STUDAY ON BIDIRECTIONAL HORIZONTAL SEISMIC RESPONSE SPECTRUM INPUT OF ECCENTRIC STRUCTURAL

BAI Yashuang [1] and SUN Jingjiang [2]

[1] *Master, Dept. of Structural Engineering, Institute of Engineering Mechanics, China Earthquake Administration, Harbin. China*

[2] *Professor, Dept. of Structural Engineering, Institute of Engineering Mechanics, China Earthquake Administration, Harbin. China*

Email: baiyashuang@163.com, jingjiangsun@sina.com

ABSTRACT :

In this paper, several representative eccentric structures are selected as analytical examples in order to investigate bidirectional seismic input problems. First, each structure is excited by response spectrum given intensity from various directions to look for the maximum response values and then these values assumed as response standard values are compared with those response results from four different bidirectional seismic input methods, which are currently used by domestic or abroad. The comparison shows that the best correlation is obtained by the input method of 1:3 scale earthquake intensity of two horizontal directions and the error results from the other three methods are also acceptable by practice engineering.

KEYWORDS: eccentric structures, bidirectional seismic input, response spectrum

1. INTRODUCTION

More and more seismic told us the fact that eccentric structures suffer the torsion effect under the earthquake; it is much easier to be destroyed than the symmetrical structures. So, how to analyze the reasonabe response of earthquake and realize the reliable seismic design of eccentric structures in structure seismic domain is an important research aspect.

For a building structure, the earthquakes may possibly will come from the random orientation, so the earthquake should be input from the most disadvantageous direction for safety when analyse the earthquake response. For the symmetrical structure, the weaker axis direction of the principal centroidal axis is the most disadvantageous direction, the structure's biggest response can be obtained when the earthquake is input along the structure weak axis direction. However, for the asymmetrical structure, how to input the earthquake action is complex, the most disadvantageous direction no longer is one of the two principal centroidal axis directions. But, there must exist a direction that cause the biggest respond of the structure when the earthquake is input from this direction. It is not applicable to seek the most disadvantageous direction through gradually changing the angle of the earthquake input in practical seismic design

So it is usually to be used that the bidirectional horizontal earthquake input Simultaneously with the earthquake action effects of two principal centroidal axis directions to reflect the adverse effect of the torsion in the practice. At present, the domestic and foreign standards have stipulated about it and some literature has discussed, example Anil K. Chopra[1], Li Hongnan[2], Shi Cheng[3] and so on. The key question of this article is which method is most reasonable and what is the difference of each method with different computing method. This article only discussed the method with the bidirectional horizontal earthquake spectrum input.

2. COMPUTING MODE AND METHOD

It's the elastic earthquake analysis of response spectrum with 6 eccentric structures with the Midas software in this article, the response spectrum is frequently earthquake of intensity 7, it's stipulated by Chinese code[6], the site-class is II, the design earthquake group is the 2nd group. As Figure 1 shows that the response spectrum is inputted at α angle with the y axis, in order to find the biggest earthquake response, the α angle changes gradually from 0° to 180° at intervals 10°, namely 0°, 10°, 20° ......180°.It is obvious that all the earthquake effect changed gradually and has not changed suddenly, so there is only one maximum value from 0° to 180°.

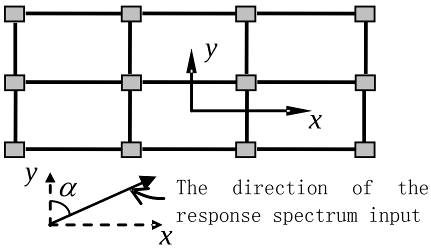

Fig.1 The method of response spectrum

Then calculate again on the both sides of the maximum value at interval 1°for the result to be more precise, the angle with the maximum earthquake response appeared is the most disadvantageous input angle, and the new maximum value is the structure biggest earthquake response when input corresponding response spectrum.As figure 2 shows that the 7 earthquake response items under input response spectrum with various angles of example 6, it is noteworthy that, the structure earthquake response item different, the earthquake input angle which obtained maximum value of earthquake response is usually different. Take the maximum value of every seismic response item as the normal value, then the structure response value which obtained on the present commonly used 4 methods of response spectrum compared with the relevant normal value and calculated the error value, and summarized the difference of 4 methods. The four methods namely:

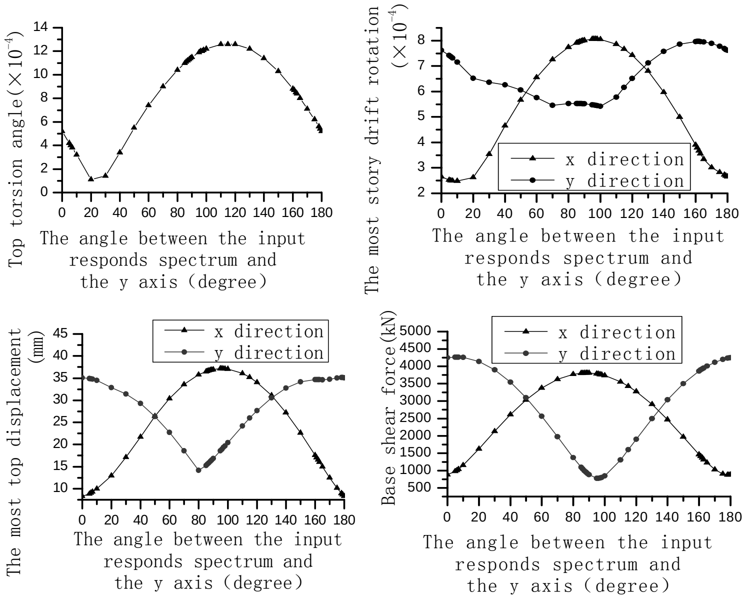

Fig.2 The action effect which one direction seismic response spectrum input along every angles of example 6

Method 1, used by Shanghai code (DBJ08-32-92[4]): Simultaneously inputs the response spectrum in two principal centroidal axis directions, and the intensity scale of two direction is 1:0.3;

Method 2, a combinatorial formula used by Euro code (EC-8[5]): $E_{Edx} + 0.30E_{Edy}$ or $0.30E_{Edx} + E_{Edy}$;

Method 3, a combinatorial formula used by Chinese code (GB50011-2001[6]): $\sqrt{S_X^2 + (0.85S_Y)^2}$ or $\sqrt{S_Y^2 + (0.85S_X)^2}$, which is called the Chinese SRSS method;

Method 4, a combinatorial formula used by the USA code (UBC97[7] and FEMA[8]): $\sqrt{S_X^2 + S_Y{}^2}$, that is standard SRSS method.

3. CALCULATION AND ANALYSIS OF MODELS

3.1 Eccentricity in one direction

Example 1: four layers frame structure of eccentricity in one direction, as shown in Figure 3, the structure and the load of every layer are completely same, the quality and the rigidity of x direction are symmetrical, the quality of y direction is symmetry, the rigidity of y direction eccentricity is 5%, the first period is 0.85s. The every item error of these 4 methods calculate value compare with the normal value which is the maximum in the earthquake response value of input response spectrum at various angles with the y axis will be listed in table 1.

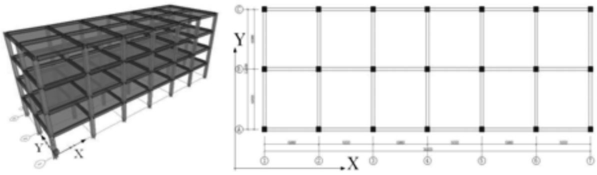

Fig.3 Analytical model and plan of example 1

The structure does not have the torsion when input response spectrum is along y axis direction because it's symmetrical in x direction, so there are no influence in x direction when input the response spectrum along y direction. Therefore, the error of top torsion angle, the most story drift rotation and the most top displacement of x direction, base shear force are 0 in table 1, only the most story drift rotation and the most top displacement of y direction have the error. Compared with these two items, the error of method 1 all does not surpass 5%, the error of method 2 close 10%, the error of method 3 all do not surpass 4%, but the error of method 4 close 6%, so the calculation result of the method 2 is biggest, and the result of the method 1, 3, 4 is all good.

Table 1 The error comparison of example 1

Method	Top torsion angle (%)	The most story drift rotation (%)		The most top displacement (%)		Base shear force (%)	
		x direction	y direction	x direction	y direction	x direction	y direction
1	0.0	0.0	4.0	0.0	4.0	0.0	0.0
2	0.0	0.0	9.4	0.0	9.4	0.0	0.0
3	0.0	0.0	3.1	0.0	3.2	0.0	0.0
4	0.0	0.0	5.1	0.0	5.1	0.0	0.0

3.2 Eccentricity in two directions

Example 2: four layers frame structure, as shown in Figure 4, the structure and the load of every layer are completely the same, the rigidity of x and y direction eccentricity are 6%, the first period is 0.87s. The corresponding item error of these 4 methods calculates result compare with the normal value which is the maximum in the earthquake response value of input response spectrum at various angles with the y axis will be listed in table 2.

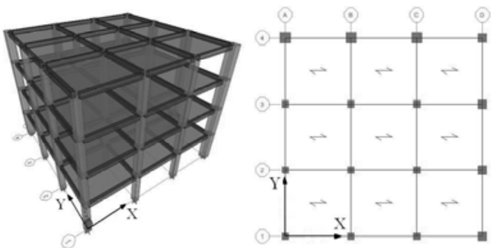

Fig.4 Analytical model and plan of example 2

As shown in table 2, that these 7 items seismic response have the error, because the structure is eccentricity in two direction. Compared with these 7 items, the error of method 1 are all within 5%, expect the first item's error is -7.4%, the error of method 2 are all over 5%, in which have 5 items to surpass 10%, and the first item's error is -7.3%, the error of method 3 have 5 items is over 5%, the error of method 4 have 5 items is bigger than 5% too, so the calculation result of the method 2 is best for this example.

Table 2 The error comparison of example 2

Method	Top torsion angle (%)	The most story drift rotation (%)		The most top displacement (%)		Base shear force (%)	
		x direction	y direction	x direction	y direction	x direction	y direction
1	-7.4	4.0	4.0	3.7	3.7	3.0	3.4
2	-7.3	12.0	12.3	12.4	12.7	10.9	8.1
3	-7.0	5.6	6.0	6.0	6.4	4.6	1.9
4	-0.1	8.3	8.8	8.7	9.1	6.6	4.0

Example 3: As Figure 5 shows that the structure is Mitsubishi Bank in Japanese Osaka, The structure's column of the most weak collapsed and the building was destroyed completely by Osaka-Kobe earthquake in Japan in 1995 the structure destroyed completely. It's a six-story frame-wall and a large-space middle structure, the lift well is located in the angle, the rigidity eccentricity of x direction is 10% and y direction is 12.2%, the first period is 0.44s.

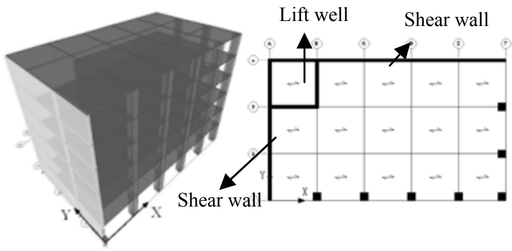

Fig.5 Analytical model and plan of example 3

The 7 items error of these 4 methods calculates result compare with the normal value will be listed in table 3. Compared with these 7 items, the error of method 1 all does not surpass 4%; two errors of method 2 surpass 10%, the max error is 25.5%; two errors of method 3 surpass 10% too, the max error is 23.4%; two errors of method 4 surpass 20%, the max error is 31.3%; it's more obvious that the method 2's advantage for this example.

Table 3 The error comparison of example 3

Method	Top torsion angle (%)	The most story drift rotation (%)		The most top displacement (%)		Base shear force (%)	
		x direction	y direction	x direction	y direction	x direction	y direction
1	0.9	1.0	0.8	1.2	0.8	1.4	3.6
2	1.3	2.3	1.2	3.2	1.3	14.1	25.5
3	-3.6	-2.5	-3.7	-1.6	-3.6	12.6	23.4
4	0.2	1.5	0.1	2.5	0.2	20.0	31.3

3.3 Plan structural irregularity

Example 4: two-layer frame building, as shown in Figure 6, the structure and the load of every layer are completely same, re-entrant corner greater than 50% on y direction, belong to the re-entrant corner irregularity in code, the rigidity of x direction eccentricity are 2.61% and y direction eccentricity are 2.42%, the first period is 0.46s. The error of these 4 methods calculates result will be listed in table 4.

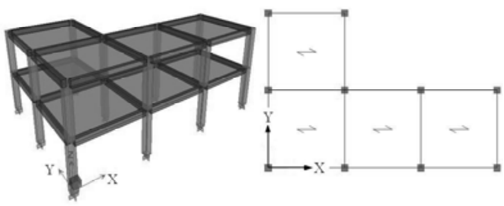
Fig.6 Analytical model and plan of example 4

As shown in table 4, the error of method 1 all does not surpass 3%; two errors of method 2 surpass 5%; the error of method 3 all do not surpass 4%; the error of method 4 all do not surpass 4%; the error of 4 methods are approximate from the example, but compare these values, the method 1 is best.

Table 4 The error comparison of example 4

Method	Top torsion angle (%)	The most story drift rotation (%)		The most top displacement (%)		Base shear force (%)	
		x direction	y direction	x direction	y direction	x direction	y direction
1	0.6	0.2	2.4	0.0	2.3	0.3	0.0
2	3.3	6.8	4.1	6.7	4.2	1.3	1.4
3	-1.1	1.8	0.3	1.8	0.3	0.1	0.1
4	3.4	2.5	0.6	2.4	0.7	0.1	0.1

3.4 Practical tall structure

Example 5: Sixteen-layer frame-wall building, height 66m, as shown in Figure 7, the structure is composed a big triangle by 6 hexagons, the core tube is composed by 3 channel shape shear-wall, the shear-wall's broadside is parallel with big triangle's side, the plane reduces one or two hexagons in the structure level 11, 13, 15 and the top layer, finally it's only a core tube on the top layer. The first period is 1.21s, it's x direction vibration mode. The error of these 4 methods will be listed in table 5.

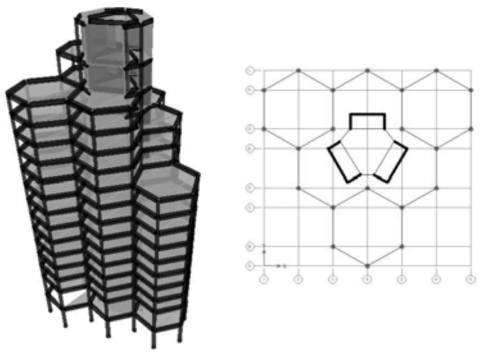

Fig.7 Analytical model and plan of example 5

As shown in table 5, the error of method 2, 3, 4 all are big, 6 errors of method 2 surpass 5%, the maximum error is 16.4%; 2 errors of method 3 surpass 5%, the maximum error is 12.3%; 2 errors of method 4 surpass 5%, the maximum error is 18.1%; but the error of method 1 all small, they does not surpass 5%.

Table 5 The error comparison of example 5

Method	Top torsion angle (%)	The most story drift rotation (%)		The most top displacement (%)		Base shear force (%)	
		x direction	y direction	x direction	y direction	x direction	y direction
1	3.6	2.8	4.3	2.6	3.0	1.0	2.5
2	3.7	9.1	16.4	6.2	14.3	6.9	5.7
3	-2.2	3.1	12.3	1.3	7.9	1.9	1.1
4	0.2	4.5	18.1	2.0	10.9	2.6	1.7

Example 6: Sixteen-layer frame-wall building with L shape plan and vertical regular, as shown in Figure 8, the shear-wall is uniform in plan, the plane re-entrant corners size surpasses the limiting value of the code stipulation. The first period is 1.47s, it's y direction vibration mode. The error of these 4 methods is listed in table 6.

As shown in table 6, the error of method 4 is biggest, in which 5 errors surpass 10% and the maximum error is 29%; the error of method 2 and 3 all is big, the maximum error of method 2 and 3 all surpass 20%, the error of method 1 is minimum, all don't surpass 5%.

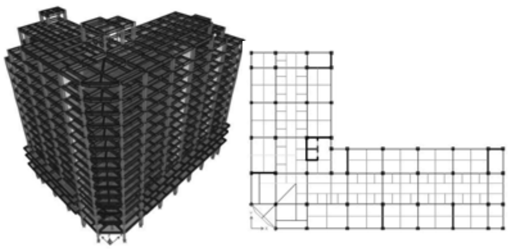

Fig.8 Analytical model and plan of example 6

Table 6 The error comparison of example 6

Method	Top torsion angle (%)	The most story drift rotation (%)		The most top displacement (%)		Base shear force (%)	
		x direction	y direction	x direction	y direction	x direction	y direction
1	-3.1	4.2	4.4	4.2	4.0	2.6	4.2
2	2.9	11.5	20.5	13.1	24.2	15.1	13.0
3	2.0	6.1	18.1	8.0	21.6	8.9	6.8
4	9.0	10.2	25.4	12.7	29.0	12.1	10.0

3.5 Brief summary

The average error of these 4 methods of 6 examples are listed in table 7, the average error of method 1 are all small from Table 7, the biggest is only 3.3%; the average error of method 2 are all big, 6 errors have surpassed 5%, two items surpass 10%; the average error of method 3 and 4 are smaller than method 2, but bigger than method 1, 3 items of the method 3 surpassed 5%, 4 items of the method 4 surpassed 5%, and two errors of the method 4 closed 10%. So we can get the conclusion from this: the computation result of method 1 is obviously better than other three methods.

Table 7 The average error comparison of four methods

Method	Top torsion angle (%)	The most story drift rotation (%)		The most top displacement (%)		Base shear force (%)	
		x direction	y direction	x direction	y direction	x direction	y direction
1	-0.9	2.0	3.3	2.0	3.0	1.4	2.3
2	0.7	7.0	10.7	6.9	11.0	8.1	9.0
3	-2.0	2.4	6.0	2.6	6.0	4.7	5.6
4	2.1	4.5	9.7	4.7	9.2	6.9	7.9

4. CONCLUSIONS AND SUGGESTIONS

When consider the structure torsion coupling phenomenon for bias when the response spectrum input, it can realize similar input effect with the same intensity the earthquake from the structure most disadvantageous direction input for asymmetrical structure's elastic calculation, when simultaneously input the response spectrum in the level two principal centroidal axis directions and the two direction scale is 1:0.3, namely a direction input response spectrum 100% another vertical direction input response spectrum 30%. If the procedure or the software used can't input the response spectrum from two directions simultaneously, the combination formula must be used, the calculation result of the combination formula of the SRSS and the Chinese SRSS is imprecise than the method of bidirectional simultaneously input, but is acceptable.

REFERENCES

Chopra Anil K. (2005).Dynamics of Structures Theory and Applications to Earthquake Engineering (Second

Edition),Tsinghua University Press，
Li Hongnan. (1998).The Theory and The Method for Earthquake Resistant Design of Structures to Multiple Seismic Ground Motion, Science Press,
Shi Cheng. (2004).Study on Several Problems of Structural Seismic Analysis and Design Considering Earthquake Actions in Two Directions Simultaneously, Chongqing University,
Shanghai Code. (1993).DBJ08-32-92, Tempory Specification for Structural Design of Tall Steel Buildings.
European Committee for Standardization,(2003). Eurocode 8, Design of structures for earthquake resistance. Part 1: General rules, seismic actions and rules for buildings.
GB50011-2001, Code for seismic design of buildings.
national Conference of Building Officials (ICBO), Uniform Building Code (UBC97) (1997).Vol.2.Structural Engineering Design Provisions. USA.
FEMA368. (2001).NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures.