1 INTRODUCTION

India is covered by a large number of rail and road bridges. They are an important component of transportation networks. Damage or collapse of bridges due to their deteriorating performance disrupts transportation systems and may result in loss to life and property. The railway bridges are well documented and have a laid down system for checking and maintenance. The Ministry of Road Transport & Highways in India has established an Indian Bridge Management System (IBMS) to carry out condition surveys and inventorization of all bridges on National Highways in India. To date, an inventory of more than 170,000 bridges and culverts has been compiled on the National Highways and the work is still going on through several consultancy firms. The work on State Highways will be taken up later on.

With so many different types of rail and road bridges covering India from North to South and East to West and quite a few in not so good a condition, safety becomes a paramount consideration. Bridges must function safely at all times. A large number of bridges are quite old and not designed for the heavier and faster moving vehicular loads they are presently being subjected to.

The main purpose of IBMS is to create an inventory of all bridges in the country, rate their structural condition, stock essential spares and maintenance tools at site and prioritize the allocation of funds so that timely repair, rehabilitation and monitoring for safety can be carried out based on criticality of the structure.
2 ENCARDIO-RITE GROUP OF COMPANIES

Encardio-rite is a more than 50 year old organization certificated to ISO-9001:2008 quality management standard since 1995. It has a D&B rating of 4A1. The R & D unit of Encardio-rite has been recognized by the Ministry of Science and Technology, Government of India since 1973.

Encardio-rite Group of Companies have a strength of around 400 personnel including about 100 engineers. More than 70 % of the total group turnover is earned in foreign exchange from about 50 countries in the world. Encardio-rite has subsidiary organisations in UAE, Bahrain, Qatar, Saudi Arabia, Greece, Singapore and Bhutan.

Main activity of Encardio-rite is to provide indigenous online monitoring services for Civil Engineering Structural Projects and Water Resources with remote access to collected data in real time. Encardio-rite is one of the few organisations in the world which in addition to providing complete monitoring services also manufactures its own sensors, dataloggers and has developed advanced integrated software in-house, for processing and displaying monitored data and web based monitoring solutions.

More details about Encardio-rite and its activities are available at [http://www.encardio.com](http://www.encardio.com) and also provided in the attached Consolidated Catalog.

3 ONLINE CLOUD BASED WEB DATA MONITORING SERVICE

Encardio-rite offers public cloud based online web data monitoring services for the safety of existing rail and road bridges. The service forms an important part of the Bridge Management System.

The heart of the online structural monitoring instrumentation system is a web data monitoring service (WDMS) offered by Encardio-rite. It is a web-based data-management and presentation tool for retrieving data from the sensors through Encardio-rite range of automatic data loggers.

WDMS consists of Drishti, a data management software that acts as a data collection agent, a data base server and a web server hosted on a high reliability server computer. The host computer periodically collects data from the remote data logger over cell phone networks. Users interact with the software using their web-browser, when connected to the Internet. The only requirement is that the data logger site is covered by a cell phone service provider who can provide reliable GSM/GPRS enabled cellular data connection locally.

Multiple authorized users at different locations assigned with an individual password are allowed to view any data or report from the structure simultaneously. Graphs & reports can be viewed using popular web browsers like Microsoft internet explorer or Mozilla Firefox amongst others.

Details like sensor identification tag, last recorded sensor reading and values of programmed alert levels can be viewed on the first page of site that shows location of installation. If any one of the alarm level exceeds, the sensor location turns to a red dot. Clicking the pop up table brings up an associated data window where the sensor data can be seen either as a table or as a graph.

Site administrators can set alarm limits which are generally considered as “alert level” and “evacuate level”. WDMS can also be programmed to send SMS alert messages or e-mail to selected users as soon as any sensor data crosses its predefined alarm levels, either while going above or going below the alarm level.

3.1 Instrumentation schemes

Two examples of instrumentation schemes are illustrated below in figures 1 & 2:
A number of other parameters can also be monitored using the same system. For details of other sensors, please refer to Consolidated Catalog attached.

Figure 1: Online web based monitoring of surface parameters like tilt, crack, load, strain, vibrations and subsurface parameters like lateral movement, settlement and piezometric pressure.

Figure 2: Online web based monitoring of lateral movement and settlement using robotic total stations and prism targets

The picture on the left is a typical installation of a robotic total station installed to automatically gather data from prism targets installed on the structure of a bridge. The picture in the middle is that of a mini prism target. The figure on the right shows points at which prism targets may be installed on a typical bridge. More than one robotic total station may be required for proper monitoring of a structure.
3.2 Screenshots of some sample long term monitoring data

Figure 3: Structural crack monitoring over a period of one year using Encardio-rite model EDJ-40V crack meter. Crack opening is in blue and variation in temperature is in red. The initial opening of the crack gauge was set at 5.12 mm.

Figure 4: Structural tilt monitoring from September 12, 2015 to December 8, 2016 using Encardio-rite model EAN-92M biaxial tilt meter. Tilt variation in the two directions is shown by the blue and black lines. The maximum change in tilt recording during this period is 0.04 deg. The two horizontal red lines at the top and bottom are the alarm limits set at ± 0.1 deg. The red line gives the temperature variation during this period.
Figure 5: Monitoring of ground water level along with daily rainfall for a period of two years. Piezometric pressure is in blue and daily rainfall is in purple. Maximum rainfall recorded on any day during this period is 73 mm. Ground water table variation during this period has been between 50 and 52 m of water column. Sensors used are Encardio-rite piezometer model EPP-30V and rain gauge model ERG-200 tipping bucket type.

Figure 6: Monitoring of sub-surface lateral movement for a period of 300 days. Encardio-rite EAN-52MV vertical in-place inclinometer system has been used for monitoring the lateral movement. A total of 11 sensors have been installed in the borehole from a depth of 12 m to 32 m. The maximum displacement recorded during this period has been a little more than 2 mm. The two vertical lines are alarm values set at ± 20 mm. Readings are retrieved once an hour and transmitted four times a day for online web based monitoring.
For bridges already constructed, it is essential to periodically or continuously monitor the health to ensure proper maintenance and hence safety. Structural Health Monitoring of old bridges is of great significance to ensure safety of man and material. As illustrated in figures 1 & 2, a range of instrumentation is available for effective monitoring of bridges. In view of the large number of old bridges in India spanning from North to South and East to West, manual monitoring becomes impractical, gigantic, expensive and unreliable. Installation of suitable sensors and automated monitoring from a central location becomes essential to assist and inform authorities about continued performance of bridges under gradual or sudden changes to their state and raise suitable alarms in case of approaching distress conditions. The state of the bridge is reflected in abnormal changes in strain, inclination and settlement values. Another parameter to be closely watched is development of cracks.

For the purpose of demonstrating a real time monitoring system for a bridge, Encardio-rite proposes to install two bi-axial tilt sensors, two arc weldable strain gages with groutable mounting blocks and two crack gauges on arched bridge near Manak Nagar Station located on the road from the Awadh Hospital Round About at Lucknow to Dubagga/Hardoi on the National Highway- NH 230. From the vast range of sensors available for monitoring bridges, tilt meters, strain gages and crack gauges have been particularly chosen because:

- Monitoring of tilt, strain and cracks provide important information on the safety of the structure. The data is very easy to interpret and generate alarms.
- Cracks have been observed on the surface of the bridge

Please refer to annexure 1 for a schematic and bill of materials of the proposed instrumentation.
4.1 MEMS based bi-axial tilt meter - 2 no.

Encardio-rite model EAN-93M tilt meter is a rugged, high resolution instrument suitable for monitoring inclination and rotation of structures. Tilt changes may be caused due to several reasons like nearby construction activity, de-watering or change in ground water level, loading of a bridge deck due to wind and traffic, solar radiations or temperature changes during the day or annually, soil deterioration or settlement that affect the ground that supports the structure. Data from the tilt meter provides early warning of threatening deformations, allowing time for corrective action to be taken.

It is proposed to install one such instrument on top of the fourth pier from the Awadh roundabout side towards Hardoi Road on Right Hand Side (RHS) of the bridge. A second similar tiltmeter, integral with the Encardio-rite model ESDL-30MT datalogger will be installed on the pier near the abutment. The instruments shall provide tilt of the piers in two orthogonal directions, one along the axis of the bridge and the other perpendicular to it.

4.2 Vibrating wire crack meter - 2 no.

Encardio-rite model EDJ-40V vibrating wire crack meter is designed for surface installation for monitoring change in width of cracks. The crack gauge has two groutable anchors that are installed on opposite sides of the crack to monitor opening or closing of the crack.

During site visit, two major cracks were noticed in the abutment of bridge, one vertical crack roughly about 8 mm wide and the other horizontal crack roughly about 1.4 mm wide. Please see enclosed pictures in annexure 2 showing the approximate measurement of crack width with a transparent crack gauge.

Two crack meters will be installed by grouting at these locations such that change in crack width is monitored in real time.

4.3 Strain gages – 2 no.

Encardio-rite model EDJ-20V-AW strain gage is designed to indirectly determine stress and its variation with time, quantitatively. Change in stress is determined by multiplying the measured strain by the modulus of elasticity. To mount the strain gage on the bridge span, two annular mounting blocks are accurately positioned and aligned with the help of a mounting jig and dummy gage and grouted to the structure. The dummy gage is then finally replaced by the actual strain gage and clamped in position by a pair of set screws on each block.

During site visit, one strain gage shall be installed at the middle of bridge span and the second strain gage shall be installed at the quarter of the bridge span. Please see enclosed pictures in annexure 2 showing the approximate measurement of crack width with a transparent crack gauge.
4.4 Web based data monitoring from two bi-axial tilt meters, two strain gages and two crack gauges

The two crack gauges on the abutment and a tilt meter on pier 2 from the Awadh roundabout (RHS) side will be connected to Encardio-rite model ESDL-30MT datalogger through six core cable. The datalogger has an integral biaxial tiltmeter incorporated in it. It also has an in-built modem for transmission of retrieved data over a GSM/GPRS network to a cloud based server. The data shall thus be available in real time to authorized users with a valid user id and password.

The data retrieved from the sensors can be automatically formatted as different types of graphs and tables and published over the internet using Drishti, the monitoring and reporting software developed by Encardio-rite. Any authorised user can log onto the web server remotely over the Internet to see the graphs and reports in real time.

The system presents the user with a log on screen where the user enters his login credentials like user name and password. Once the system verifies the user credentials, it allows the user to access data for which the user has permission. After successful logon, a user is presented with a map, diagram or photograph of the area of their interest with locations marked as small purple squares. Figure 13 is a photograph of the Bridge (on NH230) showing the position where the sensors will be installed. If the user hovers the pointer over these squares, a table pops up showing the value of the measured parameter and the last update time. Any alert condition is signalled with a change in colour of the square. If the user clicks the table a new view opens showing the change in parameter value with time in graphical form. The user has the choice to view the data in the form of graph or table. In graph view, the user can select the time period for which the data is to be plotted and can scroll the time axis in any time increment, starting from one day to many months both in the forward and backward direction as long as data is available.

The pages are preformatted and the graphs are generally composite graphs that show the relevant parameters together on a single graph. For example, a graph may show tilt, temperature, strain and crack width on the same graph. In case of alarm conditions, the system automatically sends e-mails or/and SMS to specified persons such that corrective action can be taken in time.

Figure 13: Screenshot of front page of website showing location where sensors will be installed on the Bridge (at NH 230).