# Research on the effect of vertical position of stagger transfer stories on the dynamic characteristic and seismic behaviour of structures

**C. Y. Shen[1], F. L. Zhou[2], X. Y. Huang[3], J. Q. Chen[4] , J. M. Jin[5] and S. B. Wang[6]**

[1] *Associate Professor, Earthquake Engineering Research & Test Center, Guangzhou University, Guangzhou, China*

[2] *Professor, Earthquake Engineering Research & Test Center, Guangzhou University, Guangzhou, China*

[3] *Associate Professor, Earthquake Engineering Research & Test Center, Guangzhou University, Guangzhou, China*

[4] *Associate Professor, Earthquake Engineering Research & Test Center, Guangzhou University, Guangzhou, China*

[5] *Assistant Professor, Earthquake Engineering Research & Test Center, Guangzhou University, Guangzhou, China*

[6] *Associate Professor, Northwestern Achitectural Design Institute, Xi'an, China*

**ABSTRACT :**
As a special new type of transfer structure—stagger transfer structure, the literature on the vertical position's effect on the mechanic behavior of vertical component can't be found. A FEM program is used to analyze the horizontal seismic response of high-rise building with stagger transfer structure. The various levels of the whole stagger transfer stories have little effect on the periods, main modes and relative displacement of the high-rise building. When they lie at the higher story, the sudden change of drift-angle near the transfer story will be hardened. When there are stagger transfer stories in the high-rise building, sudden change will appear in the internal force of the vertical components near the two stagger transfer stories, it should be considered during designing.

**KEYWORDS:** Stagger transfer structure；vertical position；seismic response; FEM

## 1 Foreword

Transfer structure is a special structure in order to meet the special requirement of people. Stagger transfer structure ( with two or more than two transfer stories, there is different to the position of the two or more than two transfer stories) is a special or new type of transfer structure, and is being used in the practical engineering. According to author's knowledge, there is little research about the stagger transfer structure. In the literature[L. X. Chen, 2003], a practical project about designing was discussed, in the literature[C.Y. Shen etc, 2006], shaking table test and theory analysis of a scaled-model of high-rise building with stagger transfer structure has been performed. Although there are some researches on the effect of vertical position of single transfer story on the seismic behaviour of high-rise building, but researches on the effect of vertical position of stagger transfer stories on it can't be found. In this paper, FEM will be used to investigate that preliminarily.

## 2 Structural model introduction

There are 44 stories overground (including two inter-stories) and 4 underground chambers in the model, its structural type is frame-tube structure. Because some columns in the 4th story are removed, tube-shear wall becomes single-sheet wall and there is new column in the 9th story, each transfer story will become in the 4th and 8th story. They are only partially transferring, because the two partial transfer stories will be stagger, and named as stagger transfer structure. Partial steel braces are added in the 8th and 26th story. The site of structrue is class II, the seismic fortification intensity is 7 degree. Because there are too many numbers of story-heights, in order to be convenient to analyze and research, the initial structure is standardized. It includes that inter-story

becomes a complete story and transfer story lies in the 5th story and the 10th story respectively, the story height below the transfer story is 5m, that superior to it 3.7m, steel braces in the stories mentioned before are removed, SSI can't be considered, it means that the bottom of the 1st story will be restrained. Figure 1 shows the arrangement of the stagger transfer stories in the high-rise building and the position of the vertical element. In this paper, research on the effect of vertical position of the whole stagger transfer stories on the dynamic characteristic and seismic behaviour of structure will be carried out. Table 1 gives the detail position of stagger transfer stories.

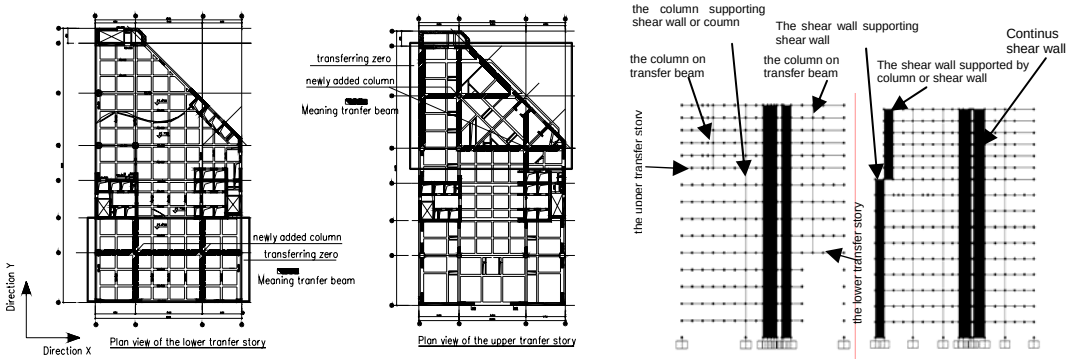



Figure 1 Arrangement of the stagger transfer stories in the high-rise building and the position of the vertical element

Table 1 Position of stagger transfer stories of the models

| | Model 1 | Model 2 | Model 3 | Model 4 |
|---|---|---|---|---|
| The lower transfer story | The fifth story | The first story | The ninth story | The thirteenth story |
| The upper transfer story | The tenth story | The sixth story | The fourteenth story | The eighteenth story |

SAP2000 program is used, and the time-history analysis and the method of response spectrum are adopted. Before analyzing, parts of main frequencies of the prototype model which are used in the latter analysis are calculated, according to the similitude law, those are converted to the small-scale model used in the shaking table test. The two results are used for comparison( see Table 2 and Figure 2). Seeing from the Table 2, there is little error between the frequencies, the maximum absolute error is about 6.4%. The mode comparison between the tested model and the calculated model are also shown to be good agereement, except that there is a little error near the upper transfer story in the 3rd mode in the X direction. To some degree, it means the calculation model has certain rightness.

Table 2 Comparison with the test value and calculation value of the frequency of the structure model

| Frequency | Direction X | | | Direction Y | | |
|---|---|---|---|---|---|---|
| | Mode 1 | Mode 2 | Mode 3 | Mode 1 | Mode 2 | Mode 3 |
| The calculation value(Hz) | 2.36 | 8.73 | 18.87 | 3.04 | 9.78 | |
| The test value(Hz) | 2.23 | 8.65 | 18.11 | 2.94 | 10.44 | 19.15 |
| error | +5.87% | +0.92% | +4.22% | +3.0% | -6.4% | |

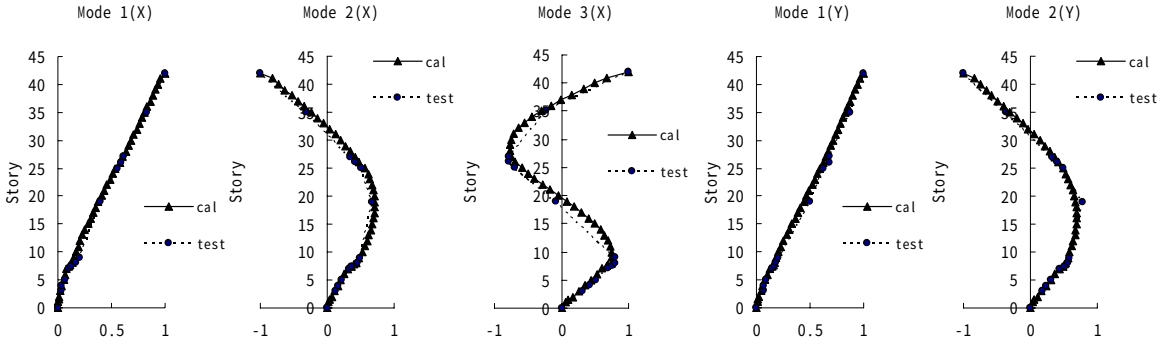



Figure 2 Comparison between the modes tested and those calculated

## 3 Dynamic characteristic

Figure 3 shows the comparison of the former 45 periods of the model 1 ~4. It can be oberved from this figure that there is little difference between the models, it means that there is little effect of the position changing of the stagger structure on the periods of structure, and on the whole stiffness of the structure with stagger transfer stories.

Figure 4 shows the comparison of the 1st mode of the model 1~4 in X, Y and Torsion direction. There is also little error as the period. It is concluded that there is little effect of the vertical position changing of the stagger transfer stories on the dynamic characteristic of high-rise building.

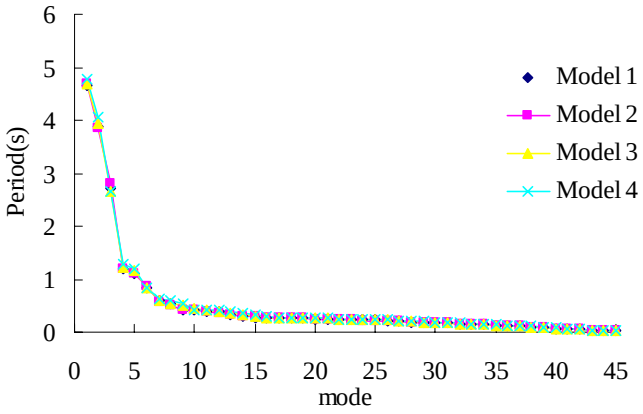
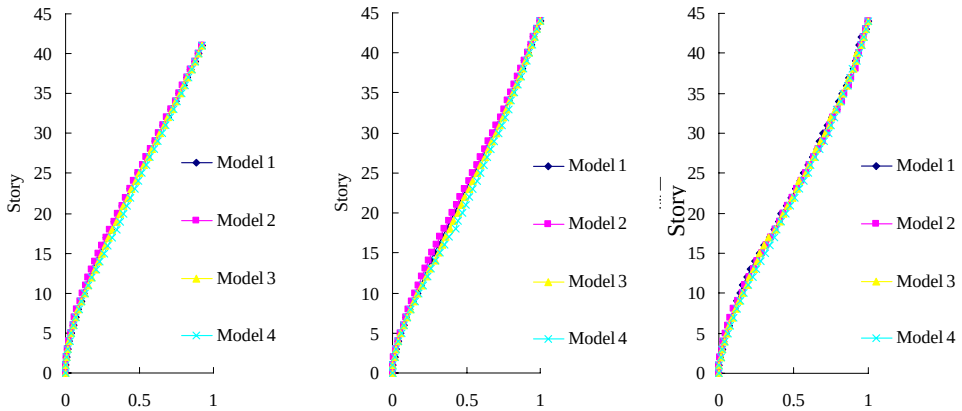



Figure 3 Comparison among the 45 periods of 4 models




(a) The 1st mode in X direction (b) The 1st mode in Y direction (c) The 1st mode of torsion

Figure 4 First mode of 4 models in X direction, Y direction and of torsion

## 4 Structure dynamic response analysis

An earthquake wave -——El Centro (NS) , its frequency characteristic is close to that of the prototype structural field, is used to perform time-history analysis. The interval is 0.02s, the amplitude of acceleration input is modified according to the minor earthquake of intensity 7 in Chinese code for Seismic Design of building. Discussion is mainly focused on the Y direction of the structure.

### 4.1.1 Acceleration and displacement response

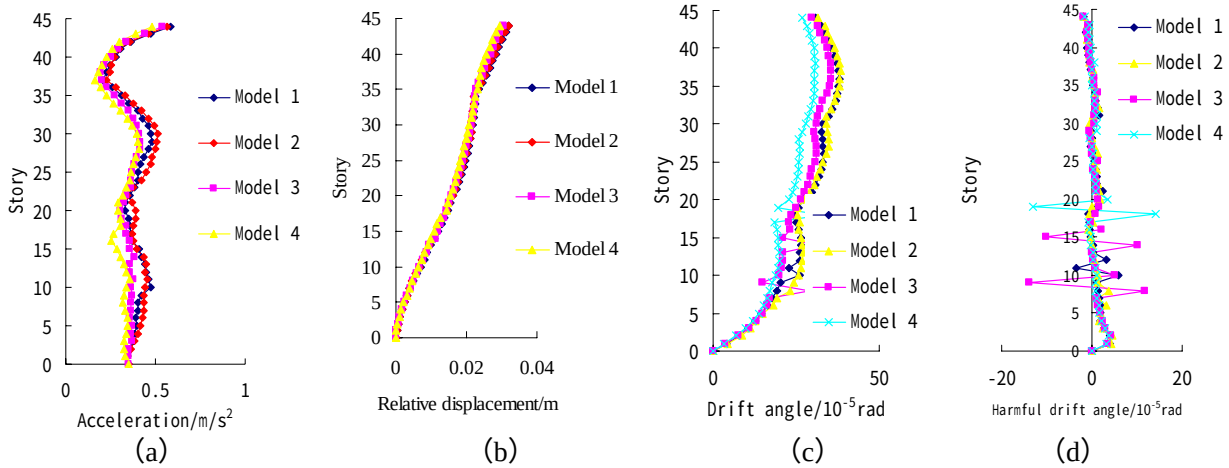



Figure 5 The acceleration and displacement response of Model 1,2,3,4 when El Centro wave is input

Figure 5 shows the acceleration and displacement response of structure when the whole stagger transfer story moves up and down. According to the comparison between the acceleration responses of the different models, there is little difference, as a whole, when the position of the stagger transfer stories is lower, the acceleration response will become larger. There is little effect on the relative displacement response. It can be observed from the drift angle response, if the sudden greater drift angle near the transfer story is not considered, as a whole, drift angle response of structure will be less with the whole stagger stories moving up, this trend is inverse to that of the acceleration response. If drift of the near two stories are subtracted each other, the result will reflect the law of the velocity of drift angle change along the height of stories. In Figure 5, there is no obviously sudden change of drift angle in model 2, but there is greater sudden change of drift angle near the transfer story with the stagger transfer stories moving up, when it lies in the 9th and 14th story respectively(such as model 3), there will appear two sudden change of drift angle. As to model 4, the degree of sudden change of drift angle will exceed that in model 3. To high-rise building with stagger transfer structure, the lower transfer story of the stagger transfer structure is advised to lie below the 9th story.

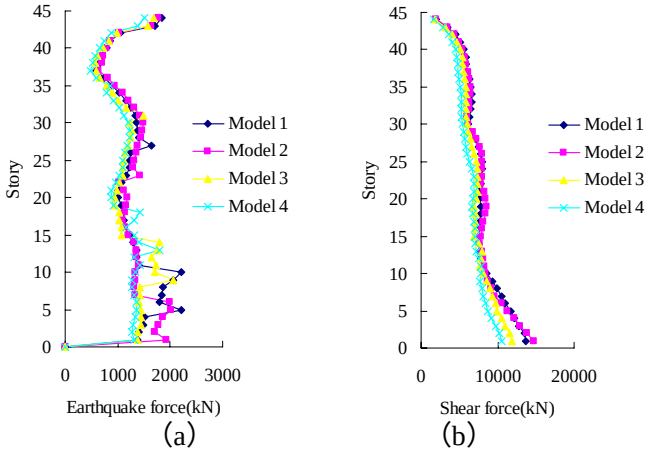



Figure 6 Earthquake force and shear force response of Model 1, 2, 3 and 4

During the time-history analysis, earthquake force of each story can be gained from mass of each story multiplying the acceleration of each story. Figure 6 shows the earthquake force and shear force response of structure. In Table 3, base shear force and base moment rotating the X axis of the model 1~ 4 are given. Comparing Figure 6 and 5, any sudden change can't be found in the acceleration response of structure, but there is sudden change in the earthquake force of structure near the transfer story, the reason is that mass of transfer story is usually larger than that of other stories and it will cause earthquake force to be sudden change near the transfer story. There is the same effect on the shear force response and the acceleration response because of the stagger transfer stories moving, but base shear force will be less with the whole stagger transfer stories going up. As a whole, with the whole stagger transfer stories moving up, because there is greater load in the stories below the transfer story than that in other stories, the equivalent mass brought by them will be more, on the other hand, the stiffness of the whole structure will be greater with the whole stagger transfer stories moving up, those will cause the period of structure to be longer and leads the whole earthquake force to being less, shear force in each story and base shear force will be decreasing, except for model 3, the base moment also has the same trend.

Table 3 Base shear force and base moment of Model 1, 2, 3 and 4

| | Model 1 | Model 2 | Model 3 | Model 4 |
|---|---|---|---|---|
| Base shear force /kN | 14150 | 15181 | 12206 | 10984 |
| Base moment/kN.m | 586733 | 613885 | 598581 | 550228 |

## 5 Effect of vertical position of the stagger transfer stories on the internal force of vertical element

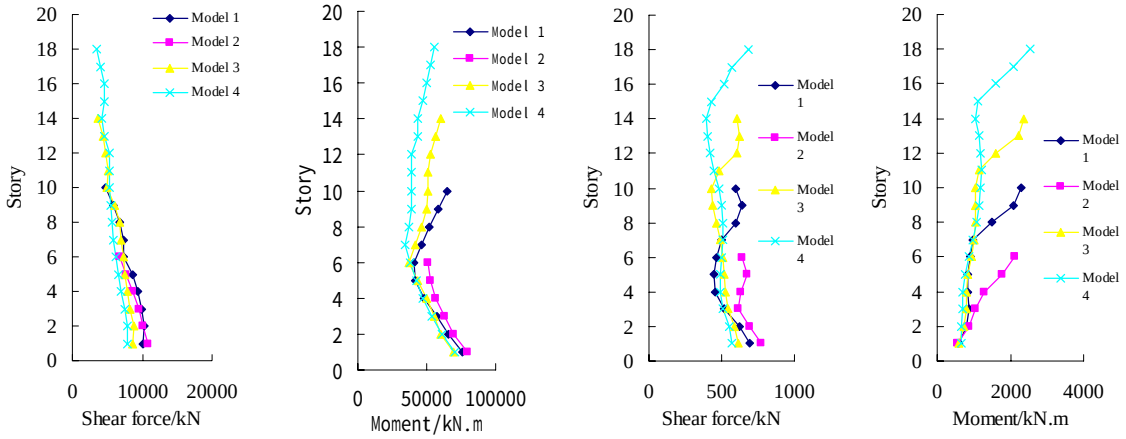
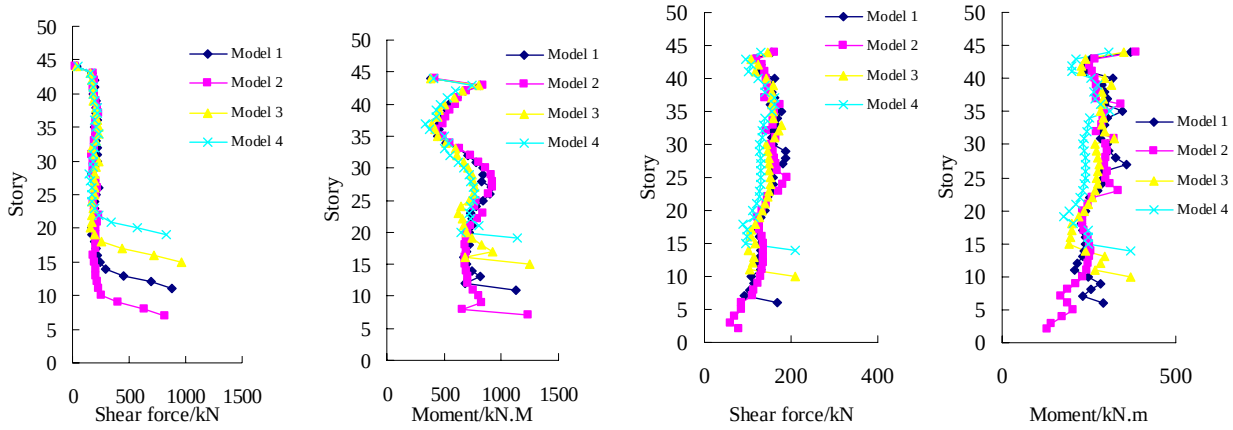



Figure 7 Influence of the vertical position of stagger transfer story on the internal force of vertical elements below transfer stories

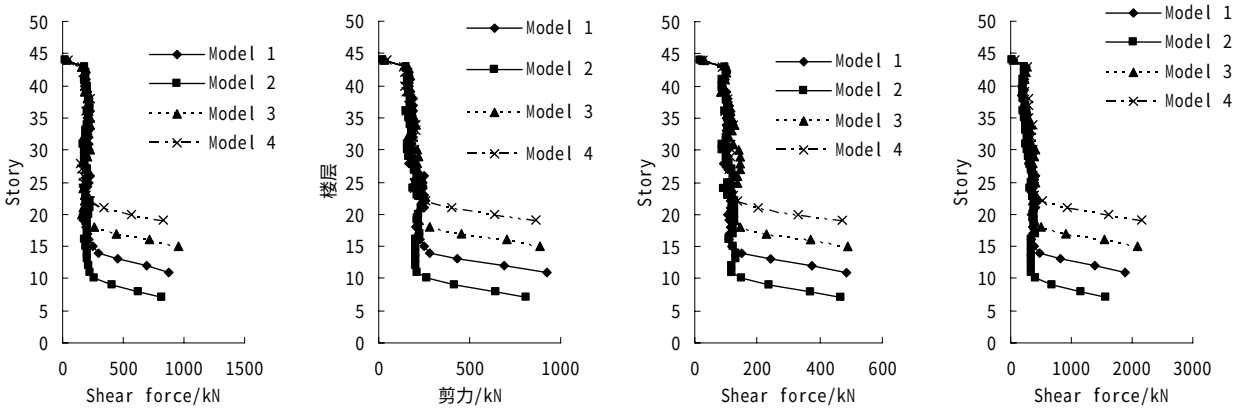



Shear wall supported by column　　Column standing on tranfer beam

Figure 8 Influence of the vertical position of stagger transfer story on the internal force of vertical elements above transfer stories

Figure 7 and 8 show the effect of position of the whole stagger transfer stories on the internal force of some vertical components. It is concluded from the shear force and moment response of the continuous shear wall below the upper transfer story (Figure 7) that they will decrease because of the total shear force reducing with the whole stagger transfer stories moving up. It can be observed that the shear force and moment of the supporting shear wall below the upper transfer story, when the lower transfer story lies below the 6th story, will not occur apparently sudden change. But for Model 1, Model 3, Model 4( in these models, the lower transfer story lies above the 5th story), they will occur the same characteristic in the 3rd story below the upper transfer story. It is advised that the supporting shear wall at least three stories below the upper transfer story should be strengthened. In Figure 8, there is apparently sudden change of the shear force of the column supporting shear wall in the lower transfer story and two stories above it, moment in the lower transfer story, moreover the tend will be more severe with the whole stagger transfer stories moving up, the column supporting shear wall in the lower transfer story and two stories above it is advised to be strengthened. In Figure 7, it shows that the whole stagger transfer stories moving up has little effect on the shear force of the shear wall supported by column. No matter the whole stagger transfer stories lie on the high or low position, the shear force of shear wall supported by column in the three stories above the upper transfer story will occur sudden change, the same phenomena of moment response will appear in the first story above the upper transfer story. To the column on the lower transfer beam, the shear force will appear sudden change in the first story above the lower trnafer story except Model 2, moreover the tend will harden with the whole stagger transfer stories moving up, the corresponding column should be strengthen. For the column supporting shear wall or column below the upper transfer story, there is no effect on the internal force of them while the whole stagger transfer stories moving up and down.

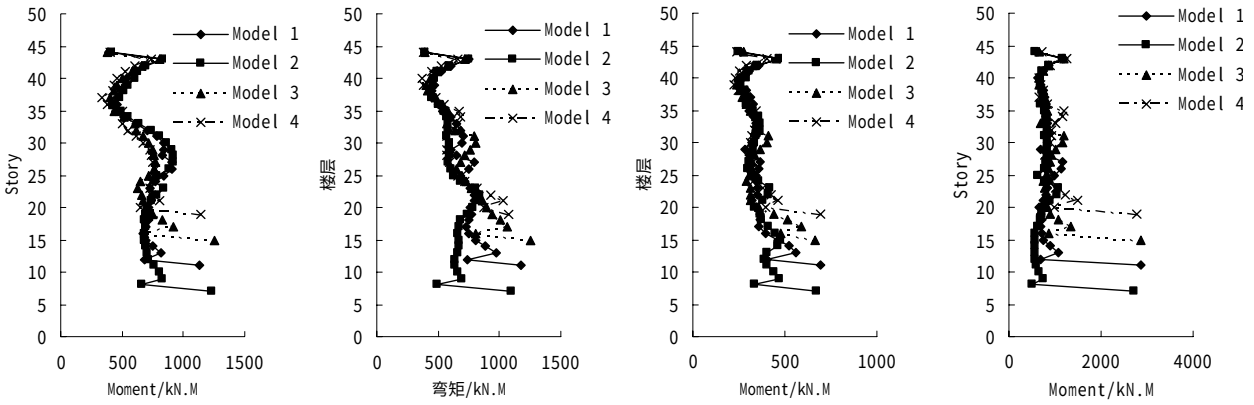
## 6 Effect of different wave on the changing tend of internal force of vertical component




(a) El Centro　(b) Taft　(c) field wave　(d) Response spectrum

Figure 9 Shear force response of shear wall supported on frame when earthquake wave is input in the Y direction or the method of the response spectrum is used

Discussion before-mentioned is mainly focused on single earthquake wave---El Centro(NS), how about the results if different wave with different frequency characteristic will be input? So other two earthquake waves are input to calculate and the method of the response spectrum is used. Because of the limitation of the length of paper, the shear force and moment of the shear wall supported on frame when the earthquake wave is input in the Y direction or making use of the response spectrum method are only given here( See Figure 9 and 10). Some results will be gained from Figure 9 and 10. No matter in figure 9 and 10, when differect waves or methods are adopt, the trend of effect of vertical position of stagger transfer stories on the internal force of the shear wall supported on frame is not changing, the only difference lies in the degree.




(a) El Centro (b) Taft (c) field wave (d) Response spectrum

Figure 10 Moment response of shear wall supported on frame when earthquake wave is input in the Y direction or the method of the response spectrum is used

**6 Conclusions**

Some FEM analysis about the effect of vertical position of the whole stagger transfer on dynamic charteristic and dynamic response of the structure is performed, some conculsions can be gained in the following:

1) There is little effect on the periods, modes, relative displacement of high-rise building with stagger transfer structure when the whole stagger transfer stories moving up and down.
2) With the position of the whole stagger transfer stories going up, acceleration, drift angle, shear force of each story and total base shear force will reduce except the stories near transfer story.
3) With the whole stagger transfer stories moving up, sudden change of drift angle of the stories near the transfer story will harden, especially when the upper and lower transfer story lies in one-third of total height or one-fourth of total height respectively, two sudden changes of drift angle will appear.
4) The shear force and moment of the supporting shear wall below the upper transfer story, when the lower transfer story lies above the 6th story, will occur the sudden change in the 3rd story below the upper transfer story.
5) With the whole stagger transfer stories moving up, there is apparently sudden change of the shear force of the column supporting shear wall in the lower transfer story and two stories above it, moment in the lower transfer story.
6) No matter when the whole stagger transfer stories lie in the high or low position, the shear force of shear wall supported by column in the three stories above the upper transfer story will occur sudden change, the same phonomena of moment response will appear in the first story above the upper transfer story.
7) To the column standing on the lower transfer beam, the shear force will appear sudden change in the first story above the lower transfer story except one model。
8) The tend of effect of vertical position of stagger transfer stories on the internal force of the vertical component has not received no matter how different wave being input to calculate.

## REFERENCES

L. X. Chen. (2003). Discussion on the multi-transfer of high-rise building. *Building technique development(chinese)*, **30:5**, 33-34.
C. Y. Shen, B. Wu, F. L. Zhou, X. Y. Huang etc. (2006). Influence of stagger transfer structure on a tall building: shaking table test and FEM analysis. *Earthquake engineering & engineering vibration(chinese)* **26:2,** 33-40.
W. S. Rong, Y. Y. Wang. (2004). Effect of the Level of Transfer Slab on Seismic Behavior of Tall Building Structures. *Architecture science(chinese)*. **20:4,** 1-7.
GB 50011-2001 Code for seismic design of buildings, Beijin, China.