CHAPTER 4

GUSTAVE EIFFEL
AND THE CRESCENT BRIDGE

The Tower and the Industrial Fair

Just as Britain had demonstrated her national superiority with the Great Exhibition of 1851, so France in 1855 put on a Paris exposition patterned after that of her rival. A second one followed in 1867, a third in 1878, and in 1884 planning began for a fourth one to commemorate the centenary of the opening of the États Généraux on May 5, 1789.

The eighteenth century had ended with two transforming European revolutions, France’s political revolution and Britain’s industrial one. Together these events seemed to promise a boundlessly improving future, and it was this future that the industrial fairs served to portray. The 1889 fair represented, in addition, France’s desire to recapture something of her eighteenth-century glory. In contrast to Britain, which in the 1880s could still consider itself the greatest nation on earth, the French felt defeated, depressed, and dishonored. Surpassed economically by Britain, and in 1870 devastated militarily by Bismarck’s new Germany, France could only look back to the period before 1814, when it had been the great European power. As the end of the nineteenth century approached, that longing for greatness remained.

Georges Berger, general manager of the 1889 exposition, expressed this sense of France’s desire to recapture its past glory: “We will show our sons what their fathers have accomplished in the space of a century through progress in knowledge, love of work and respect for liberty.” Together, science, technology, and politics had, in Berger’s view, led society to new heights. As he put it, “We will give them a view from the summit of the steep slope that has been climbed since the dark ages.” Not only was the Eiffel Tower to be climbed by every Parisian visitor, as Berger imagined, but to be built it had also to climb up on itself. It was to be the perfect symbol of the new world view, its lightness of form a contrast to the dark ages. Finally, the fair was to show that “the law of progress is immortal, just as progress itself is infinite.”

Such was the promotional language of 1889. The tower has continuously provoked aesthetic responses—some of it in the form of fine poetry and impressive painting—because Eiffel designed it to be a beautiful object with no historic precedent prior to the Industrial Revolution.

Structure and Architecture

To the shrill criticisms of the tower as “useless . . . monstrous . . . baroque, mercantile . . . dizzily ridiculous . . . like a gigantic factory chimney,” Gustave Eiffel (1832–1923) responded carefully and profoundly. “The first principle of architectural beauty is that the essential lines of a construction be determined by a perfect appropriateness to its use.” He was not referring to the architecture of the past or even of his own time; this we can see immediately by his definition of “use.” For Eiffel, use meant primarily the tower’s ability to carry loads. “What was the main obstacle I had to overcome in designing the tower?” he continued. “Its resistance to wind, and I submit that the curves of its
four piers as produced by our calculations, rising from an enormous base and narrowing toward the top, will give a great impression of strength and beauty."  

In designing the tower, Eiffel integrated form and function in a new way. For Eiffel, as for all structural artists, function or use was to be narrowly defined as the carrying of the large loads. Such problems of load and scale had already been experienced by Telford, Brunel, and Stephenson. Function was, therefore, not defined by human use in the sense of living, working, meeting, and worshiping. These more complex uses were and are the functions for which architects create forms. The more that loads play a role in design, the more a work approaches the category of pure structure.

The validity of this distinction in terms of function between structure and architecture depends upon another distinction between the two, that of scale. As Eiffel put it, "there is an attraction and a charm inherent in the colossal that is not subject to ordinary theories of art. . . . The tower will be the tallest edifice ever raised by man. Will it not therefore be imposing in its own way?" Eiffel saw clearly that the new materials and the new structural forms defined a new art form. Large scale and narrowly defined use are thus the principles upon which structural art depend. The small scale of the private house and its complex human use make it a prototypical work of architecture; the long span of a bridge and the rise of a tower combined with their heavy loads make them prototypical of the engineer's art.

But as works of art structures must have a conscious symbolic meaning, as well as an obvious response to the function of physical loads. This, too, Eiffel recognized, as is apparent in his defense of the tower: "It seems to me that this Eiffel Tower is worthy of being treated with respect, if only because it will show that we are not simply amusing people, but also the country of engineers and builders who are called upon all over the world to construct bridges, viaducts, train stations and the great monuments of modern industry." The tower was thus, in Eiffel's mind, the great symbol of a revived France—not the flounce of the Folies Bergères but the forge of the industrial future.

Thus Eiffel described his tower by identifying the three principles of structural art: large scale, narrowly defined use, and the embodiment of social values and aesthetic ideas. Scale implies a scientific approach to form because of the great risks encountered; use implies a social ethic related to cost and utility; and, finally, the ability of a structure to express ideas implies that it is symbolic in the same sense as any other type of work of art: consciously symbolic.

All of these principles depend upon the technical skill of the designer, and the simple fact is that no contemporary structural engineer had a greater skill than Eiffel. The tower climaxed a career which was, on purely technical grounds, the most impressive anywhere. As with Telford, Stephenson, and Brunel, the permanent results of Eiffel's work are both the most visually impressive and the most technically refined structures of their age. To see these results in Eiffel's designs, we need to have a brief picture of his career and to look more closely at a few of the many spectacular structures upon which he drew for the completion of his tower.

**Gustave Eiffel**

Eiffel was born in Dijon on December 15, 1832, and was raised in a middle-class family. In 1852, he failed the examination for entrance into the prestigious public École Polytechnique in Paris. Undeterred, he enrolled in the private École Centrale des Arts et Manufactures, from which he graduated in 1855 with a degree in chemical engineering. A family feud prevented him from entering his uncle's vinegar business in Dijon, so he took a job with a firm that designed and built railway equipment. It was by chance, therefore, that he landed in the great industry of the period and that his energy became directed toward its new material, iron. In 1858, he was sent to Bordeaux to build a 1600-foot-long, seven-span, cast-iron bridge across the dangerous Garonne river. His careful calculations combined with an inventive construction scheme brought the bridge to completion on schedule in 1860.

By 1867, he had left the railway firm and established himself both as a designer and as a builder with a factory for metal construction in a Parisian suburb. His business quickly grew to international propor-
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tions; by 1885, he had built hundreds of major iron structures including bridges, railway stations, exhibition halls, gas works, reservoirs, cranes, factories, and department stores. He had become France’s leading engineer in iron.7 Aside from a profitable business, however, he had designed and built a series of structures that showed his aesthetic ideas, even if the art world paid him no attention. As Le Corbusier put it years later, Eiffel “was pained by not being seen as a creator of beauty. . . . His calculations were always inspired by an admirable instinct for proportion, his goal was elegance.”8

The 1851 Crystal Palace and the 1867 Paris Exhibition

For the 1867 fair, Eiffel was asked to design the Machinery Hall, the largest part of the immense Central Pavilion, France’s version of the Crystal Palace. The contrast between the Machinery Hall and the Crystal Palace is striking, and central to a recognition of why structural art in iron reached its climax in France rather than Britain. Visually the 1867 hall could not compare to the 1851 British structure, but technically it was far more significant. For the Machinery Hall, Eiffel prepared a 110-page report on iron arch design which included one of the first full sets of computations on arch behavior.9 This structure, the largest of its kind at the time, was 1,608 feet long and 1,266 feet wide, and was made in one huge ellipse with seven concentric galleries. The outside gallery roof carried Eiffel’s arches over the hall of machines. They spanned 115 feet, and rose only 20 feet. The arches of the transept of the Crystal Palace had only spanned 72 feet, but they had risen about 36 feet. In concept, these British semicircular arches were not structural. Rather, they reflected forms antedating the Industrial Revolution. Even in their material—wood—they were not modern.10 Eiffel’s arches, on the other hand, were flat, nearly parabolic, and wrought iron, demonstrating visually the potential for structural art. By comparison, the Crystal Palace was as primitive in its structure as Iron Bridge. But, just as Iron Bridge had symbolized a new manufacturing process for bridges, so the Crystal Palace took on a similar meaning for buildings. Its hundreds of standardized pieces bolted together stimulated architects to try and imagine an aesthetic in iron that might compete with the accepted taste in stone. These designers could not succeed because the Crystal Palace was not structural art.

Eiffel explained years later why this was so. “The English engineers have almost entirely bypassed calculations and they fix dimensions of their members by trial and error and by experiments . . . and small-scale models.” By such means Eiffel continued, “the English went ahead of us in their practice, but we have had the honor, in France, to surpass them by far in the theory and to create methods which opened up a sure path to progress, disengaged from all empiricism.”11 This is a contrast radically different from that which Samuel Smiles made between Stephenson as British and Brunel as French. Smiles had contrasted the empiricism of Stephenson to the daring of Brunel, viewing the former as more reliable and hence preferable. Eiffel, however, found French theory more reliable than British empiricism because that theory “permits exact calculations [from which come] structures which are much lighter and at the same time are stronger than those built earlier.”

Eiffel’s motive for theory is therefore aesthetic, economic and technical: to build structures which are lighter, cheaper, and stronger at the same time. He believed that the “sure path to progress” came from combining theory with practice and not in by-passing theory by trial and error and numerous tests. Eiffel did not mean that scientific theory would be the stimulus to better design; rather, he meant that calculation was essential to design because, as he put it, “at the start [of modern structural design], designers multiplied the number of load-carrying members and thus complicated their structural systems; today, on the other hand, there is the tendency to simplify them as much as possible, because the more a system is simple, the more one is sure of how the loads will be carried.” Calculations, therefore, are justified only when they lead to simpler systems and lighter members. Theory has no other significance; everything is secondary to the final built object. Calculations are a means to progress, but progress itself is read in the final forms. To see the progress Eiffel made we shall look at three of his many bridges. In these are both the origins of the Paris tower and the seminal ideas for twentieth-century structural art.
Span and Tower

Between 1867 and 1869, Eiffel constructed four viaducts along the rail line between Gannat and Commentry in the Massif Central west of Vichy. Of the four, the viaduct at Rouzat (figure 4.1) is visually the most striking and accessible since the highway passes directly under as it crosses the Sioule River about 200 feet below the railway. Three 200-foot-span trellis girders carry the rails, and two 200-foot-high metal towers support the girders. These were among the first high towers in iron. But even more significant than their height is their form. At the base the towers spread out in a curve to meet masonry foundations. Here, for the first time, Eiffel used the iron towers to reflect visually the influence of the lateral wind loads.

There is only a single rail line at Rouzat and, therefore, the viaduct is both very high and very narrow. The structure is inherently weakest in the lateral direction; it is in danger of tipping sideways, especially when a train is on the structure and the winds are high. This type of danger shook the industrialized world in 1879 when the high narrow railway over the Firth of Tay in Scotland blew over in a high wind, killing all seventy-five of the people on the train that was crossing. Eiffel, already fully aware of this type of problem in 1867, provided lateral stiffness on all four viaducts by shaping the vertical towers. Here is the beginning of an evolution of form that climaxed on the Champs de Mars twenty years later. Eiffel also developed a new way of constructing the girders by building them horizontally out from the high cliffs over the towers to join in the center. In this way he could avoid all scaffolding in the deep valley. This construction idea, not seen in the final form, nevertheless played a central role in Eiffel's structural art because it made the viaducts economical.

The First Crescent Bridge: Douro

In 1875, the Royal Portuguese Railway opened an international competition for the construction of a bridge over the Douro River near Oporto. The eight different designs submitted with builders' fixed prices give a summary of long-span bridge ideas developed up to 1875. The shorter spans and river towers of two of the designs made them more expensive than comparable designs with longer spans. The other six designs, with roughly the same 525-foot center span, show a wide variety of forms and a wide range of prices.

The two simplest forms were priced the lowest. Of the two, Eiffel's crescent arch is undeniably the more elegant form; it was also the least expensive, being a full 31 percent below the other. The Douro competition confirmed the fact that Eiffel, at age forty-three, was the lead-
simplified and all those who have once made complete arch calculations know that such an advantage is not to be disdained.” Simplicity of calculation, graceful form, and suitability to the necessities of load, all went together in the evolution of the new crescent form. In Garabit, these ideas were extended as its higher arch was given a slightly different form and the intermediate railway supports were moved closer to the center of the arch span. This was done to improve the arch loading, while at the same time making the trellis girder spans equal on either side of the highest tower.

The most obvious difference between Douro and Garabit lies in the center of the span; whereas in the former, the horizontal trellis girder is interrupted, in the latter, Eiffel kept that girder visually continuous and structurally distinct. In part, this difference arises because at Garabit the railway is much higher above the valley than it is at Douro. The flatter Douro form leads to higher forces; therefore, dropping the arch fully below the railway as at Garabit would have increased the forces noticeably. Nevertheless, the Douro form is less satisfactory because it superimposes the arch on the girders without integrating the two visually. Any increased costs at Douro for an even flatter arch would have had no effect on the competition outcome. Douro was the best example of structural art in iron arch bridges built up to 1877; Garabit is the greatest work of structural art ever built in iron arch form and the masterpiece of Eiffel’s bridge career.  

The development of Eiffel’s style can be seen by comparing Garabit (figure 4.4) with Douro. In describing the Douro crescent form, Théophile Seyrig, Eiffel’s engineer, wrote in 1878 that a form was sought that would be “at the same time the most graceful and the best suited to the load-carrying necessities.” Moreover, by choosing the crescent form with hinges at the supports, “the calculations were markedly...