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Restoring method for missing data of spatial structural stress monitoring based on correlation

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ABSTRACT

Long-term monitoring of spatial structures is of great importance for the full understanding of their performance and safety. The missing part of the monitoring data link will affect the data analysis and safety assessment of the structure. Based on the long-term monitoring data of the steel structure of the Hangzhou Olympic Center Stadium, the correlation between the stress change of the measuring points is studied, and an interpolation method of the missing stress data is proposed. Stress data of correlated measuring points are selected in the 3 months of the season when missing data is required for fitting correlation. Data of daytime and nighttime are fitted separately for interpolation. For a simple linear regression when single point's correlation coefficient is 0.9 or more, the average error of interpolation is about 5%. For multiple linear regression, the interpolation accuracy is not significantly increased after the number of correlated points is more than 6. Stress baseline value of construction step should be calculated before interpolating missing data in the construction stage, and the average error is within 10%. The interpolation error of continuous missing data is slightly larger than that of the discrete missing data. The data missing rate of this method should better not exceed 30%. Finally, a measuring point's missing monitoring data is restored to verify the validity of the method.

1. Introduction

Large-span spatial structures are widely used in stadiums, airports, railway stations, convention centers, theaters, and other important public buildings [1]. For this type of structures' large body mass, complex system, difficult construction, and long service time, the safety of construction and service process is one of the most important problems of concern for engineers. Long-term serving structures can cause performance degradation. Accidents of this kind of large-scale public buildings will cause immeasurable life and economic loss. An effective way to ensure the safety of a structure is to carry out the whole life health monitoring from construction to service [2]. Structural health monitoring of major engineering structures has become a hot issue around the world [3–5]. However, the current methods of spatial structure monitoring are mainly focused on construction monitoring [6–8], whereas whole-life monitoring is less. The evolution of the structure's internal force can be fully grasped only through whole-life health monitoring [9].

The Hangzhou Olympic Sports Center Stadium is the main stadium of the 2022 Asian Games in Hangzhou. The whole stadium is lotus-shaped and consists of 28 main petals and 13 minor petals (Fig. 1a). It is 333 m long in the north–south

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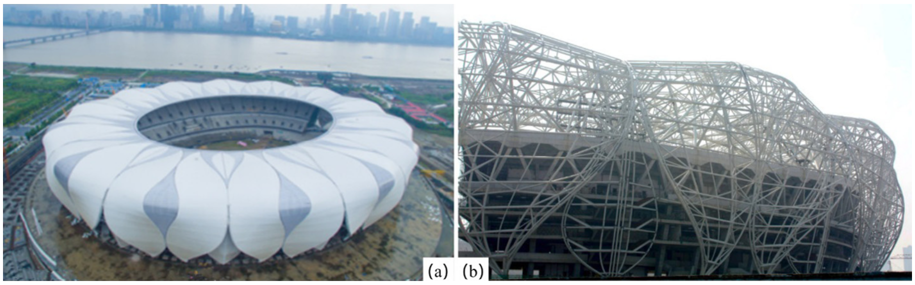


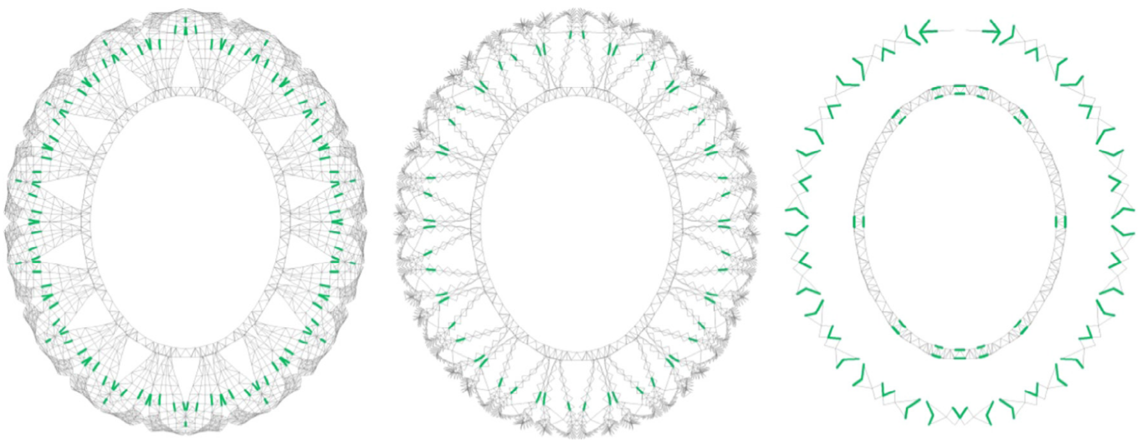
Fig. 1. Photograph of the "Lotus". (a) The entire structure of the "lotus". (b) Partial view of the steel structure.

direction, 285 m long in the east–west direction, and 59.4 m high. This is an extra-large stadium which can accommodate 80,011 spectators and will become a new landmark in Hangzhou. To meet the petal design, the structure is formed by curving space pipe-truss system (Fig. 1b), which poses great challenges to the precision of construction and integration.

In order to grasp the evolution of the structure's inner force and the changes of performance from construction to service, studies were carried on long-term health monitoring using a self-developed, wireless stress–strain sensing system [10]. Due to the large size of the stadium, a total of 828 stress–strain sensors are employed in different parts of the steel structure (Fig. 2). The data collected by the sensor nodes are transmitted to the storage and control device through four wireless communication lines.

In the long-term monitoring process, monitoring instrument failure, energy supply interruption, data transmission failure, and some other factors may lead to partial data loss, which will affect the data analysis and safety evaluation [11]. Restoring missing data is of great importance to guarantee the integrity of data and the validity of information. At present, in the field of civil engineering monitoring, there is still a lack of restoring methods for missing long-term stress and strain monitoring data, and the restoring research is mostly focused on vibration and displacement data [12–15]. The characteristics of these two kinds of data missing are not entirely consistent with the content researched in this paper. Their interpolation principles are not fully applicable. In meteorological forecast, spatio-temporal kriging, Kalman filtering and some intelligent algorithms are used to interpolate the predicted value [16–19]. These methods have wide applicability and mature application. They can be used to solve some of the problems studied in this paper. However, due to the field characteristics of stress data, these methods are no longer so suitable for interpolation in some data missing cases. In other words, they cannot deal with all the problems in this paper. In view of the characteristics of stress monitoring data loss, restoring methods for missing temperature data have a high reference [20–23].

In this paper, aiming at the data missing problem of the Hangzhou Olympic Center Stadium stress monitoring, based on the correlation between the stress changes of the measuring points, a restoring method for missing data of spatial structural stress monitoring is proposed. The paper is organized as follows. Section 2 studies the correlation between the stress changes of the measuring points. Restoring methods of missing data in the service stage and in the construction stage are expounded.



(a) Top chord **(b) Bottom chord** **(c) Support bar and ring truss**

Fig. 2. Layout of strain sensors. The green components are the ones with sensors, and the sensors are located on the surface in the middle of the components (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).