

Comparison of Wind Fragility for Sign Structure with Set Anchor and Chemical Anchor System

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Abstract: *Typhoon and strong wind disaster in the Korean peninsula is growing each year. Sign structure is one of the most vulnerable structures during wind disaster, especially those connected to the side of a concrete structure. Therefore, by using fragility analysis, the performance of sign structure could be determined. Moreover, in this study, the comparison of set anchor and chemical anchor performance in sign structure will be focused. Based on the experiment of anchor system resistance capacity and stochastic wind loads, the failure probability of sign structure could be determined. The length of set anchor installed can significantly affect the performance of the sign structure system. However, in case of chemical anchor, their diameter plays a more significant role. Additionally, chemical anchor had a better performance than set anchor.*

Keywords: Attached signs structure, chemical anchor system, Monte Carlo simulation, set anchor system, wind fragility.

I. INTRODUCTION

Development of disaster prediction and management framework has gained interested by many researchers in the last decade. Probabilistic risk assessment (PRA) has received many interests and became an increasingly popular analysis tool. Fragility analysis is the basis tool of this risk assessment tool. Furthermore, the recent increase of disasters around the globe has emphasized the necessity of PRA for all types of structure, especially those located in high density regions or metropolitan area, which prone to cause higher economic losses and social disruption.

According to Korea Typhoon White Book from Korea National Typhoon Center (2011), strong wind and typhoon events in Korea has been rising year on year. Moreover, advertisement sign structures in South Korea are those mostly found in crowded and commercial area. They are mostly constructed in the form of attachment to the side or on the roof of concrete structure. Consequently, they are prone to failure due to strong wind. Thus, evaluation of their performance when subjected to wind load is necessary. Probabilistic analysis could be employed to evaluate the performance of this structure based on their demand-capacity. The results, wind fragility parameters could be used to integrate with PRA to further analyze the loss in the event of disaster. However, most published studies use the regression method with post-disaster surveys or claim data to develop fragility curves for residential building (Cope, 2004). This method cannot be used to develop fragility curves for sign structure in Korea due to inadequate post-disaster and claim data exist (Ham et al., 2009).

Therefore, in this study, a probabilistic model is presented to predict the wind-induced damage on sign structure. This procedure uses a Monte Carlo Simulation method which generates damage information for structural component. Then, the model compares probabilistic wind load and resistance capacity of structural component based on experimental test data of the anchor system in South Korea, to determine the probability of failure over a range of assigned wind speed. Moreover, different types of anchor were used in this study; they were set and chemical

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anchor. Comparison of sign structure's performance based on the type of anchor used was shown to assist in the future advertisement sign structure design.

II. WIND FRAGILITY MODELING

Wind fragility can be defined as a conditional probability of failure of a structural member or system for a given set of input variables. It is generally expressed as follows (Porter, 2015):

$$P[LS] = \sum P[LS | D = x]P[D = x] \quad (1)$$

Where D = a random demand on the system (e.g., 3-second gust wind speed), $P[LS|D=x]$ is the conditional probability of limit state (LS) at given demand x . The hazard is defined by the probability, $P[D=x]$. The conditional probability, $P[LS|D=x]$ is the wind fragility. Equation (1) can also be expressed in the convolution integral form if the hazard is a continuous function of demand x :

$$P[LS] = \int_0^{\infty} Fr(x)h_x(x)dx \quad (2)$$

Where $Fr(x)$ = fragility function of demand x expressed in the form of a cumulative distribution function (CDF) and $h_x(x)$ = hazard function in the form of a probability density function (PDF).

The wind fragility of a structural component or system is commonly modeled using a lognormal CDF:

$$Fr(x) = \Phi \left[\frac{\ln(x) - \mu_R}{\sigma_R} \right] \quad (3)$$

In which $\Phi(\cdot)$ = standard normal CDF, μ_R = logarithmic median of capacity R , and σ_R = logarithmic standard deviation of capacity R .

Fragilities can be used to identify a level of demand that a component or system will withstand with certain probability. Fragility curves can be used in both design and condition assessment applications (Ellingwood and Rosowsky, 2004).

III. SIGN STRUCTURE WIND FRAGILITY

A. Limit States

Advertisement sign structure failure due to wind load arises when wind pressure acting on panels created sufficient force to remove the anchor bolts connecting sign structure to the concrete wall (ACI 318-14). As shown in red circles in Fig. 1, sign structure was connected to the concrete wall by anchor bolts. Therefore, the failure condition for these anchors could be shown in the limit state function written in term of the basic random variables as follows:

$$g(x) = R - W \quad (4)$$

Where R = resistance capacity of the anchor bolts, W = wind load acting on a sign structure which apply tension and shear force to anchor bolts. Failure of anchor bolts can be defined as a condition where limit state function $g(x) < 0$. The wind load, and hence the probability, is a function of the basic wind speed (V) squared (see (5) and (6)).

B. Resistance Capacity

Wind fragility analysis was performed for an advertisement sign panel ($0.8 \text{ m} \times 4 \text{ m}$) attached to the side of concrete building using a connection box (yellow circle) and anchor bolt (red circles) in Fig. 1. In this study, the connection box was assumed to be perfectly rigid, only anchor bolts were being evaluated.

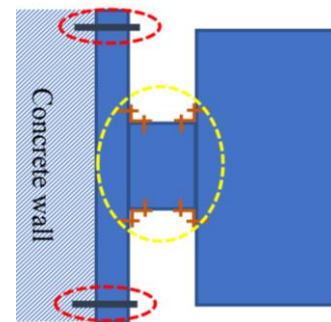


Fig. 1: Typical sign structure in Korea

Two different anchor installation procedures were considered which are set anchor and chemical anchor. Set anchor or mechanical anchor is inserted in the concrete and expands upon tightening. This expansion causes the anchor to grip the wall of the hole and provide an extremely strong

hold. Chemical anchor, a resin is injected into the hole prior to insertion of the stud. With this, the chemical naturally fills in all irregularities and therefore makes the hole airtight, with 100% adhesion. This extra adhesion creates extra strength. Furthermore, difference anchor parameters were selected; they were anchor's lengths and anchor diameters.

Table 1: Resistance strength of anchor bolt

Anchor	Diameter (mm)	Length (mm)	Pull-out (ton)	Shear (ton)	
Set anchor	M1	10	50	2.853	3.357
	M2	10	100	4.387	4.822
	M3	12	50	1.163	3.833
	M4	12	100	8.977	5.621
Chemical anchor	C1	10	50	3.367	3.317
	C2	10	100	3.907	3.657
	C3	12	50	4.623	5.421
	C4	12	100	9.247	5.977

Pull-out and shear tests, as shown in Fig. 2 and Fig. 3, were performed to determine resistance capacity of these anchor bolts. Four types of anchor, based on their dimensions, were used in the experiment. The dimensions of the anchors were selected as the following, 50 mm and 100 mm lengths and 10 mm and 12 mm diameters. The resistance capacity results for set and chemical anchors were shown in Table 1.

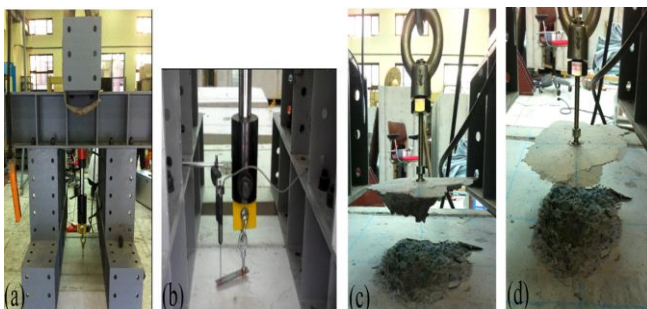


Fig. 2: Pull-out test (a) & (b) and concrete failure (c) & (d)



Fig. 3: Shear test (a) & (b) and failure of anchor bolt (c) & (d)

C. Wind Load Statistical Parameters

ASCE 7 (2010) was used to determine wind load (W);

they define two types of structural elements subjected to wind load which are main wind-force resisting systems (MWFRS) and components and cladding (C&C). Advertisement signs structure fall in the provision for MWFR with the following equation:

$$W = q_h G C_f A_s \quad (\text{Unit: } N)(5)$$

Where q_h = velocity pressure assessed at height h (top of sign panel), G = gust-effect factor, C_f = net force coefficient, and A_s = gross area of the sign structure in (m²). In this study, the height at the top of sign structure is 14.4 m (a four-story building). The velocity pressure evaluated at height (z) is given by:

$$q_z = 0.613 K_z K_{zt} K_d V^2 \quad (\text{Unit: } N/m^2)(6)$$

Where q_h is q_z evaluate at height h , 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 in open terrain at 10 m height).

Summary of wind load statistical parameters used in this study was shown in Table 2. The statistical value of K_z , K_d , and G were obtained from a Delphi study of wind parameters by Ellingwood and Tekie (1999). The information was used to determine mean-to-nominal and coefficient of variation (COV) (Lee and Rosowsky, 2005). Then, mean-to-nominal and COV value was used to determine mean and standard deviation (SD) value of each parameter from nominal value in ASCE 7.

Table 2: Summary of wind load parameters statistical value

Parameter	Category	Mean-to-Nominal	COV	Nominal	Mean	SD	CD F
K_z	Exposure B	1.01	0.19	0.88	0.89	0.17	Normal
	Exposure C	0.93	0.14	1.16	1.08	0.15	Normal
	Exposure D	0.96	0.14	1.33	1.28	0.18	Normal
K_d	MWFRS	1.05	0.16	0.85	0.89	0.14	Normal
K_{zt}		deterministic (1.0)					
G	Exposure B	0.96	0.12	0.80	0.77	0.09	Normal
	Exposure C	0.98	0.12	0.85	0.83	0.10	Normal

	Exposure D	0.98	0.08	0.85	0.83	0.07	Normal
C_f		deterministic (1.93)					

D. Failure Probability of Anchor Bolt

Monte Carlo Simulation (MCS) method was employed to simulate random wind load (W) in (5) based on their statistical normal distribution in Table 2. At each wind speed, by sampling from their normal distribution function parameters, MCS generated random velocity pressure exposure factor K_z and wind directionality factor K_d to determine random velocity exposure factor q_h . Subsequently, random gust-effect factor G was generated to determine random wind load demand (W) on the sign structure. Then, by comparing wind load demand with anchor resistance capacity, the failure of anchor could be determined. These comparisons were repeated 10,000 times to determine the probability of failure at each wind speed. Furthermore, by repeating this procedure for the next increment of wind speed, the probability of failure for anchor could be determined for all wind speeds iterations.

IV. RESULTS AND DISCUSSIONS

Wind fragility parameters μ and σ were determined by maximum likelihood estimation (MLE) method (Baker, 2015). Fig. 4 shows the wind fragility for set anchor installed in a sign structure in region with wind exposure category C. Moreover, wind fragility parameters were also shown in the legend for each anchor type based on nomenclature assign in table 1. Sign structure with anchor M4 showed the highest resistance to wind loads, with the median failure wind speed 73 m/s. Then, it was followed by anchor M2, M1 and M3 with the median wind speed 65 m/s, 53 m/s and 44 m/s respectively. Additionally, wind fragility for anchor M3 was shown for all wind exposure categories in Fig. 5. The median wind speeds for exposure B and D were 51 m/s and 40 m/s respectively.

For chemical anchor, the C4 had the highest performance as can be seen in Fig. 6, which shows wind fragility in exposure D. Like a set anchor, the result of wind fragility

was shown in the same graph for all wind exposure categories in Fig. 7. Compare to set anchor, the difference between the median wind speed of chemical was not consistence and it depended on the diameter and length of the anchor.

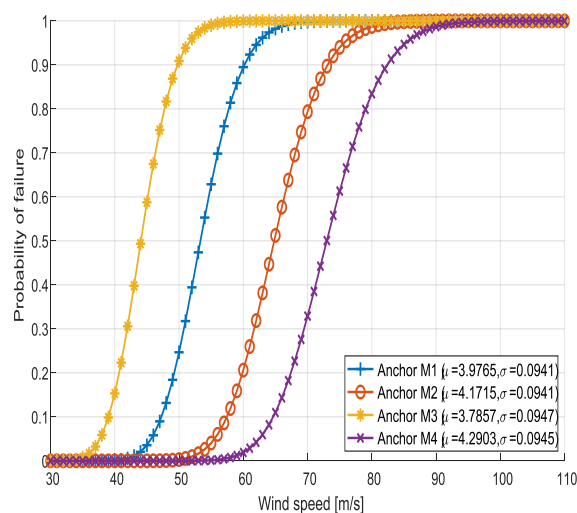


Fig. 4: Wind fragility for sign structure with set anchor in wind exposure C

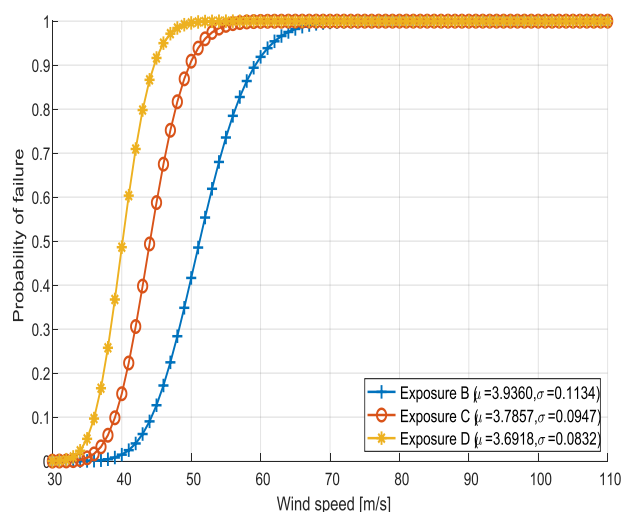


Fig. 5: Wind fragility for sign structure with set anchor M3

There was a minor difference between the median wind speed of the anchor with the same diameter, i.e. 6 m/s for 12 mm anchor and 3 m/s for 10 mm anchor. However, for anchor with the same length, a more significant difference between their median wind speed was shown. For anchors with 50 mm length, the difference between their median

wind speed were 13 m/s; anchor with 100 mm length shown a difference of 16 m/s. This trend was also shown in the other two wind exposure categories. Therefore, it could be concluded that the difference of probability of failure for anchor with the same diameter was less than the difference between anchor with the same length.

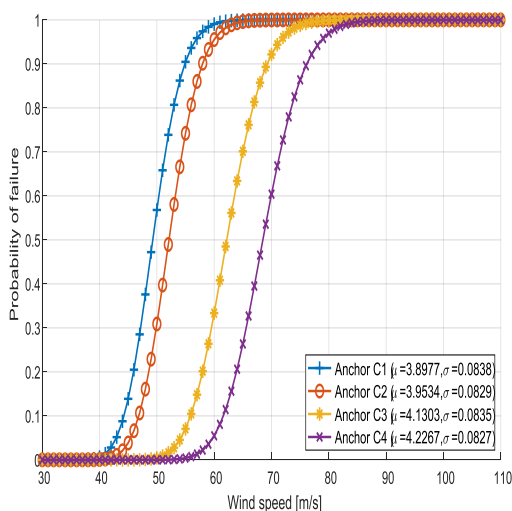


Fig. 6: Wind fragility for sign structure with chemical anchor in wind exposure D

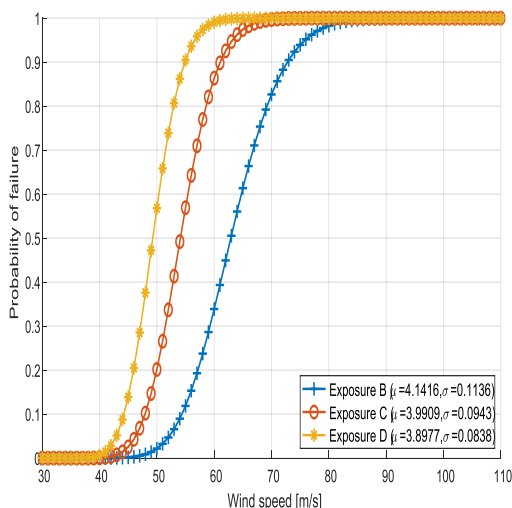


Fig. 7: Wind fragility for sign structure with chemical anchor C1

A more thorough comparison could be seen in Fig. 8 where wind fragility for all eight anchors were shown. In this figure, the dotted lines were chemical anchor and the solid lines were set anchor. For anchor with the same

diameter and length, chemical anchor showed a better performance except anchor M2 and C2.

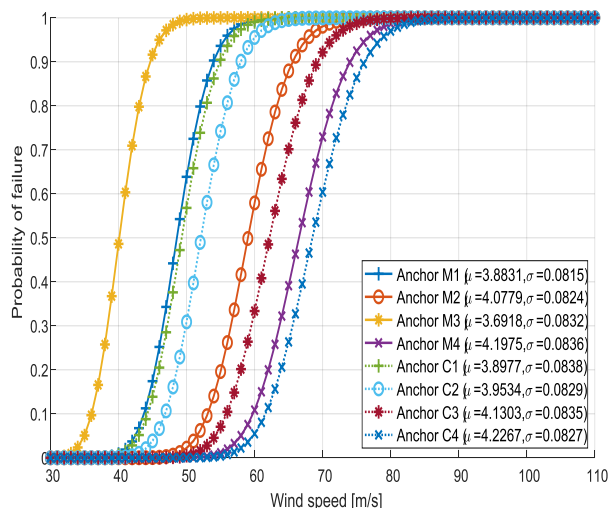


Fig. 8: Wind fragility for sign structure with difference type of anchor in exposure D

V. CONCLUSION

Performance of advertisement sign structure was evaluated by mean of probabilistic analysis with Monte Carlo Simulation. Moreover, wind fragility parameters were estimated by Maximum Likelihood Estimation method. The wind fragility parameters were presented in the form of lognormal CDF. The results were shown for anchor installed in a sign structure in region with wind exposure B, C and D.

The length of set anchor installed for the connection of sign structure and concrete wall can significantly affect the performance of the system. However, for chemical anchor, their diameter plays a more significant role compare to that of their length. For difference exposure category, the differences were consistent for both set and chemical anchor. The overall performance of chemical anchor was better than set anchor with the same diameter and length.

With this methodology, it could lead to a more predictable structure's performance and could facilitate the introduction of performance-base design guidelines for advertisement sign structure in high wind regions. Additionally, wind fragilities such as those presented here

could be used to develop a risk assessment tool, which can evaluate the potential impact of a natural hazard in public planning and mitigate the consequent economic losses and social disruption.

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