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Stress Estimation to Zhuhai Opera House Based on Monitoring Measurements

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ABSTRACT

Zhuhai Opera House is being built at Yeli Island in Zhuhai, China, which safety is significant to such public structure. Because of the wind effects, the structural health monitoring system was planned and is being implemented, in which the stresses, the temperatures, the deformations, the accelerations, the wind pressure and wind speed are planned to be monitored in construction and service phases. The stress estimation method to Zhuhai Opera House based on measurements including temperatures, wind pressures, stresses is proposed. The wind load and temperature effects are going to be estimated firstly, which are accompanied by the structural analysis using finite element model. Meanwhile, the stresses distribution of the structure can be obtained from the structural analysis using finite element model. The monitored stresses and the calculated stresses at the same placement are compared in order to evaluate the effectiveness of the calculation; the differences between them are the reasons to adjust the estimated wind load and temperature effects. And then, the stress estimation can be made by the calculated stress distribution of the structure. The steel structure of Zhuhai Opera House is taken as an example to illustrate the processes and the effectiveness of the proposed method.

KEYWORDS: *Stress estimation, Monitoring measurements, Temperature, Wind, Zhuhai Opera House*

1. INTRODUCTION

Structural health monitoring is becoming widely used in spatial structure [1, 2]. How to use the existing monitoring data to realize the structure of the stress field distribution of identification has important practical engineering significance. The structure is mainly influenced by temperature and wind load during operation. Some scholars have done research on the non-uniform distribution of temperature load [3, 4]. In this paper, based on the non-uniform environment load, the stress estimation of spatial structure using monitoring measurements is proposed.

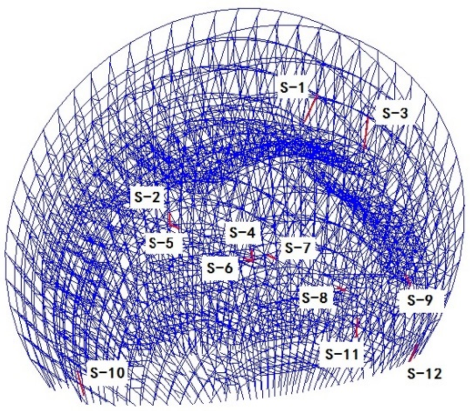
Zhuhai Opera House consists of grand theatre, little theatre and a shared lobby between two theatres, which is located at the Yeli island. The architectural effect drawing is shown in Fig. 1.1. The main structure of Zhuhai Opera House is reinforced concrete structure, and the outer shell structure is steel structure system. For the little theatre, the main body's ground and underground height are 18 m and 4.5 m, respectively, and the height of shell is 55.6 m.

Zhuhai is located in the south china coast, which is a severe typhoon affected area. It may suffer multiple typhoons every summer and autumn, where the maximum wind speed is above 40 m/s. In addition, there are no other buildings around the Zhuhai Opera House, and the unique shell shape will lead to the formation of narrow tuyere, which makes the structure wind effect be more complex. The temperature difference of Zhuhai is large as the lowest temperature is about 5℃ to 10℃, and the maximum temperature may reach 34℃ to 36℃. Therefore the influence of wind load and thermal effect on Zhuhai Opera House should be noticed.

Figure 1.1 The architectural effect drawing of Zhuhai Opera House

2. SHM SYSTEM OF THE SMALL SHELL STRUCTURE

The monitoring system of small shell structure includes the stress and temperature monitoring. The locations of stress monitoring and temperature monitoring are the same; that is to say, 12 monitoring points are selected to install the strain sensors and temperature sensors, where there are two sensors at one monitoring points. The measured points on the shell structure are shown in Fig. 2.1 and Fig. 2.2.



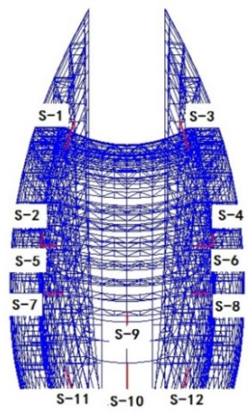


Figure 2.1 Monitoring points distribution

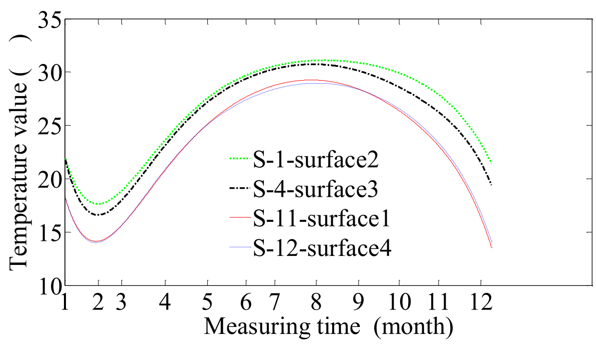
Figure 2.2 Side view of point distribution

The stress field estimation method of the small shell of Zhuhai Opera House is, (a) the thermal effect in substructural area is determined, which includes the thermal value and area partition using temperature measurements; (b) the wind load is determined using the wind tunnel test and the measurements of wind speed using local wind velocity observatory; (c) the structural finite element model which is subjected to the thermal effect and wind load is analyzed; (d) the structural stress distribution can be obtained by comparing the simulation value using finite element calculation and the monitored stress measurements.

3. REGION DIVISION AND VALUE ACQUISITION OF THERMAL ACTION

3.1. Preliminary Area Partition Using Temperature Measurements and Fitting Method

The temperature fitting curve contrast of different structure surfaces and the height direction are shown in Fig. 3.1; the temperature fitting curve contrast of vertical direction is shown in Fig. 3.2; the temperature fitting curve contrast of platform beam is shown in Fig. 3.3; the temperature fitting curve contrast of the skylight position is shown in Fig. 3.4.



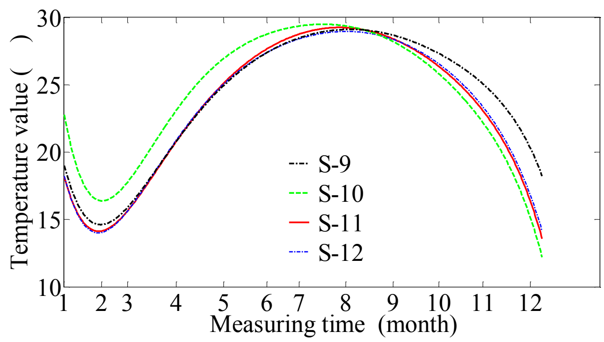


Figure 3.1 The contrast of different structure surfaces

Figure 3.2 The comparison of vertical direction

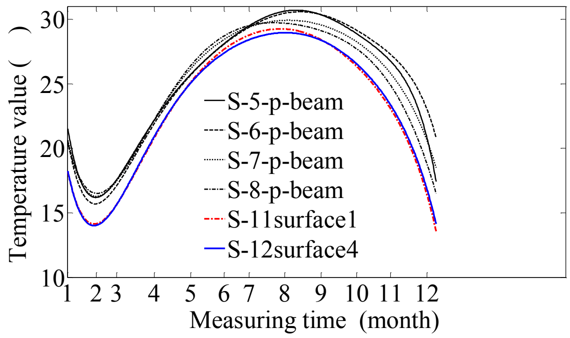


Figure 3.3 The comparison of platform beam

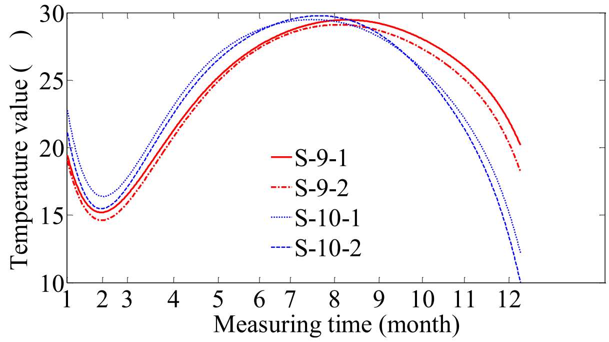


Figure 3.4 The comparison of the skylight position

It can be known by comparing the fitting curve of the temperature measurements that the same load partition of the four shell surfaces is taken. Furthermore, the concrete structure is taken as the edge of the different partition. The preliminary temperature partition is four regions which is shown in Fig. 3.5. In addition, the platform beam and the skylight are considered as two separate partitions.

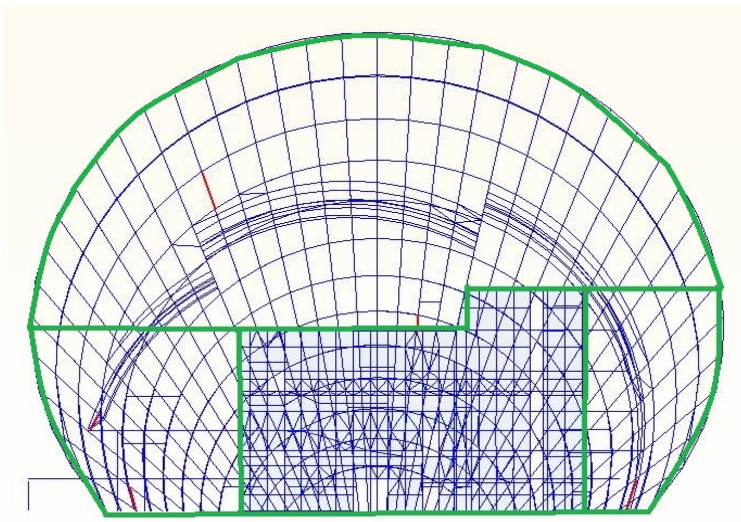


Figure 3.5 The initial partition of the small shell structure

3.2. Advanced Area Partition Using Ecotect Analysis Software

3.2.1. Shadow analysis by large theatre

The months when the sun is closest to the structure are January and July because of the location of the structure. Considering that the large theatre is on the east side of the little theatre, the shelter from large theatre may appear in the morning. By sunshine and shade analysis, the sunshine shadow of structure in January and July at 10am are shown in Fig. 3.6 and Fig. 3.7. It can be known that the moving direction of the structure sunshine shadow is far from the little theatre. In addition, the sunshine shadow area of the large theatre is only near to the bottom of the little theatre. That is to say, the shelter caused by large theatre to little theatre can be ignored.

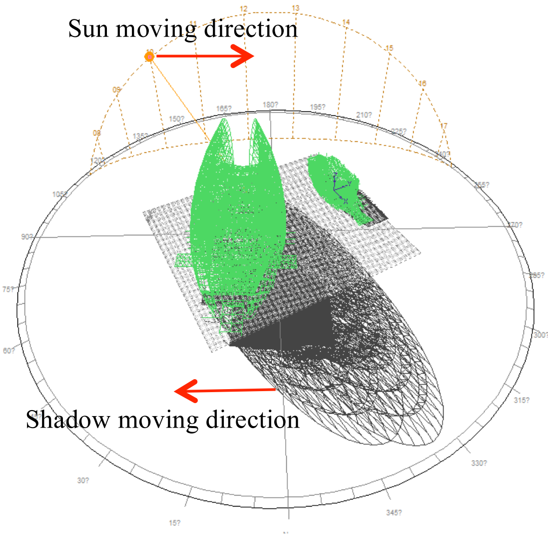


Figure 3.6 Shadow analysis in January

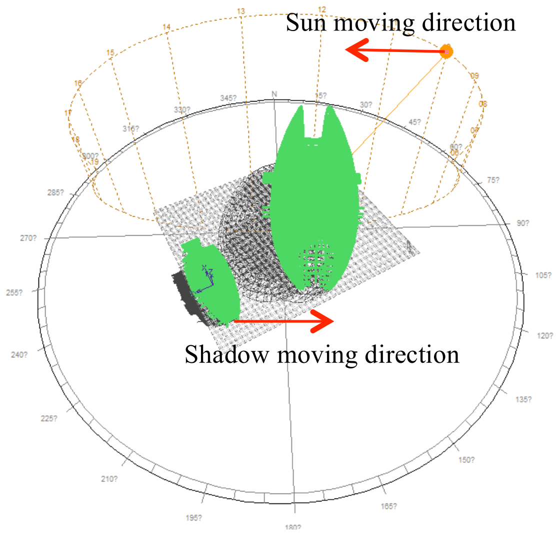


Figure 3.7 Shadow analysis in July

3.2.2. Shadow analysis by little theatre

The shadow distribution caused by the concrete structure is shown in Fig. 3.8, and the shadow distribution in the longitudinal direction is shown in Fig. 3.9. It can be seen from these two figures that the temperature partition along the vertical and longitudinal directions should be considered. In the other side, the conclusion of shadow analysis is in accordance with the preliminary partition using fitting curves of temperature measurements.

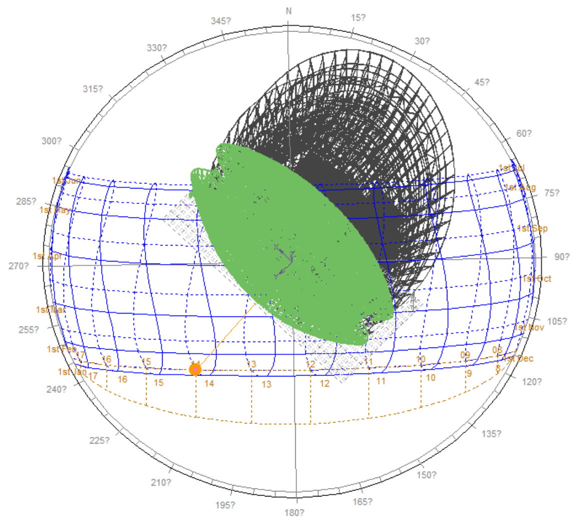


Figure 3.8 Shadow by the concrete structure

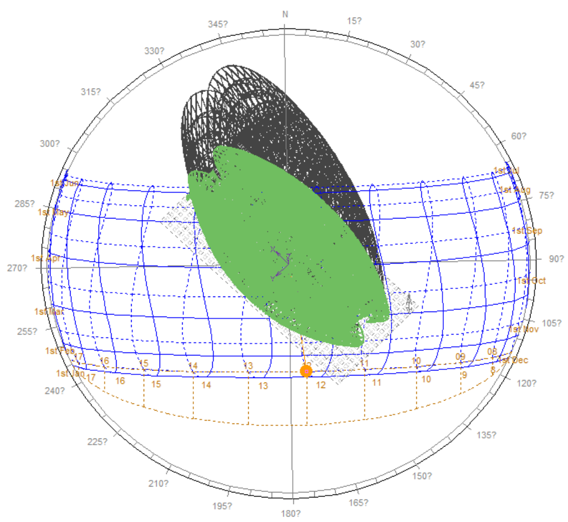


Figure 3.9 Shadow in the longitudinal direction

3.2.3. Advanced area partition based on cumulative solar radiation

Five areas are determined due to the shelter effects are mainly caused by the concrete structure and the skylight structure. The specific partition is shown in Fig. 3.10. In addition, the platform beam and the skylight are still considered as two separate partitions.

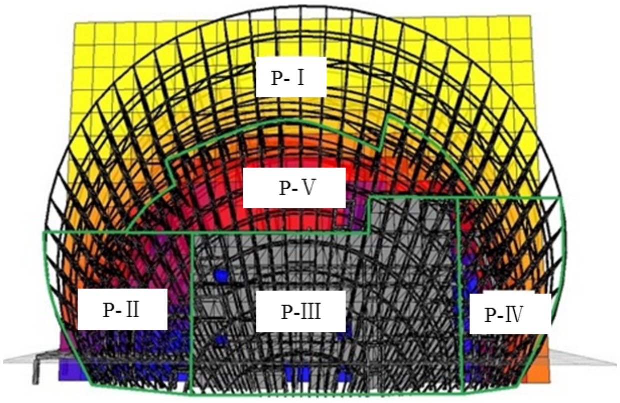


Figure 3.10 Partitions of little theatre

3.3. Value Acquisition of Thermal Action

The value of thermal action is obtained by the differences between the initial temperature in structural construction period and the temperature measured in time. The construction finishing time of the little shell structure is Dec. 24, 2013, the average of the monitored temperature is taken as the initial temperature, which is 18.95 ℃. The stress distribution analysis in the morning on June 25, 2014 is taken as an example, while the values of thermal action for different area partitions are shown in Table 3.1.

Table 3.1 Temperature value of each partitions (℃)

partitions	Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅴ	platform beam	skylight 1	skylight 2
value	28.66	27	27.675	28.55	28.725	28.01	26.85	28.4

4. REGION DIVISION AND VALUE ACQUISITION OF WIND LOAD

The little shell structure is complex in its shape, which belongs to a wind sensitive structure. The region divisions of wind load based on the wind tunnel analysis are 33. The value of wind pressure is calculated by the wind speed monitored by the local weather monitoring system in Zhuhai Yeli Island. On June 25, 2014, the wind direction is in southwest, the basic wind pressure is 0.119 kN/m^2 by considering the location of the Zhuhai Opera House. The standard values of wind load for different area partitions are shown in Table 4.1.

Table 4.1 Wind value of each partitions (kN/m^2)

partitions	load value	partitions	load value	partitions	load value	partitions	load value
1	-0.184	10	-0.243	19	-0.277	28	-0.198
2	-0.123	11	-0.235	20	-0.237	29	-0.200
3	-0.177	12	-0.226	21	-0.176	30	-0.210
4	0.195	13	-0.190	22	-0.232	31	-0.212
5	0.215	14	-0.246	23	-0.172	32	-0.191
6	0.025	15	-0.208	24	-0.116	33	-0.193
7	0.275	16	-0.303	25	-0.292		
8	0.443	17	-0.211	26	-0.221		
9	0.237	18	-0.162	27	-0.248		

5. STRESS ESTIMATION AND COMPARISON WITH STRESS MEASUREMENTS

The stress distribution of the structure can be obtained by structural finite element analysis, where the little shell is subjected to the weight, the thermal action and the wind load estimated as aforementioned. The stresses of the monitoring placements are exacted from the finite element analysis using Midas, which are compared with the stress measurements on the same date. The contrast of the calculation stress values and the stress measurements are shown in Fig. 5.1. It can be seen that the stress values are in the same level, the simulation stresses are close to the measured stresses. The stress distribution analysis method is proofed to be effective.

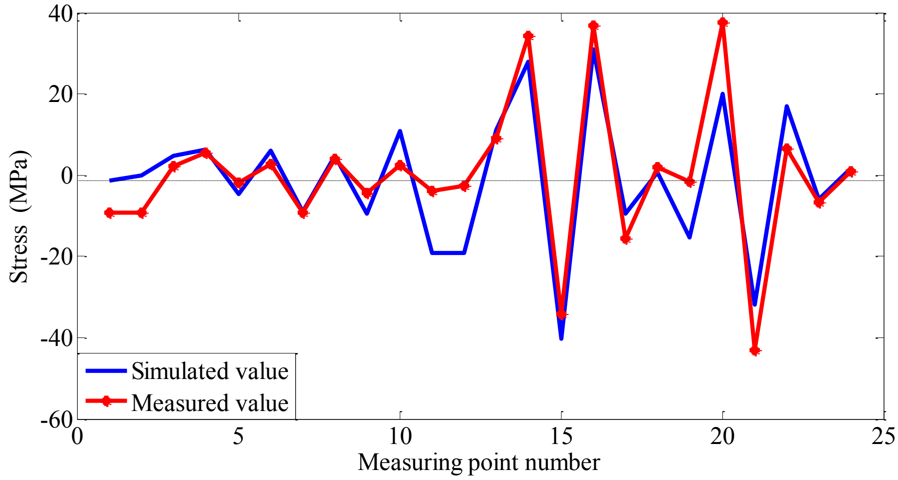


Figure 5.1 Contrast of the calculation stress values and the stress measurements

In addition, the stress distribution of the whole structure is extracted and the features of the stress distribution of different kinds of elements are concluded. The interval of stress distribution of different kinds of elements is shown in Fig. 5.2, it can be seen that the types of the elements with larger stress values are truss chord and ring element and the proportion of the elements with stress values larger than 10 MPa is 66.59%.

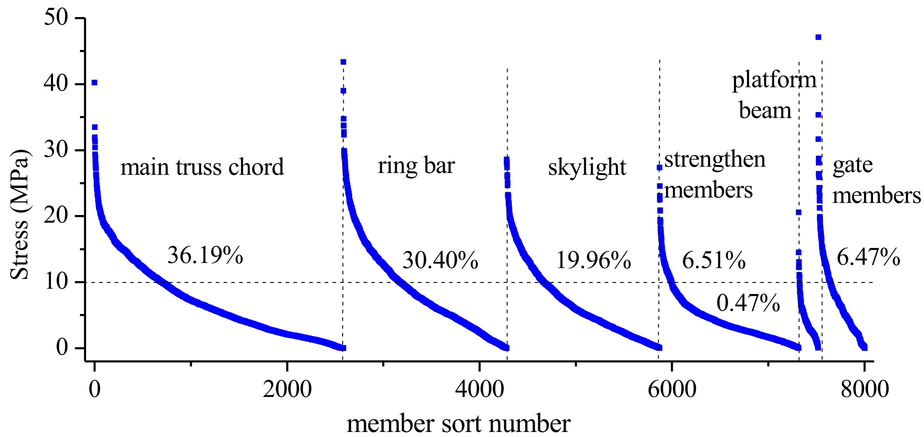


Figure 5.2 Interval of stress distribution of different kinds of elements

6. CONCLUSIONS

The structural health monitoring system of Zhuhai Opera House is being built, while the paper introduced the SHM system of small shell structure. The stress distribution estimation method based on the temperature measurements and wind speed measurements is proposed. The small shell structure is taken as an example to illustrate the process of the stress estimation, while the proposed method is proofed its effectiveness by comparing the simulated stress values with the measured stress values. Furthermore, the stress distribution of one day is taken as an example to find out the type of the element with larger stress values, while the truss chord and ring element should be paid more attention during structural monitoring.

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