Design of the new bridge over the Var River in Puget-Théniers
A small span cable stayed bridge

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Summary

For hundred of years, the Brouchier Bridge has carried the road traffic over the Var River in the town of Puget-Théniers. The narrowness and the old age of this bridge led the county Council of Alpes-Maritimes to consider the construction of a new crossing. The SETRA was involved in the project from the preliminary design to the final design process and analysis of the new structure, including finite element modelling and seismic analysis. After the preliminary design, the solution chosen by the owner was a dissymmetrical cable stayed bridge with a prestressed concrete deck. The main span is 66 m long and the side span, which is embedded in a balancing block located on the right bank, is 16 m long. A thin deck of 0.90 m depth supports two traffic lanes and two footways. Several challenging issues due to site constraints had to be overcome in the design of the structure. These included anti-seismic strategy, special thoughts to set the left bank abutment, and a specific consideration to account for very strong flows within the construction phase.

Keywords: design; prestressing; cable stay; high performance concrete.

1. Introduction

In 1999 the Department Council of Alpes-Maritimes considered the need for a new crossing facility of the Var River in the town of Puget-Théniers. The existing bridge, known as the Brouchier Bridge, links the north part of town to the south and the road leading to the Saint Raphael pass.

Fig. 1 Brouchier bridge and left bank

Built in 1888, the structure consists of a three-span steel lattice girder with a total length of 64 m. This bridge carries one lane of traffic (*Fig.1*). The narrowness and the steel corrosion of the former structure have led the county Council to study a new crossing facility with no supports in the river. The design responsibility was contracted to the SETRA.

The owner wished to build a distinctive and economic structure constituting a visible technical and architectural landmark.

The Architect associated with the design team was Laurent Barbier.

The choice was to build the new structure 50 m downstream from the former one. At this location there is a wide platform on the right bank that allows various layouts. The design includes the bridge structure, the crossroad layout on the right bank, the crossroad layout on the left bank with the national road and the railway track parallel to the river, as well as the modification of railway track level crossing. The new bridge will carry two lanes of traffic and two footways.

The main restraints were no supports in the river, a thin deck due to imposed clearance towards the floods, and a distinctive but economical structure. The conception choices were simplicity of shapes and reasonable cost.

2. Site constraints and preliminary design

The background is fairly complex. The bridge is located near the heart of town in a steep-sided valley with a torrential flow river. The width of the riverbed is approximately 70 m. In 1994, a flood swept along the railway track and the national road just downstream from the bridge site (*Fig.2*). These damages are mainly located at the river bends in the winding sections [1].

Fig. 2 Consequences of the 1994 flood

The valley is also in a moderately seismic region, and special attention had to be paid to design bearings and foundations. The size of the piles has to be limited to reduce forces due to piles deformation under seismic events.
During the preliminary design, advanced geological and geotechnical analyses were conducted to determine rock profile. Because of the mountain slopes on each side of the valley, we felt uncertain on the rock location under the riverbed and on the existence of failures or faults. EEG Simecsol investigated the geophysical and geotechnical programme, which included a refraction seismic profile and pressiometric borings. Ground consists of a clayey silt deposit layer (around 10 m), fractured calcareous marl with clay layers filling the cracks. The refraction seismic profile allowed the verification of the regularity of the rock profile, and confirmed that on the right bank the calcareous marl is inclined around 50 to 80°. The bridge will be supported on piled foundations and a balancing block for the cable stayed solutions.
The preliminary design was submitted to the owner in January 2001. Five projects were studied without any support in the river: a lattice girder solution, a tied arch bridge solution, a cable stayed composite deck solution, and two cable stayed concrete deck solutions.
Both lattice girder and tied arch bridge designs were simply supported single spans of 76m.

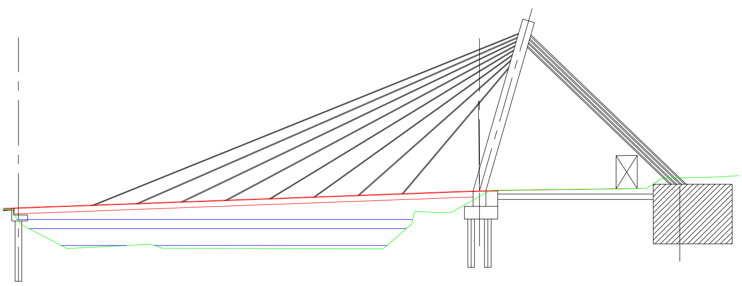

Fig. 3 Long span cable stayed solution

The prestressed concrete deck and composite deck cable stayed solutions were asymmetric with a short span over the river and a side span on the right bank, respectively 66m and 16m.
The long-span prestressed concrete deck cable stayed solution was also asymmetric with a main span, 76m long, reaching the top of the right bank platform, an inclined mast and back stays implanted in the middle of a roundabout. (*Fig*.3).

The owner chose the short span cable stayed prestressed concrete deck solution. The structure is an asymmetric cable-stayed bridge with a main span of 66m. The side span of 16m is embedded in a balancing block of 12m located on the right bank (see *Fig*.4).
The semi-fan shaped staying in the main span is made of two planes of seven stays, and the harp-shaped backstays are made of two planes of four stays. The concrete pylon comprises two 25m-high vertical masts.

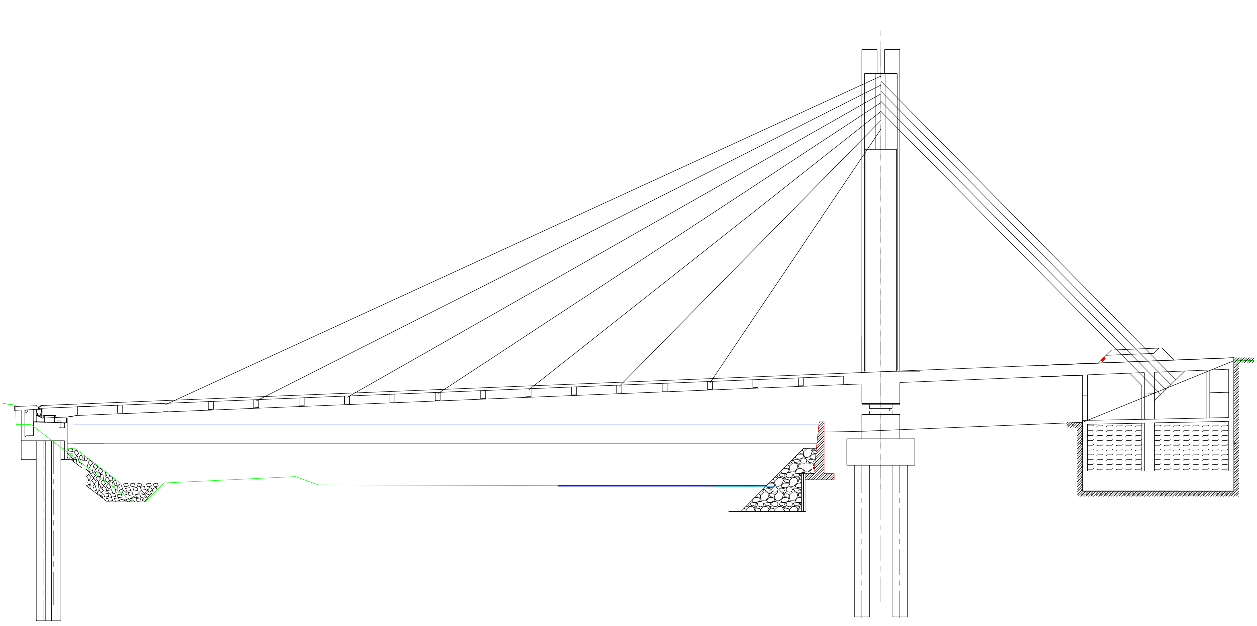

Fig. 4 Short span cable stayed solution

The 15.2m-wide deck supports two 3.5 m road traffic lanes and two 2.5 m footways (see *Fig*.5).

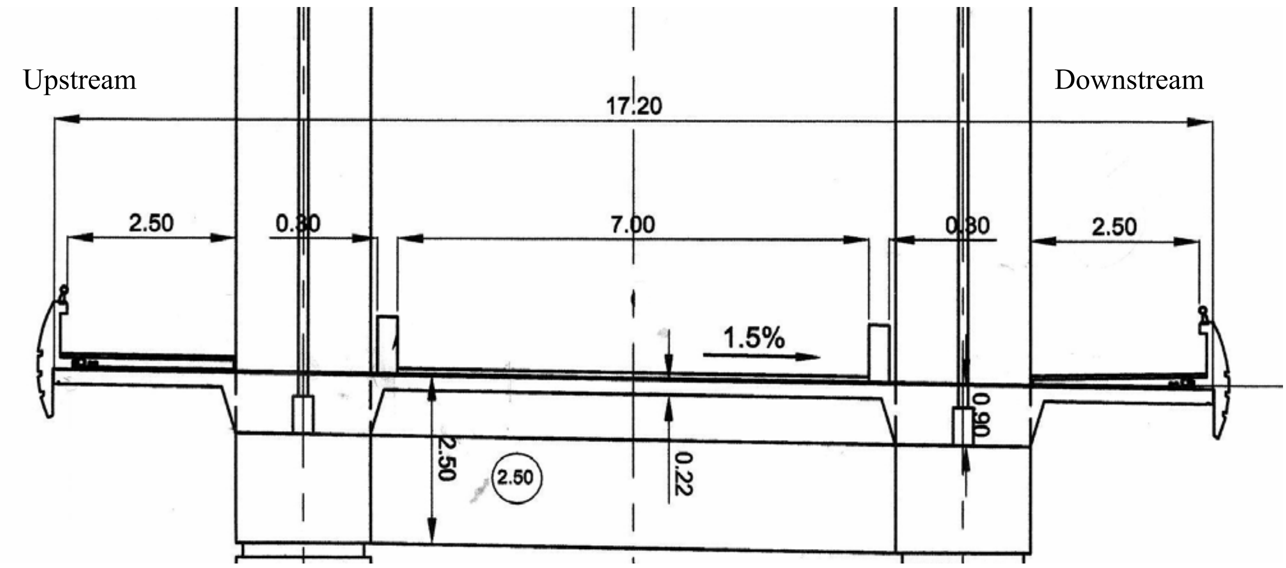

Fig. 5 Transverse section

3. Project

3.1. Deck

The concrete deck comprises a 22cm slab supported by two longitudinal ribs, 90cm high and 80cm wide, and cross girders spaced at 3.6m. The distance between stay anchorages on the deck is set at 7.2m to limit the unit capacity of the stays. The main span stays are anchored on the deck in notches located under the longitudinal ribs. This layout ensures direct transfer of staying forces. The deck is prestressed with longitudinal 19T15s type tendons located in the ribs. The number of tendons grows to seven pairs from the pylon to the abutment to complete the compression due to the stays and gives a uniform normal force along the span.

3.2. Pylons and stays

Conception of the vertical pylons agrees with technical and architectural requirements. The two masts are embedded in the deck by mean of a deep cross brace, with a square cross section of 2.5m (see *Fig*.5). The masts have an egg-shaped section of 2m by 3m. Each mast has four vertical grooves, two in the longitudinal direction, receiving the stays laid-out in a single plan, and two in the transversal direction of the bridge.
The stays design has been carried out with plastic coated parallel wire strands, but it was open to other type of stays. The fourteen span stays comprise between 15 and 22 plastic coated wire strands. Each strand comprises 7 galvanized round wires class 1770 MPa. At deck level the span stays are spaced at 7.2 m longitudinally and 9.80 m transversally. The eight backstays comprise 37 plastic coated wire strands. In the balancing block they are spaced at 0.9 m longitudinally. In the mast head the stays are distributed to obtain pure compression in the mast under self weight.

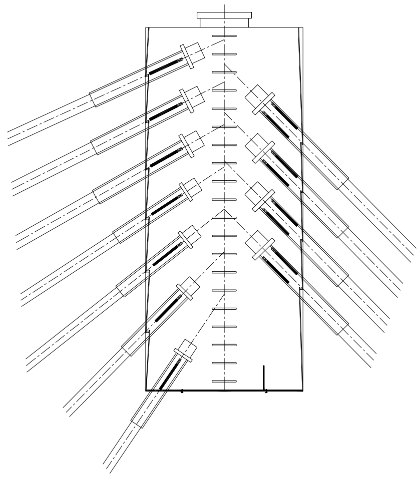

Fig. 6 Masthead steel box

The stay cables are anchored to the masthead in a steel central element integrated in the mast concrete (see *Fig.6*).
In between two vertical steel plates, 6m high, cables anchorage tubes are sustained by mean of inclined transition plates welded to the vertical ones. The transition plates give the cables longitudinal inclination. There is one pair of transition plates for the span stays and two pairs for the backstays. The vertical plates are connected on both sides in the mast concrete. The horizontal component of the anchored force is transmitted from the span stays to the backstays through the vertical steel plates, and the vertical component is transmitted through concrete by the connection.
This steel box is protected against corrosion by a zinc-based plating.

3.3. Supports and bearings

The most difficult challenge for the design was the abutment on the left bank. At this location the railway track is supported by a retaining wall that turns in a slope at mid abutment. The result was to replace the slope by a retaining wall in continuation of the existing one and to set the abutment just alongside it. The abutment stands on four bored piles 13 m long ∅120. It consists of a back wall and sidewalls built on a head beam 1.45m thick. Five rectangular pillars support the slab close to the expansion joint. Two pilasters supported by the head beam on both side receive lighting columns. Pilasters and sidewalls repeat the external form and pattern of the cornice.
The right bank counterweight abutment is laid on the rock roof with lean concrete. The counterweight is 10m thick, 15.2m wide and 12m long. It comprises several concrete cells filled with compacted graded aggregate.

The seismic resistance of the bridge is provided by a full rigid connection in the balancing block. Sliding pot bearings are used on both the pier and the left bank abutment. A transversal stopper is also placed on the left bank abutment in order to prevent deck torsion and bridge displacement.

3.4. Modelling

During the preliminary design, the structure modelling was carried out in two dimensions using ST1 bar numerical model. During the project design stage, the structure computation required three models to cope with different aspects. Longitudinal flexion and transverse bending of the deck were justified with ST1 2D bar modelling. The seismic analysis has been investigated with PCP bar numerical 3D model (see *Fig.7*). The PCP spatial model allows a modal and spectral analysis of the structure. Three longitudinal beams model the deck. The two lateral beams correspond to the ribs and the central beam to the slab. Transverse beams link them.

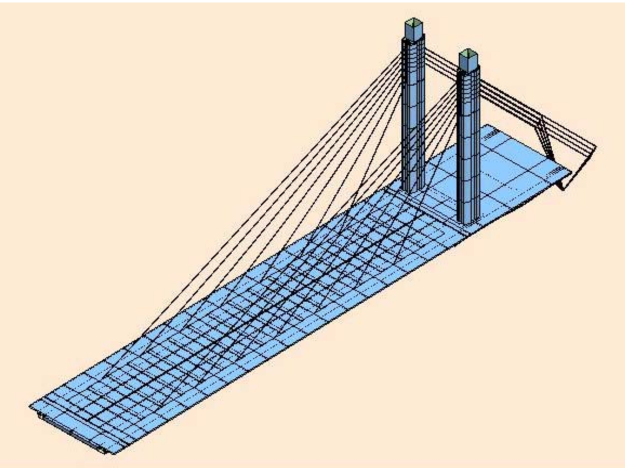

Fig. 7 PCP dynamic model

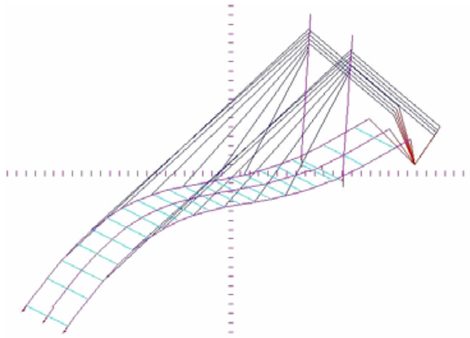

Fig. 8 Mode 1: vertical

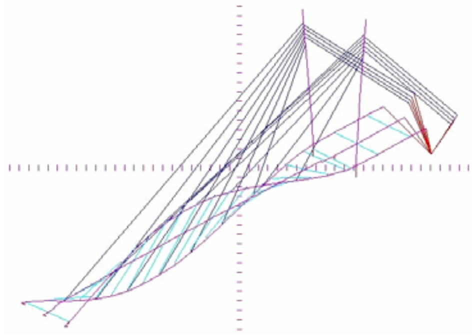

Fig. 9 Mode 2: torsion

The elastic response spectra taken into account is the one defined by the AFPS92 rules with an acceleration of 3 m/s^2 and a structural damping of 5% in reference to the guide for bridge design in seismic area [2].

Table 1 Results of modal analysis

Mode number	Frequency (Hz)	Type
1	0.862	Vertical
2	1.493	Torsion
3	1.786	Mast bending
4	1.786	Mast bending
5	1.887	Vertical
6	2.941	Torsion
7	3.333	Vertical
8	3.704	Transversal
10	5.000	Vertical

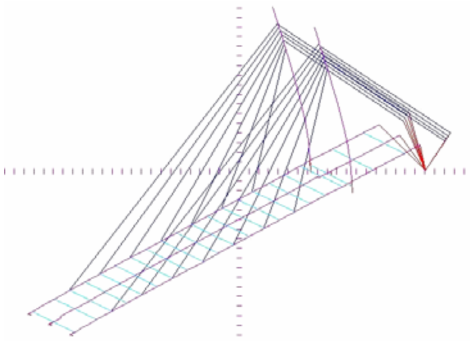

Fig. 10 Mode 4: mast bending

Towards vertical seism, the structure is justified by the 4th mode (see *Fig.10*) for the mast base, and by the 8th mode for the horizontal stopper and abutment piles (see *Fig.12*).

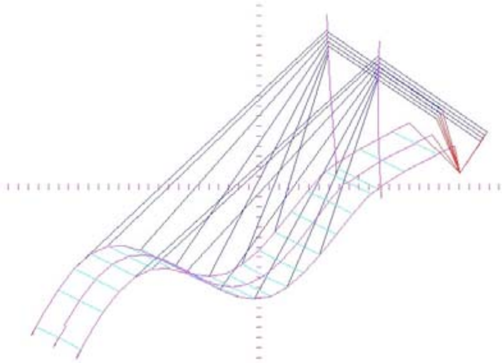

Fig. 11 Mode 5: vertical

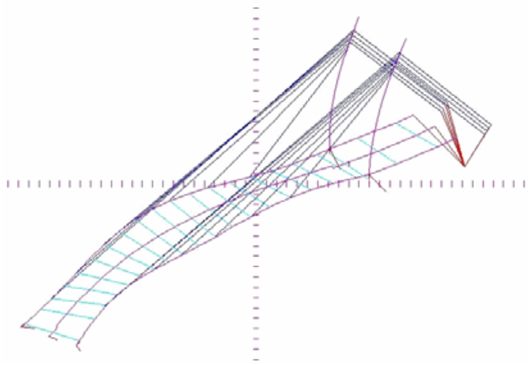

Fig. 12 Mode 8: transversal

4. Construction methods

The construction of a thin concrete deck by successive cantilevering is difficult to fix and is less economic in the case of a short span. Therefore we thought to build the deck on a general steel temporary centring. The deck is concreted in four stages from pylon to left bank abutment. The first section is concreted with the masts base and the transverse beam. The shape of the masts is relatively simple; we thought to build them using mobile formwork with lifts of approximately 4m.
Using a temporary centring, all risks had to be taken into account because of the unpredictable behaviour of the Var River. The idea proposed by the contractor finally awarded to build the bridge on the right bank and position it by rotation was received with relief. The counterweight is divided in two parts. The upper part ensures the stability of the main span during rotation and is connected to the lower part by mean of vertical columns and horizontal beams concreted after rotation. The upstream mast support is used as pivot during rotation and the other mast support moves along a circular beam based on bored piles.

5. Conclusions

The construction of this bridge started in November 2003 and the work will last about 14 months.
This structure has been designed with the practice of the average cable-stayed bridges engineered by the SETRA over the last twenty years. This was a great experience due to the site constraints that had to be overcome in the design of the structure. The final design results in an elegant structure characterize by its lightness, its simplicity and its strength.

[1] CEMAGREF, "Etude de la crue du Var du 5 novembre 1994", 1996 Cemagref Aix-en-Provence.

[2] SETRA, SNCF, “Ponts courants en zone sismique – Guide de conception”, 2000 Sétra, pp. 64-67.