Along-wind dynamic analysis and determination of gust loading factor (GLF) for large single-column billboards

Nahmat Khodaie[1]

[1]Assistant Professor, Islamic Azad University, Khormuj Branch, Khormuj, Iran

* Nahmat.khodaie@iau.ac.ir

ABSTRACT

The effective role of billboards for advertising has led to the expansion of their use in open spaces and public places. The large panel area and light weight have made billboards sensitive to wind, and many cases of their damage have been reported recently. The design of structures against wind force is generally done with the gust loading factor (GLF) method. However, this method is specific to tall structures in most codes and standards, and there are no relations for billboards. In this research, the along-wind responses and the GLF have been calculated for large single-column billboards using frequency domain analysis of MDOF models using MATLAB software. First, an example of a tall billboard was presented and the responses of the structure and the GLF were determined for it, and the effect of basic wind speed and area roughness on the GLF was investigated. Then, billboards with different geometric specifications were designed and analyzed against wind load. According to the results, aerodynamic damping was one of the important factors limiting vibration, especially in rough areas. The GLF increased with the decrease of structure's height and increase of ground roughness, in such a way that it reached 4.71 for the urban area and 10 meters high billboard, which indicates the high importance of vibrations of billboard is in this situation. Due to the high dynamic response, the safe and resistant design of these structures requires the accurate determination of the GLF.

KEYWORDS

Gust loading factor, Along-wind response, Large billboards, Aerodynamic damping, Frequency domain analysis

1. Introduction

Billboards are light-weight structures with a relatively large area under wind loads [1, 2]. Possible wind-induced damage to these structures not only causes significant economic losses, but also threatens the safety of pedestrians [3]. Vibrations caused by wind can cause fatigue and premature failure of billboards [4]. Most of the studies on billboards have been in the field of determining the overall or local wind pressure coefficient, the effect of wind direction, screen porosity and similar cases, and their dynamic response has been less investigated. Some researchers investigated the pressure coefficients and drag force of panels with different boundary conditions using wind tunnel tests and studied the effect of wind direction and the role of panel porosity [5, 6]. Similar studies investigated large single-panel, double-panel and V-shaped billboards [7, 8]. In this research, the static and along-wind dynamic responses and the gust loading factor (GLF) for large single-column billboards have been determined. First, the results for a billboard extracted from a previous study are presented, and then, billboards in the height range of 10 to 25 meters are conceptually designed and investigated.

2. Research basics

The structure was modeled as a cantilever beam with the masses concentrated in the nodes. The structural damping was assumed to be one percent. Aerodynamic damping was determined from the relationship presented in references [1 and 9]. The response of the structure was calculated using the random vibrations theory. The variance of the displacement of the structure in the *i*th degree of freedom was calculated using the following formula:

$$E\left[x_i^{\,2}\right]=\int_{-\infty}^{+\infty} S_{x_{ii}}\left(\omega\right)d\omega \qquad (1)$$

which $S_{x_{ii}}\left(\omega\right)$ is the *i*th member on the main diagonal of the response spectral density matrix. The GLF is defined as the ratio of the total along-wind response of the structure (the sum of the static and the dynamic responses) to the static response [10]:

$$C_g = 1+g_p\left(\frac{\sigma}{\mu}\right) \qquad (2)$$

where μ is the average loading effect, g_p is the peak coefficient, and σ is the standard deviation of the loading effect. The logarithmic law is adopted for the wind velocity and the along-wind dynamic force, which is dependent on the fluctuating wind speed, was determined based on the Von Karman's wind velocity spectrum.

3. Properties of the Structure and other assumptions

The schematic configuration and dimensions of the studied billboard extracted from reference [2] are shown in Fig. 1(a). The fundamental period of the structure along the perpendicular to the board plane is determined as 0.95 seconds. The structural model of the billboard was considered as a 14-degrees of freedom system with beam elements and the stiffness of the board was ignored in the structural model (Fig. 1(b)). The hourly average base speed was assumed to be between 0 and 40 m/s. The response of the structure was determined using the frequency domain analysis and the random vibrations method by programming in MATLAB software.

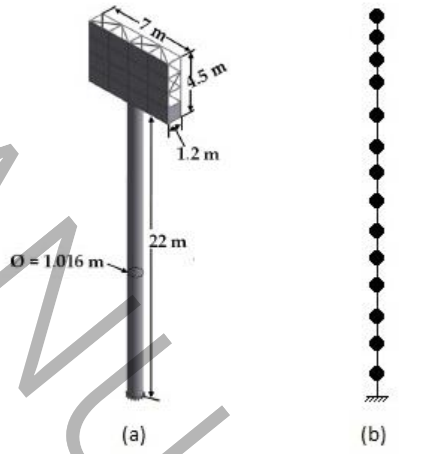

Fig 1. (a) General design and dimensions of the studied billboard [2] (b) the MDOF analytical model of the structure

4. Analysis and results

For the billboard introduced in the previous section, Fig. 2(a) shows the aerodynamic damping parameters for the three studied terrains, versus the basic wind speed. According to this figure, the aerodynamic damping in the open terrain is higher than suburb and city terrains. In such a way that its value reaches 21.89% for a wind speed of 40 m/s in the open area. Fig. 2(b) shows the changes in the GLF for the three terrains. The GLF in urban areas is higher than other terrains. High ground roughness, low aerodynamic damping and low average wind speed in urban areas compared to other areas are the main reasons for high GLF in this area. The value of the GLF in this terrain is about 3.35 for high speeds, which shows that the total maximum response of the structure is 3.35 times the static response.

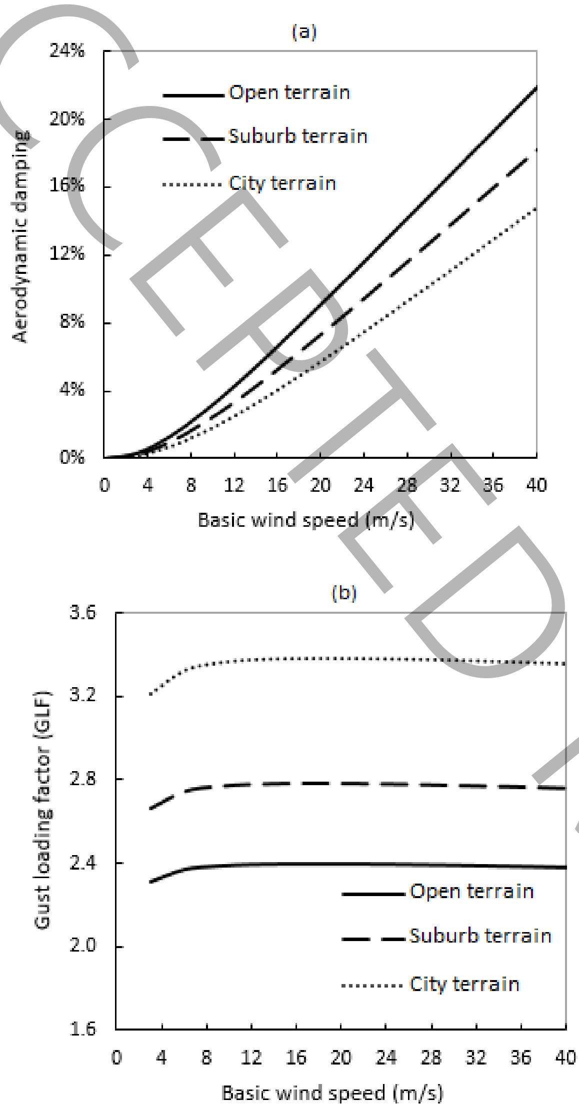

Fig. 2 Variations of a) aerodynamic damping and b) GLF versus basic wind speed for open, suburban and urban terrains

5. Conclusions

The general results of the research for the studied structures are as follows:

For the example billboard, the GLF in the open terrain was in the range between 2.3 and 2.4. This factor was higher in city and suburb terrains due to the high ground roughness, low aerodynamic damping and low average wind speed. For the basic speed of 40 m/s, the values of GLF in open, suburb and city terrains were obtained as 2.38, 2.76 and 3.35, respectively.

In the case of billboards conceptually designed with different geometric specifications, for constant height, a slight difference in the GLF was observed. With the decrease in the height of the billboard, due to the increase in the surface roughness and the decrease in the average wind speed and aerodynamic damping, the GLF increased. The average GLF for heights of 10, 20 and 25 meters in the open terrain was determined as 2.85, 2.54 and 2.45, respectively. The average values of GLF for open, suburb and city terrains were equal to 2.61, 3.11 and 3.95, respectively.

Based on the results of this research and considering the wide range of changes for GLF and its complexity, it is recommended to pay enough attention and accuracy in calculating and determining the GLF, especially in the cases of rough terrains and low billboard height.

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