on the depth below the water. To lower the caisson, air was released from a few cylinders at a time, the domes were removed, new sections were added and the cylinder was repressurized. After the caisson settled into the mud, the domes were removed and the underlying mud and composite material was removed with clamshell buckets. This continued until the caisson reached bedrock. Docks were then sent down to inspect and clean the bedrock surface. Then, concrete was lowered to the bottom using dump buckets to form a 34 ft. deep mat of concrete. The three cylinders in each corner of the caisson were filled with concrete, and the remaining ones were filled with water. The tops were sealed with a concrete slab in which anchorages for the steel towers were embedded.

WEST SPAN FOUNDATION SYSTEMS
**San Francisco Anchorage**

The San Francisco anchorage is a large concrete structure that serves as both a pier and an anchorage. It is a gravity-type anchoring system that relies on the weight of the structure and the foundation system to anchor the main cable. The structure is 194.5 ft long by 120 ft wide and rises 148 ft above the neighboring streets. The top of the structure contains a double road deck system which connects the San Francisco viaduct and the continuous spans that approach the main suspension bridge. The anchorage is located 680 ft from the end of the suspension bridge where the soil conditions are better. This position also allowed the cable to enter the structure at a lower level to minimize the overturning caused by the cable pull. The anchoring system consists of stand shoes at the cable ends, pinned to two sets of eyebars chained together, and an anchorage girder at the opposite end. The structure contains approximately 68,000 cubic yards of concrete and 1000 tons of steel. It was poured in three major steps. The first pour was up to a point would cover the steel anchorage girder, which consisted of 700 tons of steel. The anchorage girder and the first set of eyebars chains (80 total) were then encased. To permit movement of the second set of eyebars chains, (45 total), they were not enclosed in concrete until after the cable spanning was complete. The last step was to complete the remainder of the concrete structure.

**Center Anchorage**

The center anchorage was the most important anchoring system of its type, connecting two back-to-back suspension bridges. The concrete portion of the anchorage extends up to the lower road deck (225 ft above the water) and consists of two longitudinal concrete side walls with an average thickness of 13 ft and end walls averaging 10 ft in thickness. The top is concrete steel and forms the road bed of the lower deck. The side walls contain a well for the installation of the 120 ft, 30 ft frame, eyebars. These walls were ultimately filled with concrete. The interior of the structure is boxed with a series of concrete blocks. The structure above the lower deck is steel which encloses the anchorage system and provides the structure for the upper deck. The anchorage system consists of two "A" frames (one for each side of the bridge) which are on top of the concrete pier. A set of 12 eyebars set in concrete are used to anchor the two upper legs of each "A" frame. Attached to the top of the each "A" frame is a series of eyebars (38 each direction) which anchor the cable strands. The "A" frames and eyebars are encased in concrete from the lower deck. At the upper point of each "A" frame are concrete gusset plates of 40,000,000 pounds, that help form the splices between the east and west suspension cables. At this point the dead load cable pull of 30,000,000 pounds is balanced. Unbalanced live loads (resulting from the car, train and truck traffic) cause an uplift on one stem of the "A" frame, which is resisted by the eyebars extending into the pier.

**Yerba Buena Anchorage**

The Yerba Buena anchorage uses the rock island to anchor the cables. The cables bend over saddle bents and loop around the strand shoes at the back of the structure. The strands shoes are pinned to two sets of eyebars that extend into a 1.75 ft tunnel that widens toward the bottom and angles down at 7 degrees. The eyebars consist of four bars in each chain. The tunnel was filled with concrete leaving the upper most chain exposed to permit movement during the cable spinning processes. Once the cable was completed, the last chain was encased in concrete leaving only the eyebars ends and stand shoes exposed. The cable bent is 84 ft high and is lifted 19 degrees. The cable bent was allowed to move during construction of the cable to equalize the forces on the cable as it was fully loaded. This structure is at the end of the eastern suspension span and the beginning of the double deck roads to the Yerba Buena Island tunnel.

**Key Plan - West Bay Crossing**

The key plan shows the layout of the anchorage system with the main concrete structure and the anchorage girder at the opposite end. The anchorage system consists of two "A" frames (one for each side of the bridge) which are on top of the concrete pier. A set of 12 eyebars set in concrete are used to anchor the two upper legs of each "A" frame. Attached to the top of the each "A" frame is a series of eyebars (38 each direction) which anchor the cable strands. The "A" frames and eyebars are encased in concrete from the lower deck. At the upper point of each "A" frame are concrete gusset plates of 40,000,000 pounds, that help form the splices between the east and west suspension cables. At this point the dead load cable pull of 30,000,000 pounds is balanced. Unbalanced live loads (resulting from the car, train and truck traffic) cause an uplift on one stem of the "A" frame, which is resisted by the eyebars extending into the pier.

**ANCHORAGES**
San Francisco Anchorage Section B-B

ANCHORAGE & CABLELING DETAILS
Phases of Construction

Phase I (Pilot Bores)
A pilot tunnel 8' high X 6' wide, at the crown of the arch, was started July 29, 1924, and was completed Oct. 6, 1924. Material was hand-mucked into a 1-yd. car on track laid as work progressed. No timbering of this tunnel was required. Next, pilot tunnels 14' wide by 12' high were constructed at each side. Timbering in these tunnels was of 10' X 10' and 12' X 12' posts and caps, and 12' X 12' and 8' X 8' lagging. Spacing of the lagging varied from 5' to 8' centers, depending on ground conditions. The side pilot tunnels were enlarged vertically to the excavation line of the main tunnel roof by stoping and drilling. Muck was caught on a floor of 6' X 6' timbers and hauled through cars on the track below. The slope was timbered with square sets of 8' X 8' timbers, and 5' X 5' lagging as required. Spacing of sets was 4' to 8'.

Phase II (Sidewalls Poured)
Wall forms were of 5 ply 4' X 8' plywood panels with 2' X 6' studs @ 1'4" centers, on 6' X 6' whiles @ 4' centers. Delivery of concrete was supported on the tunnel timber above the pour and raised for succeeding lifts of the pour. Pipes were discharged into hoppers with elephant trunks placed in these forms at about 12' intervals.

Phase III (Cross Cuts)
Six cross cuts were made along the periphery of the arch at intervals varying from 20' to 130'. The space was cleared, 60 beams were hoisted to place in sections, bolted together, studded against the core and wedged against the ceiling. Part of the muck was dropped in the space along the side walls and part was loaded in a small car, pushed to the portals and dropped in the approach cuts.

Phase IV (Concrete Ceiling)
Two steel forms, each extending from spring line to spring line and 20' long, were moved to place on a 4-wheeled car traveling on track laid in the core along the centerline of the tunnel. After setting to line and grade, the forms were securely studded. Bulbheads were attached to the reinforcing steel and placed in the forms. Concrete for the west form was delivered through a pipe laid in the monkey drift above the arch. Concrete pipe for the east form was delivered in pipe laid alongside of the track on top of the core and turned up into the monkey drift near the form. Forms were made alternately in the west and the east form progressing towards the middle. Concrete was discharged into small hoppers fitted with two-way gates opening into sectional chutes leading down to the spring lines. As pouring progressed chute sections were removed. At the crown, workers and equipment were withdrawn into the monkey drift making it possible to pour tight against the rock and about one foot above the H beam bolts. After the arch was poured, the monkey drift was filled with concrete. Three lines of gun holes were drilled through the arch to rock above and the roof was grouted at 40 psi.

Phase V (Core Excavation)
The core excavation was begun after the arch had cured. Blasting holes 8' to 10' deep were spung with 2 to 5 shots of dynamite and then loaded with 90 to 125 pounds and flooded in relays. Excavation was completed Nov. 30, 1925.

YERBA BUENA TUNNEL
1. Trusses

The cantilever trusses of the East Bay Crossing comprise a number of different member types designed and built to resist various forces. The connections between these members are designed to transfer forces between the members and to provide freedom from extraneous restraints that cause undesirable secondary stresses in the members. In the cantilevering portion of the trusses, three types of forces must be resisted: In the top chord of the cantilever truss, bending actions result in large tension forces. These forces are carried by multiple parallel eyebars - flat pieces of heat-treated steel with round holes in their ends. The eyebars are very efficient in resisting tension but have essentially no capacity to resist compression or bending. In the bottom chord of the cantilever truss, bending actions result in large compression forces. These forces are carried by steel plates, built up into members with box cross-sections made up of angles, plates, and flat bars facing inward together which can resist the required compression forces without buckling. The diagonal members in the sides of the trusses carry shear forces. Diagonal eyebars are in tension while diagonal box sections are in compression. Tower E1 anchors the truss with concrete-embedded eyebars, which resist the uplift force generated by the cantilever arm. Tower E2 is in compression. The suspended span is a Warren type box truss suspended from the ends of the cantilever arms.

2. Sway Frames

The cantilever truss is stabilized against lateral forces with sway frames. These braces, located at the key panel points, span the trusses high above the upper deck traffic.

3. Upper and Lower Decks, Upper and Lower Laterals

The upper roadway is supported by a system of piers on top of stringers, which in turn are supported by floor beams. The lower deck is supported only by a system of stringers on top of floor beams. A 6 1/2 in. reinforced concrete slab covers the entire upper deck and the truck traffic portion of the lower deck. The rail system is supported on wooden rail ties over pairs of stringers, stabilized by steel laterals. To stiffen the deck and provide resistance to horizontal forces, a system of lateral "X" braces span between the two side trusses, both at their top and bottom. The bracing connects at each panel between the lower floor beams in the bottom plate, and between the upper studs in the top plate.

4. Assembled System

CANTILEVER TRUSS
(Half Unit Illustrated)
1. Panel Point L0
Panel point L0 is the location of the main vertical support of the cantilever span. Six major compression members converge at this panel point, so a pin-connected joint was designed and built to transfer these forces between members without unnecessary rotational restraint of the member ends, which would have caused strength-reducing secondary bending stresses. The configuration of the joint allows direct transfer of longitudinal compression forces across the joint to the complementary member on the other side and similar transfer of all vertical loads to the pier beneath (not shown). This force transfer requires a complex cellular plate system within the joint. The five transverse pins, which connect the members to the gusset plates of the joint, allow the ends of the members to rotate independently of the joint and each other, thereby eliminating or at least reducing the secondary bending stresses and allowing each member to resist compression to its full capacity.

2. Panel Point UC2
Panel point UC2 is a location where two top chord (tension) eyebars members, a diagonal box (compression) member, and a diagonal eyebar (tension) member are connected. The vertical members at this joint is a secondary framing member that does not participate significantly in the cantilever system of the bridge. The three eyebar members are connected together with bearing pins into a gusset plate. The combined forces in the three eyebar members and the vertical secondary member result in a net force aligned directly down the diagonal member. The pins that anchor the eyebars can not transfer bending; the orientation of the pins is set to minimize eccentric loads due to differential forces in the eyebars. The result is a design that efficiently transfers forces between members (through the pins and gussets) and minimizes secondary bending stresses in the diagonal compression members.

3. Panel Point LS0
Panel point LS0 marks the end of the purely cantilevered portion of the span, where the tip of the cantilever supports the suspended span that comprises the center portion of the structure. During construction, this joint was required to resist and transfer vertical and longitudinal forces. Then, upon completion of the suspended portion, the joint configuration was changed so that the suspended portion would deliver only vertical forces. The member forces are much smaller at this location than they are at L0 and UC2, so the compression members are lighter, with locking on some faces instead of solid plates, and the tension members use fewer eyebars. In the final configuration of the joint, the pin plates also contain loads between the suspended and cantilever portions and allows independent rotation of the two largely independent substructures. The detail also allows some free thermal expansion of the connector, with the gussets at the suspended portion nested inside those of the cantilever portion.

Construction Sequence
The construction of the cantilever truss system began at the east support (E-4) and proceeded west over three temporary bents and over tower E-3 until the cantilever arm panel point LC-7 was reached. The first temporary bent was removed after the truss was in position. Construction of the western section proceeded east from tower E-1 in the same sequence as the east side, also stopping at the point LC-7. The construction continued from the west and east panel points LC-7 toward the center, cantilevering each panel section until the center of the suspended section was reached. The final connection at the center of the suspended section was assisted with hydraulic jacks located in the tip chord members at the end of each cantilever arm and the end of the east approach.

The erecting equipment consisted of two guy derricks mounted on one trailer, the Yerba Buena trailer with two booms in front and a lighter boom at the rear, and a pinlock. The pinlock was used for light work such as placing floor members, curbs, etc. The Yerba Buena Island trailer, used for constructing the continuous span trusses, was also used to construct the suspended sections. The derricks moved on skids made up of the railway stringers borrowed from the suspended section and was supported by the floor beams of the upper deck. The upper deck floor beams were shifted up from the lower floor deck beams to support the weight of the derrick. At panel line 4, the derricks were raised in two steps and supported on temporary floor beams attached to the vertical truss members. The derricks were positioned at each panel point, lifting members into place in a particular order. Once all stanchion members were installed, the derricks were moved out to the next panel point to lift the subsequent set of members ahead of itself. At panel points L9, L9A, and U9, the derricks were raised into higher positions, in two steps, lifting designated members at each step. This process was continued until the west and east joined.

Key Elevation
Truss piers are indicated using industry standards. The first letter denotes whether it is an upper, middle, or lower pier. The second letter denotes which section of the truss it belongs to: anchor arm, cantilever arm, or suspended span. The digit numbers the joint beginning from the point of support.
1. Trusses

The vertical truss is a Warren type truss which performs as a simple beam spanning between two points. The majority of the truss members are steel box sections made up of angles, plates, and flanges. Riveted together. High tensile strength eyebars serve as the bottom chord. The vertical members stiffen the truss and provide anchor points for the deck floor beams. The diagonal members resist the shearing forces in tension or compression as they are distributed to the pinned supports at the ends of the truss.

2. Upper & Lower Laterals

Laterals X bracing occurs at the top and bottom of the trusses. The braces resist the horizontal forces caused by wind and earthquakes. The bracing at the top of the truss is between each panel point. The bracing at the bottom of the truss spans between two panel points.

3. Sway Frames

The upper part of the truss is also stabilized against lateral forces by a series of sway frames. These braced portal frames stabilize the ends of the truss. Intermediate frames are located at the major panel points.

4. Lower Deck Framing

Lower deck floor beams span between the two trusses at each panel point. Floor stringers (parallel to the trusses) are installed between the floor beams. The stringers under the truck roadbed are evenly spaced to support a 6-1/2 in. reinforced concrete slab. The stringers under the rail system are installed in pairs (one pair for each track) to support the wooden rail ties. The stringers that support the track system have their own lateral bracing made of steel angles.

5. Upper Deck Framing

Like the lower deck, the upper deck has floor beams connected to vertical members of the trusses. Between the floor beams are stringers that are set slightly below the top flange of the floor beams to accommodate steel floor Joists. The steel floor joists are installed parallel to the floor beams with a cross slope for drainage. A reinforced concrete slab sits on the floor joists. There is no lateral bracing in the upper deck.

6. Assembled Systems

Construction Sequence: First, end towers were constructed to provide support for the truss construction. Then, temporary supports were erected at the live major panel points. Finally, the individual truss panels were raised into place by cranes and secured with rivets. The floor system was completed after.
1. Trusses

The series of deck trusses, carrying two decks, are often referred to as continuous truss spans. This Warren type truss has a continuous top and bottom chord separated only by expansion joints over the piers. The deck truss performs as a simple beam spanning between two piers. The majority of the truss members are steel box sections made up of angles, plates, and flange lacing riveted together. The vertical members stiffen the truss and provide anchor points for the deck floor beams. The diagonal members resist the shear forces in tension or compression as they are distributed to the support ends of the truss. No webbings are used in the deck truss spans.

2. Upper Deck Framing

The upper deck is a simple framing system with floor beams spanning between the trusses. Between the floor beams are stringers that are set slightly below the top flange of the floor beams to accommodate steel floor posts. The steel floor posts are installed parallel to the floor beams with a cross slope for drainage. A 6-1/2 in. reinforced concrete slab sits on top of the floor posts. There is no lateral bracing in the upper deck.

3. Lower Deck Framing

Lower deck floor beams span between the two trusses at each panel point. Floor stringers (parallel to the trusses) are installed between the floor beams. The stringers under the track roadbed are evenly spaced to support a 6-1/2 in. reinforced concrete slab. Originally, the stringers under the rail system were installed in pairs (one pair for each truss) to support the wooden rail ties. Lateral "X" bracing, which resists wind and earthquake loads, occurs in the plane of the bottom truss chords. The "X" bracing covers two panel points. It is interrupted by the deck floor beams forming a series of opposing chevron braces. There is a separate level of lateral bracing between the floor stringers that support the track system.

4. Assembled Systems

Construction Sequence

End towers were first constructed to provide permanent support for the truss system construction. The deck truss was then constructed by building temporary supports under three major panel points, which were left in place until the span was completed. This permitted the individual panels to be raised into place by crane and riveted together.

DECK TRUSS/288' SPAN
(Half Unit Illustrated)
Interurban Facilities Via Bridge

The Bridge Railway was completed in January of 1938. It consisted of the San Francisco Terminal and viaduct loop, connections with existing lines in Alameda County, and all tracks and appurtenances as required to connect the two. In addition, it also included storage tracks in the East Bay yard, the complete power distribution system, except substations; the signal system; telephone system; inspection buildings in the East Bay yard and all incidents to provide complete facilities for electric interurban service. The design of the railway facilities was based on ten-car trains operating at approximately sixty trains per hour on each track. Such a density of traffic had never before been attempted and was made possible by using a four-speed continuous cab-signal and train-control system. Railwork consisted of double tracks and a third rail system. Weight restrictions required an open-deck track construction on the bridge. The Yerba Buena Island crossing and the San Francisco loop (including viaduct and terminal) were of ballasted construction.

Cross Section @ Tunnel

Cross Section @ Through Truss

Ties for the bridge were of redwood, averaging 8 in. by 9 in., spaced on 12 in. centers. Long ties, at 3 ft. spacing, carried planking sidewalks between and at either side of the tracks. Since the bridge is an inherently flexible structure, design of expansion joints was complicated. Movement at the towers of the west crossing was the most extreme, and controlled the design. At these points, in addition to the usual longitudinal motion, there is vertical motion produced by the link connections of the suspended trusses to the towers, a change in the grade line arising from the vertical deflections of the spans, and a pivoting horizontal action arising from the deflection of the spans under lateral forces. This combination of motions required the joints to be universal in their action.
CHANGES 1958-1961

General
The cessation of the bridge relay in 1958 prompted a number of structural and traffic changes. The bridge railways were removed from the lower deck, which was converted to all westbound traffic including autos, trucks, and buses. The upper deck carried the same traffic westbound. At the same approximate time, the S.F. approach was converted to the new S.F. freeway.

East Bay Approach
The major reconstruction of the East Bay approach was associated with re-framing the alignment transition at the east end. At this location, where the East Bay Crossing is framed with girders in an extended sluice-like structure, the transverse framing was strengthened and reinforced to remove existing columns from the revised highway alignment.

San Francisco Approach
The remodeling of the San Francisco approach consisted mainly of reinforcing columns that supported the upper deck roadway from the viaduct. The columns would otherwise have obstructed traffic on the new east-bound lower deck. To facilitate removal of the center columns, the outer columns were reinforced with new steel/steel plates on the outside faces of the remaining columns at the edges of the roadway, and the floor beams and bent caps were reinforced with new concrete and post-tensioned to transfer the loads that were carried by the center columns to the remaining columns. Additional remodeling of the main-line structure consisted of adding a new lower hood west of the Terminal ramps. This new structure consisted of steel plate girders carrying a slab and stringer deck supported on reinforced concrete columns.

West Bay Crossing
The remodeling of the West Bay Crossing consisted mainly of reinforcing the upper deck to carry heavier truck loads, and of removing the rails and widening the slab on the lower deck. The upper deck was strengthened by adding cover plates to the transverse floor beams. The cover plates were pre-cut, packed to a prescribed load, and then fastened with bolts or rivets to the existing lower flange of the floor beams.

Yerba Buena Island Crossing
The remodeling consisted mostly of work associated with removing the columns that supported the middle of the upper deck and lowering the upper deck so that adequate headroom would be provided for trucks on the upper deck. Additional work was performed to bring both sides of the lower deck to a uniform grade for one-way traffic use. The column removal and upper deck lowering work required replacing the upper deck floor with a new floor at a lower elevation that spanned all the way across the tunnel without intermediate support. The new floor consisted of pre-tensioned concrete tress, that were installed one at a time beneath a short temporary bridge that allowed both decks to remain in service during the reconstruction.

BRAE"