Recent Structures Worldwide: An Introduction

Both our regular readers, the IABSE members, as well as new readers who may be getting this special issue of "Structural Engineering International" at the Structures Congress 2005 in New York City, will be delighted to go through this Recent Structures series, aimed at showcasing a wide range of structures recently completed. They all share common features: they were challenging to design and to build, unconventional in their own way, and innovative. They were built all over the world, and in many cases by a truly global partnership of designers, detailers, fabricators and constructors.

As structural engineers in a world where country borders are increasingly just a line on a map, we strive to feed on the experience of other engineers, geographically or by specialty both near and far from us. Designs conceived in Switzerland are executed in Japan, software developed in the USA creates a barrier-free language for the exchange of data in Europe. Bridge technologies get applied to long-span building roofs, architectural aspects traditionally found in building design become a driving force for signature bridges. In a rapidly evolving world, becoming aware of sophisticated analysis techniques and new construction materials and methods as they develop will influence our next project, small or large as it may be. IABSE is the prime professional organization for structural engineers truly committed to the exchange of knowledge and to the advancement of the practice of structural engineering worldwide, as reflected in this and in every SEI issue, and, if you are not a member yet, I invite you to join!

This carefully selected group of recent structures, many of which will be presented by their designers at Structures Congress 2005, is certain to stimulate our creativity. I invite you to read the articles, and to attend the Congress. While in New York, hometown to some of the best and internationally recognized structural engineering firms, don't forget to visit the local outstanding structures, both new and old.

For more information on the Congress, which is organized by the Structural Engineering Institute, please visit www.asce.org/conferences/structures2005. I am looking forward to greeting you in New York City!

Maria Grazia Bruschi
Member, IABSE SEI Editorial Board
Member, Steering Committee Structures Congress 2005

Millau Viaduct, France

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Fig. 1: View of Millau Viaduct near completion *(Photo: Phototheque Eiffage/D. Jamme)*

Introduction

The Millau Viaduct is the major bridge on the A75 motorway between Clermont-Ferrand and Béziers, which will be part of a new link between Northern Europe and Eastern Spain (*Fig. 1*). The city of Millau is located at the confluence of two rivers, the Tarn and the Dourbie Rivers, that cut two deep valleys in the old Massif Central plateau. As the motorway had to pass from a plateau on the North, at an altitude of about 600 m, to the Larzac Plateau on the South, at an altitude of about 720 m, selecting a road alignment was not an easy task, and the more so considering that the lower portions of the hills are made of unstable soil, mainly clay.

After eliminating different options it was decided to erect a viaduct passing directly from plateau to plateau, 275 m above the Tarn River. The concept of the final structure that was erected, a cable-stayed bridge with eight spans suspended from seven pylons, was first proposed by Michel Virlogeux in 1990. The basic idea was to design a very slender bridge, thus cable-stayed, with a series of equal spans which would look logical from the city of Millau, from where the lower part of the Tarn valley cannot be seen due to the multiple river bends. Several other solutions were developed with his design team at SETRA (French national highway department) in 1992–1993.

Through a quasi-brainstorming competition, in 1993–1994, several designers and architects had the opportunity

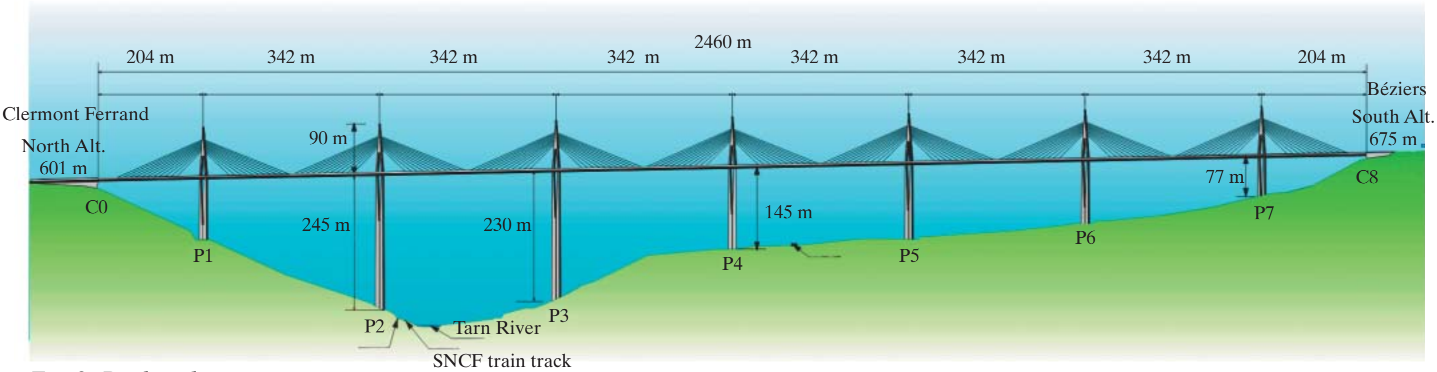

Fig. 2: Bridge elevation

to analyse the SETRA solutions and propose new ones. Finally a quasi-competition was organized between five design teams, each in charge of one type of solution, the five families of solutions being derived from those proposed by SETRA and enhanced by the new ideas that came from the brainstorming competition. The design teams were appointed to develop the solution that was as close as possible to their proposals made during the brainstorming competition. In July 1996, the jury selected a cable-stayed bridge with multiple spans. The project was developed between 1997 and 1998 by the winning team which included Sogelerg (now Thalès Engineering and Consulting), EEG Simecsol (now Arcadis), SERF, and Foster and associates, together with Michel Virlogeux. In actuality, there were two parallel projects, one in prestressed concrete and one in steel.

Due to the high global cost of the motorway, the French government decided that the bridge would be built within a concession. Three major groups took part in the competition in 2000–2001, and the concession for 75 years was awarded to Compagnie Eiffage du Viaduct de Millau, a specific company created for this occasion. Construction work began on October 10, 2001. As the group Eiffage includes a steel constructor, Eiffel Construction Métallique, the steel solution was preferred. Construction was carried out by Eiffage Travaux Publics and Eiffel under the supervision of an independent checker, a joint venture of SETEC and SNCF (the French railways). The final detail design was developed by Greisch (for the steel parts of the bridge), Arcadis, Thalès E and C, SERF and Eiffage TP.

Bridge Cross-Section

The Millau Viaduct, 2460 m in length, consists of eight spans; two side spans 204 m long, and six intermediate spans 342 m long (*Fig. 2*). The cross-section is a streamlined orthotropic steel box-girder with two vertical webs required by the selected erection technique. Triangulated cross-beams, spaced at 4,17 m longitudinally, were preferred to full diaphragms. This box-girder carries two lanes of traffic in each direction with 3 m wide shoulders to increase the distance between the traffic and the bridge edge, in order to reduce the risk of vertigo (*Fig. 3*). The box-girder is equipped, in addition to classical barriers, with wind screens designed to limit the wind velocity on the viaduct to the value at the approach ground level, in order to avoid wind shocks to vehicles arriving on the bridge; and of fairings intended to improve both the aerodynamic streamlining and aesthetic quality (*Fig. 4*).

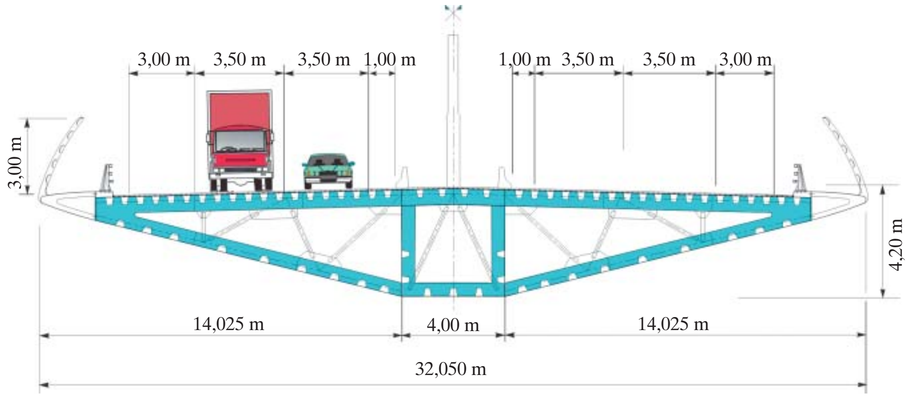

Fig. 3: Cross-section of bridge deck

Fig. 4: View of wind-screen

Piers

The design of the bridge results from major structural demands; to balance unsymmetrical live loads in the multiple cable-stayed spans, as well as to adapt to the length variations due to temperature effects in the box-girder. To resist the high bending moments due to their extreme height, the piers were designed as wide strong box-sections that split into two flexible shafts in the upper last 90 m (*Fig. 5*).

The box-girder deck is tied down to the pier by vertical prestressing tendons in line with the two fixed bearings on each shaft, and the pylon, above, has the shape of an inverted V. Under the effects of unsymmetrical live loads or extreme wind loads, the vertical load on each bearing can reach 100 MN. To reduce the bearing size, spherical Maurer bearings covered with a new composite material which can resist stresses up to 180 MPA under ultimate loads were used.

The piers have a variable cross-section, the shape of which has been designed by the architect in close collaboration with the engineers to allow for ease in

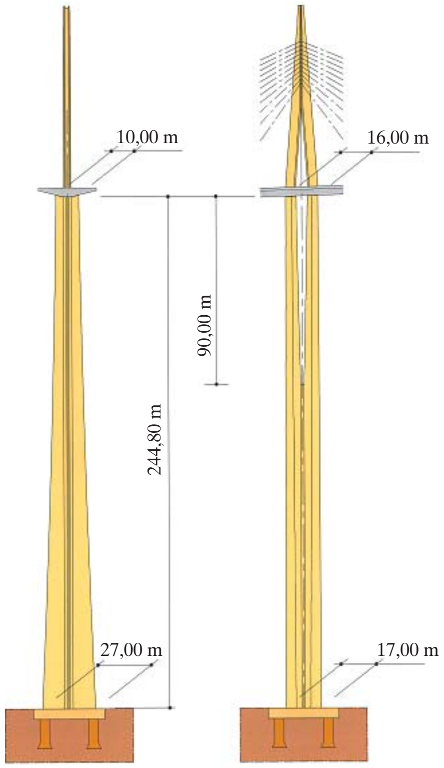

Fig. 5: Typical pier elevation

Fig. 7: Launching of girder with front pylon and cables in place

Fig. 8: Launching operations nearing completion

construction despite its variations. Four panels have fixed dimensions, and the other four change slightly in each segment, including their orientation. This allowed for an erection with external self-climbing forms developed by Peri, and classical internal shutters moved by the tower crane.

Fig. 6: Tower crane used to construct piers

The two taller piers are 245 m (P2) and 223 m (P3) high. The tallest tower crane, for P2, reached a height of 275 m. It was therefore necessary that each tower crane was fixed to the corresponding pier, step by step, according to the construction progress (*Fig. 6*).

Each pier is founded on a series of four "artificial" wells, 4 or 5 m in diameter, 9 to 16 m deep.

Launching System

The steel box-girder deck was launched from both ends, with a final closure made above the Tarn River between piers P2 and P3. Intermediate temporary supports, each in the shape of a tubular truss, were installed in each span except for the closure span. In the intermediate spans, these temporary supports, 12 m by 12 m, were at mid-span with two lines of launching equipment to reduce the launching span to about 150 m. The temporary supports in the side-spans were simpler, smaller and with only one line of launching equipment.

Each of the two launched structures was equipped with its front pylon (without the summit to reduce wind effects during launching, limiting the pylon height from 87 to 70 m) and with six stay-cables in order to reduce bending moments during launching (*Figs. 7, 8*).

Each launching operation, or launching span, corresponded to 171 m and took five days, for the first launching operations which were more complex, to three days for a typical one, under good weather conditions. No launching operation could begin if winds of more than 37 km/h (average speed) were to be anticipated by the meteorological station during the launching period.

The launching system, developed by Eiffel, Greisch and Enerpac, is highly innovative. Due to the extreme pier height, friction forces had to be directly balanced within each support. Each support was thus equipped with active launching bearings (two per line of bearings). Horizontal hydraulic jacks at the bearings produced the horizontal motion with a central command from a computer and sensors to control that the displacement was the same on all supports at all times.

Fig. 10: Pylon being tilted up into position

Pylons

After the closure above the Tarn River, on May 18, 2004, the pylons (*Fig. 9*), which had been fabricated in different factories and assembled behind the bridge abutments, were transported one by one onto the deck, each by two crawlers. The weight of a convoy reached 8 MN, producing an extreme load test for the structure. Then the pylon, in a horizontal position, was tilted up by Sarens with the help of a cable-stayed temporary support tower (*Fig. 10*). The structure construction ended with the installation and tension of stay-cables by Freyssinet.

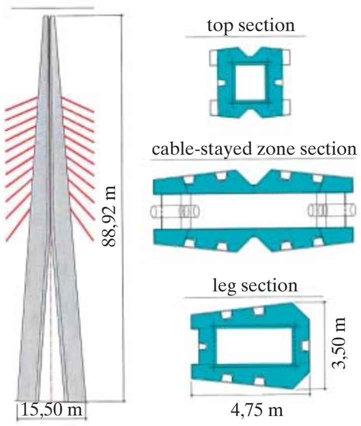

Fig. 9: Pylon elevation and cross-sections

Conclusion

The Millau Viaduct was inaugurated on December 14, 2004, only 38 months after construction started, and opened to traffic on December 16. Extensive measurements will be made during the first two or three years to monitor and control the structure behaviour, and especially its response to wind and temperature.

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SEI Data Block

Public Authority:
Direction des Routes, France
Arrondissement interdépartemental des ouvrages d'art de l'autoroute A75, Millau, France

Design Engineer:
Michel Virlogeux, Bonnelles, France
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Arcadis, Sèvres, France
Thales E et C, Rungis, France

Architect:
Foster and Partners, London, UK

Concessionaire:
Compagnie Eiffage du Viaduct de Millau, Millau, France

Contractor:
Eiffage TP, Neuilly sur Marne, France
Eiffel Construction Métallique, Colombes, France

Concrete (m^3):	72 000
Reinforcing (t):	26 200
Structural Steel (t):	40 600
Stay-cables (t):	1500
Project cost (EUR million):	300
Service date:	December 2004