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The structural Health Monitoring of the Grande Ravine Viaduct

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The island of la Reunion in the Indian Ocean is the host of amazing landscapes. Developing infrastructure in this environment presents numerous challenges. The island is currently building a new highway: La Route des Tamarins, this project included the construction of a viaduct to cross the Grande Ravine a gap 1050 ft. wide and 557ft deep, with very steep sides. To protect the environment the structure was developed to be launched from both side of the ravine.

The Grande Ravine Viaduct is a 944ft-long steel deck with orthotropic slab, which is hinged on two high-performance pre-stressed concrete braces inclined at 20° to the horizontal. Numerous elements make this structure unique: the braces are cantilevered from counterweight abutments and maintained at their heads by external pre-stressing cables situated inside the deck.

To ensure two monitoring systems were put in place: a construction monitoring and a long-term structural health monitoring.

The construction monitoring was installed to ensure that the behaviour of the structure is as predicted. This included the surveillance of the tilte of the foundations and cantilever. But most importantly the launch of the deck cantilevers were fully monitored. As well as ensuring safety for the contractor, the monitoring process also serves as a 'guarantee' to the client that the permanent structure has not been overloaded during construction.

The long-term monitoring was based on the construction monitoring but included additional sensors. The objective in this case is to guarantee that the behaviour of the permanent structure is as predicted, particularly under wind loading. Typhoons regularly hit the island, therefore the data gathered will help to determine how the structure is behaving versus the designs assumptions.

After a brief presentation of the challenges and technical details of the Grande Ravien Viaduct, this paper will present in details the two side of the monitoring systems. First how the construction monitoring was used, then how the long-term monitoring was installed and how data is currently gathered and analyzed. Finally feedbacks and results of the monitoring systems will be discussed.

1 INTRODUCTION

At first there may be no obvious similarities between a modest composite bridge in Reunion Island in the Indian ocean, and France's mighty Millau Viaduct, but scratch the surface and you will find that there are some very direct connections at work. Despite the huge difference in scale and the contrasting structural forms, the designs of the steel box girder decks on the two bridges are very similar and because of the same specific construction equipment that has been used for the Millau Viaduct was reused for this structure.

The bridge crosses a 320m wide and 170m deep valley. The structure is part of the recently constructed, 34km long, highway called Route des Tamarins. One main criteria for the design of the Bridge was that all construction work had to be taken place from the sides of the ravine. This criteria was mainly due to the depth of the ravine and the fact that is protected habitat which made it impossible to use any kind of support from below.

2 THE DESIGN AND SPECIFITIES OF THE BRIDGE

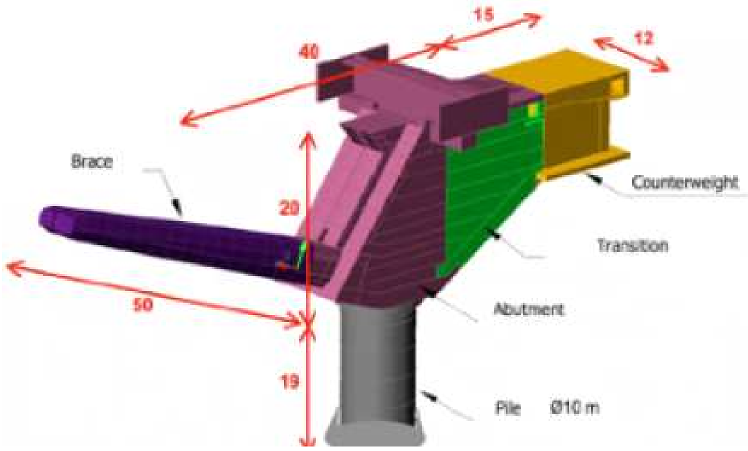
The structure consist of a 288m long steel deck with orthotropic slab, which is hinged on two high-performance pre-stressed concrete braces inclined at 20°. To be able to launch the structure from the two sides of the ravine, the braces are cantilevered from counterweights abutments and maintained at their heads by external pre-stressing cables situated inside the deck.

The construction of the bridge from both sides of the ravine has been continuing in parallel until they met. The piles which are positioned on the edge on both sides of the ravine are 10m in diameter and 20 meters deep and have been designed to meet the environmental constrains that required a minimum impact on the ravine.

The abutments were designed to have two functions – as the support of the end of the steel deck, and also as the connection between the counterweights and the pile footing. It also houses the anchors of the pre-stressing cables for the permanent structure and the temporary cables for the launching of the deck.

The braces are designed to support their own weight, thanks to some 32 post-tensioning cables in each brace. The temporary cables that are installed across the top are to support the deck.

The deck is made up of 24 sections, which ranges from 8.3m long to 13.9m long all 20m wide. For shipping purposes the units were divided into 12 elements. Assembly of the deck took place at both sides of the ravine and manoeuvred into its permanent position in six launching phases from each side.



A set of temporary stays was used to support the deck cantilever as it passed the top of the brace and extended towards the centre of the span. Twelve temporary cables were used on each side. After the completion of the construction these cables were transferred from the outside to the inside of the deck where they were used to limit the arch effect of the acting on the structure.

The phasing of construction and the different structural behaviour before and after mid span connection as well as the role of the provisional and final stays make it a very special structure. To ensure these different phases two monitoring systems were put in place: a construction monitoring and a long-term structural health monitoring

3 DEFINITION OF A MONITORING SYSTEM

Besides from the development of calculation tools, other fields are constantly under progress. Amongst them, the monitoring capabilities are evolving to provide accurate information, at always lower costs.

The question of the definition of an efficient monitoring system is very constant. Managers complain with the fact that monitoring systems provides non comprehensive readings. Monitoring systems are providing values, but in some cases, those values are not of any interest to give to managers good orientation for the actions to be undertaken. In too many cases monitoring systems that are installed on the structures are not used as there isn't any clear procedure, or process to be done with the readings. The transfer of knowledge between the designer and the manager is not properly done.

Regarding this last aspect, a risk analysis is of great help. It allows defining the monitoring systems according to the pertinent indicator, and information that are required to qualify a risk. The definition of the monitoring system is then performed in the downwards direction instead of upwards. A risk analysis allows defining the information that is required to control a risk. The choice of the sensor is then almost automatic. This methodology is in opposition to the choice of a sensor only because it is thought as necessary for the understanding of the behaviour of the bridge. Some other information linked to the loading for instance may then not be available, because they were too expensive to install. In this situation, the information provided by the sensor has no meaning, as it is not correlated to any load case. The risk analysis method allows as well classifying the risk according to their importance, and therefore to chose according to a certain budget, which sensors shall be installed, and which sensors shall be left apart.

The definition of a monitoring system is done to respond to different classes of needs, and before choosing a sensor, one should ask at least the following questions:

- Is the sensor related to a short (design criteria evaluation), or long term (deterioration detection) ?
- Is it possible to control the point visually or not?
- When it is able to be controlled visually, is it more economical to install a sensor rather than having a too often inspection?
- Which is the criticality of the information? Shall it be redundant?

The application of this type of questions to every identified risk will allow defining the most cost efficient system that will allow keeping the criticality of the risk under an acceptable threshold.

4 THE MONITORING SYSTEMS APPLIED ON THE GRAND RAVINE VIADUCT

While the bridge was under construction the construction monitoring system ensured that the erection and launching was proceeding as planned. The long-term structural health monitoring system was put in place to monitor the in service conditions of the structure.

4.1 Construction monitoring

Objectives for this monitoring system besides ensuring the safety of the contractor, it also serves as a “guarantee” to the final owner that the permanent structure was not overloaded during construction, or has not suffered repetitive loadings that could give rise to concerns about fatigue.

4.1.1 Movements of the foundations

The first phase of construction on site was the construction of the large foundations which were positioned very close to the edge of the ravine. In these kinds of locations even the slightest movement of the foundation could have dangerous implications for the bridge. The movements were monitored by measuring the tilt in 2 directions of the foundations.

4.1.2 Movements & stress of the cantilever

As the concrete strut for the main span was cantilevered out from the edge of the ravine, any unpredicted movement of this structural element was also monitored by measuring the tilt of the cantilever, but the second and perhaps more significant effect to be measured during construction was the stress and deformation at the bottom of the cantilever. Movement at the bottom of the cantilever, the difference in stress measurement between the top and bottom of the cantilever, and the longitudinal force were all monitored during this phase

4.1.3 Additional sensors

To correlate the information from the sensors above 2 weather stations were installed on both sides of the structure consisting out of a 3D anemometer and an ambient temperature sensor. Also the behaviour of the deck while it was moving forward from both sides towards the middle was monitored by the use of 2 bidirectional accelerometers (1 at both end).

Figure 1: Accelerometer 2D

4.2 Permanent monitoring

The aim of this long term monitoring is to ensure that the behaviour of the permanent structure is as predicted, particularly under wind loadings. Wind data from the site of the bridge was not available at the time of the design, so data from the nearest weather station (1 km away from the bridge site) had to be extrapolated for this purpose.

The intention will be to establish a correlation between the cause and the effect, to detect any changes, and to compare the results with the assumptions that were made in the design of the bridge.

The permanent monitoring system consist out of the following elements:

4.2.1 Weather stations

A total of 5 weather stations were installed on the bridge which are providing an accurate profile of the conditions at the bridge. 4 weather stations including temperature and 3D anemometer were installed on the bridge and 1 2D anemometer at 1 km from the bridge site.

4.2.2 Aerodynamic loading

Wind pressure sensors are installed on the soffit of the deck in order to measure the lift created by aerodynamic loading.

4.2.3 Deck movement

The 2D accelerometers from the construction monitoring are repositioned within the deck for the measurement of the deck vibration.

Figure 1: Wind Pressure sensor

4.2.4 Data acquisition

Real time data acquisition was assured by a data acquisition unit on site which includes a specific developed software that handles the data acquisition and transmission, visualization & analysis. It also manages automatic alerts in case of abnormal movement or behaviour or detection of problematic signal of a sensor.

5 CONCLUSION

The monitoring systems have provided valuable information for the engineer and safety during construction and will continue this during its life time.
During the construction period no significant movement of the foundation was measured and the tilt of the cantilever was also found negligible.

The permanent structural health monitoring system ensures a high level of safety to the users.