An Infrastructure Information System for Bridges in India through Scientific Monitoring

Jitendra Kumar Goyal

Abstract - The emphasis for the highway industry in the country is now centered on maintenance, rehabilitation, and conserving the existing road network spread in the form of Expressways, National Highways, State Highways, etc. With the enormous growth in the volume of National Highways across the length and width of the country and more and more State Highways are adding up in the stream of National Highways, the Ministry of Road Transport and Highways and other bridge owner agencies now estimates that more than 80,000 bridges are inadequate to handle the growing demand of traffic, consequently, the higher axle loads both prevalent and nonpartisan. Many of these are due to insufficient strength assessments that often lead to a posted or closed structure. In evaluating existing bridges, the Engineer must consider options including posting, permit regulation, closing, rehabilitation, and replacement. Fortunately, the circumstances of the evaluation, such as past performance experience, shorter expected remaining bridge life, and the opportunity to perform further in-depth study on an existing structure, all provide greater flexibility for evaluations. In order to address effectively, there is a need for a comprehensive framework that covers all bridge conditions, yet is flexible enough for the evaluation agency to consider its own needs and willingness to invest resources, when necessary, in the evaluation investigations. Like many other developing nations, in India too, there is a need for establishing an infrastructure information system for the bridges complemented with bridge management programs. Such infrastructure will provide for a long range bridge evaluation process that considers bridge condition, site traffic, maintenance and inspection cost in a scientific manner.

The scientific monitoring has emerged as a powerful tool to assess the condition of structures both in short and long term basis to assist bridge management planners for implementing any bridge management programmes. The CSIR-Central Road Research Institute has accomplished monitoring of many bridges in India in different parts of the country. The paper highlights the salient features of scientific monitoring carried out, the interpretation of results helpful in assessing the condition of the structure and usefulness of such monitoring practices in bridge management programmes.

***Keywords* – Bridge, CSIR-CRRI, Monitoring, Management, Metrics, Performance, Sensors.**

Author is Chief Scientist (Bridges and Structures) CSIR-Central Road Research Institute, New Delhi, India and also Ex-Chief General Manager (Tech) with National Highways Authority of India, Ministry of Road Transport & Highways, New Delhi.,

I. Introduction

Major civil engineering structures such as bridges, containment vessels, dams etc constitute a major portion of national wealth. The cost of maintenance for such structures is high and even a small percentage reduction in cost of maintenance can give significant savings. Monitoring the structures is one of the most cost effective maintenance methods. Early detection of problems, such as, cracks at critical locations, delaminations and corrosion can help in avoiding a catastrophic failure and structural deterioration beyond repair. And when such efforts are combined with bridge management tasks through a well designed and well thought through bridge information system, the bridge management regime turns out to be more amenable.

The ability to monitor the condition of a structure and to detect damage at the earliest possible stage is of significant interest in many engineering disciplines. Currently, the most widely used damage detection methods rely on subjective, incremental visual assessments or localized testing techniques. These methods require the location, or possible location, of damage to be known prior to the assessment. Often, these locations can be estimated through appropriate engineering analysis. However with the increasing complexity of many of the nation's bridges, the potential damage locations are not known or are too numerous to be economically tested or inspected using conventional damage detection techniques. As a result, performance monitoring techniques have been developed and employed as a means to economically and reliably provide for an overall, continuous condition assessment of complex bridge structures. The outcomes of such technique broadly fulfill the following requirements:

- Accurately determine the condition of the structures.
- Provide condition factors for load rating calculations.
- Ensure that the real cause of any deterioration is diagnosed.
- Determine appropriate rehabilitation works.

The scientific monitoring and management strategies for highway structures benefit significantly when there are data from well targeted testing regimes, proper execution of the site investigations, appropriately trained technical staff and appropriate interpretation of site and laboratory testing results by engineers experienced in testing and in structures. Scientific monitoring techniques enable enhanced bridge management decision assisting in expediting a maintenance and repair of deficient structures at significantly lower cost, and at the same time minimizing disruption. Basing management activities on better quality information will also enable owners/managers, including maintaining agencies, to make better informed

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submissions to local national and international funding agencies [1].

II. STRUCTURE OF BRIDGE INFORMATION SYSTEM IN INDIA

In India transportation industry and Bridge Authorities, in particular should look forward to manage their "Assets" in an integrated manner through an "Information System" which ensures that the funds are used most effectively. The system is designed to bring all bridge management related activities under one umbrella with appropriate links to other systems, and yet remain flexible and versatile as far as possible [2]. The establishment of linkages between the sub-modules of the proposed BMMS can best be explained in fig.1 as below:

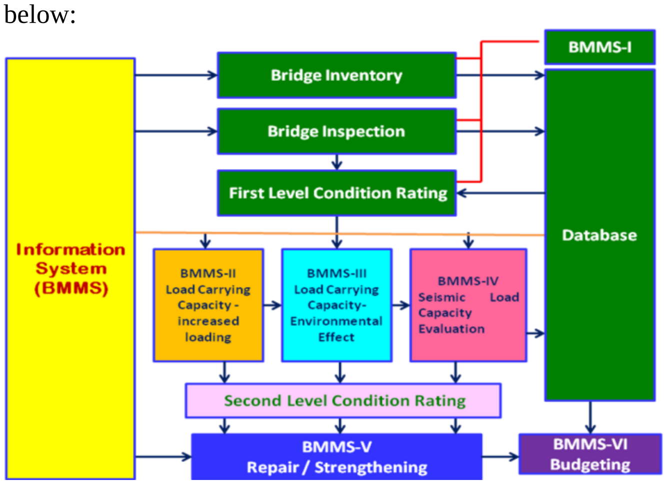

Fig. 1 Framework of Bridge Management System

Bridge Inspection is one of the most important aspects of database management relates to periodic inspections of system components. BMS efficiency depends upon quality of input information. Bridge inspection information plays an important role in administration of bridge systems. Accurate inspection can prevent failures, detect repair need, and aid in the allocation of funds. Furthermore, the input information for predicting bridge deterioration is based upon inspection information. It is at this point the role of "Scientific Monitoring" becomes crucial specially for unique and important bridges in the network. There are three types of inspections in practice e.g. superficial inspection, principal inspection and special inspection. The task of identifying commonly occurring damages is carried out during inspection of the bridges. This module include data related to various inspection reports, maintenance work taken up from inception, non-destructive testing if any, load carrying capacity carried out by the bridge authorities based on condition monitoring outcomes as explained below.

III. STRUCTURAL PERFORMANCE PARAMETERS

A. Measurement Metrics

Various performance parameters or measurement metrics have been monitored in a number of bridges by CSIR-CRRI by deploying suitable instrumentation techniques [3], [4]. Monitoring metrics is a system of parameters intended to measure bridge condition and performance. Depending on the type of bridge and the needs of the bridge owner, different measurements are being taken in order to properly monitor bridge health. Some metrics can be measured for any type of bridge; however, there are some measurements specific to concrete and steel bridges. It is important to know how each metric applies to the bridge of interest and what will be useful in monitoring the health of the bridge.

It is emphasized herein that the monitoring schedule of the bridges should coincide with the requirement of the inspection regime of bridge information (Bridge Management) priorities which follow measurement metrics as explained below:

B. General Metrics

- **Acceleration** - the instantaneous rate at which the velocity of a point in a vibrating bridge is changing with time. Acceleration is the most common measure taken to characterize vibrations. It is possible to define the frequencies and shapes of the different modes of vibration from a single acceleration trace. The frequencies and modes can be compared to values obtained from previous acceleration measurements to determine if the bridge has deteriorated or has been damaged.

- **Climatic Conditions** - pertains to the environmental conditions in the area of the bridge that may relate to bridge performance. Parameters that can be measured include: air temperature, wind speed, wind direction, relative humidity, and solar radiation.
- **Curvature** - the rate of change of slope along the length of a flexural member and produced by loading normal to the longitudinal axis. From principles of structural mechanics, curvature is known to be directly proportional to bending moment in the member.
- **Displacements** - the overall linear movement (i.e., translation) of a bridge either in relation to its original position or on a global scale. It is possible to measure the displacement in one, two or three independent directions.
- **Load** - the total load of objects passing over a particular area of a bridge. This measure can be useful to enforce weight restrictions, as well as to define the range (i.e., spectrum) of typical traffic loads.
- **Tilt/Slope** - the angular change of components in a bridge. This is useful in determining distortion in bridge geometry. Slope is the rate of change of deflection of a flexural member with respect to length. Angle changes with respect to a vertical plane are also useful to assess 'out-of-plumb' elements. It is useful to know if there has been a large change in angle on an element.
- **Scour** - the removal of soil around the foundation of bridges due to fast moving water currents during flooding. **Corrosion** - It is possible to determine whether or not the steel reinforcement embedded in concrete is at risk of depletion from attack of chloride or carbon dioxide. Some corrosion monitoring techniques determine the probability of corrosion occurring, while others determine the approximate corrosion rate. Different sensors and/or procedures may be required to monitor the corrosion of epoxy coated and non-epoxy coated rebar.
- **Cracking** – the separation of concrete surfaces at the location of fractures is typically characterized by the width,

length and number of cracks. Small-scale cracking (i.e., few, short, narrow cracks) is expected to take place in all concrete; however wider, longer and/or more numerous cracks are not expected. It is possible to detect the formation of these cracks through acoustic emission sensors. It is also possible to monitor known cracks using strain gauges placed over the area of interest.

- **Location of rebar/delaminations** – The location of reinforcement in concrete can be determined using several non-destructive methods. These or similar techniques can be used to determine if the concrete above and below the reinforcement has begun to delaminate.
- Removal of soil can lead to instability of piers.

C. Concrete Metrics

- **Strain** – the relative elongation or shortening present in the concrete in specific locations of a bridge. In the service load range, the concrete behaves in a linear manner allowing the estimation of the stresses present at the particular location in the bridge.
- **Strength** – the strength of concrete is typically characterized from tests of cylinder or cubes that are cast at the same time and from the same mix as the bridge member or component. For determining the initial in-situ strength of the concrete, measurements of concrete temperature can be taken while the member or component is curing and compared to previously obtained temperature-strength correlations for the particular concrete mix. This can be useful for quality control of the concrete during construction.
- **Tension (in rebar/tendons)** – In post-tensioned systems, the tension in the cables is important to the overall strength of the concrete member. Also, if delamination occurs in reinforced concrete, the concrete cannot transfer forces to the rebar causing a reduction in stress. Thus, tension measurements can be used to assess the overall health of the structure.

D. Steel Metrics

- **Corrosion** – the chemical reaction whereby steel loses electrons to water and oxygen and other corrosive materials (e.g., road salts). Monitoring is useful in order to determine extent and rates of corrosion within the structure.
- **Crack Growth** – the elongation and/or widening of a known crack. Fatigue cracks may grow or remain static, with the former posing larger concerns than the latter regarding potential failure. Therefore, it is useful to a bridge owner to know if a fatigue crack is growing under the current loading conditions.
- **Cracking** – the number, width and length of cracks in a steel member or component at locations of stress concentrations or fatigue loading. Such information is useful for predicting the remaining life in a steel bridge or for averting a sudden failure. Quantification of cracking is important because extensive cracking at a critical location or member in a steel bridge can cause large changes in stresses at other bridge locations.
- **Strain** – the relative elongation or shortening present in the steel in specific locations of a bridge. In the service load range, the steel behaves in a linear manner allowing the estimation of the stresses present at the particular location in the bridge.
- **Tension (in cables) –** Cables in suspension bridges are designed to handle tensile forces. Monitoring the magnitude of these forces is of interest, especially in cases where bridge loads have increased beyond design levels, or if deterioration of the cables is suspected or known.

IV. Monitoring Systems Used In Bridges

The CSIR-CRRI has collected lot of data from instrumentation and monitoring of Highway and Railway bridges on National Highways and on the commercial routes of Indian Railways. These bridges offered a unique opportunity to design the instrumentation scheme matching with the needs of bridge management authorities and aiming at short and long term monitoring view. The data obtained from the field studies and their corroboration with the theoretical results yields a significant basis for strengthening of existing bridge information system (BMMS) for estimating lifetime characteristics of elements of bridges and predicting the future conditions of networks of bridges on Indian Highways and Rail network. The Information System for Bridge Networks Condition Monitoring under GIS Environment has been developed for Department of Science and Technology by CSIR-CRRI. The conceptual departure from the standard bridge management systems may be made using a novel stochastic process built out of the gamma process [5]. The statistical model can then be designed for the estimation of infrastructure lifetime, based on the analysis of more than 15 years of bridge inspection data already available and under study from these bridges.

With the help of a case study, pertaining to a national highway bridge on the river Ganges which incorporates the features of monitoring carried out (in different bridges) at various bridge components of the bridges, explains fallout of the measurement metrics. Instrumentation and monitoring of a twin cell prestressed box girder balanced cantilever" bridge was carried out in early 1990's right from the stage of its foundations [3]. A general arrangement of the bridge is as shown in Fig.2.

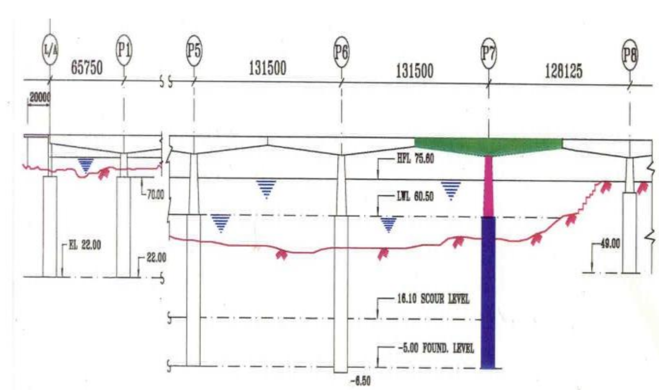

Fig. 2: General arrangement of the instrumented bridge by CSIR-CRRI.

The superstructure's arm P-7 of balanced cantilever bridge as shown in Fig. 2 was provided with "state of the art" instrumentation as considered appropriate at that point in time.

The features of the bridge and parameters monitored are described below:

- **The dimensions of the bridge:**

Well Foundation Depth = 65m
Diameter of well foundation = 13m
Height of Pier = 23m
Depth of box girder = 2.0m to 8.5m
Top width of box = 19.6m
Superstructure Segments= 2 to 4m, Max. Span= 135m

- **Parameters for monitoring:**

- **Well Foundation and Abutment** (Fig.3)
  - Lateral Soil Pressure
  - Hoop and longitudinal strain
  - Tilt/Inclination of well
  - Corrosion
- **Pier and Pier Head** (Fig. 4,5)
  - Tilt of Pier
  - Strains and Thermal Gradient
- **Superstructure** (Fig. 6,7,8)
  - Strains/stress
  - Accelerations
  - End Rotations/Tilt
  - Deflection
  - Temperature Gradient
  - Corrosion

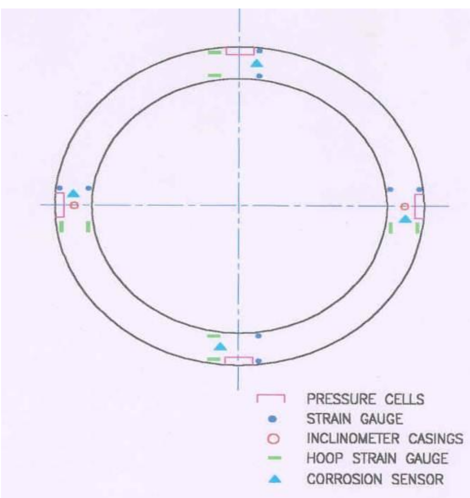

Fig. 3: Sensors for performance parameters in well foundation

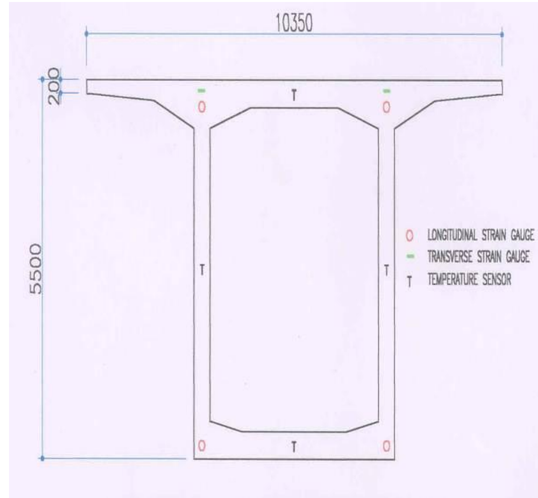

Fig. 4: Typical scheme for performance parameter in Pier head segment**.**

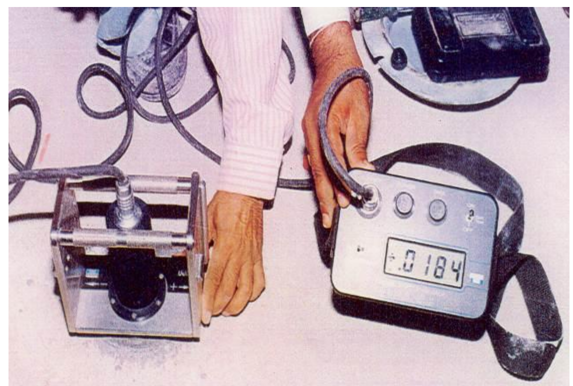

Fig. 5: Tilt/End rotation in Well/Pier/ Superstructure.

Fig. 6: Strain (Rosette) in pier/superstructure

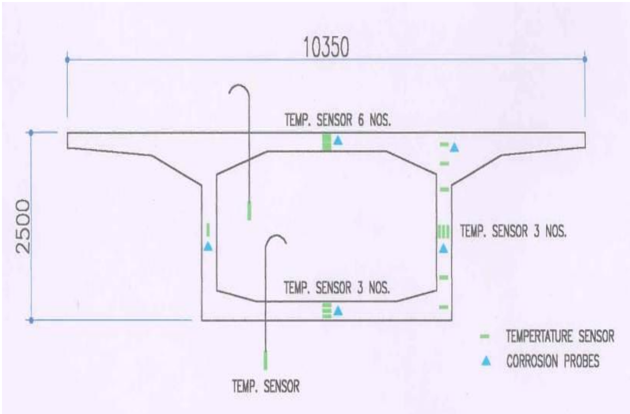

Fig.7: Location of Sensors at mid span section**.**

Fig.8: Corrosion sensors for monitoring of corrosion.

III. Monitoring Stages For Compilation Of Data In Bridge Management

In order to make use of scientific monitoring data into the bridge management system, a phased long term monitoring programme has been prepared and explained below:

Phase-1: **Installation of sensors and collection of data during construction and a set of base line data before opening the bridge to traffic comprises of following:**

- Detailed Planning of instrumentation scheme
- Preparation of Detailed specification for Procurement of various sensors and equipments
- Calibration/performance checking of sensors & equipments after procurement
- Installation of sensors as per construction schedule and the instrumentation scheme
- Preparation of test specimens for shrinkage/creep etc for laboratory study
- Collection of field data as per scheme i.e. during hardening of concrete, pre stressing, load test etc.
- Installation of data acquisition system for automatic collection of data
- Collection of base line data of all the installed sensors
- Structural integrity test for dynamic characteristics.

Phase-2: Long-term Performance monitoring of the bridge comprises of followings:

- **Monitoring during peak summer:** A set of measurements of all the installed sensors and diurnal (repetitive pattern) hourly variation of strain and temperature, deflection profile of bridge due to change in temperature.
- **Monitoring during peak winter:** A set of measurements of all the installed sensors and diurnal hourly variation of strain and temperature, deflection profile of bridge due to change in temperature.
- **Health status of structure through study of performance parameter:** Variation of all the performance parameters to be studied due to change in seasonal and diurnal temperature, losses of prestress and degradation material properties.
- **Development of degradation model:** On the basis of long-term data collected a degradation model has to be developed for prediction of remaining life of the bridge.

V. Conclusions

The paper describes only few features of bridge condition monitoring strategies implemented on a typical bridge by CSIR-CRRI. The result of continuous monitoring of performance parameters from the base-line data on long-term basis yields useful information to detect the early distresses in the structure. These results form the part of detailed inspection regime in the bridge management programme.

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REFERENCES

[1] Donald Pearson-Kirk, Benefits of Bridge Condition Monitoring, Proceedings of the Institute of Civil Engineers, Bridge Engineering, 161, September 2008, issue, BE3. https://doi.org/10.1680/bren.2008.161.3.151

[2] Lakshmy P., Goel R., Goyal JK., Report on Infrastructure Information System for Bridges in GIS Environment, July 2011.

[3] Ghanekar VK, Tamahankar MG, Sahu GK, Goyal JK, Report on Long term Performance Monitoring of Balanced Cantilever Bridge on river Ganges, Varanasi, India- 1999.

[4] Premchand, Tamahankar MG, Sahu GK, Goyal JK, Report on Long term Performance Monitoring of Simply Supported Box PSC Girder Bridges on Thane Creek, Airoli, Navi Mumbai, July 2000.

[5] Khalid Abour and Bijan Samali, The Information System for Bridge Networks Condition Monitoring and Prediction, International Journal of Information Technologies and Systems Approach, 5(1), 1-18, January-June 2012 https://doi.org/10.4018/jitsa.2012010101

Mr. J. K. Goyal Born on 28.11.1966 did his B.Tech in Civil Engineering from MITS Gwalior and Post Graduation in Structural Engineering in 1990 from Birla Institute of Technology and Science, Pilani. He has more than 30 years of experience in R&D, project implementation and execution related to Highway and Bridge Engineering Projects involving multifarious tasks. He has carried out pioneering work in long term performance monitoring of the bridges and nuclear power structures. He has also accomplished instrumentation of many railway bridge projects for their capacity evaluation for Indian Railways. He has been the Chief General Manager and Project Director for implementation of National Highway Projects on various National Highways and Expressways of the Country. He has played a significant role in execution, planning monitoring and Policy framework for development of National Highways in India. He has published more than 20 R&D papers in National and International Conferences/Seminars/Journals and 50 national research reports.