First Middle East Conference on Smart Monitoring,
Assessment and Rehabilitation of Civil Structures
8 – 10 February 2011, Dubai, UAE

SMAR 2011

Web based Monitoring and Assessment of Bridges and Structures

Peter Furtner[1], Roman Berger[2]

[1] VCE – Vienna Consulting Engineers, Vienna, Austria
[2] mageba SA, Bülach, Switzerland

ABSTRACT: Structures like bridges are exposed to a variety of environmental influences like wind, rain or traffic load which induce corrosion and material fatigue. Owners of structures want to or even have to know exactly the condition of the structure due to different reasons. Therefore over the last 10 years numerous monitoring systems for bridges and structures have been installed. Permanent monitoring systems in remote areas often have to work without connection to the local power and telecommunication networks. Moreover site visits to pick up measured data and automatically generated reports are costly and impose a certain time delay from measuring until notification of the owner. This fact emphasizes the need of energy autonomous and web-based remote monitoring and assessment.

1 INTRODUCTION

Over the last 10 years numerous permanent monitoring systems for bridges and structures have been in-stalled. In the beginning a site visit for picking up measurement data and carrying it to the office was necessary due to the lack of data transfer possibilities. There was even no possibility to remotely get informed if the system was running properly.

Standards like ISDN would have offered an opportunity for remote monitoring but bridge owners or owners of structures mostly weren't willing to install necessary cables.

The rise of wireless standards like GPRS and UMTS paired with steadily decreasing costs for data transfer offered the opportunity to implement remote control as well as remote monitoring capabilities. Likewise internet access was simplified and got more and more widespread thus developing web based remote monitoring and assessment of bridges and structures was just a logical consequence of this development.

2 MOTIVATION

Due to different facts owners or operators of bridges and structures want to or even have to know exactly the condition of the structure, the loads and environmental influences to which the structure is ex-posed. Many bridges which were built in the past to different design and construction standards may not necessarily satisfy today's increasingly rigid safety demands. Furthermore, many structures may have been built on unstable ground or be subjected to particularly harsh environmental conditions. Therefore in many cases there is a need for structures to be continuously monitored to ensure that relevant data such as changes in bridge movements or bearing forces, which might indicate a critical condition, are recognized sufficiently early to allow remedial action to be taken. The traditional manual bridge inspection is either incapable of picking up the required data, or the inspection interval is not sufficiently tight to ensure that changes in a structure's condition are recognized early enough. There-fore a market has developed for a product that can continuously monitor a structure at reasonable cost to the owner. A lot of existing structures already are and will be provided with a permanent monitoring system over the next years. A trend towards providing new structures with a permanent monitoring sys-tem because of their extravagant design, their dimensions or the application of special high-tech material is noticeable.

Permanent monitoring systems for bridges and structures are varying in shape, size, components, etc. substantially but in fact they do have in common some things. Although some of them consist of multiple subsystems, mostly they are realized with one central node which could be a PC or some kind of central DAQ-Unit that offers the opportunity to real-ize interfaces to remote control the system and re-mote monitor the structure. By realizing a remote control and monitoring interface, site visits to pick up data or reconfigure the monitoring system be-come dispensable.

3 DESIGN AND FEATURES OF A PERMANENT MONITORING SYSTEM

Modern monitoring systems can be designed to constantly measure changes in parameters such as length, position, force, pressure, temperature or natural frequencies. This information is measured at desired time intervals and recorded for analysis. The potential applications of automated monitoring systems are almost unlimited, but would underlie the following general areas among others:

- Safety concerns: ensuring immediate notification of the occurrence of a change in a structure's condition that may indicate that the structure is becoming or has already become unsafe to use. Use of such a system can enable the owners or operators to increasingly trust in the available information about the structure's condition, potentially allowing costly and disruptive retrofitting to be postponed or even deemed unnecessary.
- Engineering data: supplying records of the loading and movements to which a bridge is subjected, and the structure's response to these conditions.
- Usage data: providing records, such as weight and speed of traffic using a bridge. Cameras can be integrated to gather photographic proof of traffic events.

Basically a modern monitoring system consists of a central processing node (industrial computer), at least one sensor (that measures some variable like length, position, force, pressure, temperature or vibration), and some kind of connection to the central processing node (cable or wireless). A power source – connection to the local power supply system or some kind of independent power supply system – as well as enough memory to store data is required, too. More sophisticated systems can also offer additional features like dynamic weight registration, to enhance the capabilities of the system depending on local circumstances and client's requirements.

Independent power supplies are particularly beneficial where structures to be monitored are not located close to an existing power supply network. That can be realized for instance by using solar energy panels in connection with battery packs. A solar panel that provides power to a monitoring system at Incheon Grand Bridge is shown in Figure 2. This solar panel paired with backup batteries is able to provide the monitoring system with sufficient power to operate 24 hours a day all over the year regardless of weather or season. Using such a solution facilitates provision of a monitoring system in even the most remote area.

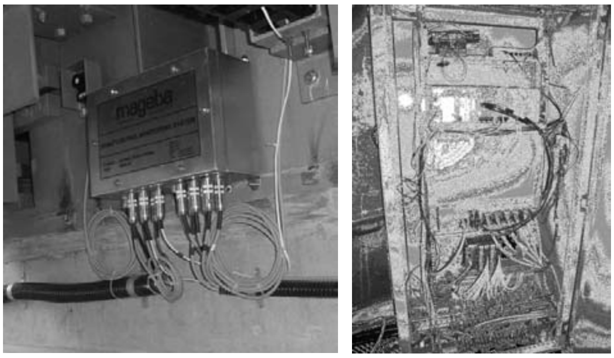

Figure 1. Small autonomous system (left), larger more sophisticated system (right)

Figure 2. Incheon Grand Bridge (South Korea) with independent power supply for the monitoring system

4 ADDITIONAL FEATURES OF A WEB BASED MONITORING SYSTEM

The basic monitoring system described before has enough capacity to store data. However this data must then be physically downloaded from the computer unit in order to be available for analysis which may be sufficient in many cases, but often it is desirable to have the data automatically transmitted to another computer, for instance a file server in an office. Automatic transmission offers two benefits: firstly, it saves the time and effort required for a trained operative to visit the structures site to download the data at regular intervals; and secondly, it results in real-time data being available to the bridge owner at all times. This immediate availability of data to the structure owner may be particularly useful, for example, where safety concerns exist, as the structure owner will have immediate access to data which may indicate a problem that requires attention (for example, unusually large movement of a bridge deck or excessive force on a bridge bearing).

The data can be transmitted from the bridge via a fixed line telecommunications network, where such a network exists. Alternatively a mobile (cellular) telecommunications network can be used.

Once the data has been transmitted from the site, it can be made available in different ways to the user. It may be e-mailed directly to a user in the form of basic numerical data, or it may be processed by a central server and made available in user-friendly format, using graphs and well-arranged diagram. See Figure 3 for an example of such a presentation of data. Afterwards it is possible to export data in form of a spreadsheet as desired. To further enhance user-friendliness, the processed data can be made available via the internet – an authorized user can log on to a secure website and access the information at any time, from anywhere in the world.

Of course the fact that information is available for downloading at all times does not mean that it will be downloaded when it is needed, or that the importance of the information will be recognized when it should be. Therefore modern monitoring systems offer automatic notification by SMS (text message) or e-mail to the bridge's engineers should a pre-defined threshold be exceeded or pre-configured alarm scenarios arise.

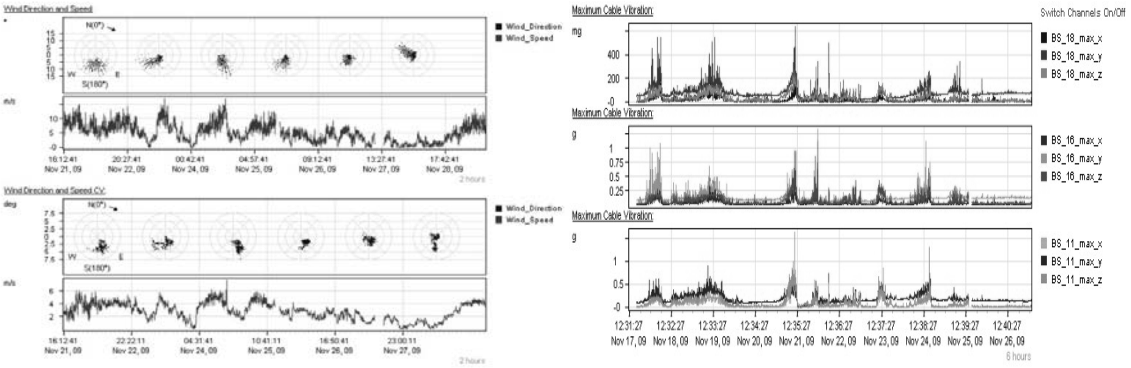

Figure 3. Web-Interface: Various ways of presentation

5 WEB BASED MONITORING WITH BRIMOS® AND ROBO®CONTROL

VCE's BRIMOS® and mageba's ROBO®CONTROL system for permanent monitoring include a web-interface for getting access to the measured and processed data.

Depending on the monitoring tasks data recorded by the monitoring system is either transmitted via cable connection or wirelessly using GPRS or UMTS from the central computer to a remote server or processed before transferring. As shown in Figure 4 the user gets an overview of all structures accessible with his account. After deciding which structure to have a closer look on a dashboard with general information on the structure as well as important notifications opens. On the left top of the dashboard (Figure 5) a description of the bridge as well as the measuring tasks is given. Below the project description measurement data of the different sensor categories can be accessed. In the middle and on the upper right some pictures and maps give an impression on the structure and the site. The sensor layout is displayed on the right bottom. Anything on the dashboard is linked so that a simple click enlarges pictures or leads to measurement data and assessment results.

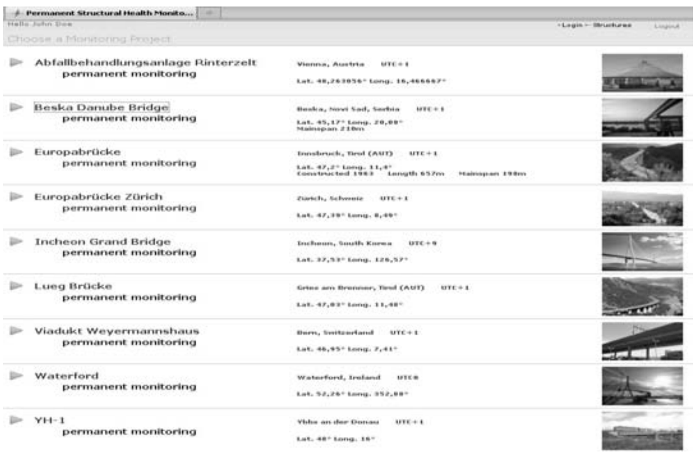

Figure 4. Overview on accessible structures

Pre-defined alarms are signalized on the dashboard. By following the link details for emerged alarms are displayed and have to be acknowledged by the user to disappear as notification from the dashboard.

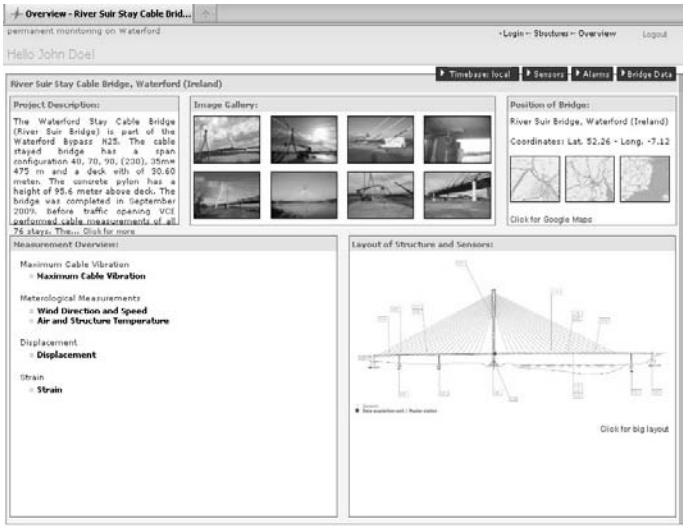

Figure 5. Dashboard of River Suir Bridge (Waterford, IRELAND)

Entering the measurement data page the screen gives detail on measured data from each sensor in different ways of presentation. Data can be displayed over different periods of time beginning or ending on any date. This allows assessing the change in behavior of a structure from one season to the next, or from on day to the next. The data thus presented in graphic or tabular form can also be exported in spreadsheet format for use in calculations etc. Download of further information like online generated reports, risk assessment results is offered here as well. For an example of risk assessment result diagram see Figure 6.

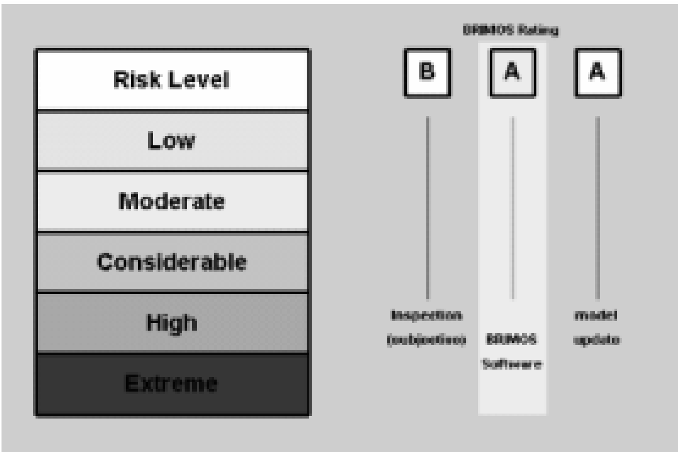

Figure 6. Example of risk level diagram

6 PRATICAL EXAMPLES

This chapter demonstrates the implementation by 3 practical examples all over the world.

6.1 *Monitoring of a cable stayed Bridge (South Korea)*

At 12.3km long with a main cable stayed span of 800m the new Incheon Bridge (Figure 2) is one of the five longest of its type in the world. Its 33.4m wide steel/concrete composite deck will carry six lanes of traffic 74m above the main shipping route in and out of Incheon port and link the new Incheon International Airport on Yongjing Island to the international business district of New Songdo City and the metropolitan districts of South Korea's capital, Seoul. The cable stayed section of the crossing is 1,480m long, made up of five spans measuring 80m, 260m, 800m, 260m and 80m respectively, and the height of the "inverted Y" main towers is 230.5m.

In order to measure the movement of the cable stayed bridge section and the performance of the modular expansion joints of type LR24, a ROBO®CONTROL remote monitoring system was installed at one at the expansion joint locations. This serves to measure the movements of the first, second and last lamella beams of the joint, as well as the entire gap width, air and structure temperatures.

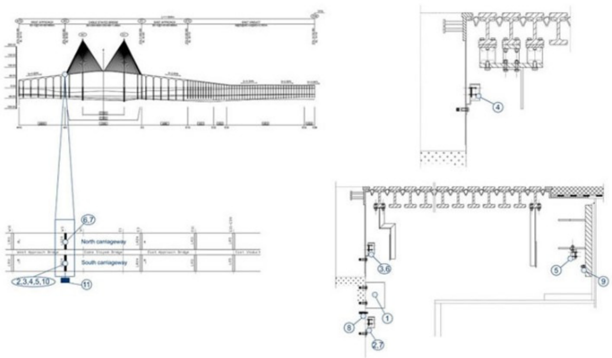

Figure 7. Sensor Layout of Incheon Grand Bridge (SOUTH KOREA)

The monitoring system was realized as autonomous system which means that there is no connection to the local power supply network. Power is provided from a photovoltaic panel paired with a battery pack. The autonomous power supply is design to work 24 hours a day, 365 days a year independent of time of the day and weather conditions. Measurement data is stored on site and transmitted in different time intervals to save power.

6.2 *Monitoring of a concrete Bridge (Weyermannshaus, Switzerland)*

The viaduct Weyermannshaus is part of the so called section "Grenze FR / BE bis Verzweigung N1 / N1" of the national road N12 in Switzerland and was built during the years 1974 – 1977. Every direction consists of 3 lanes. The viaduct crosses the regions Bümpliz and Weyermannshaus and thus connects the N12 with the N01. Two access ramps in the west and east of the bridge serve as entry and exit.

The northern abutment is situated in the section of the intersection N1/N12 besides the Murtenstraße. The southern abutment is located behind the access ramps Bümpliz near the undercrossing Bümpliz.

Close to the southern abutment cracks (Figure 11) in the concrete were found. The client wants to know the reasons for the cracks to act accordingly referring to the causes during the overall refurbishment of the bridge. The position of the cracks is the same as the position of the coupling joints of the interior pre-stressing cables.

Figure 11. Viaduct Weyermannshaus, concrete crack (SWITZERLAND)

The monitoring of the cracks is intended to assess the condition of the concrete cross-section and the fatigue of the untensioned and prestressed reinforcement.

In the case of the monitoring system Weyermannshaus the webinterface offers the user the opportunity to compare the behavior of the structure for instance from one day to another, or one week to another just in time. This is possible from anywhere in the world.

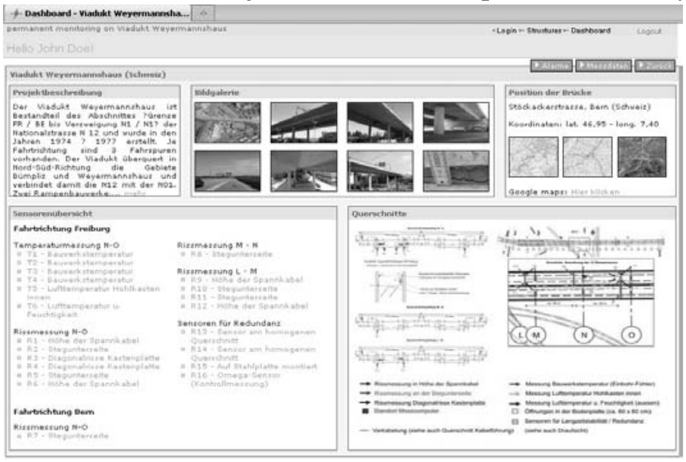

Figure 12. Dashboard and sensor layout of Viaduct Weyermannshaus (SWITZERLAND)

6.3 Monitoring of a danube Bridge (Beska Danube bridge, serbia)

In the course of the completion of the E75 (part of the European Corridor 10) on 4 lanes the construction of a new bridge over the Danube is required between Novi Sad and Belgrade near Beska. This bridge will be erected as a so-called "twin"- bridge parallel to the existing bridge, which currently accommodates two lanes in both directions and is to have the same appearance. The Danube is bridged with spans of 60m+105m+210m+105m+60m (without foreland structures).

Figure 13. Beska Danube Bridge, Serbia

The old bridge, built as pre-stressed concrete bridge in 1975, is to be maintained and continued to use. November 2008 a BRIMOS® measurement for the assessment of the condition was carried out at this structure. In addition the effects of the existing sliding slope on the structure were analyzed. In January 2009 a BRIMOS® monitoring system for permanent supervision of the bridge pier movements was installed additionally in order to be able to identify negative effects of the foundation works for the new construction on the old structure on time. Furthermore movements of the sliding slope are to be detected by means of the measuring system.

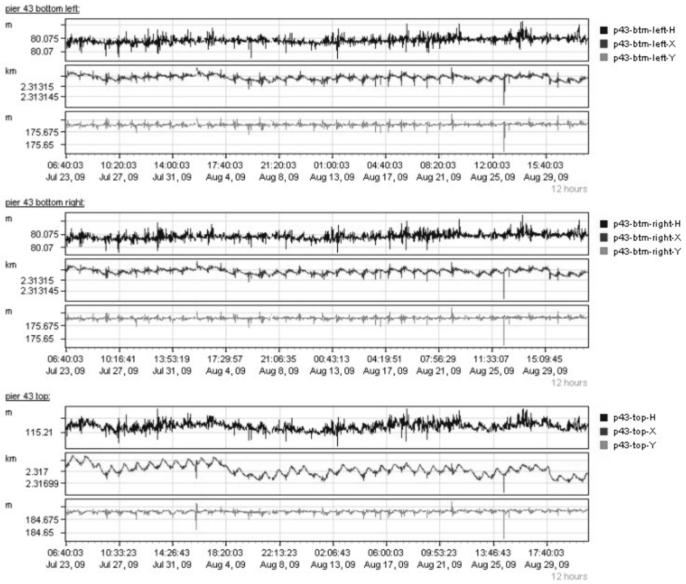

Figure 14. Measurement data presentation of Beska Danube Bridge (SERBIA)

The measuring system includes a tachymeter (Figure 13, right) for continuous monitoring of the pier movements as well as acceleration sensors for vibration supervision during sheet pile and bored pile works.

Figure 14 shows measurement data of 3 positions in 3 dimensions at pier 43 (bottom left, bottom right, top) presented in the web-interface.

7 CONCLUSIONS

The potential uses and benefits of modern web-based remote monitoring systems to the development and maintenance of structures are almost unlimited. Engineering data can easily be recorded with minimal effort, and made available in any desired format. More advanced systems offer immediate transmission of information from the structure to be viewed online from anywhere in the world, at any time, automatic generated reports of assessment, and automatic notification by SMS or e-mail to the bridge owner of the occurrence of predefined critical events. These systems can be installed in even the most remote locations, with power supply by photovoltaic panels and battery packs, and transmission of data using mobile telecommunications networks.

The more elaborate systems available, using latest sensor and measuring technologies and requiring computer analysis of data, offer the capability to collect enormous quantities of data. The authors believe that such systems have an exciting future in the area of research and development, and for special applications, for example those which require the measurement of vibrations (e.g. modal shape analysis). However the majority of structures would benefit from monitoring technology, such as in the assessment of the suitability of an old bridge to carry modern traffic loading.

The key factor for the future success of structural health monitoring is to change the approach from scientific driven goals to the needs of the non-scientific end-user. This includes a need for objective consultation with the client right from the start of a potential project, a clear and easy to understand presentation of the data, reliable services during the whole life-time of the health monitoring system and easy access to measurement data and analysis results anytime anywhere.

8 REFERENCES

Wenzel, H. 2009. Health Monitoring of Bridges. Chichester England: J. Wiley and Sons Ltd, ISBN0470031735.

Wenzel, H and Veit-Egerer, R. 2009. Measurement based traffic loading assessment of steel bridges – a basis for performance prediction. International Journal of Structure and Infrastructure Engineering. New York: Taylor & Francis Group.

Veit-Egerer, R and Wenzel, H. 2007. Monitoring based weak point determination of a steel bridges's torsional bracings with regard to fatigue threat. Proceedings of the 2nd International Conference - Experimental Vibration Analysis for Civil Engineering Structures (EVACES'07). Porto, Portugal: ISBN 978-972-752-094-4.