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Evaluating Responses of Regular and Irregular Concrete High-rise Buildings under Wind Load by Using Dynamic and Static Analysis

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ABSTRACT

Equivalent static wind loads based on the gust load factor, GLF, and the base moment gust load factor, MGLF, are two of the most accepted approaches by relevant codes and standards such as ASCE-7 to evaluate the response of structures. Furthermore, dynamic time history analysis can be performed by using a generated artificial time series for wind flow. In this paper, three concrete buildings with 36 stories are considered, including one case with a regular shape in height and two cases with set-backs to be representative of irregularity in height. The structural response under wind load is evaluated using the equivalent static (GLF or MGLF) method and dynamic time history analysis. The results are compared to see the accuracy of equivalent static methods for regular and irregular buildings.

1. INTRODUCTION

In the design phase of building, one of the most important concerns of structural engineers is to evaluate logically and accurately loads which act on the structure, including wind load. High-rise buildings should withstand larger lateral loads because of increasing mean wind pressure by the elevation within the boundary layer. Moreover, since frequency contents of wind flow in the boundary layer have more energy in lower frequencies (larger time period), flexible structures such as tall buildings are more susceptible to wind load. It is essential to choose an appropriate approach to calculate wind load and structural response correctly for obtaining a proper assessment of building performance. In this study, dynamic time history and static analyses are used to evaluate the response of high-rise building structures and the results are compared.

2. MODELING ASSUMPTION

Three, 36-story concrete buildings with a total height of 126 m were considered; one case has a regular shape in height, while other two cases have step-backs as shown in Fig. 1.

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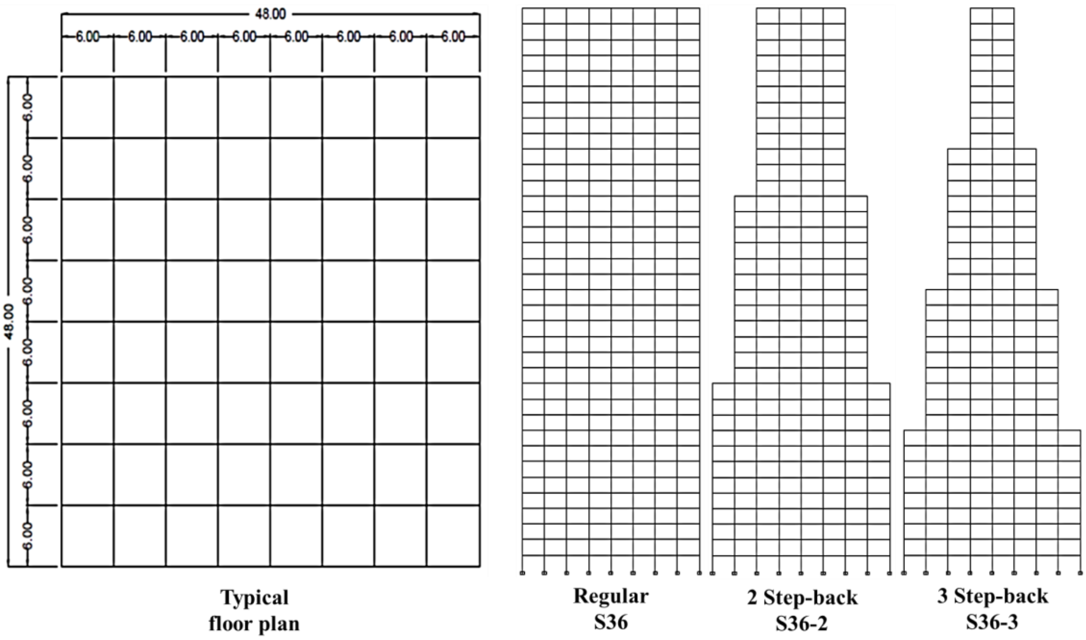

Fig. 1 Structural configuration

The height of each story and the span length are 3.5 and 6 m, respectively. Step-backs are located at the heights of 42 and 84 m in Model S36-2 and at the heights of 31.5, 63 and 94.5 m in Model S36-3. It is assumed that the facade of buildings is smoothly changed throughout the height and the step-backs cannot affect aerodynamics characteristics of structures.

All buildings are designed for gravity loads, where 5 and 2 kN/m^2 are considered for dead and live loads, respectively, and 30 MPa and 27.39 GPa assumed for specified compressive strength and modulus of elasticity of concrete, respectively. It is assumed that all beam-to-column connections are rigid, building supports are fixed, and rigid diaphragm exists for each floor. Analysis and design have been done by using ETABS-2016. All of the beams are considered to have a rectangular shape section with 400 and 600 mm, and the width of the columns ranges from 350 to 1000 mm.

3. DYNAMIC BEHAVIOR OF STRUCTURES

Fundamental frequency and damping are substantial dynamic properties of a structure. In case of wind load, the damping ratio is considered smaller than the value for seismic load because it is desirable that the structure remains in the elastic range. ISO (1997) suggested 1.5 percent for concrete buildings, which is utilized for the calculation of this study. Since the wind turbulence-structure interaction is sensitive to fundamental frequency, it is very important to calculate this parameter properly. Due to a lot of simplification in structural modeling (e.g., panel zone behavior, infill wall-frame interaction, etc.), the use of representative fundamental frequency is important for verification of analytical results, which is calibrated based on a wide range of real structures. A wide range of research has been done and many equations were proposed, such as the research by Saketa et al. (2003) and Goel and Chopra (1997).

Chapter 12 of ASCE 7 (2010) for seismic design includes a couple of equations based on the lateral resisting system for the calculation of approximate fundamental frequency. Here, to take into account the maximum impact of wind turbulence-structure interaction, the equation from ASCE 7 is chosen for concrete moment frames and high seismic zone, as it is also used by engineers to design for the seismic load. For this reason, the mass of structure is adjusted to get same fundamental frequency with the equation.

4. WIND LOAD

Since the wind pressure on the structure is not constant, it is usually decomposed to mean (static load) and fluctuation (dynamic) components. Based on ASCE 7, the mean value of wind pressure is calculated by using Eq. (1).

$$q(z) = 0.613 C_D K_z K_{zt} V^2 \equiv \frac{1}{2}\rho_{air} C_D V(z)^2 \tag{1}$$

where V is basic mean wind speed and here assumed to be equal to 40 m/sec; K_{zt} is a topographic factor to consider wind speed-up over hills, etc., which is not dealt with the scope of the paper and is just assumed to be equal to one; K_z is velocity pressure exposure coefficient to take into account the vertical wind speed pattern in the boundary layer, which is calculated based on terrain exposure and chosen to be Type D in this study; and C_D is drag coefficient for considering aerodynamics of a structure, which is considered to be equal to 1.3 for all three cases of this study.

Design wind load is based on the peak value. In the equivalent static load procedure, the idea is to amplify the mean wind force to mitigate the peak response. The basic way is called Gust Loading Factor approach (GLF), which was proposed by Davenport (1967). In this method, equivalent static wind load is calculated by the mean wind force multiplying by gust load factor.

To overcome the disadvantage of the method, Base moment gust factor (MGLF) was proposed by Zhou and Kareem (2001), by decomposing gust factor and applying this component to mean, background and resonant components separately. The gust factor and its components are calculated from Eq. (2), and general procedures for calculating wind load based on GLF and MGLF are illustrated in Table. 1. All the notations are deferred to the original literature (Zhou and Kareem, 2001).

$$G = \bar{G} + \sqrt{G_B^2 + G_R^2}$$

$$\bar{G} = 0.925\frac{1}{1+1.7g_v.I_{\bar{Z}}} \qquad G_B = 0.925\frac{1.7I_{\bar{Z}}.g_Q.Q}{1+1.7g_v.I_{\bar{Z}}} \qquad G_R = 0.925\frac{1.7I_{\bar{Z}}.g_R.R}{1+1.7g_v.I_{\bar{Z}}} \tag{2}$$

Table. 1 General steps of calculating wind load based on GLF and MGLF method

GLF method	MGLF method	
$P = G.\bar{P}$	$P = \bar{\mathbf{P}} + \sqrt{\mathbf{P}_{\mathbf{B}}^2 + \mathbf{P}_{\mathbf{R}}^2}$ $\bar{\mathbf{P}} = \bar{G}.\bar{P}$ $\mathbf{P}_{\mathbf{B}} = G_B.\bar{P}$ $\mathbf{P}_{\mathbf{R}} = C_M.M_R$	$\bar{M} = \sum \bar{P}.z$ $M_R = G_R.\bar{M}$ $C_M = \dfrac{W.\phi}{\sum W.\phi.z}$

Here, $\bar{P}$ is mean wind load and calculated based on mean wind velocity pressure, *q(z)*; $\mathbf{P_B}$ and $\mathbf{P_R}$ are background (peak value of wind load itself) and resonant response (peak dynamic response of the structure), respectively. Moreover, the background and resonant response can be calculated directly by applying appropriate dynamic time history analysis. Power spectral density (PSD) of the gusty component, which is representative of the energy of the wave in each frequency, can be obtained for a turbulence intensity, and then by applying some noise, artificial wind time series could be obtained through inverse Fourier transforms. Based on the review done by Zhou et al. (2002) on major international codes, Von Karman and Kaimal PSDs are the most common PSD functions used in the codes. Following the wind load chapter of ASCE 7, Kaimal formulation is utilized and turbulence intensity is calculated at the 60 percent of building height.

The results from MGLF static analysis and peak values from dynamic time history analysis are matched well each other. The results from GLF static analysis are larger at the lower story and smaller at top stories in comparison with the other methods.

5. CONCLUSION

To sum up, three concrete high-rise buildings were considered and their responses to wind load were evaluated by different methods. Based on the results, MGLF methods and time history analysis had very close results. The comparison between the GLF and MGLF methods shows that the results from GLF method are more conservative for the lower part of the structures, while its results are smaller in top stories.

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