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EVALUATION OF THE WIND PRESSURE BY WIND TUNNEL TEST USING THE 3D LASER SCANNING DATA IN BAYON TEMPLE, CAMBODIA

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Abstract. *The wind force the building receives strongly depends on the shape of it. To evaluate the influence of the wind pressure on the building with the complicated shape, the wind tunnel test is commonly conducted. Recently, it has been possible to make delicate models by using the 3D printer. This paper shows the trial of the wind tunnel test with the model made with the 3D laser scanning data and the 3D printer to the remains with the complicated shape. In this paper, the trial is applied to the central tower of the Bayon Temple located in the center of Angkor Thom, Cambodia. It has the risk of the partial collapse such as sudden falling rocks, and the shape of the upper part of the central tower now is rugged and complicated because of the partial collapse in the past. The method of making a model for the wind tunnel test with the 3D scanning data and the 3D printer is proposed. Then the wind tunnel test is conducted by using the model made by the proposed method, and the values of the wind pressure caused on the surface of the tower are estimated.*

1 INTRODUCTION

Some of the historical structures in the world sometimes lose its own value by the natural disasters like strong wind, earthquake, and etc. Angkor in Cambodia is one of them, and now immediate measures to prevent partial collapse of the tower are demanded.

The Bayon Temple of Angkor was built in the 11th century. It is composed by many masonry towers, and they were piled without any bonding. The central tower of it is about 40 meters height from the ground. The shape of the central tower now is asymmetry because of the partial collapses of the rocks of the tower in the past, and it has the risks of the future collapse. The one of the main causes of the collapse is the wind force.

To take measures to stabilize the piled stones of the tower from the strong wind, it is very important to evaluate the effect of the wind force accurately. It is common to use the value of the wind force gotten by the wind tunnel test when the complicated structures are designed, whereas it is difficult to do the wind tunnel test of the big and complicated historical structures like the Bayon Temple. It is mainly because making the drawings of complicated historical structures in order to make the model which is used for the wind tunnel test is very difficult. However, in case of the Bayon Temple, 3D laser scanning data have been obtained by Ikeuchi and Oishi laboratory, The University of Tokyo, in order to preserve as digital archive and make use of it to plan the restoration methods. In this study, the method to make the model for the wind tunnel tests by substituting the scanning data for the 2D drawings are proposed, and it is applied to the central tower of the Bayon Temple to make the model of it with the 3D printer. The methods like this can be very useful and generic to the structures which are difficult to draw.

Fig.1 The Bayon Temple

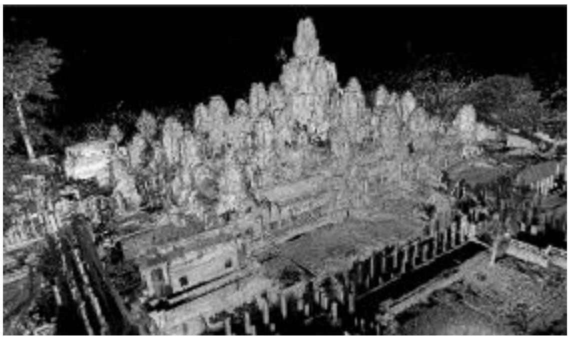


Fig.2 3D laser scanning data of the Bayon Temple (made by Ikeuchi and Oishi lab.)

2 METHOD OF MAKING THE MODEL

2.1 Procedures of the method

Fig.3 shows the data obtained from the 3D laser scanning. Although the model is generated with the 3D printer, it is impossible to output it without any processing. This is because the scanning data is composed of many triangular parts without the thickness. It is common that if something is made with the 3D printer, the 3D data of it needs the thickness. So, the process of making the model of the tower is as follows; ①changing the scanning data to the modeling data by giving it the thickness. ②making the holes in the modeling data. ③outputting the data with the 3D printer. ④attaching the copper pipes and vinyl tubes to the output model. In this procedures, ③ and ④ has become the common methods when making the model for the wind tunnel test. So, detailed descriptions about the procedure ① and ② are provided on this paper.

2.2 Algorithm to give the thickness to scanning data

To fix the copper pipes in the model, thickness of the modeling data needs to be given in equal width. Algorithm to do so is explained as follows.

First of all, the scanning data is cut horizontally at a certain height, and closed curve is obtained as shown in the Fig.4. Since the mesh of the scanning data is the shape of triangle as shown in the Fig.5, a node is obtained from the equation(1) by focusing on the intersection point of a certain triangular part and the horizontal plane cutting the scanning data.

$$\begin{Bmatrix} x_1 \\ y_1 \\ z_1 \end{Bmatrix} = \frac{z_a - z_s}{z_a - z_b} \begin{Bmatrix} x_b - x_a \\ y_b - x_a \\ z_b - z_a \end{Bmatrix} \tag{1}$$

In the equation (1), suffix shows the number of the node to get the node-1 in Fig.5, and the value of the z_s means the height of the plane cutting the scanning data. If the node-1 is obtained, the node-2 can be obtained through a similar process by focusing the next triangular parts. When all of the intersection nodes are obtained, the closed curve can be made by connecting these nodes with each other as shown in the Fig.8.

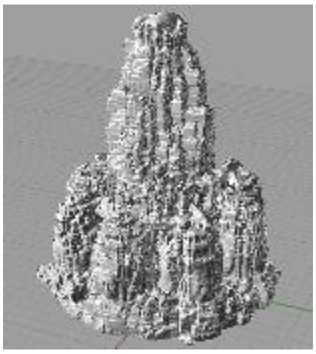


Fig.3 Measuring data of the central tower

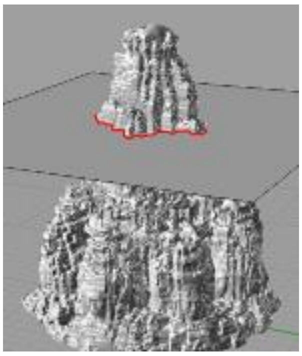


Fig.4 Model cut at a certain height

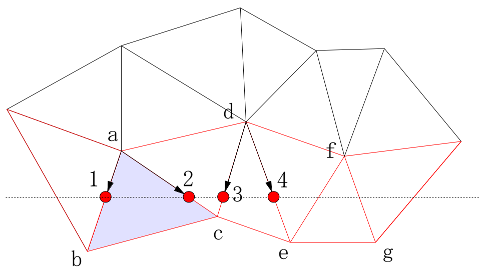


Fig.5 Nodes obtained in order to make the outer line.

Next, the aim of this stage is to obtain the inner nodes which become the standard of the thickness. So, the line which the closed curve obtained in a previous process on the inward side is composed of is duplicated and moved, as shown in the Fig.6. The distance of the moving is the thickness needed for the model. And the Fig.6 shows the inner nodes are obtained as the intersection nodes of the duplicated lines. The location of the intersection node is calculated by the equation (2) from the relation as shown in Fig.7.

$$\begin{Bmatrix} C_x \\ C_y \end{Bmatrix} = \begin{Bmatrix} A_{1x} \\ A_{1y} \end{Bmatrix} + \frac{S1}{S1+S2} \cdot \begin{Bmatrix} A_{2x} - A_{1x} \\ A_{2y} - A_{1y} \end{Bmatrix} \qquad (2)$$

In this equation, suffix as x and y means the value of x-coordinate and y- coordinate of the node. The equation (2) can be applied to the intersection of the lines, whether the angle made by the two lines is acute or not. To do this process between all combination of two adjacent lines, it is in a condition as shown in the Fig.9.

Finally, by filling the area surrounded by the closed curve and the inner nodes, it is in a condition as shown in the Fig.10.

After programming the above-mentioned process with a computer, by starting this process from the top of the central tower of the Bayon Temple to about 27 meters height from the ground at the same division width, thickness data are obtained by each height. Then, the thickness data are given the height as the same value of the division width and all of them are piled. By doing this, the model data is obtained, as shown in the Fig.11. When the model data made by the division of 2 millimeters width is compared with the scanning data, both almost matches each other though the model data has the very small roughness caused by the division. So the accuracy of this model data is adequate for the wind tunnel test.

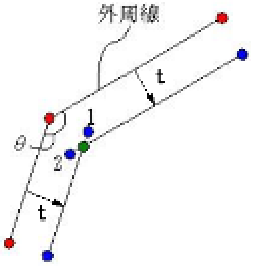


Fig.6 Inner node is obtained

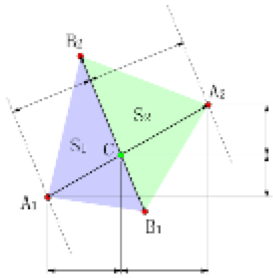


Fig.7 Intersection

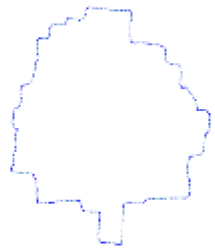


Fig.8 Closed curve(Outer line)

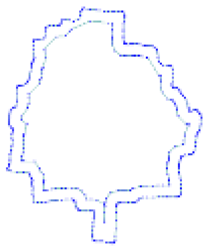


Fig.9 Outer and inner line

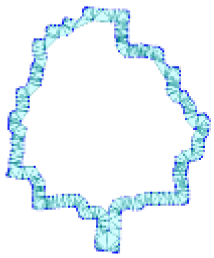


Fig.10 Filled by the mesh

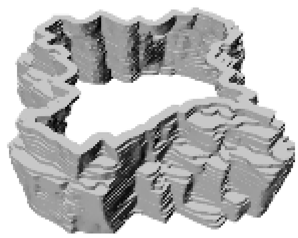


Fig.11 Piled thickness data

2.3 Making holes on the model data and the output

After the works are finished as shown in the paragraph 2.2, many holes to measure the wind pressure are made with the CAD. As shown in the Fig.12, the only parts establishing the measurement points are taken out, and holes are made when their position and angle are regulated. It is able to make the holes at the appropriate position because adjustment of the measurement point is performed in this way. After this is finished, all the parts are attached. And the model data is completed and ready to be output.

Fig.14 shows the model made by connecting the tubes through the inside of the model after the output with the 3D printer. The model of the central tower of the Bayon Temple has the 430 holes.

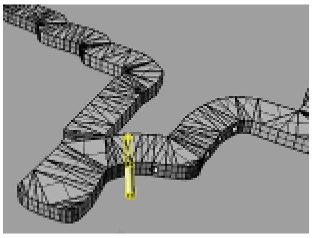


Fig.12 Making the hole

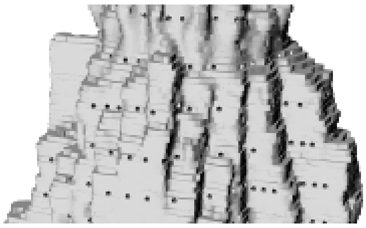


Fig.13 Model data

Fig.14 Model for the wind tunnel test

3 EVALUATION OF THE WIND FORCE TO THE UPPER PART OF THE TOWER

3.1 Condition of the test

The model made in the chapter 2 is used in this test as shown in the Fig.15. 0 degree means the case in which the wind flows to the north side of the tower of the direction, and measured 73 directions of the wind with 5 degrees pace from 0 degrees to 360 degrees. The mean wind velocity of the current of air in the test is 10m/s at the top of the tower, and the current simulates the ground category Ⅲ in the reference [2]. Scaling in the test is as follows; Geometric scale is 1/50, the scale of the wind velocity is 1/4, and the time scale is 1/12.5. 10 data are measured by every 10 minutes for real time by each direction of the wind. Sampling frequency is 800Hz, and the coefficient of the wind pressure is calculated by standardizing it by the velocity pressure of the tower top. In addition, the moving average is calculated from the result of the test by 1 second for real time based on TVL method when the peak of the wind pressure is calculated.

Fig.15 Wind tunnel test and the definitionof the wind direction

3.2 Coefficients of the wind pressure on the tower

The central tower today has the different shapes of its plan, because of the partial collapse many times in the past. Although, in the test, many measurement points were made, the coefficients of the wind pressure of the four plans shown in the Fig.16 were compared to know the generous tendency. When the coefficients of the wind pressure were compared as the direction of the wind was changed, the results shown in the Tab.1 were obtained. Tab.1 shows the comparison of the pressure from the direction of 0 and 45 degrees. (in case of G.L.+33.3m are 0 and 80 degrees) Tab.1 shows that maximum values of the coefficients of the wind pressure were similar when the direction of the wind was different. But minimum values were big.

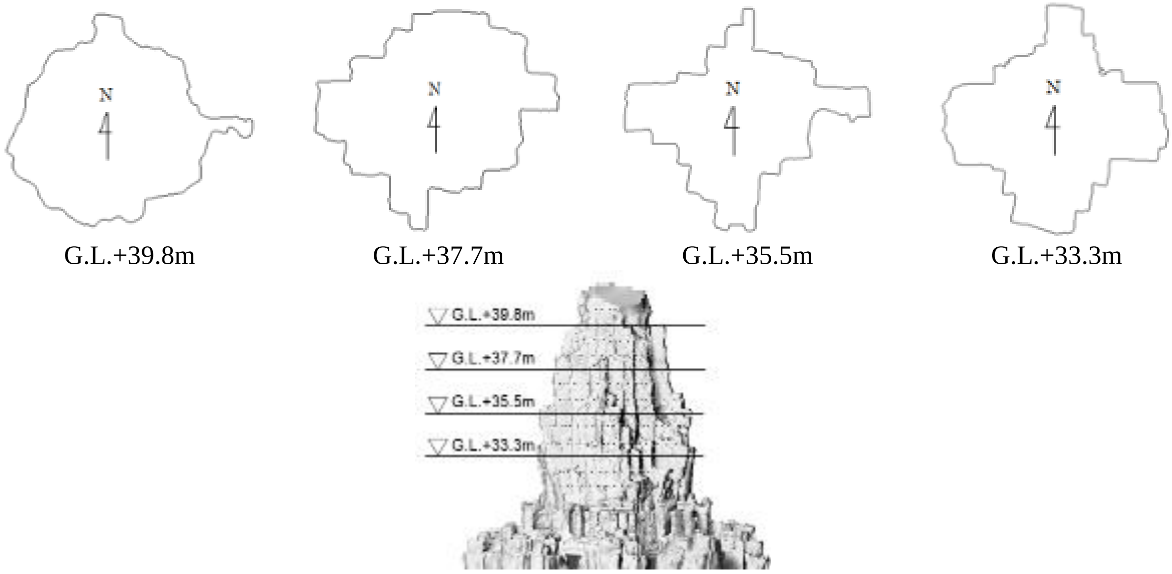
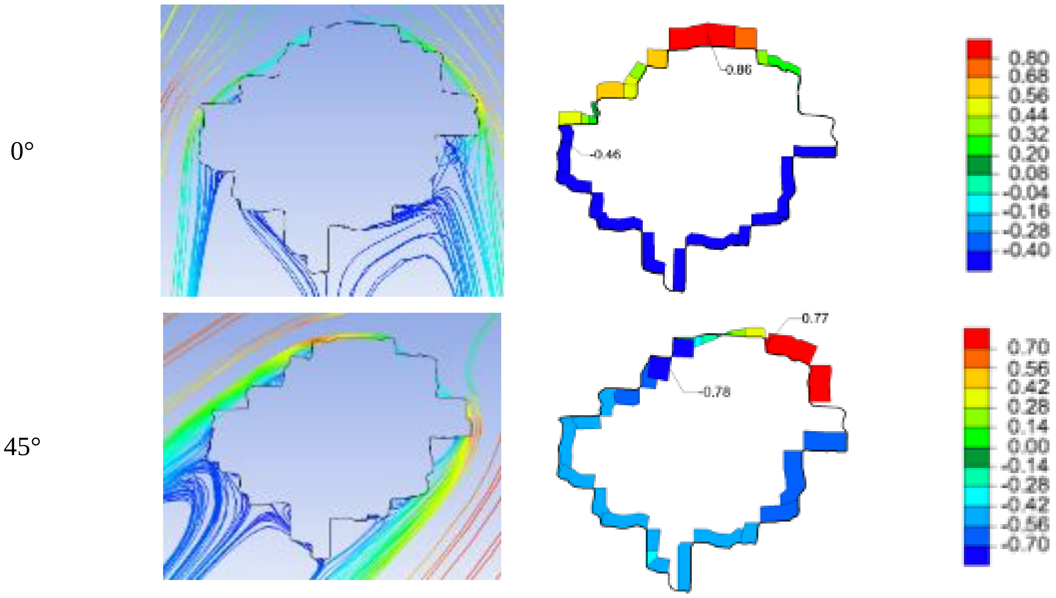


Fig.16 four plans of the Bayon Temple

Tab.1 Comparison by the wind direction

Height from the Ground	Mean Coefficient of Wind Pressure			
	Wind Direction 0°		Wind Direction45° (80° for G.L.+33.3m)	
	Maximum	Minimun	Maximum	Minimun
G.L.+39.8m	0.58	−0.52	0.73	−0.91
G.L.+37.7m	0.86	−0.46	0.77	−0.78
G.L.+35.5m	0.74	−0.55	0.83	−0.78
G.L.+33.3m	0.73	−0.83	0.75	−1.04

To know why the difference occurred in the Tab.1, figures of airflow were obtained by the analysis of the general purpose analysis soft ANSYS and eddy flow was modeled by RANS. For example, coefficients of the wind pressure at the height of 37.7m from the ground are shown in the Fig.17. When the wind flowed from the north (0 degree), the minimum of the mean coefficient of the wind pressure was -0.46 at the rough part of the west side. According to the figure of airflow, this negative pressure was caused because the current of the wind departed from the surface of the stones at the corner. However, after the current of wind departed, it flowed parallel to the surface of the tower. So the absolute value of the minimum of the negative pressure was relatively small. Whereas, when the wind flowed from the northeast (45 degrees), the minimum of the mean coefficient of the wind pressure was -0.78 at the rough part of the north side. This is because the eddy was caused at the concavity after the current of the wind departed from the salient of the tower.



Wind Direction　　Figure of the Airflow　　Mean Coefficient of the Wind Pressure

Fig.17 Comparison of the mean coefficient of the wind pressure based on the airflow

Next, the maximum and minimum of the wind pressure from the result of the test at a certain height of the tower were compared with the value calculated assuming that the shape of the plan of the tower was the circle or rectangle, based on the reference[2]. In this comparison, wind speed was 40m/s at the top of the tower based on the observation measured by the building near the Bayon Temple in the past. As shown in the Fig.18, the values of the maximum of the wind pressure by the test and the assumed calculation were almost same. Whereas, the absolute value of the minimum of the wind pressure by the test was a little smaller than that by the assumed calculation. This is because the rough shape of the tower decreased the wind pressure.

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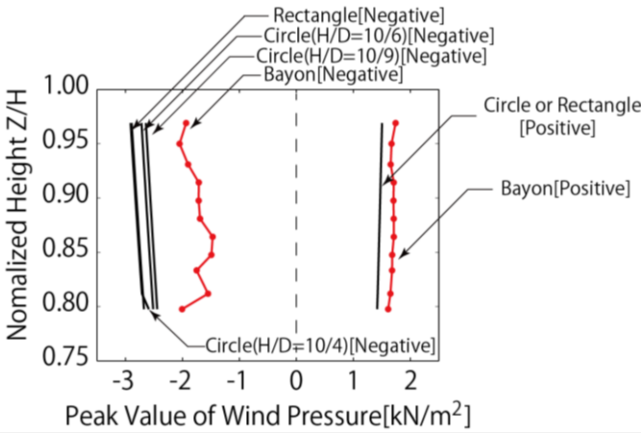

Fig.18 Comparison of the wind pressure of the central tower, the circular plan and the rectangular plan

4 CONCLUSION

Conclusions of this study are shown below.

1) The method to make a model for the wind tunnel test widely applied to the complicated structures like remains was proposed, and the test of the central tower of the Bayon Temple was done.

2) The central tower of the Bayon Temple has the different plans, and by a certain direction of the wind, the absolute value of the negative pressure is not big only at the point from which the wind departs but also the concavity in rear of it where the eddy is caused. However the value of the tower is smaller than the value of the circular or rectangular plan shown in the guidelines like reference[2].

5 REFERENCES

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[2]Architectural Institute of Japan, *AIJ Recommendations for Loads on Buildings(2004Edition).* Architectural Institute of Japan, 2004