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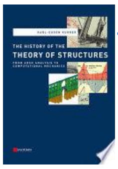
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Ryd søgning Resultat **1** af **1** i denne bog for **parabolic arch of garabit**

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[Walbrach, 2006, p. 278]. It was this structure that placed Eiffel on the international stage for the first time. Eiffel's assistant Théophile Seyrig played the leading role in the planning and execution of the work. The 160 m span of the arch of the Maria Pia Bridge is semicircular, and the arch takes on the function of the beam-like superstructure in the vicinity of the crown. Seyrig's structural calculations are based on the following actions:

– imposed load due to railway operations q_z = 40 kN/m

– wind pressure on unloaded construction q_y = 2.75 kN/m^2

– wind pressure on loaded construction q_y = 1.50 kN/m^2.

Seyrig investigated only three loading cases: maximum load, imposed load on one half of the arch with q_y (asymmetrical loading case), and imposed load on both halves of the arch with q_y acting on a length extending 40 m left and right of the crown (symmetrical loading case).

Eiffel's success led to him being appointed by the Minister of Public Works to build the Garabit Viaduct – along the lines of the Maria Pia Bridge – on 14 June 1879 at the suggestion of the state engineers Bauby and Léon Boyer (1851 – 86) – without issuing a tender [Eiffel, 1889, pp. 135 – 140]. Shortly afterwards, Eiffel sacked his assistant Seyrig because he had asked for a share in the revenue; Karl Culmann recommended his pupil Maurice Koechlin as a replacement. Koechlin substantially revised Boyer's preliminary design for the Garabit Viaduct, which had taken the Maria Pia Bridge as its starting point:

– arch axis follows a quadratic parabola

– distribution of mass in trussed arch adapted to suit local loading conditions

– separation of trussed girder of superstructure from trussed arch

– replacement of cast-iron tubular sections for the columns by box-like riveted rectangular sections made from steel plates.

Koechlin obtained the rise/span ratio by solving an optimisation exercise in which he minimised the weight of the arch. The deviations of the parabolic arch axis from the line of thrust are considerably smaller than for a circular arch axis.

The structural calculations for the Garabit Viaduct which stem from Koechlin's pen form the main part of the book published by Eiffel in 1889 [Eiffel, 1889]. In the calculations, Koechlin achieves an independent combination of Jaques Antoine Charles Bresse's (1822 – 83) elastic arch theory [Bresse, 1854] and Culmann's graphical statics [Culmann, 1864/66] accompanying the elastic arch theory. Both thermal effects and the influence of moving loads were considered in the static indeterminacy calculations. The numbers were evaluated in graphic and tabular form. For instance, when determining the arch displacements, Koechlin evaluated the integrals graphically, a method that Otto Mohr introduced into graphical statics and which would later be called "Mohr's analogy" in the engineering literature.

FIGURE 2 - 47 How the arch of the Garabit Viaduct was erected [Eiffel, 1889]

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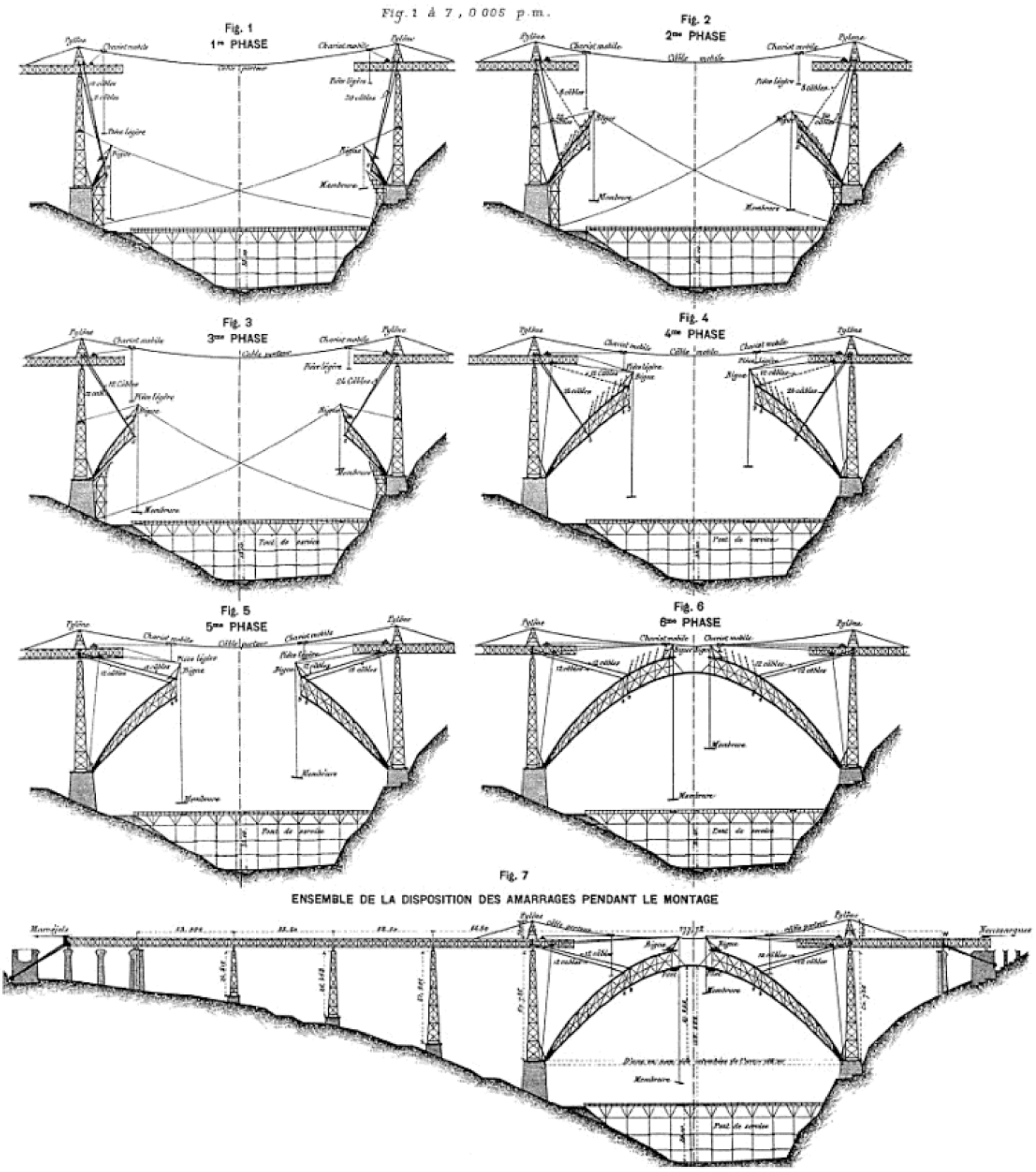

But it was not only the conception, calculations and design that posed new challenges – the building of the Garabit Viaduct also tested Eiffel's company. The necessary infrastructure had to be created first in this uninhabited region of the Auvergne: accommodation, canteen, offices, workshops, stores, cattle stalls and even a school for the children of the workers, who were expected to remain on site for several years and so brought their families with them. At times there were up to 500 workers on site, mostly Italians [Stiglat, 1997, p. 87]. Construction work began in the spring of 1880 with the foundations for the arch abutments. Fig. 2-47 shows how the arch was erected between 24 June 1883 and 6 April 1884. Eiffel's longserving assistant Émile Nouguier (1840 – 98) was responsible for the entire erection procedure.

Like with the Maria Pia Bridge, the arch was built up from both springings like guyed cantilevers: the guy ropes were draped over the tops of the piers rising from the springings and continued to the abutments, where they were anchored [Stiglat, 1997, p. 87]. Some 4000 t of iron and 20 000 m^3 of granite had to be transported the 34 km from the railway station at Neussargues using teams of horses, oxen and cattle. The iron members were then carried across the timber temporary bridge on railborne wagons (see Fig. 2-48) before each piece, weighing about 2 t, could be heaved into position with manually operated cranes. The guyed cantilever construction employed such "mathematical precision in the calculation, fabrication and erection that reworking of the rivets inserted on site – about half of the total of 500 000 – was

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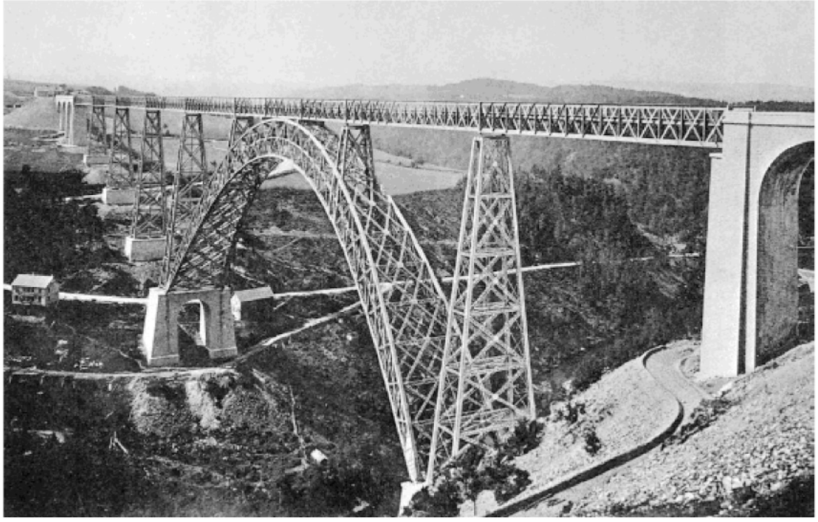
by his company for the Exposition – and named after him but actually designed by his chief assistant Maurice Koechlin (1856 – 1946). But back to the Garabit Viaduct (Fig. 2-45).

FIGURE 2 - 45 The Garabit Viaduct shortly after completion [Eiffel, 1889]

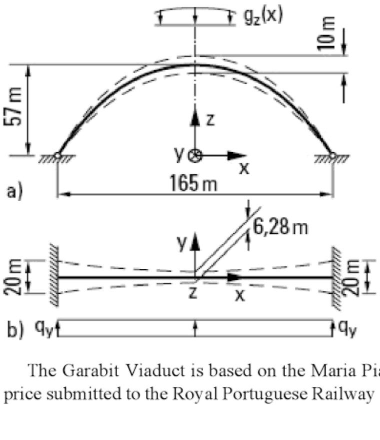


The Garabit Viaduct spans the gorge cut by the River Truyère about 12 km south of the small town of Saint-Flour, enabling the single-track line from Marvejols to Neussargues to cross the deep divide at a height of 122 m (difference between top level of rails and water level before the river was dammed, measured at the centre of the arch). The Garabit Viaduct therefore held the height record for arch bridges for 92 years [Pottgießer, 1985, p. 227]. The total length of the bridge is 564.65 m and the crescentshaped trussed arch (Fig. 2-46) has the following dimensions [Eiffel, 1889, – p. 71 ff; Stiglat, 1997, p. 86]:

– span: 165 m
– rise: approx. 57 m
– depth of arch cross-section at crown: 10 m
– width of arch cross-section at crown: 6.28 m
– width of arch cross-section at springing: 20 m.

As the trussed arch is designed as pinned at the springings (acts like a cylindrical bearing with its axis in the y-direction), the structurally effective depth of the cross-section at this point is zero – in the longitudinal direction the system is an elastic two-pin arch with one degree of static indeterminacy with respect to the self-weight g_z and the vertical imposed load due to railway operations q_z (x–z-plane = vertical plane) (Fig. 2-46a). The trussed arch (the outline of its elevation is shown as a dotted line in Fig. 2-46a) has to withstand bending and axial forces. On the other hand, the system with regard to the wind loads acting horizontally q_y (x–y-plane = horizontal plane) on the crescent-shaped trussed arch is a curved elastic trussed girder fixed at the supports, i. e. three degrees of static indeterminacy (Fig. 2-46b). The trussed girder (the outline of its plan shape is shown as a dotted line in Fig. 2-46b) is subjected to bending and torsion. The main arch of the Garabit Viaduct can therefore be classified as an externally statically indeterminate space frame.

FIGURE 2 - 46 Details of the arch of the Garabit Viaduct: structural system a) on elevation, and b) on plan



The Garabit Viaduct is based on the Maria Pia Bridge over the River Douro at Porto, Portugal, which Eiffel completed in 1877. Eiffel's price submitted to the Royal Portuguese Railway Company was about 40 % lower (per linear meter of bridge) than the next cheapest tenderer

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