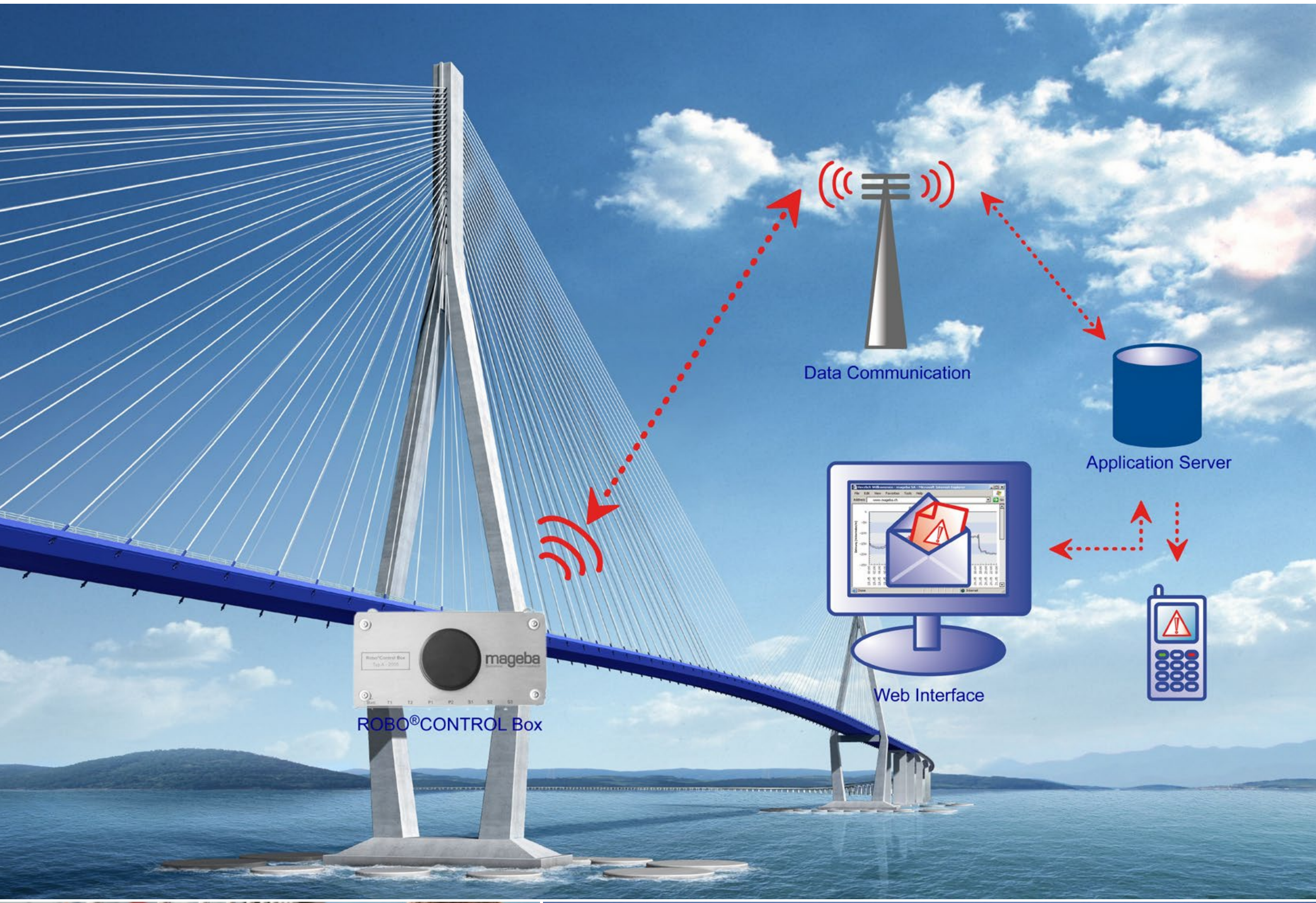
Structural monitoring

Infrastructure | Buildings | Industrial structures

ROBO®CONTROL – Monitoring Solutions

Portable and Permanent Systems



Structural monitoring

Automated data collection and processing

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1 System configuration on site
2 Installation of a 3D-acceleration sensor
3 Dynamic measurements on a railway bridge

Structural Health Monitoring (SHM)

How does a SHMS work

A Structural Health Monitoring System (SHMS) is an assembly of sophisticated electronic devices installed on civil structures with the purpose of assessing the actual conditions of the structure. During health monitoring of structures, global and local structural properties are assessed on the basis of continuously recorded measured variables.

It is therefore possible to predict further development of the structural condition with great accuracy. It is also possible to provide simple and quick identification and recording of changes in the load-bearing behavior.

An advanced SHMS is composed by

1 **Measurement devices (sensors)**
Sensors are installed directly on the structural elements, they measure physical parameters and transfer the information as a digital or analog signal.

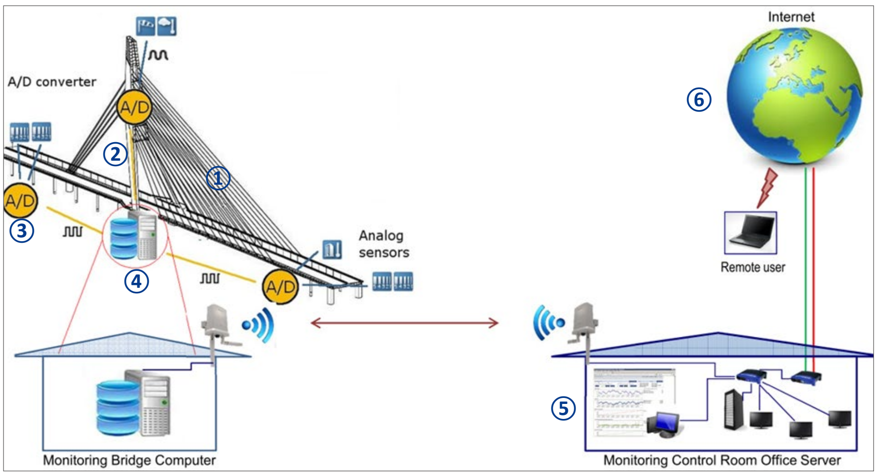
2 **Cables / radio waves**
Means for transmitting the signals from the sensors to the acquisition units.

3 **A/D converters, signal conditioners, filters**
Electronic devices transforming the analog signals to digital information. Signal amplifiers and Conditioners are used to amplify very small ambient signals, thus enabling a reliable evaluation.

4 **Data acquisition unit**
A data-logger that receives all the signals measured by the sensors. This is accompanied by an industrial PC equipped with large hard disks since large amounts of measuring data have to be processed.

5 **Data processing software**
Specifically designed software capable of data management and remote control of the system.

6 **Internet router**
Network connection enabling data transfer to end users. This enables also the possibility to receive alarms and notifications anytime from the system.



Scheme of a typical SHMS

Services provided

Safety Monitoring

Main drivers are specific concerns of the client regarding the stability or usability of a structure. mageba offers complete solutions to monitor the critical elements of a structure, including immediate alarm notification of significant changes.

Structural Health Monitoring

Tailor-made solutions for long-term monitoring of structures are offered by mageba to assess the overall behaviour of the structure. SHM systems provide crucial information to the owner to optimise length of service and life cycle costs.

Inspection & Measurement services

Structure owners' needs for detailed condition assessment can be fulfilled by mageba's inspection services. Relevant data is monitored and assessed and the overall condition of the structural elements is summarised in detail.

Consulting services

Remedial works often change the load scenarios and the static system of a structure. Assessment of the actual conditions before renovation, using the experience of mageba's global network, allows recommendations for new structural components to be made.

Applications and benefits

Applications

ROBO®CONTROL's efficient and reliable automated data collection offers benefits to many fields of engineering, such as:

- Bridges
- Tunnels
- Buildings
- Dams
- Substructures
- Mining
- Historic protection
- Environmental applications

Benefits for end-users

Owners & Authorities

- Enhanced safety of overall structure and its critical elements
- Risk minimisation by Safety Monitoring - immediate notification of changes
- Increased lifespan of structure and reduction of lifecycle costs
- Improved investment planning
- Optimisation of maintenance activities
- Efficient support for structure inspection department
- Risk management: Properly defined and measurable risks

Designers & Engineers

- Verification of designed / expected structural performance
- Confirmation of design parameters
- Model updating to optimise design calculations
- Increase of design experience and technical excellence

Construction companies

- Proof of properly executed construction work
- Optimisation of construction processes

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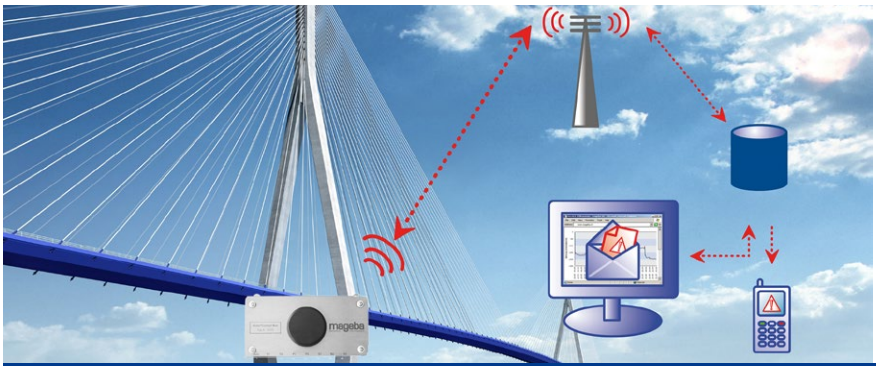
1 Protection of historical buildings
2 Detailed monitoring of vital elements of high-rise buildings
3 Structural monitoring of dams
4 Safety monitoring of tunnels
5 Structural monitoring of bridges
6 Updating of structural modeling

6


Overview of systems



ROBO®CONTROL systems

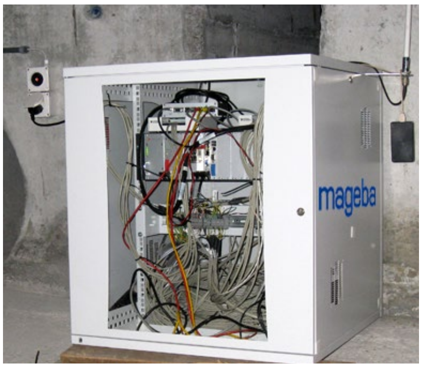
Permanent systems
for long-term monitoring and investigative applications, featuring battery or permanent power supply and transmission of data to a central server

Portable systems
for short-term investigative applications

"BASIC"

- Limited to static monitoring applications at low frequencies
- The number of sensors that can be integrated is limited

"ADVANCED"



- Dynamic and static monitoring missions possible at all frequencies
- Unlimited number of sensors can be integrated

"PORTABLE"

- Dynamic and static monitoring tasks possible at all frequencies
- Measuring time limited due to battery capacity

ROBO®CONTROL “BASIC”

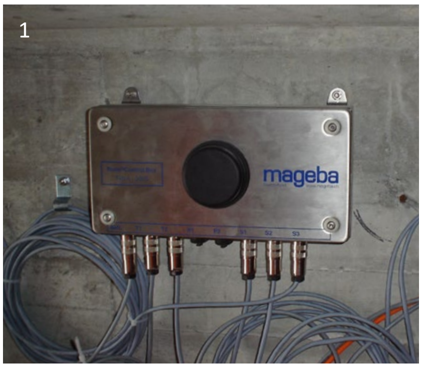
ROBO®CONTROL systems		
Permanent systems		Portable systems
BASIC	ADVANCED	PORTABLE
Structural control and long term monitoring		

Main features

- Components designed for continuous, remote and independent operation
- Data transmission via GPRS / GSM to mageba's or client's server
- Alarm function possible (notification of pre-defined events and load cases)
- User-friendly web interface

Infobox

Measuring Frequency	> 0	1		500 Hz
No. of sensors	0	20		>100
Required investment	0	25,000	50,000	200,000 EUR
Yearly cost	0		500	>1,000 EUR/year
Power supply	Solar panel ✓	Mains / grid ✓	Battery ✓	
Data memory	Server			
Data presentation	Internet Browser			
Alarm notification	E-Mail ✓	SMS ✓		
Warranty	Standard 1 year (extendable up to 5 years)			
Contract type	System may be purchased			



1 Applied system at Ponte Nanin Bridge, Switzerland
2 User-friendly web interface
3 Installation of ROBO®CONTROL Box

ROBO®CONTROL “ADVANCED”

ROBO®CONTROL systems		
Permanent systems		Portable systems
“BASIC”	**“ADVANCED”**	“PORTABLE”

Main features

- Structural control and long term monitoring
- Components designed for continuous, remote and independent operation
- Data transmission via GPRS / GSM to mageba’s or client’s server
- Alarm function possible (notification of pre-defined events and load cases)
- Tailor-made solutions
- User-friendly web interface

Infobox

Measuring Frequency	> 0	1 – 500 Hz
No. of sensors	0	20 – >100
Required investment	0	70,000 – 200,000 EUR
Yearly cost	0	500 – >1,000 EUR/year
Power supply		Solar panel ☐ Mains / grid ☑ Battery ☐
Data memory		Server
Data presentation		Internet Browser
Alarm notification		E-Mail ☑ SMS ☑
Warranty		Standard 1 year (extendable up to 5 years)
Contract type		System may be leased or purchased

1 Online presentation of measured data
2 Integration of any type of sensor or application, for example webcams
3 Installation on site

ROBO®CONTROL “PORTABLE”

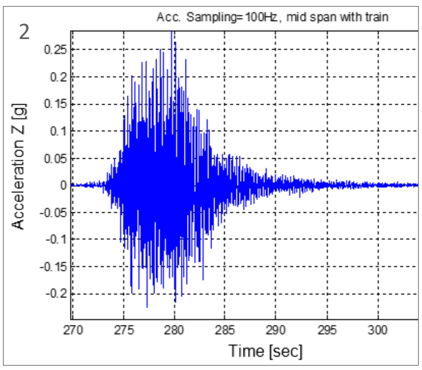
ROBO®CONTROL systems		
Permanent systems		Portable systems
“BASIC”	“ADVANCED”	**“PORTABLE”**

Main features

- Structural identification and short term monitoring Robust electronics for repeated, temporary use
- No connection to power grid required (battery powered)
- Flexible arrangement of all system components to suit project requirements

Infobox

Measuring Frequency	> 0 — 500 Hz
No. of sensors	0 — 10 — >100
Required investment	0 — 25,000 — 200,000 EUR
Yearly cost	No transmission costs
Power supply	Solar panel ☐ Mains / grid ☐ Battery ☑
Data memory	USB Stick, Local
Data presentation	Internet Browser in real time on computer
Alarm notification	Not applicable
Warranty	Not applicable
Contract type	Not applicable



1 Removable storage device (USB stick)
2 Viewing of data on computer
3 Easy handling and use of “PORTABLE” system

Measurement devices at a glance

Sensors

Today, virtually any physical parameter can be measured with extremely high accuracy, and the information technology generally exists to transmit the large volumes of data often generated.

Sensors are widely available and frequently used to measure all types of movement, 3D acceleration, GPS positioning, tilting, structural temperature, vibrations and environmental conditions.

The types of sensor to be used are chosen according to the client's needs. During the design, an extensive analysis of costs, accuracy, sampling frequency, environmental conditions and data generation is performed, thus defining the optimal sensors to deploy.

Force sensors

- Various types of load cell can be integrated
- Load cells of all major stay cable and anchor suppliers can be connected
- Integration of mageba's RESTON®POT bearings with measuring devices is possible

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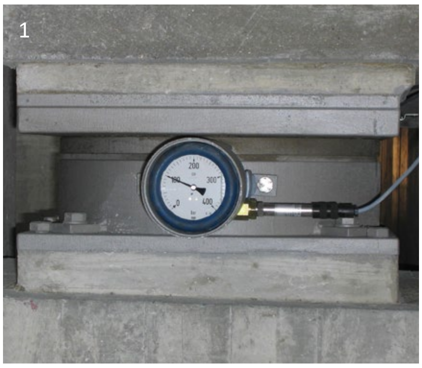

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Strain and tilt sensors

- Strain in steel elements measured by strain gauge devices, incremental changes are measured at the surface, stress and fatigue analysis for designers
- Integration of sensors into a structure during construction for absolute values
- Embedded sensors inside concrete structural elements
- Tilting of structures or elements measured

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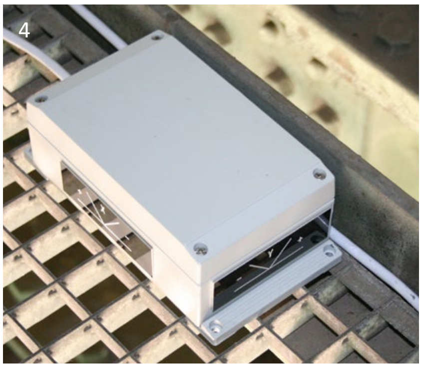

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Movement sensors

- Inductive movement sensors for small changes (e.g. concrete crack monitoring) or for medium displacements
- Wire sensors for larger movements (e.g. bearing and expansion joint movements)
- Extreme degree of accuracy (~1µm) possible due to highly sophisticated devices

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1 Instrumented pot bearing with barometer and digital pressure sensor
2 Ultrasonic displacement sensor
3 Strain gauge
4 Tilt sensor
5 Geodetic survey
6 Rectilinear displacement sensor on a bearing
7 Inductive movement sensor measuring crack width

Acceleration and vibration

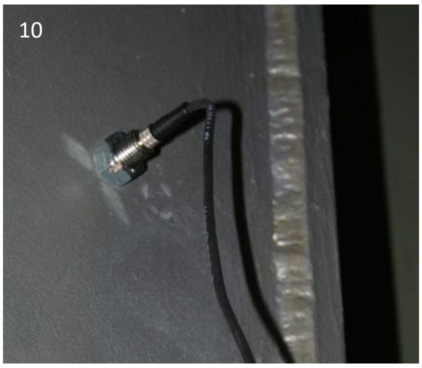
- System identification and damage detection by 3D-Acceleration sensors
- Stay cables: sensors to measure modal frequencies and forces
- Vibration sensor integration to assess dynamic influences on the structure

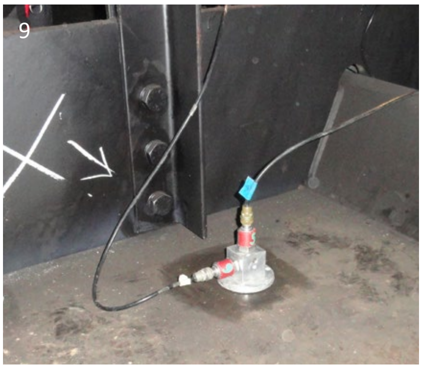
Structural temperature sensors

- Devices for measurement of steel temperature, externally applied
- Concrete temperature measured by integrated sensors (installed during construction or inserted into drilled holes)

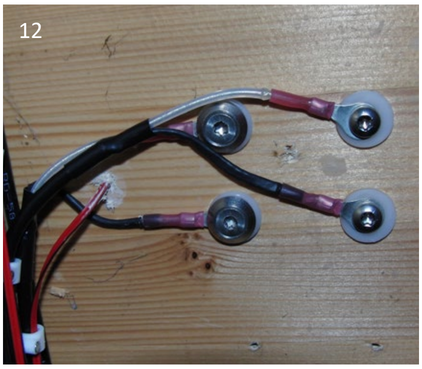
GPS position monitoring and meteorological surveillance

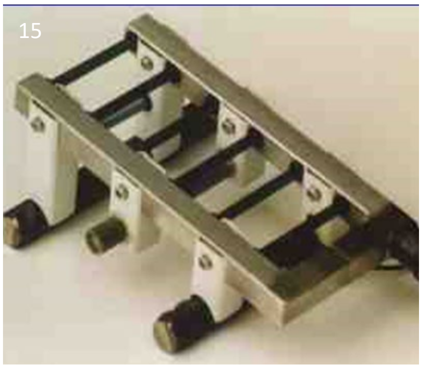
- High precision GPS devices available, with accuracy as required by project
- Meteorological surveillance required for most projects (air temperature, humidity etc)





8 3D acceleration sensor
9 Vibration measurement
10 Temperature measurement
11 Concrete temperature sensor
12 Moisture detection sensor
13 GPS position sensor
14 Wind and air temperature sensor
15 Corrosion monitoring





Durable and open-sourced technology

State-of-the-art system

mageba's monitoring systems are updated to the latest technology, using the optimal equipment available in order to suit monitoring purposes

- Only 'open-source' software
- Only hardware that is available on the free market is used

Power supply

ROBO®CONTROL monitoring systems can be powered regardless of the conditions found at the bridge site:

- Any electricity source available at the bridge (e.g. street lighting) is sufficient for the operation of the system
- Back-up batteries for cases of interrupted power supply can be integrated if required
- In remote locations with low frequency measurements, power needs can normally be fulfilled by solar energy with a battery back-up system, guaranteeing power 24 hours a day, 365 days a year

Data transmission

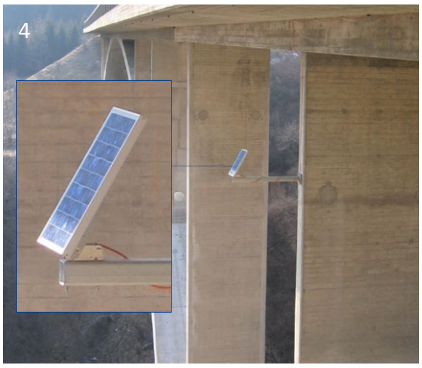
For the transmission of data from the sensors to the ROBO®CONTROL acquisition unit on site, the majority of projects use wires, barely visible on the structure. Existing cable trays or ducts may be used if possible. Data is transmitted to mageba central server through internet.

Wireless systems

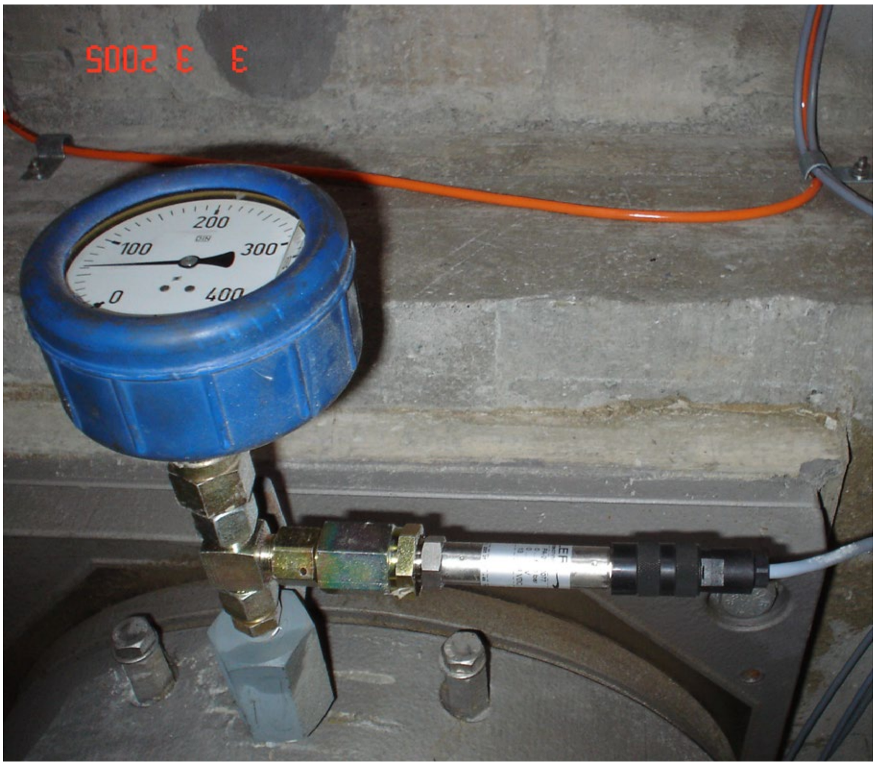
The use of sensors with wireless transmission of data offers the following benefits:

- Increased speed of installation
- Less impact on the structure (very few cables)
- Positioning of sensors can be easily adapted

It has to be considered that the battery life of sensors is currently limited to applications of up to one year. Therefore, some maintenance visits to the bridge may be required for long-term monitoring purposes when using wireless sensors.



1 Wired sensor
2 Wireless 3D-acceleration sensor
3 Bearing with measurement of pressure through manometer and load cell
4 Remote system powered by solar energy



Case study

Rhine Waterfalls (Switzerland)

System
Permanent "Basic"
Services provided
Safety monitoring

Description of the structure

The rock wall of particular interest is about 20m high and was stabilised with 11 additional rock anchors. The installation conditions were challenging due to high exposure, noise and dampness.

Problem statement

The Rhine Falls in Schaffhausen, Switzerland is visited by hundreds of thousands of tourists every year. It is one of the region's most important tourist attractions and visitors marvel at the beautiful scenery from a terrace at the castle of Laufen.

Rock anchors installed to stabilise the rock wall below the castle showed unexpected force changes, leading to concerns that some sliding surfaces had developed. To ensure the ongoing safety of the terrace, additional rock anchors with measuring devices were installed, with a ROBO®CONTROL system monitoring anchor force changes.

This enables the responsible design engineer to draw conclusions about the rock wall's movement behaviour, ensuring appropriate action can be taken if required.

Monitoring approach

A ROBO®CONTROL permanent "BASIC" system was connected to the installed rock anchors, its flexibility allowing compatibility with the load cells of the anchors.

After the system calibration had been successfully conducted, the long term monitoring was set up, transmitting all data to a central server. The responsible authorities and design engineers are then able to monitor all anchor forces from their own offices, via a web interface.

The designer set some critical limitations for the anchor forces, which are implemented in the alarm notification feature of the ROBO®CONTROL system. Should any alarm value be exceeded, immediate notification will be sent by email and SMS to the designer and owner.

Outcome and benefit for the customer

It could be concluded that the rock wall has been well stabilised by the additional rock anchors. The forces are now very stable and rock movements are negligible.

And although movements may develop in the future, the ROBO®CONTROL system's alarm feature gives the local authority the confidence it needs to safely manage one of Switzerland's most frequented and spectacular public terraces.

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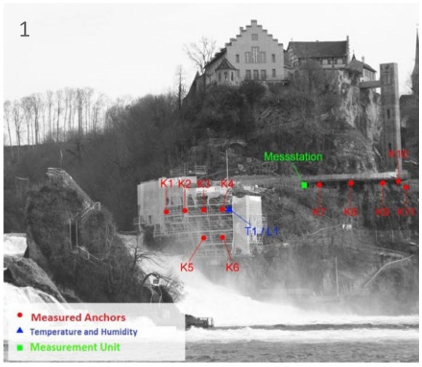

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1 Overview of anchored sensors at rock wall

2 Graphical presentation of data on the web interface, including immediate alarm notification

Case study

Incheon Grand Bridge (South Korea)

Description of the structure

12.3 km long and with a main cable stayed span of 800 m, the new Incheon Bridge is one of the five longest of its type in the world.

Its 33.4 m wide steel/concrete composite deck carries six lanes of traffic 74 m above the main shipping route in and out of Incheon port and links 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 1480 m long, made up of five spans measuring 80 m, 260 m, 800 m, 260 m and 80 m respectively.

Problem statement

The design of this exceptional bridge required deck expansion joints with extraordinary movement capacity (1920 mm). The bridge engineers required verification of:

- the forecasted movement behaviour of the bridge and
- the overall functionality of the modular expansion joints on a continuous basis

Monitoring approach

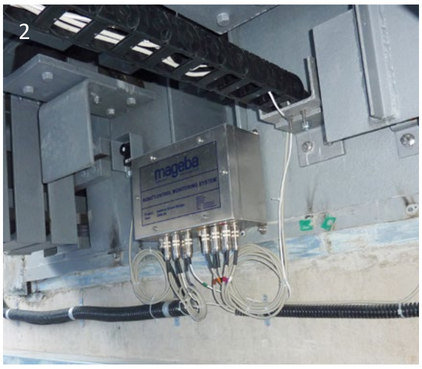
In order to measure the movement of the cable stayed bridge section and the performance of the 24-gap modular expansion joints, a ROBO®CONTROL remote monitoring system measures the longitudinal and transverse movements of the deck at the joint.

The system measures the longitudinal movements of the first, second and last lamella beams of the joint, and the entire gap width. It also measures deck rotations and air and structural temperatures.

Outcome and benefit for the customer

Measurements to date allowed the following conclusions to be drawn:

- The foreseen design movement and rotation behaviour of the bridge deck was confirmed
- The exceptional expansion joint is performing very well, with no impacts and with satisfactory opening and closing of all gaps.



1 Installation of exceptional TENSA®MODULAR LR24 expansion joint

2 ROBO®CONTROL box as installed

Case study

River Suir Bridge (Ireland)

System
Portable „Advanced“
Permanent „Advanced“

Services provided
Consulting
Structural Health Monitoring

Description of the structure

The River Suir Bridge is part of the N25 by-pass of the city of Waterford. The cable stayed structure has an overall length of 465 m, with individual spans of 40 m, 70 m, 90 m, 230 m and 35 m, and a width of 30.6 m. Its concrete pylon has a height of 95.6 m above the deck, and the bridge was completed in September 2009.

Problem statement

The design of this cable stayed bridge was determined to be critically dependent on the dynamic behaviour of its cables. The costly installation of stay cable dampers was to be assessed in two steps:

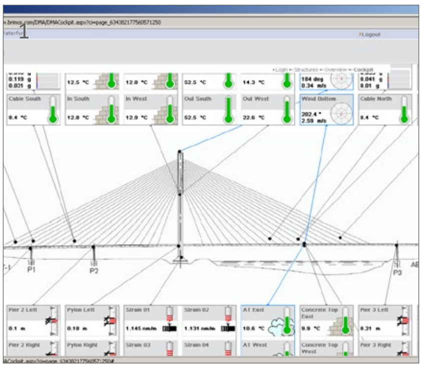
- Assessment of the characteristics of each stay cable by temporary measurements to determine its natural frequency, damping and tension
- Assessment of the ongoing structural health of the bridge to confirm that there is no need for permanent damping of the stay cables, and thus saving the expense of costly damping systems

Monitoring approach

Before opening to traffic, measurements on all 76 stay cables using a ROBO®CONTROL “Portable” system were performed, providing data on actual cable forces and cable damping. Afterwards, a ROBO®CONTROL “Permanent” monitoring system was installed. The system includes 62 measurement channels in total. The data is automatically analysed on site with an overview of the current situation and graphical representation of the overall performance to date presented in a web interface.

Outcome and benefit for the customer

Thanks to the data provided by the monitoring system, it could be concluded that it was not necessary to install dampers on all cables, resulting in great financial savings for the client. However, some selected cables may be fitted with well-specified dampers at a later date.



1 Presentation of measured data on web interface

2 Wind sensor as installed on the top of the pylon

Angus L. Macdonald Bridge and A. Murray MacKay Bridge (Canada)

Description of structure

Two suspension bridges connect the city of Halifax in Nova Scotia, Canada across the sea inlet that divides it in two. Having been opened to traffic in 1955 and 1970 respectively, both bridges have already provided several decades of service. The A. Murray MacKay Bridge was renovated in recent years, and similar renovation works are currently being planned for the Angus L. Macdonald Bridge. It will receive an entire new deck, and computer modelling of the deck, verified by measured data, will play a key role in the design process.

Problem statement

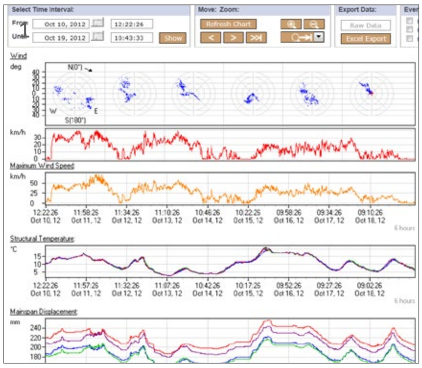
It was determined that a structural health monitoring (SHM) system should be used to measure and record the movements and rotations of the deck of the Macdonald Bridge at its expansion joints, providing the data needed by the computer modelling. It was also decided to monitor the movements of the previously renovated deck of the MacKay Bridge, so that the changes to the deck support system could be accounted for in the planning of the proposed works.

Monitoring approach

Both structures are equipped with ROBO®CONTROL BASIC permanent systems, with sensors at each tower recording rotations and displacements (both longitudinal and transverse) of the decks of the bridges, as well as data relating to temperature and wind strength and direction. Since the two suspension bridges are similar and located close to each other, comparing their behaviour can provide valuable insights.

Outcome and benefit for the customer

The gathered data was used by the design engineers to verify their computer models and design critical components. It also provided a very interesting insight into the movements of the deck of the MacKay Bridge, showing that it experiences accumulated movements of up to 35 kilometres per year at its expansion joints. Such accumulated movements are many times higher than the movements measured at the deck of the neighbouring Macdonald Bridge, which are just 700 m per year at its joints, and thus likely to accelerate wear and deterioration of the bridge's expansion joints and bearings. The understanding of deck movements provided by the SHM system will thus play a crucial role in supporting the planning of renovation works and the correct choice of sliding materials for the bearings and expansion joints.



2

1 Correlation of wind speed and direction, air and structure temperature, and deck movements, as presented on the SHM system's web interface

2 ROBO®CONTROL box installed under each of the four bridge towers (two per bridge)

Turnkey solutions offered

Clarification of objectives

In order to achieve maximum value for the customer, it is critical that requirements are carefully analysed before commencing work.

Clients, designers and mageba's monitoring team must clearly define the monitoring system's purposes and the benefits of the obtained data. Ideally, the measured values can be directly integrated in the designer's calculation model.

The required accuracy, the sampling frequency of the signal, the duration of the monitoring and type of data analysis is decided in close collaboration with the client in order to achieve the right conditions for an optimal analysis or damage detection of the structure.

In addition, close ongoing cooperation with the responsible structural engineer is beneficial in order to ensure that sensible and useful results continue to be achieved. Cooperation with specified engineers and experts will always be supported by mageba.

Any monitoring system must be tailored to suit the specific conditions and features of any individual structure. To achieve optimal results, mageba should be involved in the project development at an early stage, ideally right from the beginning of the conceptual approach.

Project requirements

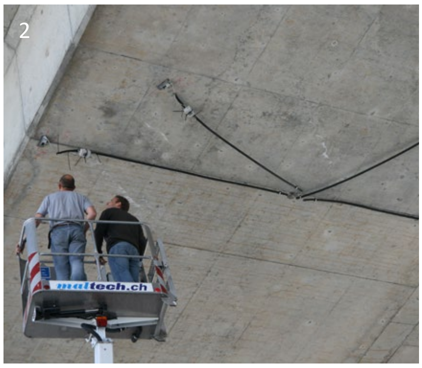
In addition to the clear definition of objectives, the following items should be agreed when placing an order for a monitoring system:

- Layout of system
- Arrangements for data management
- Definition of engineering tasks and responsibilities
- Contract for data transmission costs (if any)
- Service contract requirements to ensure long-term performance

Delivery

Fabrication and pre-setting of the system begins as soon as the customer has approved mageba's final proposal. Delivery time is highly dependent on type and size of the applied monitoring system and its components.

Installation typically takes a few days, depending on the complexity of the system and local access conditions and taking care to protect it from environmental conditions, vandalism and theft.



1 Close cooperation between clients, designers and mageba's monitoring team
2 Inspection of monitoring system after installation by mageba experts

References ROBO®CONTROL Monitoring


Rhine Waterfalls (CH)


Weyermannshaus (CH)


Steinbachtal Bridge (DE)


Alvsborg Bridge (SE)


Dintelhaven Bridge (NL)


River Suir Bridge (IRL)

mageba ROBO®CONTROL Monitoring Systems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