Implementation of Structural Health Monitoring System for live monitoring of the cable forces at Barddhaman ROB

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Synopsis

For monitoring of structural health of cable stayed bridge constructed recently at Barddhaman, 6 (six) Nos. of sensors have been installed on the stay cables which are subjected to maximum loads. The ROBO control system of M/s Mageba has been used for the said purpose. The structural monitoring system can issue along with notifications based on the measurements on structure instrumentation with pre-defined threshold values. The alarm criteria can be configured on the structural design of the bridge and as per the requirement of the site. In this paper, effort has been made to highlight the bridge structural health monitoring system along with their integration, description of the management principle, system over view, software programming, assembling of ROBO control monitoring system along with web interface installation, web interface manual, live monitoring of forces in critical cables etc.

1.0 Introduction:

Mageba's ROBO®CONTROL Monitoring system can be used to measure and record various physical parameters from the cable stayed bridge to understand the structure's behavior during various load conditions.

This data can then be used to monitor the safety of the structure along with the performance analysis of the cable stayed bridge.

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The Bridge structural health monitoring system consists of the following integrated components:

- Design, Installation, Commissioning of Bridge Structure Health Monitoring System (BSHMS).
- Operation, Maintenance, Data Recording, Analysing and Reporting
- Sensors to measure environmental and structural response factors.
- Signal acquisition solution including signal capture from the sensors, signal verification and temperature adjustment, conversion of signal to digital format. Signal time synchronization, signal transport to pre-processing data acquisition unit, signal pre-processing and buffering prior to transferring to data processing.

2. Design:

The hardware has been incorporated strictly as per the "Proposal for the Stay Cable Force Monitoring of the 4-lane cable stayed road over bridge over Barddhaman yard submitted by Mageba in May 2015". The location of each required sensor is represented in the web.

The sensors are placed to measure the various physical performance parameters with the following general requirements

2.1 Solution was designed for bridge monitoring application and all components is of such design as to sustain severe environmental conditions and stand for several years of operation.

2.2 Hardware and sensors are available on open markets. Alternatively any proprietary components is replaceable with components available on open markets with reasonable modifications to the overall configuration.

2.3 Software operating system is based on Windows.

2.4 Software application packages is an open source or code available based programs in case vendor unavailability to support the solution at any time in the future

2.5 User interface is very easy to operate and very much user friendly.

2.6 User interface is standard Web Browser based to ensure compatibility to any future operating environment.

2.7 Bridge Structural Health Monitoring System (BSHMS) is designed to sustain partial damage and the undamaged parts remain operational and not lose real time and stored data.

2.8 Manual has been made in electronic format (PDF) and paper copy.

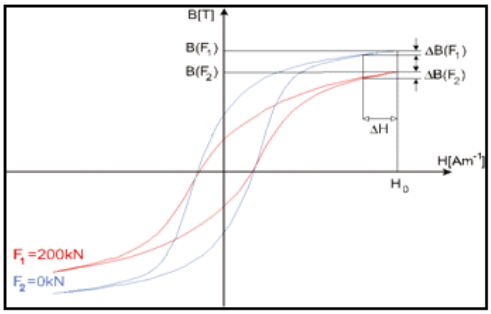
2.9 Mageba has on-line auto diagnostic, trouble shooting and support services for hardware and software.

2.10 Archived data has on-line controlled access.

3. Location of the sensors:

6(six) Nos. of sensors have been provided on the central pylon and extreme cables to monitor the forces on these critical cables which are subjected to maximum load.

4. Basic principle of measurement:



Sensor Characteristics

Sensor Characteristics Electromagnetic measures magnetolastic characteristics (magnetic flux) of the ferromagnetic materials which are in relation with the mechanical stress. According to the Faraday's law magnetic flux can be calculated by integration of induced voltage. The readout unit (DAU) generates the current pulse through the sensor's primary winding and integrates the voltage induced in the sensor's secondary winding. Current pulse is generated by discharging capacitor charged to voltage Vcap through the primary winding. Integration starts at the time t1 when the instanteous value of the current (the falling edge) is equal to I high and stops at the time t2 when the instantenous value of the current is equal to I low. Two precise analog comparators are used to generate the start and stop impulses for the analog integrator. DAU is controlled by the remote computer (via RS232 or

RS485interface). The settings of I high and I low are entered as settings from configuration file (there are LH and LL values in invertor for each working point).

$$I_{av} = \frac{I_{high} - I_{low}}{2}, \quad \Delta I = I_{high} - I_{low}$$

Relative permeability is then calculated using the formula

$$\mu_{calc}(\sigma, T) = 1 + \frac{S_0}{S_f}\left(\frac{\Phi(\mu)}{\Phi_0} - 1\right)$$

where

S_f is the cross-sectional area of the cable in m^2

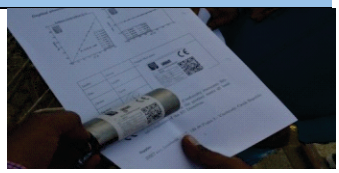
S_0 is the effective cross-sectional area of the sensor secondary coil in m^2

Φ_0 is the magnetic flux for empty sensor (without cable inside it)

Φ is the magnetic flux measured with the cable inside the sensor

5. System Overview:-

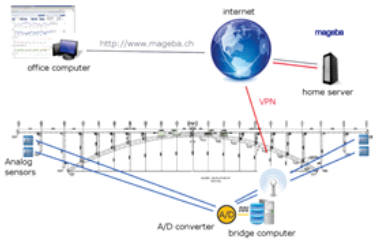
The entire system comprises of the following parts.

Sensor	Logo	Number	Channels	Picture
Electromagnetic Sensors	EM	6	6	
Data Acquisition System	DaQ	1	NA	

Apart from the following sensors the other accessories are.

- UPS – For backup of power till a certain limit.
- Router – For internet connection to the system.
- Power Cables – These are used for power supply to the sensors & other equipments.
- Signal Cables – The signal cables are the ones used for signal transmission for the sensor to the measurement unit.
- Consoles – These steel boxes have contained all the DAQ & data logger devices & some of the sensors. The protection against water ingress category is IP 67.

6. Software Programming:



The ROBO CONTROL data software is adapted and complemented according to the requirement of the design document. Adopted were performed according to the sensors internal data collecting system in order to enable a correct data acquisition at the ROBO®CONTROL monitoring box.

7. Assembly of ROBO CONTROL monitoring systems:

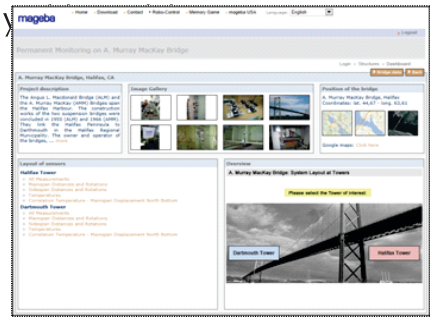
ROBO® CONTROL Monitoring systems assembled & installed in Cable Stayed Bridge Barddhaman ROB. The solutions are tailor-made and designed to withstand harsh environmental conditions. Design criteria are chosen conservative to avoid failures and to ensure a long lifetime.

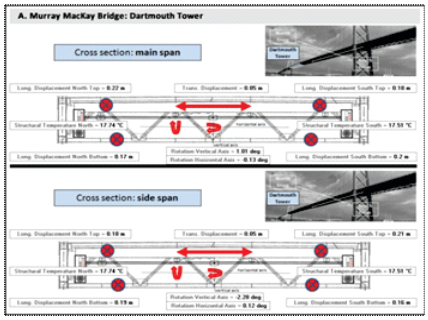
All these sensors are fixed permanently on the strands which are fixed inside the stay cables. These sensors measure the force directly.

8. Setting up of ROBO CONTROL Web interface:

The operator-chosen information is presented in a user-friendly and simple to understand format. All measured data, together with all data provided from the Station at site, is displayed in clear and easy to understand graphics (e.g. mimic panel format).

The web interface is protected against unauthorized access by a secure login. Data transfer from the bridge to Mageba's server is by FTP connection. The web interface is accessible via internet from anywhere at any time using any

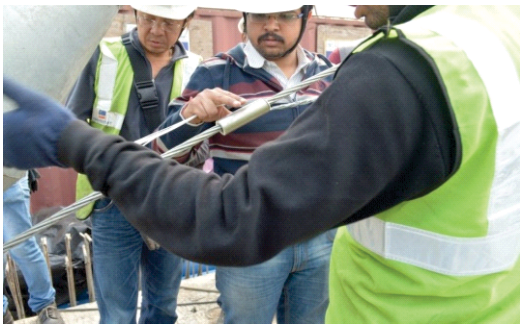




Also login Id and password is provided to the client/users for the viewing of the data online. The separate web user interface (WEB UI) manual is provided separately along with this document for the ease of understanding the interface.

9. Installation of the system:

The installation works started in line with the cable force stressing and calibration of the sensors were done accordingly.



10. Web Manual:

10.1 Login to the Web-Interface:

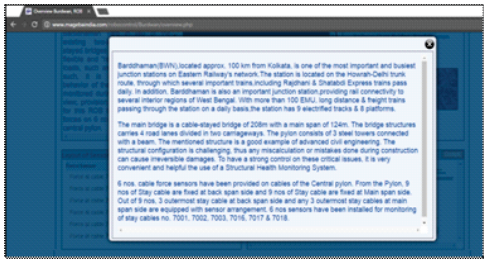
All major data can be down loaded in time in tabular form in excel or note pad. The said web interface is protected by a sensor scanned log in. The web interface is accessible by the user via the internet from anywhere at any time with standard web browser.

10.2 Dashboard:-

The Dashboard is split in 7 parts:

- Project Description
- Image Gallery
- Geographical position of the bridge
- Layout of sensors
- Overview
- Link to Threshold detail page
- Link to Cockpit page

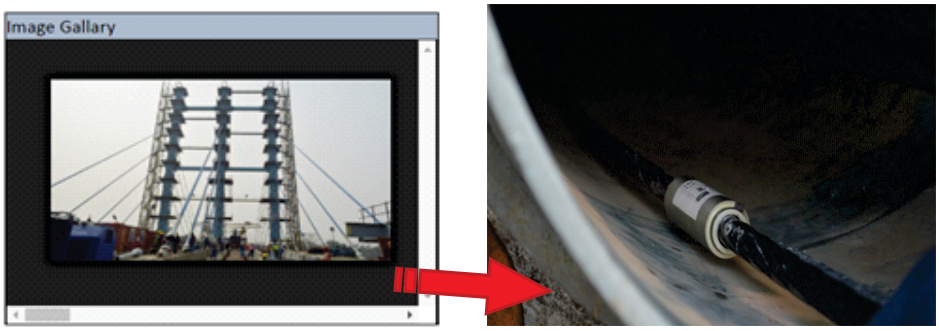
10.3 Project Description:



The project description provides summarized information on the monitored structure and the scope of the monitoring system and project.

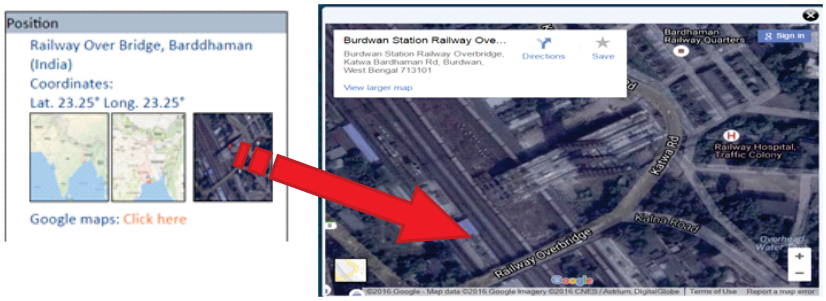
10.4 Image Gallery:

The image gallery shows a selection of pictures of the structure and of the installation works. The pictures are enlarged and slide shows when clicked on.



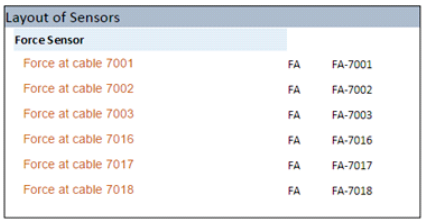
10.5 Geographical position of the bridge:

This field shows the position of the bridge and is linked to Google maps. The coordinates of the bridge are shown with the respective lateral and longitudinal values.



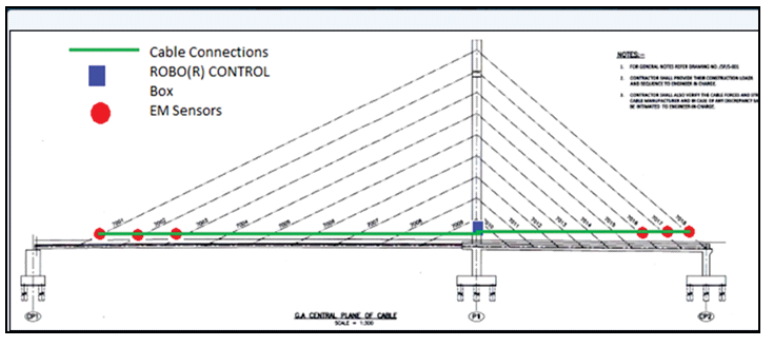
10.6 Layout of Sensors:

Data of every sensor can be displayed independently. The measured data is classified in different categories (e.g. displacement, temperature etc).



10.7 Overview:-

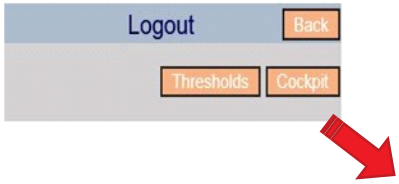
Here one can scroll through the picture for Sensor position on the bridge. Clicking this picture will provide with an enlarged view of the same. Also you can view Cockpit by clicking cockpit button.



10.8 Threshold detail page:-

Threshold values of every sensor is displayed in Threshold page which is accessible by clicking Threshold button in dashboard. Threshold value, both maximum and minimum with implementation date are shown on this page. One can search or can see all details via "Show entries" and "Search" utilities available.

The monitoring system includes an alarm system that informs the bridge operator pro-actively via email, if pre-set threshold values (e.g. max. displacements) are exceeded. The threshold values can be set and modified at any time by the site administrator.



10.9 Cockpit:-

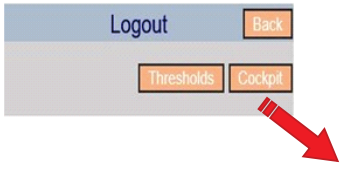
The Cockpit basically contains 2 parts:

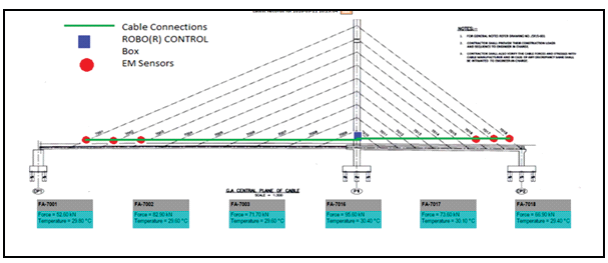
1. **Individual Sensor Graphic with reading.**

   The individual measurements of each sensor are shown in the overview graphic. The data displayed is based on readings done at the instance of the user's login into the Web-Interface. The detailed monitoring graph page is accessible by clicking individual graphic.

2. **Report generation button**

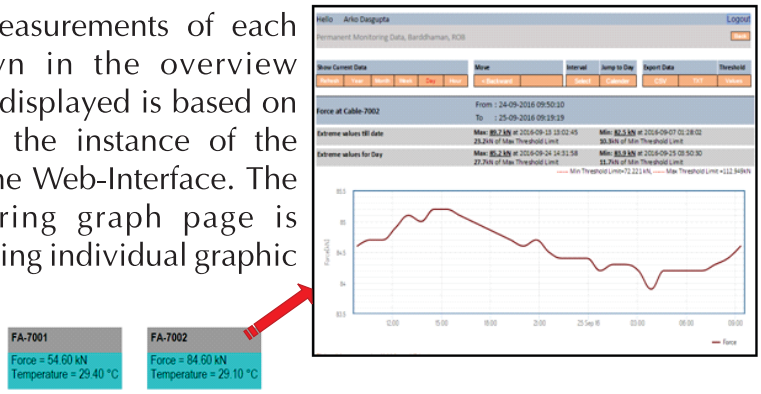
   One can generate a report with Maximum values of BSHMS in the last 24 hours in PDF format by clicking "Report Button" on this page.





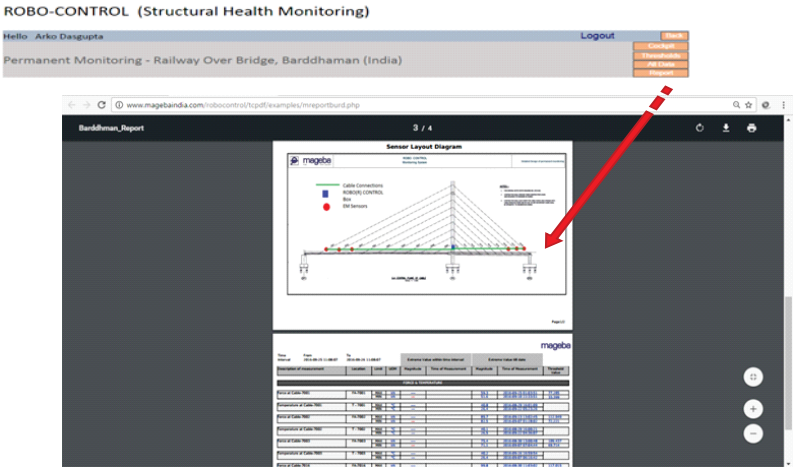
10.9.1 Individual Sensor Graphic with reading:-

The individual measurements of each sensor are shown in the overview graphic. The data displayed is based on readings done at the instance of the user's login into the Web-Interface. The detailed monitoring graph page is accessible by clicking individual graphic tile.



10.9.2 Report generation:-

One can generate a report with Maximum values of BSHMS in the last 24 hours in PDF format by clicking "Report Button" on this page. The data displayed is based on readings done at the instance of the click of "Report" button. For daily report to be generated in PDF, browser need to support PDF extension. A file named "weh24rpt.pdf" can be downloaded from here.



10.10 Miscellaneous:

The ROBO control structural health monitoring system can prepare charts depending upon the users requirement. The current data such as hourly, daily, weekly etc. can be checked through the web interface. The thresh-hold values for the forces are displayed in the screen. The chart can be zoomed, panned etc.

11. Validation of the report:

6(six) Nos. of load cells have been provided at cable No. 7001, 7002, 7003, 7016, 7017 and 7018. Thresh-hold values for each of the cable (lower limit and upper limit) have been provided by the DDC based on the calculation.

11.1 Validation during load test conducted on 30.08.2016:

With the full load test subjected to the maximum load as per the design, the readings recorded with the help of sensors along with their thresh-hold limits are as follows:

Cable No.	Observed Value	Reference range	
	Reading during load test on 30.08.2016 (KN)	Lower limit (KN)	Upper limit (KN)
7001	55.7	33.39	77.28
7002	89.4	72.22	112.95
7003	75.4	69.71	109.44
7016	99.8	84.97	117.01
7017	78.1	50.99	91.21
7018	75.8	41.70	82.26

11.2 Live monitoring:-

The forces are being monitored live through the monitoring system and latest reading as recorded on 28.09.2016 with respect to the thresh-hold values are as under:

Cable No.	Observed Value	Reference range	
	Latest reading on 28.09.2016 (KN)	Lower limit (KN)	Upper limit (KN)
7001	55.5	33.39	77.28
7002	85.1	72.22	112.95
7003	72.9	69.71	109.44
7016	96.5	84.97	117.01
7017	73.3	50.99	91.21
7018	67.7	41.70	82.26

11.3 Few Screen shots taken are as under :

12.0 Conclusion:-

This Bridge Structural Health Monitoring System (BHMS) of this kind is probably the first project in the Indian Railways. The technology for cable stayed bridge is not very common in India and such instrumentation provided in the Cable Stayed bridge has got big future in time to come. A lot of additional parameters can also be added depending upon the user's requirement.