RESEARCH PROJECT ON PROPRIETY AND RELIABILITY OF DESIGNING WIND LOAD AND WIND PRESSURE COEFFICIENTS

Comparison of gust effect factors and wind pressure coefficients between several codes and standards

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ABSTRACT

This paper describes the outline of the research projects carried out in a committee since 1998, which is composed of Japanese academic people and researchers in charge of wind tunnel experiments. The main work is a comparison of products of gust effect factors and wind pressure coefficients between current codes and standards used in several nations. In this study, these products were adjusted based on consistent concept for the comparison, since each provision does not always use the same averaging time of basic wind velocity and reference height. This paper shows the results about gable roof and vaulted roof as examples and points out the difference of the design concepts.

***Key Words**: Reliability, Wind pressure coefficient, Gust effect factor*

1. Introduction

Wind pressure coefficients and gust effect factors are essential for evaluation of wind loads on whole buildings and their claddings. Structural designers usually get those data by carrying out wind tunnel experiments, or otherwise by referring standards or guidebooks. Therefore, the wind tunnel experiments should be carried out carefully and the data listed in those sources should be reliable. And information of the reliability or statistical data such as mean and variable pressure coefficients should be needed for the reliability analysis. However, very few information of the reliability has been offered so far. While structural design is now oriented toward the performance-based design, it is necessary to make clear how wind pressure coefficients are reliable, which discussion of the wind resistant performance is based on.

From 1998, Building Research Institute (BRI) has launched the research project for evaluation of wind pressure coefficients' reliability, where the main purposes are as below:

- Survey on the reliability of wind pressure coefficients regulated in current codes and standards used in several nations
- Survey on the reliability of experimental data derived from wind tunnel experiments

Based on the former purpose, last year we organized a committee in the Building Center of Japan (chairperson: Prof. Takeshi OHKUMA, Kanagawa Univ.). The committee is composed of the academic people and researchers in charge of wind tunnel experiments in research institutes of the private sectors. The names of the working members are listed in the section 4.

As the initial activity, we carried out the comparison of wind pressure coefficients and gust effect factors between various codes and standards. Holmes[1] did the similar survey and highlighted the large difference between them. We would like to make clear the reason why

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such large difference exists. This survey has just initiated and now is ongoing. This paper describes the procedure of the comparison and preliminary report of the results.

2. Comparison of Products of Gust Effect Factors and Wind Pressure Coefficients

2.1 Procedure of Comparison

Gust effect factor is important as well as wind pressure coefficient to evaluate the wind load. Some codes and standards regulate the products of gust effect factor and wind pressure coefficient, not them separately. Therefore, the product of them must be considered to understand and compare their design concepts. Codes and standards concerned in this study are the following:

(1) ISO International Standard, ISO/DIS 4354[2]
(2) EUROCODE 1, ENV 1991-2-4[3]
(3) ASCE Standard, ANSI/ASCE 7-95[4]
(4) SAA Loading Code Part 2, AS1170.2[5]
(5) National Building Code of Canada[6]
(6) Swiss Standard[7]

These codes and standards regulate internal pressure coefficients and several patterns of external pressure coefficients for enclosed buildings as shown in Table 1.

This study focuses on the comparison of the internal pressure and the external pressure effects on claddings. From these lists, we selected several pressure coefficients as examples for comparison, which are internal pressure coefficients and five external pressure coefficients for frat roof, gable roof, shed roof, vaulted roof and walls. And the comparisons of pressure coefficients were applied for two types of enclosed rectangular buildings with these roof shapes as below:

- Type 1: Span 20m x Ridge 30m x Mean roof height 10m
- Type 2: Span 60m x Ridge 60m x Mean roof height 10m

Table 1. Lists of Wind Pressure Coefficients regulated for Enclosed Buildings

Codes and Standards	Regulated Wind Pressure Coefficients	
ISO4354	Frat roof * Gable roof * Vaulted roof and doom * Sphere	Cylinder, Chimney and Tank Wall * Internal pressure *
EURO CODE ENV-1991	Frat roof * Gable roof * Shed roof * Hipped roof Multi-span roof	Vaulted roof and doom * Sphere Wall * Internal pressure *
ASCE 7-95	Frat roof * Gable roof * Shed roof * Hipped roof Multi-span roof	Stepped roof Vaulted roof and doom * Chimney Wall * Internal pressure *
AS1170.2	Frat roof * Gable roof * Shed roof * Multi-span roof Vaulted roof and doom *	Mansard roof Circular bin, Silo and Tank Wall * Internal pressure *
NBCC 1990	Frat roof * Gable roof * Shed roof * Vaulted roof and doom *	Sphere Cylinder, Chimney and Tank Wall * Internal pressure *
SWISS Standard	Frat roof * Gable roof * Shed roof * Multi-span roof Mansard roof	Roof with ventilated ridges Cylinder, Chimney and Tank Wall * Internal pressure *

*) Wind pressure coefficients considered in this study

The mean roof height is the same each other. Type 1 is the general size of the low-rise building for evaluating internal pressure coefficients and external pressure coefficients except vaulted roof. Type 2 is the size of the gymnasium for evaluating external pressure coefficient of vaulted roof.

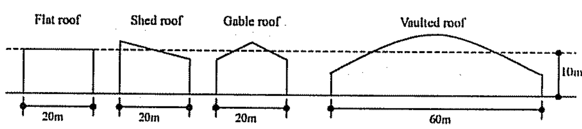


Figure 1. Concerned Patterns of Roof Shapes and Spans

Generally, different codes and standards may define different averaging time or different reference height for the reference wind pressure as shown in Table 2. For example, the reference wind pressure in ISO 4354 corresponds to the mean wind pressure with averaging time of 10 minutes and its reference height is higher one, mean roof height or 6m, for designing claddings. On the other hand, AS 1170.2 defines the maximum 2-3 seconds gust as the basic design gust speed and its reference height is the same as height of the building. Therefore, before comparing the products of gust effect factor and pressure coefficient, it is necessary to take such conceptual differences into consideration and introduce consistent reference wind pressure. In this study, the consistent reference pressure q_H is defined as below:

- Averaging time : 10 minutes
- Reference height H : mean roof height
- Roughness condition : open terrain

For simplification, structural importance multiplier and effects of local topographic condition such as hills and escarpments are neglected.

Table 2. Definitions of Averaging Time and Reference Height

Codes and Standards	Averaging time	Reference height
ISO4354	10 minutes	Mean roof height, or 6m
EUROCODE ENV-1991	10 minutes	Height of the building
ASCE 7-95	3 seconds	Mean roof height
AS1170.2	2-3 seconds	Height of the building
NBCC1990	1 hour	Mean roof height, or 6m
SWISS Standard	2-3 seconds	Height of the building

In the codes or standards concerned, the equation for external pressure w can be generally expressed as below:

$$w = q_{ref}\left(G_{pe}C_{pe}\right) \tag{1}$$

Where q_{ref} and $(G_{pe}C_{pe})$ denote the reference wind pressure and the product of gust effect factor and wind pressure coefficient provided in the code or standard, respectively. Based on the consistent reference pressure q_H, the following equation can be substituted for Eq.(1).

$$w = q_H\left[\frac{q_{ref}}{q_H}\left(G_{pe}C_{pe}\right)\right] = q_H\left(G_{pe}C_{pe}\right)^* \tag{2}$$

Where $(G_{pe}C_{pe})^*$ denotes converted product of gust effect factor and wind pressure coefficient.

Table 3. Converted Products of Gust Effect Factor and External Pressure Coefficient

Codes and Standards	(GpeCpe)*
ISO4354 (Simplified Method of Analysis)	$2.5\left(\frac{z}{H}\right)^{0.28} C_{pe}$ z : Mean roof height or 6.0m, whichever is greater
EURO CODE ENV-1991	$\left\{\frac{C_r(z)}{C_r(H)}\right\}^2\left\{1+\frac{1.3}{C_r(z)}\right\}C_{pe}$ C_r : Roughness coefficient z : Height of the building (Mean roof height for vaulted roofs)
ASCE 7-95	$1.7C_{pe}$
AS1170.2 (Static Analysis)	$2.0\left\{\frac{M_{(z,cat)}}{M_{(H,cat)}}\right\}^2 K_l C_{pe}$ $M_{(*,cat)}$: Gust wind speed multiplier K_l : Local pressure factor z : Height of the building
NBCC 1990 (Simple Procedure)	$2.2\left(\frac{z}{H}\right)^{0.2} C_{pe}$ z : Mean roof height roof or 6.0m, whichever is greater
SWISS Standard	$2.0\left\{\frac{C_h(z)}{C_h(H)}\right\}C_{red}C_{pe}$ C_{red} : Reduction coefficient C_h : Height coefficient z : Height of the building

Table 3 shows the converted products of them in the codes and standards concerned, where Cpe is external pressure coefficient regulated in the code or standard. Fig.C6-1 in ASCE 7-95 Commentary[4] is utilized for converting averaging time into 10 minutes.

2.2 Result of Comparison

This section shows examples of the converted products $(G_{pe}C_{pe})^*$ about claddings of gable roof and vaulted roof. The compared values are based on wind pressure effects on the effective wind area of 1.0m^2.

2.2.1 Gable roof

The external pressure coefficients for the gable roof are regulated in all the codes and standards. Applied building model following the size of type 1 is shown in Figure 2. Wind direction is perpendicular to the ridge.

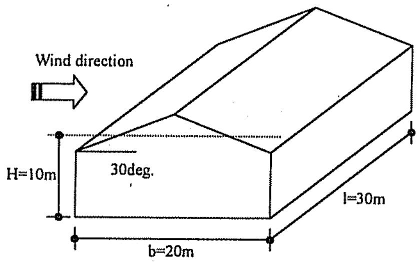


Figure 2. Building Model with Gable Roof

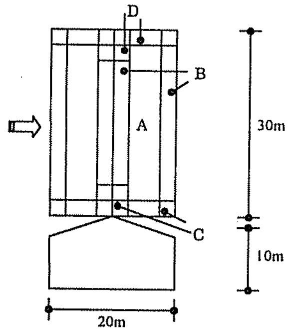
The converted products are shown in Tables 4-9. All the codes and standards take into consideration negative pressure due to suction at corners or ridge of the roof, but the results as shown below are different one another.

In ISO4354, ASCE7-95 and NBCC1990, they regulate negative value of around -4.0～-7.0, while AS1170.2 and Swiss Standard regulate not so conservative values. As for ISO4354 and NBCC1990, the regulated gust effect factors and external pressure coefficients themselves are the same each other, but the converted products (GpeCpe)* result in being different each other and the values in ISO4354 seem to be more conservative. It is seen that negative values in ASCE 7-95 have tendency to be more conservative than those in others.

(1) ISO 4354(Simplified Method of Analysis)

Table 4. (GpeCpe) for gable roof in ISO 4354*

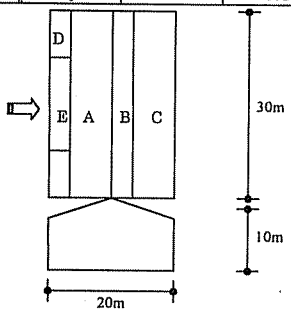
Area	A	B	C	D
(GpeCpe)*	-1.6	-2.0	-4.1	-3.1



(2) EUROCODE ENV 1991-2-4

Table 5. (GpeCpe) for gable roof in ENV1991-2-4*

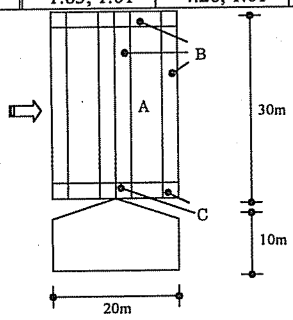
Area	A	B	C	D
(GpeCpe)*	-0.4, 0.8	-1.0	-0.8	-3.0, 1.4



(3) ASCE 7-95

Table 6. (GpeCpe) for gable roof in ASCE7-95*

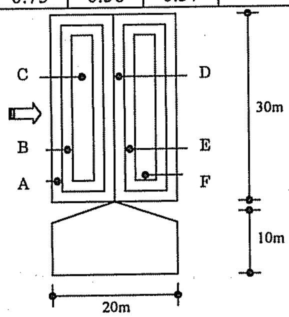
Area	A	B	C
(GpeCpe)*	-1.83, 1.01	-4.26, 1.01	-7.51, 1.01



(4) AS1170.2(Static Analysis)

Table 7. (GpeCpe) for gable roof in AS1170.2*

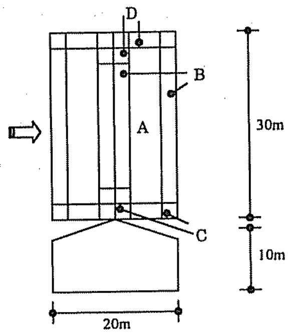
Area	A	B	C	D	E	F
(GpeCpe)*	-0.75 0.75	-0.56 0.56	-0.37 0.37	-2.24	-1.68	-1.12



(5) NBCC 1990(Simple Procedure)

Table 8. (GpeCpe) for gable roof in NBCC1990*

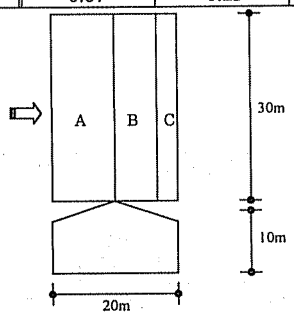
Area	A	B	C	D
(GpeCpe)*	-1.4	-1.75	-3.58	-2.70



(6) Swiss Standard

Table 9. (GpeCpe) for gable roof in Swiss Standard*

Area[m]	A	B	C
(GpeCpe)*	0.67	-1.23	-1.45



2.2.2 Vaulted roof

The external pressure coefficients for the vaulted roof are regulated in all the codes and standards except Swiss Standard. Applied building model following the size of type 2 is shown in Figure 3, and in this case, wind direction is also perpendicular to the ridge.

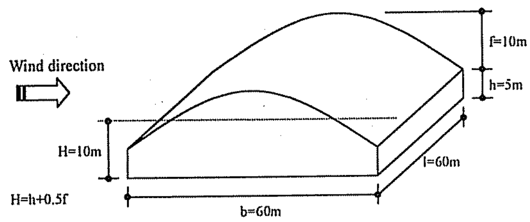


Figure 3. Building Model with Vaulted Roof

The converted products are shown in Tables 10–14. On the whole, converted values in AS1170.2 are the most conservative than others.

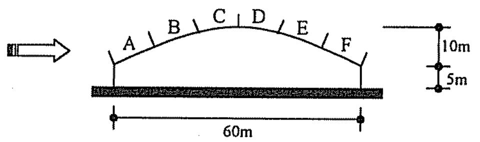
High suction observed at separation area is of great concern for the cladding design and it is necessary to regulate more conservative coefficient at such areas. With regard to this important point, it is found out that the concerned area is different in the codes and standards. AS1170.2 and ASCE 7-95 regard windward corner as the most conservative area, while ISO4354, EUROCODE and NBCC1990 do top roof area. The reason of this discrepancy should be investigated.

As being pointed out in section 2.2.1, the values in ISO4354 are also more conservative than those in NBCC1990.

(1) ISO 4354(Simplified Method of Analysis)

*Table 10. (GpeCpe)*for vaulted roof in ISO 4354*

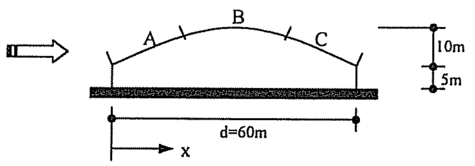
Area	A	B	C	D	E	F
(GpeCpe)*	-0.25	-1.25	-2.00	-2.00	-1.00	-0.25



(2) EUROCODE ENV 1991-2-4

*Table 11. (GpeCpe)*for vaulted roof in ENV1991-2-4*

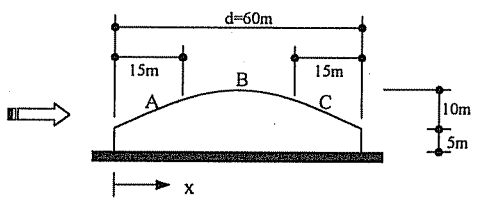
Area [m]	A 0<x<15 (=d/4)	B 15<x<45 (=3d/4)	C 45<x<60 (=d)
(GpeCpe)*	0.04	-2.00	-0.93



(3) ASCE 7-95

*Table 12. (GpeCpe)*for vaulted roof in ASCE7-95*

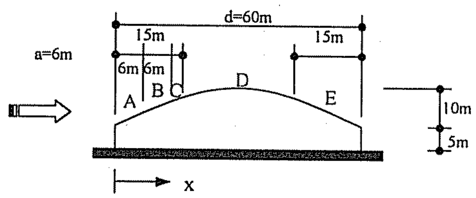
Area [m]	A 0<x<15 (=d/4)	B 15<x<45 (=3d/4)	C 45<x<60 (=d)
(GpeCpe)*	-1.34	-1.29	-0.74



(4) AS1170.2(Static Analysis)

*Table 13. (GpeCpe)*for vaulted roof in AS1170.2*

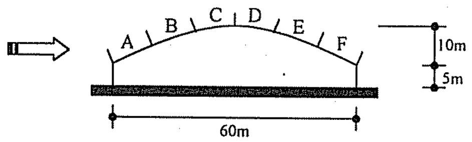
Area [m]	A 0<x<6 (=a/2)	B 6<x<12 (=a)	C 12<x<15 (=d/4)	D 15<x<45 (=3d/4)	E 45<x<60 (=d)
(GpeCpe)*	-4.00	-3.00	-2.00	-1.90	-1.10



(5) NBCC 1990(Simple Procedure)

*Table 14. (GpeCpe)*for vaulted roof in NBCC1990*

Area	A	B	C	D	E	F
(GpeCpe)*	-0.22	-1.09	-1.74	-1.74	-0.87	-0.22



3. Conclusion

This paper presented the outline of our committee's ongoing works, which is the comparison of products of gust effect factors and wind pressure coefficients between current codes and standards used in several nations.

From this study, it was proved that there are differences of wind pressure level and concept between each code and standard. The work will be continued, and after making clear causes that lead to such differences, some of the results will be refereed in the revised works of Recommendations for Loads on Buildings in Architectural Institute of Japan.

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