광주월드컵 경기장 지붕면의 풍압특성에 관한 실험적 연구

An Experimental Study on Characteristics of Wind Pressure on Long-Span Roof of the Kwangju World Cup Stadium

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요　　약 : 본 연구에서는 광주월트컵 경기장을 같은 형태의 지붕이 하나인 경우와 두 개인 경우로 구분하여 풍동실험을 수행하였으며 그 실험결과에 대해서 고찰하였다. 본 실험에서는 1/400의 축소모형을 이용하였다. 지붕이 1개가 설치되는 경우와 2개가 설치되는 경우에 대한 풍압측정결과, 2개의 지붕면이 설치되면 단위면적당 풍하중이 1개의 지붕면의 경우에 비해 구조골조용 풍하중은 최대35%정도의 감소됨을 알 수 있었다. 이러한 결과는, 지붕면에 작용하는 풍하중은 높이에만 의존되어 결정되는 현행 풍하중 규준의 적용한계를 나타냄과 동시에 대형 구조물의 경우 풍동실험이 반드시 필요함을 나타내는 내는 일례라고 할 수 있다.

ABSTRACT : In this study, the wind tunnel test for Kwangju World Cup Stadium with long span roof was carried out and its results were considered in the two roofs: one is the case of one roof, and the other is the case of two roofs which are identical. In this experiment, a 1/400-scale model was used. As a result of measuring wind pressure in the case of one roof and then two, when two roofs are set up, wind load for structural frame decreases by 35%, compared to that of one roof. These results show that the current criteria for wind loadings, which specify that wind pressure on the roof depends only on the altitude, have limitations for adoption, and a wind tunnel test is essential to design.

핵 심 용 어 : 풍하중, 풍동실험, 풍압, 풍압계수, 스페이스 프레임

KEYWORDS : wind load, wind tunnel test, wind pressure, wind pressure coefficient, space frame

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1. Introduction

The Kwangju World Cup Stadium is currently under the construction after finishing its design. The Kwangju World Cup Stadium is structured with a long-span roof with a space frame design, of which the major axis is about 150m in the north-south direction, set up on the west and east side (Fig. 1). The long span roof with the space frame structure is relatively weak under wind load, and it is known that the structure can have a problem of dynamic behavior. In order to predict the exact dynamic and static behavior caused by the wind load, it is required to measure wind pressure effects on the long span roof: The best method for this is a wind tunnel test. In the original specifications, it was plann- ed to set up only one roof on the west side, but consequently it was decided to build another roof on the east side. The wind tunnel test was carried out and its results were considered in the two roofs: one is the case of one roof, and the other is the case of two roofs under the consideration that the roofs are identical. In the view of external form, it means that the area covering the roof is changed. Also, under this situation, the change of wind load was considered.

2. Wind Tunnel Test

2.1 Scale Model for Experiments

In this experiment, a 1/400-scale model was used, which was made of acryl and built using CNC(Computer-aided Numerical Control) to raise its elaborateness. The holes of wind pressure were installed at regular intervals on the surface of the model. Those were made of aluminum pipe whose inside diameter is 0.9mm. Each pipe is related to polyvinyl chloride tubes, which are gathered to the lower part of the model and then connected to a multi-point pressure anemometer which is in the lower part of a turn table. The holes of external pressure and internal pressure were built

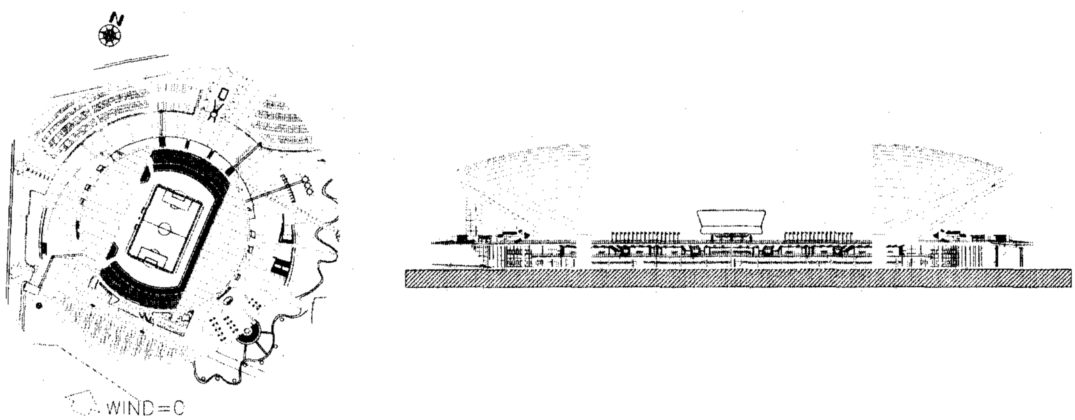
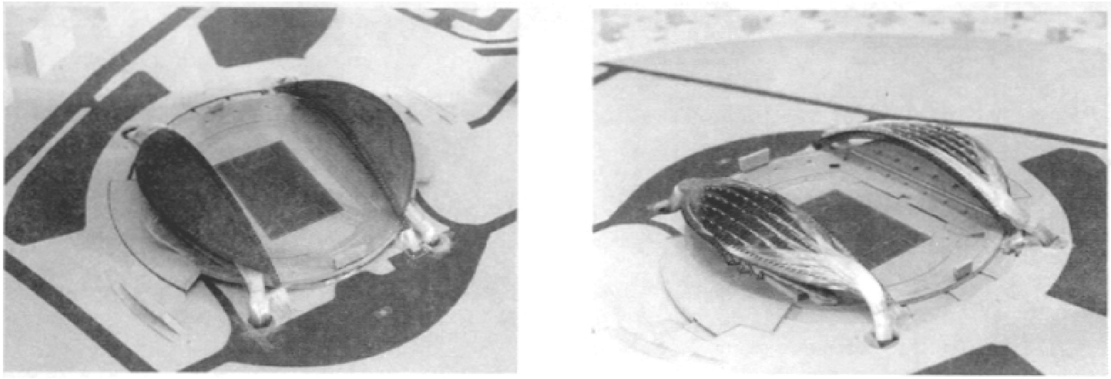


Fig. 1 Kwangju World Cup stadium



(a) model for external wind pressure measurement

(b) model for internal wind pressure measurement

Fig. 2 Model for wind pressure measurement

respectively, and a total of 412 holes of external pressure were installed: 188 on the west-side roof surface, 188 on the east-side roof surface, 12 on a main electric sign, 12 on a auxiliary electric sign, and 12 on a control center. A total of 376 holes of internal pressure were installed: 188 on the west-side roof surface and 188 on the east-side. Fig. 2 illustrates the scale model for experiments.

2.2 Wind Velocity for Design and Air Current of Wind Tunnel

As a result of considering roughness specification B of the current construction criteria and revising the tunnel altitude to the height of the roof surface (58m), a wind velocity of 37.3 m/s was produced. Therefore, the design wind velocity pressure is 87.0 kgf/m^2. Fig. 3 illustrates the distribution of wind velocity and turbulence intensity inside the wind tunnel. The altitude revision index took aim at $\alpha = 0.22$ by

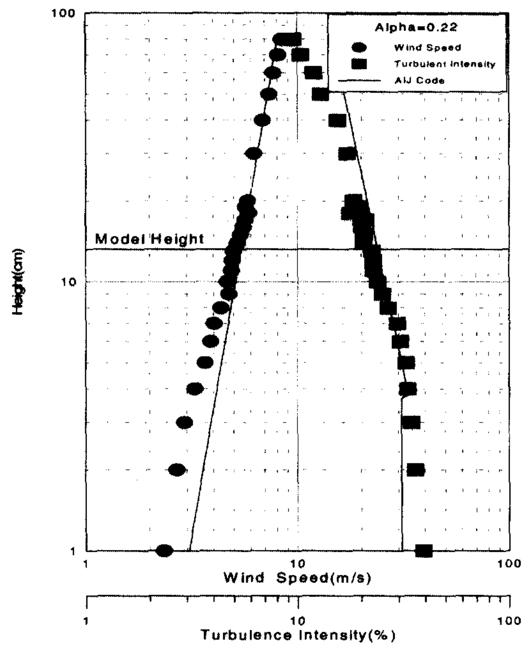


Fig. 3 Distribution of wind velocity and turbulence intensity

the ground configuration B, and the standards of the Japanese Architecture Society were adopted since there are no domestic standards. Fig. 4 illustrates the wind velocity spectrum of wind dynamic convection.

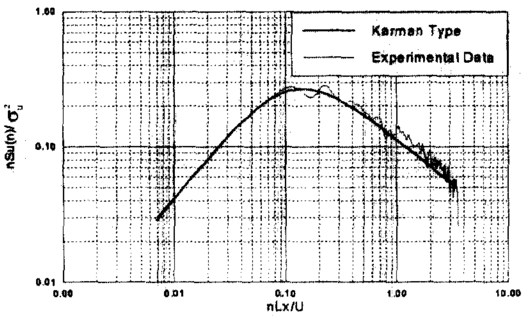


Fig. 4 Spectrum for variation wind velocity

2.3 Measurment Items

There are three measurement items of these experiments.

- Average wind pressure and its coefficient ($C_{P_{Mean}}$)
- Maximum wind pressure and its coefficient ($C_{P_{Max}}$)
- Minimum wind pressure and its coefficient ($C_{P_{Min}}$)

2.4 Measurement Conditions

The wind velocity(U_H), the upper side velocity of the model's roof inside the wind tunnel, is about 5.85 m/s. The experiment of wind pressure was carried as the direction of wind was changed at regular intervals of 10°. The measurement conditions were as follows:

- model scale: 1/400
- wind velocity scale: 1/6.4
  (design wind velocity: 37.3 m/s,
  wind velocity of tunnel:5.85 m/s)
- time scale: 1/62.5
  (measurement time: 10 s,
  real time: 625 s)
- sampling frequency: 200 Hz
  (time period: 0.3 s)
- total number of data: 200 Hz×10s. =2000/ch
- average shifting time of every
  3 data: average 0.015 s.
  (real time: average 0.9 s)
- measurement number: 3 times

3. Result of Wind Tunnel Test

3.1 Wind Pressure Coefficient in the Case of the Model with One Roof

Fig. 5 and Fig. 6 illustrate the wind pressure

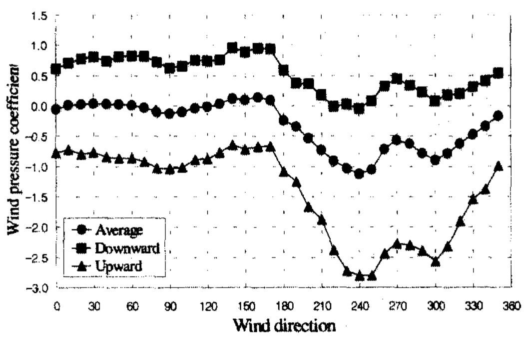


Fig. 5 wind pressure coefficient for structural frame

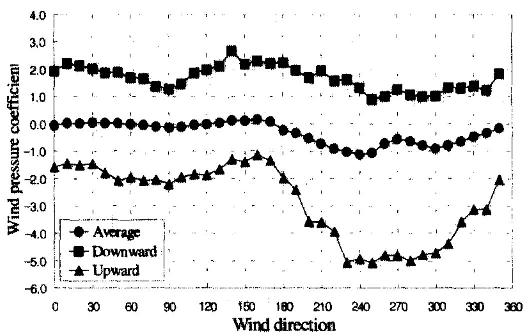


Fig. 6 wind pressure coefficient for exterior materials

Table 1. Wind pressure coefficients of one roof (in the west side)

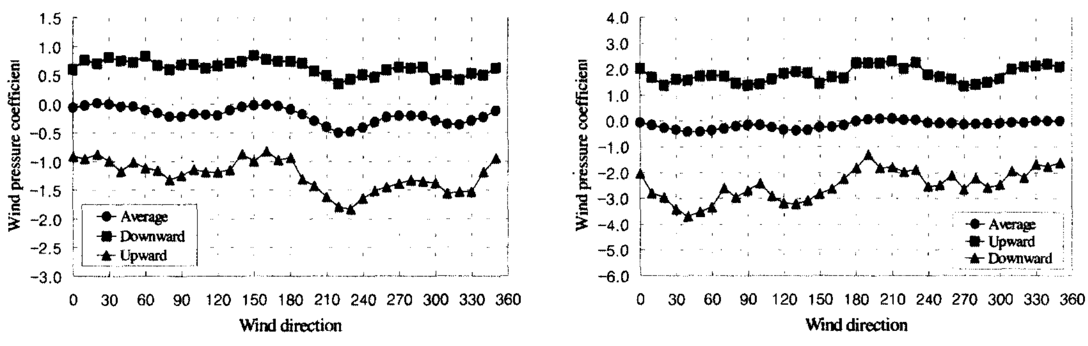
content	working direction	wind direction	external coeff.	internal coeff.	summation of coefficients
structural frame	downward	140°	0.31	0.66	0.97
	upward	250°	-1.82	-0.98	-2.80
exterior materials	downward	140° (159 pt)	1.28	1.39	2.67
	upward	250° (134 pt)	-3.78	-1.30	-5.08

coefficients for structural frame design and exterior design of each direction of wind. The coefficient for structure design was the average value of each maximum and minimum coefficients, and that for exterior design is the maximum value among them. Also, the summation of the wind pressure coefficient is defined to add the external wind pressure coefficients to the internal in the same direction. Table 1 summarizes maximum values for design.

As the figures illustrate, while the coefficients for structure and exterior design showed few changes in the range of 0 to 170°, they change sharply when in the range of over 180 degrees. The wind direction was defined from zero degrees of south wind moving clockwise. therefore, The change rate of the pressure coefficient of the wind blowing inside the roof is higher than against the roof surface. Especially, it is known that the wind pressure of "upward direction(of lifting the roof surface)" increases sharply[4,5].

3.2 Wind Pressure Coefficients of the Model With Two Roofs

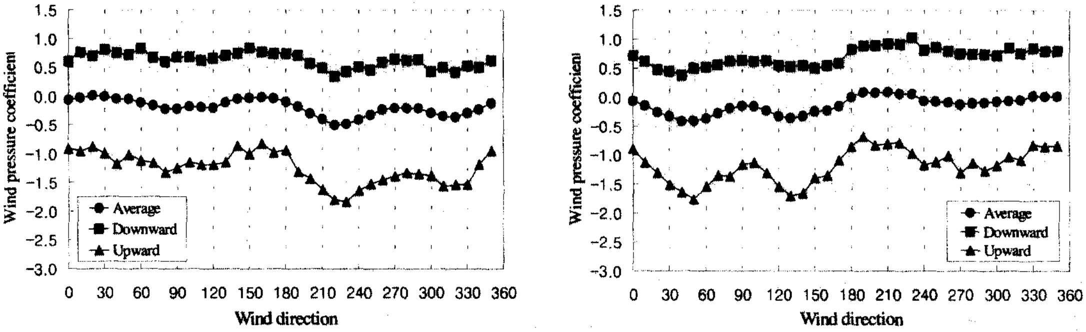
Fig. 7 and Fig. 8 illustrate the results of the experiment, which are summarized in Table 2. When the same roofs are set up on the west and east side, the change of wind pressure in the range of 180 to 360° (in case of the east roof 0 to 170°) was alleviated compared to the case of one roof. It is estimated that the wind blowing inside the roof is subsided by the roof on the other side.



(a) roof of the west side

(b) roof of the east side

Fig. 7. Wind pressure coefficient for structural frame



(a) roof of the west side (b) roof of the east side

Fig. 8 Wind pressure coefficient for exterior materials

Table 2. Wind pressure coefficients of two roofs

roof	content	working direction	wind direction	external coeff.	internal coeff.	summation of coefficients
roof of the west side	structural frame	downward	150°	0.37	0.48	0.85
		upward	230°	-1.22	-0.61	-1.83
	exterior materials	downward	150° (157 pt)	1.12	1.11	2.23
		upward	230° (64 pt)	-3.00	-0.77	-3.77
roof of the east side	structural frame	downward	230°	0.33	0.71	1.04
		upward	50°	-1.10	-0.65	-1.75
	exterior materials	downward	210° (218 pt)	1.19	1.12	2.31
		upward	40° (264 pt)	-2.91	-0.79	-3.70

4. Consideration

4.1 Wind Pressure In Accordance with Roof Area

Fig. 9 and Fig. 10 illustrate the change of wind pressure(of the west roof) in accordance with the roof area by comparing Fig. 5 to Fig. 7 and Fig. 6 to Fig. 8. As the figures illustrate, upward wind pressure as well as downward wind pressure decreased as the area covering the roofs increased. As mentioned earlier, in the case of an extensive roof area, upper wind pressure against the adverse wind decreased sharply because the roof alleviates the wind blowing into it.

4.2 Wind Load in Accordance with Roof Area

The wind load naturally decreases as wind pressure coefficients decrease. In the case of the Kwangju World Cup Stadium, it was considered how much wind load can be dropped off. To compute wind load, the following equation was used, and Table 1 and 2 were referred to for wind pressure.

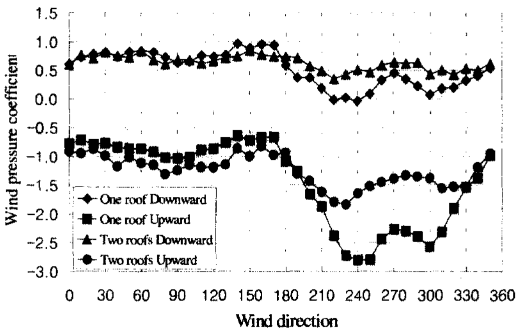


Fig. 9 Wind pressure for structural frame

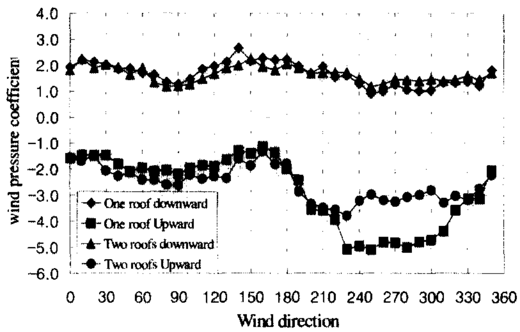


Fig. 10 Wind pressure for exterior materials

Table 3. Design wind load in accordance with roof area (in case of west roof)

content	structural frame		exterior material	
	downward winds load	upward winds load	downward winds load	upward winds load
one roof	65.2 kgf/m^2	-188.2 kgf/m^2	179.4 kgf/m^2	-341.4 kgf/m^2
two roofs	57.1 kgf/m^2 (-12%)	-123.0 kgf/m^2 (-35%)	149.9 kgf/m^2 (-16%)	-253.3 kgf/m^2 (-26%)

$$W_C = q_H \times (C_{pemax} + C_{\pi\,max}) \times A$$

where, q_H(wind velocity pressure for design) $= 1/2 \cdot \rho \cdot U_d^2 = 87.0 kgf/m^2$, A : roof area($m^2$)

C_{pemax}, $C_{\pi\,max}$: max./min. value of external/internal wind pressure coefficient

5. Conclusion

The above is the summary of the results of a wind tunnel test for wind pressure on the long-span roof of the Kwangju World Cup Stadium. As a result of measuring wind pressure in the case of one roof and then two, when two long-span roofs are set up, wind load for structural frame decreases by 35%, compared to that of one roof. Therefore, as the area covering the roof is extensive, air current streaming inside the roof decreases, that is the wind load per unit of area decreases, although the same roofs are set up on the same altitude. These results show that the current criteria for wind loadings, which specify that wind pressure on the roof depends only on the altitude, have limitations for adoption, and a wind tunnel test is essential to design.

References

1. Hyundai Institute of Construction Technology, A study on Result of the Wind Dynamic Experiment in the World Cup Stadium, Hyundai Engineering & Construction., 1999
2. Emil Simiu, Robert H. Scanlan (Contributor), Wind Effects on structures : Fundamentals and Applications to Design, John Wiley & Sons, 1996
3. Arnold M. Kuethe, Chuen-Yen Chow,

Foundations of Aerodynamics : Bases of Aerodynamic Design, 5th Edition, John Wiley & Sons, 1997
4. Claes Dyrbye, Svend Ole Hansen, S. H. Hansen (Contributor), Wind Loads on Structures, John Wiley & Sons, 1997
5. Henry Liu, Wind Engineering : A Handbook for Structural Engineers, Prentice Hall, 1991

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