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To cite this article: Zhong Jiawei 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **643** 012164

View the article online for updates and enhancements.

The Application of Structural Health Monitoring in Different Engineering Fields

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Abstract: Recently, SHM is applied not only in civil infrastructure aspect, but it is also applied in buildings and aircraft maintenance and many other aspects, which is fundamentally used in our daily life. But, as it is becoming more and more significant in structural health, we are on an urge to apply it in more different fields, and a valuable attempt is found to bear in archeological field. In the process of providing existing applications of SHM, the subsequent articles in this theme are cited in an effort to show how SHM is used in many kinds of circumstances. In conclusion, technical challenges that must be addressed if SHM is to gain wider application are discussed in a general manner.

1. Introduction

1.1. Background

The process of implementing a damage identification strategy for aerospace, civil and mechanical engineering infrastructure is referred to as structural health monitoring (SHM). Here, damage is defined as changes to the material and geometric properties of these systems, including changes to the boundary conditions and system connectivity, which adversely affect the system's performance. A wide variety of highly effective local non-destructive evaluation tools are available for such monitoring. However, the majority of SHM research conducted over the last 30 years has attempted to identify damage in structures on a more global basis. The past 10 years have seen a rapid increase in the amount of research related to SHM as qualified by the significant escalation in papers published on this subject. The increased interest in SHM and its associated potential for significant life-safety and economic benefits has motivated the need for this theme issue.

1.2. The purpose and significance

Structural health monitoring is a method of non-destructive monitoring through the physical and mechanical performance of a structure, thus to real-time monitor the structure. In the long-term use process, civil engineering structure will be unavoidable damaged due to a variety of natural and human factors. These damages are divided into two categories: accidental damage and cumulative damage[2]. The accidental damage refers to earthquakes, storms, floods and many other accidental natural disasters and terrorist attacks, the destructive factors will cause serious damage to civil structures in a very short period of time[1]. The cumulative damage is mainly about in the long-term use process, the environmental changes and components degradation, fatigue and rust and many other factors will also cause a certain degree of damage. Both types of damage can cause severe structural damage, namely the changes in the material and geometric properties of the whole structure or certain parts, which can affect the future performance of the structural system.

In recent years, natural disasters and terrorist bombings have caused great damage to important structures. The sudden break of the bridge and the accidental collapse of the building occur frequently, which causes great losses to lives and properties and arouses people's attention to the safety of the buildings and infrastructures. How to prejudge and announce disasters before the destruction and take urgent actions to avoid serious loss, how to make a proper assessment of the extent of cumulative damage to buildings on a regular basis to ensure the safety and stability of a structure, has become an urgent problem to be solved. Therefore, structural health monitoring has come into being and become an important research field of civil engineering[4].

Structural health monitoring is mainly used to evaluate the overall behavior of a specific structure, diagnose the location and extent of structural damage, and intelligently evaluate the use status, reliability, durability and carrying capacity of the structure. When these conditions occur, it triggers an early warning signal that the building is in emergency or Serious abnormal conditions provide guidance and basis for building maintenance and management decisions[3].

2. Practical application of SHM

2.1. Application of SHM in buildings

Zhai Weilian and his team installed a structural health monitoring system in the mesh-shape roof of the 486m in length and 156m in width of the Shenzhen Civic Building, which consists of a sensor subsystem and a structural analysis subsystem. Among them, the sensor subsystems measure the wind pressure and the reaction of the roof part, and the structural analysis subsystems calculate the reaction of the structure and make a safety assessment. Sensor subsystems include optical fiber sensors, strain gauges, anemometer, a draught gauge and an accelerometer, where the optical fiber sensors and strain gauges measure the strain response of the structure, the accelerometer measures the displacement and acceleration reaction of the structure, and the anemometer and draught gauge measure the wind pressure distribution of the roof. Based on the structural measurement reaction, the structural analysis subsystems can achieve the damage identification, model correction and safety assessment of roof structure. All monitored signals are stored in a database that is transmitted remotely over the LAN and Internet. The bend top of Kumagu, Japan, is a giant elliptical string bend top structure with a long axis of 250m, a short axis of 150m and a height of 45m. Sumitro's team had installed magnetic telescopic sensors on nearly half of the ropes at the top of Japan's Kumagu Bend (1,200 radial pulls), meanwhile, they have developed a spatial structural monitoring system to monitor the stress of the rope during construction and using process[5].

Therefore, from the examples mentioned above, we can draw a conclusion that the SHM system is not a rigid system, instead, it is a system that varies a lot according to the terrain, geographical location, climatic conditions and even the difference in the angle of sunlight intrusion. Different sensing systems and monitoring systems are chosen to be used under different specific circumstances, so as to improve the efficiency of the system, which is of great significance for the improvement and promoting of SHM system[6].

2.2. Application of SHM in bridges and dams

Since the 1990s, China has installed structural monitoring systems of different sizes on some large-scale and important bridges, such as the Humen Bridge, which have already been installed sensing equipment at the beginning of construction stage, to real-time monitor the safety during operations in the future. And the monitoring system of Xupu Bridge includes vehicles load, temperature, deflection, strain, main beam vibration, and oblique cable vibration. A complex monitoring system, including four subsystems of sensing systems, data acquisition systems, data processing and analysis systems and control centres, has been installed on the three bridges in Hong Kong (Tsing Ma Bridge, Kap Shui Mun Bridge and Ting Kou Bridge), among which a total of 756 sensors are used in seven categories. China's Sutong Bridge, Runyang Bridge, Nanjing Three Bridges, Shandong Binzhou Yellow River Road Bridge, Harbin Songhua River Sloping Bridge, Shandong

Dongying Yellow River Road Bridge, etc. have also been or are in the process of installing a structural health monitoring system[7].

In the research and application of comprehensive judgment and decision-making on dam safety, Wu Zhongru's team put forward and developed an expert system of comprehensive evaluation of dam safety on the basis of "one machine four libraries" (inference machine, database, knowledge base, method base and gallery). They apply pattern recognition and fuzzy evaluation, make comprehensive calls to four libraries through comprehensive inferencing machine, combine quantitative analysis and qualitative analysis, and realize the online real-time analysis and comprehensive evaluation of the safety status of the dam[8]. This system has been applied to the safety analysis of Danjiangkou, Gutianxi three-stage dam and Longyangxia dam.

Bridges and dams have higher requirements for SHM, for it is not only matters the life of the bridges and dams, but also have a strong relationship with the safety of people. So, it should be monitored real-time. At the same time, with the help of the Internet and database, the environmental circumstances of each structure need to be spread to the database with the form of remote signal transmission, so as to form a external monitoring of all the bridges and dams structures, so that maintenance will be more targeted and advanced.

3. Application of structural health monitoring in archaeology

3.1. The workflow of the ancient structure health monitoring system

There are three parts: structural characteristics research, monitoring system organization and health assessment. As shown in Figure 1, information research on ancient architectural sites is the foundation. Through the study of load conditions, structural damage, geometric information, and dynamic characteristics, etc., the finite element method is used to evaluate the safety rate. Monitoring system organization is an important practice segment in the design of structural health monitoring system including monitoring content parameter index, sensing and data subsystem through early research and analysis, whose work is mainly about hardware installation and software design as well as system maintenance[9]. Structural health diagnosis and evaluation is the result of the design of structural health monitoring system, and its main work includes: structural safety status assessment and early warning mechanism of structural damage. Through the ancient structure health monitoring system, it becomes more easier to qualitative, positioning and quantitative analysis of the damage to the space structure, so as to prevent the problem before it really occurs.
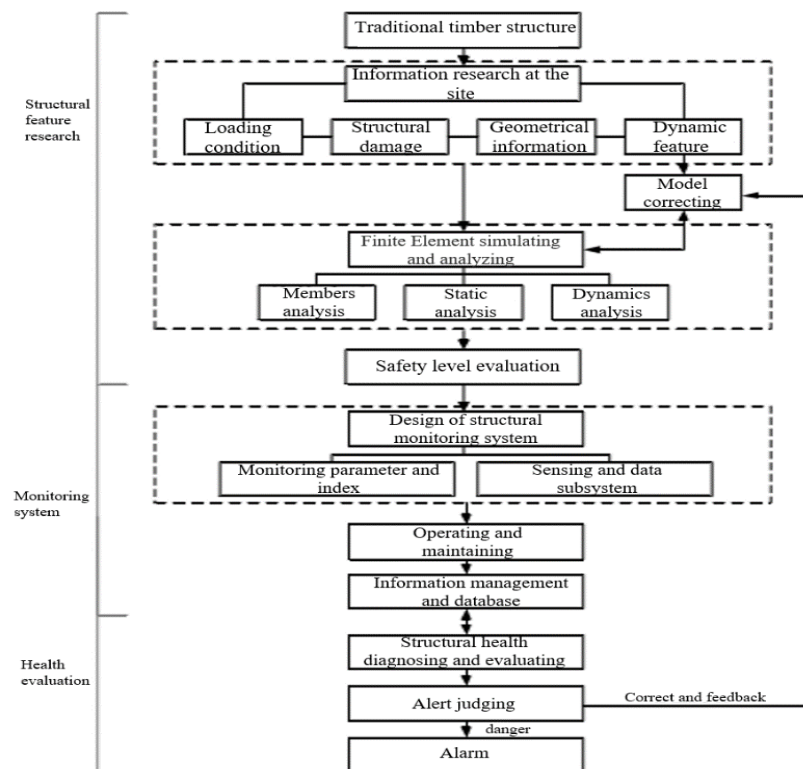
Figure 1 Workflow of the design of the health monitoring system of ancient structure

3.2. A new framework for predicting the life of ancient structures

Considering that the ancient structure has been in a high humidity environment for a long period of time, the serious corrosion of the material causes the structure to suffer damage of different degrees, which leads to the collapse and destruction of different degree of the structure[10]. The life of the remaining materials of the ancient structure needs to be estimated, which helps us find the best way to maintenance the ancient buildings. The method used in this paper is to introduce the deformation results of the structural health monitoring system of the ancient structure on the basis of the existing material-level prediction based on the carrying capacity index, and finally determine the failure time of the structure by considering the influence of the deformation value index on the structural life prediction at the component and even the structural level.
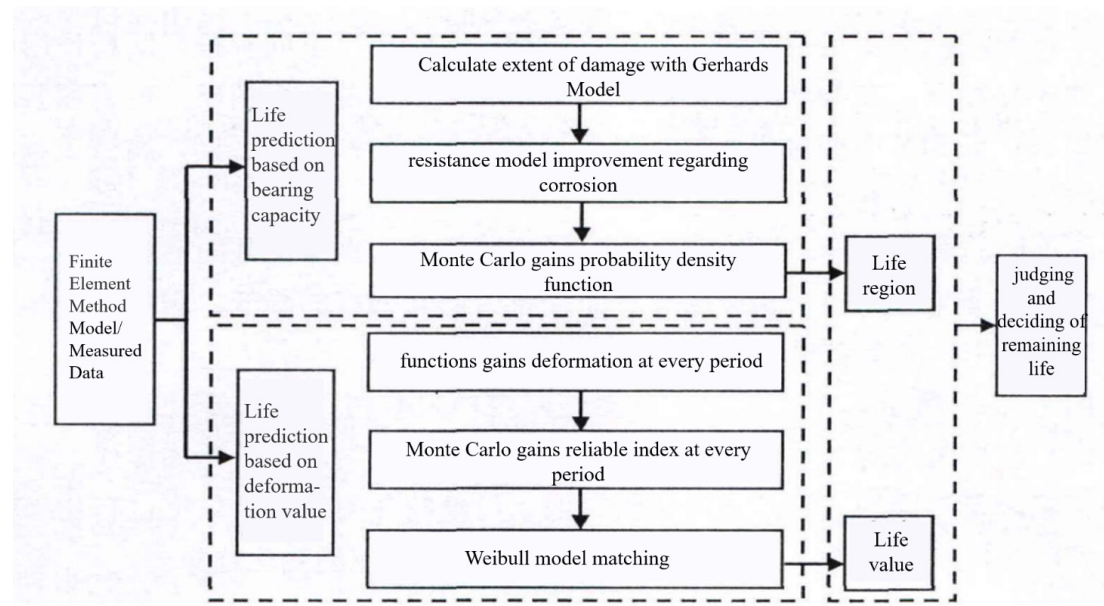
Figure 2 A new framework for predicting the life of ancient structures

4. Discussion

From the discussion mentioned above, it can be concluded that there are still great limitations in the use of SHM system limited by the development of structural monitoring system. We can estimate the carrying condition and service life of the structure by the size of the maximum carrying capacity of the ancient structure. However, for some deep underground tomb structures, such as the tomb of First Emperor of Qin, it shows great limitations because technology has not yet reached the level that SHM system can be installed under the ground without causing any damage or impact. There is still a long way to go to use structural health monitoring system for archaeological purposes.

5. Suggestion

Several suggestions needed to be put forward to point out some probable ways of development of SHM system. A sensing system that relies on ultrasonic and infrasonic waves to monitor the structure can be explored. Through the penetration of ultrasonic or infrasonic waves, we can test the structural material and its internal force and then finally judge its service life without destroying the structure on the surface.

The application of structural health monitoring system in archaeology is not limited to the age judgment of ancient buildings, but also has certain advantages in the exploration and excavation of ancient buildings. The location and position of the ancient buildings can be easily determined by the penetration of sound waves or other exploration techniques and the elimination of the newly generated ground effects. In this way, we can discover as many historical monuments as possible, thus promoting the development of the archaeological industry.

6. Conclusion

Like its non-destructive detection mechanism, the advantages of SHM should be fully utilized according to local conditions, changing from time to time through a variety of different ways to monitor the structure in real time. At the same time, apart from what mentioned above, SHM can also be applied to other fields, such as aerospace engineering, non-destructive testing of wings or rocket structures and inference of the life of the space station, the evaluation of the safety performance of port terminals in the field of navigation, and the maintenance of rails in transportation, so as to better protect people's safety during journey. More importantly, instead of finding the limitations of SHM, we should pay more attention to its optimization and development, break through the limitation of

penetrating objects and homogenous working patterns, and use a combination of sound waves and resistance strain and other ways of working patterns to enrich its usage in the future.

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