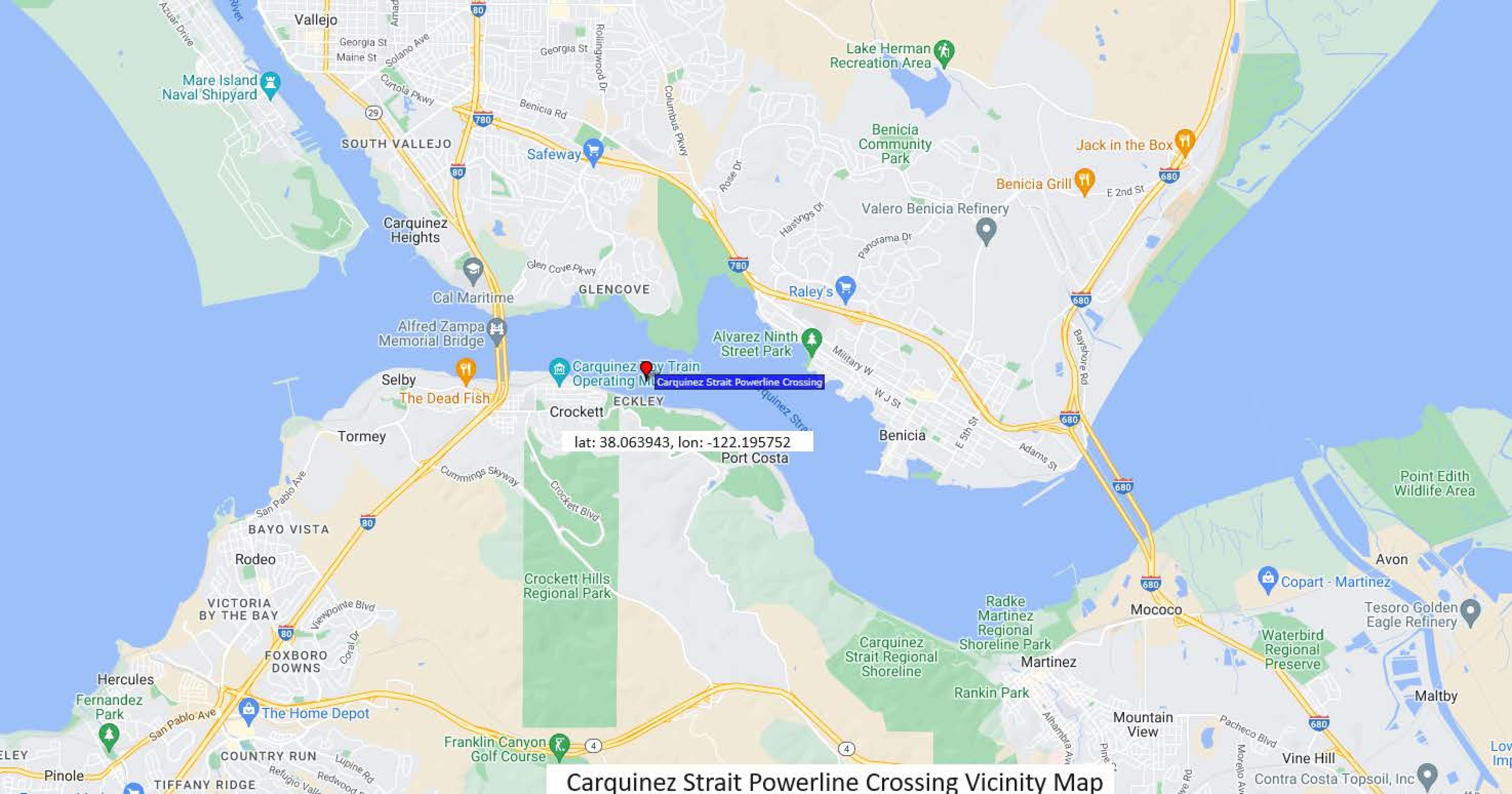

Carquinez Strait Powerline Crossing Vicinity Map

SOUTH TOWER, AT CROCKETT, LOOKING OVER CARQUINEZ STRAITS

About

The first crossing of the Carquinez Straits by a high-tension transmission line was one of the stepping stones in the progress of the electrical industry. The Carquinez Strait Powerline Crossing was a significant engineering achievement as it was the world's first powerline crossing of a large river. Built in 1901, it was designed to carry a 60 kV powerline operated by the Bay Counties Power Company to deliver electricity from the Colgate powerhouse to Oakland, California. For this a crossing of Carquinez Strait was required, which has at its narrowest point at Dillon Point a width of 838 metres (0.52 mi).

Such a span width was impossible with wooden poles, which were common in those days. Installing an underwater cable was considered, but for reliability reasons an overhead power line was installed, which used at the north side of the river a 68 metres (223.10 ft) tall lattice tower and at the south side one with a height of 20 metres (66 ft).

In 1922, coincident with the replacement of 60,000-volt pole lines by a 110,000-volt tower line, the crossing was modified to allow 110,000 volts on the two circuits, thus again practically doubling the transmission capacity. The original design made use of insulating materials in compression.

I. DESCRIPTION

Carquinez Straits is a narrow waterway separating Solano County and Contra Costa County, both in California, and connecting San Pablo Bay and Suisun Bay, which together form the northern extremity of San Francisco Bay. Where the Carquinez Straits Transmission Span crosses, the waterway is about 2,750 feet wide with a depth ranging up to 120 feet. Through this area flow the Sacramento and San Joaquin rivers, as well as a Pacific Ocean tide of about five feet which creates a heavy current (Low 1901a:92) (CA-191-1, CA-191-2).

In this text, the cable crossing is called Carquinez Straits Transmission Span. On current maps the associated waterway is labeled Carquinez Strait (USGS 1959). On historical maps and in historical text the waterway is referred to as Carquinez Straits (Galloway 1901; Low 1901a and 1901b). The latter version of the waterway's spelling was chosen due to its correlation with the span's period of significance.

The nearly century-old transmission span crosses Carquinez Straits just east of Interstate 80. The north tower and main tower of the span are on the Solano County side of the waterway and the south tower is on the Contra Costa County side of the waterway. These steel towers carry cables that continue the transmittal of power along the Colgate-Oakland Transmission Line (see HAER No. CA-190 for a further description of the Colgate-Oakland Transmission Line).

On the north and south sides of Carquinez Straits are rolling, grassy hills with steep, poison-oak-choked gullies (CA-191-1, CA-191-2). The north tower, or leaning tower, is located on a gentle northern slope of a hill near Vallejo and is inclined in a northerly direction in order for the strain from the weight of the span's cables to be properly met (CA-191-3, CA-191-4, CA-191-5). Located north of this tower are the span's northern anchorages (CA-191-11) and a transformer facility. The north tower is 1,400 feet north of the span's main tower.

The main tower (CA-191-13) is located approximately one-tenth of a mile north of the Carquinez Straits northern shoreline, atop one of the hills at Dillon Point in the vicinity of Vallejo.

The south tower is located across the strait from the north and main towers. It rests on the northern slope of a hill that leads down to the bank of Carquinez Straits in the vicinity of the town of Crockett (CA-191-19, CA-191-20). Located south of the south tower are the span's southern anchorages (CA-191-25, CA-191-26, CA-191-27) and remnants of the original associated transformer facility. This tower is less than half of a mile south of the Carquinez Straits southern shoreline.

The Carquinez Straits Transmission Span appears much as it did at the end of modification work that was completed in 1924. The latticed appearance of the towers and the appearance of the cables passing over the towers have changed little since 1901. The towers have been regularly painted and structurally maintained through the years. The cables were painted regularly from

1901 until the 1950s. Aerial markers were installed on the cables in April 1992 (Rasler 1997) (CA-191-2). In general, alterations have been minimal and are limited primarily to general maintenance and upkeep.

II. ENGINEERING INFORMATION

Original 1901 Transmission Span

In 1901, the general design of the Carquinez Straits Transmission Span consisted of a main span of cables, 4,427 feet in length, with a deflection of 227 feet from the highest elevation. The lowest wire was 206 feet above the water at its lowest point. This distance allowed large ships with high masts to travel under the cable and continue up the river to Sacramento and Stockton (Forney 1975; Galloway 1901:232). The span was designed for one 60,000-volt circuit (Corbett ca.1924:887).

John A. Roebling Sons Company designed the cables for the span with the primary focus on their electrical conductivity. The cables were designed to carry the current, not just to support a copper conductor. Originally, there were four cables over the span. The cables were 7/8-inch in diameter and were each composed of 19 solid plow-steel wires twisted into one strand. Each cable had a breaking strength of 96,000 pounds (Galloway 1901:232; Low 1901a:98).

The span's north tower, or leaning tower, was placed at the north side of the span to deflect the cables to the ground and to shorten the shore span (CA-191-4, CA-191-5). This tower was built 96 feet high. A main tower, measuring 225 feet high, was erected just south of the north tower on Dillon Point (Forney 1975; Galloway 1901:230; Low 1901a:100-101) (CA-191-13, CA-191-14, CA-191-15, CA-191-16). (A drawing depicted in George P. Low's May 1901 article in *The Journal of Electricity, Power and Gas* labels the main tower as being 224 feet in height.) Across the Straits, a south tower anchored the span and was 64 feet high (Forney 1975; Low 1901a:100-101) (CA-191-19, CA-191-20).

All three towers were built of steel and iron throughout, except for the original cross-arms, or the cable supports, which were wood (Low 1901a:94). The legs were composed of latticed channels and the bracing was composed of four latticed angles. Rods were included only in the horizontal bracing (CA-191-4, CA-191-14, CA-191-15, CA-191-16, CA-191-19, CA-191-20). The legs of all the towers were set on concrete piers founded on the underlying bedrock. The north tower's legs rested on four piers that formed the corners of a quadrangle measuring 31 feet by 28 feet on the pier centers (Low 1901a:94). The 12 legs of the main tower rested on 12 piers. The main tower's four corner piers, each having eight-foot-square sides (CA-191-18), were arranged in a quadrangle measuring 69 feet by 89 feet between the pier centers (Low 1901a:94). The legs of the south tower rested on four concrete piers (CA-191-23, CA-191-24) that formed the corners of a quadrangle measuring 16 feet by 20 feet on the pier centers. A ladder was provided as part of each tower's design (CA-191-4, CA-191-15, CA-191-20, CA-191-22). All ironwork was painted with silicon graphite paint (Galloway 1901:233).

The cable supports of all three towers were identical in design, dimensions and materials. Each tower originally had four cable supports, two extending to the eastern side of the tower and two extending to the western side. All timber members were of kiln-dried Oregon pine, which were puttied and then given two coats of spar varnish. Two main cross-arms, each 17 feet eight inches long by seven-and-three-quarter inches thick by 15-and-three-quarter inches deep, supported three cross-timbers, each seven-and-three-quarter-inches by nine-and-three-quarter-inches by six feet long. Upon each of the cross-timbers were mounted two steel insulator pins. These pins carried micanite insulators. Steel bolts held the pins to the lower side of the cross-arms. The bolts were drawn up by nuts placed under washers and held by check-nuts (Low 1901a:94-95).

There were six micanite insulators mounted to each cable support. The head of each insulator was countersunk into two upper platform timbers. The countersunk timbers measured four feet two inches by one-foot, eight inches and were boiled in paraffin (spelled "paraffine" in the reference used). Above these were placed two courses of three two-and-three-quarter-inch by four-and-a-half-foot planks. The whole upper platform was covered with heavy canvas and painted. Wooden spouts on the platforms carried rainwater away from the insulators (Low 1901a:95).

A cable saddle was mounted upon the upper platform, secured to the upper course of the planking by six bolts. The saddles were of galvanized cast-iron and measured three feet long by two feet, two inches wide by nine inches in extreme height. All cast-iron pieces associated with the saddle that were exposed to the weather, including a channel and five sheaves (grooved rollers), were also galvanized. The sheaves were supported on steel pinions (Galloway 1901:232; Low 1901a:95,97).

The four cables passed over each tower on the sheaves. The two cables running along the same side of the towers were 20 feet apart vertically and the all cables were 20 feet apart horizontally. There was a vertical distance of 10 feet from one cable on one side of the tower to the nearest cable on the opposite side of the tower. This arrangement allowed for considerable swing at the center of the cables and no possibility of contact. Although only three cables were needed for the transmission, four were set so as to have one in reserve (Galloway 1901:232). This allowed the power company to alternately cut the power to one of the cables and made possible the safe continual inspection and cleaning of each cable (Low 1901b:166).

Each cable exerted a pull of approximately 24,000 pounds on the original four concrete anchorages set to the north side of the north tower as well as on those to the south side of the south tower. Individual anchorages were provided for both ends of each of the cables. Each anchorage consisted of a mass of concrete--nine feet by ten feet by five feet high--set into the underlying bedrock. Steel eyebolts with pin connections extended from the channels and plates. The connections first led to two sets of steel car springs, then to a turnbuckle, then to two tandem yokes connected to heavy micanite strain insulators, and, lastly, to a 24-inch sheave around which the cable was turned and secured with clamps and clips. All iron parts of the anchorages were galvanized (Low 1901a:97).

Since the cables carried the current, it was necessary to insulate them from the earth with the strain insulators mentioned above. The first strain insulators designed for the span were of porcelain and were similar in shape to the insulator design that eventually was adopted. Many of the porcelain insulators that were tested broke on the first application of the current. The insulators chosen were primarily of micanite, "a preparation of sheet mica and shellac formed under hydraulic pressure." This micanite core was surrounded by an insulating transformer oil within a copper tank. Two insulators were used at each anchorage for safety reasons. Each anchorage was housed inside a wood-frame structure that had a large plate glass window at its front. The cable passed through a nine- or six-inch-diameter hole in the plate glass to connect with its respective anchorage (Galloway 1901:232-233; Low 1901a:97).

A transformer station or substation was constructed both on the north side and on the south side of Carquinez Straits, near the cable anchorages associated with the north and south towers, for the purpose of reducing the extremely high pressure used on the main transmission lines to a lower pressure for commercial use (Galloway 1901:233; Low 1901b:166). Each station was 34 feet six inches by 55 feet in plan and was of steel-frame construction with galvanized corrugated-iron exterior surfaces and a wood floor. To introduce the high-tension wires into each building, two lengths of 24-inch-diameter standard salt-glazed sewer pipe were framed into the walls, on an incline. The inner sides of the sewer pipes were covered with glass. The equipment housed in each station consisted of four 500-kilowatt, oil-insulated and water-cooled Stanley transformers, a combination fuse and switch board, lightning arresters and electrically-driven pumps for circulating water in the transformers (Galloway 1901:232-34).

Few changes were made to the entire Carquinez Straits Transmission Span from 1901 to 1913.

1914 Modifications

In 1914 two more cables were added, making two 60,000-volt circuits at approximately 20-foot separation with three cables at 10-foot spacing in each circuit. The original wood cross-arms on all three towers were removed and replaced with steel cross-arms to accommodate six cables, three on each side of the towers (CA-191-6, CA-191-7, CA-191-17, CA-191-20, CA-191-21, CA-191-22). Wood parts associated with the original saddles were removed. The four original concrete anchorages associated with the north tower were left in place, but the two new anchorages for the two added cables consisted of a steel structure pulling against six pin-type, 60-kv insulators in compression (Corbett ca. 1924:887).

1922-1924 Modifications

On May 16, 1922, PG&E authorized the modification of the Carquinez Straits Transmisson Span to allow 110,000-volts on the two circuits, practically doubling the transmission capacity (PG&E 1924). The original design made use of insulating materials in compression. A clear record for over 20 years led the company to adhere to the compression-type design in the reinsulation for the higher voltage, even though this technology was somewhat outdated. This retention of the compression design made the crossing unique among high-voltage spans (Corbett ca. 1924:887).

Between 1922 and 1924 several modifications were made to accommodate the upgrade in capacity. Work included further changes to the tower support system (saddles) for the cables, the addition of supplementary cables at the tower supports, and the replacement of the original four concrete anchorages at either side of the span with steel anchorages designed similar to those added in 1914. Engineer L. J. Corbett designed the above-mentioned equipment for the 1922 to 1924 modifications. By 1924, all anchorages were housed in steel-frame structures with corrugated-iron exterior wall surfaces and roofs (Corbett ca. 1924:887-890).

At each of the six supports on the three towers a cast-steel saddle was mounted on six pillar insulators consisting of three units each (CA-191-A-6, CA-191-A-7, CA-191-20, CA-191-21, CA-191-22). A jack was at the bottom of each pillar to allow equalization of the load. In order to oppose side strains caused by wind on the cable and uneven strains in the direction of the line without introducing unacceptable bending moments in the insulators, the insulators were mounted in two inclined planes at 22-and-a-half degrees from the vertical. The two outer insulators on each side were inclined at the same angle relative to the center insulator in that plane. The insulators were mounted on cast-steel brackets on the 15-inch I-beams that formed the cross-arms of the towers and on the two H-beams that spanned between them. The new saddles of the north and south towers were stationary so that any unequal stresses in the direction of the line would be transmitted to the towers by the insulator structure. The new saddles of the main tower were made to have a movable top that would glide back and forth on rollers. This movable top compensated for the unbalanced stresses resulting from changes in temperature on the different lengths of cable span at either side of the main tower (Corbett ca. 1924:889).

It was noticed that the cables on the Carquinez span were subject to serious vibration which in time would cause crystallization of the steel at the tower supports unless precautionary measures were taken. To provide cushioning for such vibrations and to add to the strength of the cable at the tower supports, two supplementary cables of the same size and quality as the main cable were used over each tower support. The supplementary cables were arranged with turnbuckles so that all or part of the tension could be taken off the main cable (Corbett ca.1924:890) (CA-191-4, CA-191-5, CA-191-6, CA-191-7, CA-191-19, CA-191-20, CA-191-21, CA-191-22).

The new anchorages were similar to those added in 1914 (CA-191-8, CA-191-9, CA-191-10, CA-191-11, CA-191-12-25, CA-191-26, CA-191-27). The goal of the design was to completely relieve the insulator of bending moment, leaving them to resist compression only. Each cable was passed around a 24-inch sheave and securely clamped. From the sheave axle the pull was transmitted through a system of springs to a round bar which formed an axle at the end of the stem of a deep Y-shaped steel frame, or yoke (Corbett ca. 1924:888) (CA-191-10).

The arms of the Y-shaped frame were braced across, and at the extremity of each arm was a round bar which acted as an axle for one end of a set of three pillar insulators on each side. The insulators were inclined outward from the arms of the Y-shaped frame (CA-191-9, CA-191-10). At the insulators' extremities additional axles transmitted the strain to two columns which formed part of a steel cage. The steel cage surrounded the insulator system and converged to a point at which it was attached by a hinge to a concrete anchor block (Corbett ca. 1924:888) (CA-191-8, CA-191-12).

The weight of the Y-shaped frame was supported by two additional pillar insulators with universal joints at top and bottom (CA-191-9, CA-191-10). Each pillar insulator had a simplified jack at its base by which the strain could be roughly equalized in each set. The new anchorages were housed in steel and corrugated iron structures allowing substantial clearances (Corbett ca. 1924:888).

Post-1924 Upkeep and Modifications

The Carquinez Straits Transmission Span appears much as it did at the end of the 1922-1924 modification work. The towers have been regularly painted and structurally maintained throughout their existence. The cables linked with the towers and anchorages, as well as the rest of the span, were painted regularly from 1901 until the 1950s. This effort likely ended due to time factors and safety hazards. Aerial markers were installed on the cables over the waterway in April 1992 (Rasler 1997) (CA-191-2). The steel and corrugated-iron structures, built between 1922 and 1924, that covered the north and south side anchorages were removed at an unknown date (CA-191-9, CA-191-10, CA-191-12, CA-191-13, CA-191-25, CA-191-26, CA-191-27). Many parts of the towers and anchorages, including the insulators, have been upgraded over the years without altering the 1920s look of the span. A transmission station still exists at the north side of the span near the north tower and anchorages (CA-191-13, CA-191-12). The original transmission station facilities at the south end of the span were removed by 1959 (USGS 1959).

In general, alterations to the span have been minimal and are limited primarily to general maintenance and upkeep. The hum of electricity through the wires, the lattice appearance of the towers, and the cables crossing Carquinez Straits are little changed since 1901.

III. HISTORICAL INFORMATION

Hydroelectric plant design started around 1880 when early direct current stations were being built for arc and incandescent lighting. By the mid-1890s, the western United States had powerful hydroelectric plants in the mountains that were connected to distant urban areas by long, high-voltage, transmission lines. These systems were noted to have extremely high heads, remote powerhouse locations, and sophisticated point-to-point transmission. The longest transmission lines of the time were built in California (Hay 1991:xi, 28).

In 1895, the world's largest hydroelectric plant was established at Niagara Falls, New York. Due to high publicity, the Niagara Falls plant stood at the forefront in demonstrating the "economic viability of hydroelectric development coupled with long distance power transmission," establishing "standards for the industry" and highlighting the "fact that hydroelectricity demanded significant changes in hardware and attitudes toward the use of falling water in conjunction with electrical distribution" (Hay 1991:xi).

The time from 1895 to around 1915 saw rapid change in hydroelectric plant design. Innovation and experimentation sparked by the success of earlier plants led to several modifications, including those in waterwheel design, setting and accessories (Hay 1991:xi, 27).

It was during this time that the Carquinez Straits Transmission Span was established as a crucial part of the Colgate-Oakland Transmission Line. The Carquinez crossing was considered one of the "stepping stones in the progress of the electrical industry" (Corbett ca. 1924:887). The following text provides an overview of the history of the transmission span over Carquinez Straits. (See HAER No. CA-190 for specific historical information about the entire Colgate-Oakland Transmission Line.)

The Carquinez Straits Transmission Span

As a result of demands for power, especially in Oakland, the Bay Counties Power Company with the mastermind of Eugene de Sabla and John Martin, set the stage for a new and record-breaking transmission project – a 142-mile-long transmission line from the Colgate power plant to Oakland, with an aerial cable crossing over Carquinez Straits (see HAER No. CA-190 for more specific historical information about the entire Colgate-Oakland Transmission Line and about Eugene de Sabla and John Martin).

Carquinez Straits is a narrow waterway separating Solano and Contra Costa counties in California, and connecting San Pablo and Suisun Bays, which together form the northerly extent of the San Francisco Bay. In debating this crossing, the Bay Counties Power Company had to decide whether to install transformer stations on both sides of Carquinez Straits to first step down the voltage by transformers and then (after its passage under the river) to step it up again, or to carry the wire across the Straits as an overhead crossing. The Carquinez Straits' strong water currents, the frequent passing of large ships, the cost of the transformer stations, and the constant loss of electricity due to the two transformations led to the adoption of the overhead system. The span's designers had quite a job ahead of them considering there was no precedent for determining the behavior of cables of such a long span in a heavy wind (Galloway 1901:232).

Pacific Construction Company of San Francisco was hired to identify the ideal location for the crossing and construct the towers, anchorages, and other features involved in the span. After several surveys of various points, the crossing was located about one mile west of Port Costa (Galloway 1901:232; Low 1901a:102).

The plan of the Carquinez crossing, including the design of the three towers, the mechanical features of the anchorage connections and the plan for hoisting the cables, were the undertaking of Pacific Construction Company's chief engineer, Mr. F. A. Koeditz (also spelled Koetitz). Mr. Koeditz's ideas were approved by Mr. R. H. Sterling, superintendent of the Bay Counties Division of the Bay Counties Power Company, and by Mr. ~~James D~~ John Debo. Galloway, hired by Bay Counties Power Company as the span's chief consulting civil engineer (Galloway 1901:232; Low 1901b:102). Mr. Galloway, an up-and-coming hydroelectric civil engineer at the time, designed the overall line and the transmission stations on either side of the Carquinez crossing. He later went on to design the de Sabla powerhouse system in Butte County and later took a leading part in the development of the PG&E system (Coleman 1952:150; Galloway 1901:234). The electrical features for the crossing, including the saddle and strain insulators, were designed by Mr. Sterling, and the original cables were designed by John A. Roebling Sons Company. The erection of the span was executed under the general direction of Mr. Koeditz and under the immediate supervision of Mr. F. M. Butler, secretary, and Mr. F. B. Field, general superintendent of the Pacific Construction Company (Galloway 1901:232-233; Low 1901a:102).

Bay Counties Power Company became part of California Gas and Electric Corp in 1903, which incorporated with nine other companies on October 10, 1905 to become Pacific Gas and Electric Company. Martin and de Sabla, instigators behind the Colgate-Oakland line, are often called the fathers of PG&E. Few changes were made to the span for the first seven years that it was controlled by PG&E (Coleman 1952:343-44). Between 1914 and 1924 several modifications were made to the span to accommodate increased voltages within the system. Engineer L. J. Corbett was responsible for the majority of the modifications made between 1922 and 1924.

The original design made use of insulating materials in compression. A clear record for over 20 years led PG&E to adhere to the compression type in the 1922-1924 reinsulation for higher voltage. This made the crossing unique among long high-voltage spans of the time (Corbett ca. 1924:887).

Since 1924, alterations were minimal and limited primarily to general maintenance and upkeep. Two helicopter accidents, one in the 1970s and one in 1992, sparked PG&E to install aerial markers on the cables over the waterway (Rasler 1997). Many parts of the tower and anchorages, including the insulators, were upgraded over the years without altering the 1920s look of the span.

In 1975, the Carquinez Straits Transmission Span was listed as a National and California Historic Civil Engineering Landmark attesting to its continued importance in the engineering field and in American engineering history (Forney 1975).