

## Lessons in Tenuity: Frank Lloyd Wright's Bridges

Richard Cleary

At seven o'clock on a July morning in 1947, structural engineer Jaroslav Joseph Polivka (1886-1960) was awakened by a ringing telephone and what he later described as the "hearty" voice of Frank Lloyd Wright (1867-1959) (UBA, PP, MS 48, 22 July 1947). Capitalizing on the two-hour time difference between Taliesin, his home near Spring Green, Wisconsin, and Polivka's residence in Berkeley, California, the architect pressed his groggy target to put aside whatever he was doing and make a "vacational trip" to Taliesin with his wife and, by the way, his slide rule (**Fig. 1**).



Figure 1. Frank Lloyd Wright (L) and Jaroslav Polivka, undated photograph, c. 1950s (University Archives, State University of New York at Buffalo, PP, MS 48, misc. photographs)

Polivka, who had been assisting Wright on issues of structure and materials for over a year, was accustomed to such requests and accepted the invitation knowing that there was little chance he would receive much more than his host's hospitality for the services he would render. He was enthusiastic about the plans on the drawing board for the Solomon R. Guggenheim Museum (1943-1959) in New York City, the matter at hand, and also had projects of his own for which he hoped to secure Wright's participation. A change in Wright's schedule forced the cancellation of this trip, but the men pursued their respective agendas in a relationship combining business and friendship that would continue until Wright's death in 1959.

High on Polivka's list in 1947 was a proposal he had in mind for a bridge the state of California planned to build across San Francisco Bay (UBA, PP, MS 48, 21 July 1947). He soon interested Wright in the project, which became a formal collaboration, and they completed their design by May 1949 (**Fig. 2**).

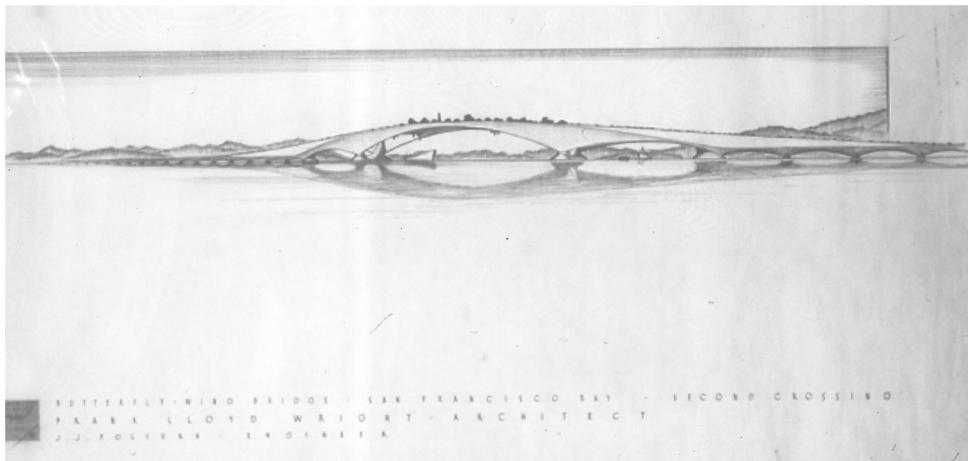


Figure 2. San Francisco Bay “Butterfly-Wing” Bridge (project), F. Wright and J. Polivka, 1949 (FLWF 4921.018. © Frank Lloyd Wright Foundation)

From that date, the San Francisco “Butterfly-Wing Bridge” has had a Phoenix-like history, although none of its incarnations has been realized. The most recent was in 1999, when the design captured the imagination of Oakland, California, mayor Jerry Brown who unsuccessfully petitioned Governor Gray Davis to have the state's department of transportation consider adapting it to replace the east span of San Francisco-Oakland Bridge, which had been damaged by an earthquake (Hendricks 1999).

The San Francisco Bay bridge project was one of four proposals for long-span bridges prepared by Wright's studio between 1947 and 1949. The others included a pair of bridges crossing the

Wisconsin River near Spring Green (Jacobs 1947) and two schemes for twin bridges spanning the Allegheny and Monongahela Rivers in Pittsburgh, Pennsylvania (Cleary 2000, pp. 86-97). None was realized, and it is easy to lose sight of them among the studio's profuse and inventive output in the years after World War II, which included such built works as the Guggenheim, the H. C. Price Tower (1952-56) in Bartlesville, Oklahoma, Beth Shalom Synagogue (1954-59) in Elkins Park, Pennsylvania, and scores of single-family houses throughout the United States. Nevertheless, they merit attention for the light they shed on Wright's receptivity to advances in structural engineering and his interactions with engineers, topics which the architect often obscured when discussing his buildings. They also illuminate Wright's refinement of his theory of organic architecture in terms of a structural principle that he termed "tenuity".

The bridge projects are variants on a structural theme illustrated most clearly by the drawings for the Wisconsin River crossings (Figs. 3, 4).

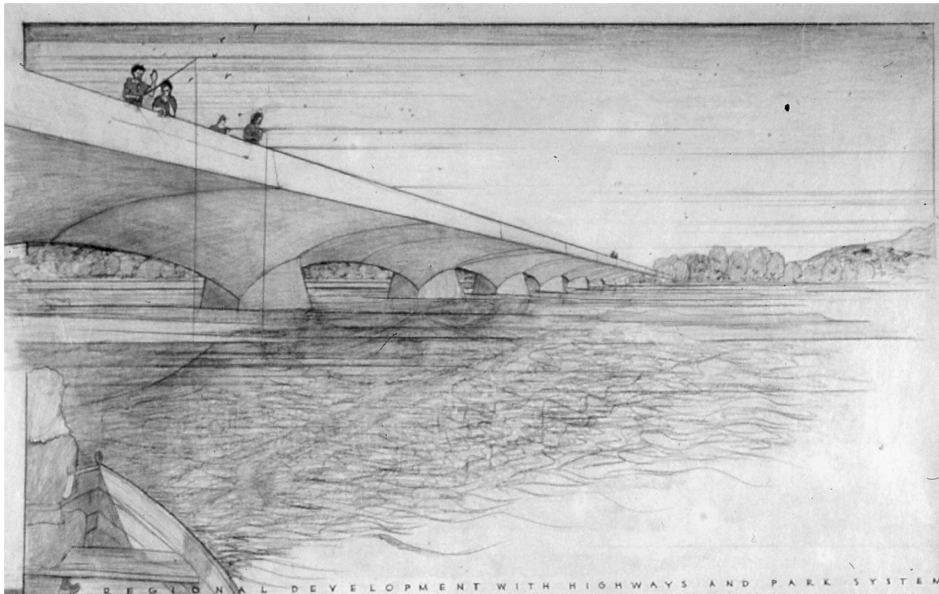


Figure 3. Wisconsin River "Butterfly-Wing" Bridge (project), F. Wright, 1947  
(FLWF 4723.002. © Frank Lloyd Wright Foundation)

Wright conceived each bridge as a series of reinforced-concrete cantilevers composed of prefabricated, prestressed segments. Each cantilever consists of a single, deep girder tapered from the supporting pier to mid-span, where it meets the girder cantilevered from the next pier. Attached to the girder are ribs and a thin, concrete shell formed by steel mesh sprayed with gunite that support the deck. Wright likened the design to the thorax and wings of a butterfly and named it the "butterfly-wing" bridge.

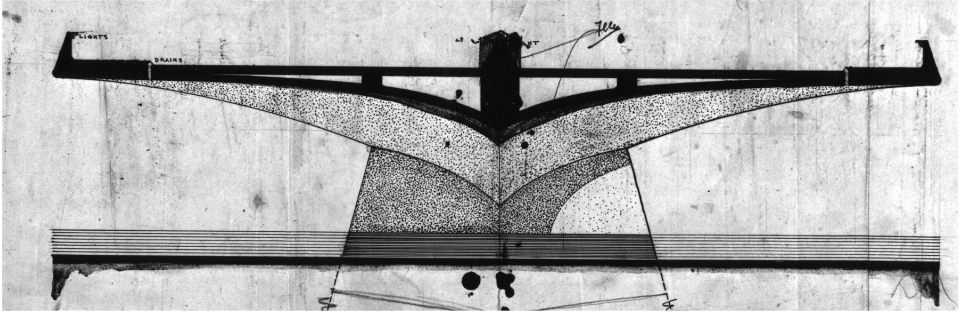


Figure 4. Wisconsin River “Butterfly-Wing” Bridge (project), cross section, F. Wright, 1947  
(FLWF 4723.003. © Frank Lloyd Wright Foundation)

He applied the concept on a much larger scale in the projects for San Francisco and Pittsburgh. The main span of the San Francisco bridge was to have been 1 000 feet, an unprecedented length for reinforced concrete bridges at the time, and the approximately 700-foot-long Pittsburgh bridges were to have multiple decks (Fig. 5). In the second proposal for Pittsburgh (Fig. 6), Wright modified the structural system by adding suspension cables that transformed the simple cantilevers into cable-stayed spans.

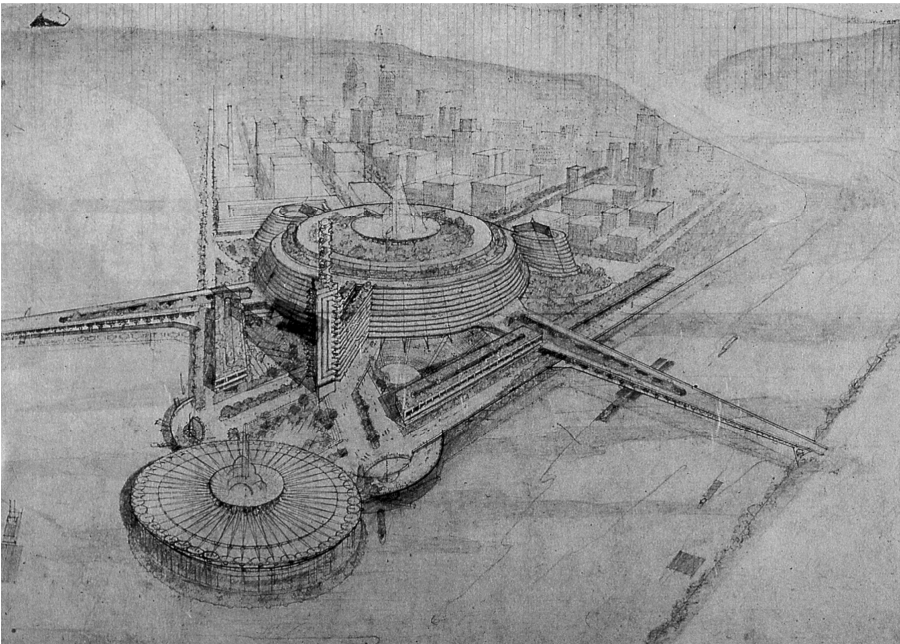


Figure 5. Pittsburgh Point Civic Center (project), Scheme 1, F. Wright, 1947  
(FLWF 4821.004. © Frank Lloyd Wright Foundation)



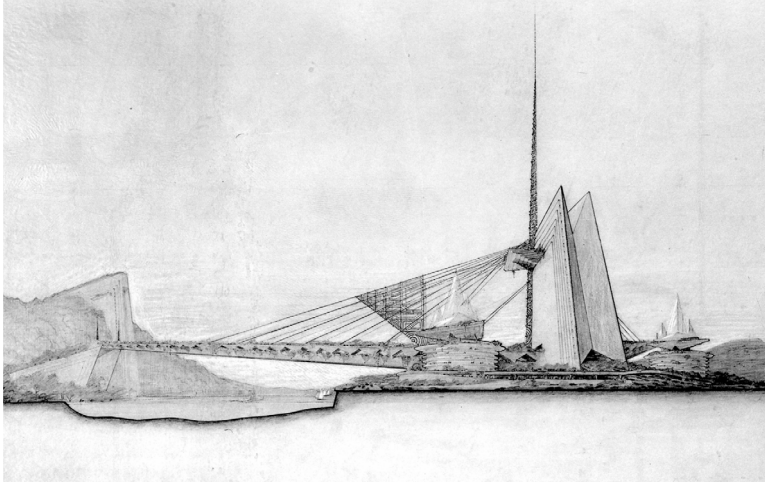


Figure 6. Pittsburgh Point Civic Center (project), Scheme 2, F. Wright, 1947  
(FLWF 4836.004. © Frank Lloyd Wright Foundation)

The concepts were structurally plausible, but their scale required a degree of technical innovation and aesthetic vision outside the conventions of American bridge engineering at mid-century. Steel was the favored material for long-span bridges, and the suspension and cantilevered-truss spans of the San Francisco-Oakland Bay Bridge (**Fig. 7**), completed in 1936, exemplify the prevailing standard of practice.



Figure 7. San Francisco-Oakland Bay Bridge, southwest view with Yerba Buena Island, Frank Deras, Jr., photo  
(Library of Congress, Historic American Engineering Record, HAER CAL,038-SAN FRA,141-81)

The use of reinforced concrete in bridge construction, introduced at the end of the nineteenth century, was becoming increasingly common, but most designers conceived it in terms of arches. A leading figure in this respect was Conde B. McCullough (1887-1946), who designed elegant highway bridges in Oregon (**Fig. 8**) during the 1920s and 1930s.



Figure 8. Isaac Lee Patterson Bridge, Gold Beach, Oregon, Conde B. McCullough, 1930-32. Jet Lowe, photo (Library of Congress, Historic American Engineering Record, HAER ORE,8-GOBE,1-5)

Wright, however, envisioned his bridges as cantilevered beams, and they anticipate the first prestressed reinforced-concrete bridge erected in the United States by a few years (Walnut Lane Bridge, Philadelphia, 1949-50) and the first use of segmental construction by more than a quarter century (Corpus Christi, Texas, 1974). The cable-stayed structural system Wright proposed for Pittsburgh was equally unconventional. Cable-supported bridges in the United States were with few exceptions suspension spans, like that of the San Francisco-Oakland Bridge, composed of primary cables strung from tower to tower from which hangers support the deck. American engineers had little interest in the cable-stay concept by which cables run directly from deck to tower, although they did occasionally employ such diagonal stays as a method of resisting deflections caused by traffic and wind.

Europe was more fertile ground for Wright to find fellow travelers and precedents. Among them were the sleek, structurally efficient, and economical bridges of Robert Maillart (1872-1940) and

the techniques for prefabricated, segmental, prestressed, reinforced-concrete bridge construction pioneered by Eugène Freyssinet (1879-1962). Noteworthy, as well, were the innovations in thin-shell concrete construction by engineers such as Pier Luigi Nervi (1891-1979) and Eduardo Torroja y Miret (1899-1961). These are familiar names today, and they were not unknown in the United States in the 1940s. For example, Conde McCullough employed some of Freyssinet's techniques in his Rogue River Bridge, but in general, the different conditions of education and professional practice on each side of the Atlantic created a barrier in engineering culture that restricted the transfer of knowledge (Plowden 2002, p. 326).

Particularly close parallels to Wright's designs may be seen in Germany where the pressing need to replace bridges destroyed during the war and shortages of steel spurred research in reinforced concrete spans. For example, in 1948, the *Engineering News-Record* (1948) published German designs for a family of reinforced-concrete truss, arch, and suspension bridges utilizing a deep, central beam similar to the butterfly concept. Cable-stayed bridges were another topic of investigation. By 1952, Fritz Leonhardt (1909-99) had designed a group of three cable-stayed bridges with steel towers and decks crossing the Rhine at Düsseldorf (built 1953-75). The similarities between these innovations and Wright's work, and the overlapping chronology raise the question of whether he was aware of them. In general, Wright's own accounts of his design process offer few clues as to how he learned from the work of contemporaries, but the circumstances of his relationship with Jaroslav Polivka suggest that the engineer served as a window to new developments in structural engineering in Europe and the United States.

A native of Prague, Polivka received his professional training at the college of technology there and the ETH in Zurich (Muskat 2000, pp. 6-8). Following service in the Austrian army during World War I, he established himself in Prague, working on a variety of architectural and engineering projects. He acquired special expertise in the photo-elastic stress analysis of reinforced concrete structures and took particular pride in his contributions as a consulting engineer on the design of the Podolsko Bridge over the Vltava River (1938-41), which features a center arch spanning 492 feet (Muskat 2000, pp. 22-4). Also in the 1930s, he received commissions as the structural engineer for the Czech pavilions at the world's fairs in Paris (1936) and New York (1939) (Muskat 2000, 29-34). The latter provided him and his wife, Maria, who was Jewish, the opportunity to immigrate to the United States. He found employment as a research associate at the University of California at Berkeley and also established a private practice as a consulting structural engineer.

Polivka's association with Wright began in February 1946, when he wrote the architect a fan letter in response to an article on the Guggenheim Museum in *Architectural Forum*. He admitted that even though he was an engineer, he had to agree with Wright's assertion that engineers often failed to see beyond the received knowledge of conventional practice.

Engineers in their structural conceptions are very seldom guided by eternal laws of the [sic] Nature. Take for example cobwebs of a spider which definitely should be studied by an engineer whose specialty is to build suspension bridges and two- or three-dimensional structural network[s]

(UBA, PP, MS 48, 15 February 1946)

Sensing a kindred spirit possessing useful skills, Wright invited Polivka to Taliesin West in Scottsdale, Arizona. Jaroslav and Maria made the trip at the end of April, and Wright put him to work assisting William Wesley Peters (1912-91), his son-in-law, lieutenant, and resident specialist on structures, analyzing structural systems for the Guggenheim and the Johnson Wax Research Tower in Racine, Wisconsin (1943-50) (UBA, PP, MS 48, 4 May, 5 June 1946). Polivka's expertise was not limited to reinforced concrete, and over the next decade he also advised Wright on the thermal properties of glass for the Rogers Lacy Hotel project in Dallas, Texas (1946-49) (UBA, PP, MS 48, 30 July 1946) and the use of plastics for the roof of a project for a grandstand at the Belmont Park racetrack in Elmont, New York (1957) (UBA, PP, MS 48, 6 February, 10 March 1957). Although not a celebrity in his profession, Polivka maintained ties with structural engineers throughout Europe and the United States and boasted that as a student of Joseph Melan (1853-1941) and an associate of Fritz von Emperger (1862-1942) (UBA, PP, MS 48, 5 February 1956) he had been at the "cradle of prestressed concrete" before Freyssinet (UBA, PP, MS 48, 30 December 1949). He was well positioned to introduce their innovations to Wright's studio.

It would be tidy to assert that Polivka introduced new structural systems and Wright, in turn, gave them expressive form, but the archival record of the San Francisco Bay bridge project suggests a more fluid relationship. Polivka certainly initiated the project. In February 1947, five months before he would ask Wright to collaborate with him, Polivka submitted a schematic design for the bridge to the California Department of Public Works (UBA, PP, MS 48, 21 July 1946). He proposed a multi-span, 16 600-foot, double-deck structure crossing the bay south of the San Francisco-Oakland Bridge between Army Street in San Francisco and Bay Farm Island in Alameda (**Fig. 9**). A reinforced concrete arch with a suspended roadway spanning 3 200 feet permitted unobstructed navigation through the main channel by the large warships stationed at the nearby naval yards.

The design changed significantly over the eighteen months between the time Wright accepted Polivka's invitation to collaborate on the project and the public presentation of their joint proposal on 20 May 1949 (UBA, PP, MS 48, "Testimony"). They recommended two possible sites (**Fig. 10**) and offered four schemes, all based on the butterfly-wing concept.

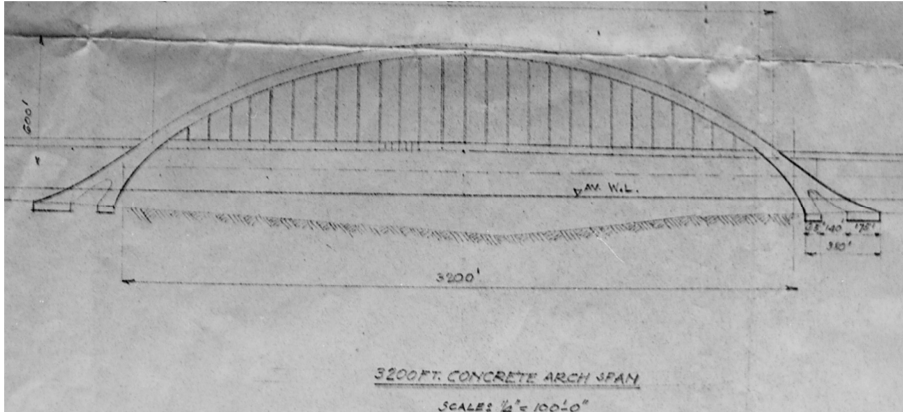


Figure 9. San Francisco Bay Bridge (project), elevation, J. Polivka, 12 February 1947 (University Archives, State University of New York at Buffalo, PP, MS 48, “New Crossing”, detail)

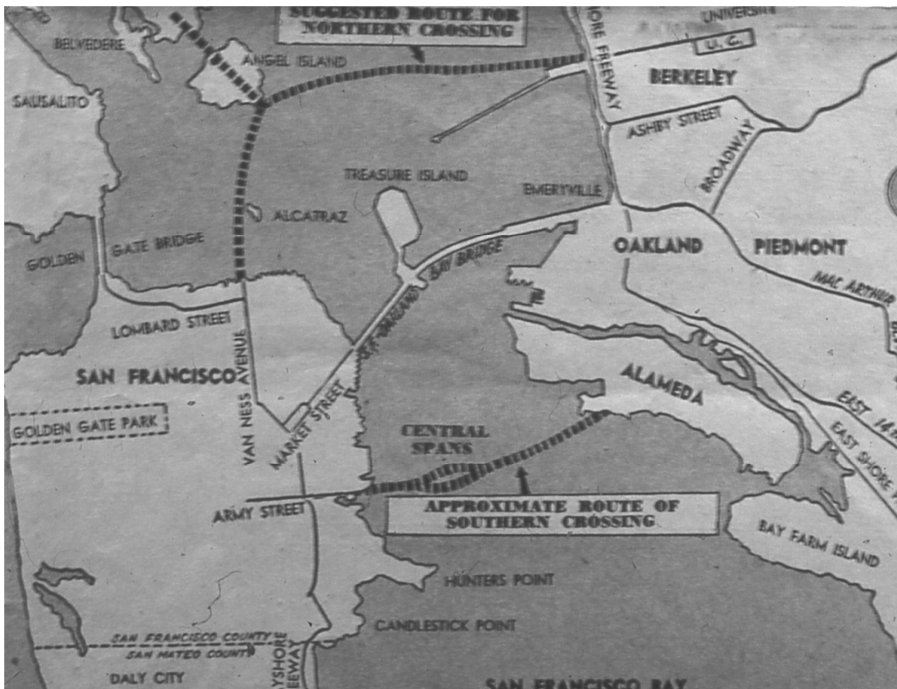


Figure 10. Suggested routes, San Francisco Bay Bridge, F. Wright and J. Polivka (*San Francisco Call Bulletin*, 1 June 1949)

The southern site was similar to that Polivka had used in his first proposal. It began at Army Street in San Francisco, but rather than crossing to Bay Farm Island, it spanned a shorter distance directly to the heart of Alameda. The other route was north of the San Francisco-Oakland Bay Bridge and would have begun at Van Ness Avenue in San Francisco, touched Alcatraz Island, crossed the tip of Angel Island, and entered Berkeley around University Avenue. The four schemes may be classed in two pairs. The preferred and most widely publicized solution consisted of a series of spans that were to gradually increase in length and height to a climactic, 1 000-foot, central arch rising 175 feet above mean sea level to provide clearance for warships (**Fig. 1**). The views from the arch would have been spectacular, and Wright and Polivka transformed what ordinarily would have been a passing glimpse into a leisurely experience by separating the inbound and outbound roadways and inserting a park between them (**Fig. 11**). The variant for this scheme reduced costs by eliminating the split roadway and park. The second pair of proposals replaced the center arch with two pivot spans. The more expensive variant added double-deck roadways and railroad tracks.

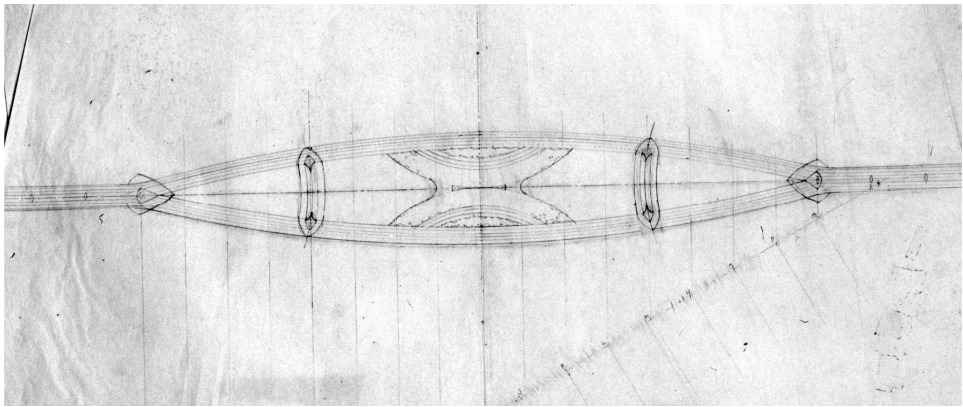


Figure 11. San Francisco Bay Bridge (project), central span with park between divided roadway, F. Wright and J. Polivka, 1949, drawing by Wright's office (FLWF 4921.016. © Frank Lloyd Wright Foundation)

The presentation documents indicate the collaboration between Wright and Polivka. The drawing set consists of renderings by Wright's studio and structural details prepared by Polivka's office. Characteristic of the latter is a sectional elevation for the central girder that would have composed half of one of the shorter, 156-foot spans (**Fig. 12**). Polivka configured it as a partially prestressed concrete Vierendeel girder with a substantial steel skeleton that was to have had a depth of 29 feet – 6 inches at the pier and 14 feet at the unsupported end. Cantilevered from it transversely at 12-foot intervals are reinforced concrete ribs supporting a gunite shell and 6-lane deck.

The language of the project description includes phrases characteristic of each man (UBA, PP, MS 48, "Testimony"). The archival record offers few clues, however, regarding the project's evolution from Polivka's initial scheme to the butterfly-wing design. A similar lack of accurately dated





Bridge (1931) in New Jersey, the longest arch at the time, and four times the length of the Sandöbron (1943) in Sweden, the longest reinforced-concrete arch. For Wright, this was the work of an engineer who could think outside the bonds of conventional practice. That said, Polivka treated the supporting structure and roadway separately and hung the deck from the arch. The joint project integrated them, and such synthesis of form and structure was a theme in Wright's work that Polivka admired.

It seems likely, then, that the joint design for the San Francisco bridge and, perhaps, the other butterfly-wing designs reflect concepts brought to the table by both men. Polivka offered not only his knowledge of advanced engineering practices but also a desire to fully explore their potential. Wright contributed an architectural vision that, characteristically, he had been pursuing in a number of projects over the past twenty years. Among them were designs for tall buildings, such as the St. Mark's-in-the-Bouwerie apartment tower project in New York (1928-30) and the Johnson Wax Research Tower (on which Polivka worked), in which he cantilevered the floors from a central core that was itself a cantilevered beam anchored by what he termed, using a botanical analogy, a "tap root" (Fig. 13). The cantilevers of tower and bridge are two expressions of a single structural idea with the axis of support rotated ninety degrees from vertical to horizontal.

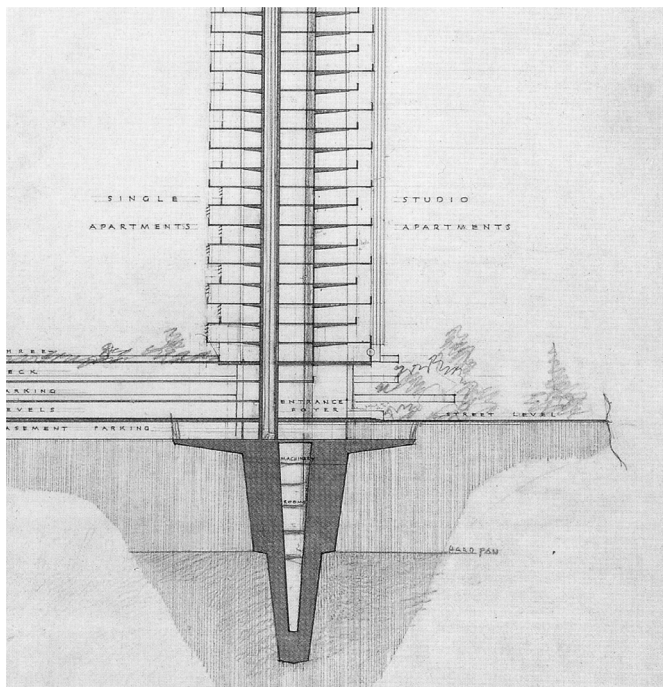


Fig. 13. The Golden Beacon, Chicago (project), Frank Lloyd Wright, 1956 (FLWF 5615.003. © Frank Lloyd Wright Foundation), detail showing the "tap root" foundation for the 50-story apartment building

Wright also had undertaken explorations of tensile structures that informed his design for the cable-stayed bridges in Pittsburgh. In 1931, for example, he proposed a cable-supported exhibition pavilion for the Century of Progress Exposition in Chicago (Fig. 14), and around the same time, he included a cable-supported bridge as a highway overpass (Fig. 15) in the model of Broadacre City (completed 1935), his concept for decentralized development across the United States.

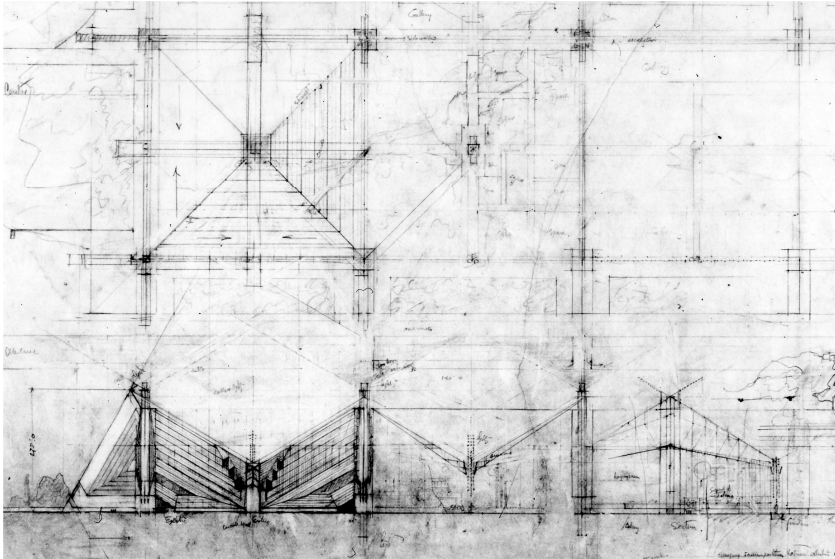


Figure 14. Pavilion for the Century of Progress Exposition, Chicago (project), Frank Lloyd Wright, 1931, detail (FLWF 3103.001). © Frank Lloyd Wright Foundation



Figure 15. Model of Broadacre City (detail), showing cable-supported highway overpass, Frank Lloyd Wright, 1935 (FLWF 3407.001). © Frank Lloyd Wright Foundation

Wright's investigations of cantilevered and cable-supported structures appear in a variety of building types, but he tied them to a common theoretical principle, which he called "tenuity," a real if infrequently used word referring to thinness of form or slenderness. Fond of word play, he conflated tenuity with "continuity," a central tenet of his theory of organic architecture, "tensility," pertaining to the tensile properties of steel and reinforced concrete, and, one might presume, "tenacity," a word equally applicable to architectural materials and Wright's personality. He used the term in the first edition of his *Autobiography* (Wright, 1932, p. 370), elaborated it in the 1943 edition (Wright 1943, pp. 366-68), and offered the most succinct explanation of its meaning in his *Testament*, published in 1957:

Steel gave rise to a new property: I call it *tenuity* [Wright's italics]. Tenuity is simply a matter of tension (pull), something never before known in the architecture of this world. [...] With tensile strength of steel, this pull permits free use of the cantilever, a projectile and tensile at the same time, in building-design.

[...] The principle of the cantilever in architecture develops tenuity as a wholly new human expression [...] This brought into architecture for the first time another principle in construction – I call it continuity – a property which may be seen as a new, elastic, cohesive, stability. [...] Thus architecture arrived at construction from within outward rather than from outside inward; much heightening and lightening of proportions throughout all building is now economical and natural, space extended and utilized in a more liberal planning than the ancients could ever have dreamed of. This is now the prime characteristic of the new architecture called organic.

(Wright 1957, pp. 216-18)

Such insistent, repetitive language leads editors to reach for their blue pencils, but it served an important purpose for Wright who wanted his readers to know that in the 1920s, he had come to understand that steel and reinforced concrete offered the means of integrating structure and the component parts of buildings (e.g. walls, ceilings, floors) in ways that could hardly be imagined before. Again and again in his writings he declared that he was on a quest to master tenuity, and the bridge projects of the late 1940s are essays on that theme. But why, with long odds against being able to realize any of them and so many other more promising commissions on his plate, did the 80-year-old architect undertake them? After all, the design of bridges in the United States had become the nearly exclusive domain of engineers; when architects were involved, their scope typically was limited to cosmetic issues.

Opportunity, undoubtedly, was a factor. Wright designed the Wisconsin River crossings in response to plans by the state to build what he regarded as an unsatisfactory structure close to his home. The Pittsburgh bridges were an integral part of his ambitious redevelopment scheme for the city, and the San Francisco Bay bridge had been initiated by Polivka. But by taking on these

projects Wright also proclaimed himself as the heir to one of America's greatest builders, John Roebling (1806-69). Looking back at the history of architecture and engineering in the first edition of his *Autobiography*, Wright singled out the engineer as a prophet of tenuity: "So this tremendous new resource of *tenuity* [...] we see it ushering in our new era in John Roebling's Brooklyn Bridge [New York, 1883]" (1932, p. 370). And in his "Two Lectures on Architecture" published in 1931, he observed:

Yes, in a spiritual sense, a higher *order* is the sense of sunlit space and the lightness of the structure of the spider spinning as John Roebling saw it and realized in his Brooklyn Bridge. Inevitably, it seems to me, this sense of building is to construct the physical body of our Machine Age.

(Wright, 1931, p. 89)

Wright was 16 when the Brooklyn Bridge was dedicated in 1883, and although aware of it throughout his professional career, he did not invoke its significance in his writings until he began articulating the principle of tenuity. Roebling's achievement then became for Wright a sublime statement of potential to which he applied his own intuitive understanding of materials and structure to design a new family of edifices that were not so much of the earth, such as his prairie houses of the early 1900s, as set lightly upon it, like the bridges and the Beth Sholom Synagogue. In this effort, he found fellow travelers among the ranks of structural engineers.

In 1956, Wright dedicated his project for the "Illinois Mile-High Cantilever Sky City" to this community (Pfeiffer 1990, p. 119). At the bottom of the oversized rendering of the skyscraper, he inscribed an honor roll listing just one architect, his "leiber meister," Louis Sullivan (1856-1924), among ten engineers of whom seven stand out as pioneers of tenuity. Led by Roebling, they include the pioneers in reinforced concrete François Coignet (1814-88) and Joseph Monier (1823-1906), Maillart, Nervi, Torroja (whom Polivka had introduced to Wright) (UBA, PP, MS 48, 13 April 1950), and Polivka himself. In highlighting this group, rather than a list of architects known for skyscrapers, Wright distanced himself from his professional rivals and signaled his allegiance to an architecture in which form and structure are inseparable.

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