HAER No. CA-297 CAL 48-VALL, 1-

CARQUINEZ BRIDGE
Interstate 80 Spanning Carquinez Strait
Vallejo
Solano County
California

PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

Historic American Engineering Record
National Park Service
Department of the Interior
San Francisco, California

HISTORIC AMERICAN ENGINEERING RECORD

Carquinez Bridge
HAER No. CA-297

Location: Crossing the Carquinez Strait between the City of Vallejo, Solano County, and the unincorporated village of Crockett, Contra Costa County, California

USGS 7.5 Minute Series – Benicia, Calif.
UTM Coordinates: 10.569020.4212660
548041.4212676

Date of Construction: 1923-27

Engineers: Charles Derleth, chief engineer
William Burr, consulting engineer
David Steinman, design engineer

Present Owner: State of California, Department of Transportation (Caltrans)

Present Use: Highway bridge

Significance: The Carquinez Bridge is a cantilever truss structure which carries three lanes of westbound Interstate-80 traffic across the Carquinez Strait. (Eastbound I-80 traffic is carried by a parallel structure, erected in 1958.) The 1927 bridge was the first major auto bridge in the San Francisco Bay Area, predating by a decade the Golden Gate and San Francisco-Oakland Bay Bridges. Replacing an auto ferry across the Carquinez Strait, the bridge was an important link in north-south traffic from the Bay Area to Northern California and the Pacific Northwest, as well as connecting the Bay Area to Sacramento and points east. The bridge's importance as a north-south link diminished somewhat with the opening of the Golden Gate Bridge in 1937, but it remains a critical highway link between the Bay Area and Sacramento, carrying an average of more than fifty thousand vehicles per day.

With two main spans of 1100' each, the Carquinez Bridge at the time of its completion was the fourth largest cantilever truss bridge in the world, and the second largest in the United States. (The Queensboro Bridge in New York City, constructed in 1909, was the largest cantilever truss bridge in the U.S., with spans of 984' and 1182'.)

Only five bridges of any type in the U.S. had spans exceeding 1100' in 1927 (the other four being suspension spans). The Carquinez Bridge was the largest bridge west of the Mississippi River, and the first major bridge designed to resist seismic forces.

One of the biggest challenges for the engineers was the construction of piers in the deep and swift waters of the Carquinez Strait. Two of the bridge's piers extend approximately 135' below mean high water to bedrock, through 80'-90' of water and 45'-55' of earth beneath the channel. These were the deepest water piers ever constructed at that time, a record later surpassed by the Golden Gate and San Francisco-Oakland Bay Bridges.

Author: Andrew Hope, Associate Environmental Planner (Architectural History), California Department of Transportation.

Project Information: The first Carquinez Bridge does not meet current seismic safety standards and would be difficult to retrofit without extended closures. It also has a substandard width for its three lanes of freeway traffic. Consequently, the California Department of Transportation is constructing a third bridge across the Carquinez Strait, parallel to and just west of the 1927 bridge. The new bridge will be a suspension structure, and will carry the westbound I-80 traffic currently carried by the 1927 bridge. When the new bridge is completed in 2003, the 1927 bridge will be demolished after seventy-six years of service.

This documentation is intended to comply with part of the mitigation requirements for the removal of the historic bridge, in accordance with Section 106 of the National Historic Preservation Act.

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1. DESCRIPTION

The Carquinez Bridge is a double cantilever, through-truss structure, 3350' in length.[1] In addition, the south approach viaduct (converted to a freeway exit ramp in 1958) is approximately 1130' long, giving the original structure a total length of approximately 4480'. The bridge spans the western end of the Carquinez Strait, about twenty miles northeast of San Francisco. The strait, which is about nine miles long and varies from about 2500' to 6000' in width, connects Suisun Bay to the east with San Pablo Bay to the west. California's vast Central Valley is drained by the Sacramento and San Joaquin Rivers, which meet in the delta area east of Suisun Bay. All of this water flows west through the Carquinez Strait, then south from San Pablo Bay to San Francisco Bay, and west again through the Golden Gate to the Pacific Ocean. The Carquinez Bridge is one of eight large toll bridges in the San Francisco Bay Area which link the various land areas separated by the extensive bay and river network.

The bridge extends from the vicinity of the city of Vallejo on the north shore of the strait to the unincorporated village of Crockett on the south shore. It carries three lanes of traffic in a single direction, as a component of the westbound Interstate-80 freeway. The west Carquinez Bridge, which is the subject of this documentation, was originally the sole crossing at this location, carrying traffic in both directions. In 1958 a second, parallel span was opened to the east of the original bridge. The newer bridge carries eastbound I-80 traffic.

The cantilever truss is a bridge type which consists of "anchor arms" spanning from the abutments to the main piers, "cantilever arms" forming part of the main span, and a "suspended span" which is hung from the ends of the two cantilever arms and bridges the gap between them. Each of the anchor arms balances the weight of the corresponding cantilever arm and half of the suspended span. The Carquinez Bridge has two main spans, with anchor arms at the north and south ends and four cantilever arms. The large center pier supports cantilever arms extending both north and south.

1.1 Substructure

The bridge piers are numbered consecutively from north to south. Pier 1 is the north abutment, located at the top of the steep slope on the north side of the strait. This abutment is a concrete structure 60' wide, 12'–9" in length (along the longitudinal axis of the bridge), and having a total height of 25'–6". It rests on a rock shelf excavated from the hillside. The bridge superstructure is anchored to this abutment at the ends of the two parallel trusses and at the longitudinal centerline of the bridge.

Piers 2 through 4 are located in the strait, with reinforced concrete foundations supporting steel towers, which in turn carry the truss superstructure. The pier 2 foundation consists of a pair of reinforced concrete caissons, each 40' square, placed 83' apart (center to center). The pier 3 foundation consists of two pairs of concrete caissons, of the same dimensions as those of pier 2, placed in the middle of the strait. The north and south pairs are placed 150' apart (center to center), with the shafts in each pair spaced 83' on center, as with pier 2. The six foundation structures for these two piers are each about 145' in height, extending from bedrock up through about 50' of sand and clay and 85' of water in the strait, with the top 10' exposed above mean high water. The top 35' of each shaft is circular rather than square in plan, with a diameter of 34'. The pier 4 foundation consists of concrete shafts which are similar to those of pier 2, except that they are much shorter, extending only 22' below mean high water. Rather than resting on bedrock as with piers 2 and 3, they are supported by a large concrete footing, 28' thick and covering an area 43' x 139', which is supported in turn by reinforced concrete piles driven to bedrock.

Pier 5 is on the south shore of the strait and supports the south anchor arm and the northernmost span of the approach roadways. The original foundation of this pier was a reinforced concrete structure, 23' x 84' in area and varying from 8' to nearly 17' thick, supported by timber piles. The pier 5 foundation was enlarged in 1958 when the tower legs were encased in concrete, providing additional support for the I-80 freeway connection which was built at that time.

At piers 2 through 4, steel towers extend from the tops of the concrete pier shafts up to the bottom chords of the superstructure. The towers at piers 2 and 4 have legs of riveted, solid steel plate, with horizontal bracing between the legs dividing each tower vertically into four sections. The wide north and south faces of the towers have chevron bracing in each section, while the narrow east and west faces have x-bracing. At their bases, where they are bolted to the concrete pedestals, the tower legs are 24' apart in the north-south direction and 83' apart in the east-west direction (centered on the pedestals). These tower legs converge at the bottom chord of the superstructure in the north-south direction, and narrow to 42' (the width of the superstructure) in the east-west direction.

At pier 3, the tower also narrows from 83' to 42' in width, but the tower legs remain parallel and 150' apart as viewed from the east or west. The north and south faces of tower 3 are similar to those of towers 2 and 4. However, tower 3 has a more complex bracing configuration on its 150' wide east and west faces. Each face is divided vertically into two sections by a single horizontal brace, with a major chevron brace in each section. There are also intermediate verticals and additional diagonal bracing, similar to the superstructure portion of this tower. Most of the bracing members of towers 2 through 4 consist of parallel, solid steel plates held together by small, diagonal lacing bars.

The tower at pier 5 was originally constructed with two steel legs, spaced 64' apart at the base and narrowing to 42' at the bottom chord of the superstructure. The tower legs are braced horizontally, with v-bracing within the rectangular panels bounded by the horizontal braces and vertical legs. (The v-bracing is similar to the chevron bracing of towers 2 through 4, except that the diagonals of the chevron bracing converge at the top rather than the bottom.) In addition to being bolted to the concrete foundation, the tower legs at pier 5 are anchored by steel eyebars partially embedded in the foundation. This is to prevent uplift of the tower and the superstructure above it, as the end of the anchor arm can have a negative load under some conditions. (When the total load on the cantilever arm is greater than on the anchor arm, pier 4 acts as a fulcrum and the end of the cantilever arm will tend to lift off its support.) Tower 5 was altered in 1958 when the new freeway approach was connected, with the tower legs given a thick concrete encasement.

1.2 Superstructure

The Carquinez Bridge superstructure is comprised of riveted steel members, carrying a roadway deck of reinforced concrete. It has two 500' anchor arms, two main spans of 1100' each, and a 150' length of roadway over the large center pier. The width of the structure, measured from the center lines of the parallel trusses, is 42'. The total height of the superstructure is 168' from the truss bottom chords to the tops of piers 2, 3, and 4. The truss bottom chords have a minimum clearance of 135' above mean high water, giving the bridge a total height of more than 300' from the water to the tops of the piers.

The bridge roadway slopes down from north to south on a grade of about 1 percent. To simplify construction, the truss vertical members were set perpendicular to the slightly sloping bottom chords, rather than being true verticals. Thus, the vertical members lean slightly to the south, so that the top of pier 2, for example, is about 1'-8" farther south than its connection to the truss bottom chord.

The two anchor arms have eighteen truss panels, each approximately 27'-9" in length, while the shorter cantilever arms have twelve truss panels of the same length. Major truss verticals, extending from the bottom chord to the top chord, occur only at every other panel point, with minor verticals (extending only from the bottom chord to the intersecting truss diagonal) at alternate panel points. The major verticals are box members with solid steel plate on their east and west sides and lacing bars on their north and south sides. The minor verticals are lighter in section, comprised of paired steel channels held together by rectangular steel plates riveted to the channels at regular intervals, somewhat resembling ladders. All of the diagonals in the anchor arms and some in the cantilever arms are box members, similar in construction to the major verticals. However, some of the diagonals in the cantilever arms consist of groups of four steel eyebars. The truss bottom chords are box members, 3'-4" deep, with solid steel plate on the sides and lacing bars at the top and bottom.

The truss top chords are comprised of eyebars in the cantilever arms and portions of the anchor arms. The top chord segments adjacent to piers 2 through 4 (from the pier to the first major truss diagonal) where the greatest tension stresses occur, consist of ten parallel eyebars in each segment. The number of eyebars is reduced to four in each segment over the remainder of the top chords of the cantilever arms, and six eyebars are used in each segment of the top chord across the 150' length of the center pier. Over most of the length of the truss anchor arms, the top chords are solid, boxed members. Steel eyebars are used less extensively in the anchor arms than in the cantilever arms because many of the anchor arm truss members must be able to resist both tension and compression forces as the bridge loading conditions change. Eyebars are used only for truss members that are always in tension.

The two suspended spans have trusses of the Pennsylvania-Petit type, a variation of the Pratt truss, with the top chords having a slightly convex curvature. Each truss has fourteen panels approximately 30'-11" in length, giving the suspended spans a total length of about 433'-2". As with the cantilever and anchor arms, major verticals occur only at every other panel point, with minor verticals extending only from the bottom chord to the intersecting diagonal. The suspended span trusses are 72' in depth at mid-span, sloping down to 60' at the "hip," where they meet the cantilever arms. The truss members are similar in construction to the cantilever and anchor arms. However, the stresses in the top and bottom chords of the suspended spans are the reverse of those in the cantilever arms. Consequently, the suspended span bottom chords are eyebars (with four parallel bars in each segment) while the top chords are solid, boxed members.

Bracing between the two parallel side trusses includes lateral braces between the top chords at each major vertical, with x-bracing in the rectangular area bounded by the side trusses and each adjacent pair of lateral braces. In addition, lateral braces and x-bracing are located in the vertical plane at the major truss verticals, as well as diagonally along some of the major truss diagonals. All of this bracing consists of relatively light steel channels connected by lacing bars.

At the bottom chords, the two parallel trusses are connected by floor beams (perpendicular to the trusses) at every panel point. These floor beams are 5' deep, and their bottoms are flush with the bottoms of the truss bottom chords. Six stringers (parallel to the trusses) span between each pair of floor beams, and support the concrete deck. Also below the deck are braces in the horizontal plane, within the rectangular areas bounded by the truss bottom chords and each adjacent pair of floor beams. In the anchor arms, these are chevron braces which point toward the shore, while the cantilever arms have chevron braces pointing toward mid-span. The suspension spans have x-bracing rather than chevrons. The concrete deck has low curbs on both sides of the roadway. The protective railing consists of a single metal tube, rectangular in section, along the inside faces of the two side trusses.

On the truss top chords, wire guardrails strung between steel posts allow access on foot along the top of the superstructure over the entire length of the bridge. In addition, there are ladders at various locations which allow maintenance crews to access the top of the superstructure from the roadway. Below the deck are rolling scaffolds which provide access to the underside of the superstructure for maintenance and painting.

1.3 South Approach Viaduct

The south approach viaduct (now a southbound I-80 exit ramp) connects the bridge to San Pablo Avenue in Crockett. From the south end of the bridge at pier 5, the viaduct roadway curves about 45 degrees to a southwesterly alignment where it meets San Pablo Avenue. The viaduct extends from pier 5 over a series of steel towers and bents (6 through 11) to abutment 12. It includes four deck truss spans (from pier 5 to bent 9) and three steel girder spans (from bent 9 to the abutment). The viaduct passes over the Union Pacific railroad tracks between pier 5 and tower 6, Dowrelio Drive between tower 8 and bent 9, and Wanda Street (with a very low clearance) between bent 11 and abutment 12.

Towers 6 through 8 are located in a low area, just a few feet above the water level, that was filled in the early twentieth century. These towers have concrete footings supported by timber piles. Each tower has four legs which consist of a box section with solid steel plate on two parallel faces and lacing bars on the other two faces. Horizontal braces divide the towers vertically into three sections, with v-bracing in most of the resulting rectangular panels. All of the bracing is similarly constructed of parallel, solid plates connected by lacing bars. Bent 9, tower 10, and bent 11 are located on the steep slope up to San Pablo Avenue, and diminish in height as they approach the abutment. They are similar in construction to towers 6 through 8, although their footings rest on rock close to the surface rather than being supported by timber piles.

The deck truss spans vary in length from approximately 146' to 193'. The parallel trusses, each 30' deep, are spaced 28' apart. The truss verticals, diagonals, and top chords are built-up members of solid steel plate and lacing bars, while the bottom chords consist of paired eyebars. The parallel trusses are connected by x-bracing in the vertical plane at each panel point, as well as lateral bracing at the bottom chords. The trusses support steel floor beams at each panel point. Steel stringers span between the floor beams and carry the concrete deck. The floor beams cantilever out beyond the trusses to carry the deck, which varies in width from 38' to 40'-6".

The amount of overhang varies at each truss panel point, since the trusses extend in straight lines between the towers, while the roadway follows a curved alignment.

The spans from bent 9 to abutment 12 consist of paired steel girders, spaced 28' apart. As with the deck truss spans, these girders support a system of floor beams and stringers which carry the concrete deck. The girder spans also have x-bracing in the horizontal plane between the floor beams, at the level of the floor beam bottom flanges.

The viaduct roadway has low concrete curbs, and retains its original steel railings. The railings have a round top rail, with closely spaced vertical pickets consisting of small metal bars. The viaduct terminates at abutment 12, a concrete mass 24'-6" high and 11'-6" thick at the base.

1.4 Alterations

The Carquinez Bridge served for nearly thirty years with only minor repairs and routine maintenance. The first extensive alterations were undertaken in 1956-58, in conjunction with the construction of the new I-80 freeway and a second span across the strait. The original bridge was converted to one-way traffic, southbound across the strait (designated westbound I-80), with the new bridge handling the northbound crossing (eastbound I-80). As part of this conversion, the 4' wide sidewalks on both sides of the bridge were replaced by 1'-10" wide concrete curbs, increasing the roadway width from 30' to the present 34'-4". The new freeway connection at the south end of the bridge relegated the original south approach viaduct to the role of freeway exit ramp. This viaduct was also modified at its south end, to accommodate a new exit ramp connection from eastbound I-80. Pier 5 was greatly enlarged and strengthened, as noted above, to receive the new freeway approach viaduct. In addition, the center pier protective fender was enlarged to include both the original and new bridges, and a new toll plaza was constructed on the north side of the strait.[2]

The next major modification was a project to strengthen the bridge superstructure, carried out in 1974. As originally built, the truss top chord members at the ends of the cantilever arms and some of the major diagonals in the suspended spans consisted of only two eyebars. Corrosion of the steel superstructure, attributed largely to airborne salt and pollution, led to the concern that if one of the eyebars in these members should fail, the entire load would be shifted to the single remaining eyebar. To improve the margin of safety, the number of eyebars in each of these members was increased from two to four.[3] Four years later, a similar project was carried out to strengthen the deck truss spans of the south approach viaduct. Additional eyebars were installed at the bottom chords of all four of these spans.

1.5 Comparison of the 1927 and 1958 bridges

The second Carquinez Bridge was constructed 200' upstream (east) of the original. Its overall form and dimensions are similar to the 1927 bridge, with the same span lengths, pier locations, and superstructure height, and a nearly identical truss configuration. The pier foundations for the second bridge were constructed in a manner similar to the original, but much larger caissons were used. A single caisson was used for pier 2, with two caissons of the same size used for pier 3. Each caisson is 53' x 102'-6" in area, and was constructed with 18 dredging wells. In contrast, the 1927 bridge used a total of six caissons for piers 2 and 3, each 40' square and having only four dredging wells.[4]

The most immediately apparent differences between the two bridge superstructures are that the suspended spans of the 1958 bridge have horizontal rather than convex top chords, and the newer bridge is substantially wider. The side trusses of the 1958 bridge are 60' apart (center to center), compared to only 42' for the 1927 bridge. There are other, more subtle differences in the truss configurations of the two bridges. For example, the center pier of the 1958 bridge has fewer vertical and diagonal members on its 150' long east and west faces, and the newer bridge also omits some of the transverse bracing in the vertical plane at the major truss verticals.

The suspended spans of the 1958 bridge were constructed by building out from the ends of the cantilever arms, rather than lifting a pre-assembled truss into place as was done with the 1927 bridge. There are other significant differences in the construction methods and materials of the two bridges. Rivets were not used on the 1958 bridge, with high-strength bolts and extensive use of welding employed instead. The truss members of the newer bridge are all box shapes, with perforated plates used instead of the small lacing bars of the older bridge. This gives the newer bridge a heavier, more solid appearance.

The 1958 bridge makes extensive use of steel alloys of much higher strength than were available in the 1920s, allowing for a substantial reduction of the overall dead load of the structure. The stronger alloys and extensive use of welded connections greatly simplified the construction of the 1958 bridge. For example, the truss bottom chords in the cantilever arms of the 1927 bridge are 40" deep and weigh 840 pounds per foot. A cross-section of these members would reveal fourteen separate components (eight vertical plates, four corner angles, and top and bottom cover plates) fastened together with rivets. In contrast, the same members of 1958 bridge are 36" deep, use only five steel plates, and weigh only 470 pounds per foot.[5]

2. HISTORICAL INFORMATION

2.1. Transportation context prior to construction of the bridge

Prior to the construction of the eight major highway bridges and two railroad bridges in the San Francisco Bay Area, the waters of the San Francisco, San Pablo, and Suisun Bays, as well as the Carquinez Strait and the Sacramento River delta, were formidable obstacles to land transportation. The major auto route from Oakland to Sacramento and points east avoided these water barriers by heading south from Oakland to Hayward, then east to Livermore and through the Altamont Pass to Stockton in California's Central Valley, and finally turning north to Sacramento. This was the route designated as the Lincoln Highway in 1913, the first auto route crossing the United States from New York to California. The Carquinez Bridge, when opened to traffic in 1927, reduced the driving distance between Oakland and Sacramento by thirty miles.[6]

In response to the barriers to travel presented by the bay and river system, an extensive network of ferries developed in the Bay Area. At the Carquinez Strait, ferries were transporting horses, wagons, and passengers on foot long before the advent of the automobile. The earliest of these date from the mid-nineteenth century, and ran between the cities of Benicia and Martinez, about six miles upstream from the site of the present Carquinez Bridge. There was also a train ferry from Benicia to Port Costa which operated from 1879 until the construction of the Southern Pacific railroad bridge between Benicia and Martinez in 1930.[7] The first auto ferry service across the strait was begun in 1913 by the Martinez-Benicia Ferry & Transportation Company.[8]

Ferry service at the west end of the strait, where the Carquinez Bridges are now located, began with the incorporation of the Rodeo-Vallejo Ferry Company in 1918. This ferry carried vehicles between Vallejo and the small town of Pinole, about three miles southwest of Crockett.[9] From Pinole, drivers could continue south by road to Richmond, Berkeley, and Oakland. The ferry company's first boat was the 144' long *Issaquah*, which was purchased in Seattle and began service crossing the Carquinez Strait on July 4, 1918.[10] In 1922 the Rodeo-Vallejo Ferry Company built the *Aven Hanford*, named for the company's president. This new boat was larger than the *Issaquah*, at 177' in length.[11]

The Six-Minute Ferry began operations a year after the Rodeo-Vallejo Ferry, running between Crockett and a terminal at Morrow Cove on the north shore, just west of the present bridge on land now owned by the California Maritime Academy. This was a much shorter and faster route across the strait than the competing Rodeo-Vallejo Ferry, and the company promoted this advantage in their name. The Six-Minute Ferry was operated by the Association of Mare Island Employees, which also operated the Vallejo-Mare Island Ferry. The company bought the fire-damaged *San Jose* from the Key System in Oakland, for use on the Crockett-Vallejo route, giving the ship a major rebuilding to accommodate autos.[12] The *San Jose* was comparable in size to the *Aven Hanford*, with a length of 176'.[13] Competition from the Six-Minute Ferry almost ruined the Rodeo-Vallejo Ferry Company, until a landslide in 1922 destroyed the Six-Minute Ferry's terminal at Morrow Cove.[14] Shortly thereafter, the Rodeo-Vallejo Ferry Company purchased its rival and began using the *San Jose* for the Carquinez Strait crossing, sending the *Aven Hanford* to work for the Golden Gate Ferry Company, which was also owned by the officers of the Rodeo-Vallejo Ferry Company.[15]

The need for a bridge spanning the Carquinez Strait became increasingly acute with the explosive growth of automobile travel in the early twentieth century. The population of California was 3½ million in the early 1920s, and motor vehicle registrations in the state were growing at a rapid pace. There were 930,000 registered motor vehicles in the state by January 1923, up from about 555,000 only three years earlier.[16] The Rodeo-Vallejo Ferry carried more than 1 million passengers per year in 1923 and 1924, in more than 400,000 vehicles.[17] The ferry had revenues of $428,000 in 1922, up from less than $40,000 only four years earlier.[18] This ferry was a critical link in north-south travel, as well as the major route linking the San Francisco Bay Area to Sacramento and all points farther east. The number of vehicles using a new bridge to cross the Strait was expected to be greater than the number using the ferry, since some motorists took the longer route from Oakland to Sacramento via Stockton to avoid the long lines of cars and trucks waiting to take the ferry.

The earliest published reference to the construction of a bridge across the Carquinez Strait appeared in the *San Francisco Call* on January 8, 1909.[19] This article reported that the Napa Chamber of Commerce had passed a resolution calling upon the state to construct such a crossing. The City of Napa, about twelve miles north of Vallejo, along with other North Bay cities such as Petaluma and Santa Rosa, stood to benefit from easier tourist travel from the much larger cities of San Francisco and Oakland, as well as easier access to these larger markets for the North Bay's agricultural products. An editorial in the *Call* on January 31, 1909, advocated the construction of a bridge that would accommodate both rail and automobile traffic, to be built and operated by the state.[20]

Although the state failed to take any action at that time, the proposal was revived in 1911 and supported by Boards of Trade and Chambers of Commerce across the state.[21] The proposal was again supported by the *Call*, which editorialized that a high-level bridge should be constructed, "wholly or in considerable part at the expense of the state and made available for use by the trunk railway systems as well as for general transit."[22] As in 1909, however, the state failed to follow through with a plan for construction of a bridge. The issue did not reappear in Bay Area newspapers until 1922, when plans for a privately built and operated toll bridge were being put forth by entrepreneurs. An editorial in the *San Francisco Examiner* in September of that year supported the construction of a bridge, but noted that "it is unfortunate that the initiative for this new project is private and not public. It is difficult not to be a little antagonistic to private capital financing a project so plainly a public affair." The editorial went on to suggest that "perhaps, when built, the counties benefited will find a way for taking it over and making it the public enterprise it should be."[23]

2.2. The American Toll Bridge Company and approval to build a bridge

The Carquinez Bridge, built by the American Toll Bridge Company, began as the vision of two men, Aven Hanford and Oscar Klatt. Hanford was the owner of several grocery stores in the Bay Area, who was frustrated by the difficulty in getting from his store in Vallejo in the North Bay to his Oakland and Alameda stores in the East Bay.[24] The route by auto in 1917 involved travel east to Benicia, where one could take the ferry to Martinez on the south shore of the strait, then continuing south by road to Oakland. This route included passage through a narrow tunnel in the Oakland hills which had been built for horse-drawn vehicles in 1903 and slightly enlarged in 1915, the precursor to the Caldecott Tunnel of 1937. Klatt was a traveling salesman for a grocery wholesaler who often had to travel between East Bay and North Bay communities, and therefore was also a frequent patron of the Benicia-Martinez Ferry.[25] The two men initially decided that a ferry across the Carquinez Strait from Vallejo could compete successfully with the Benicia-Martinez Ferry, and would allow drivers from the North Bay to take San Pablo Avenue to Berkeley and Oakland via Rodeo, Pinole, and Richmond, thus avoiding the longer and more difficult tunnel route through the Oakland hills. They formed the Rodeo-Vallejo Ferry Company, described above, in 1918. In the early 1920s, with the success and continued growth of the ferry business, the two men decided that a toll bridge would be economically viable and more convenient than the ferry. Planning for the bridge was begun by the Rodeo-Vallejo Ferry Company in 1922, and Charles Derleth was hired by the company that autumn to act as chief engineer for the project.[26]

After the company had secured approval to build a bridge in early 1923, the American Toll Bridge Company was incorporated to carry out the project, with Hanford as President (and major investor) and Klatt as Vice-President.[27] The original financing plan called for the issuance of stock in the American Toll Bridge Company. In early 1925, with construction well underway, this was changed to include the sale of revenue bonds in addition to stock.[28] The sale of both stocks and bonds was relatively easy in the mid-1920s, a time of investment frenzy. David Steinman's biographer noted that "it was child's play to sell stocks, bonds, and debentures for almost any kind of speculative enterprise. Investment bankers made fortunes only to lose them in the 1929 crash."[29]

In addition to the Carquinez Strait crossing, the American Toll Bridge Company also planned to build a second bridge about twenty-five miles farther east. This bridge would cross the San Joaquin River in the delta area, where the San Joaquin and Sacramento Rivers meet before flowing west into Suisun Bay and the Carquinez Strait. The Antioch Bridge, extending from the city of Antioch in Contra Costa County to Sherman Island in the delta, was constructed simultaneously with the Carquinez Bridge. It was a multi-span, through truss structure, with a short lift span near the south shore. This bridge, although by no means a small structure, was easier and cheaper to build than the much larger Carquinez Bridge, and did not pose the engineering challenges of crossing the Carquinez Strait. The road north from the Antioch Bridge through the delta provided an alternative route to Sacramento from the San Francisco Bay Area. Although the Antioch bridge carried only about one-seventh of the traffic carried by the Carquinez Bridge in the late 1920s, it was believed to have been built to pre-empt the construction of another bridge that would have competed with the Carquinez crossing and diminished the revenues of the American Toll Bridge Company.[30] Charles Derleth was not involved in the Antioch Bridge project, which was handled by a completely separate engineering staff from that responsible for the Carquinez Bridge.

Contra Costa County approval

State law dating to the nineteenth century stated that authority over the construction and operation of toll bridges over navigable rivers was vested with the county on the "left bank descending."[31] In the case of the Carquinez Bridge, this meant that approval was needed from Contra Costa County on the south side of the Carquinez Strait. The Rodeo-Vallejo Ferry Company therefore applied to the county for a franchise to construct and operate their planned bridge. Securing approval from Contra Costa County was not a simple matter, however, with the Rodeo-Vallejo Ferry Co. facing competition from two other applicants to bridge the Carquinez Strait and maritime interests voicing opposition to any bridge as a menace to navigation.

The Dillon Point Development Company proposed to construct a bridge from Dillon Point in Solano County, a little less than two miles east of the present bridge location, to a point about halfway between Crockett and the much smaller community of Port Costa on the Contra Costa County side of the strait. This is the narrowest point on the western portion of the Carquinez Strait, and therefore an advantageous location for a crossing. The Dillon Point Development Co. was headed by Alfred Kelly, a director of San Francisco's Hibernia Bank, and the other directors of the company were bankers as well.[32]

Although the Dillon Point Development Company did not take their proposal beyond a very preliminary stage, more serious competition for the bridge franchise came from a succession of companies headed by Dr. Otto Freyermuth of San Francisco. The first of these was the San

Francisco Transit Company, which was incorporated in June 1922 and quickly received approval from the War Department to build a bridge across the Carquinez Strait, contingent on the approval of Contra Costa County. Also choosing the Dillon Point location, Freyermuth's company proposed a suspension bridge with a 1500' main span and 750' side spans. The proposed bridge was designed by Charles Evan Fowler, designer of the Detroit-Windsor suspension bridge (later named the Ambassador Bridge) which was at that time under construction. David Steinman, who would later serve as design engineer to the American Toll Bridge Company, was a consultant to Fowler on the San Francisco Transit Company's proposal.[33]

Charles Derleth, writing in 1937, stated that Hanford and Klatt did not originate the idea of a bridge at the western end of the Carquinez Strait, but were provoked into action by the proposals of the Dillon Point Development Co. and the San Francisco Transit Co.[34] Any bridge at the Dillon Point location would quickly drive the Rodeo-Vallejo Ferry out of business. Hanford and Klatt therefore hastily came up with their own bridge proposal, at a location farther west, in order to protect their business. Derleth stated that the Dillon Point location, rather than a more westerly location, was chosen by the ferry's potential competitors because they were prohibited from applying for a franchise within two miles of the existing ferry route.

The two competing companies (the Rodeo-Vallejo Ferry Co. and the San Francisco Transit Co.) appeared before the Contra Costa County Board of Supervisors on November 6, 1922, to present their respective proposals and seek the county's approval. Subsequent meetings were held on December 11, 1922 and January 8, 1923.[35] At the January meeting, the county supervisors voted four to one to grant a franchise to the Rodeo-Vallejo Ferry Company.[36] The county decided in favor of the Rodeo-Vallejo Ferry Company in part because it appeared to be the stronger company financially. In addition, the more westerly location of this company's proposed bridge was seen as preferable to the Dillon Point location with respect to the construction of the necessary access roads.[37]

Freyermuth, however, was not easily dissuaded from his quest to build a bridge across the Carquinez Strait. Following the decision of the county supervisors, Freyermuth's Northern California Development Company (successor to the San Francisco Transit Company) proposed that a franchise for a second bridge (at the Dillon Point location) be granted. The American Toll Bridge Company, not surprisingly, objected to this proposal, citing harm to their stockholders. The County Board of Supervisors voted unanimously to reject the proposal for a second bridge on September 15, 1924.[38] Following the county's rejection of this proposal, Freyermuth went to court in early 1925 to compel the county to place the question on the ballot.[39] The California Supreme Court voted unanimously in April of that year to uphold the County's refusal to put a second franchise to a vote.[40]

Contra Costa County Ordinance 171, which granted the franchise to the Rodeo-Vallejo Ferry Company, went into effect on February 5, 1923.[41] The terms of the franchise included a stipulation that construction begin within four months, and be completed within three years. According to Charles Derleth, the relatively short time frame was included as a response to accusations by Freyermuth and his allies that the Rodeo-Vallejo Ferry Company was not serious about constructing a bridge, but was merely trying to prevent the San Francisco Transit Company from doing so.[42] The franchise was to be in effect for twenty-five years, with the bridge and attendant facilities reverting to Contra Costa and Solano Counties at the expiration of the franchise in 1948. The county was to receive $100 per month plus 2 percent of gross receipts from tolls over the life of the franchise. Toll rates were to be set by the California Railroad Commission, with the maximum toll set at 75 cents per car plus 15 cents per passenger in the absence of action by the Railroad Commission. (In fact, the Commission did not begin to regulate bridge tolls until the bridge had been in operation for ten years, as described in Section 2.6, below.)

War Department approval

In addition to a franchise from Contra Costa County, approval from the War Department was necessary to construct a bridge across the Carquinez Strait. The War Department's authority stemmed from the River and Harbor Act of 1899, which gave the Secretary of War jurisdiction over the construction of bridges, dams, causeways, and other structures in or over navigable waters of the United States.[43] The arguments and debates before the War Department between the two competing companies were as contentious as those before the county supervisors.

The War Department held the first of two public hearings to consider the Rodeo-Vallejo Ferry Company's bridge proposal on November 14, 1922. At this point, the company was proposing a suspension bridge, with a main span of about 1600'. The south tower of this bridge was located in the strait about 400' north of the Crockett piers.[44] Objections to this design were voiced by the California & Hawaiian (C&H) Sugar Company in Crockett, the Matson Navigation Company, and the Grangers Business Association, which exported wheat and barley from the warehouses in Port Costa. These businesses considered the location of the south tower to be a serious obstruction to navigation in the strait. The C&H Sugar Co. also expressed a preference for the Dillon Point location if a bridge were to be built, as this was east of their refinery in Crockett.[45] One of the responses to the criticism from shipping interests was to contend that the additional ferry traffic across the strait that would be needed to serve the anticipated increase in demand would be a greater navigation hazard than a stationary bridge pier.[46]

In addition to the objections raised at the hearing, Freyermuth wrote to Col. Herbert Deakyne of the War Department on November 17, arguing for the superiority of the Dillon Point location.[47]

Freyermuth also complained that the San Francisco Transit Co. had invested "many thousands of dollars" in surveys and plans for its proposed Dillon Point crossing, and suggested that the Rodeo-Vallejo Ferry Co. was unlikely to bring their bridge proposal to fruition.

Charles Derleth wrote a lengthy rebuttal to Freyermuth's letter, which was sent to Col. Deakyne on December 12.[48] Derleth gave several arguments for the superiority of the bridge location chosen by the Rodeo-Vallejo Ferry Co., among them the fact that the deeper water at the Dillon Point location (105' to 117' at mean low water, compared to about 83' for the more westerly site) would make the foundations more difficult and expensive to construct. Derleth also asserted that the high bluffs on the south side of the strait at the Dillon point location would require a steep and lengthy connector from the south end of the bridge up approximately 100' to the level of the Crockett-Port Costa road. By contrast, the bridge proposed by the Rodeo-Vallejo Ferry Co. would require only a short and nearly level approach structure to connect the bridge to San Pablo Avenue in Crockett.

The War Department declined to approve either of the two competing proposals until the Contra Costa County Board of Supervisors had concluded its deliberations on the issue.[49] A second War Department hearing was conducted on March 6, 1923, two weeks after a franchise had been granted to the Rodeo-Vallejo Ferry Co. by Contra Costa County. Two plans were presented at this meeting, a cantilever bridge with two main spans of 1100' each, and a suspension bridge with a main span of 1950'. Both designs had the southerly piers behind the northern edge of the Crockett piers, in response to objections raised at the hearing of November 1922.[50] On April 17, the War Department approved the Rodeo-Vallejo Ferry Company's proposal to build a bridge across the Carquinez Strait, conditioned on review and approval of more detailed plans.[51]

2.3. The engineers

To design a bridge on the scale of the Carquinez span requires the collaborative effort of many people. In addition to a team of civil engineers, such a task requires the involvement of experts in geology, foundations, fluid dynamics, metallurgy, electrical engineering, and other fields. Although the design of a bridge is often attributed to a single engineer, in practice no individual, no matter how talented, can do all of the work required for such an enormous task. For a major bridge project the Chief Engineer is the person with overall responsibility for the design and construction of the bridge. Much of this person's work is administrative, including the oversight of the engineering staff and contractors, as well as being responsible for contracts, schedules, and budget matters. Although the Chief Engineer is often not the primary designer, he/she has the ultimate authority over what gets built and thus usually gets the lion's share of the credit.

Charles Derleth

Charles Derleth was hired by the Rodeo-Vallejo Ferry Company in September 1922 to act as Chief Engineer for the Carquinez Bridge project, for which he was paid $100 per day plus expenses.[52] Derleth (1874-1956) was born in New York City and received degrees from the City College of New York in 1894 and Columbia University in 1896. He taught civil engineering at Columbia for several years beginning in 1896, and moved to Berkeley in 1903, where he taught at the University of California. Derleth was appointed Dean of the College of Civil Engineering at the University of California in 1907, a position he still held when hired by the Rodeo-Vallejo Ferry Company fifteen years later.[53] When the colleges of civil, mechanical, and electrical engineering were combined in 1930, Derleth became Dean of the new College of Engineering, and held this position until his retirement in the early 1940s.[54]

Derleth had made a study of the effects of the 1906 San Francisco earthquake on buildings and other structures, and published his findings in 1907 as "The Destructive Extent of the California Earthquake: its Effect Upon Structures and Structural Materials Within the Earthquake Belt." He served as consulting engineer for the City of San Francisco from 1911 to 1918, and in that capacity was involved in the design and construction of many of the city's large civic buildings and public works projects.[55] Following the completion of the Carquinez Bridge, Derleth was one of three consulting engineers hired by Joseph Strauss in 1929 to advise him on the design for the Golden Gate Bridge in San Francisco.[56] Derleth also served on the Board of Consulting Engineers for the San Francisco-Oakland Bay Bridge, and acted as consulting engineer on several other Bay Area projects, including the Posey Tube (an underwater auto tunnel connecting the cities of Oakland and Alameda).[57]

William Burr

One of Derleth's first acts as Chief Engineer for the Carquinez Bridge project, in January 1923, was to retain William H. Burr as Consulting Engineer.[58] The role of the consulting engineer is to provide an independent review of the work of the design team as a check against errors and oversights, to offer design recommendations, and to provide expertise on particular issues. Although the role is largely advisory, usually lacking direct authority over design or construction, the consulting engineer is typically a person of eminent stature within the engineering profession by virtue of long experience and recognized accomplishment.

William Hubert Burr (1851-1934) was more than 70 years old when he began serving as consulting engineer on the Carquinez Bridge project, with a long and distinguished career in civil engineering. He was born in Watertown, Connecticut, and received a degree in civil engineering from Rensselaer Polytechnic Institute in Troy, New York in 1872. He taught engineering for over thirty years, at Rensselaer (1875-84), Harvard (1892-93), and Columbia (1893-1916). Both

Charles Derleth and David Steinman had been Burr's students at Columbia. Engineering texts authored by Burr include: *Elasticity and Resistance of the Materials of Engineering* (1883), *The Design and Construction of Metallic Bridges* (1905), and *Suspension Bridges, Arch Ribs and Cantilevers* (1913).[59]

Burr worked for the Phoenix Bridge Company of Phoenixville, Pennsylvania from 1884 to 1891, eventually becoming general manager of the company and designing numerous bridges, including two large structures spanning the Ohio River and one spanning the Colorado. He was appointed by President Roosevelt to the board of consulting engineers for construction of the Panama Canal, and consulted on several large engineering projects in New York State, including the Catskill Aqueduct, the State Barge Canal, and the Holland Tunnel. Burr was also retained, after the 1907 collapse of the Quebec Bridge, to advise on design changes for the Queensboro Bridge, another cantilever truss structure then nearing completion.[60] Derleth knew that design and construction of pier foundations would be the most challenging part of the Carquinez Bridge project, and appointed Burr as consulting engineer in large measure because of Burr's expertise in the problems associated with construction in deep water.

David Steinman

David Steinman (1886-1960) was the third major figure in the design and construction of the Carquinez Bridge. Steinman offered his services to Derleth in December 1922, noting that he was no longer involved in Charles Fowler's competing proposal for a bridge across the Carquinez Strait, promoted by the San Francisco Transit Company.[61] Derleth responded that he would take up the matter of hiring Steinman with the Rodeo-Vallejo Ferry Co. after they had secured approval to build their bridge from Contra Costa County and the War Department.[62] Approval from the War Department came in April 1923, and Steinman was hired in May as design engineer.[63] Steinman was only in his mid-thirties at this time, but had been involved in several major bridge projects and was a rising star in the engineering profession. He quickly hired a staff of twenty to carry out the design work, which included drafting, calculating and recalculating stresses in the bridge components, investigating alternatives for each design decision, working out construction details, and preparing cost estimates.[64]

Steinman was born in New York City, and grew up just a short distance from the Brooklyn Bridge on the city's Lower East Side.[65] He claimed that fascination with this bridge was the source of his lifelong interest in bridge design and engineering.[66] Steinman entered the City College of New York in the fall of 1900, in a six-year program intended to include high school studies, and also took night courses in engineering at Cooper Union.[67] He later enrolled in the civil engineering program at Columbia University, his application having been endorsed by William Burr, who was then on the faculty.[68] A prodigy in mathematics and engineering, Steinman's thesis project of 1909 was "The Design of the Henry Hudson Memorial Bridge as a Steel Arch." (In the 1930s, the bridge was built by Steinman's firm, essentially as the young student had designed it more than twenty years earlier.)[69] Steinman spent an additional year at Columbia and received his Ph.D. in June 1910, with a dissertation titled "Suspension Bridges and Cantilevers; their Economic Proportions and Limiting Spans."[70]

After leaving Columbia, Steinman taught at the University of Idaho from 1910 to 1914, and in 1917 he founded the School of Engineering at the City College of New York, where among his other duties he taught the country's first courses in aeronautical engineering.[71] His textbook, *Suspension Bridges: Their Design, Construction, and Erection*, was published in 1923 and remained the standard text on the subject for many years thereafter.[72]

Between these two periods of teaching, from 1914 to 1917, Steinman worked in the New York office of Gustav Lindenthal, one of the country's leading bridge engineers. As Lindenthal's assistant, Steinman played a major role in the design of New York City's Hell Gate Bridge, and supervised its construction. With a span of 977', it was the longest steel arch bridge in the United States at the time. The other major bridge project that Steinman worked on while in Lindenthal's office was the Sciotoville Bridge over the Ohio River between Ohio and Kentucky, a railroad bridge which had two steel truss spans of 775' each.[73]

In the early 1920s, Steinman formed a partnership with Holton Robinson, who was more than twenty years Steinman's senior. The firm designed the Florianopolis Bridge in Brazil, which opened in 1926 as the Carquinez Bridge was nearing completion. The Florianopolis Bridge was an unusual suspension structure, with chains of steel eyebars rather than cables for the main suspension supports. At the center of the main span, the eyebar chain also formed the top chord of the stiffening truss, an economical use of materials and a significant innovation at the time. This bridge had a main span of over 1100', making it the longest bridge in South America.[74]

After completion of the Carquinez Bridge in 1927, Steinman went on to design several large suspension bridges at locations throughout the country. One of these, the Thousand Islands Bridge over the St. Lawrence River between New York and Ontario, exhibited excessive sway and vertical motion during high winds as it was nearing completion in 1938. Steinman faced this same problem in his contemporary Deer Island Bridge in Maine. The wind-induced motion in both bridges was dampened by the addition of cable stays extending from the towers at the level of the roadway, diagonally up to the main cables. Both of these bridges had relatively shallow girders at the roadway level rather than deep stiffening trusses, consistent with a trend among designers of suspension bridges toward a more sleek and minimalist profile.[75] This trend toward progressively shallower stiffening girders reached its apogee in the Tacoma Narrows Bridge, designed by Leon Moissieff and completed in 1940. Although slender and elegant, this bridge proved to be insufficiently rigid, and collapsed in a windstorm only a few months after its completion. Steinman's experience with the Thousand Islands and Deer Island bridges, as well as the shocking collapse of the Tacoma Narrows Bridge, led him to an intensive study of the effects of wind on suspension bridges. As a result of his investigations, Steinman became a leading authority on the subject, developing methods for predicting the frequency and amplitude of vibration in a structure for a given wind direction and velocity, and publishing a series of articles on the subject in the journal *Civil Engineering*.[76]

The culmination of Steinman's career was the Mackinac Bridge, connecting Michigan's upper and lower peninsulas. Completed in 1957, its 3800' main span was at that time second only to the 4200' span of the Golden Gate Bridge in San Francisco. The Mackinac Bridge has a stiffening truss 38' deep, and incorporates the results of Steinman's nearly twenty years of studies on the effects of wind on suspension bridges.[77]

2.4 Design of the bridge

Development of long-span bridges up to 1927

As early as 1849, engineers had designed and built a structure spanning more than 1000' between supports. The suspension bridge over the Ohio River at Wheeling, West Virginia, with a center span of 1010', was the world's longest span at that time.[78] Two American bridges of longer span, both also of the suspension type, were constructed later in the nineteenth century. The first of these also spanned the Ohio River, between Cincinnati and Covington, Kentucky. Completed in 1867, this bridge had a main span of 1057'.[79] The Brooklyn Bridge, opened in 1883, greatly surpassed these two earlier structures with a center span of 1595'.[80] Other long span suspension bridges constructed in the United States prior to the Carquinez Bridge include: the Williamsburg Bridge in New York City (1903; 1600'); the Bear Mountain Bridge over the Hudson River at Peekskill, New York (1924; 1632'); and the Benjamin Franklin Bridge crossing the Delaware River between Philadelphia and Camden, New Jersey (1926; 1750').[81]

The spans achieved by suspension bridges up to this time were within the feasible range for cantilever truss structures as well. Scotland's Firth of Forth Bridge, with spans of 1710', surpassed the Brooklyn Bridge and established a new world record in 1890.[82] This was in turn surpassed in 1917 by the Quebec Bridge over the St. Lawrence River, also a cantilever structure, with a main span of 1800'.[83] In the United States, the longest cantilever bridges were the Mississippi River Bridge at Memphis and the Queensboro Bridge in New York City. The former was completed in 1892 and had a 790' span and two 660' spans. The latter was opened in 1909, and had spans of 1182' and 984'.[84] (The Queensboro Bridge is an unusual example of the type in that it has no suspended spans. Instead, the cantilever arms meet at mid-span.) Prior to the

1930s, no other bridge types could compete with the cantilever and suspension designs in the length of their main spans. The Hell Gate Bridge of 1917 in New York City, with its roadway suspended from a steel arch, was the longest example of its type at 977'.[85] Thus, when the Carquinez Bridge was opened in 1927, with its two main spans of 1100' each, it had the second longest cantilever spans in the country and the fourth longest in the world. Among suspension bridges in the United States, only four had spans exceeding 1100'.

In the late 1920s and 1930s, however, several bridges were constructed which surpassed the Carquinez Bridge in span length, including two cantilever trusses and one steel arch design. The Longview Bridge in Washington State was a cantilever truss with a 1200' span, constructed in 1930.[86] In 1936 the cities of Oakland and San Francisco were joined by the Bay Bridge, which included a cantilever segment with a center span of 1400'.[87] The Bayonne Bridge in New Jersey, completed in 1931, was the only steel arch bridge with spans exceeding that of the Carquinez Bridge. It was the largest steel arch bridge constructed up to that time, with a 1675' span.[88]

While incremental increases were being made in the size of cantilever bridges, substantial increases in the length of suspension bridges were leaving all other bridge types out of the competition for the longest spans. The Ambassador Bridge connecting the United States and Canada at Detroit briefly held the record, with its 1850' span surpassing the Ben Franklin Bridge by 100'.[89] The George Washington Bridge in New York City, completed in 1931, dramatically surpassed this record with a span of 3500', nearly double that of the Ambassador Bridge.[90] San Francisco's Golden Gate Bridge of 1937 set a new record with a main span of 4200', which was not surpassed until the completion of the slightly longer (4260') Verrazano Narrows Bridge in 1964.[91]

At the time that the Carquinez Bridge was being designed, it was recognized as one of the largest highway bridge projects yet undertaken in the United States, and the largest west of the Mississippi. Also at this time, the cantilever truss type had fallen somewhat out of favor with bridge engineers, primarily because of problems in the construction of two earlier long-span cantilever truss bridges.[92] The collapse of the Quebec Bridge during construction in 1907 was caused by the buckling of truss compression members on the south cantilever arm, resulting in the death of eighty-two workers. In the aftermath of this disaster, bridge engineers conducted more experiments on larger bridge components, more attention was paid to the design and construction of truss joints, and more analysis was done on secondary stresses caused by deflection of the structure under its own weight. The Quebec Bridge was redesigned and construction resumed several years later, this time with the cantilever span lifted into place from barges using hydraulic jacks, rather than being extended out from the cantilever arms as in the original design. A second tragedy occurred in 1916 during the lifting operation, when the cantilever span, weighing 5200 tons, had been lifted about 12' before slipping off its supports and falling into the river. This time eleven men were killed. A new suspended span was constructed and successfully lifted into place in 1917, bringing to a conclusion a long and troubled process.[93]

The Queensboro Bridge was nearing completion at the time of the first Quebec disaster, and was hastily redesigned to reduce the dead load of the structure prior to being opened for traffic.[94] Although the Queensboro Bridge was completed without experiencing the spectacular failures of the Quebec Bridge, the redesign and cost overruns contributed to the sense that the cantilever truss was a bridge type fraught with difficulties. Following the completion of the Queensboro Bridge in 1909, no major cantilever truss bridges were constructed in the United States until the Carquinez Bridge went up in the mid-1920s.

Selection of a bridge type: cantilever truss vs. suspension

Both cantilever truss and suspension bridge designs were initially considered for the Carquinez Strait crossing. Five different preliminary studies were developed by Derleth between October 1922 and the granting of a franchise by Contra Costa County in February 1923. Three of these were for suspension bridges and two were cantilever designs.[95] At the November 1922 hearing before the War Department, the American Toll Bridge Company presented plans for a suspension bridge with a main span of 1600'.[96] As described above, there was substantial objection to this design from shipping interests, who considered the location of the south tower to be a hazard to Navigation. By February 1923, Derleth had narrowed the alternatives to two: a cantilever truss bridge with two main spans of 1100' each, and a suspension bridge with a main span of 1950'. Both designs had their south piers behind (south of) the northern edge of the Crockett piers, in response to concerns about navigation.[97] These two designs were presented to both the county Board of Supervisors and the War Department.

The franchise granted by Contra Costa County stated that the bridge was to be a suspension structure, unless a different type of bridge was specified by the War Department.[98] In its application to the War Department, the American Toll Bridge Company requested approval of both designs, so that the final decision could be based on more detailed cost estimates, to be prepared after further design studies. However, the application stated a preference for the cantilever truss bridge:

> We most strongly urge the cantilever type, Plan A; and if only one plan can be approved, we earnestly ask for consideration and approval of the cantilever scheme. It is the most economical; in our judgement it fits the location best; structurally it adapts itself most satisfactorily to traffic; it is stiffer than the suspension type, both for moving loads and laterally against wind forces.[99]

In April, Derleth sent additional information to the War Department, providing more detail on his reasons for preferring the cantilever to the suspension design. Among the several reasons given by Derleth were that the cantilever design would be simpler and faster to construct, allowing the company to open the bridge and begin earning revenue sooner. The expectation that the bridge would probably carry a trolley line at some time also made the greater stiffness of the cantilever design preferable to the more flexible suspension design. In addition, the wire cables required for a suspension bridge were of a particular grade of steel not widely available. Derleth noted that "the firm of John Roebling's Sons has a virtual monopoly on this wire. By contrast, there are many potential suppliers of steel for a cantilever bridge, resulting in price competition and lower cost."[100]

One reason that the cantilever bridge was considered simpler and less costly to construct was that a suspension bridge with a single main span would have only two major piers, compared to three for the cantilever design. Consequently, each of the suspension span piers would have to carry substantially more weight and would therefore need to be larger. Since construction of pier foundations in the strait was one of the most technically difficult and expensive issues facing the bridge's designers, preference was given to the cantilever design. Another difficulty with the suspension bridge design was the expense and difficulty of constructing the required cable anchorages at the north and south ends of the bridge.[101]

When David Steinman was hired as Design Engineer in May 1923, he wanted to reconsider the question of what type of bridge to build, in spite of Derleth's clear preference for the cantilever design. Steinman's specialty was suspension bridges, and he had only the previous year assisted Charles Fowler in developing the San Francisco Transit Company's proposal for a suspension bridge across the Carquinez Strait. This proposed bridge was to have a main span of 1500', which would have made it the third longest suspension span in the United States.[102] After being hired by the American Toll Bridge Company, Steinman expressed his preference for the suspension bridge alternative, with its 1950' main span, rather than the cantilever truss structure with its two shorter spans. An ambitious man with a keen interest in breaking records, Steinman was undoubtedly attracted to the suspension design in part because it would have been the longest bridge span in world at that time. According to Steinman's biographer, discussions between Derleth and Steinman on the issue of whether to build a cantilever or suspension bridge sometimes "turned into full-scale arguments."[103] In the end, however, it was Derleth who had the ultimate authority over all design decisions, and he overruled Steinman on this issue.

Design refinements and details

The cantilever truss design had been presented in preliminary form to both the Contra Costa County Board of Supervisors and the War Department, as part of the application for the franchise. An artist's rendering showing the proposed structure is dated May 1, 1923, and was published in the *San Francisco Examiner* on May 13.[104] The rendering shows that the proposed bridge was similar in its overall configuration to the structure as actually built. Since this was before Steinman had been hired as design engineer, it is clear that the overall form of the structure and length of its spans was originally conceived by Derleth, possibly in consultation with Burr. Steinman's task was to complete the working drawings for the structure, refining the original conception and working out all of the details.

The preliminary rendering shows a much heavier structure than the bridge as actually built, with more boldly scaled vertical and diagonal truss members, as well as heavier pier towers topped with decorative finials. It also shows fewer (but therefore longer) truss panels, with a correspondingly greater height for the superstructure. In the rendering, the top chords of the truss anchor arms and cantilever arms incline in strait lines to the tops of the pier towers, and the top chords of the suspended spans are parallel to the bottom chords.

The bridge as actually constructed, however, has a gentle concave curvature to the truss top chords in the anchor arms and cantilever arms, and the suspended spans have a convex, "camel back" curvature. The visual result is a more gently undulating structure, which appears lighter and more graceful than the early rendering. The total height of the superstructure on the completed bridge is only slightly greater than the distance from the water up to the truss bottom chords, whereas in the rendering the superstructure appears to be about twice as tall, dwarfing the supporting piers beneath the roadway. In addition, the truss members of the completed bridge are lighter than those depicted in the preliminary design, with the pier towers in particular being noticeably lighter and without the ornamental finials. It appears that Derleth was not entirely happy with this result, as he remarked in a letter to Burr on October 28, 1926: "had I more money at my command in the beginning and had I been guided solely by my sense of proportion, I should have made these towers 2 and 4 heavier. ... I wanted greater longitudinal stiffness. 1 must rely on it chiefly from pier 3."[105]

The final design for the bridge and the contract drawings were developed by Steinman and his staff at his New York office, in consultation with Derleth and Burr, from May through December 1923. Three different cantilever truss designs were initially developed and studied, differing in their width, height, proportions, and truss configurations.[106] The most economical design was determined from these studies, meeting the required engineering criteria for strength and stiffness with the least material.

The initial bridge designs had a width of 35' between the centerlines of the trusses. However, increasing the width to 42' provided additional stiffness in the superstructure and allowed for the inclusion of two sidewalks in addition to the 30' roadway. The additional cost to make the bridge 7' wider was calculated to be $137,000, which was considered a prudent expense to achieve the additional structural stiffness and provide for sidewalks. By comparison, the cost of adding a single sidewalk on brackets attached to the outside of one of the trusses was calculated to be $172,000.[107]

In designing the suspended spans, the most economical length was determined to be 500', taking into consideration only the cost of the structural steel required. However, when construction methods were taken into consideration, the spans were shortened to 433'. Since it was anticipated that these spans would be lifted into place from barges in the strait, the shorter spans would be easier and less expensive to lift. It was also determined that the curved top chords of these trusses, which allow for a lighter structure without loss of strength, would result in a savings of about $80,000 compared to trusses with straight, horizontal top chords.[108]

The possibility of future electric rail traffic on the bridge was anticipated from the earliest planning stages. The bridge was designed to accommodate the load on the structure from a single rail line down the center lane. Longitudinal joints were included in the deck slab to facilitate removal of the slab from the center lane and its replacement with rail tracks.[109] Rail facilities were never installed, however, since interurban rail service was never extended to Crockett and the era of trolley transportation was being rapidly eclipsed by private auto ownership during the period that the bridge was under construction.

The Carquinez Bridge was the first major bridge in the United States designed with seismic forces taken into consideration.[110] The bridge expansion joints were carefully designed to limit excessive movement, and hydraulic buffers were installed to resist earthquake forces. Six of these hydraulic buffers, each 5'-2" long, were located at critical expansion joints in the bridge superstructure. The bottom chords of each of the two side trusses had buffers at three locations: the shore-side connections of the suspended spans to the cantilever arms, and at tower 5 (where the bridge meets the south approach viaduct). These buffers were designed to allow slow movement due to thermal expansion, but resist the rapid movement induced by an earthquake.[111]

2.5 Construction of the bridge

Construction of the Carquinez Bridge began in April 1923, following approval of the plans by the state engineer of California in February of that year.[112] For the next four years, it was one of the major construction projects in the San Francisco Bay Area, predating by a decade the construction of the Golden Gate and San Francisco-Oakland Bay bridges and other major public works projects of the 1930s. Erection of the bridge required a substantial amount of preliminary construction, including a dock on the Crockett side of the strait which served as a loading and staging area as well as a construction platform. In addition, a large portion of the flat shoreline area at the south end of the bridge, with direct access for deliveries by the adjacent Southern Pacific Railroad, was set aside for the storage of equipment and materials.

Substructure

Construction of pier 1, the north abutment, required a large amount of preliminary excavation. The steep face of the north shore, a virtual cliff, was lowered 30' by blasting and hauling away 20,000 cubic yards of earth, which was used in the construction of connecting roads.[113] Blasting was also used to create a horizontal shelf of exposed rock to serve as a base for the concrete abutment. After the ground was shaped as needed, building the abutment was a straightforward exercise in reinforced concrete construction, which began at the end of August 1923.[114]

It was construction of piers 2 and 3 in the deep and swift waters of the Carquinez Strait which posed the biggest challenge to the engineers and contractors. The current in the strait is sometimes as high as 7' per second, but varies throughout the depth of the channel, complicating the task of accurately placing the caissons for these piers.[115] In addition, the strait is at times heavily infested with teredos, a type of shipworm which is a voracious consumer of wood. Piers 2 and 3 are founded on concrete caissons which extend down to bedrock, about 135' below the mean high water level in the Carquinez Strait. These were the deepest water piers ever constructed for a bridge up to that time, a record which was later surpassed by the Golden Gate and Bay Bridges.[116]

In order to keep the caissons upright and properly positioned in the strait, steel guide frames were constructed at the locations of piers 2 and 3.[117] Each guide frame was constructed by driving steel columns, each 120' long and weighing thirty tons, into the mud at the bottom of the channel. The columns extended up through the 80' to 90' of water in the strait, with the tops of the columns exposed above the water. The columns were then fastened together with a framework of steel, and reinforced with horizontal and vertical wood trusses. The completed frame was secured in place by four anchor barges, connected by cables to the corners of the guide frame and pulling the frame simultaneously in four directions. There were six columns for each guide frame, two on the east and west sides and one on the north and south sides. The west, north, and east sides of the frame were constructed first, and then the caisson was floated into place through the open south side. The south column was then driven and the guide frame completed. The frame had interior dimensions of 46' x 46', allowing 3" of clearance on all sides around the 40' x 40' caisson. A total of six guide frames were needed for the two caissons at pier 2 and four caissons at pier 3. In order to conserve materials, only two guide frames were built, and each was dismantled and reconstructed three times.

The caissons consisted of reinforced timber cribs with four dredging wells, each 8' square, from which mud and clay could be excavated as the caisson sank into the bed of the strait. The timber crib was a hollow framework which surrounded and separated the four dredging wells. Extensive precautions were taken to protect the timber caissons against the teredo. During construction, each caisson was coated with a wood preservative (a mixture of asphalt and creosote) followed by a layer of tarred felt and another coat of preservative. The structure was then covered with an outer layer of wood planking, and a coat of preservative on this outer layer. It was anticipated that this treatment would allow the wood caisson to last for at least a year, which would provide plenty of time to finish pouring the concrete.

Concrete was poured into the caisson in stages as it sank from the bottom of the strait through 45' to 55' of material at channel bottom, until it reached bedrock. After the caisson had cut through the channel bottom and reached bedrock, the dredging wells were also filled with concrete. A concrete mixing plant was set up on a barge so that it could be floated out to the pier locations, to avoid the costly process of transporting large quantities of concrete from the shore.

The bottom of the caisson tapered to a narrow cutting edge to facilitate its sinking through the mud and clay at the bottom of the channel. The cutting edge of the first two cribs was relatively blunt, with a horizontal face about 10" wide. Subsequent caissons were built with a much narrower cutting edge, just the thickness of two steel plates riveted together. The narrower cutting edge reduced the time required to sink the caisson to bedrock, but the more blunt-edged caissons proved to be more stable and were easier to keep in a vertical position during sinking.

To aid in the sinking of the caissons, a water jet system consisting of a network of 2½" and 4" diameter pipes was installed inside the timber crib structure. These pipes fed nozzles along the outside of the crib. Water pumped through the jets at the bottom of the caisson made the bed material more slippery and easier for the caisson to cut through, while the jets along the side walls reduced the surface friction between the caisson and the bed material. The water jet system reduced the time required for sinking of the caissons, but proved to have been significantly overdesigned, providing much more water than was necessary to aid in sinking the caissons. The water jet system was designed by H. F. Topping, while the timber caissons were designed by George C. Haun.

Sinking the caissons was a slow and methodical process. The work of the water jets, combined with excavation from the dredging wells and the increasing weight of the caisson as more concrete was added, resulted in the caissons sinking at an average rate of just 6" per eight-hour work shift. The only problem occurred during the sinking of the first caisson. On September 22, 1925, when it had reached 122' below water level (through 30' to 40' of the channel bottom), the caisson suddenly tilted 13' to the south. The guide frame also deflected from the weight of the caisson leaning against it. The caisson was righted by pulling cables attached to the top of the north wall, while simultaneously using the water jets on the north side only and excavating material from the two north dredging wells. Three days of work were required before the caisson began to tilt back to the north, and it was not completely restored to a vertical position until October 4. After this frustrating experience, no further problems were encountered in the construction of piers 2 and 3.

Pier 4, located in relatively shallow water near the south shore of the strait, does not have a caisson foundation. This pier consists of reinforced concrete piles supporting a concrete footing, which in turn supports two pier shafts which are similar in appearance to those of piers 2 and 3. Pier 4 was constructed by installing a cofferdam around the pier location and dewatering inside the cofferdam to provide a dry work area to construct the footing. What was expected to be a simpler process turned out to be much more frustrating, however, due to the lack of a watertight seal at the bottom of the wood cofferdam. The cofferdam was attacked by teredos and became porous, and there was also leakage at the bottom of the cofferdam caused by erosion of the soft bottom of the strait by the swift current. As a result, construction of the concrete tremie seal at the bottom of the cofferdam was hampered by concrete washing out of the porous structure, and the initial construction was unacceptably weak as a result.[118] Much of the concrete in the pier 4 footing ultimately had to be removed and replaced, an embarrassing and costly problem that led to the replacement of the original foundation contractor, Duncanson and Harrelson of San Francisco. This firm worked on the bridge project from summer 1923 until February 1925. They had completed the foundations for piers 1 (the north abutment) and 5, and portions of piers 3 and 6, in addition to the rejected work on pier 4. Duncanson and Harrelson also built the construction wharf on the Crockett side of the strait. In April 1925, the foundation work was taken over and completed by the Missouri Valley Bridge and Iron Company of Leavenworth, Kansas.[119]

Superstructure

The contract to erect the bridge's steel superstructure was awarded to the American Bridge Company, a subsidiary of the United States Steel Corporation.[120] Bridge components were assembled at a dock on the south side of the Strait in Crockett, and lifted into place from barges. The north anchor arm, extending from the north abutment to pier 2, posed a construction challenge because the depth of water in the strait precluded the use of falsework (temporary supports) except in the area closest to the abutment, above the steeply sloping hillside. Falsework was erected on the hillside to support the truss superstructure only between the north abutment and panel point 8 (not quite halfway to pier 2). Beyond this point, the superstructure was cantilevered out over the water in stages until it reached pier 2. The completed anchor arm then served as support for the cantilever arm, which was extended south in stages from pier 2. On the south side of the bridge, the shallow water allowed for the simpler method of using falsework for the construction of both the anchor arm (between piers 4 and 5) and the cantilever arm extending north from pier 4.[121] The double cantilever arm in the center of the bridge, extending north and south from pier 3, was constructed in a manner similar to the north cantilever arm. To maintain an even distribution of weight on the pier supports, the two cantilever arms were built simultaneously from the 150' long superstructure atop the pier. With the completion of the cantilever arms, the bridge consisted of three separate structures, each centered on one of the major piers, awaiting the installation of the two suspended spans to link these separate components into a single bridge.

The most dramatic aspect of the Carquinez Bridge construction project was the lifting of the two suspended spans. Each of the suspended spans was 433' long and weighed 620 tons, and had to be lifted more than 135' up to the level of the bridge cantilever arms. A great deal of planning and calculation was required to ensure the success of this critical operation, with the Quebec Bridge disaster of 1916 fresh in the minds of the engineers and contractors.[122]

The suspended spans were constructed on falsework over shallow water on the Crockett side of the strait. When ready for lifting, the suspended spans were transferred to barges by floating the barges under the structure at low tide. The barges, constructed specifically for this job, were equipped with jacks which lifted the truss off the falsework. The suspended span truss structure, supported at each end by one of the barges, was then pulled by four tugboats into the middle of the strait and into position below the bridge cantilever arms. In order to reduce the weight of the structure to be lifted, the suspended spans were initially constructed with only the two side trusses, transverse bracing connecting the truss top chords, and floor beams connecting the truss bottom chords. (The floor stringers and decking were added after the suspended spans had been lifted into place.) With the barges anchored in place, the suspended spans were ready for lifting.

The suspended spans were hoisted into place using cables in a block-and-tackle system, with sand-filled boxes as counterweights. With cables temporarily connected to the ends of the cantilever arms, the counterweights were lifted from barges using an electric hoist. Four counterweights were used to lift the suspended span, each consisting of a wooden box approximately 14' square and 19' deep and weighing more than 150 tons when filled with sand. The combined weight of the four boxes was slightly more than the weight of the suspended span, in order to overcome friction and inertia and allow for the smooth lifting of the truss structure.

With the counterweights in place, their weight was transferred to cables which were connected to the corners of the suspended span truss. With the cables running through pulleys attached to the ends of the cantilever arms, the counterweights could then be slowly lowered to waiting barges, lifting the suspended span up to the level of the bridge superstructure. Some of the complexities of the lifting operation included taking into account an expected 6½" deflection in the cantilever arms under the combined weight of the suspended span and counterweights, a calculated 18" elongation of the wire cables, and the fact that the barges would rise 21" in the water as the weight of the suspended span was lifted from them.

The north suspended span, between piers 2 and 3, was lifted first, on March 3, 1927. No problems were encountered in the lifting, and the process took less than an hour. The south suspended span was lifted two weeks later, on March 19, and took only about thirty minutes. The openings for the suspended spans were two panel lengths longer than the suspended span trusses themselves. After the suspended span was lifted into position, it was connected by steel eyebars extending vertically from the top chord of the cantilever arm to the bottom chord of the suspended span. The remaining gap at each end of the suspended span was then bridged across the top and bottom chords to form a continuous structure.

After completion of the truss superstructure (including the addition of floor beams, stringers, and diagonal bracing) a rail track was laid down the center of the bridge to expedite the delivery of materials to be used in constructing the roadway deck. The concrete deck slab was poured in sections on either side of the track, using a rail-mounted concrete hopper. After completion of the two outside lanes, the track was removed in sections and the deck slab installed in the middle lane.[123]

Center pier protective fender

During construction of the Carquinez Bridge, shipping interests and the C&H Sugar Company resumed their complaints about bridge piers in the strait posing a hazard to navigation. They appealed to the War Department, requesting that it order the American Toll Bridge Company to install protective fenders around the bridge piers, particularly at pier 3, the large center pier in the middle of the strait. As described by Charles Derleth, discussions over this issue were acrimonious, and the navigation interests were consistently critical of the American Toll Bridge Company's proposed solutions.[124] In November 1926, the War Department advised the Toll Bridge Company that it would be necessary to install some kind of pier protection.[125] While plans for protective fenders were being drawn up and debated, the Toll Bridge Company anchored eight barges around pier 3, four upstream and four downstream. The barges were connected by cables, forming a sort of net for restraining errant ships.[126] The company's opponents thought this inadequate, even as a temporary measure, and sought an injunction in federal court in early 1927 to prevent the opening of the bridge to traffic.[127] Although the request for an injunction was denied, the Toll Bridge Company removed the barges in May 1927, replacing them with four old wooden sailing vessels. The four ships were loaded with rock ballast and equipped with lights and fog signals.[128]

The War Department held hearings in Washington in summer and fall 1927 concerning the construction of permanent fenders.[129] By this time, David Steinman's tenure as design engineer had come to an end, and the Toll Bridge Company hired the engineers Frank G. White and Harry E. Squire of San Francisco, working under Derleth's direction, to come up with a permanent solution.[130] The engineers developed several different proposals for the fender at pier 3, "all of which were severely criticized by Navigation interests," according to Derleth.[131] In September, the War Department granted a permit for the design that was eventually built, conditioned on the review and approval of detailed plans.[132] This final review occurred in late January 1928, putting an end to the controversy.[133]

The fender as built was shaped like a pointed ellipse, designed to deflect an oncoming ship and result in a glancing rather than direct impact. The design included radial and circumferential girders of reinforced concrete, as well as a reinforced concrete deck slab. The deck slab was intended to cut into any colliding ship, helping to bring it to a halt before it can collide with the bridge piers. The concrete fender was constructed around and connected to the concrete portion of the bridge piers, making the whole structure a single unit. It was 350' long in the east-west direction and 250' from north to south.[134] (The fender has since been enlarged to incorporate the center pier of the parallel bridge, constructed in 1958.) Construction of the fender included placing 200,000 tons of rock fill around the bridge piers at the channel bottom, and driving 454 reinforced concrete piles to support the lemon-shaped fender.[135] Work was begun by the Healy-Tibbits Construction Company in July 1928, and was completed in December 1930.[136]

Cost

Various figures have been given for the cost of constructing the Carquinez Bridge. A 1929 report by the California Highway Commission listed the amounts of the various construction contracts, totaling $5,136,728.[137] Of this amount, about 45 percent was for foundation work, with about 55 percent going toward the steel superstructure and concrete roadway deck. Engineering and inspection costs totaled $365,644, equal to about 7 percent of the construction contracts.[138] Additional costs included acquisition of right-of-way in Crockett, business expenses such as bond financing, and the cost of the center pier protective fender (which was not completed until 1930). The center pier fender was built at a cost of over $600,000 (plus the cost of installing and removing the two versions of temporary pier protection) which was a significant portion of the entire bridge construction cost and well in excess of the American Toll Bridge Company's initial expectations.[139] In addition, the American Toll Bridge Company contributed $42,500 to Solano County's cost of improving the road at the north end of the bridge, and $8,500 to the state's cost of improving Highway 14 (San Pablo Avenue) in Contra Costa County to handle the anticipated increase in traffic.[140]

The *San Francisco Examiner* stated at the time of the bridge's opening that it cost $8 million to build, a figure which must have included engineering fees and business expenses, but would not have included the center pier fender.[141] Charles Derleth stated in 1937 that the bridge cost $7,863,451 to build, a figure which undoubtedly included engineering fees and all construction costs, but may or may not have included the American Toll Bridge Company's business expenses.[142]

2.6 Operation of the bridge

American Toll Bridge Company, 1927-40

The Carquinez Bridge was opened for traffic on May 13, 1927, a week before the official opening ceremony which had been scheduled for May 21.[143] Aven Hanford, who along with Oscar Klatt was the person most responsible for bringing the Carquinez Bridge from vision to reality, did not live to see the completion of the structure. Hanford died at his home in Berkeley on the morning of October 26, 1926.[144] Following Hanford's death, Klatt assumed the presidency of the American Toll Bridge Company, while George Calder was made vice-president and general manager. Calder was at that time the company's resident engineer on the Carquinez Bridge job, with primary responsibility for management of the construction process and oversight of the contractors.[145]

The grand opening festivities included sailboat and motorboat races, rowing competitions, and an aerial show performed by a squad of airplanes. The dedication, by the widow of Aven Hanford, began at 1:30 pm, followed by speeches by the governors of California, Nevada, Oregon, and Washington.[146] The presence of dignitaries from other states was an indication of the regional importance of the new bridge, particularly as an important link in the automobile and truck route along the coast from California to the Pacific Northwest, as this was a decade before the construction of the Golden Gate Bridge in 1937. In fact, the cover of the opening day program shows a bear (the symbol of California) standing in front of the flags of Canada, the United States, and Mexico, with the slogan "uniting three flags."[147] Charles Derleth called the new bridge "the most spectacular structure yet built west of the Mississippi River" and noted that there were only three other cantilever bridges in the world of comparable size.[148] At 2:30 pm, after an hour of speeches, President Calvin Coolidge turned a key in Washington that set off fireworks at the center pier and unfurled an American flag.[149] An estimated 47,000 vehicles lined up to drive across the new bridge that day.[150] In spite of the significance of the occasion, the grand opening was bumped off the front pages of the newspapers by Charles Lindbergh, who completed his Trans-Atlantic flight on the same day.

The opening of the Carquinez Bridge (replacing the former ferry service) closed a gap in two important West Coast auto routes: the north-south route of the Pacific Coast Highway, extending from Mexico to Canada, and the east-west route from the Bay Area to Sacramento and all points east. The designated route of the Lincoln Highway, established in 1913 as the first coast-to-coast auto road, was shifted from its original route between Oakland and Sacramento via Stockton, taking advantage of the shorter route across the Carquinez Bridge.[151]

With the cessation of ferry service between Rodeo and Vallejo, the company's two boats were sold to other ferry lines operating on San Francisco Bay waters. The *San Jose* was sold to the Richmond-San Rafael Ferry Company, which carried out an extensive refurbishing and rechristened it the *Sonoma Valley.*[152] The *Issaquah* was acquired by the Martinez-Benicia Ferry Company, which continued in operation until 1940. The City of Martinez took over the company's property and operated the ferry until 1956, when it was taken over in turn by the State of California. With the opening of the Benicia-Martinez Bridge in 1962, the state ceased operation of the ferry between these two cities, which marked the end of auto ferry service in the San Francisco Bay Area.[153]

Auto travel across the Carquinez Bridge immediately exceeded expectations. More than 13,000 vehicles made the crossing on Memorial Day 1927, with no significant delays. This was about twice the 24-hour capacity of the former Rodeo-Vallejo ferry.[154] The first nine days of toll collection brought in more than $50,000, equal to about one-twelfth of the annual revenue that had been projected for the purpose of financing the revenue bonds.[155] The bridge's first full fiscal year of operation, from July 1, 1927, through June 30, 1928, saw 1.1 million vehicles make the toll crossing. The American Toll Bridge Company received more than $900,000 in toll revenue during this period, more than 50 percent above the projected revenue and approximately three times the company's expenses.[156] As of July 1928, with the bridge in operation for a little more than one year, the Carquinez Bridge was getting an estimated 80 percent of the traffic across the Strait, while the Antioch Bridge was getting 11 percent and the Benicia-Martinez Ferry (the last remaining ferry service across the Strait) was getting just 9 percent.[157]

Traffic on the Carquinez Bridge continued to increase to 1930, then declined by about 25 percent from 1930 to 1933 due to the depression.[158] Use of the bridge rebounded after 1933, however, increasing annually to total of more than 2 million vehicles in 1939. The opening of the Golden Gate Bridge in 1937 did not result in a drop in traffic on the Carquinez Bridge, but only briefly slowed the trend of significant annual increases. The number of vehicles using the bridge increased by only 2.4 percent from 1937 to 1938, compared to an increase of about 17 percent between 1936 and 1937 and more than 13 percent between 1938 and 1939. Even this brief slowdown from 1937 to 1938 may be more attributable to economic factors than to competition from the Golden Gate Bridge.

The initial toll rate established for the Carquinez Bridge, 60 cents per car plus 10 cents per person, was based on the rate previously charged by the ferry service.[159] (The practice of charging for both the vehicle and passengers was consistent with the way ferry tolls were traditionally calculated.) At $1 each way for a party of four, the toll was a subject of much complaint among motorists. Criticism of the "excessive" toll and calls for public ownership of the Carquinez Bridge began to appear in Bay Area newspapers in 1937, after the bridge had been in operation for ten years. These complaints were probably stimulated by the opening of the Golden Gate and San Francisco-Oakland Bay Bridges, both of which were publicly owned and had lower tolls than the smaller Carquinez Bridge. The *San Francisco Chronicle* editorialized in March 1937 that the state of California should acquire the bridge and pay for its maintenance from the state's gasoline tax, arguing that the bridge toll on a state highway and the gasoline tax amounted to double taxation.[160] In September of that year, a *Chronicle* article referred to "a storm of protest against the prevailing toll rates on the bridge."[161] Lt. Governor George Hatfield publicly suggested a month later that the California Toll Bridge Authority build a second, parallel span if the existing bridge could not be purchased by the state at a reasonable price.[162]

The State of California passed legislation in 1937 which declared toll bridges to be public utilities, subject to the authority of the State Railroad Commission. The Commission scheduled a hearing in October of that year to take testimony related to tolls on all four of the state's private toll bridges – the Dumbarton, San Mateo, Carquinez, and Antioch, all of which were in the San Francisco Bay Area.[163] After studying the finances of the Carquinez Bridge, the Commission ordered a reduction in tolls in February 1938 from 60 cents per vehicle plus 10 cents per passenger (including the driver) to 45 cents per vehicle and 5 cents per passenger.[164] The American Toll Bridge Company challenged the Commission's authority to regulate tolls on its bridges, but the California Supreme Court ruled in favor of the Commission on September 27, 1938.[165] This decision was upheld by the U.S. Supreme Court on June 5, 1939.[166]

Following the Supreme Court decision, the American Toll Bridge Company was required to refund $387,000 in excess tolls collected over the fifteen months since the initial decision of the Railroad Commission. Twenty additional clerks were hired temporarily to process and mail 600,000 refund checks, averaging 65 cents each, to motorists who had paid the higher tolls. The last of the refund checks were mailed after five months of effort, in late October 1939.[167] This was not the end of complaints about the Carquinez Bridge tolls, however. Only a week after the American Toll Bridge Company had finished mailing out refund checks, Frank Clark, Director of the State Department of Public Works, declared that his department would begin assembling data to support a substantial reduction in bridge tolls.[168] However, rather than relying on the regulatory power of the State Railroad Commission to further reduce tolls on the Carquinez Bridge, the state purchased the bridge from the American Toll Bridge Company in 1940.

Acquisition and operation by the State of California, 1940-1958

Although the state did not acquire the Carquinez Bridge until 1940, the California Highway Commission investigated the economics of public vs. private ownership of toll bridges in 1929, at the request of the state legislature. Privately owned toll bridges in California at that time included the Dumbarton, San Mateo, Carquinez, and Antioch bridges in the San Francisco Bay Area, and the Ehrenburg Bridge over the Colorado River between California and Arizona. The Highway Commission's report to the legislature described the legal basis for the construction of the private toll bridges:

> It is found that the laws relating to the right to operate toll bridges and the granting of franchises therefore, date back to the Political Code (1872) and Statutes of 1881 relating to bridges over navigable streams. No amendments have since been made which change the principle of application of these laws which are based upon the idea of delegating these rights to the counties, and therefore are found to be more or less incompatible with the existing idea of a state highway system.[169]

The report went on to state that with respect to the Carquinez Bridge in particular, "public officials failed to recognize the necessity of building a publicly owned structure."[170]

It was concluded that public financing of bridge construction is less costly primarily because the state can issue revenue bonds at a lower rate of interest than corporations can issue stock or bonds, because of the lower risk to investors. The cost of bond financing and interest for the privately constructed Carquinez and Antioch bridges was stated as 8.7 percent, considerably higher than the interest on government bonds. In addition, the report stated that the American Toll Bridge Company spent more than $1.1 million on promotion and organization (incorporation, legal fees, the cost of issuing and selling stock, etc.) for the two bridges, and estimated that these costs would have totaled only $153,500 if the bridges had been constructed by the state.[171]

The Highway Commission concluded that all future bridge construction on state highways, or roads that might become state highways, should be undertaken by the state, that the construction of privately owned toll bridges should be prohibited, and that the Highway Commission should be given the power to acquire existing toll bridges. It was further suggested that the state could acquire the Carquinez Bridge and lower tolls while still generating sufficient revenue from tolls to pay for continued maintenance and amortize the revenue bonds issued for the acquisition.[172]

In response to the California Highway Commission's report to the legislature, the California Toll Bridge Authority Act was passed in 1929. This act declared it the policy of the State of California to acquire and operate all toll bridges on state highways.[173] However, the stock market crash in October of that year and the onset of the Great Depression delayed acquisition of the Carquinez Bridge for more than a decade.

Additional legislation was passed in 1937, authorizing the California Toll Bridge Authority to purchase the state's existing toll bridges.[174] The Authority voted to begin negotiations for the purchase of the Carquinez and Antioch bridges in March of that year.[175] However, negotiations were not concluded until May of 1940, when the Toll Bridge Authority offered the American Toll Bridge Company $6,480,000 for the two bridges. The company's board of directors accepted the state's offer on May 20, and the stockholders voted to approve the sale on June 15.[176] The purchase price was based on the anticipated future revenue from the date of purchase to the expiration of the franchise in 1948. The value of the bridges as physical assets was not considered, since they were to revert to Contra Costa County at the end of the franchise.

The state sold revenue bonds, bearing interest of only about 1¾ percent, for the purchase of the American Toll Bridge Company's assets. The bonds were expected to be retired by toll revenues in seven to eight years, after which the bridge was to be operated without tolls.[177] Some critics of the state's action noted that the Carquinez and Antioch bridges were to revert to public ownership anyway in early 1948, about the same time that the state would retire the bonds issued for their acquisition. The state, said these critics, was "buying dead horses."[178] However, acquisition of the bridges by the state had the advantage of allowing tolls to be reduced, which was estimated at the time to save motorists a total of $3 million over the eight years from the date of acquisition to the original expiration date of the franchise.[179]

The State of California assumed ownership of the Carquinez Bridge on September 16, 1940, and immediately replaced the American Toll Bridge Company's toll collectors with state employees.[180] Effective December 16 of that year, tolls were reduced to 30 cents per car.[181] Bridge traffic increased dramatically in the first years of the 1940s, stimulated by increased activity at the Mare Island Naval Shipyard in Vallejo. Bridge traffic in June 1941 was 88 percent higher than for June of the previous year.[182] During the first twenty months of state ownership (through April 1941) the bridge carried more than 7 million vehicles, compared to slightly less than 19 million vehicles during the entire thirteen years of ownership by the American Toll Bridge Company.[183] With such a dramatic increase in traffic, bridge tolls were reduced again in June 1942, to 25 cents per car.[184] On August 1, 1945, with the state's revenue bonds retired earlier than anticipated, the collection of tolls on the Carquinez Bridge was discontinued entirely.[185]

Incorporation into the I-80 freeway and construction of a parallel span

Traffic on the Carquinez Bridge continued to increase in the post-war years, with the growth of auto ownership and rapid suburban development. By 1955, traffic on the bridge exceeded 10 million vehicles per year, compared to just over 1 million during the bridge's first full year of operation.[186] This was the era of freeway building, and in 1955 the California legislature authorized the state's Division of Highways to construct a second, parallel span at the Carquinez Strait, with both bridges to be incorporated into a new freeway.[187]

More than eight miles of new freeway construction was carried out in Contra Costa County, extending the Eastshore Freeway (originally U.S. 40, now I-80) from Richmond to Crockett, bypassing the original route along San Pablo Avenue through the communities of Pinole, Hercules, and Rodeo. This construction included the "big cut," southwest of Crockett, the largest earth moving project undertaken by the Division of Highways to that time. In order to reduce the freeway grade over the rolling terrain, a cut through the hills involved the excavation of more than 8.5 million cubic yards of earth. The cut was 350' deep, with 2/1 side slopes and 30' wide benches for every 60' of depth. The resulting "V" notch through the hills was more than ¼-mile wide at the top.[188]

Construction contracts for the second bridge were awarded in 1955, including $5.5 million for the substructure and $9.5 million for the superstructure, as well as separate contracts for the Crockett interchange and construction of a new toll plaza.[189] The superstructure contract was awarded to the American Bridge division of U.S. Steel, the same company that erected the superstructure of the 1927 bridge.[190] The second Carquinez Bridge was completed and opened to traffic on November 25, 1958.[191]

Because the new bridge was financed by revenue bonds, toll collection was reinstated on the Carquinez crossing in 1958, thirteen years after the elimination of tolls on the original structure. The initial toll was 25 cents per car, with trucks charged according to the number of axles.[192] Beginning in 1999, the State of California increased tolls from $1 to $2 per car on seven of the Bay Area toll bridges to finance seismic retrofit work, construction of the new Carquinez and Benicia-Martinez Bridges, and replacement of the eastern portion of the San Francisco – Oakland Bay Bridge. (The Golden Gate Bridge, which is operated by a separate public agency, already had a $3 toll.)

The twin spans of the Carquinez Strait crossing presently carry an average of 105,000 vehicles per day.[193] The 1927 bridge does not meet current seismic safety standards, has a substandard roadway width for its three lanes of freeway traffic, and would be difficult to retrofit without extended closures. Consequently, the California Department of Transportation (successor organization to the Division of Highways) has begun construction of a new bridge to replace the 1927 structure. The new bridge will be a suspension span, parallel to and just west of the 1927 bridge. The I-80 freeway will be realigned to connect with the new bridge, and the Crockett interchange will be reconstructed. The new suspension bridge will have its two main piers aligned with piers 2 and 4 of the existing bridges, giving it a center span of 2350'. This new bridge, the third structure to be built across the Carquinez Strait between Crockett and Vallejo, is expected to be completed in 2003.[194] The 1927 bridge will then be taken down after seventy-six years of service.

3. NOTES

Section 1:

1 The dimensions given throughout Section 1 are taken from microfiche copies of the original drawings, on file at Caltrans' District 4 office in Oakland. Much descriptive information can also be found in two articles from *Engineering News-Record*:

Derleth, Charles. "Cantilever Highway Bridge Across Carquinez Strait." September 24, 1925, pp. 504-507.

Steinman, David B. "Designing the Carquinez Cantilever Bridge." May 12, 1927, pp. 777-781.

2 Microfiche copies of construction plans, Caltrans' District 4 office, Oakland. Also Hollister, Leonard C. "Now Read This: Carquinez Bridge Project Tests Ingenuity of Engineers." *California Highways and Public Works,* Mar.-Apr. 1957, pp. 40-45.

3 Microfiche copies of construction plans, Caltrans' District 4 office, Oakland. Also "Corrosion Closes Bridge for Repair." *Engineering News-Record*, October 24, 1974, p. 16.

4 Microfiche copies of construction plans, Caltrans' District 4 office, Oakland. Also, the new bridge is described in the following articles by Hollister in *California Highways and Public Works*:

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