PARADIGM SHIFT - PERFORMANCE DRIVEN BRIDGE MANAGEMENT

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Abstract: Deterioration models are the key to initiation of bridge management system. Initial concept was based on symptoms of distress. This was upgraded in first decade of twenty first century to Cause based models. The idea to utilize the performance of various elements of the bridge structure for generating the deterioration model was born out of the need to have a more robust, realistic and reliable deterioration model. The challenges to this were the intense mathematical operations essential to determine the presence of distress based on raw data generated from Structural Health monitoring of those elements under live loading. Advent of computing tools made this possible. The next challenge to determine the location, orientation and severity of the distress in the elements was solved by use of photogrammetry tools. Research to apply computing algorithms to SHM data resulted in enhanced solutions to the 3D model generated by photogrammetry tools. This protocol has resulted in the paradigm shift in conceptualization of performance driven deterioration model generation. Resulting in more efficient and effective usage of funds in providing MRSR intervention to distressed bridges. This resulted in a real time, robust and efficient Bridge Management.

This paper is the first of the series of papers that our Research Group will publish illustrating the details of the concept to integrate Automated data capture, Application of photogrammetry tools, Short duration SHM, Analytics involved and resultant cost efficient results.

Introduction:

Concrete is a construction material, whose durability properties can be improved easily and in a versatile manner simply by selecting its constituents appropriately or by using proper admixtures. Concrete is generously used as a construction material for these reasons.[14] Nevertheless, these probabilities have not been exercised sufficiently, because too often, the cheapest possible concrete type has been selected for the structure. This is done in spite of the demanding environmental conditions to which it will be exposed. Primarily economic considerations during the building phase governed the selection of concrete type. Lack of knowledge of different deterioration mechanisms and of the ways to improve the durability properties of concrete also resulted in wrong choice of concrete. Compromise during the selection, has been one of the prime reasons why the service lifespan of many concrete structures has been abruptly cut short. At the horizon level, the cost of renovating deteriorating concrete structures is immense. It is usually the case that, relatively inexpensive measures taken at the design and erection stage could have increased the service lifespan of these structures by a factor of two or even three.

In this paper, the causes and deterioration mechanisms is being reviewed. The emphasis has been on the most important deterioration features which affect large volumes of concrete structures.

The initiation of the Bridge Management system starts with the collection of data required in the Bridge Information system [BIS]. Data collection during Inventory, Inspection and Testing process contribute to this process. Bridge Management system [BMS] begins when BIS data collection ends. The definition of the Deterioration mechanism is the initiation of BMS. Once the primary and secondary causes are defined, it is essential to be able to determine the deterioration process. Unified Bridge Management System [UBMS] relies on the realistic estimation of the deterioration model to be able to utilize all other tools of UBMS. Deterioration model preparation is the initial step of UBMS to utilize all other tools of management in UBMS. Deterioration models presently depend on the cause of distress in various elements of the bridge. This deterioration model is used in risk estimations and to optimize fund allocation.

This renders the present BMS as a Cause based system. This entire exercise of defining deterioration process and risk analysis is based on elements of bridge as a whole**.**

Present day inspection procedure also provides sufficient geometric data of various elements of the bridge to be used to generate a full scale-down 3D geometric model of the bridge. This 3D model helps us to understand the bridge geometry and structural placement. It also allows us to mark the distressed elements. Based on the inspection data it is also possible to have a clear picture about the severity of distress in the element. The main missing data is related to the geospatial location, the extent and the severity of distress in the various bridge elements.

Present day Deterioration model

Inspection process entails each bridge element to be inspected by the bridge inspectors. This inspection has to be done from close hand touch distance. Inspection should yield an understanding in the behaviour of the bridge structure to the bridge inspector. The bridge inspector is able to correlate various symptoms with each other. The inspector can draw his inference as to the probable cause of distress. UBMS initiates deterioration model using causes of distress as defined basically as Mechanical process [Impact, Abrasion, Erosion, Cavitation and wear-tear, Overload, Fatigue], Physical process [Temperature, Shrinkage induced, Settlement induced], Chemical process [Carbon dioxide and Chloride, Sulphate, Carbonation, Alkali – aggregate reaction].[1] A total of these 11 causes attribute to the distress in any concrete element of the bridge. The bridge Inspector will assign ratings to each of the probable cause which results in the observation of distress in the bridge. This assignment of rating is based on the prognosis established by the bridge inspector. Based on the prognosis of distress the inspector assigns ratings from 0 to 9 for various causes of distress. This process is done easily by the procedure of eliminating one by one the causes of distress. The matrix resulting from this is called the "Cause Matrix ".

Based on the assigned ratings primary cause of distress can be identified. All other contributory causes are called the secondary causes. These observations conclude the inspection process and to a large extend the Bridge Information system. Next step involves confirmation of the prognosis. Till date, this confirmation was done by Non-destructive testing techniques. Confirmed Cause Matrix is used as the first of the important data by the Bridge Management System.

Some pictures of cause related distress in bridge including the failure of bridge.

The Bridge Management system starts with the help of data collated during BIS namely Inventory, Inspection and Testing process helps to confirm the prognosis of the Deterioration process. Once the primary and secondary causes are defined, it is important to be able to determine the deterioration process.

We have already identified and listed out three main reasons for the need for identification of location of damage being critical to the structural evaluation and the deterioration process in our Concept document.[11] Different modes of failure are location dependant and that assume criticality based on their location along the length of the element. The strength of the element as evaluated using the deteriorated cross section affects the load capacity of the member along the length of the element. None on the existing BMS including UBMS is able to provide accurate digitized data relating to the location of the damage or distress.

The Inspection process in any BMS is database centric. [2] Data is collected in a manner it can be stored into a database. Historical evidence of distress even if collected is oriented in a manner it is impossible to contextualize distress and then corelate exact location of previous distress symptom over present symptom location. This in reality hampers the correct evaluation of deterioration models.

These shortcomings within BMS are required to be overcome by using all available new innovative technologies. [3] Integration of technologies, that can provide data regarding the correct geospatial location of distress would be the first phase in the refinement. Moreover, the next phase is to identifying the critically distressed elements and evaluates performance of such severe distress elements under live loading using Structural health monitoring [SHM] for short durations only. Using this data as a base data, we shall need to repeat our SHM observations over time to create a time series data that is used to compare with base data collected initially.

The sequence of application in the bridge management will require us to refine the following, keeping in focus that performance shall be the driving factor:

1. Location, extent and severity of distress- Identification using photogrammetry tools.
2. Structural Health monitoring – Real time analysis of the structure under live load.
3. Application of computing algorithms to SHM to evaluate performance.

Location, extent and severity of distress- Identification using photogrammetry tools.

The first step in refinement shall need us to define a 3D model of the bridge. Sufficient data collected within the inspection process enables us to use 3D open-source software to generate such 3D model of the entire bridge. Such 3D models for bridges are termed Bridge Information Model (BrIM). [4,5] This 3D model helps us to understand the bridge geometry and structural placement. It also allows us to mark the distressed elements. Based on the inspection data it is also possible to have a clear picture about the severity of distress in the element. The most severe distressed elements can be identified and pinpointed.

Our research was focused on the need to establish the geospatial location, the extent and the severity of distress in the various bridge elements. This digital imagery provides geospatial data on the distress. Use of Drones changes the way inspection can be done. [3,4,5] The use of drone/ UAV to capture still photos of distress areas and also videos of bridge components/ elements will enhance the usefulness for indicating location and extent of distress. UAV/ Drone is able to capture multiple photos with large overlaps or videos files which are then used by photogrammetry tools to create 3D model of individual distressed elements. [6,7,8] All such imagery had embedded geospatial information.

With the geospatial information of distress, it becomes possible to identify the element which can be monitored for performance evaluation. [9,10]

Structural Health monitoring – Real time analysis of the structure under live load.

Having identified the geospatial locational details along with the extent and severity of the distress in the element, the Bridge inspector can then focus on identification of the most severe distressed elements. Such elements will need to be subjected to Structural Health Monitoring. Structural Health Monitoring (SHM) needs to be integrated with Bridge Management System (BMS) to enable BMS become more robust, realistic and efficient.

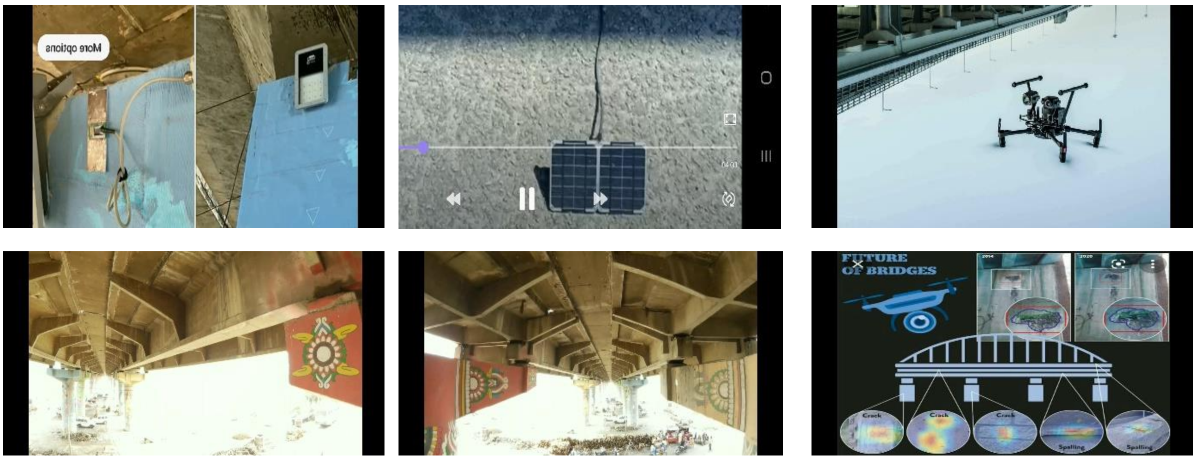
Two types of SHM are envisaged to achieve the objective.

1. Remote or No contact SHM: System wherein the parameters essential like Vibration, acceleration, frequency, strain, displacement is captured by technology without being in contact with the bridge or bridge elements.
2. Close Contact SHM: System wherein major strain, stress, linear displacement, inclination, vibration, frequency, acceleration, corrosion potential is measured by sensors [Strain Gauges, Linear Variable Differential Transformer (LVDT), Tilt Meter, Inclinometer Sensors, Acoustic Emission Sensors (AE), Fibre Optic Sensors, Corrosion Sensors, Accelerometer] in close contact with various desired components/ elements of bridges.

Both the "No contact" and "Close Contact" systems will yield results that identify typical changes in performance parameters to determine the correlation between decrease in performance parameters with increase in distress zone and severity. SHM is to be applied for short durations of 2 to 3 days only under existing live loads to monitor the distressed elements of the bridge. Such monitoring will be repeated for four or five times to generate time series performance snap shots. The analysis of the performance will enable us understand the magnitude of decrement that occur in the performance. Such decrements are then corelated to the increment in distress in the elements. Corelation empowers us to define a new cause matrix which is based on decreasing performance of the bridge elements.

Our aim is to shift the Cause-Based Bridge Management to Performance based Bridge Management.

Some actual photos of integration of drone imagery and SHM in use within UBMS



Application of computing algorithms to SHM to evaluate performance of bridge under live loads.

Changes in Performance parameter can be identified by SHM based on the time series observations of Performance between base scenario which exhibits 'No/ initial Distress Situation" and with operational scenario which shows "Presence of Distress situation". Further the Performance monitoring should be able to correlate decrease in Performance level with increments in the extent along with the severity of Distress.

This correlation needs to be established by known and proven techniques of analysis like: Optical matrix updating methods, Sensitivity based updating methods, Stochastic model updating methods, Empirical mode decomposition, Wavelet techniques, Frequency response function, Methods using mode shapes (Modal assurance criterion), Method using curvature/ strain modes, Modal strain energy techniques, Dynamic flexibility techniques, Artificial Neural networks (MLP: Multi-Layer Perception and RBF: Radial Basis Function), Hybrid ANN namely Imperial Competitive Algorithm and Genetic Algorithms, Principal Component Analysis (PCA), Structural Deterioration Analysis, Reliability Analysis, Symmetry Index Analysis, Dynamic Index Analysis

The typical analysis process could be evolved with one of the above techniques or a combination of few. Below is one such examples of analysis process techniques. Similar techniques have been evaluated by our team and can be used.

V.V. Nguyen and Ulrike Dackermann have studied that the application using OMA, FRF, PCA, ANN: [12,13] Operational modal analysis (OMA) which can be Cepstrum based. This could be applied for the regeneration of frequency response functions (FRFs). This will yield detection of distress zones. Such detection can be implemented by the use of ANNs or its hybrid versions. Distress / damage features can be identified in the regenerated FRF data. Response measurements comprise effects due to excitation and transmission. Their separation is essential before relevant transfer functions can be determined. The employed technique should achieve source-path separation with the cepstrum, which is able to deal with 'frequentially smooth' inputs. After separation, the transfer function should be obtained by curve-fitting the transfer path cepstrum, from which the desired FRFs are generated. FRF's are very data intensive, Principal Component Analysis (PCA) techniques can be used to reduce their size and to provide suitable input data for ANN training. ANN training can yield Artificial Intelligence application to forecast the probability of distress propagation. Such forecasts should be incorporated in the report prepared.

Such analysis yields identification of typical distress zones, its extent and severity. The severity is generated by study of SHM time series snap shots. The generated severity and extent enhance the prognosis generated by the Bridge Inspector. This prognosis by the bridge inspector was hypothetical. Now with the confirmed propagation of distress identified by SHM data analysis, we have more authentic data related to distress and its cause. [11] This information is used to update the Cause matrix which was previously generated by the Bridge Inspector. Such modified and updated Cause matrix empowers us to create a Deterioration model which is based on performance of the bridge under live loads and the propagation of distress in realistic scenario.

Deterioration model preparation is the initial step of UBMS to utilize all other tools of management in UBMS. Deterioration process leads us to estimates for Balance Service Life [BSL] of the bridge. This updated Deterioration models depend on the performance-based propagation of distress in elements of the bridge. Our use of this enhanced and updated model in risk estimations, yields decisions in all further tools of bridge management which are dependent on performance-based. This entire exercise of defining deterioration process and risk analysis is based on elements of bridge as a whole. Risk analysis results in absolute efficient and effective fund allocation for MRSR interventions which is the final goal of any bridge management system.

Conclusions

This research yields to upgrade the existing method of application within the Bridge Management system the world over. UBMS is the probably the first BMS in the world to move from cause-based system of decision making to performance-based system. The whole concept of using performance as the key factor for decision making has been under the eyes of the researchers the world over for the past many years. Many researchers have provided important key element essential in the process of creating a performance driven BMS. The main stumbling block in definition of the procedure was to effectively transform the evaluated distress propagation into updated cause matrix. The deterioration of any element is generated only from the cause application. We had to determine the time essential for the element to fully deteriorate dependant on the type of cause. Collated data over the past 7 to 8 years enables us to derive the logical time essential for complete deterioration to happen. The knitting of all such key elements into a procedure that results into efficient and effective fund allocation is the result of our research. Such integration is used for analysis and prediction of deterioration models, risk analysis and prioritization of fund allocation. These three functions being the key functions of any Bridge Management System.

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