

# Structural Health Monitoring of Signature Bridge in Delhi - the Bridge-Structural-Health-Monitoring-System for the Wazirabad Bridge Project

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## **Summary**

A new cable-stayed bridge is currently under construction across the River Yamuna in Wazirabad, Delhi. The bridge will have a total length of 675 m, with a main span of 251 m. Its steel-concrete composite deck, with a total width of 35.20 m, will carry four lanes of traffic in each direction. Its dramatic inclined steel pylon, with a height of 154 metres, and elegant stay cable design, will make it a particularly attractive and imposing addition to the Wazirabad skyline.

The bridge will be equipped with a sophisticated structural health monitoring system, supplied by a joint venture of Mageba India, Mageba Switzerland and Vienna Consulting Engineers.

The paper describes the purpose of the system and the requirements it will fulfil, and presents the general system layout, a description of the equipment and the technical solution for data transfer. A special focus is given to the subject of data management, which includes the archiving, analysis and presentation of the recorded data. In addition to the compulsory control room devices, the system will include a user interface which allows secure internet access to the monitoring data and results, from any location at any time.

**Keywords:** SHM, permanent structural health monitoring system, internet user interface, turn-key solution, automatic data analysis, professional monitoring services

## **1. Introduction**

This document describes the bridge structural health monitoring system (BSHMS) which is to be provided for Delhi's new Signature Bridge. It covers the development and design of the instrumentation systems for the monitoring of behaviour, performance and condition of the structure.

The system is intended to fulfil three major purposes:

- structural health monitoring and damage detection;
- monitoring of weather loading (e.g. temperature, storms); and
- earthquake monitoring

The monitoring system needs to be implemented by means of industrial-grade components capable of continuous uninterrupted operation during earthquakes or rough weather conditions. The system will monitor:

- environmental factors;
- load factors; and
- bridge structural response

## 2. The Signature Bridge

The Signature Bridge will be an eight-lane road bridge across the Yamuna River. With its semi-harp shaped cable-stayed design, it will be Wazirabad's most striking landmark. It has an overall length of 575 m, and a main span of 251 m. The composite deck contains three main girders, with cross girders at 4.5 m spacing.

The polygonal shaped pylon provides, to a substantial extent, the stress balance required to support the deck. It also contains lifts and stairs providing access to the top of the 151 metre pylon, for maintenance and sightseeing purposes.



*Figure 1: Wazirabad's new Signature Bridge – currently under construction*

## 3. Basic Design of the System

As described above, the monitoring system is being provided to fulfil three main requirements:

- structural health monitoring and damage detection;
- monitoring of weather loading (e.g. temperature, storms); and
- earthquake monitoring

The system which has been proposed to address these needs will consist of the following:

- a total of 104 sensors, using 171 data channels, to measure environmental, load and structural response factors as described in Section 4 (see Figure 3);
- a signal acquisition solution, including signal capture from the sensors, signal verification and temperature adjustment, conversion of signal to digital format using 24 bit architecture, 1/1000 sec. signal time synchronisation, signal transport to pre-processing data acquisition unit, signal pre-processing and buffering prior to transferring to data processing;
- data processing to generate reports, prompt control actions and provide alarms as may be required;
- data storage; and
- a user-friendly interface to enable necessary operational intervention, maintenance optimisation and support high-level analysis such as finite element.

All components shall be able to sustain severe environmental conditions. The system is designed to sustain partial damage with undamaged parts remaining operational without losing real-time or stored data. Design assumptions are highly conservative to maximise the mean time between failures (MTBF).

Hardware and software are designed and selected to ensure that they can be engineered or replaced with commonly available alternatives in the future – for example, should the current supplier be unable to meet the need.

Authorised users will have on-line access to current and archived data. The user interface shall be intuitive and easy to use, showing “analogue instrument” display in the form of a “mimic panel”.

## 4. Data to be Recorded

The following data will be recorded by the system.

### 4.1 Environmental Factors

Environmental conditions at the top of the pylon will be recorded by a weather station which will measure ambient temperature, relative humidity, precipitation levels, barometric pressure, as well as wind speed and direction. Wind speed and direction will also be measured at deck level, by an ultrasonic sensor.

Factors affecting specific structural members will also be assessed. Relative humidity and temperature inside the hollow sections of the deck structure will be measured by four hygrometers, and the level of corrosion in the pylon base structure will be monitored by means of embedded chloride ion and corrosion sensors.

In addition seismic events, which could have a serious impact on the entire structure, will be measured at the pylon base using 3D high-definition accelerometers in each leg plinth.

### 4.2 Load Factors

Natural vibrations will be measured by eight 3D-accelerometers, which will be capable of relocation along the length of the structure to provide total coverage on a cyclical basis.

Traffic data will be recorded by laser analysers, enabling lane usage, average lane speed and vehicle classification are to be determined.

Traffic congestion, accidents and other anomalies will be captured by a video surveillance unit featuring colour cameras, capable of recording 30 frames per second and night-time usage.

### 4.3 Bridge Structural Response

Strain in the pylon, compensated for temperature, will be measured by welded strain gauges, while strain in the deck girders, also temperature compensated, will be measured by bolted strain gauges.

Stay cable forces will be measured by electromagnetic sensors, weatherproof and telecommunications shielded, on the longest, shortest and medium length cables of each set of cables – two sets on the main span and one on the back span.

Cable vibrations will be recorded by 3D-accelerometers, which will be detachable to allow relocation during and after the construction phase to assist in calculation and verification of damping, as well as assessment of changes in harmonics during operation.

Tilt of the deck on each span and of the pylon (above and below the elbow) will be measured by inclinometers, and displacement of the deck by strain gauges at the expansion joints.

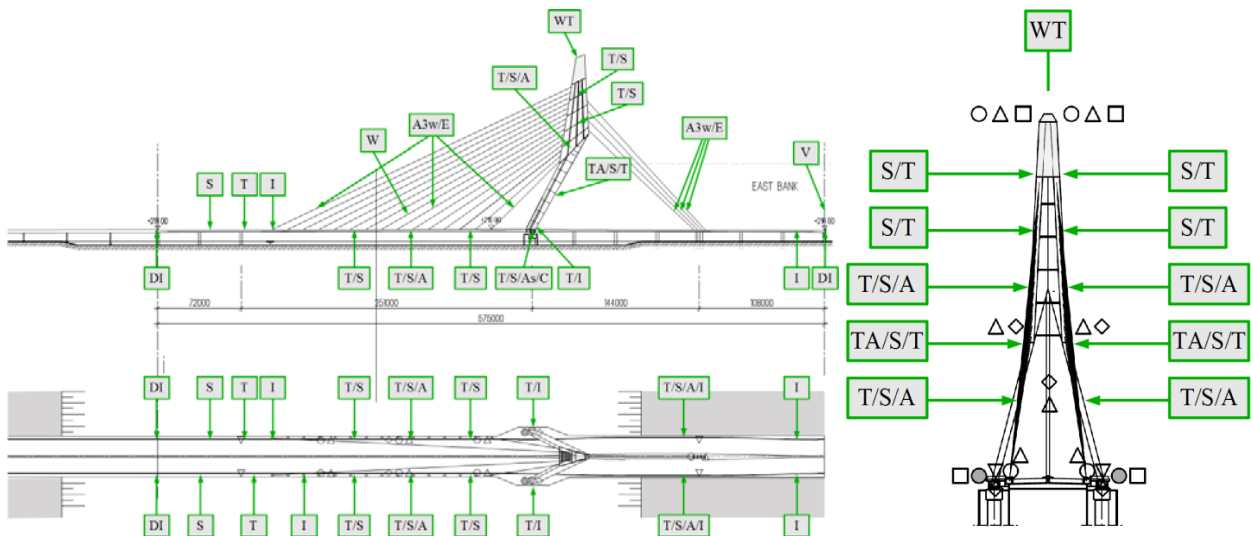


Figure 2: Sensor layout

Sensor	Logo	Sensors according to Specifications	Channels according to Sensors
		Sensors	Channels
Structural temperature	T	20	24
Strain gauge boltable	S	10	10
Strain gauge weldable/ glueable	S	10	10
Wind sensor 3D	W	1	4
Wind multi-sensor (Wind 2D direction and speed, ambient temperature, precipitation levels, barometric pressure, relative humidity)	WT	1	6
3D accelerometers, cables	A3w	18	54
3D accelerometer, deck & pylon	A	8	24
Seismic accelerometers	As	4	12
Displacement sensor	DI	4	4
Inclination, tilt	I	4	8
Corrosion	C	3	6
DV Camera	V	4	
Traffic analyzer	TA	8	
Electromagnetic sensors	E	9	9
<b>Sum</b>		<b>104</b>	<b>171</b>

Figure 3: Summary of sensors included in the monitoring system

## 5. Data Collection Unit at the Bridge

### 5.1 Master Station

The data acquisition unit is based on industrial graded cPCI systems with dual-core CPUs, running data acquisition and data calculating software. The unit controls all sensor functions and provides all measured data with source codes (name and position of sensor) and time stamps to allow accurate time synchronisation. A/D-conversion is done by multi-channel, 24-bit converter modules, located as closely to the sensors as possible. All raw data measured by the sensors is stored on two independent hard discs to prevent data loss in case of disc failure. Pre-processing of the monitoring data also takes place here.

The master station is equipped with independent time sources (GPS) to ensure self-sufficiency should connection to the local network be lost. This ensures preservation of records during critical events such as traffic accidents or earthquakes. The unit is also protected by an air-conditioned cabin to enhance reliability and durability.

### 5.2 Power Supply

The system will be equipped with an uninterruptable power supply (UPS) in order to guarantee power supply at all times and prevent data loss, especially during a critical event. The UPS will also protect the equipment against fluctuation and voltage peaks in the public power supply. The battery capacity will be adapted to the actual power requirements in order to guarantee power during a two hour interruption of the main supply. Battery lifetime of several years can generally be expected.

## 6. Data Transfer from the Master Station to the Local Data Server

The data connection between the master station on the bridge and the bridge operator's control room is by means of a wireless LAN bridge using a private static IP. This can operate over a distance of four to five kilometres. This system enables real-time data transmission, independent of mobile telecommunication service providers.

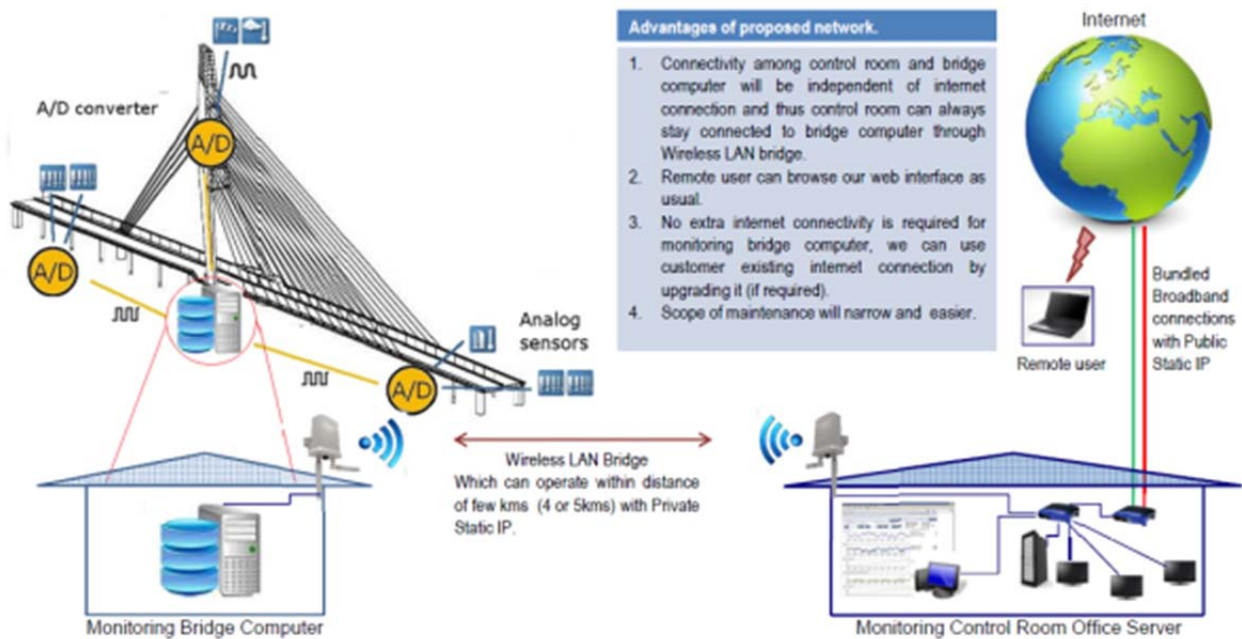


Figure 4: Data transmission

## 7. Data Presentation

### 7.1 Local Data Server

Data presentation is controlled by a local monitoring data server in an office of the client's choice. Since the server is connected to the internet and the data transfer from the master station on the bridge to the server is wireless, the location can be freely chosen.

All data received from the master station is stored permanently on two independent hard discs to prevent data loss in case of disc failure.

The server is also capable of processing, managing and presenting data from any other permanent monitoring system that might be connected in the future.

### 7.2 Web User Interface

The user interface enables an authorised user to log on to the system, and view any data which may be of interest, for any period of time during which measurements were made (Figures 5 to 7). It also enables the user to input condition and event values and, if necessary, instructions for personnel. Information is presented in a user-friendly and simply understandable format. High frequency data is displayed in clear graphics (e.g. mimic panel format).

The user can also instruct the system to provide an alarm if predefined threshold values of any variable are exceeded. Such alarms can take the form of a visual notification on a monitor, or an email or SMS to a selected person.

This user interface is accessible at any time, from anywhere in the world with an internet connection.



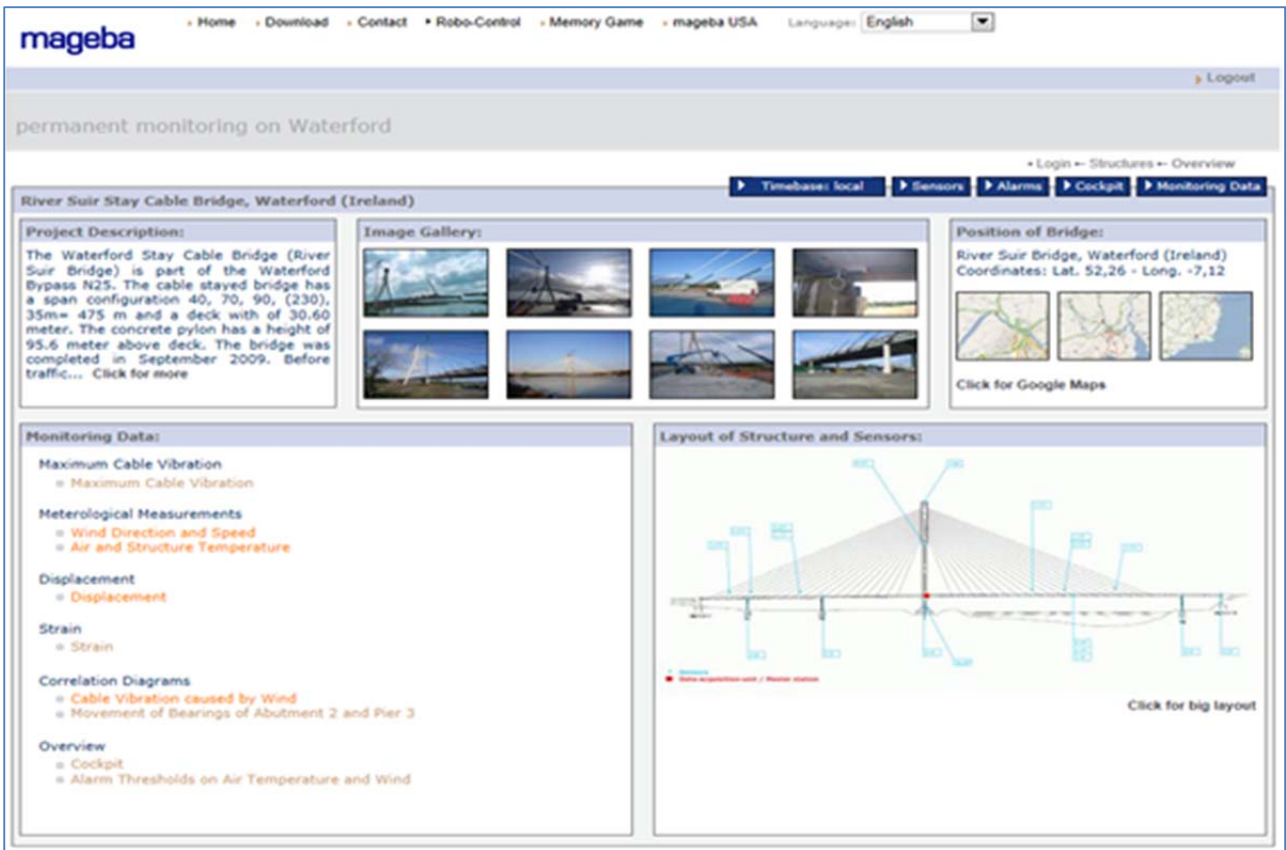


Figure 5: "Dashboard" of user interface (example)

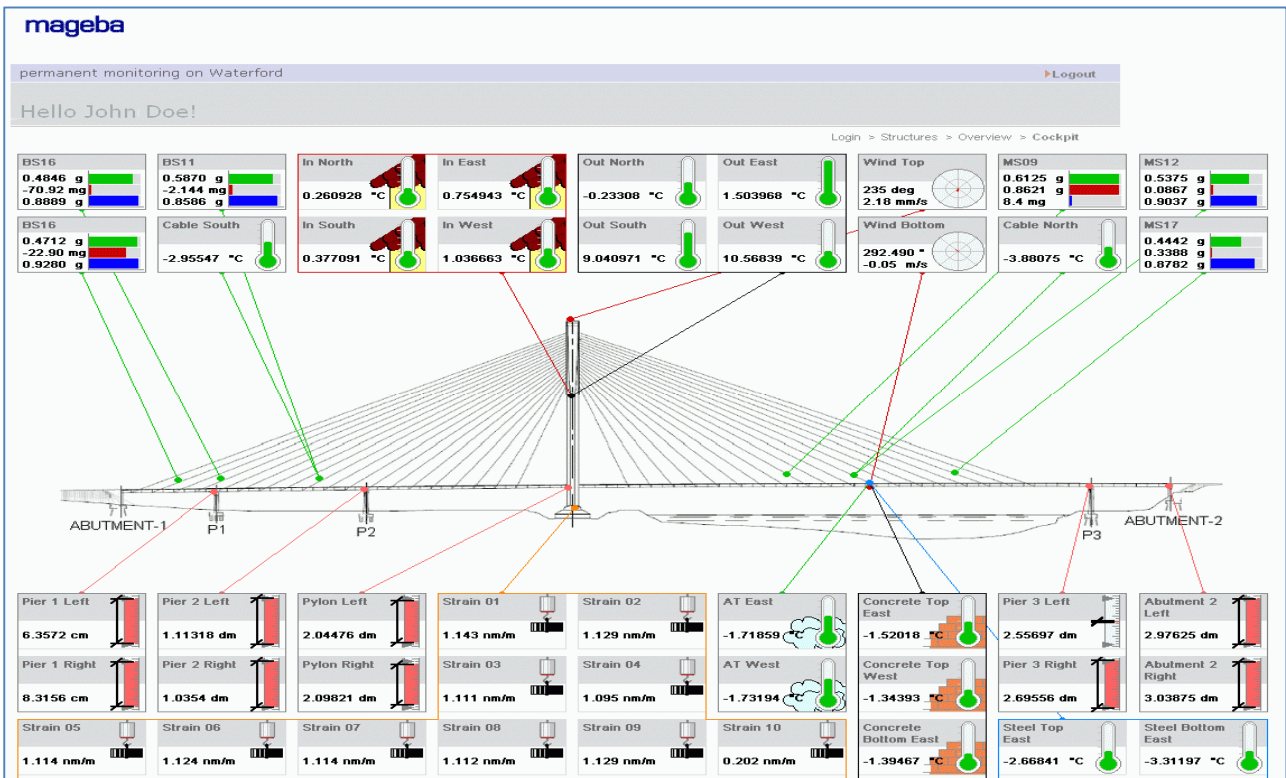


Figure 6: "Cockpit" of user interface (example)



Figure 7: Graphical display of recorded data (example)

A live view function is available which allows real-time access to the high-frequency measurements (see Figure 8).



Figure 8: "Live view" function, with real-time presentation of measured data

The user interface enables the download of measured data and results for any user-selected time period. The data can be exported in graphic form, or, if preferred, in tabular format for ease of analysis (see Figure 9).

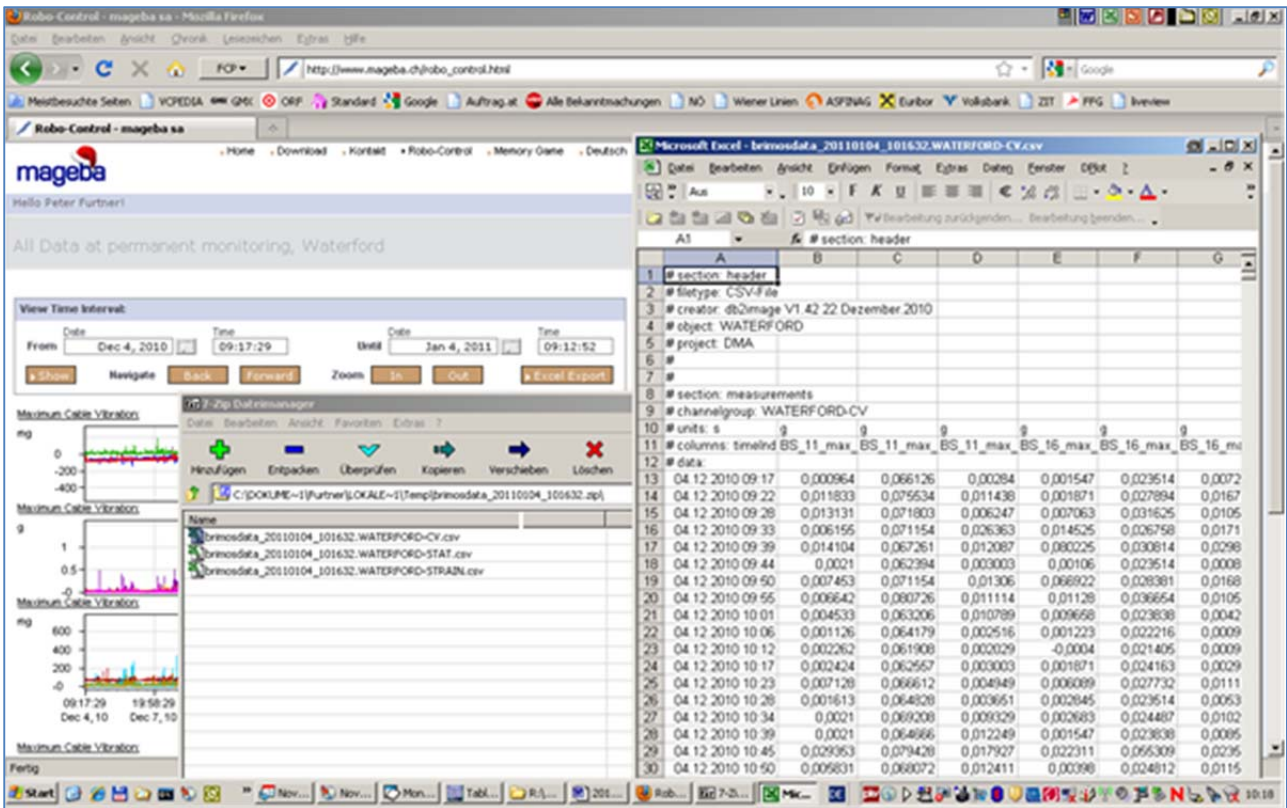


Figure 9: Data export in tabular format (example)

### 7.3 User Interface at the Control Room

The user interface in the control room is displayed on a Digital Signage Technology Suite (DSTS) comprising six wide-screen LCD monitors connected to computer workstations. This high-performance system boasts many advanced features to improve screen performance, lower total cost of ownership and enhance display management.

In addition to the features offered by the web interface as outlined above, the control room user interface also offers real-time data viewing, table-based data viewing, historical data file browsing and a configuration interface for alarm levels and notification emails.

### 7.4 Presentation on a Tablet Computer

For the user's convenience and flexibility, mageba also provides an application allowing the user to view monitoring with data tablet computers such as the "iPad".



Figure 10: Access to web interface using an "iPad"



## 7.5 Report Generation

A data file with summarised results is automatically generated and stored on the hard disc at the end of each month. This report file summarises the month's data on environmental conditions, bridge behaviour and bridge performance. If desired, the reporting period can be adjusted to cover shorter or longer intervals.

The generated reports are presented in PDF format, and are password protected for security. For each report, two emails are sent to a previously defined list of recipients - one with the report and the other with the corresponding password.

## 8. Delivery of the Monitoring System

Smooth delivery, installation and operation of the system are ensured by a number of measures. First, the system will be pre-assembled in the factory to enable a test of every component and of the whole system to be carried out. This also includes the initial calibration of the sensors, the creation of quality control documentation and final updates of pre-installed PC and server operating systems.

Following installation of the system (taking approximately 16 weeks), final calibration of all sensors and a function test of the complete system are carried out. This includes, for example, checking of the horizontal fixation of tilt sensors, subtraction of static offset values of accelerometers and similar tasks. It also includes the initial operation of the operator's workstations.

Operation and maintenance training is then carried out, in relation to the monitoring system on the bridge, the web interface and the user interface in the monitoring office. Maintenance tasks performed by the bridge owner's personnel include, for example, software updates, replacement of batteries and general visual inspection of components. The operation and maintenance manual defines the relevant tasks.

Finally, a comprehensive maintenance package is included, for a period of five years from completion of installation.

## 9. Conclusions

The automated monitoring system which is being provided for the new Signature Bridge in Wazirabad will provide enormous amounts of information which will enable the condition to which the bridge is subjected, and the structure's condition and performance, to be precisely evaluated with a minimum of effort. It is thus a good example of the type of comprehensive service which can be provided by modern SHM systems, if sensibly conceived, detailed and implemented.

## 10. References

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