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Parametric study and comparison of overturning moment and base shear of tall buildings under earthquake and along-wind loads

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ABSTRACT: Increasing the population of large cities and the lack of construction area have increased tall buildings. In the present article, the overturning moment and base shear due to the along-wind and earthquake loads have been compared for tall buildings. The buildings are assumed to be located in Tehran city on type 2 soil and the structure is regarded as a vertical cantilever beam. The along-wind and earthquake loads are computed using the gust-loading-factor method and the linear spectral approach, respectively. First, an example of the 120-m high building is presented and evaluated, and then, the effect of the height and aspect ratio parameters are examined in the ranges 80 and 200-m, and 5 to 10, respectively, for the two square and circular cross-sections. For the primary example, the earthquake overturning moment and base shear were dominated respectively by the first and second vibration modes. For the square and circular sections, the ratio of wind-induced overturning moment to the earthquake effect were 1.1 and 0.81, respectively. For the parametric study, the wind and seismic overturning moments were equal to each other at the specific values of the studied parameters, and the wind effects were dominant for the higher values of these parameters. For instance, for the square cross-section, the equal point of the overturning moment and base shear were respectively 110m and 175m. Finally, by increasing the height and aspect ratio, the wind forces were dominant.

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1- Introduction

Design of tall buildings is governed by lateral wind and seismic loads. Overturning moment due to the lateral loads is one of the main considerations in tall structures. The effect of wind and seismic loads on tall buildings is widely studied. However, previous studies generally investigated the effect of wind and seismic loads separately and limited studies compared their effect on tall buildings.

Moat codes and standards use the gust loading factor (GLF) method to estimate the along-wind dynamic response of tall buildings. This method was proposed by Davenport [1] and several modifications were proposed by other researchers [2-4]. Ali and Moon [5] divided the structural systems of tall buildings into two main categories: interior and exterior structures. Vibration control of tall buildings under wind dynamic loads is extensively studied in recent years [6-8]. The seismic response of high-rise buildings is evaluated in the previous investigations [9-11]. Some researchers compared the effect and demands of the wind and earthquake loads for tall buildings [12-14].

In the present article, the overturning moment and base shear due to the along-wind and earthquake loads are parametrically obtained and compared for tall buildings by the assumption that the building is located in Tehran. The effect of building height, aspect ratio and type of the building cross-section type are investigated on the effect of the lateral loads.

2- Methodology

The structural behavior of tall buildings under the lateral loads is assumed as a multi-degree-of-freedom vertical cantilever beam with the masses lumped at the nodes. This assumption is widely used in similar studies. The equation of motion for a discrete MDOF system under dynamic loads has the following general form:

$$\mathbf{M}\ddot{\mathbf{X}} + \mathbf{C}\dot{\mathbf{X}} + \mathbf{K}\mathbf{X} = \mathbf{F} \tag{1}$$

Where, M, C and K are mass, damping and stiffness matrices, respectively, X is the vector of structural displacements, and F is the vector of external forces. The along-wind load is computed using the GLF method provided

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in the Iranian national building code (Part 6) [15]. The external pressure of along-wind load can be obtained as:

$$p = I_w q C_e C_g C_p \quad (2)$$

Where, I_w is the importance factor, q is the basic pressure, C_e is the exposure factor, C_g is the GLF factor, and C_p is the pressure coefficient.

The seismic load is computed using the linear spectral analysis presented in the Iranian code of practice for seismic resistance design of buildings [16]. The equation of motion of the structure, presented by Eq. (1), can be stated in the following form using the modal analysis method:

$$\ddot{y}_i + 2\xi_i \dot{y}_i + \omega_i^2 y_i = \frac{P_i}{M_i} \quad (3)$$

$$P_i = \phi_i^T \mathbf{F}, \quad M_i = \phi_i^T \mathbf{M} \phi_i, \quad X = \phi \mathbf{y}$$

Where Mi, î$_i$ and ù$_i$ are mass, damping ratio and modal frequency, respectively. ϕ is the mode shapes matrix, and y is the modal displacement and ϕ_i is the ith mode shape vector. The effect of different modes is combined using the square root of the sum of the squares (SRSS) procedure.

In the first stage, the wind and seismic responses are obtained and compared for a primary example tall building. The example building height is assumed 120 m with two square and circular cross sections with the plan dimension 20 m. The structural stiffness is selected in such a way that the total wind-induced top-floor displacement is equal to the allowable limit provided for tall buildings [17]. Then, the effects of different parameters as the height of the building and aspect ratio, respectively, in the ranges 80-200m and 5-10 for the two square and circular cross-sections are investigated.

3- Results and Discussion

The results of the effect of the building height and aspect ratio related to the parametric study are presented here. In order to investigate the effect of the height of the building, the lateral forces are obtained for a building with a plan dimension of 20 m, and a height range 80-200m. Figure 1 shows the variation of base shear versus building height for the square cross-section. Base shears due to wind and seismic loads are equal at the height 145 m. For the higher values of the building height, wind base shear is more than the seismic one. For h=200 m, wind shear is 17% more than the seismic shear force.

Figures 2 and 3, show the variation of the overturning moment versus building height for the square and circular

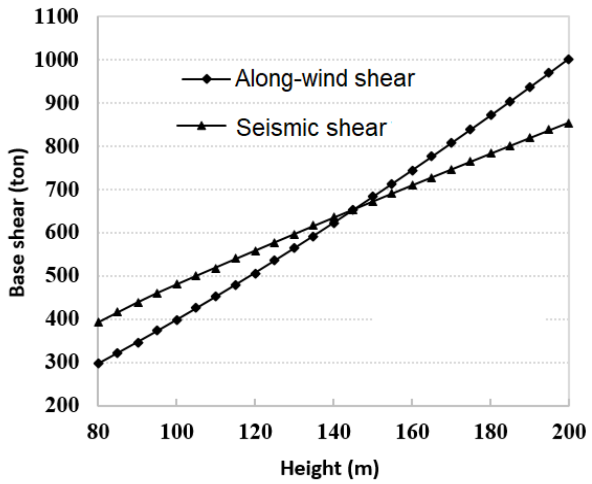

Fig. 1. Variation of base shear versus building height for square section

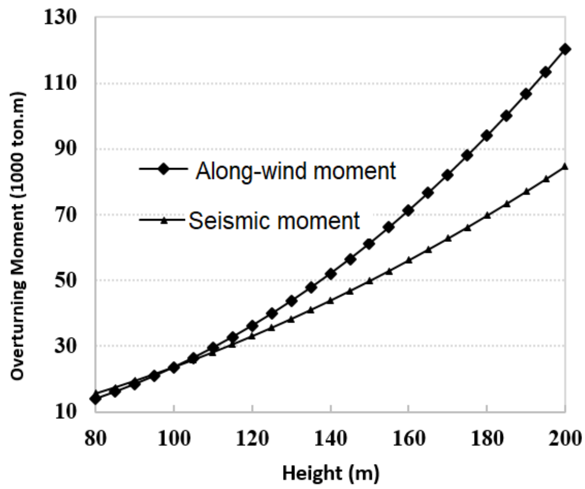

Fig. 2. Variation of overturning moment versus building height for square section

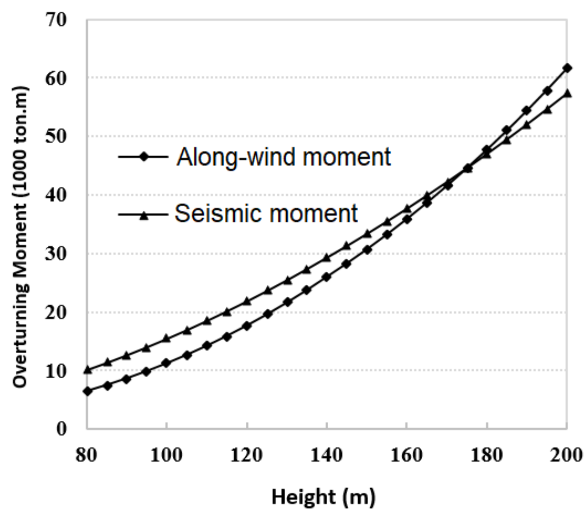

Fig. 3. Variation of overturning moment versus building height for circular section

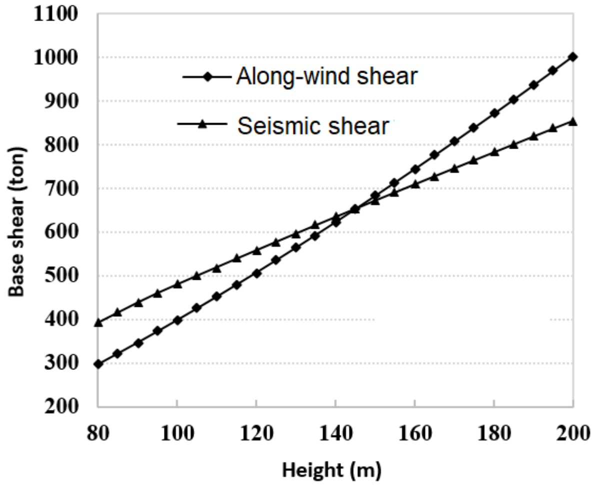

Fig. 4. Variation of overturning moment versus aspect ratio for square section

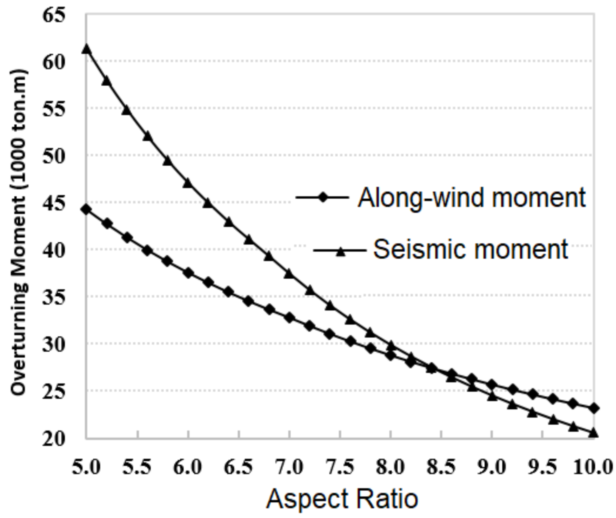

Fig. 5. Variation of overturning moment versus aspect ratio for circular section

cross-sections, respectively. The seismic and wind-induced overturning moments are equal at h=100 m and 175 m, respectively, for square and circular cross-sections. The ratio of wind to seismic overturning moment increases by increasing the building height. This result indicates that the wind forces govern the overturning moment by increasing building height.

In order to examine the effect of the aspect ratio, the lateral forces are obtained for a 150-m high building with the aspect ratio in the range of 5-10. Figures4 and 5, show the variation of the overturning moment versus the aspect ratio for the square and circular cross-sections, respectively. The seismic and wind-induced overturning moments are equal at the aspect ratios of about 5.5 and 8.5, respectively, for the square and circular cross-sections. The ratio of the wind to the seismic overturning moment increases by increasing the building height. By increasing the aspect ratio, the overturning moment decreases for both square and circular cross-sections.

4- Conclusion

In the present study, the overturning moment and base shear of tall buildings under wind and earthquake loads are parametrically obtained and compared by the assumption that the building is located in Tehran. The structural behavior of the building is regarded as a vertical cantilever building. The along-wind and seismic loads are estimated using the gust loading effect and linear spectral methods, respectively. Some of the main results can be summarized as follows:

By increasing the building height, wind lateral forces govern the overturning moment and base shear compared with the seismic effects. For instance, for h=200 m, the wind-induced overturning moment is 42% more than that of the seismic loads for square cross-section.

The ratio of the wind-induced overturning moment and base shear to those of seismic loads increases by increasing the aspect ratio. For the aspect ratio of 10, the ratio of wind to seismic overturning moment are 1.13 and 1.49 for circular and square sections, respectively.

Using a circular cross-section for tall buildings compared with the circular section results in lower lateral forces. For instance, for a 200-m high building, the overturning moment for the circular section is 49% less than that for the square section.

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