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Evaluation of Wind Fragility for Set Anchor Used in Sign Structure in Korea

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***Abstract*—**Recently, damage to domestic facilities by strong winds and typhoons are growing. Therefore, this study focused on sign structure among various vulnerable facilities. The evaluation of the wind fragility was carried out considering the destruction of the anchor, which is one of the various failure modes of the sign structure. The performance evaluation of the anchor was carried out to derive the wind fragility. Two parameters were set and four anchor types were selected to perform the pull-out and shear tests. The resistance capacity was estimated based on the experimental results. Wind loads were estimated using Monte Carlo simulation method. Based on these results, we derived the wind fragility according to anchor type and wind exposure category. Finally, the evaluation of the wind fragility was performed according to the experimental parameters such as anchor length and anchor diameter. This study shows that the depth of anchor was more significant for the safety of structure compare to diameter of anchor.

***Keywords*—**Sign structure, wind fragility, set anchor, pull-out test, shear test, Monte Carlo simulation.

I. Introduction

RECENTLY, due to the abnormal weather phenomenon caused by global warming, the damage caused by strong winds and typhoons is increasing nationwide. Due to this growing concerned, government agencies and related companies are taking a big interest in devising countermeasures against wind disasters [1]. In the United States, the Hazus-MH disaster prediction system has been developed and used to assess risk and loss due to hazard events [2]. Therefore, it is necessary to examine the safety of vulnerable facilities due to strong wind and also to contribute to the risk assessment methodology in South Korea.

Fig. 1 Failure of sign structure

In this study, we focused on sign structure among vulnerable facilities. Considering the opinions of related companies that sign structure are frequently damaged to attachment surface, we selected the anchor as vulnerable member. Finally, the wind fragility of the set anchor which is the representative anchor most commonly used in Korea was evaluated. Multiple parameters of anchor and installation condition were considered such as anchor length, anchor diameter, and torque applied on the anchor.

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II. Performance Evaluation of Set Anchor

Through the experiment, we performed pull-out and shear tests on set anchor, one of the most used anchors in Korea. Based on these experimental results, the wind fragility was evaluated. The dimensions of the set anchors were selected to be the most commonly used values in the market with lengths of 50 mm and 100 mm and diameters of 9.45 mm (D10) and 12.7 mm (D12). The experiment was carried out according to three parameters: Torque value, penetration depth and anchor diameter. Here, torque value refers to the force which indicates tightening when an anchor is installed after perforating the specimen.

Fig. 2 Selected anchor and parameter setting

A. Performance Tests and Results of Set Anchors

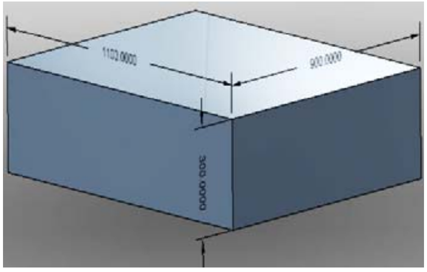
The performance of the set anchor was measured three times per experimental variable and the mean value was obtained for each experimental parameter. The experimental procedure and the experimental results were shown in Fig. 3, Tables I and II.

TABLE I
SET ANCHOR PULL-OUT TEST RESULT

No.	Set Anchor	Displacement (mm)	P (ton)
1	T50D10L50	9.611	2.853
2	T50D10L100	37.682	4.387
3	T50D12L50	30.088	1.163
4	T50D12L100	25.085	8.977

TABLE II
SET ANCHOR SHEAR TEST RESULT

No.	Set Anchor	Displacement (mm)	P (ton)
1	T50D10L50	18.713	3.357
2	T50D10L100	39.123	4.822
3	T50D12L50	18.527	3.833
4	T50D12L100	21.554	5.621



1.Design of Concrete specimen

2. Construction of concrete specimen

3. Concrete hole drilling

Set Anchor Test parameter

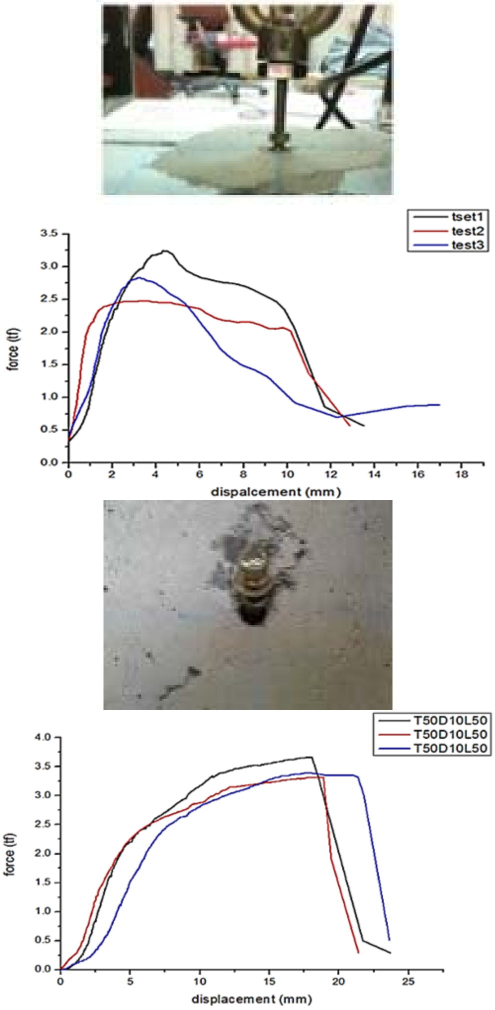
Torque value	Length (mm)	Diameter (mm)	Test number
Torque 30%	50	10	X3
	50	15	X3
	100	10	X3
	100	15	X3
Torque 50%	50	10	X3
	50	15	X3
	100	10	X3
	100	15	X3
Torque 70%	50	10	X3
	50	15	X3
	100	10	X3
	100	15	X3

Chemical Anchor test parameter

Length (mm)	Diameter (mm)	Test number
50	10	X3
50	15	X3
100	10	X3
100	15	X3

4. Parameter setting

5. Pull-out and shear test



6. Analysis of results

Fig. 3 Experimental process of set anchor performance

In both experiments, the strength of anchor bolts was measured using a hydraulic double acting cylinder (TDC-3030) and a load-controllable server, and the displacement values were also measured by installing an LVDT. Tables I and II show the results of the pull-out and shear test. The resistance capacity was estimated based on the experimental results. Finally, we derived and evaluated the wind fragility based on the performance of these anchor.

III. Structure Model Setting

In this study, the sign structure model is set up as shown in Fig. 4 for wind load calculation. It is assumed that the advertisement panel (0.5 m×8 m) and the concrete wall are connected by fixation box and that they are attached by using 8 screws and 4 anchors. Failure modes of the sign structure due to strong wind include angle dropout and anchor failure, and this study considers only the anchor failure.

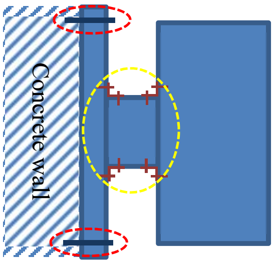


Fig. 4 Typical sign structure model in Korea

IV. Evaluation of Sign Structure Fragility

A. Wind Load Statistics

ASCE 7-10 [3] was used to determine wind load (W) acting on sign structure. ASCE 7-10 defines two types of structural elements subjected to wind load: (a) main wind-force resisting systems (MWFRS), and (b) components and cladding (C&C). The wind load acting on solid freestanding sign was determined as MWFRS with:

$$F = 0.613 K_z K_{zt} K_d V^2 G C_f A_S \text{ (unit: } N) \quad (1)$$

where, K_z = velocity pressure exposure factor, K_{zt} = topographic factor, K_d = wind directionality factor, and V = basic wind speed in (m/s) (3-second gust wind speed at 10 m and in open terrain), G = gust-effect factor, C_f = net force coefficient, and A_s = gross area of the freestanding solid sign in (m^2). Summary of wind load statistics used in this study are in Table III.

TABLE III
Summary of Statistical Wind Load Parameters [4], [5]

Parameters	Category	Mean	Standard Deviation	CDF
K_z	Exposure B	0.89	0.17	Normal
	Exposure C	1.08	0.15	Normal
	Exposure D	1.28	0.18	Normal
K_d	MWFRS	0.89	0.14	Normal
	Exposure B	0.77	0.09	Normal
G	Exposure C	0.83	0.10	Normal
	Exposure D	0.83	0.07	Normal
C_f	Deterministic (1.93)			
K_{zt}	Deterministic (1.00)			

In Table III, following ASCE 7-10, nominal value for these parameters could be found. The statistical distribution of wind load parameters was obtained based on Ellingwood and Tekkie [4] research; they determined the distribution through Delphi's questionnaire with the expert in structural and wind load damage. They used normal probability distribution function to model these parameters. Hence, by multiplying mean-to-nominal value with the nominal value from ASCE 7-10, one could obtain the mean value of statistical wind load parameters. Moreover, the standard deviation is the multiplication of COV with the mean value. The mean and standard deviation of each wind load parameters shown in Table III were used to generate random wind load describe in the next section.

B. Calculation of Probability of Failure for Set Anchor

A Monte Carlo Simulation was used to simulate probabilistic wind loads and anchor bolt resistances. For each wind speed, this model simulated velocity exposure factor, wind directionality factor, and force coefficients by sampling from the assumed normal distributions. Then, following (1), the force acting on sign structure was determined. Consequently, by comparing wind loads with the resistance capacity of the anchor, the failure of anchor could be determined [6]. These comparisons were repeated 5,000 times to develop the component probability of failure for each wind speed. In this simulation, each parameter was assumed independent. Furthermore, wind fragility was described by lognormal cumulative distribution function (CDF) [7]:

$$Fr(V) = \Phi\left[\frac{\ln(x) - \mu_R}{\sigma_R}\right] \quad (2)$$

in which $\Phi(\cdot)$ = standard normal cumulative distribution function, μ = logarithmic median of resistance capacity, and σ = logarithmic standard deviation of resistance capacity R.

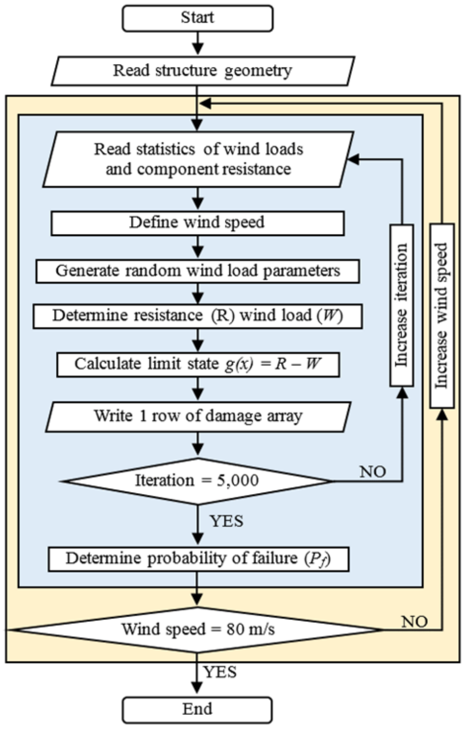


Fig. 5 Monte Carlo Simulation flowchart

C. Evaluation of the Wind Fragility Set Anchor

Fig. 6 shows the wind fragility of set anchor installed on the sign structure in the wind exposure category B. Type 4 showed the largest resistance wind speed when an anchor with a diameter of 12 mm had a penetration depth of 100 mm. Anchor type 1,2 is the 10 mm diameter anchor and Type 3,4 is the 12 mm diameter anchor. The increase in diameter of the anchor did not affect the intensity of wind fragility. When comparing Type1,3 and Type2,4, it can be concluded that probability of failure decreases when the anchor length increases. Therefore, it can be concluded that the change of the penetration depth rather than the change of the diameter affects the wind fragility more.

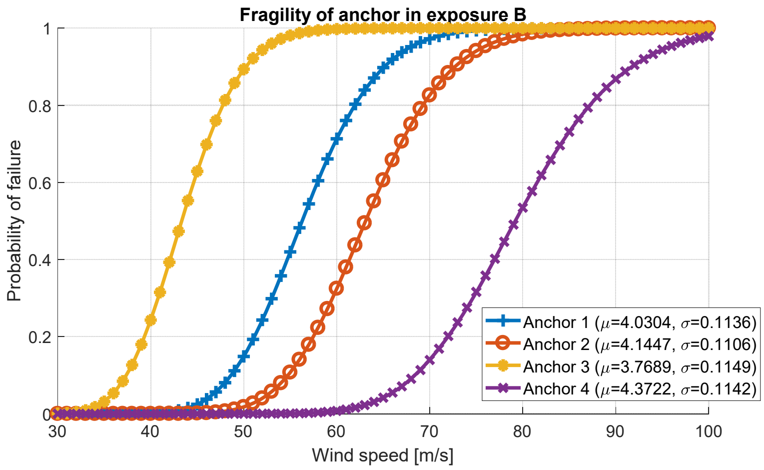


Fig. 6 Wind fragility of set Anchor (Exposure B)

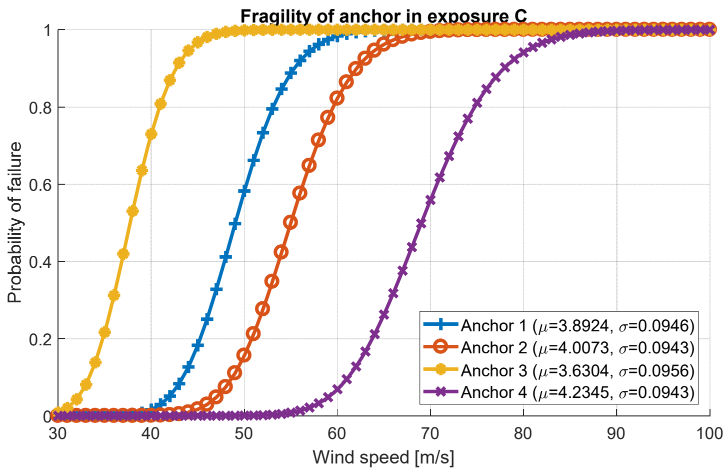


Fig. 7 Wind fragility of set Anchor (Exposure C)

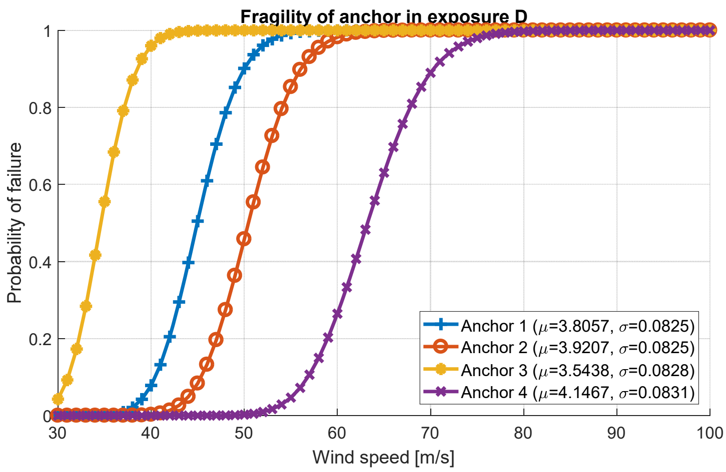


Fig. 8 Wind fragility of set Anchor (Exposure D)

Fig. 7 shows the wind fragility of set anchor installed on the sign structure in the wind exposure category C. The pattern of the graph was similar to the previous results. However, the resistance wind speed based on wind exposure category B decreased by about 5 m/s for 10, 12 mm diameter anchor. This shows that the differences in wind exposure category also affected the performance of anchor.

Fig. 8 shows the wind fragility of set anchor installed on the sign structure in the wind exposure category D. The pattern of the graph was consistent with the wind exposure category B and C. The wind speed based on wind exposure category B decreased by about 10 m/s for 10, 12 mm diameter anchor. This is because the effect of the wind on the structure changes with the change of the wind exposure category. The parameters of the wind fragilities obtained were summarized in Table IV which shows the anchor type and wind exposure category.

TABLE IV
WIND FRAGILITY PARAMETERS

Anchor Type	Exposure	μ_R	σ_R
1	B	4.0304	0.1136
	C	3.8924	0.0946
	D	3.8057	0.0825
2	B	4.1447	0.1106
	C	4.0073	0.0943
	D	3.9207	0.0825
3	B	3.7689	0.1149
	C	3.6304	0.0956
	D	3.5438	0.0828
4	B	4.3722	0.1142
	C	4.2345	0.0943
	D	4.1467	0.0831

V. CONCLUSIONS

In this study, the sign structures which have been increasingly affected by strong winds in Korea were selected as research subjects, and the evaluation of the wind fragility was performed for the anchor in the connection between sign structure and concrete wall. Four types of anchor were selected; their differences were based on two experimental parameters which are anchor diameter and anchor length (penetration depth). As a result, when the penetration depth increases, the median failure wind speed increases and the probability of safety also increases. However, it was refereed that the diameter of the anchor did not have influence on the probability of safety. We can get more reliable results through various model settings and variable settings in the future. Also, it is necessary to carry out more research to compare and evaluate the performance of anchor connection by mean of fragility analysis.

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