STRENGTHENING OF THE MARTIGUES VIADUCT

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Introduction

The Martigues viaduct is carrying the A55 motorway and crosses the navigation channel connecting the Berre pond to the Mediterranean Sea (Fig.1). It is made of two distinguishable structures: the main steel bridge – a 300 m long delta-leg bridge that is 40 m high and 115 m wide – and four approach viaducts – two on the north and two on the south. These viaducts are the subject of this paper since these structures are concerned by strengthening operations [10].

The approach viaducts are twin independent decks, each carrying one traffic direction. The northern viaducts are made of 6 continuous spans, with 45.00 m for the standard span, excepting the span close to the north abutment that is 34.50 m long (total length of 259.50 m). The southern viaducts have 7 continuous spans with standard length of 45.00 m, except the span close to the south abutment that is 44,50 m long (total length of 314.50 m). These viaducts have longitudinal and transversal slopes of 4 % and 2 %. The decks are 3.00 m high ribbed slabs: they are longitudinally and transversally prestressed. The longitudinal prestressing has coupling joints located at the connection joints. The distance between ribs is 8.40 m and the ribs have variable width from 0.86 m at the bottom to 1.00 m at the top. . The deck was erected by a movable scaffolding system.

The decks are supported by « I » piers with a variable height ranging from 23 m to 43 m toward the steel bridge. At one side, the decks sit on hollow abutments while, at the other side, they are on piers shared with the steel structure. On these piers, four damping seismic systems (oil jacks) of 150 tons are installed between the steel and the concrete decks.

Fig.1. General view of the Martigues bridge ©photothèque BYTPRF

This paper present the strengthening works carried out on this bridge between 2011 and 2014 under the supervision of the DIR Méditerranée. It is based on the author's paper published in the « Travaux » journal (N°896) [10]. Works have been performed by Bouygues TP Région France.

The works

Several experimental investigations were made between 1981 and 2003 in order to identify the bridge pathology: cracks in the vicinity of construction joints located at 9.00 m from the support lines (coupling area of the longitudinal prestressing). These cracks follow the line of the construction joints and expands over the three quarters of the rib height from their bottom part. They are due to an incorrect functioning of the coupling joints, the non-inclusion of the thermal gradient and the poor concrete quality in these complex construction zones (segregation, holes…).

A serious disrepair of the bearing systems and out-of-service seismic devices complete the bridge condition.

The different structural analyses have concluded that the strengthening of the bridge was recommended and it was proposed to add additional prestressing tendons anchored at each end, designed to constrain critical sections. This strengthening also consists in grouting cracks, replacing bearing systems and modifying the seismic design of the bridge (the city of Martigues being reclassified from low to moderate seismic zone from the new French seismic regulations).

Execution studies

Regulation and design assumptions

The execution studies of the Martigues bridge strengthening has been performed according to the following assumptions:

- *Design code: BPEL 91 [1],*
- *Load code for bending moment calculation: Fascicule 61 Part II (traffic loads with Al and Bc scenarios, and military scenario MC120) [2],*
- *Temperature loading (uniform temperature -40°C/+30°C, gradient +8°C),*
- *Seismic loading recommendations or standard: AFPS 92 and Eurocode 8-2 [3-4].*

The strengthening project is not intended to comply the bridge to current standards or codes, but to close crack openings located at the coupling joints of the existing prestressing. Under these assumptions, the additional prestressing has been designed in such a way that:

- *At the construction joints (coupling zones with the existing prestressing):*
    - *Criterion 1: the cross-section must remained compressed under all actions (« SLS frequent » combination) and under the prestressing effect only;*
    - *Criterion 2: for « SLS characteristic », tensile stresses in the reinforcement and the overtensions on the tendons (designed under Class III assumption of BPEL 91) must be in agreement with the BPEL specifications;*
    - *Criterion 3: for ULS, deformations of the different materials are in agreement with the BPEL specifications;*
- *At other points:*
    - *Criterion 4: the additional prestressing does not induced tensile stresses in the cross-sections.*

The studies regarding the nailing of the anchor/deviator blocks for the additional prestressing have been made according to the NFP 95-104 standard [5]. The block connection has been designed by using prestressing bars and reinforcement sealing according to the guidelines given the paper [6]. A composite design (prestressed/reinforced concrete) led to:

- *Under SLS scenario, the anchor block are designed with NFP 95-104 for the prestressing alone,*
- *Under ULS scenario, the anchor blocks are checked with reference [6].*

Bending loading

A grid-model of the bridge deck has been used for the studies of the bending load effects (ST1 software from Cerema [7]). The total prestressing (existing and additional) has been included in the model and the delayed concrete effects (creep, shrinkage, relaxation) have been introduced in the different calculations.

This model allowed to evaluate the new reaction load on the bearing systems and to check the normal and shear stresses in the decks for the different phases of the bridge life (current structural condition, structural condition after repair, structural condition with additional jacking, structural condition at 50000 days).

The cross-sections have been designed with the CDS software from Cerema [8] under the assumption of cracked cross-sections. For this assessment, the prestressing load effect has been introduced:

- *In case of a perfect functioning of the coupling joint, by 100 % of the prestressing load,*

- *In case of a degraded functioning of the coupling joint, by 70% of the prestressing load.*

Anchor blocks

The anchor blocks are equipped by prestressing bars for the following objectives:

- *Vertical bars:*
  - *To balance the shear loads induced by the existing and additional prestressings,*
  - *To maintain the connection of the steel members supporting the PDS under the ribs.*
- *Horizontal bars :*
  - *To design the block nailing under the effect of the additional prestressing,*
  - *To balance the slippage induced by the vertical prestressing at the block/rib interface,*
  - *To balance the slippage comming from the moment induced by the PDS on the anchor block under seismic loading.*

The studies of load transfer in deck outer face have been made according to the analytical approach from Annex IV of BPEL [1] with local calculations with finite element models (Fig.2).

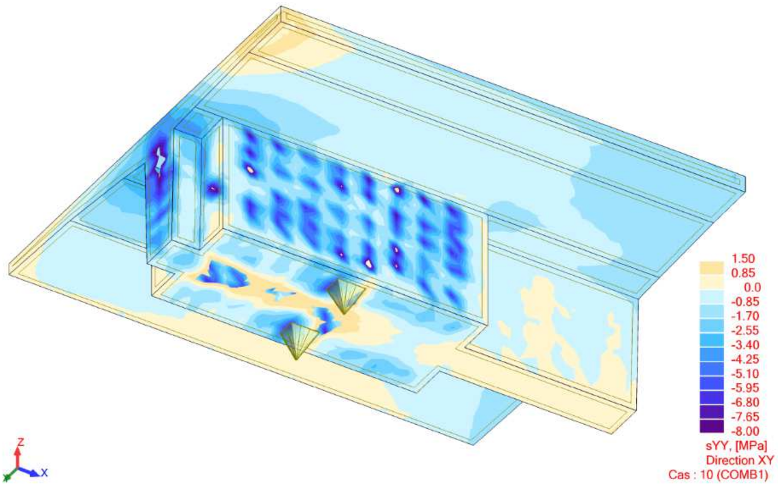

Fig.2. Finite element modelling ©COGECI

Seismic analysis

Seismic loading in transverse and vertical directions have been studied with a multi-mode analysis with the ROBOT software [9] (Fig.3). This modelling helped to determine:

- *The transverse load effects to sustain by the seismic blocking systems located at pier head,*
- *The transverse movements of the decks,*
- *The reaction loads on the bearings.*

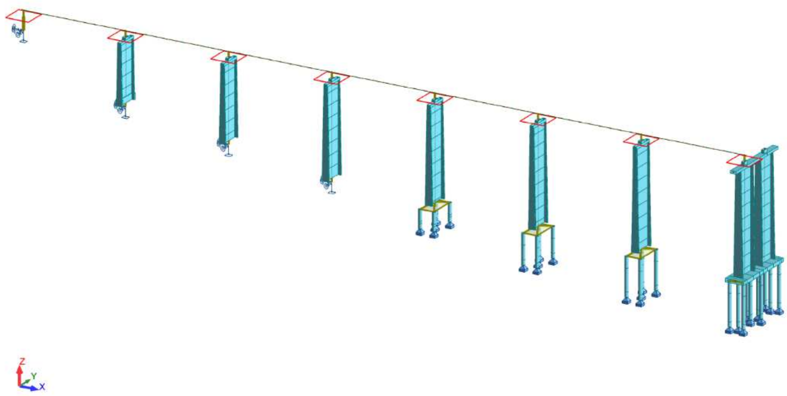

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Fig.3. View of the seismic design (south-east deck) ©COGECI

In the longitudinal direction, Prestressed Damping Springs (PDS) have been installed between the decks and the abutments in order to restrain the seismic load on the abutments. PDS are designed according two criteria:

- *To obtain a longitudinal seismic loading lower than 1200 t on the abutments (load-carrying capacity of the abutments),*
- *To obtain a deck movement lower than 20 mm.*

These criteria are checked with a time-domain analysis using the AK SISM software [10]. The seismic loading has been introduced by an acceleration signals provided by the bridge owner.

Additional prestressing

The additional prestressing is composed of two tendons 27T15S for each rib (i.e. 1000 t of compressive load per rib) following a polygonal drawing. The prestressing system is a VSL type GC6-27 and the tendons are acting over the total length of the deck with deviators on piers and on main spans. The HDPE pipes are installed span by span and connected by electro-weldable sockets. Specific temporary devices (« hammock » type) are used to support the tendons threading operations. Injected with petroleum wax, the tendons can be replaced and tensioned.

Then tendons are anchored at the decks by means of anchor blocks, nailed on the ribs by horizontal transversal prestressing bars. 45 prestressing bars (40 mm diameter) per block are required for an efficient load transfer. The surface between the existing concrete and the blocks is prepared by scarification using hydro-demolition method (2800 bars). This technique has the advantage to be less aggressive than other ones (bush-hammering or tapping).

Deviators on piers and on main span are nailed to the existing structure by means of two prestressing bars (36 mm diameter).

Tensioning is preceded by crack injection with epoxy resin to reconstitute the monolithic condition of the cracked cross-sections and to stress these areas.

Replacement of the bearing systems

Jacking platforms are installed for each pier. They are nailed to the bridge with 8 prestressing bars (50 mm diameter) and tensioned at 140 tons to provide the necessary pressure for uplifting the bridge (Fig.4).

Fig.4. Jacking devices ©photothèque BYTPRF

Four groups of three jacks (260 tons each) allow to support the bridge and to proceed to the cutting of bottom bosses. The allowable differential displacement (from one support to another) is restricted to 0.3 mm. The new neoprene bearings (800 mm x 800 mm) are installed with specific provisions for anti-lifting or slip plane.

Access to the site

The dimensions of the bridges require specific site accesses.

At the pier head

The works located at the pier head (replacement of the bearings, seismic blocking device, deviators) are made from peripheral platforms and lifted (Fig.5).

Fig.5. Access at pier top ©photothèque BYTPRF

The lifting equipment is composed of 4 sets of gantries/air hoists with a capacity unit of 3.2 tons. The platform base is controlled during lifting and unlifting operations in order to avoid any excessive deformation of the structure (Figs.6).

Fig.6. Lifting devices ©photothèque BYTPRF

In operating phase, the platforms are supported by 8 steel corbels connected to the pears.

At the abutment pier

The anchor blocks require specific formwork and access due to the geometrical constraints of the bridge.

For each rib, a formwork platform is lifted from the deck (43 m high), with the same process than the pier head accesses (Fig.7). The first part form a cradle helping to lift and to shift the second part dedicated to bottom moulding and work zone. During operating phase, it is suspended by 14 formwork 30 mm diameter tie rod. The total weight is 8 tons.

Fig.7. Formwork platform ©photothèque BYTPRF

Seismic devices

The upgrading of the seismic devices is intended to fulfil the new requirements in terms of seismic regulations. It includes:

- *The installation of seismic blocking systems on the piers and on the abutments and abutment piers (Fig.8).*
- *The installation of threshold effect damping devices on the abutments (4 units per abutment) (Fig.9).*

Fig.8. Safety blocking on standard piers ©photothèque BYTPRF

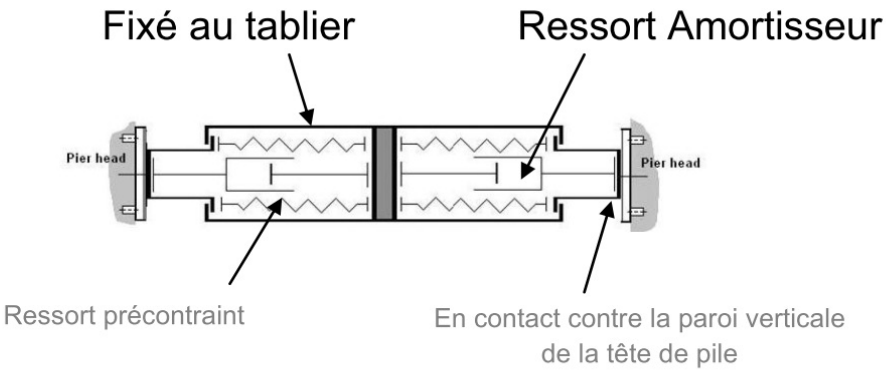

Fig.9. Functioning principle of PDS ©DYNA SHOCK SYSTEM

The prestressed damper is a device intended to mitigate seismic energy. The PDS (Prestressed Damping Spring) decreases the longitudinal displacement to 25 during earthquake event. They are located between the prestressing anchor blocks of the additional prestressing (on which they are fixed) and reinforced concrete blocks. They act as shear keys that have the capacity to regenerate after a seismic event.

Seismic energy is damped instead to be transferred to the structure. These devices are designed to cope with the longitudinal displacement induced by creep/shrinkage and thermal expansion.

The damper is based on the principle of a viscous flow moving quickly in a thin tube: it creates a high resistance, mitigating a large amount of the energy. To avoid any displacement, a 120 tons prestressing load is applied to the spring.

As soon as the seismic load is applied to the damper, the spring is able to recover his initial position (it is said « resettable »). The value of the returning force is designed to exceed the frictional force of the slipping bearing. A double effect PDS is installed in order to be effective in both transversal and longitudinal directions.

Conclusions

Built between 1969 and 1972, the Martigues Bridge (also named the Caronte viaduct) carries 80000 vehicles per day. Since its opening, numerous investigations were made on the prestressed concrete approach bridges in order to identify the origins of the inspected degradations. The actual pathology reveals regulation and technological inadequacies: cracking at the coupling joints, damage in bearing systems, obsolescence of the seismic devices with resulting damage due to traffic-induced deformations.

The structural analyses and inspections led to elaborate a repair project consisting in crack injection, additional prestressing, bearings replacement and new seismic damping devices.

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