Millau Viaduct (France) – Monitoring design and implementation

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Summary

Viaduct of Millau monitoring was designed by a team of experts already involved with the structural design of the viaduct. With the owner, they have identified objectives and priorities. An expert in Structures Monitoring was in charge of Technical Specifications, implementation and costs evaluation. Data management, supervision and maintenance of the Monitoring System were studied as well. We first describe the monitoring program and results measured during of the construction phase are then presented.

Keywords : monitoring, bridge, monitoring design, data management, monitoring implementation.

1. Aims of the Monitoring

The general objectives of the structure monitoring have been specified by the authorities in the annex 10 of the "Specifications for the Concession". In this document, monitoring is divided into three phases: construction, acceptance and long term survey. The aims of the monitoring of the viaduct are different at each phase:

During construction, measurements are necessary to control the geometry and the displacements, mainly during launchings of the deck. Topographic techniques are mainly used; they allow to check that the behaviour of the viaduct is in conformity with the predicted values.

At the Acceptance of the viaduct the reference state of the viaduct is recorded. This will be used as the "starting point" for the long term monitoring.

Long term survey includes three aspects: control of specific parameters related to the safety of vehicles and passengers, control of the behaviour of the viaduct and control of the aging of the structure.

2. Monitoring Design

Monitoring measurements correspond to precise goals, which were debated upon by experts and with the owner. After priorities were agreed, detailed technical specifications were written by a structures monitoring expert and a budget estimation was set up (figure 1).

Data processing and analysis of monitoring measurements must be easy. It means that they could be analysed by specialised and even by non specialised people, often in a short time, with clear criteria. The first analysis after data processing is the comparison with levels with predefined acceptable deviations. Then, if necessary, a detailed analysis will be carried out by a group of engineers and experts.

In the owners mind, monitoring is often designed for a very long period. A first three years period for a continuous monitoring of the Viaduct of Millau was decided. After this time, knowledge of the behaviour of the viaduct, particularly under windstorms ought to be complete. Monitoring will then be revised accordingly for the long term operation and actual time life of instruments will be taken into account.

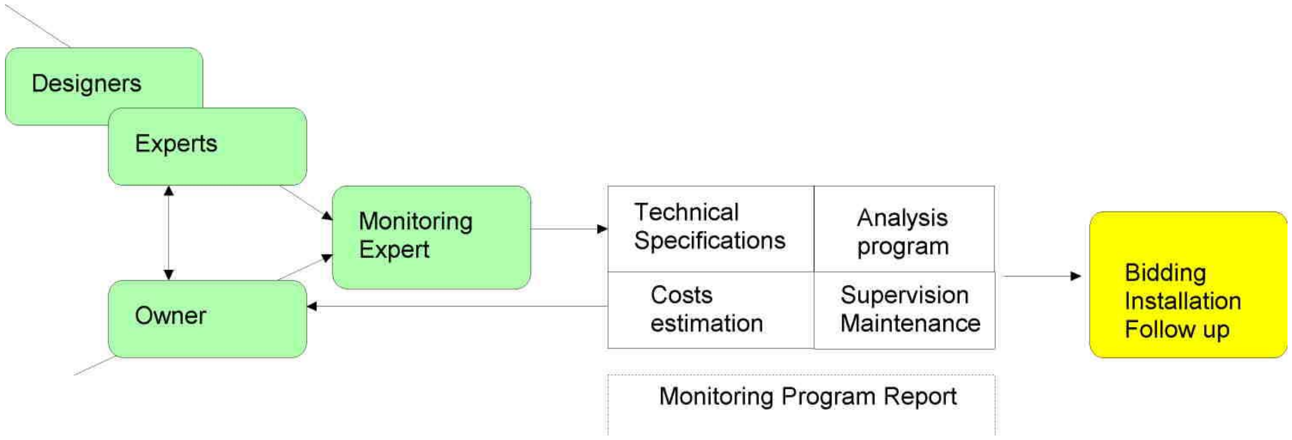

Fig.1 - Monitoring of the viaduct - Organisation

2.1. Data Management

Management of thousands of data requires careful attention. Data were organised at the beginning of the monitoring: codes, records formats, file formats, name of files, data processing. Recorded data and data files are structured to be directly exported to a spreadsheet software instead of a database for a better efficiency.

3. Monitoring program

The viaduct monitoring has been voluntarily separated from the monitoring systems used for safety purpose. The structural monitoring system has no warning or alarm use. In service, although it will use the same optic fibre backbone, the measure of the wind speed that can trig a closing of the viaduct will follow a separated way.

Most of the instruments for the monitoring - sensors, data acquisition modules, and network - are industrial devices. Except for concrete behaviour of foundations, we did not select fibre optic extensometers, because of their poor frequency response and their price: long base extensometers - an invar bar with an industrial displacement sensor fixed to the structure - were preferred.

The meteorological instruments used for the traffic supervision includes cup anemometers, vanes, ice detectors, visibility, temperature and hygrometry, rain and snow height, pavement temperature and state.

Table 1

Measure of.	Using...	Number	With the aim to...
During construction			
Deformation of the foundations concrete (footing P2)	Fiber optic extensometers	8	Measure the effect of the shear stress following the thermal curing and shrinkage of the footing concrete.
Geometry of the structure	Total station and optical prisms	141	Control the position of points
Position of the slip form	Differential GPS (DGPS)		Control the position of forms
Vertical displacement and rotation of foundations	High precision optic levelling of 4 targets	4 targets / footing	Compare settlement and rotation of foundations with the increasing weight of the pier with time.
Thermal deformations of piers (P2 and P6)	Temperature sensors installed in concrete	103	Compare horizontal displacements of piers with temperature with results of a numerical simulation.

Measure of.	Using...	Number	With the aim to...
Launching of the deck			
Speed and direction of wind	Ultra sonic anemometer	1 +1 for safety	Measure wind speed and compare to warning and alarm levels
Position of the deck	Total station and DGPS	1	Compare real and theorical position of the deck.
Deformation of steel of the deck (patch loading)	Displacement sensors on a fixed and a mobile device	36	Measure the normal displacements of the steel between two diaphragms of a deck section moving on a pier or on a bent.
Dynamic movements of deck and pylon	Accelerometers	72 in the deck 12 in the pylon	Control accelerations during launching
Real time displacement and twist of the heads of temporary bents	Laser distancemeters	5	Control the displacements of temporary bents
Real time displacement of piers heads	Laser line reference	1 per pier	Control displacements of piers heads during launching (with alarm levels)
Force in the stays	Electronic load cell	4	Control variations of forces in stays during launching
In service			
Temperature		274	Measure temperature of steel to determine effect of temperature on the deck. Calculate temperature corrections for simulation.
Wind speed, direction and turbulence	Ultra sonic and cups anemometers	Ultrasonic 1 Cups 2	Measure speed and direction of wind to determine effect of wind on pylons, stays, deck and piers.
Rotations	Inclinometers	Pylons 2 Piers 2	Measure rotations of the structure.
Deformation	Extensometers	52	Measure deformation of piers concrete. Used mainly to determine creep of concrete (P2, P7)
Vibrations	Accelerometers	Deck 6 Pylons 3 Stays 3	Measure amplitude and frequency of oscillations and vibrations (effect of wind)

4. Data acquisition system

Electronic sensors are linked to data acquisition modules. They will converge to digital modules connected to the fibre optic backbone used for the process automation of the viaduct (Ethernet link). Supervision of the monitoring network and recording of measurements will be carried out by a computer linked to the network. Validity of data will be tested by the computer and recorded. Only some data files will be analysed according to the program and upon request after exceptional events, as storms.

5. Data processing and analysis

Data will be processed locally by the computer and recorded. This data will be sent to specialised teams in charge of the analysis: effect of temperature (Figure 5), effect of wind on the deck or on the stays, creep of concrete for example. These topics will be listed and detailed in the Monitoring Management Report.

6. Supervision and maintenance

Supervision of the monitoring network will be part of the general supervision of the viaduct; the teams, which will work day and night at the toll office will be in charge of this supervision. They will assure a part of the maintenance. This is a new view of the monitoring organisation, but we know from experience that this option works better than fully remote supervision.

7. Position and displacements survey

Survey of the position and of the displacements of the viaduct make extensively use of the latest technology in geodesy survey: DGPS with on site radio linked receivers on stable points, total station with prisms screwed in piers concrete or in the pylons steel flanges. Many of the prisms used for the construction controls were designed to remain on the structure for long time survey of the viaduct.

8. First results

Following figures show some data recorded during construction and launching. Each footing is equipped by four rods for levelling. As an example, figure 4 shows the measured and calculated settlement of P6 footing. The accuracy of the high precision levelling ±0,3 mm leads to a very good measurement of the settlement (and rotation) and an easy comparison with the model.

Modelisation of temperature effect on concrete piers deformation (figure 5) from numerous automatic temperature measurements, allows to predict the displacements of the top of the piers.

During launching, many parameters are recorded and compared with the designers' calculations; the position of the temporary "neck" of the deck, measured with a total station and a DGPS receiver is shown on figure 6. Figure 7 shows the increasing load applied on the top of a pier during the launching of the deck. This control used the measurement of the load applied to the launching jacks installed at the top of piers and temporary bents.

9. Conclusion

The monitoring project of the Viaduct in Millau has followed the mandatory steps for an effective design: definition of the objectives, priorities - a budget is always limited – preliminary design, technical feasibility, technical specifications, technical and financial optimisation of choices, data processing, management, responsibilities. What is the usefulness of the monitoring? What type of instruments to install? Who is in charge of the monitoring system? Who analyses the data? These questions have been debated. The analysis of the monitoring, the data management used on large bridges- Normandy Bridge (France), Vasco da Gama Bridge over the Tagus in Lisbon (Portugal) for example - and more generally on large structures, show that good design, organisation and management are the essentials to the monitoring. Too often, monitoring systems are designed - when designed! - by instruments suppliers instead of specialized engineers. It is indeed mandatory that a thorough analysis be done by experts including a monitoring specialist, prior to any tendering procedure.

The monitoring system should meet the experts' expectations. First results show that this concept is very effective and economically optimised.

10. References

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Servant C. Viaduc de Millau - L'instrumentation. FNTP Conference Paris. 25- 26 november 2003

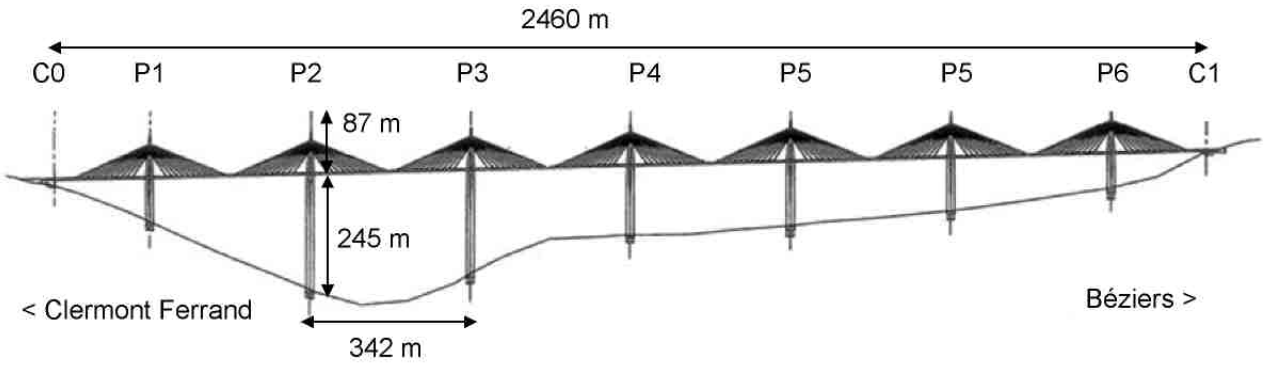

Fig.2 - General dimensions of the viaduct.

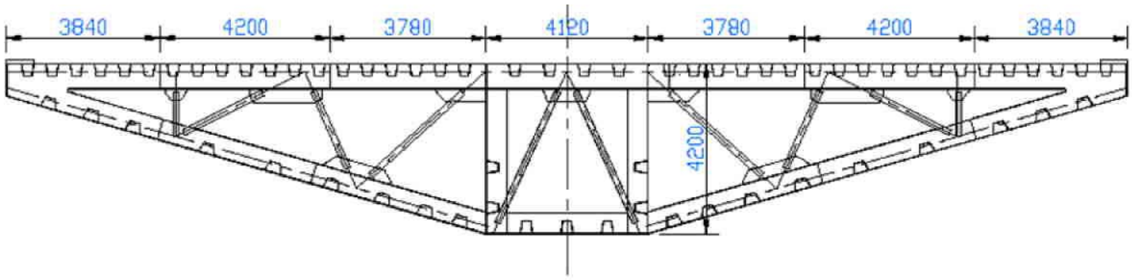

Fig.3 – Deck cross section

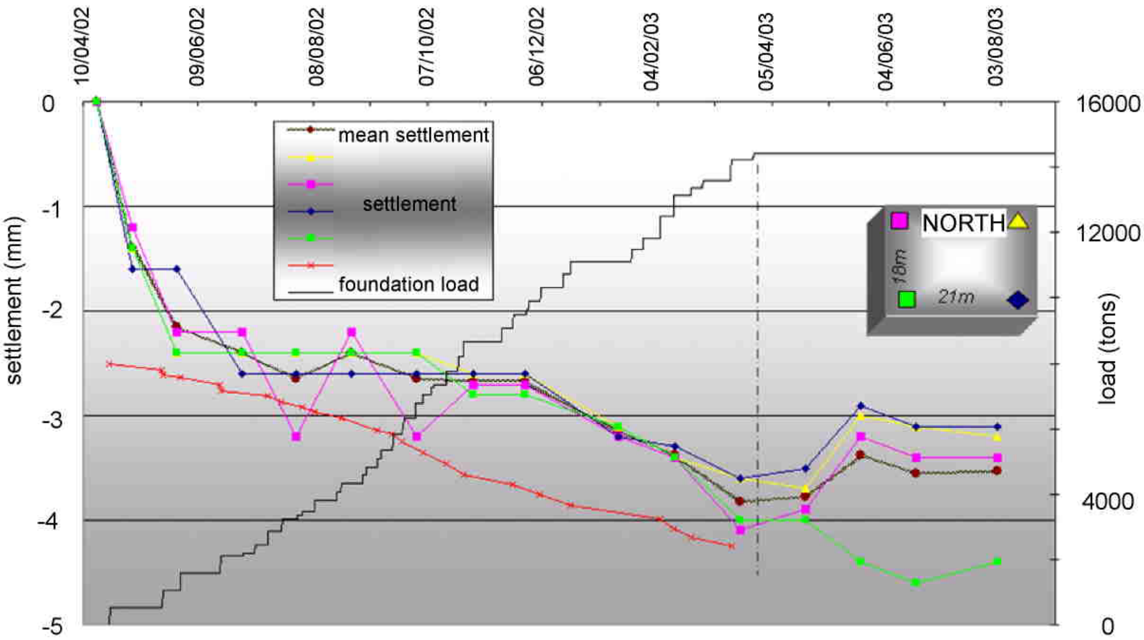

Fig 4 - Settlement of footing P6. Settlement is in very good accordance with the calculated values (measurements: Eiffage, document Eiffage).

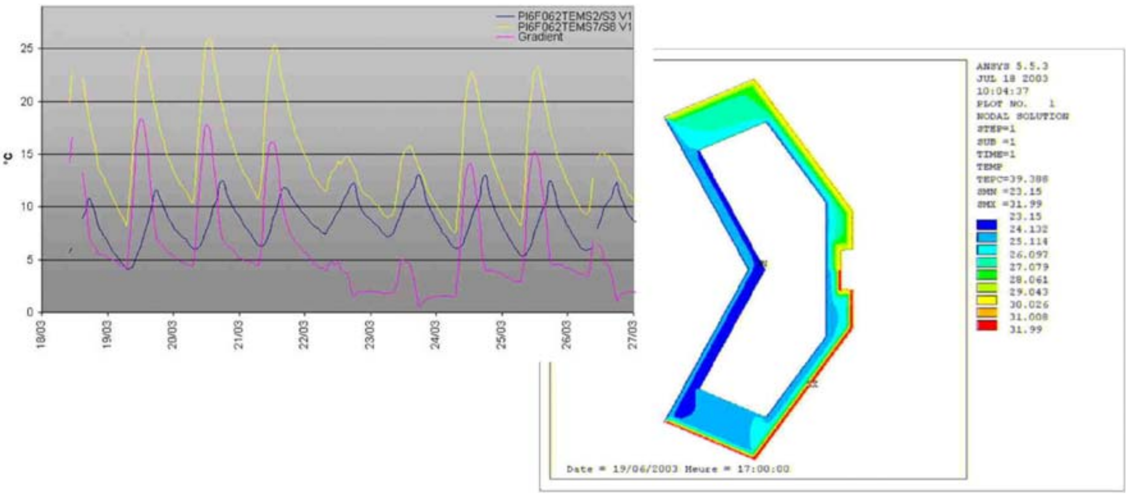

Fig 5 - Temperature of concrete surface of P6 and subsequent modelisation (measurements: Sites, document:Geonumeric /Eiffage)

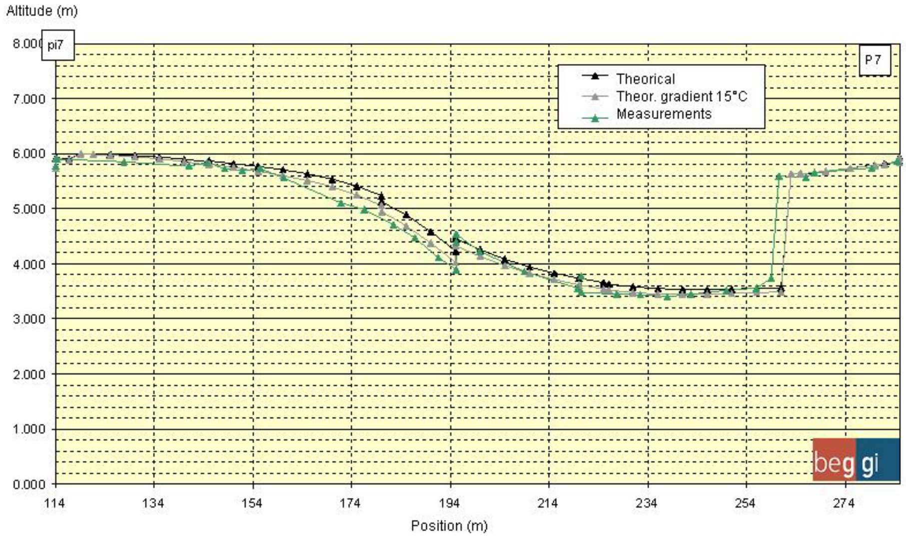

Fig.6 - Computed and measured levels of the deck during launching (measurements: Eiffage, doc.BEG)

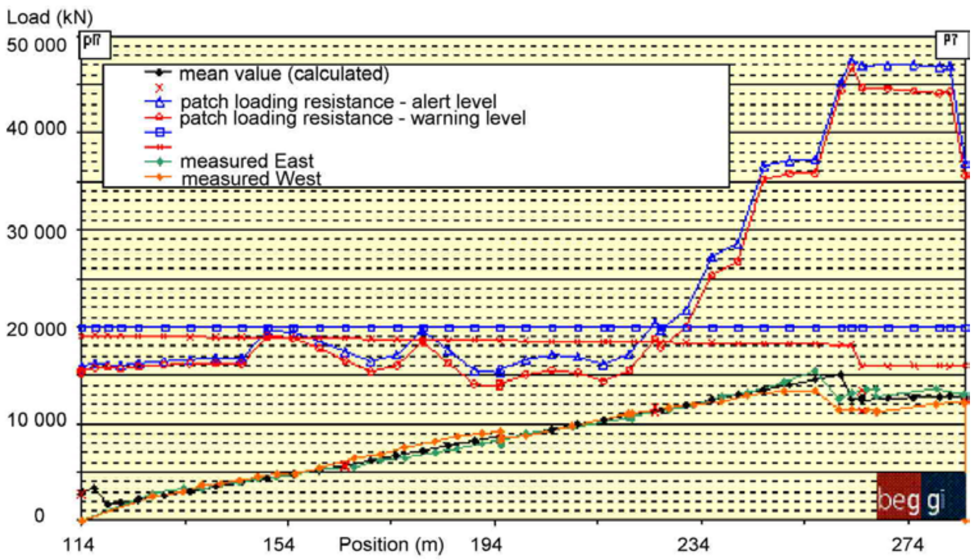

Fig.7 - Computed and measured load on the top of pierP7 (measurements: Eiffage, doc. BEG)