Wind Engineering Joint Usage/Research Center
FY2020 Research Result Report

Research Field: Wind Hazard Mitigation
Research Year: FY2020
Research Number: 20203001
Research Theme: Aerodynamic Characteristic of Elliptical Retractable Dome Roofs

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Budget [FY2020]: 350000Yen

1. Research Aim

The dome roof used on the large space is long span and lightweight to have relatively low rigidity and natural frequency, and the exterior material composing the roof is also used with film or thin metal plate to have great dynamic impact from wind. Cheon & Yoon (2017) investigated on the cases of damage according to the various dome roof types, and as a result, it was verified as in <Fig. 1> that open or retractable type dome roof were occurred with frequent damage from wind load. There were various study cases on the closed dome roof, but the study on open dome roof or retractable dome roof actually occurred with damage frequency is very limited globally.

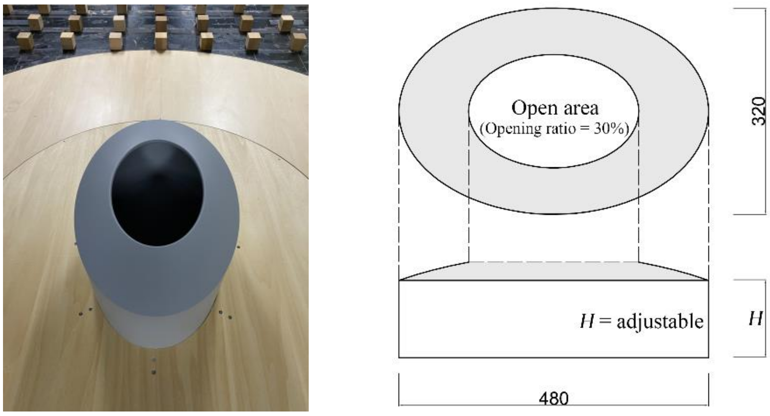
	Building Name	Cause	
		Snow	Wind
Closed or Opened roofs	Hartford Civic Centre	●	
	Kumagaya Dome	●	
	BC Place	●	
	Metro Dome	●	
	Seoul Gymnastics Stadium	●	
	Cowboy`s Practice Arena		●
	Jeju Soccer Field		●
	Inceon Munhak Stadium		●
	Louisiana Super Dome		●
Retractable roofs	Roof of skating rink		●
	Roof of stadium		●
	Montreal Olympic Stadium, 1988		●
	Montreal Olympic Stadium, 1991		●
	Montreal Olympic Stadium, 1998	●	
	Montreal Olympic Stadium, 1999	●	

<Fig. 1> Example of damage to the dome roof due to wind load

As a result of investigating the case on the retractable dome roof that was actually constructed, it was mostly constructed in the circular or elliptical form. There is a case of study conducted by Kim et al. (2019) regarding the circular-type retractable dome roof, but there were no study cases on the elliptical type. Therefore, wind tunnel test will be performed about the elliptical type retractable dome roof.

2. Research Method

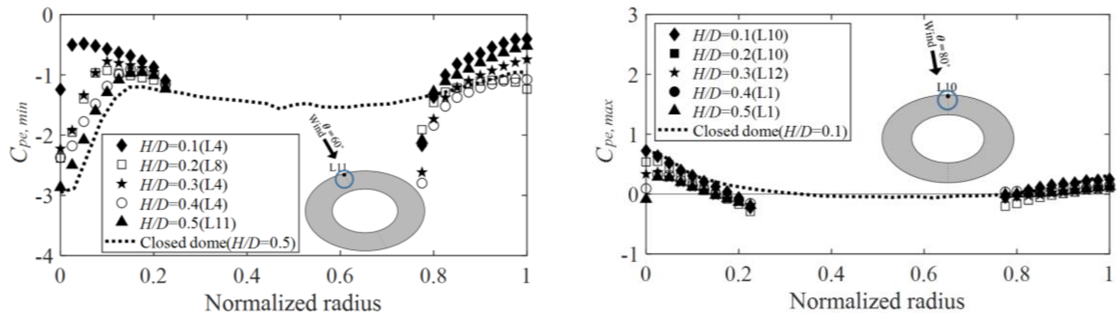
In this study, the model of central open method will be used to perform the test. The opening ratio of the roof is defined by area of roof, and as shown in <Fig. 2>, the test was performed in opening ratio of 30%. The conditions of the experiment are set as follows. Referring to the existing studies, the geometric scale is set to 1/150 and velocity and time scales are set to 1/3 and 1/50, respectively. For the flow in the wind tunnel, ground surface roughness ($\alpha = 0.21$) are reproduced by referring to the wind load criteria (AIJ-RLB, 2015).



<Fig. 2> Model

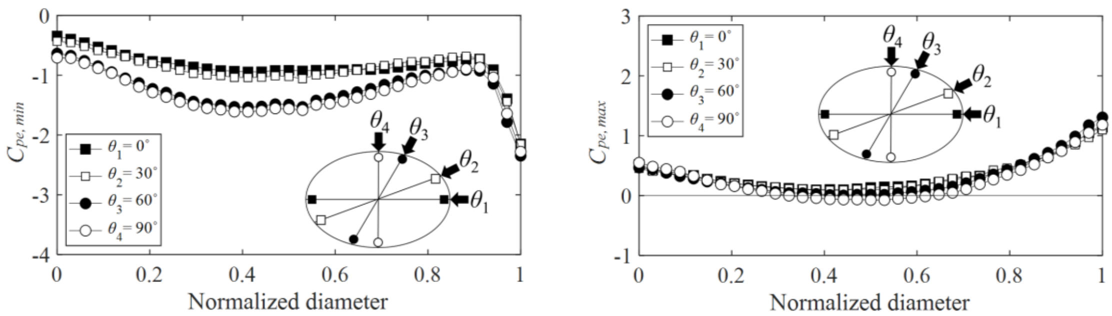
3. Research Result

Fig. 3 is the wind pressure coefficients of the central open dome. x axis is normalized diameter based on the distance of pressure tap installed at the roof and diameter D. Normalized diameter 0 is the roof edge of the windward region and 1 is the roof edge of the leeward region. y axis is each wind pressure coefficient. <Fig. 3(a)> is negative peak pressure coefficient ($C_{pe,min}$). Absolute value is large due to the influence of separation in the range of about 0 to 0.2 of normalized diameter, showing a trend of variation very similar to the closed dome indicated by the dotted line. However, around 0.8 normalized diameter, the value of $C_{pe,min}$ tends to increase rapidly again like the windward region due to separation. This is considered to be related to the boundary layer formed on the dome surface. From around 0.82 in normalized diameter, the variation of $C_{pe,min}$ is similar to that of the closed dome roof. <Fig. 3(b)> is positive peak pressure coefficient ($C_{pe,max}$). Absolute value is large due to the influence of separation in the range of about 0 to 0.2 of normalized diameter, and the decrease in $C_{pe,max}$ is greater compared to the closed dome indicated by the dotted line. Afterwards, $C_{pe,max}$ slightly increases due to pressure recovery from around 0.8 of the normalized diameter. The trend of variation was similar for $C_{pe,max}$ except for the opening in the range of about 0.2 to 0.8 of normalized diameter.



(a) $C_{pe,min}$ (b) $C_{pe,max}$

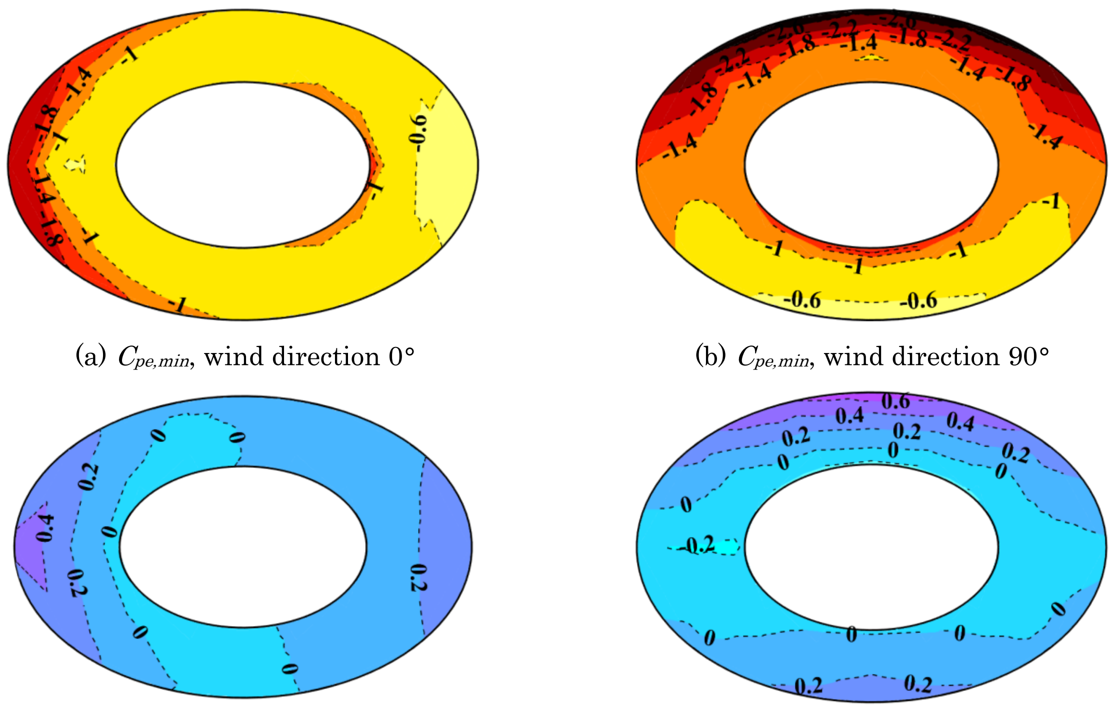
Fig. 3 Peak pressure coefficients of central open dome



(b) $C_{pe,min}$ (b) $C_{pe,min}$

Fig. 4 Wind pressure coefficients according to wind direction

In the case of an elliptical dome roof, the peak pressure varies according to the wind direction because the dome lengths in the longitudinal and transverse axis directions are different. <Fig. 4> depicts a graph showing the absolute value of the streamwise line for each wind direction with the corresponding peak pressure coefficients. The x-axis represents the normalized diameter and the y-axis represents the negative and positive peak pressure coefficients. In this case, the normalized diameter 0 represents the leeward side of the dome, 0.5 the centre of the dome, and 1 the windward side of the dome. Additionally, θ_1 represents L1 and L7 when the wind direction is 0°, θ_2 represents L12 and L6 when the wind direction is 30°, θ_3 represents L11 and L5 when the wind direction is 60°, and θ_4 represents L10 and L4 when the wind direction is 90°. <Fig. 4> (a) shows the peak pressure coefficients according to wind direction for the negative peak pressure coefficient on the roof surface, $C_{pe,min}$, under wind directions θ_1–θ_4. On the windward side, the difference in absolute value for each wind direction was small because the location of the separation on the roof wall was the same, but in the center of the dome and on the leeward side, θ_4 showed a larger absolute value than θ_1. That is, the absolute value of the wind pressure coefficients tended to increase as the wind direction angle increased to 90°. <Fig. 4> (b) shows the value of the positive peak pressure coefficient on the roof surface, $C_{pe,max}$, under wind directions θ_1–θ_4. The absolute value of θ_1 was larger than that of θ_4 in the center of the dome and on the leeward side, but this difference was insignificant. Similar to the case of $C_{pe,min}$, the absolute value exhibited a decreasing tendency with an increase in the wind direction angle to 90°. This can be seen in the wind pressure distribution of $C_{pe,min}$ and $C_{pe,max}$ according to wind direction in <Fig. 5>.

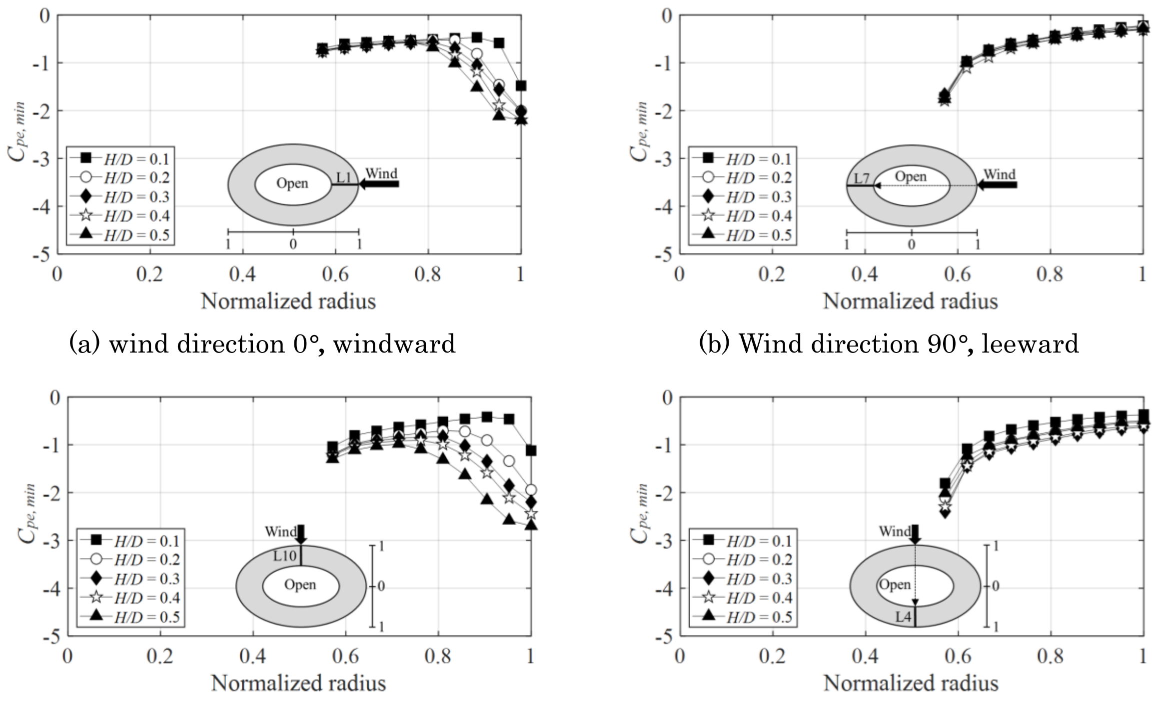


(a) $C_{pe,min}$, wind direction 0°　　(b) $C_{pe,min}$, wind direction 90°

(c) $C_{pe,max}$, wind direction 0°　　(d) $C_{pe,max}$, wind direction 90°

Fig. 5 distribution of $C_{pe,min}$ according to wind direction

Based on the results of analysis, $C_{pe,min}$ and $C_{pe,max}$ on the windward side and leeward side were analyzed at two wind directions of 0° and 90° <Fig. 6>.They were analyzed in five types of *H*/*D*.

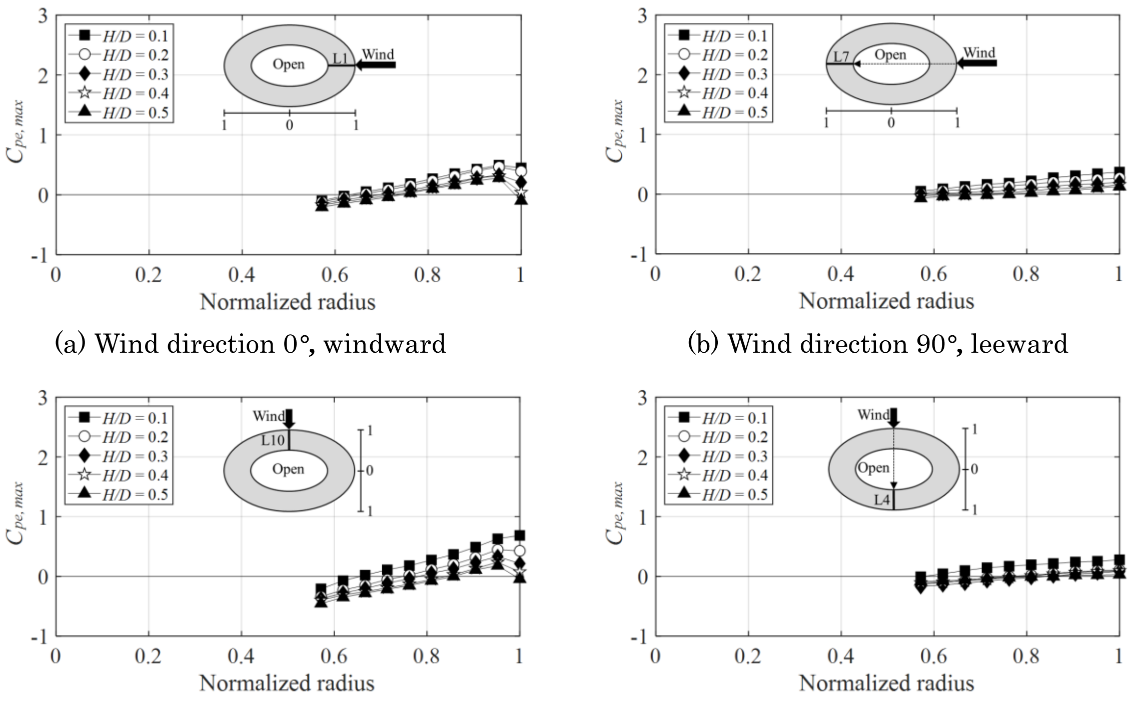


(a) wind direction 0°, windward　　(b) Wind direction 90°, leeward

(c) Wind direction 90°, windward　　(d) Wind direction 90°, leeward

Fig. 6 $C_{pe,min}$ according to wind direction

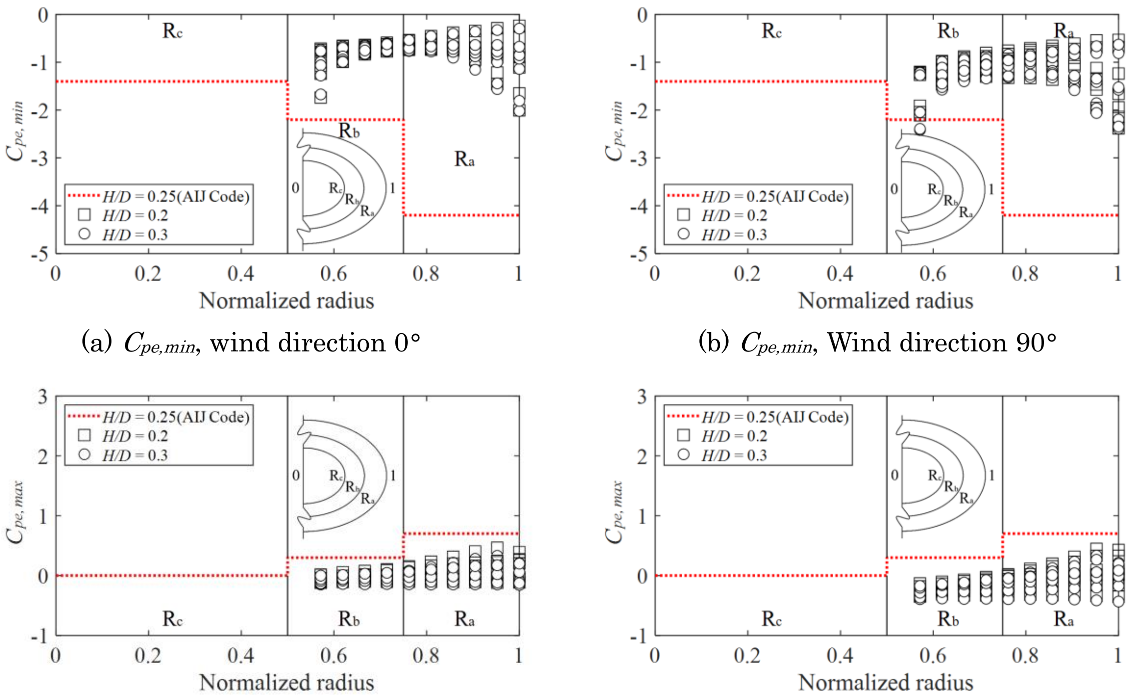
As H/D increases, the reattachment distance also increases, thereby increasing the absolute value. This is related to the turbulence intensity. At a low level of turbulence intensity, separation easily occurs and the space where the vortex is formed due to separation increases, resulting in an increased influence of negative pressure. After reattachment, the absolute value gradually decreases due to the influence of the boundary layer formed on the dome surface. <Fig. 6(a)> shows the variation of $C_{pe,min}$ on the windward side at 0° wind direction, and (c) shows that at 90° wind direction. The value is larger at 90° wind direction as in (c) since the length of the dome is shortened and is influenced differently by separation, reattachment and boundary layer. On the leeward side in <Fig. 6(b), (d)>, $C_{pe,min}$ is larger at 90° wind direction in (d).



(a) Wind direction 0°, windward
(b) Wind direction 90°, leeward
(c) Wind direction 90°, windward
(d) Wind direction 90°, leeward

Fig. 7 $C_{pe,max}$ according to wind direction

<Fig. 7> shows the variation of $C_{pe,max}$. The smaller the H/D, the larger the absolute value and the wider the area influenced by the negative pressure. Due to the low turbulence intensity, the area influenced by separation is shortened and the area directly influenced by the flow becomes wider. However, as the negative pressure is dominant due to the low f/D, the magnitude and change of the absolute value are small compared to the maximum negative pressure coefficient. <Fig. 7(a)> shows the variation of $C_{pe,max}$ on the windward side at 0° wind direction, and (c) shows that at 90° wind direction. The value is larger at 90° wind direction as in (c) since the area directly affected by the flow becomes wider. On the leeward side of <Fig. 7(b), (d)>, the absolute value is rather small compared to that on the windward side as the flow does not directly act due to the separation of the deviated flow and the shape of the roof.



(a) $C_{pe,min}$, wind direction 0° (b) $C_{pe,min}$, Wind direction 90°

(c) $C_{pe,max}$, Wind direction 90° (d) $C_{pe,max}$, Wind direction 90°

Fig. 8 Comparison with AIJ-RLB(2015)

<Fig. 8> shows the graphs of the analysis results in comparison with the Japanese wind load standard AIJ-RLB (2015). $C_{pe,min}$ exceeded the R_b area at 90° in <Fig. 8(b)>. $C_{pe,max}$ did not exceed the standard in all areas and at all wind directions in <Fig. 8(c), (d)>.

In a future study, the peak pressure coefficients for cladding design suitable for an elliptical central open dome roof will be proposed.

4. Published Paper etc.

[Underline the representative researcher and collaborate researchers]

[Published papers]

1. None

[Presentations at academic societies]

1. None

5. Research Group

1. Representative Researcher

Sungwon Yoon

2. Collaborate Researchers

Yongchul Kim

Jongho Lee

Dongjin Cheon

Sangwoo Park

6. Abstract (half page)

Research Theme: Aerodynamic Characteristic of Elliptical Retractable Dome Roofs
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The characteristic of wind pressure for elliptical central open dome roof is surveyed in this research. As a result of analyzing the pressure coefficient, the windward and leeward regions showed the same changes as the closed dome roof, but it was confirmed that separation occurred again in the center of dome region. In addition, as a result of comparison with the current wind load code (AIJ-RLB (2015)), it was confirmed that the experimental value in the center of the dome exceeds the code value because of separation. These results can be useful for the development of wind load code related with the cladding design of retractable dome roofs.