Safety Evaluation of Billboards According to Some Random Factors in the Southwest of Vietnam

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Abstract. Billboards are present in many localities of Vietnam, with typical structure of large surfaces, so wind load is one of the main loads during the design stage. In the Southwest region of Vietnam, during the rainy season, there are usually thunderstorms accompanied by strong winds, causing many billboards to be damaged. To avoid such damage, the structure of the billboard is simulated by random quantities such as wind load, material strength, geometric dimensions, resulting in the reliability of the structure was evaluated. The results show that there may be a high risk of the integrity of the billboards, even if the safety of these structures is implied by the design code. This study analyzed reliability index of billboard structure under wind speed, material, geometric characters by Monte Carclo simulation to indentify the reliability of billboard design.

Key words: Safety, billboard, reliability, probability, windload, Vietnam.

1. Introduction

The need for advertising is indispensable, especially in VietNam where is under strong economic development. Outdoor advertising has been researched and evaluated to bring good communication efficiency, strong growth momentum, and has increased of 6.4% from 2011. Four megacities, including, Hanoi, Ho Chi Minh City, Da Nang and Can Tho recently stand more than 17,000 billboards [1]. Outdoor large billboards are often placed on the main roads such as highways, national highways, provincial roads, etc., at bus stops, between intersections of streets, on buildings, skyscraper, etc.

Figure 1. Damage of Billboard and partial damage building (Highway 1A, Binh Tan distric, Ho Chi Minh city, 10 August 2018) [2]

Double-sided tables and single or double columns are the main structures of the outdoor billboard design. A large billboard usually has a surface area of over 40 m^2 [3], due to the large surface, the main load of the billboard design is the wind load. The impact of the wind load is not only the effect of the static component but also the dynamic component, making billboards more complex such as oscillation, air turbulence, vibration types, etc. This study focuses on analyzing billboard structure according to Vietnamese standards and simulation to assess its reliability under static load, construction location in the southern region, typically Ho Chi Minh City and neighboring provinces.

Table 1. Statistics of typical storms in Ho Chi Minh and the Southwestern provinces **[2]**

No.	Name of Storm	Characters
1	Linda, 31 October 1997, Ca Mau, Bac Lieu province	Wind speed 100km/h, gust grade of 8,9
2	Storm, 1 December 2006, Southwest	Wind speed 150km/h - 185km/h
3	Tembin, 25 December 2017, in Tien Giang, Ben Tre, Tra Vinh, Vinh Long, Can Thơ, Kiên Giang provinces	Wind grade of 6, gust grade of 8
4	Storm No 9, 23 November 2018	Wind grade of 7, gust grade of 9
5	Storm No 9 (Pabuk), 1 January 2019, Southern provinces	Wind grade of 8, gust grade of 10

According to [4] Ho Chi Minh City and neighboring provinces are less affected by storms (Region IIA) [5], but by the rainy season, the number of damaged billboards tends to increase. The billboards affected by weather, rain, sun are the cause of steel rust, especially tornadoes that can collapse the billboards at any time. Ensuring safe working for billboards is an urgent issue not only for Ho Chi Minh City, where there are many billboards, but also for other provinces like Vinh Long where there are only about 50 outdoor billboards, and many of them have been degraded, resulting in a loss of safety, some of which have been built for a long time but have not been re-tested for quality [6].

Figure 2. Damage of Billboard (Dong An industrial area, Binh Duong province, 7 August 2013) [6]

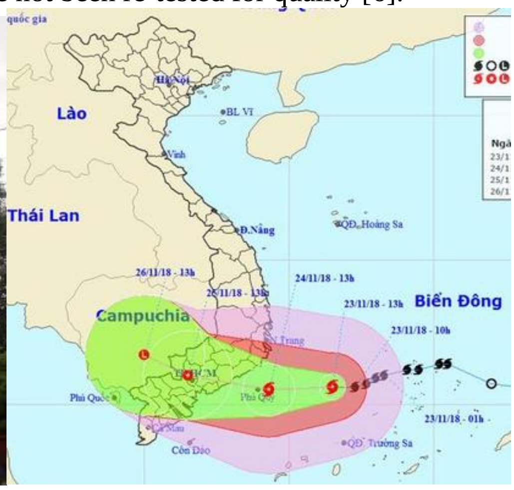


Figure 3. The direction of the storm No. 9 [2]

Table 2. Statistics of damage to houses in Southern provinces [2] [7]

No	Date	Location in Map	Damages
1	18/11/2017	Ho Chi Minh City	82 houses were unroofed, 134 trees fell, due to the impact of the storm 14
2	4/7/ 2019	Bac Lieu province	23 houses were unroofed due to tornado
3	15/7/2019	Tien Giang province, Long An province	100 houses were unroofed due to tornado, more than 300 houses were unroofed, damaged
4	23/7/2019	Tinh Biên town, An Giang province	604 houses collapsed and unroofed by tornado

5	1-3/8/2019	Soc Trang province	heavy rain with tornadoes collapsed, roof speed 194 homes
6	3/8/2019	Hau Giang province	more than 100 houses were unroofed due to tornadoes
7	4/8/2019	Can Tho province Kien Giang province	83 houses were unroofed due to tornado 200 houses were damaged, unroofed
8	12/8/2019	An Giang province	96 houses were damaged, unroofed

Table 1 shows that the quantity of storms tends to increase in quantity and intensity, and they often form the ocean and then move in to the land (Fig.3). During the cyclone storm in Ho Chi Minh City and the Southwest provinces, wind speed / pressure is still under the allowed limits in the standard, its level is approximately to the wind grade of 12 in Beaufort scale [8]. During the rainy season (June to December) in the Southern provinces, there are thunderstorms accompanied by heavy rain, strong wind gusts, that cause many damage residences, broken trees, and electricity poles. Table 2 indicates that although the wind speed grade of 13 [8], but the consequences were heavy, as house collapse, roof break, electric poles, fallen trees. It can be results of environmental climate change; leading to the actual wind speed is higher than the current standards.

There are many studies related to analyzing the reliability of large-scale structures, such as, K. Ohdo analyzed Reliability of construction scaffoldings system under wind storms [9], Le T.N [10] studied about impact of wind load on large plate billboards in Vietnam, Giang L.T [11] researched about damage caused by wind load standard for building in Vietnam, Huong C.T at el. studied about variations and trend of maximum wind speed in Vietnam during 1961-2007 [12], the report on zoning of wind pressure for use in construction industry over Vietnam was written by Lien T.V [13]. However, there is no study about the reliability of billboard structure in Viet Nam.

2. Materials and methods

In this study, the author will calculate an example of billboard structure according to Vietnamese Standards [14], then analyze the safety of the billboard structure according to some typical random variables.

2.1. Load and action

The load used to design billboard structure was from TCVN 2737–1995 Load and action- Design code [5], including:

a) Self weight of the billboard.

b) Wind load: In [5], there are instructions for calculating wind loads for different types of buildings. In 2009 to supplement the changes due to the environment Vietnam Construction Code (Natural Data & Climate for Construction) QCVN 02-2009 / BXD [4] was issued. However [4] was not widely used because most engineers were still familiar with [5], which made the design work incompatible with the natural conditions and regulations of law.

Table 3. Criteria wind pressure depending locations **[5]**

Loacation in Map	I		II		III		IV	V
	IA	IB	IIA	IIB	IIIA	IIIB	IVB	VB
$W_o(kN/m^2)$	0.55	0.65	0.83	0.95	1.1	1.25	1.55	1.85

For wind load design, [5] is divided into 5 zone of wind pressure (Table 3). Conversion factors to obtain wind speed/pressure at higher return periods, 50 to 100 year-return periods, also is given in the [4].

Table 4. The adjust- factor, a_t **[5]**

Assumption life time of building (years)	5	10	20	30	40	50
a_t	0.61	0.72	0.83	0.91	0.96	1.0

According to [4], mean-wind-speed V_o using in design depend on the 3-seconds mean wind speed of 10 m height in open-flat terrain (type B), with a return period of 20 years. Wind speed converted value from 10 minutes in 50 years (V_{10}^{50}) to 3 seconds in 20 years (V_3^{20}) is 37.21m/s, and a deviation changes from 3.1m/s - 6.6m/s ((0.084-0.18)V_0) based on [5] and [12], resprectively. Therefore, the mean and deviation of the wind load should be considered when designing the billboard structure.

The value of wind load static component W at the height Z above the reference level is determined by the formula in [5]:

$$W = W_o \times k \times c \qquad (1)$$

where: W_o- the standard value of wind pressure; k – factor of wind pressure variation height; c - aerodynamic factor (reliability of wind load) is taken equal to 1.2.

2.2. Materials

Material suitable for the structure of the billboard is steel, with high strength, convenient for transportation because of its low weight, easy to erect. However, the steel billboard structure is susceptible to corrosion due to moisture, which leads to structural damage, so steel protection measures should be taken. In Vietnam, commonly used are low carbon steel ($f_y \le$ 290Mpa, $f_u \approx$380 ÷ 400Mpa) such as CT34, CT38, SS400, S235, Q235, A36 and relatively high strength steel (f_y = 310÷400Mpa, f_u = 450 ÷ 540Mpa) such as Q345, A570 [14].

2.3. Limit state design and System Reliability Evaluation

The structural design standards of Vietnam use the design method according to the limit state, this is shown in the Vietnamese standard 5575 - 2012 – “Steel structure - Design standard” [14]. The meaning of the method is that the structure will be safe when the load effect U (expressed in a suitable unit) is smaller than the structural strength B, which can be written in inequality:

$$U < B \qquad (2)$$

Assuming that structural failure occurs when condition (2) is not satisfied, therefore a hypothetical boundary distinguishing between the safety and failure states of the structure is given by the following equation:

$$B - U = 0 \qquad (3)$$

Equation (3) is the fundamental form of the so-called limit state (performance) function (Fig. 4).

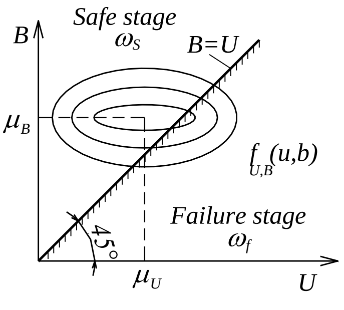


Figure 4. The limit state function

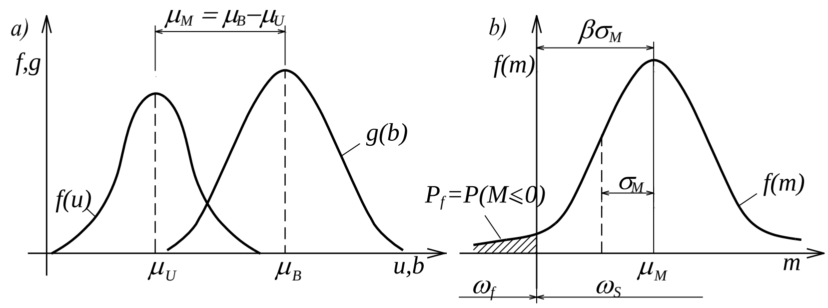


Figure 5. Safety margin (a) and reliability index (b)

Both U and B are generally random variables and the validity of inequality (2) cannot be guaranteed absolutely, i.e. with the probability equal to 1. Therefore, it is necessary to accept the fact that the limit state described by equation (3) may be exceeded and failure may occur with a certain probability. The essential objective of reliability theory is to assess the probability of failure p_f and to find the necessary conditions for its limited magnitude. For the simple condition in the form of inequality (2), the probability of failure may be formally written as

$$p_f = P(U > B) \qquad (4)$$

To analyze reliability, A.R. Rzannhitsun [15] and V.D. Raizer [16] assumed that both basic variables, U and B are random variables. It is then more complicated to assess the probability of failure defined by equation (4). Then, the difference M, called the reliability margin, has a normal distribution.

$$M = B - U \qquad (5)$$

Distribution of M has mean value $\mu_M = \mu_B - \mu_U$, and on the Fig. 5 presents the calculation of standard deviation (σ_M) and probability density (*f(m))*.

When B and U are independent random variables, we have:

$$f(m)=\int_{-\infty}^{\infty} g(m+u)f(u)du, \qquad (6)$$

When: g(m+u) – probability density of strength, the variable is m+u; f(u) – probability density of load effect.

Reliability of structure:

$$R=P_s=P(M>0)=\int_{0}^{\infty} f(m)dm=\int_{0}^{\infty}\int_{0}^{\infty} g(m+u)f(u)dudm \qquad (7)$$

And probability of failure is then given as:

$$P_f=P(M<0)=1-R=\int_{-\infty}^{0} f(m)dm \qquad (8)$$

In practice, there is often not enough statistical data to determine the specific density function of each variable. To obtain an analysis of probability of failure or safety determined by the expression (6) (7), using FORM and SORM can approximate reliability (V.D Raizer [16], Holický [17]). However, the disadvantage of this method is the complex state function when the number of variables is many. In that case the Monte Carlo simulation method has the advantage of being accurate and powerful technique to analyze this problem.

In fact, U and B often do not know in advance or have no clear mathematical expressions, or maybe they are not independent variables. In that case, it is best to represent the basic variables $x_i, i = 1,2,\dots,n$, which are statistically independent and have known distribution functions. Monte Carlo method aims to create a set of values for independent representations of x_i for each basic variable and thereby determine the corresponding values of the safey margin M.

$$m=f(x_1,x_2,\dots x_n)=f(\overline{x}) \qquad (9)$$

By generating random numbers, this process is repeated many times to create a large set of m values, from which the probability distribution of the quantity M can be simulated. So, the probability of failure is then given as:

$$P_f=P(M\le 0)=lim_{n\to\infty}\frac{k}{n} \qquad (10)$$

In which: n - the total number of tests, k - the number of trials with $f(\overline{x})\le 0$

3. Numerical example

3.1 Example Description

Consider a typical billboard built in the HCM city. Structure consists of an open-web column lattice, each branch is a angle steel welded from two plates, the ties are made of hot-rolled steel (L)(Fig. 6). Impact load: self load (structure system, technical equipment ...); Wind load is calculated with HCMC area (region IIA). All the billboard parameters are presented in Table 5, Table 6 and in Fig. 6, Fig.7.

Table 5. Input parameters of the billboard analysis

Parameters of Billboard (m)					Column shape branch (mm)			Material (MPa)	
H_1	H_2	L	B	l_b	d_1	b	t	E	f_y
15	10	20	2	2.5	L75x5	250	12	2.1E5	275

Table 6. Geometric characteristics

Geometric characteristics	One branch of column	Gross section
Area, A	$60cm^2$	$240cm^2$
Momen of inertia, I	$3639.6cm^4$	$2111747.2cm^4$
Radius of gyration, r	7.79cm	93.8cm
Equivalent slenderness ratio, λ_o	32.09	26.65
Conventional slenderness ratio, $\overline{\lambda}$	1.08	1.3

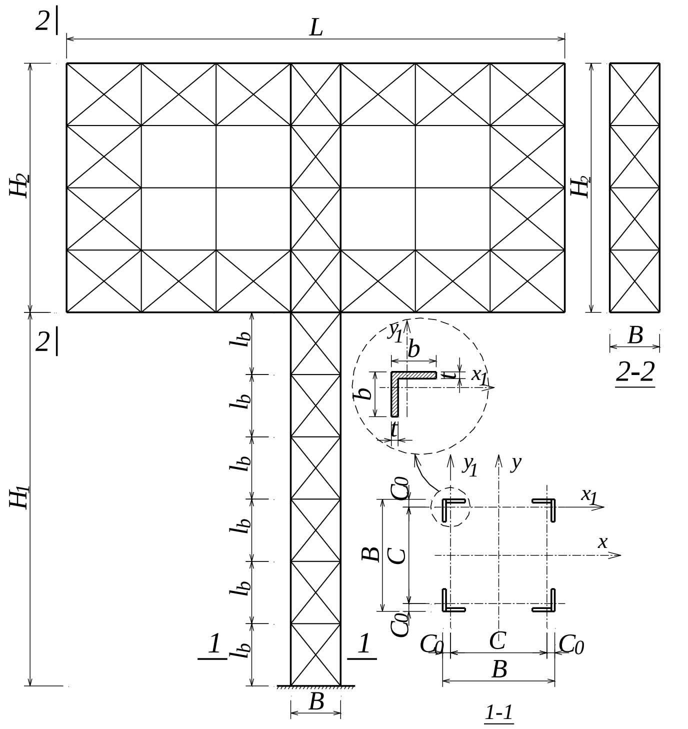


Figure 6. Type of Billboard structure

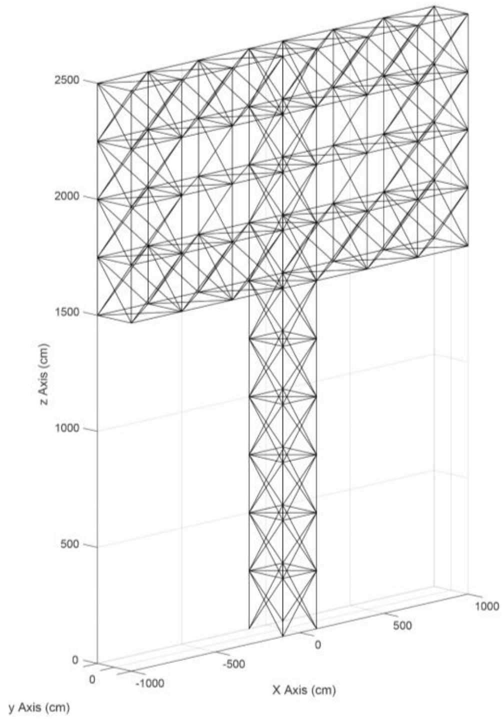


Figure 7. 3-D model of the billboard

3.2 Statistic Properties of Random Variables

The random variables of reliability analysis and parameters of these are mean (μ), standard deviation (σ) and coefficient of variation $CV=\sigma/\mu$, and displayed in Table 7.

Table 7. Statistic parameters of random variables

No	Property	Random variables	Mean, μ	Standard Deviation, σ	CV	Probability Distribution
1	Material property	Yield strength, f_y (MPa)	270	$0.05\ \mu_{fy}$	0.05	Lognormal [18]
2	Geometric property	Leg size, b (cm)	25	$0.05\ \mu_B$	0.05	Normal [19]
		Leg thickness, *t* (cm)	1.6	$0.05\ \mu_{tf}$	0.05	Normal [19]
3	Load	Wind speed, V_o(m/s)	36.8	$(0.084\text{-}0.18)\mu_V$	0.084-0.18	Gumbel [15]

3.3 Structural design case and reliability estimation

With a life of 20 years, the billboard structures designs have a wind speed $V_o = 36.8m/s$. So, according to in [5], the standard value of wind pressure is determined as $W_o = 0.613V^{20}x10^{-3} = 0.83kN/m^2$. Analysis results indicated that the column foot section is the most dangerous, it have the moment M= *5515.39 kNm* and axial force N= *-154.52kN*.

For billboards, the following conditions must be checked:

- Check the buckling of branch columns, $\sigma_1 = 20.15MPa < f.\gamma c=24.43MPa$, *OK*
- Check local buckling of the column: $\sigma_c = 18.07MPa < \sigma_{lim} = 40.46MPa$, *OK*
- Check the global stability of the column (compressive strength): $\sigma_f=21.02MPa<f.\gamma c=24.43MPa$, *OK*.
- Horizontal transfer conditions guaranteed.

For effective design, the stress limit $\sigma\approx 0.9f_y/(\gamma_m.\gamma_c)$. The analysis results show that the most dangerous of billboard is the loss of overal stability of column. Therefore, this study focus on the global stability of column structure under of random factors in Table 7, the limit state function has the form:

$$g(X) = f\gamma_c - \sigma = f\gamma_c - \frac{N_1}{\varphi_{min} A_1} > 0, \qquad (11)$$

In which: N_1 - total axial force on one side of compression; A_1 - the area of 2 branches on the side of the compressive surface; φ_{min} - determined from the conventional slenderness $\bar{\lambda}$, equivalent slenderness λ_0.

To assess the system reliability of the billboard frame, Matlab program is used to implement Monte Carlo simulation, with N = 10^5 samples (Fig. 8, Fig. 9).

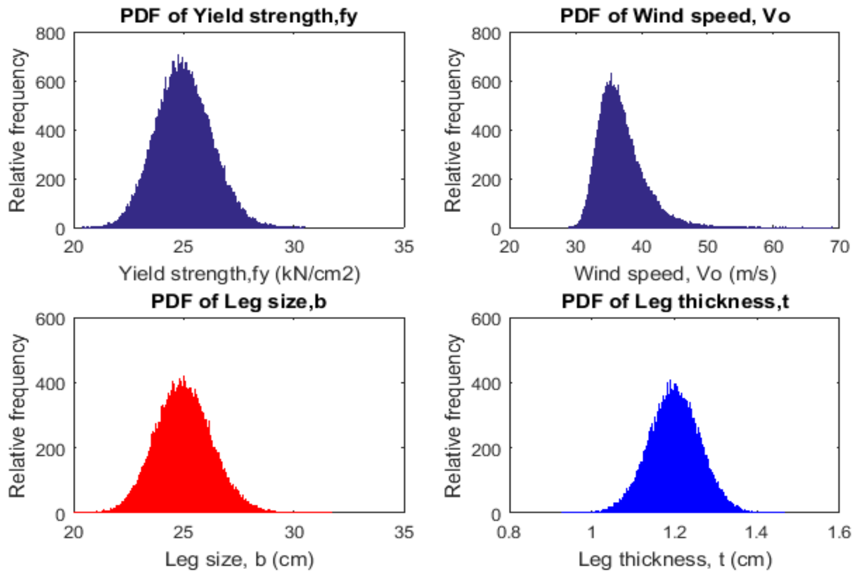


Figure 8. Probability density function (PDF) of Yield strength (fy), Wind speed (Vo), Leg size (b), Leg thickness (t)

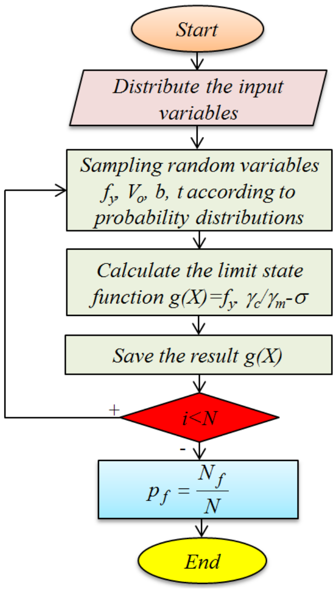


Figure 9. Flowchart of Monte Carlo simulation.

Table 6. Relation between Mean and standard deviation of windload

μ_{Vo} (m/s)	36.8	36.8	36.8	36.8	36.8	36.8
σ_{Vo}(m/s)	0.9	1.8	2.7	4.4	5.3	6.1
CV_{Vo}	0.024	0.049	0.073	0.120	0.144	0.166
μ_{Wo} (kN/m^2)	0.838	0.8388	0.8452	0.8577	0.8667	0.8765
σ_{Wo} (kN/m^2)	0.0414	0.084	0.128	0.2133	0.2612	0.3072
CV_{Wo}	0.05	0.100	0.15	0.20	0.25	0.30

By the Gumbel density distribution of the wind speed, the mean, standard deviation, and coefficient of variations of wind pressure obtained from the results from Eq (1) are presented in Table 8 and Fig.10 indicate that the coefficient of variation of wind pressure is 2 to 2.2 times those of wind speed.

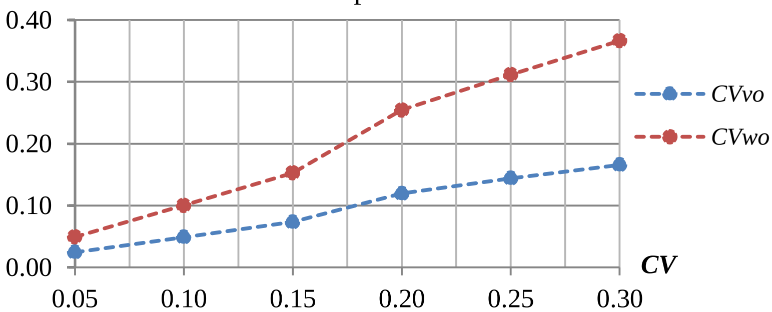
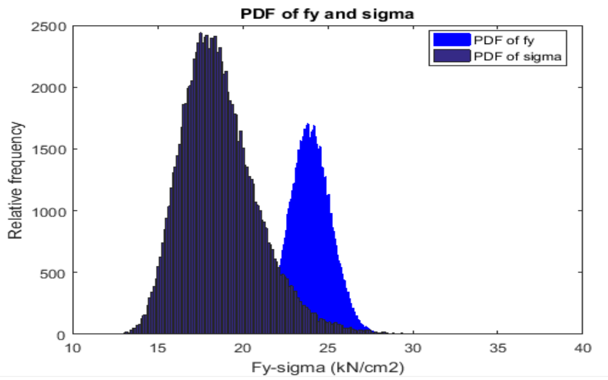


Figure 10. Relation of coefficient variation of wind speed and win pressure

4. Result

Analyzing the reliability of the billboard structure in the 5 different cases, are displayed in Table 9. The failure probability distribution of case 3 and the reliability margin M are presented in Fig.11 and Fig.12, respectively.



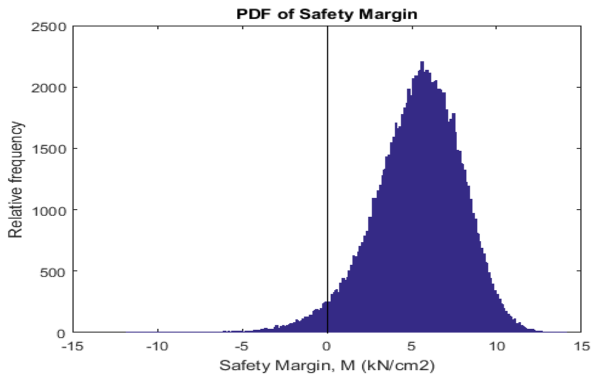


Figure 11. PDF of Yield strength (fy), stress (σ)

Figure 12. PDF of Safety margin, M

Table 9. Case of analysis

N°	Case of safety margin		coefficient of variation, CV			
			CV_{Wo}	CV_{fy}	CV_b	CV_{tf}
1	Case 1:	$\gamma_1 \approx 0,1$	0,05 →0,3	0,05	0,05	0,05
2	Case 2:	$\gamma_2 \approx 0,15$	0,05 →0,3	0,05	0,05	0,05
3	Case 3:	$\gamma_3 \approx 0,2$	0,05 →0,3	0,05	0,05	0,05
4	Case 4:	$\gamma_4 \approx 0,25$	0,05 →0,3	0,05	0,05	0,05
5	Case 5:	$\gamma_5 \approx 0,3$	0,05 →0,3	0,05	0,05	0,05

In which: cases considered on the relationship between the safety margin of the structure and the strength of materials: case(i): $\gamma i = \mu_{Mi}/(f_y \gamma_M \gamma_c)$, i=1..5.

Reliability-based design has found wide application in structural engineering [16], for example as the basis of the partial safety factors applied in the Standards [20] [21], the target reliability index (β) is given for the working life and related not only to the consequences but also to the relative costs of safety measures, see Table 10, Table 11.

Table 10. Target β-values for elements (lifetime), ISO 2394:1998 **[22]**

Relative costs of safety measures	Consequences of failure			
	Small	some	moderate	great
High	0	1.5	2.3	3.1
Moderate	1.3	2.3	3.1	3.8
Low	2.3	3.1	3.8	4.3

Table 11. Classification of reliability for different periods according to (EN 1990 2002) **[20]**

Reliability classes	Failure consequences Small	Reliability index		Examples
		1 year	50 years	
RC3	0	5.2	4.3	Bridges, public buildings
RC2	1.3	4.7	3.8	Residences, offices
RC1	2.3	4.2	3.3	Agricultural builidings

According to [20], billboards can be classified into the third class (RC1), in which the target of structure reliability value (β) is select of 4.2 for one year. Then, the reliability level corresponding to arbitrary remaining working life can be expressed as follows:

$$\beta_{tref} = \Phi^{-1}\{[\Phi(\beta_1)]^{tr}\} \qquad (12)$$

where β_1 - target reliability index, which is taken from Table 11 for a relevant reliability class with the reference period t_{ref}= 1 year. Thus, β≈3.34 should be considered for t_{ref}= 20 years of the billboard structure.

5. Discussion

Table 12 shows the analyzed results, in which, reliability index (β), reliability (P_s), probability of failure (P_f) of 5 cases correspond to different safety margins. Figure 13 shows the relationship between reliability (P_s) and standard deviation of wind pressure in 5 safe marginal cases.

Table 12. Characteristic reliability

No	Safety margin	Characteristic reliability	Variable coefficients of wind pressure, CV_{Wo}					
			0.05	0.1	0.15	0.2	0.25	0.3
1	Case 1:	P_s=	0.98295	0.94382	0.89887	0.85632	0.81977	0.79462
	γ_1=0.1	P_f=	0.01705	0.05618	0.10113	0.14368	0.18023	0.20538
		β=	2.12	1.59	1.28	1.06	0.91	0.82
2	Case 2:	P_s=	0.99324	0.96594	0.92869	0.88985	0.85325	0.82708
	γ_2=0.15	P_f=	0.00676	0.03406	0.07131	0.11015	0.14675	0.17292
		β=	2.47	1.82	1.47	1.23	1.05	0.94
3	Case 3:	P_s=	0.99859	0.98486	0.95674	0.92735	0.89473	0.86777
	γ_3=0.2	P_f=	0.00151	0.01514	0.04326	0.07265	0.10527	0.13223
		β=	2.97	2.17	1.71	1.46	1.25	1.12
4	Case 4:	P_s=	0.99968	0.99374	0.9774	0.95387	0.92577	0.90285
	γ_4=0.25	P_f=	0.00032	0.00626	0.0226	0.04613	0.07423	0.09715
		β=	3.41	2.50	2.00	1.68	1.44	1.30
5	Case 5:	P_s=	0.99994	0.99739	0.98751	0.96953	0.95089	0.92638
	γ_5=0.3	P_f=	0.00006	0.00261	0.01249	0.03047	0.04911	0.07362
		β=	3.85	2.79	2.24	1.87	1.65	1.45

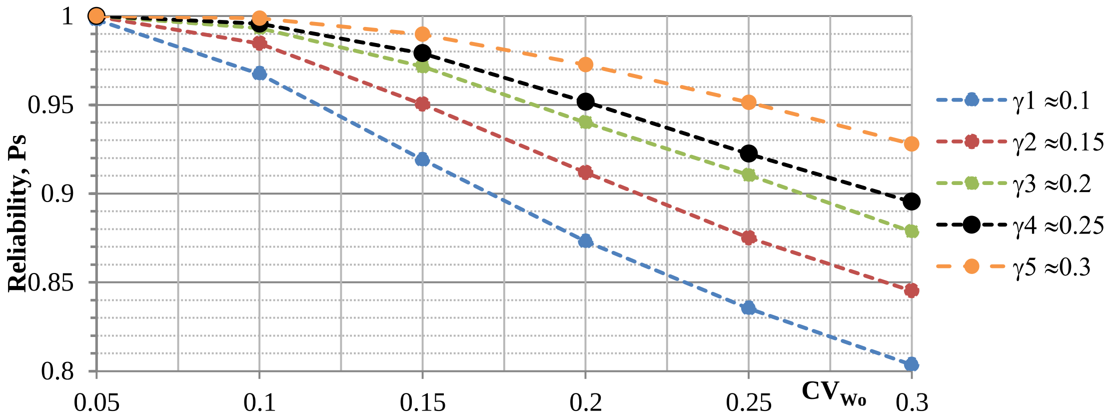


Figure 23. Reliability analysis following to the cases

From Table 12 and Figure 13 notice that: The standard deviation of the wind pressure is small (i.e CV_{Wo} =σ/μ=0.05) and the safety margin with γ_4=0.25, γ_5=0.3) then β is 3.41 and 3.85, the reliability is 0.999 and 0.9999. When CV_{Wo} = 0.05, the safety margin is γ=0.15-0.2 and CV_{Wo} = 0.1, the safety margin is from 0.2-0.3, β value has a pretty similar value 2.47 ÷ 2.79, the reliability is quite low P_s= 0.98÷0.99. When CV_{Wo} from 0.1, the reliability decreases rapidly (the slope of the lines in Fig. 13 increases gradually), the damage of the structure is more likely. It can be said that the choice of safety margin has a great impact on structural reliability, the safety margin greater, the structure more secure. With the conventional design, the safety margin is usually 0.1-0.15, but when considering the randomness of the calculated quantities, this safety margin needs to be increased [23], but the selection of the safety margins need to consider economic factors because then will use more materials.

6. Conclusions

This study assessed the safety of billboards in Ho Chi Minh City and neighboring provinces due to a number of random factors. Based on the results of the studies in sections 3 and 4, a density chart of four random quantities such as wind speed, steel strength and column section size has been developed. The main impact on the billboard is the wind load, so the evaluation of the standard deviation of wind speed and wind pressure is taken from the standard [4,5], the results indicate that small changes in

wind speed lead to large changes in wind pressure in unpredictable climate change conditions. Therefore, considering the value of wind load should be carefully considered for the designer.
The Monte Carlo simulation is used to analyze reliability with the state function being the global stability condition of the billboard column, paying attention to the relationship between random variables (Table 7) and the safety margin.
In addition, analysis of many shapes of columns (2 branches, 3 branches), type of load (dynamic components of the wind, due to subsidence of the ground, etc.) and dimension factors (distance between column branches, branch length ...) will do in the next study.
State management agencies need to have regulations and guidelines to evaluate the quality of outdoor billboards over time to ensure safety for society.

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