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Contrastive Study on Seismic Calculation Methods of the Structure - Example of Shifang Telecom Building under Wenchuan Earthquake

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***Abstract*-This paper analyzed the Shifang Telecom Building under 5.12 earthquake by finite element software SAP2000, then compared with three seismic calculation methodologies, including equivalent base shear method, mode breakdown responsive spectrum analysis and time-history method. The equivalent base shear method is the most simple, which can be used as the method of estimation and approximate treatment in the preliminary design phase. The mode breakdown responsive spectrum analysis is the main one, which can calculate the high-rise buildings, and the time-history method is a compensation method, which can calculate the complex high-rise building. At last the paper summarized the characters and the scope of application of the three methods. According to the change of the storey drift and force and seismic animation, the engineers can get intuitive and in- depth understanding.**

Key Words- equivalent base shear method;mode breakdown responsive spectrum analysis;time-history method;finite element analysis

I. INTRODUCTION

Currently, there are mainly three building seismic calculating methodologies, which are equivalent base shear method, mode breakdown responsive spectrum analysis and time-history method. Recently, there are so many earthquakes in China which caused huge loses, such as Wenchuan earthquake in 2008, Yushu earthquake in 2010, and Lushan earthquake in 2013, thus it is necessary that the engineers understand and study the building seismic calculating methods. This paper compared the above three methodologies with the scope application and characteristic, then performed seismic calculation as Shifang Telecom Building under Wenchuan earthquake by finite element software SAP2000, at last made engineers get a better grasp of seismic calculating of irregular structure.

II. BUILDING SEISMIC CALCULATING METHODS

A. Equivalent base shear method

In China, building seismic design and Codes [1] provide the application condition of equivalent base shear method, which is the height of building is not exceeding 40m, the building deformation is based on the shear deformation, and the quality and the rigidity are well distributed along the height of the building, when the building is vibrating, the drift is based on the first mode of vibration which is nearly a straight line.

1) The total earthquake action (the bottom shear force) F_{Ek} is:

$$F_{Ek} = \alpha_1 G_{eq} \tag{1}$$

Among the formula（1）, G_{eq} is the total equivalent gravity, and $G_{eq} = 0.85\sum_{i=1}^{n} G_i$, α_1 is a horizontal earthquake influence coefficient corresponded to natural vibration period of the building which can be got from the earthquake influence coefficient curve (Figure 1). [2]

2) The earthquake action of mass point in every storey is :

$$F_i = \frac{G_i H_i}{\sum_{k=1}^{n} G_k H_k} F_{Ek} \tag{2}$$

The earthquake action of calculating mode is shown in Figure 2.

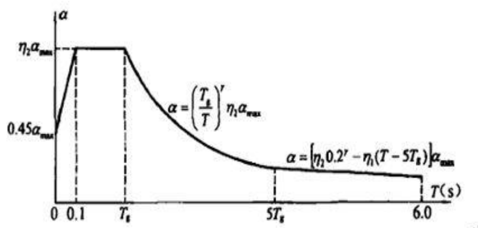

Fig.1. the curve of the earthquake influence coefficient

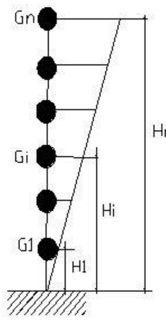

Fig.2. the mode based on equivalent base shear method

B. Mode breakdown responsive spectrum analysis

The Codes in China set that the seismic calculating of the building also needs mode breakdown responsive spectrum analysis except that it comforts to equivalent base shear method. The deformation is shear deformation, as well as flexural deformation, even is shear and flex deformation. The assumption of mode breakdown responsive spectrum analysis is:

1) The earthquake reaction is linear-elastic, which can be got by superposition principle.

2) The base of the building is rigidity.

3) The maximal earthquake reaction is that the building is in the most unfavorable condition.

4) The process of earthquake motion is smooth and random.

The procedure of mode breakdown responsive spectrum analysis is calculating the natural modes of vibration firstly, then calculating the maximal earthquake action corresponding to the proceeding modes of vibration, and calculating the internal force under the maximal earthquake action which has been already obtained, at last combining with the above maximal force which have been got, gaining the internal force of the building under the earthquake.

C. Time-history method

The Codes in China set that the building which is quite irregular, class A or exceeding the certain height needs additional seismic calculating by elastic time-history method in the frequent earthquake. When calculating the building deformation under the rare earthquake, should adopt elastic-plastic time-history method.

Time-history method is a dynamic analysis method which means we can attain the result by step-by-step integration straightly through dynamic formula（3）. By the Time-history method we can get the drift, velocity and acceleration of the every mass point under the earthquake, even the changing process of the internal force and the information.

$$M\ddot{x}(t)+C\dot{x}(t)+Kx(t)=-MI\ddot{x}_g(t) \quad (3)$$

Sum up the above three calculating methodology, we know that the equivalent base shear method is the most simple, and easiest to implement, mode analysis method is a little bit difficult to implement because it needs modal analysis and spectrum analysis, but in the above three methods the time-history method is the most difficult because it needs selecting the earthquake wave and modifying the earthquake wave, meanwhile needs iterative computation as well. However the software SAP2000 can complete the above three calculating methods because of its mature theory and simple operation.[3][4][5]

III. PROJECT OVERVIEW

STB is a reinforced concrete frame structure locating in the center of Shifang city, which is built in early 1980s. The total area is 2300m2, containing office and a bell tower. The office section is five-storey, with partial four-storey and bell tower sections nine-storey. Furthermore, the equipment mass on the 7th, 8th, 9th floor is 6 ton and steel tower on top is 10 ton. Figure 3 and 4 show the layout and elevation of the building.

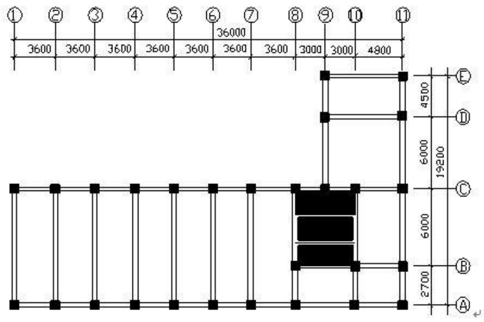

Fig.3. Layout of the structure

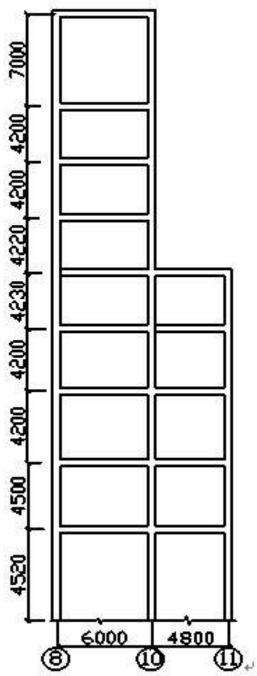

Fig.4. Elevation of the structure

Referred to related data, the building is C-class, with seismic fortification intensity 7 degree, design basic acceleration of ground motion is 0.10g, the ground is II-class, and the design earthquake classification is second. Though there are no equipment or steel tower designed on the 7th to 9th floor, those were installed without permission after STB was put into use. Both the equipments and the tower are disadvantageous to the seismic behavior of the structure.

Under the impact of Wenchuan earthquake in May 2010, STB had some damages in beams and columns on the 6th and the 7th floor in bell tower section, as shown in Figure 5 (a), (b).

(a) Damage of beam

(b) Damage of column

Fig.5. Earthquake damage in the bell tower

To discuss the above three calculating methodology, this paper set a building calculating mode by the finite element software SAP2000, which is shown in Figure 6.

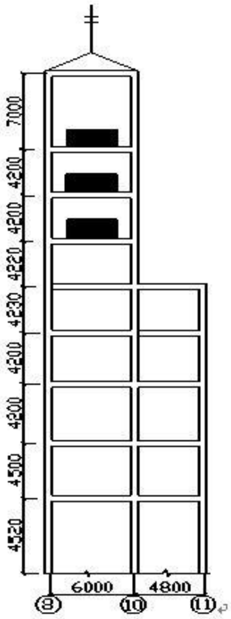

Fig.6. the building calculating mode

As the height of STB exceeds 40m, the seismic calculating is not fit to adopt equivalent base shear method. But the building is irregular, the seismic calculating adopts mode breakdown responsive spectrum analysis under the frequent earthquake and elastic time-history method as supplement.

IV. MODE BREAKDOWN RESPONSIVE SPECTRUM ANALYSIS

According to the site condition, seismic design classification and seismic fortification intensity and etc., referring to the code for seismic design, seismic influence coefficient is 0.08 under conventional earthquakes, characteristic period is 0.40s, damping ratio is 0.05, and the number of the mode shapes is 20, and this paper adopts CQC combination method. This paper adopts two working conditions that is shown in Table 1.

1) The shear force of building

TABLE.1. THE WORKING CONDITION

Working Condition	Coefficient Of *x* Direction	the coefficient of *y* direction	combining
1	1.0	0.85	x+0.85y
2	0.85	1.0	0.85x+y

The base shear force is shown in Table 2 and Figure 7.

TABLE.2. THE BASE SHEAR FORCE

Working Condition	F_x(kN)	F_y(kN)
1	647	374
2	706	434

1) The drift of the building

The peak drift of two working condition is shown in Table 3, and drift of every storey in the first working condition is shown in Fig.8

TABLE.3. THE MAXIMAL DRIFT

Working Condition	Drift of Every Storey	
	x(mm)	*y(mm)*
1	38	24
2	42	28

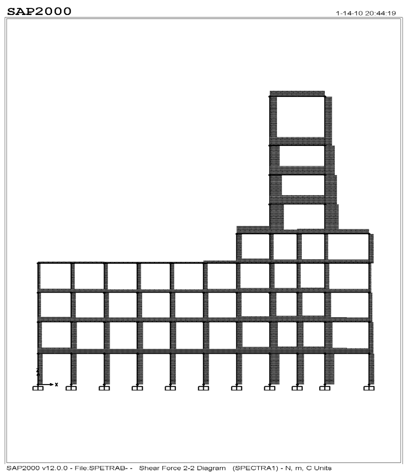

Fig.7. the shear force

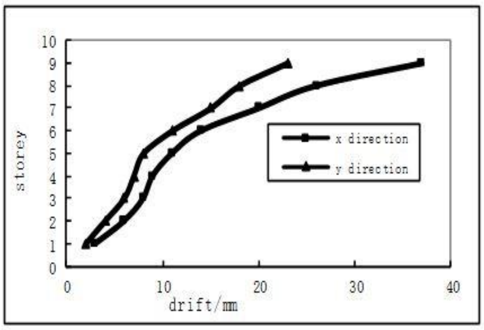

Fig.8. the maximal drift

3) The result

Based on Figure7 and 8 and Table 1~3, the base shear force is less by mode breakdown responsive spectrum analysis, (including the sudden-change shears in bell tower), though there is sudden increase of displacement in bell tower, the value of drift is within the limit. At the same time, the shear force in beams and columns on the 6th to 8th floor increase suddenly in the diagrams, even larger than the base shear force, which shows the equipment and tower can amplify the seismic response of the structure indeed.

V. ADDITONAL DYMAMIC TIME-HISTORY ANALYSIS

Because of the homogeneous rigidity of structure and asymmetric structure shape, it is necessary to carry out the spectrum analysis, as well as the time history analysis as a supplement.

Based on the ground classification and grouping, we carry out the elastic time-history analysis separately under two natural waves (El-Centro wave and Tangshan wave) and one artificial wave. While calculating, input the acceleration time-history curve both in *x* and *y* direction, and we take the ratio 1:0.85 in the working condition 1 and 0.85:1 in working condition 2. The earthquake sustaining period is 10s, the maximum value of the acceleration is 35cm/s^2, and the amplitude of waves is disposed.

In Table 4, there is contrast of the base shear between the spectrum analysis and the time-history analysis of the working condition 1, but the working condition 2 omitted. Through computation by two means, the result is accordance with the reality. The result of the base shear by time history method in each wave is not less than 65% that by the spectrum method and the average value of the base shear in the three waves is not less than 80% that by the spectrum method. The above mentioned can both meet the requirements of the codes.

TABLE.4. COMPARISON OF BASE SHEAR FORCE

Working Condition	Base Shear F_x (kN)					Base Shear F_y (kN)				
	Result of time-history analysis	Average value of time-history analysis	Result of spectrum analysis	0.65 times the Result of spectrum analysis	0.80 times the Result of spectrum analysis	Result of time-history analysis	Average value of time-history analysis	result of spectrum analysis	Result of spectrum analysis	0.80 times the Result of spectrum analysis
El-Centro wave	935					447				
Tangshan wave	880	756	647	421	518	375	377	374	243	299
Artificial wave	452					309				

There are horizontal drift in *x* and *y* direction and envelope diagram of horizontal storey drift ratio in Fig.9.In this diagram, a sudden change in the 6th, 7th, 8th floor appears in the model. The average of the storey drift ratio in the model is 1/500, and larger than the limit of 1/550, the steel tower on top can amplify the seismic effect indeed, and the weakness of numerical simulation tallies with the reality.

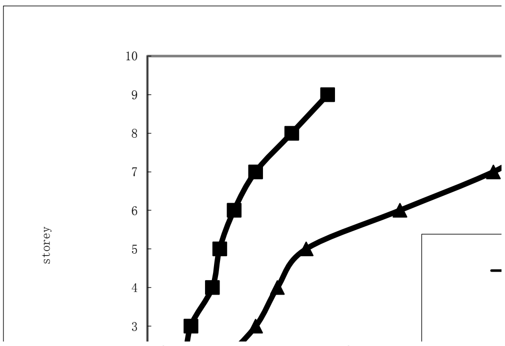

Fig.9. envelope diagram of horizontal storey drift in working condition 1

VI. CONCLUSIONS

According to the actual engineering project, we know that the equivalent base shear method is the most simple, fast and easy to implement, which can carry out in the preliminary design phase, mode breakdown responsive spectrum analysis method not only think about the characteristic of earthquake, but also the modes of vibration, which is the main method for high-rise building, while the time-history method is carried out as a supplement for complicated high-rise building structure.

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