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Structural Engineers and Architects of the Golden Gate Bridge

The Real Story – Part 2

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This is Part 2 of the real story of the Structural Engineers and Architects of the Golden Gate Bridge. Part 1 (STRUCTURE® July 2012) described the history of spanning the Golden Gate. Joseph Strauss proposed a hybrid steel truss suspension bridge across the Golden Gate in 1921. From 1921 to 1930, Strauss had the good fortune to have hired Charles Ellis to be the Vice President in charge of bridge engineering and construction at his firm and have the Golden Gate Bridge District include Leon Moisseiff as an expert advisor for this monumental bridge project. The history continues.

Trying to sell his vision of the bridge, Strauss mentioned Ellis' credentials as often as he could in business meetings and proposals, often prefixing Ellis' name with "Doctor" or "Professor." Ellis was too immersed in his duties to pay much attention. He was spending months working out the calculations and then refining the design and details of a suspension bridge dreamed up by bridge designer, Leon Moissieff. The two visionaries worked in tandem to master all of the equations necessary to calculate forces at the Golden Gate, though they were separated by hundreds of miles. Telegrams flew between Ellis in Chicago and Moissieff in New York, aggravating Strauss, who did not understand the complexity of the engineering work. Strauss did not understand the complex calculations or appreciate the necessity to have confidence in the calculations. This was pioneering engineering and new territory for a 4,000 foot long suspension bridge. A pioneering step that went too far proved disastrous for Moisseiff five years later when his Tacoma Narrows Bridge failed in a wind storm, with the steel girder bridge deck destroyed and in the water.

In the twenty years from 1915 to 1935, the science and art of long span bridge design and engineering went through a great deal of change. One man, Leon Moisseiff, was a key member of this revolution. Moisseiff had developed a theory to distribute wind stresses on suspension bridges by balancing the lateral displacement of the cable and bridge deck structure. Leon began by estimating the share of the wind load carried by the truss. The remainder is supported by the main suspension cable. This generates a load line and stress limit, for both the cable and the truss. By using the principles of integral calculus, he was able to use the estimated load line to determine the shear curve and then the moment curve and the displacements along the length of the bridge. Four different integrations were required to find the slope of the elastic curve for the truss, and two integrations were required for the cable. The relationship of the vertical dead load – weight of the bridge – to the horizontal wind load at any point in the truss determines the slope of the suspender; once this was known, the difference between displacement of the truss and that of the suspension cable were known. Moisseff compared the calculated displacement of the truss with the calculated displacement of the main cable and suspenders. The first trial did not check, so the truss wind load line was refined and the calculations repeated until the displacement converged to a solution. Each iteration of these calculations took several days, and it required several iterations of these manual calculus calculations to converge on a solution. From these calculus integrations, Moisseiff was able to determine the displacement of the stiffening trusses which yielded the forces and stresses that needed to be supported.

Golden Gate Bridge – 75th Anniversary. Courtesy of Reinhard Ludke.

According to this theory, developed by Moisseiff and Frederick Lienhard, as much as half the wind pressure could be supported by the main cables in a long suspension bridge and transmitted to the towers and cable anchorage. At the same time, the deflection of the truss and of the cable would tend to balance each other, thus restoring the bridge to equilibrium under gravity loads only; after the wind stops, the lateral displacements return to zero. In a properly balanced bridge, the wind loads would not damage the bridge if it is flexible enough to bend and sway without overstressing the truss structure. The Golden Gate could be lighter, longer, and narrower than thought possible, which resulted in construction that took less time and cost less.

Charles Ellis fully grasped and embraced Moisseiff's theory and the implications of the mathematics. The Golden Gate was an opportunity to implement these new suspension bridge theories. Ellis applied this mathematics in the design for the suspension bridge. America had moved to the forefront of long span bridge engineering and construction. Strauss had abandoned his promotion of his hybrid bridge concept. It was heavy, used more material, and would take at least a year longer to construct.

Leon Moisseiff worked in tandem with Charles Ellis on the engineering of the Golden Gate Bridge. Moisseiff especially contributed to the

force calculations related to wind loading on the bridge. From his New York office, he traded telegrams with Ellis in Chicago, going over numerous engineering questions. Ellis was responsible for directing the thousands of calculations required for the computation of stresses, refining the structure design, as well as development of the technical specifications, construction contracts, and proposal forms. Ellis worked tirelessly on the calculations for the suspension span, and he also tackled the frame calculations for the towers.

Strauss was getting impatient with "all the time" Ellis was taking to finalize the bridge design. Ellis would not release the design until he was confident that the structural analysis calculations were correct. All these calculations had to be done manually and he did not have multiple staff members who could complete some of this complex work, so he did much of the analysis himself. Finally, on December 5, 1931, by telegram from San Francisco, Strauss insisted that Ellis take a vacation. Three days before his vacation was over, Charles Ellis received a letter from Strauss instructing him to turn all his work over to his assistant Charles Clarahan, Jr., and to take an indefinite unpaid vacation. The reason(s) Joseph Strauss removed Ellis from his pivotal role as Structural Engineer are not documented in the records. Clifford Paine took over Ellis' role as the "Assistant to Joseph Strauss" on the project. Strauss remained as the "Chief Engineer."

For reasons not clear today, Mr. Strauss had fired Ellis. Whether it was a disagreement on technical matters, a conflict of personalities, or some other issue, Charles A. Ellis had lost his place in the engineering and design history of the Bridge and received no credit for his critical role in the final design of the landmark Bridge upon its opening. He went on to join the engineering faculty at Purdue University in 1934, from where he retired as Professor Emeritus of the Division of Structural Engineering in 1947. Forced into semi-retirement, Ellis revisited the computations for the Golden Gate Bridge. He labored over the numbers obsessively. Investing about 70 hours per week, he executed a complete review of the numbers in five months, working unpaid. Unfortunately for him, his connection with his primary obsession for so many years had been severed. When the Golden Gate Bridge opened in 1937, many men were credited with "building" it, among them Strauss, Moisseiff, and Clifford Paine, Ellis' successor on the project. Yet Charles Ellis was not mentioned.

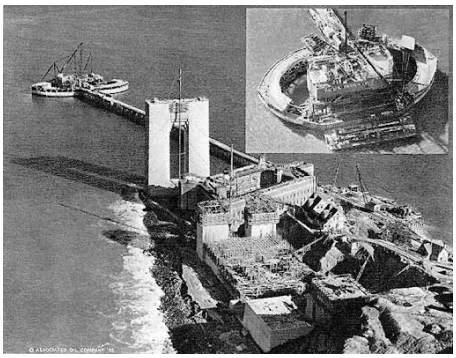
Not until 1949, when an obituary named him as the bridge's designer, did Ellis receive any recognition for his enormous role in the design and engineering of the bridge. Whether he ever saw or stood on the bridge is not known. In all the years Ellis spent laboring over the numbers – in ten volumes of calculated dimensions, loads, wind stresses, and the like – he had made the bridge his own.

Ellis, Moissieff, and Othmar Ammann were great engineers in their own right and, for the bridge project, they brought their own unique contributions to the ultimate collective effort. Chief Engineer Joseph Strauss was the leading visionary, campaigner, and organizer for the development of the Bridge. Consulting Engineers Leon Moisseiff and Othmar Ammann were among the leading suspension bridge designers of their time; Moisseiff having developed the deflection theory and Ammann was known for developing traffic load theories which lead to design of light weight and economical bridges. Charles Ellis was the dedicated engineer performing endless calculations seeking to bring perfection to the design. He is the Structural Engineer of the Golden Gate Bridge. Clifford Paine completed the detail construction plans that carried the Ellis design to completion through construction. Resident Engineer, Russell Cone, lead the on-site construction engineers and had significant contributions in engineering the construction of complex tower foundations, erection of the towers, and managing Roebling spinning the main cables.

Strauss first sought out John Eberson, a famous movie theater architect of the time, to consult on bridge design and architecture. Some of his sketches remain in the historic archives, and he is recognized for his contribution of the Art Deco vocabulary of the bridge towers.

Strauss considered Eberson's fees too high, so in 1930 he replaced the consulting bridge architect with Irving F. Morrow. Irving F. Morrow, a local Berkeley architect, is responsible for the Golden Gate Bridge's graceful art deco design and paint color. Morrow expressed his visions in charcoal drawings. He designed small detail elements like street lamps, railings and pedestrian walkways, added vertical fluting to the bridge towers, stylized geometry in the era's Art Deco style. He created the two magnificent 700-foot tall Art Deco Sculptures – the main suspension cable support towers.

Morrow's most famous contribution to the Golden Gate Bridge was its distinctive burnt red-orange hue called International Orange. Others had suggested the bridge be painted aluminum, dull gray, or the Navy's preference, highly visible yellow with black stripes. He states in his April 6, 1935 report, "the bridge should be a color which contrasts with the surrounding sea, sky and land regardless of weather or season." One by one, members of the bridge's brain trust relented, as Morrow identified a paint durable enough to need less frequent reapplication. In the end, the bridge's design fit harmoniously into the bay's natural palette of sky, water, and land.



South Anchroage & Tower. Courtesy of Associated Oil Company.

In early 1936, Morrow sent lighting guidelines for the bridge to Strauss. Though lighting was normally a job entrusted to electrical engineers, Strauss followed Morrow's recommendations. After his work on the Golden Gate Bridge, Morrow returned to designing residential and small commercial buildings.

The suspension bridge used less steel and was faster to build. Persuaded by these cost and time considerations, Strauss endorsed the suspension plan. Seventy five years later, the bridge that resulted from Charles A. Ellis and Leon Moisseiff's engineering and Irving Morrow's architecture and color is the international icon for San Francisco.

It is the collective efforts of the structure engineers that created the design of the iconic Golden Gate Bridge. Joseph Strauss, Leon Moisseiff, Clifford Paine, Russell Cone, and especially Charles Ellis share the legacy that is celebrated in 2012. The contribution of each, as individuals and as a team, led to the premier suspension bridge of all time. We would not be celebrating the 75th Anniversary of the bridge without the efforts, promotion and leadership of Joseph Strauss. The imagination, engineering, pioneering technical achievements, art, and spirit of this bridge, at this location, was created by Charles A. Ellis, Leon S. Moissieff, and Irving F. Morrow.

On May 25, 2012, as part of the 75th Anniversary of the Bridge, the Golden Gate Bridge District acknowledged and celebrated the contributions of Charles A. Ellis. ASCE and the Structural Engineers Association of California placed a plaque at the south bridge plaza, that states "American Society of Civil Engineers, recognizes the contributions of Charles A. Ellis, Bridge Engineer, on this 75th Anniversary of the Golden Gate Bridge."▪