Bridges safety control in real time

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ABSTRACT: Following the developments in equipment and new technologies, improved methods, for observation of structure's behaviour, are taking place. With the automation of several tasks, starting with the data acquisition and data storage all the way to through data management and data sharing it became possible to control bridges' safety in real time. Due to this it is available the assessment to all the information related to the structure, in real time, anywhere in the world as long as we have network connection.

1 INTRODUCTION

The observation of structure's behaviour is an activity with large development along the last years, particularly due to technological innovation that provided not only the improvement of existent sensors, but also the appearance of new equipment based on the recent technologies, like fibre optic or GPS.

However, in the long-term observation, the most significant contribute was provided by the introduction of new techniques for automatic acquisition of the measurements. Automatic acquisition gives us the possibility of reading several equipments simultaneously, without the presence of operators, plus the capability of establishing a remote connection to a centre of studies through phone, radio, GSM or Internet.

The combination of automatic readings with remote connection opens new perspectives on structure's safety control allowing better attendance, in real time.

In order to guarantee the observation of the structure in real time, alert and alarm levels were established to control, permanently and *in situ*, the development of selected variables, allowing a more efficient evaluation of the conditions of safety of the structure.

To face the high volume of observed data, resulted from the increased cadence of observations, new methodologies of processing were developed at the level of the study centre to fasten structure analysis. This procedure involved comparisons between experimental data with computed values, as well as, comparisons between the data themselves, with the intention of understanding the dependence of different measurements observed.

We can divide the control of bridges safety into three distinct processes:

- Data Acquisition;
- Data Transfer;
- Data Management.

The way these operations interact with each other and their internal proceedings are schematized in Figure 1 and will be described with more detail in the next chapters.

Finally, it is presented the application of the developed methodologies to the International Airport of Madeira in Portugal that is being observed by National Laboratory for Civil Engineering (LNEC).

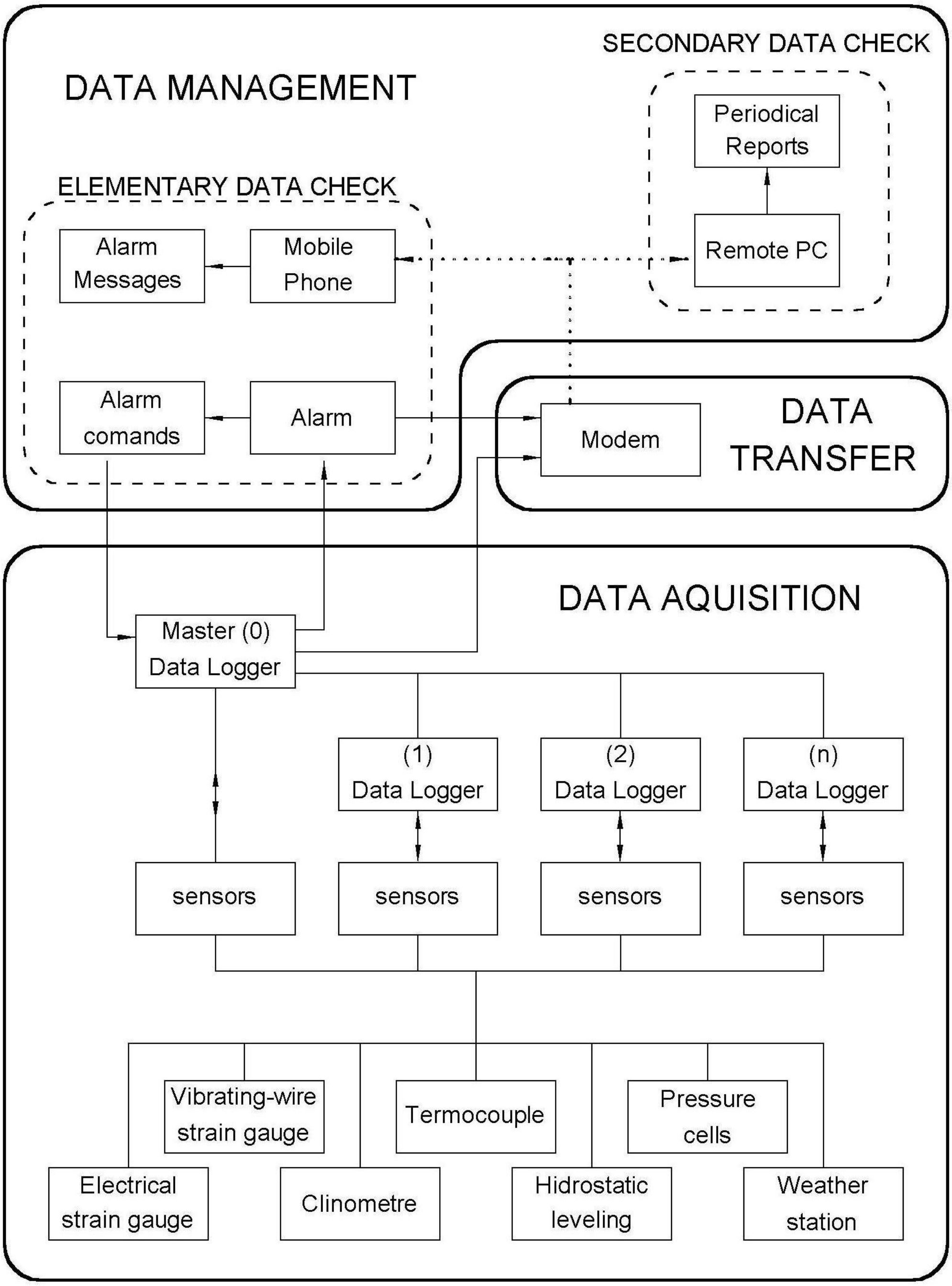

Figure 1. Simplified scheme of the bridges safety control processes.

2 DATA ACQUISITION

2.1 *Sensors*

Nowadays, with the development of the sensors used in structure's observation, measurement methods are changing, as we are replacing mechanical sensors. This way it stopped being necessary the presence of a human operator to carry though the readings allowing those to be made by specific equipment.

The choice of the sensors to install on the structure, depend of the materials as well as the type of bridge that we are monitoring.

The most common measurements monitored are listed next as well as some examples of sensors to apply.

- Deformations – with a system of hydrostatic levelling along the deck it is possible to measure vertical displacements of the bridges deck; with electrical clinometers located in the deck and in the piles we can evaluate the rotation of the structure.
- Strains – to measure concrete's strains we can use vibrating-wire strain gauges that are left inside the concrete structure; in metallic elements we may use electrical strain gauges.
- Forces – if we want to measure the force on the cables we can install pressure cells on one of the strain and this way estimate the tensile force acting on the cable.
- Temperatures – thermocouples can be placed inside the concrete in different heights in order to measure the variation of temperature along the concrete's thickness.
- Dynamic parameters – to define the vibrating mode shapes of the bridge we may install accelerometers along the structure.
- Durability – corrosion sensors or chloride sensitive sensors.
- Environmental conditions – to measure the temperature, wind, relative humidity of the air and rain, a weather station is installed near the bridge.

2.2 *Dataloggers*

Complementing the sensor's capability to execute measurements without the need of human order, the datalogger gives instructions the sensors to do the readings and after that stores the data into its internal memory or in a memory card.

With the datalogger it is possible to acquire the measurements from all the sensors distributed along the structure simultaneously, allowing the right comparison of the data because they are exactly referred to the same moment in time. Measurement's rate can be specified according to the variability of the data that we are observing.

The dataloggers can be linked to each other's building a local network that is commanded by the master data logger.

3 DATA TRANSFER

The acquiring system is located in the field, but the data has to be available in the office where it will be analysed by the engineers. The operation of going to the field to collect the data it isn't compatible with the real-time analysis, so it became necessary to install a modem to make possible the remote assessment to the measurements.

With the local network, created with the dataloggers, way we can monitor all the structure with multiple dataloggers spread along the bridge, however the connection is made through the master logger that is linked to the modem.

4 DATA MANAGEMENT

The activities of data management can be divided into two separate blocks, one consisting on the elementary data checks that is performed *in situ* by the datalogger and the secondary data checks, carried out by specific programs in a remote PC.

4.1 *Elementary data checks*

The elementary data checks activities allow the real time control of the safety of the bridge and, as said before, are carried out *in situ* by the datalogger.

This processing stage consists on the analysis of the general state of the bridge instantaneously so it cannot include all the measurements made by the data loggers.

In the development of this processing stage that consists on the analysis of the general state of the bridge in real time, there are several steps to consider, those steps are explained in the next paragraphs.

First, we have to choose from all the data read by the sensors distributed along the bridge those ones, which are going to become the system control variables. This election depends specially on the capability that a specific measurement has to reveal the general state of the structure.

After acquiring the data, the datalogger starts the analysis by checking if the value read is under the alert or alarm level and if not it unchains the alert or alarm procedures like it is represented in Figure 2.

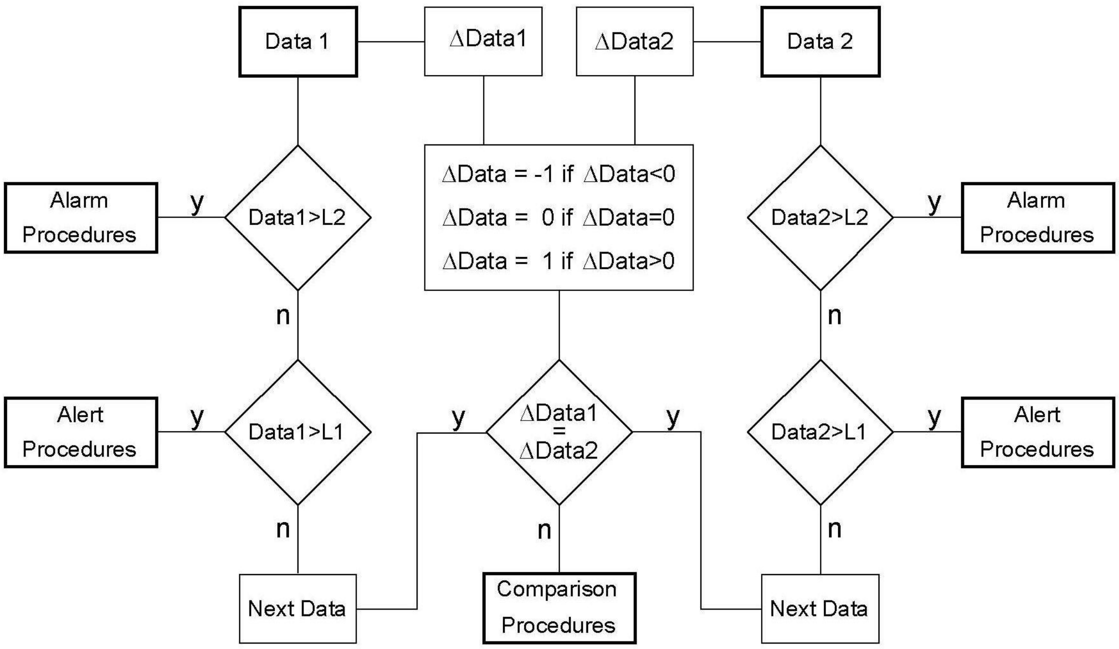

Figure 2. Elementary data check procedures

Those procedures include increasing the frequency of the readings but also sending a message to a mobile phone. With the former route it is possible to confirm the validity of a certain value discarding errors that may occur due to a combination of factors that happened at the time that the equipment is being read, like the lack of energy or equipment damages.

The definition of the limits, above which the measurements are considered to be abnormal it is a difficult task because we don't know have the complete information about the loads that are acting on the structure. The other problem is the estimation of the data expected to be measured even when we have the applied loads, due to the complexity of the structures.

To deduct these limits we must have a computer model of the structure that can predict the behaviour of the bridge in terms of its response in the sections where we have installed the equipment.

The levels defined as limits aren't static values, they change whenever we have new information about the structure. All the information that we can gather about the real behaviour of the bridge must be added to the model in order to make if as reliable as possible. The modification of the limit values may be done with the periodicity of the pos-processing analysis or every time a change in the structure justifies it.

The procedures and the limits considered in this stage are gathered in Table 1.

The information may not come from a single data, but by comparison of more than one type of measurements read simultaneously and how they gradually change with time, loads or weather (Fig. 2). For instant I can get important information by relating the development of concrete's strains with the evolution of concrete's temperature or the progression of creep or shrinkage in time with the data obtain by the weather station.

Table 1. Definition of pre-process procedures

	Levels	Procedures
Alert	L1 – value expected to be measured by the sensor, regarding the most probable loads acting in the structure during the monitoring, plus a tolerance margin.	Increase the acquisition rate up to 10 times until the data is under the defined limit. Send an alert SMS to a mobile phone.
Alarm	L2 – value of the measurement if subjected to loads much higher than those most probable to act during the monitoring, plus a tolerance margin.	Repeat the measurement immediately and increase the acquisition rate to 5 minutes. Send an alarm SMS to a mobile phone.
Comparison	ΔData1 ≠ ΔData2 – the evolution of data1 isn't compatible with the evolution of data2	Increase the acquisition rate up to 10 times until the data are compatible. Send an SMS to a mobile phone.

4.2 *Secondary data checks*

Regularly all the data from the sensors installed on the structure are collected and analysed and the evolution of the measurements with time and the conclusions about the safety conditions of the structure are published in a periodical report.

Due to the automation of the monitoring process, the amount of data has increased substantially.

The interpretation of the data was, until now, almost manual therefore the time necessary to obtain the results starts increasing with the growing of the data quantities.

If the process of analysing the data becomes much delayed we began to accumulate useless data (raw data from the datalogger) and when we finally calculate the processed data those measurements are no longer actual.

So, the only option to follow the automation of the acquisition system is to develop the automation of some procedures used to analyse the data.

In this stage is once again necessary the computer model of the bridge to do the interpretation of the data acquired. We must than have an interactive program based on the computer model capable of receiving the data read in a certain moment in time and than calculate approximately the rest of the measurements at that same time.

If differences between measured and calculated data are detected the program should have probability scenarios capable of identifying and justifying such discrepancies and recommend solutions to those situations.

After the data control the program will print the graphics that represent the evolution of the measurement data with time. This graphics together with the interpretation of the data will be used to make the periodical reports of the structural behaviour of the bridge.

5 INTERNATIONAL AIRPORT OF MADEIRA

5.1 *Description of the structure*

Madeira's new international airport inaugurated on the15th of September 2000 is a unique structure and represents a massive investment on the development of the Madeira Island. This new structure consists on an extension of the existing airport allowing the landing of the biggest commercial airplanes in service (Boeing 747 - 400).

Several locations were studied and the selected one was the original site, Santa Catarina. From the point of view of length, is was determined that the runaway needed to be around 2800m, since it is situated in the coast of the island, and it didn't have land to expand the option was to enlarge the deck in the direction of the sea. The runaway was built over the sea creating a large bridge for airplanes.

This particular structure was developed in two phases allowing the extension of the existing platform from 1800m to 2781m, the first phase consisted on a bridge with 178m wide and 546m long and the second phase, similar to the first, had the same width and 457m of length. The old runway has been turned 3º37' to the North.

The structure consists on a set of porticos guided transversally to the runaway and spaced by 32m. The transversal porticos are constituted, in general, by 6 pillars spaced by 32m that are connected to the beams that have 5 central spans of 32m and consoles of 14m in each end.

The slab, supported in the beams of the porticos, has 178m of width and has 1m of thickness in a central band of 12m and 1.7m thickness on the porticos.

The circular pillars with 3m of diameter have heights around 50m above the platform of earth built with the material from the excavations of the hillside, and its foundations, made of piles, reach 60m of depth under the sea.

The beams have an I shape with variable heights between 3.6m in the middle of the central spans, as well as, in the end of the consoles and 5.6m over the pillars.

Figure 3 – View of the old runaway and the extension of the International Airport of Madeira

5.2 *Bridge monitoring system*

The extension of the airport began in 1995 and was finished in 2000, during the construction approximately 750 sensors were installed inside the concrete on the structure to monitor strains, temperature as well as the evolution of time dependent effects as creep or shrinkage. The locations of the porticos and slabs instrumented are on Figure 4 (1st phase) and in Figure 5 (2nd phase), the resume of the sensors, in these sections, is presented on the Table 2.

Beside the sensors mentioned above it were also installed clinometers to measure the rotations of the land support walls and active measuring bases to control the evolution of joint movement.

Weather stations were mounted to measure the temperature of the air and its relative humidity as well as to register the rain.

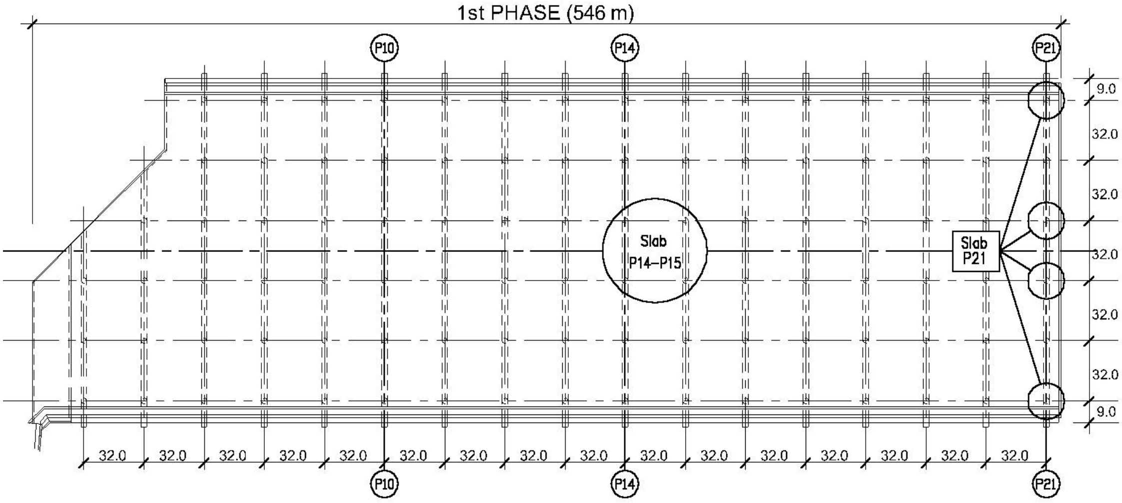

Figure 4 – 1st Phase - Location of the instrumented sections

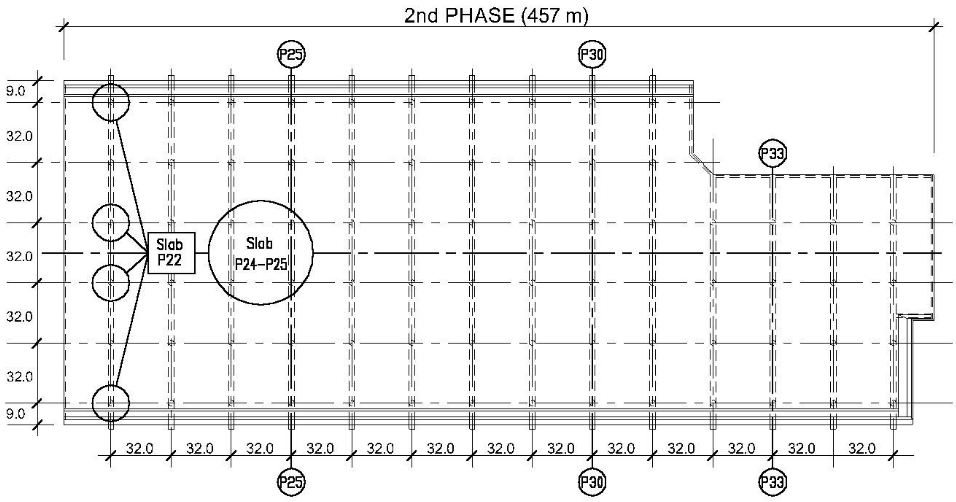

Figure 5 – 2nd Phase - Location of the instrumented sections

Table 2 - Sensors installed on the structure.

		Vibrating-wire strain gauges			Thermocouples
	Location	strains	shrinkage	creep	Temperature
1st Phase	Portico P10	60	9	-	-
	Portico P14	84	21	9	35
	Portico P21	24	-	-	-
	Slab P14-P15	46	6	6	9
	Slab P21	24	15	9	-
2nd Phase	Portico P25	84	21	24	25
	Portico P30	60	6	-	-
	Portico P33	60	9	-	5
	Slab P22	8	12	9	-
	Slab P24-P25	42	6	9	9
	Total	492	105	66	83

Because of the dimensions of the structure, two distinct local networks of dataloggers make the acquisition of the data. It was used 15 dataloggers in total, 9 in the sea network and 6 in the land network. The transference of the data is made by two GSM modems connected each to a local network.

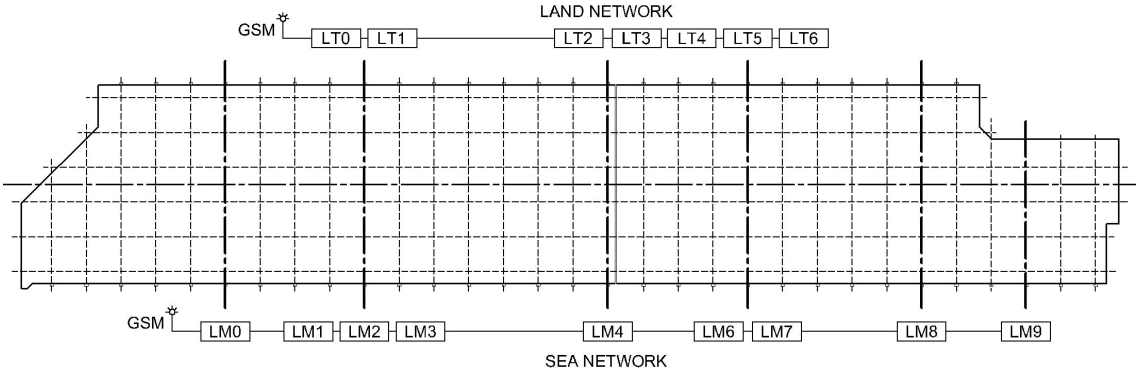

Figure 6 – Datalogger networks

The management procedures regarding the alarms and alert commands as well as the automated analysis are in development.

6 CONCLUSIONS

The purpose of this paper is to explain, resume and organise some of the procedures that we have to follow in order to develop real time monitoring activities on a bridge, taking advantage of some of the most recent technology improvements.

Depending on the type of bridge and the materials we define the locations of the monitoring sections ant the sensors as well as the limits to interpret the data.

The safety evaluations procedures talked in this article are referred only to the interpretation of the measurements made by the sensors installed on the bridge, however one of the most important stages of the monitoring process are the visual inspections. The data resulted from this inspections should also be analysed in order to help us understand some of the results gathered by the analysis of the sensors.

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