Innovative Investigations in a Prestressed Concrete Bridge

Adrien Houel, Michel Valade, Didier Germain, Auguste Mathey

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Adrien Houel[1], Michel Valade[1], Didier Germain[1], Auguste Mathey[1]

[1] *Cerema, DterCE, DLL, 25 avenue François Mitterrand, 69674 Bron*

adrien.houel@cerema.fr

Abstract

In France most of prestressed concrete box-girder bridges are the object of reinforcements these last years per addition of prestressing tendons in most cases following classical complementary investigations carried out within the framework of project of repair. An innovating investigation was realized on a motorway viaduct close to Lyon in May 2013: strain gauges will be positioned on four steel tendons of prestressed right to significant cracks of the box-girder, cracks also instrumented by displacement sensors. Indeed, risks of overstretching in the tendons are expected under road traffic. A first relation will be established between the overstretchings evaluated from the measurements of the gauges and the openings of cracks from the displacement sensors. Moreover, measurements of temperature gradients were also carried out to distinguish solicitations from traffic loads and temperature effects. All these measurements are realized from a new Wi-Fi platform called PEGASE developed by IFSTTAR and the society A3IP. Finally, a fatigue analysis has been carried out in order to establish the residual lifetime of the bridge. An analysis in robustness will be undertaken. Three approaches are described in this paper. The most realistic approach is the experimented one. At the conclusion of this analysis, a decision will be made by the owner based on the opinion of experts to possibly launch the project of heavy repair of the bridge per external additional prestressing.

Keywords : *prestressed concrete bridge, fatigue, residual lifetime, non-destructive investigation.*

Introduction

Before starting a huge maintenance project of bridges, many investigations (non-destructive, destructive or half-destructive) are performed in order to justify repair or rehabilitation actions.

This paper describes the case of a prestressed concrete box-girder in France near Lyon on which reinforcement is in project. This kind of bridge in France is generally the object of reinforcements these last years per addition of prestressing tendons. Nevertheless, the future of this particular bridge, called the Pasteur Viaduct, is uncertain. Indeed, it supports an important highway at the entrance of Lyon, but in a medium run, it is largely possible that it will be destroyed when a new bypass of the city will be created. So, the matter of the current investment such as huge repair is posed. In this context, many investigations had been performed on this bridge. According to the latest assumptions, the lifetime of repair is 20 years, without compromising the possibility of a further extension of this lifetime.

Firstly, the bridge will be described. Then different investigations including innovative investigations will be precised and finally the methodology of the calculation of the residual lifetime will be explained. At the conclusion of this analysis, a decision will be made by the owner based on the opinion of experts to possibly launch the project of heavy repair of the bridge per external additional prestressing.

1 Presentation of the investigated bridge

1.1 Key features

The Pasteur Viaduct built in 1967 is a straight bridge composed of two independent and parallel decks, each with a total length of 178.30 m. Each deck has 6 spans, respectively 21.0, 30.0, 37.5, 37.5, 30.0 and 21.0 meters (Figure 1). The decks have a width of 13.10 m off ledges and slopes of

2% (east to the eastern deck, west to the west deck) and are separated by 2.5 m. The structure has a dome-shaped profile whose longitudinal peak is situated on the centre pier. Traffic of the A7 motorway is done in 2x3 lanes. Each deck supports around 55,000 vehicles per day. The structure of each deck is composed of two box-girders prestressed longitudinally (with tendons 12T13 and vertical stirrups anchored into the top slab). The box-girders are connected by a transversely prestressed top slab. The abutment's cross-beams are prestressed (Figure 2). The decks are embedded on fives piers which are based on concrete clumps cropped on the natural terrain, through reinforced elastomeric bearings. The decks also rest on two abutments via reinforced elastomeric bearings.
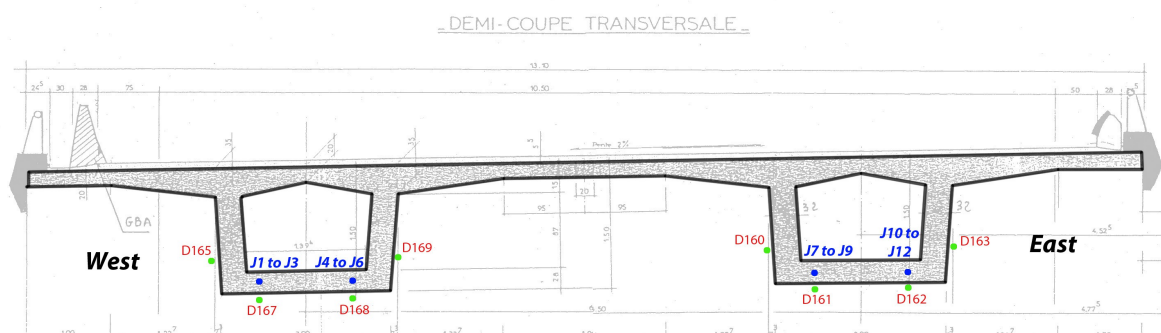

Figure 1: Overview of the Pasteur Viaduct

Figure 2: Cross section of one deck of the Pasteur Viaduct and position of main sensors (strain gauges and displacement sensors)

1.2 The exceptionnal inspection of 2005

For the current study, the inspection report of 2005 [1] indicated the presence of transverse cracks in the lower slab, back in the webs and reaching the junction with the top slab in some cases, outside construction joints between construction phases. Few cracks that traverse the thickness of the lower slab had been a classical instrumentation under traffic load with displacement sensors. The results of this instrumentation and the analysis made by the consulting engineer suggest that these cracks are present in the most vulnerable areas which exceed of regulatory limits.

1.3 Objectives of new investigations

After further engineering, it was shown the existence of significant overstretchings in longitudinal tendons under "normal" traffic, and therefore a risk of fatigue break of tendons. So it was decided to set up an instrumentation on cracked sections in order to measure the load supported by tendon under real traffic. Two cracks sections were selected.

Moreover measurements of temperature gradients in a section near cracked sections will be also carried out to distinguish solicitations from traffic loads and temperature effects [2, 3, 4]. To achieve these objectives, the following steps were performed:
- Locating tendons by non-destructive method (radar) in cracks sections;
- Opening windows in the intrados of the structure for easy access to position instrumentation directly on wires of tendons;
- Installing of instrumentation in accordance with specifications approved by an expert committee;
- Measuring of thermal stress gradient;
- Measuring of stress in tendons under traffic solicitation and a known load.

The following parts of the paper show the instrumented areas, the instrumentation program and the main results of the two proposed solicitations.

2   INSTRUMENTED AREAS, EXPERIMENTAL PROGRAMME

2.1   Cracked sections and instrumentation of cables

Two cracks considered as critical concerning the existence of any overloads in tendons have been identified: two fractures in the lower slab up in the webs of the two box-girders on the west deck respectively 6 and 4 meters from pier P5 (between piers P4 and P5).

In each section, two tendons were identified in the lower slab by radar method [4]. Moreover, this non-destructive test enables to determine the depth of cables. A main result is that tendons are higher in the webs than as expected from construction plans. This is a good reason of the existence of these cracks (Figure 3).

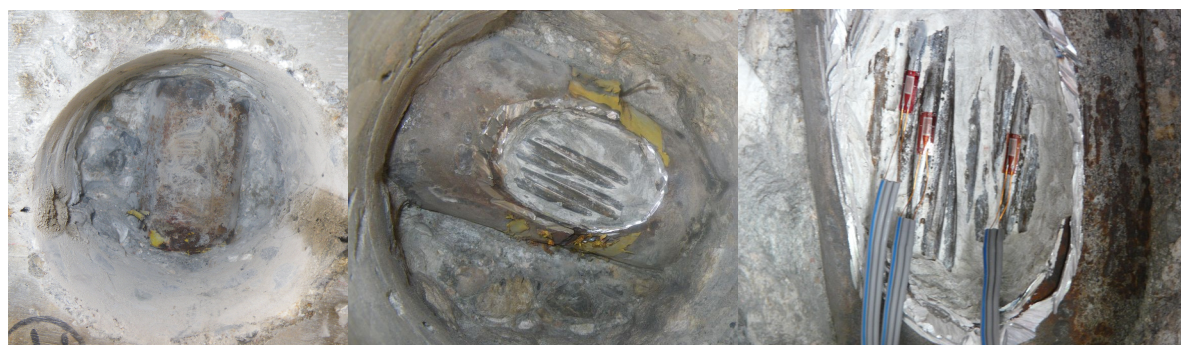Figure 3: Transverse crack and marking of tendons in the lower slab

Figure 4: Window and protective steel duct of prestressing; Opening of the steel duct and elimination of cement grout around wires; Gluing of strain gauges on wires

Then, windows were made gradually and carefully not to degrade the strand. Figure 4 shows the successive steps of the creation of a window. Firstly the steel duct of prestressing is reached, then cut. The protective cement grout is eliminated delicately. The last step is the gluing of strain gauges on wires. For each of the four instrumented tendons, three strain gauges (gauge prewired FLA-3-11-3LT type TML) were glued. In each case, two tendons were visible. Two gauges were

glued on two wires of one tendon and the third one on a wire of the second tendon. Gauges J1 to J6 are placed in the lower slab under right lane (heavy traffic load, gauges J7 to J12 under the left one).

Moreover, four displacement sensors are positioned in each section around the cracked section with a range of ±2.5 mm (two outside lower slab, one outside by web of the box-girder).

2.2 Heat gradient

The two cracked sections are close. So one section was instrumented with temperature sensors. The following temperatures were positioned to the right of the west section with eight temperature sensors PT100:

- T1 to T4: the internal concrete temperature in the thickness of the top slab (respectively 2, 8, 15 and 25 cm from the surface of the structure);
- T5: internal temperature in concrete in the web in the middle of its height;
- T6: temperature inside the concrete in the lower slab;
- T7: outdoor temperature;
- T8: indoor temperature in the box-girder.

2.3 Datalogger

The acquisition system for strain gauges and temperature sensors shown on Figure 5 is the wireless platform called PEGASE developed by IFSTTAR (the French Institute of Science and technology for transport, development and networks, formerly the French Laboratoire des Ponts et Chaussées).

The acquisition frequency of 5 Hz for measurements under traffic load and dynamic influence's lines. It is lowered to 1 Hz static influence's lines.

Furthermore, for measurements under traffic load, each sensor is read at a frequency of 5 Hz. The average and the maximum amplitude signals for each sensor during two minutes are recorded.
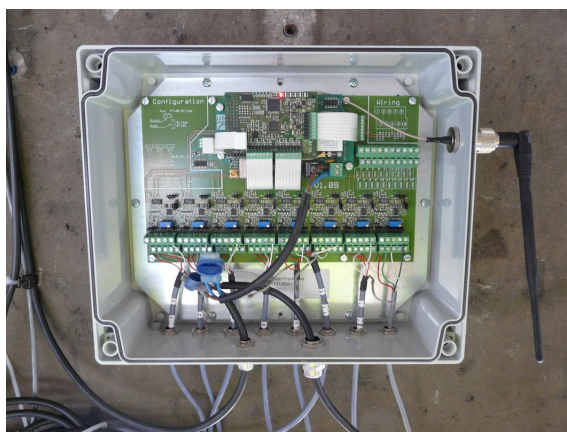

Figure 5: Wireless platform PEGASE for temperature sensors

3 RESULTS

3.1 Heat gradient

Temperature gradient is calculated with "Thermoa1" software developed by the Regional Laboratory of Bridges and Roads from the measures of temperature sensors inside the deck.

Figure 6 shows the monitoring of temperature gradient of the Pasteur Viaduct in may 2013 according to the total height of the box-girder. It varies between -2°C and + 7°C. In the first modelling of the bridge, the temperature gradient was not taken into account. Yet it is not insignificant in the dimensioning in the bridge. Besides since 1975 in France this solicitation has been taken into account in a current project: + 12°C according to Eurocodes 1 EN 1991-1-5 [6, 7, 8].

Measurements also show that the temperature gradient is maximum in the evening around 9 PM and minimal in the morning around 9 AM.
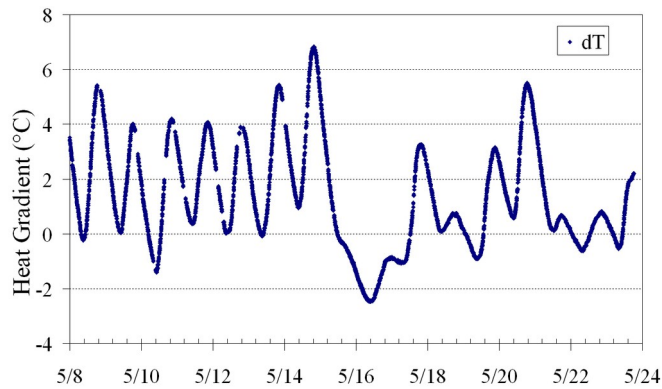
Figure 6: Monitoring of temperature gradient during may 2013

3.2 Measurements under trafic load

Figures 7 and 8 show the results of the average and the maximum amplitudes of strain in tendons under slow lane. The results in stress (MPa) can be deduced with a Young's modulus E = 190,000 MPa.

Average strain is very sensitive to temperature gradient. Tension effort in cables are maximum when heat gradient is high.

The level of strain amplitude under slow lane with the heaviest loads. Strain results are between 200 and 360 μdef (or around 70 Mpa).

Futhermore by comparison between Figures 11 and 12, strain levels from temperature gradient (environnemental ambiance) are very close to traffic load.

Results of displacement sensors under slow lane show that crack opening is larger under lower slab than in the web of the box-girder. Their amplitude is higher than 0.1 mm. Maximum amplitude is 0.25 mm compared to 70 MPa measured in tendons.
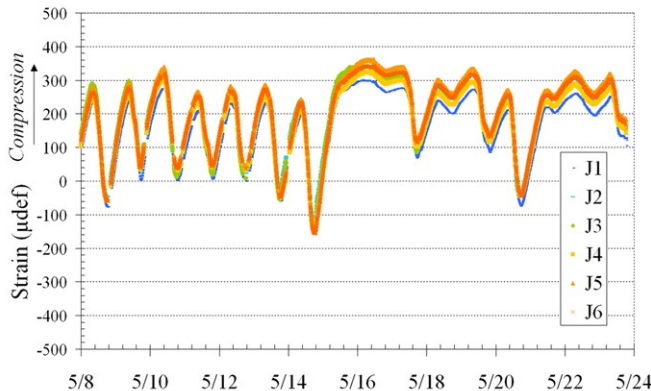

Figure 7: Average strain in tendons under slow lane (west box-girder)

Tables 1 and 2 sum up results under traffic load. As expected, maximum measures of crack openings from displacement sensors are higher under slow (right) lane than the fast one (left).

Table 1: Maximum measures under traffic load – West box-girder (under slow lane).

Tendons	Strains (μdef)	Stress (MPa)	Crack opening (mm)
West tendon	364	69	0.25
East tendon	330	63	0.24

Table 2: Maximum measures under traffic load – East box-girder (under fast lane). Strains under fast lane were not measured in the first part of the program

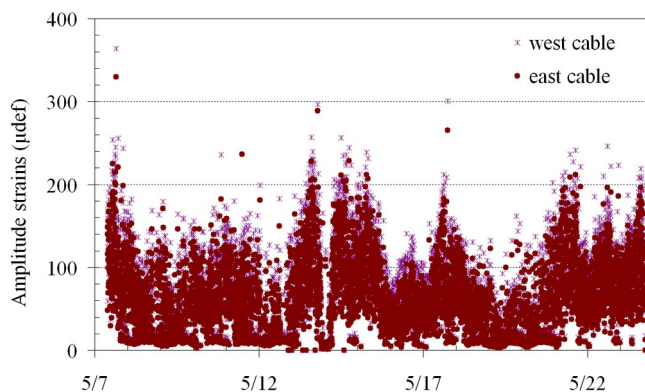| Tendons	Strains (μdef)	Stress (MPa)	Crack opening (mm)
West tendon	-	-	0.15
East tendon	-	-	0.14

Figure 8: Maximum amplitude of strain in tendons under slow lane (west box-girder).

3.3 Measurements under well-known load

The main objective is to determine the influence's line in cracked sections under well-known load. The tests took place in an average temperature of 20.2°C and a temperature gradient between 4.5°C and 4.8°C.

3.3.1 Static load

The different points of static loads are positioned every 5 m on the upper structure except on 10 meters either side of the instrumented crack sections where the step was reduced to 1 meter. The abscissa 0 is on the abutment C5.

The convoy consists of three trucks, each one on a lane (4 axles, 30 tons). Figure 9 shows measurements of strains in tendon under the static load as a function of its position on the structure. Table 3 sums up main maximum results of static load.
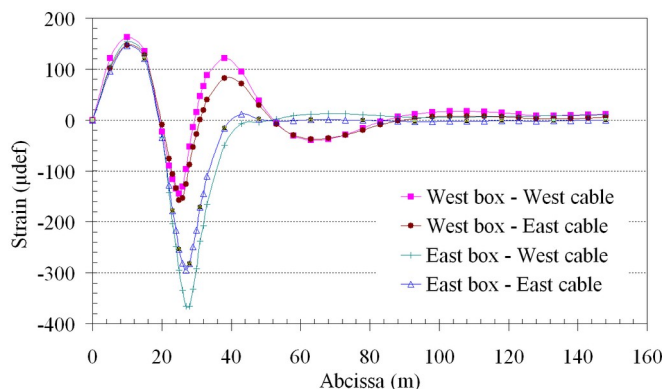

Figure 9: Influence's line under static load. Measures of tendon's strain.

Table 3: Maximum measures under static load.

Tendons	Strains (*μ*def)	Stress (MPa)	Crack opening (mm)
West box / West tendon	308	59	0.10
West box / East tendon	304	58	0.09
East box / West tendon	520	99	0.18
East box / East tendon	441	84	0.15

The behaviour of the two box-girders is very different. The east one is deformed more than the west one (+ 57%). This difference can be explained by a larger concrete interface degradation with prestressing tendons on the west box-girder than on the east one due to the presence of lorries on the west box-girder.

Moreover, these measurements enable to establish a relation between strains in tendon and crack's opening.

3.3.2 Dynamic load

Several loads and speeds are studied. Tables 4 to 6 sum up results of maximum amplitudes of measures under dynamic loads on slow lane at 30, 50 et 70 km/h.

Table 4: Maximum amplitude under dynamic load at 30 km/h on slow lane.

Tendons	Strains (μdef)	Stress (MPa)	Crack opening (mm)
West box / West tendon	178	34	0.104
West box / East tendon	153	29	0.105
East box / West tendon	84	16	0.024
East box / East tendon	50	10	0.025

Table 5: Maximum amplitude under dynamic load at 50 km/h on slow lane.

Tendons	Strains (μdef)	Stress (MPa)	Crack opening (mm)
West box / West tendon	166	32	0.098
West box / East tendon	146	28	0.099
East box / West tendon	80	15	0.024
East box / East tendon	47	9	0.023

Table 6: Maximum amplitude under dynamic load at 70 km/h on slow lane.

Tendons	Strains (μdef)	Stress (MPa)	Crack opening (mm)
West box / West tendon	193	24	0.102
West box / East tendon	170	21	0.103
East box / West tendon	98	15	0.024
East box / East tendon	63	9	0.024

Main lessons of these measures are:
- The two tendons of each box-girders are loaded in the same way;
- There is no effect of the speed of the convoy on the slow lane;
- Under a dynamic load of 30 tons, stress is around 30 mm and crack's opening around 0.1 mm;
- These measures are coherent with observed levels of traffic load which are largely constituted by heavy trucks.

3.4 Other monitoring thanks to this instrumentation

In June 2013 reinforced elastomeric bearings had been remplaced by new ones thanks to flat jacks. The instrumentation enabled to monitor the temperature gradient of the deck and strains in longitudinal tendons in the two crack's sections.

The assumptions of temperature gradient was +12°C whereas the real temperature gradient was +7°C during the repair. It enables to lift the deck to 14 mm whereas modelling was only 10 mm.

Moreover, strains from this lift were lower than strains from traffic load. So the instrumentation facilitated this work without raising strains in tendons in a wrong way.

4   ANALYSIS FOR FATIGUE CALCULATION OF TENDONS

4.1   Regulatory approach

The first approach was attempted based on the fatigue convoys of Eurocodes EC1 – Fatigue Load Model 3 [9]. This approach is not usable. Indeed, the modelling is a non-cracked analysis, strong

hypothesis on the results. The calculated and theoretical overstretchings are therefore not consistent with those measured under well-known load.

Checking stress amplitudes based on theoretical overstretchings is not a good approach.

4.2 Approach based on linear damage hypothesis

A second approach based on past and future traffic is difficult to implement.

Indeed, the traffic history supported by the bridge since its introduction is very difficult to estimate (lorry's volume, average weight, composition of traffic).

Results in residual life are very sensitive to calibration of assumptions and therefore can not be made reliable in the case of the viaduct Pasteur.

4.3 Experimental approach

The third approach is a more realistic analysis of records stress under traffic load with an acquisition frequency of 50 Hz.

This analysis has been performed using the CASTOR and POLLUX software developed by IFSTTAR (rainflow method) to determine the stress amplitude under traffic load and the number of corresponding cycles. This study is not described here. First results are not yet available.

Results will use to feed a calculation method based on accumulated fatigue damage. One challenge will be to choose a representative fatigue law for tendons of our particular bridge.

CONCLUSION

Innovative investigation by tendon's instrumentation in an existing bridge enables to feed the realistic assumptions into modelling. A relation between crack's opening and stress in tendons was established. It will be useful for the monitoring of the two cracks.

Levels of strains under load traffic and temperature gradient in tendons were identified.

Moreover, a fatigue analysis will be particularly carried out in order to establish the residual lifetime of the bridge and an analysis in robustness will be undertaken. Three approaches are described in this paper. The most realistic approach is the experimented one. That's why measures had been realized at a frequency of 50 Hz in order to obtain an accurate analysis.

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