

Information fusion between bridge management system and structure health monitoring system

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Abstract. Through the application status investigation of the bridge management system and the structural health monitoring system, it was found that the two systems were not fused well, which resulted in resources waste and inaccurate outcomes. Based on the research of status and application of the two systems, the paper analyzed the necessity and feasibility of the information fusion of the two systems. Finally, the specific information fusion of the two systems is presented through the exact information fusion of the systems in the bridge structural condition assessment, one of the most important modules of the bridge management system. More accurate results of the condition assessment and remaining life prediction of bridges can be obtained by the bridge management system after the fusion, which will offer some evidence for the bridge maintenance strategy made by bridge management decision-makers.

Keywords: structural health monitoring; bridge management system; information fusion; condition assessment.

1. Introduction

Since 1980s, there have been dozens of sudden damage incidents of bridge structure at home and abroad successively. Since 2009 alone, there have been more than ten bridge collapse accidents in our country. These catastrophic accidents made the life and property of the country and people suffer great loss, which not only aroused the attention of the social media and public opinion. It has also made governments and scientific institutions aware of the urgent need to study the health of bridge structures^[1-3]. By the end of 2009, there were 621900 highway Bridges with a total length of 27260.6 km, an increase of 27300 and 2013.7 km over the end of the previous year, among which there were 1699 large Bridges with 2886.6 km and 42859 Bridges with 9819.0 km. More than one fourth of the Bridges have structural defects, damage of different degrees and hidden dangers of functional failure, among which important Bridges are in urgent need of safety monitoring, performance evaluation, maintenance and reinforcement. In the coming period of time, bridge maintenance, reinforcement, reconstruction and other costs will be significantly increased. It can be predicted that after the high tide of construction, the health diagnosis and maintenance of bridge structure will be another hot spot of bridge engineering in our country^[4-7]..

In view of this situation, the bridge management system and structure health monitoring system have been paid great attention in the field of engineering and research at home and abroad. From the current research status, the research of bridge management system and structural health monitoring system does not become an organic whole, but two mutually independent systems. This leads to a bridge with two independent systems, resulting in a waste of resources, a lot of data is not well used^[8-12].. For example, the bridge management system and the structural health monitoring system of Donghai Bridge have been established at the same time. However, the design, operation and management of the two systems are carried out by two independent units respectively, resulting in low efficiency of the two systems^[13].. To this end, the paper makes an exploratory research on how to integrate the information of the two systems.

2. Current status of bridge maintenance management system

According to Yanev's definition, bridge maintenance management system is a computer information system about basic bridge data, daily inspection, condition assessment, structural degradation prediction, bridge maintenance strategy and management plan and economic analysis. The main solution of this system is to analyze how the bridge will degrade in the future on the basis of the existing data, how to improve the performance of the bridge, and when to adopt the most convenient and economical repair and reinforcement program to ensure that the degraded bridge can fully play its function within its life cycle.

The sudden collapse of the Silver Bridge across the Ohio River at Point Pleasant on December 15 1967, killed 46 people and caused social and political shock. In response, the U.S. government mandated that highway Bridges be inspected every two years, and in 1968 established the National Bridge Archives Database (NBIS), regarded as the first bridge management system in the United States^[14-17]. Subsequently, the United States Federal Highway Administration of the United States Federal Highway Research Cooperation Group developed PONTIS system and BRIDGIT system respectively on this basis, the two systems have the bridge data storage, state assessment, degradation prediction, cost-benefit analysis and optimization decision and other functions, and have been widely used in practical engineering. In the following years, many countries have developed their own bridge management systems, such as DANBRO of Denmark, Edouard of France, NATS of Britain, BRUTUS of Norway, NATS of Switzerland, J-BMS of Japan, SHBMS of South Korea and so on. Although the research of bridge management system in our country started late, some exciting results have been made, such as the CBMS2000 system of Ministry of Communications and its subsequent version and the corresponding maintenance management system for the development of long-span Bridges^[18].

Through the study of bridge management systems in various countries, it is not difficult to see that the basic framework of bridge management system is shown in Figure 1.

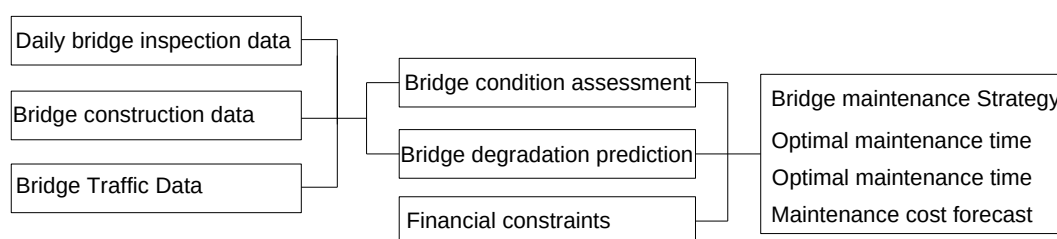


Figure 1. The basic framework of bridge management system

According to the basic framework of bridge management system shown in Figure 1, referring to the "Code for the Maintenance of Highway Bridges and culverts" (JTGH11-2004) issued by the Ministry of Communications and the "Technical Code for the Maintenance of Urban Bridges" (CJJ99 -- 2003) issued by the Ministry of Construction in 2004, we can see that, At present, the bridge maintenance and management work basically stays in the establishment of technical files, cleaning Bridges, dredging drainage pipes, repairing damaged railings and bridge deck pavement. Even if the inspection is carried out, the main inspection and maintenance measures are manual visual inspection or instrument inspection. The health of Bridges is also assessed by manual visual or portable instrument measurements. However, these methods have significant limitations in practical application. A survey by the Federal Highway Commission found that 56 percent of assessments based on manual visual inspection were inappropriate. At the same time, the main defects of this method are also reflected in: (1) it requires a lot of manpower, material and financial resources; (2) The detection means are limited and there are many blind spots; (3) Strong subjectivity, difficult to quantify; (4) Lack of integrity; (5) Affect the normal traffic flow; (6) Long cycle and poor real-time performance; (7) It is difficult to meet the needs of inspection and maintenance of large Bridges.

The above shortcomings and limitations determine that the traditional visual inspection method cannot be directly and effectively applied to the health condition inspection of large Bridges.

Therefore, a new method is needed to monitor the structural response of Bridges under various environmental and load factors in real time, and provide effective scientific basis for bridge maintenance and management, so as to significantly improve the overall management level of Bridges. Thus, the integrated monitoring system can ensure the safe operation of the bridge to the maximum extent, diagnose the bridge disease and extend the service life of the bridge.

3. Status quo of structural health monitoring system

In 1997, Housner et al. gave the following definition of structural health monitoring: using nondestructive sensing in the field and analysis of structural system characteristics (including structural response) to detect structural changes and reveal structural damage and structural performance deterioration. It combines nondestructive testing (NDD) and structural characteristic analysis (including structural response) to diagnose whether there is damage in the structure, determine the location of the damage, estimate the extent of the damage and the consequences of the damage to the structure.

The concept of bridge health monitoring has been around since the 1960s. In 1987, sensors were installed on the Foyle Bridge, a three-span continuous steel beam bridge with a total length of 522m, to monitor the structural response of the bridge under load during operation. Since then, Norway, the United States, Denmark, Mexico, Japan and South Korea have all established dozens of bridge structural health monitoring systems of varying sizes in their countries. China started a little later in this field, but made rapid progress. From the early Qingma Bridge in Hong Kong to Humen Bridge, Jiangyin Yangtze River Bridge, Sutong Bridge and Donghai Bridge in mainland China, more than 100 Bridges of various scales have been installed with structural health monitoring systems in just a few decades.

It is a development trend in the field of bridge health monitoring in recent years to use real-time health monitoring system to evaluate the health status of bridge structures. It integrates modern sensing technology, network communication technology, signal processing and analysis, data management methods, computer vision knowledge mining, prediction technology, structural analysis theory and decision theory and other fields of knowledge and technology, greatly extends the connotation of the field of bridge detection, and improves the reliability of prediction evaluation. An overview of the existing bridge health monitoring systems at home and abroad can be divided into three stages. The first stage is the early single health monitoring system, with limited sensor types, unsafe acquisition equipment and intermittent monitoring. The second stage is the integrated monitoring and diagnosis system, which has a great variety of sensors, perfect collection system, continuous collection, and database management software to manage the data. The third stage is the integrated monitoring and diagnosis system. On the basis of the second stage, it emphasizes the processing of the data, and uses the data to carry out online assessment and online early warning of the structure monitoring state, and provides convenience for the offline assessment of deep human and ground. More features, wireless and Internet technology is used in the system.

After 20 years of active exploration, some achievements have been made in the field of bridge health monitoring. However, it should be clearly recognized that there are still many unsatisfactory aspects in the current bridge health monitoring system due to the complexity and uncertainty of the bridge structure itself, as well as the limitations of many objective conditions: (1) the optimal arrangement of limited sensors and reasonable determination of the system scale; (2) The change of bridge structural performance is not sensitive to the structural fingerprint, and the damage identification is still in the theoretical research stage; (3) The real-time processing and analysis of a large number of original data lag behind, and the information obtained cannot meet the engineering requirements; (4) The evaluation method of structural health status is not perfect, and it is difficult to give reasonable conclusions and explanations; (5) The structural health status only considers the performance of the structure itself, but does not consider the health status of the auxiliary components; (6) There is no unified standard and specification for bridge structure supervision and monitoring,

and the system is too different; (7) How to effectively combine with other related systems, especially with the traditional inspection and maintenance system.

4. Necessity of information fusion

According to the definition of bridge management, the ultimate goal of bridge management is to put forward economic and reasonable maintenance strategies on the basis of understanding the existing health status of the bridge, so that the bridge can give full play to its functions within its service life cycle. From the perspective of project quality management, the health status of bridge structure mainly includes the following points: applicability, durability, safety, reliability, economics and coordination. The applicability information mainly comes from the appearance characteristics of the bridge, such as physical and chemical characteristics, such as whether the appearance size of the bridge has changed, whether the bridge panel has changed, whether the surface of the main structure of the bridge has occurred unacceptable cracks and so on. The main consideration of safety is whether the bearing capacity of the bridge structure decreases and how much it decreases. The former information is mainly obtained from routine examinations, sometimes assisted by the use of simple instruments. The latter information is mainly obtained through the detection or monitoring of the bridge structure, and the mechanical properties of the bridge are obtained through the installation of various sensors or the installation of various strain gauges. The former is the main work of the bridge management system before the month, while the latter mostly appears in the structural health monitoring.

However, the current situation is that the bridge management system and the structural health monitoring system are two independent systems, and the two carry out their own work, and the information obtained is used by themselves, but not shared with each other. This is where the results produced by these two systems have their own one-sidedness. For example, for the bridge management system, the relevant information is obtained mainly through daily inspection, mainly visual inspection, and then the information is analyzed and the health of the bridge structure is assessed subjectively. The information obtained is bound to have some shortcomings. Because the mechanical properties of the structure are not considered, sometimes the analysis results show that the condition of the bridge is already very low. From the point of view of mechanics, the bearing capacity may not be much reduced, as long as the surface is treated a little. For the structural health monitoring system, because only the essential characteristics of the structure are considered, without considering the information of the appearance of the structure, the obtained results may be less conservative. Sometimes, it may not be necessary to take relevant measures mechanically, but the actual situation is that large deformation or cracks have appeared on the surface without being detected.

To sum up, the integration of the two systems is urgent. Only by the fusion of the two information, can we get more objective and practical results, and provide a good basis for the health of the bridge.

5. Bridge management system after information fusion

After the integration of bridge management system and structure inspection system, the basic framework of bridge management and bridge construction system is shown in Figure 2.

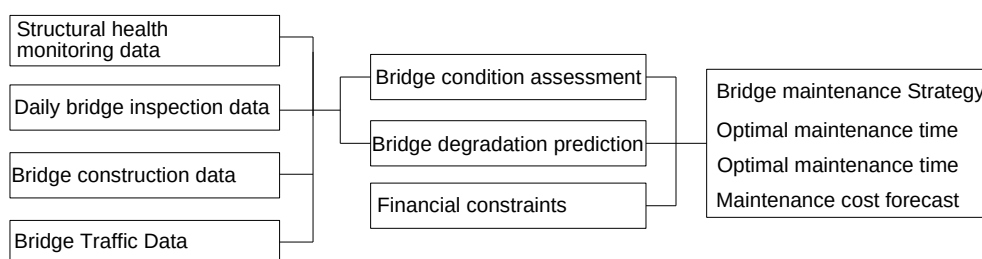


Figure 2. Basic framework of bridge maintenance management system after information fusion

From the above studies, it is obvious that most of the results obtained by the bridge management system are qualitative data, while most of the structural health monitoring data are quantitative data. How to integrate the information obtained by the two systems is a major content of this study. In order to illustrate the process of the integration of the two systems more clearly, the integration of the two systems in the bridge status assessment, one of the main modules in the bridge management system, is taken as an example to illustrate.

6. Fusion of two systems in structural state assessment

The overall condition assessment of the bridge in the NBIS is based on the assessment results of each major component, and all the bridge component lists are based on the direct comparison of the current state of the structure with the pre-assumed completed structure to obtain the overall scoring status of the bridge. The scoring range is an integer from 0 to 9.

At present, the status assessment, suitability assessment and maintenance scoring results of the bridge in the bridge management system are based on the appearance inspection and daily inspection results, and there is no analysis of the mechanical properties of multiple Bridges from the overall performance of the bridge structure. In order to make the evaluation result more effective and reasonable, it is suggested that the content of structural health monitoring should be included in the evaluation of structural condition.

Bridge status is assessed based on a combination of subjective scores from bridge management and quantitative analysis results from structural health monitoring. The same bridge condition assessment table that incorporates structural health monitoring is shown in better.

7. Conclusion

At present, due to various reasons, the bridge management system and the structural health monitoring system are two independent systems, which are designed, implemented, operated and managed by different departments respectively, thus leading to the waste of resources, information can not be used well, and the final results are inconsistent with the actual situation and other defects. Therefore, the paper first analyzes the characteristics of the two systems and points out that the information fusion of the two systems has great necessity and good feasibility. Finally, how to integrate the information of the two systems is proposed. In order to explain the information fusion process of the two systems more clearly, the paper describes in detail how to carry out the information fusion of the two systems in the bridge state assessment, one of the most important modules in the bridge management system. The results show that the two systems should not only be integrated, but also can be integrated. The integrated two systems can provide a direct basis for the formulation of bridge maintenance strategy, which makes the bridge maintenance strategy more practical and effective.

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