Reliability Analyses of the High-rise Building′s Vertex Displacement

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Abstract—The main purpose is to calculate the reliability of high-rise building under wind load. According to the structure of the wind response calculation theory, ANSYS static analysis module and the random vibration analysis module was used to calculate the high-rise building under the action of static wind load and fluctuating wind load wind to the displacement. It is feasible to analyze the reliability of high-rise building by using the method. The distribution form of this method is relatively old, and it remains to be further calculated.

Keywords-The High-rise Building; the Downwind Response; Displacement control; Reliability; ANSYS Structural Analysis

I. INTRODUCTION

The reliability of structure[1] refers to the probability of performing a predetermined function, within the prescribed period of time, under specified conditions. It is developed on the basis of People's understanding in uncertainty factors during in the influence on engineering design, construction and use process reliability. The reliability is safety, applicability and durability. The Main control loads are wind and earthquake Horizontal loads for tall buildings. The seismic load does not often appear, so the wind loads became the major consideration in process of structural design. A schematic diagram of the horizontal load of high rise structure is shown on the right of Fig. 1. Therefore, in order to ensure the safety and applicability of the high-rise structure under wind load, we must meet the requirements of strength, stiffness and comfort. Wind load is a random dynamic load, performance of the structure of the material is random, and the structural reliability theory, different to previous design will multiply it by certain, assurance coefficient as determine the amount to calculate. In the reliability theory, the randomness of wind load and resistance, and the relationship between safety and economy are balanced on the level of probability.

In this paper, we presented the reliability analysis of the wind direction displacement control of high rise building structures under wind load as an example of tall building. This analysis is given by the building structures" annual maximum wind pressure distribution in “Uniform standard for architectural design"(GBJ68-84) on the basis, combined with high-rise building wind to the wind characteristics and the related design specifications are given.

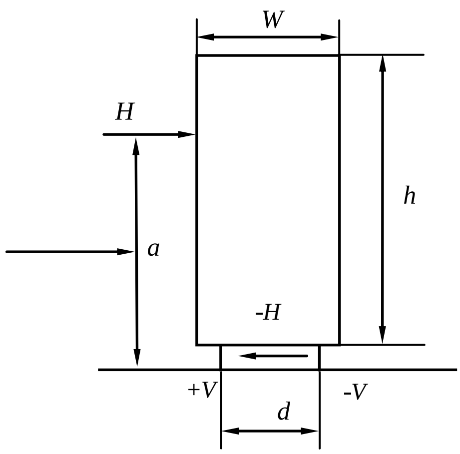

Figure 1. Schematic diagram of horizontal load of structure resistance

II. DISPLACEMENT LIMIT VALUE STANDARD OF HIGH RISE BUILDING STRUCTURE[2]

In the high-rise building structure design, because of its "high, flexible" and other characteristics, must control the lateral displacement. According to the bearing capacity limit state design, you must limit its horizontal displacement, to prevent due to gravity generate second-order delta effect sometimes make the building suddenly collapsed. For the serviceability limit state. First of all, we must control displacement in a relatively small range, allows non structural members such as lifts and doors and other parts of the component has the right amount of displacement; secondly, to avoid too much shock caused by stiffness reduction, and avoid load redistribution to the non load bearing parts such as filling wall, maintenance wall, glass curtain wall, etc; Third, the structure must have full rigidity in order to prevent the larger dynamic movement when people are not feeling comfortable , to avoid overly sensitive flexible state that construction work.

At present domestic and foreign all use horizontal displacement index to estimate the lateral rigidity, which is defined as the ratio of the maximum displacement and the total height of the building. In addition, the horizontal displacement index corresponding to the layer height can be used to control the local deformation of the building. For the general structure of the high-rise building, in early in simplified calculation, control of the structure under the horizontal loads the top horizontal displacement, and leave adequate room, general can also satisfy the structural constraints in the horizontal displacement of the lower load level[3].Therefore, in the calculation of the reliability, only the horizontal displacement of the structure vertex is considered[4].

TABLE I. DISPLACEMENT LIMITS OF TALL BUILDINGS UNDER WIND LOAD

Type of structure			Vertex displacement limit $[u/H]$	Inter story drift limit $[\Delta u/h]$
Frame	Infilled wall	Solid brick	1/450	1/400
		Hollow brick	1/500	1/500
Frame--Shear wall			1/800	1/750
Frame--tube structure				
Tube-in-tube structure Frame tube structure			1/900	1/700
Shear wall structure			1/1000	1/800

III. HIGH-RISE BUILDING STRUCTURAL ANALYSIS AND CALCULATION

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According to "Uniform standard for architectural design"(GBJ68-84, the annual maximum wind pressure of the structure W_{0s} is subject to extreme I type distribution, and the distribution function is:

$$F_{W_{0s}}(w) = \exp\left[-\exp\left(-\frac{w - 0.364 w_{0k}}{0.157 w_{0k}}\right)\right] \quad (1)$$

The mean and standard deviation are respectively：

$\overline{W}_{0s} = 0.455 w_{0k}$ and $\sigma_{W_{0s}} = 0.202 w_{0k}$ 。

Considering the annual wind pressure, the vertex displacement of the structure is calculated. It can be assumed that the probability distribution of the vertex displacement of the structure is I type, and then the probability distribution is:

$$F_{W_{0s}}(w) = \exp\left[-\exp\left(-\frac{w - t}{s}\right)\right] \quad (2)$$

Parameters t and s:

$$t = \overline{U}_m - 0.5772\sigma_{U_m};\ s = \frac{\sqrt{6}}{\pi}\sigma_{U_m} \quad (3)$$

The mean $\overline{U}_m$ and standard deviation σ_{U_m} of the vertex displacement of the structure are respectively：

$$\overline{U}_m = \overline{C}\,\overline{W}_{0s};\ \sigma_{U_m} = \sqrt{\overline{W}_{0s}^2\sigma_C^2 + \overline{C}^2\sigma_{W_{0s}}^2} \quad (4)$$

In the formula, $\overline{W}_{0s}$ and $\sigma_{W_{0s}}$ are the mean and standard deviation of the annual maximum wind pressure. In practical applications, as mentioned above, if the amount of C is a constant, thus the simplified formula is:

$$\overline{U}_m = C \cdot \overline{W}_{0s};\ \sigma_{U_m} = C \cdot \sigma_{W_{0s}} \quad (5)$$

Coefficient C is called the wind load effect coefficient of the vertex of the high building structure.

Although the above calculation model has a certain approximation, in the engineering design, the accuracy can also meet the requirements according to the reference[5]. In "Design and construction regulations for reinforced concrete high rise building structure"(JGJ3-91), it provides the wind load generated by the lateral displacement of the structure should be less than the provisions of lateral displacement limit value, in the calculation of the side when not considering gravity effect, only considering the wind load of single effect [2], so structure function can be expressed as[6]:

$$Z = \Delta_m - U \quad (6)$$

In the formula:

Δ_m ——refers to the product in the vertex displacement limit value and total building height h in the regulation, it is a constant and can be get in the table;

U——refers to structure vertex displacement under wind load.

The wind load and its effect coefficient in the structural apex displacement are considered as a whole. The failure probability is

$$P_f = \int_{\Delta_m}^{+\infty} f_{U_m}(w)\mathrm{d}w \quad (7)$$

Where, $f_{U_m}(w)$ is the probability distribution density function of the vertex displacement of the structure.

In this paper, a finite element model of a high-rise structure is established by using the engineering software ANSYS, and then the response of the average wind and fluctuating wind is analyzed. This structure belongs to the frame tube structure, and its geometrical model is shown in Fig. 2.

According to the local actual situation, the basic wind pressure is $w_{0k} = 0.75$ kN/m² in "Load code". According to the Unified standard for reliability (GB50068-2001) and the annual maximum wind pressure of the structure W_{0s} is subject to extreme I type distribution:

$$F_{W_{0s}}(w) = \exp\left[-\exp\left(-\frac{w - 0.364 w_{0k}}{0.157 w_{0k}}\right)\right]$$

The mean and standard deviation are respectively：

$\overline{W}_{0s} = 0.455 w_{0k}$ and $\sigma_{W_{0s}} = 0.202 w_{0k}$ 。

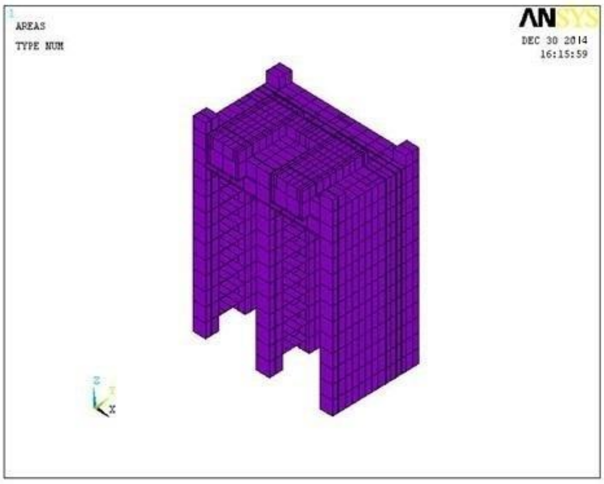

Figure 2. Schematic diagram of the structure of the plant.

Gravity has a positive effect on the lateral load of the structure, so this case only considers the effect of horizontal wind force, but not the gravity. Its peak factor is 2.2. Firstly, the maximum displacement of the structure under static wind load is calculated by using the static analysis module of ANSYS. Using the random vibration analysis module of ANSYS, the maximum displacement of the structure under fluctuating wind load is calculated. Afterwards, the whole displacement response of the structure is superimposed; then according to the previous method of structure design of the pulsating wind load equivalent static wind load, using ANSYS static analysis module to calculate the peak structural maximum displacement response value. The results of two methods are compared, and the results are shown in Table 2.

TABLE II. FAILURE PROBABILITY AND RELIABILITY OF DISPLACEMENT CONTROL

		node number	Node coordinates	Static wind response /m	Fluctuating wind response/m	total response/m	Failure probability	reliability
1	X	55	(0,45.8,93.5)	0.69E-2	0.32E-2	0.14E-1	3.33E-10	6.17
	Y	421	(73.6,45.8,93.5)	0.13E-1	0.75E-2	0.30E-1	4.87E-09	5.74
2	X	55	(0,45.8,93.5)	--	--	0.14E-1	4.66E-10	6.12
	Y	421	(73.6,45.8,93.5)	--	--	0.33E-1	3.30E-04	3.41

This high-rise building belongs to the frame tube structure, and the structure vertex displacement limit can be found in Table 1.1/800=1.25 E-3.The structure vertex displacement limit of this high-rise building in Table 3.

TABLE III. FAILURE PROBABILITY AND RELIABILITY OF DISPLACEMENT CONTROL

		node number	Node coordinates	total response/m	The ratio of the maximum displacement and the total height of the building
1	X	55	(0,45.8,93.5)	0.14E-1	0.14 E-3 < 1.25 E-3
	Y	421	(73.6,45.8,93.5)	0.31E-1	0.31 E-3 < 1.25 E-3
2	X	55	(0,45.8,93.5)	0.15E-1	0.15 E-3 < 1.25 E-3
	Y	421	(73.6,45.8,93.5)	0.34E-1	0.34 E-3 < 1.25 E-3

The structural displacement limits are generally determined by the material and the type of the structure and the practice and the experimental data. According to Table 3 shows that the ample degree of the structure is relatively large, and the displacement reliability analysis of the structure also meets the requirements. Therefore, according to the above structure calculation method is feasible.

IV. CONCLUSIONS

It can be seen from the example, the high-rise buildings vertex displacement of the structure controls the static reliability analysis method is feasible, and the calculation result is acceptable. However, this high-rise buildings vertex displacement of the structure control the static reliability analysis method relies on the computation model of the vertex displacement of tall building structures, think vertex displacement of the structure also obeys the type I extreme value distribution, assumed structure stiffness is constant. Therefore, the calculation model still needs to be further rationalized.

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