

Analysis of the Interaction between Stair and Frame under Horizontal Earthquake Action Based on ETABS

Zhi-Wei CAO^{1,a}, Chen BIAN^{2,b}, Chun-Yi XU^{3,c}

^{1,2,3}School of Civil Engineering Shenyang Jianzhu University, Shenyang, 110168, China

^aeve.soul@163.com, ^bbchappy_5166@sina.com, ^c80215314@qq.com

Keywords: ETABS, Frame Structure, Staircase, Seismic Performance.

Abstract. Two computer models of concrete frame with staircase were made and the seismic-performance of the models in elastic-phase was calculated by adopting base shear method, spectrum analysis by ETABS. The results show that including staircase into models will change the seismic performance of frame structure significantly. The paper proposes that the computer model with staircase and the response spectrum analysis should be used firstly in the seismic design of concrete frame with staircase.

Introduction

The conceptual design is always used to consider the impact of the stairs on the structural performance during the previous seismic design of buildings, for example, the short columns in stairwells should have more stirrups in its full-height, the asymmetrical layout of the stairwells could make a significant torsion effect to the whole structure[1, 2]. The damage survey in 5 • 12 Wenchuan earthquake indicates that a considerable number of stair risers fracture occurred in the earthquake zone, which shows that stairs as an integral part of the structure have a significant impact on the whole structure dynamic performance. Based on the above concepts and damage investigation, the newly revised GB 50011-2010 "Code for Seismic Design of Building Structures" begins to consider the impact on the overall structure seismic performance by the stairs[3]. As described in Section 3.6.6 "Calculation model, necessary simplified calculations should be in line with the actual working conditions; Stair component should be taken into consideration when doing the calculation." Several research have been taken about the interaction behavior between stair and frame in China, which indicates that stairs have a great influence on the structural layer stiffness. In this paper, analysis models of a 12 layers framework with or without stairs have been made by ETABS, relevant analysis has been made about the influence of stairs[4,5,6].

The Establishment of the Calculation Model

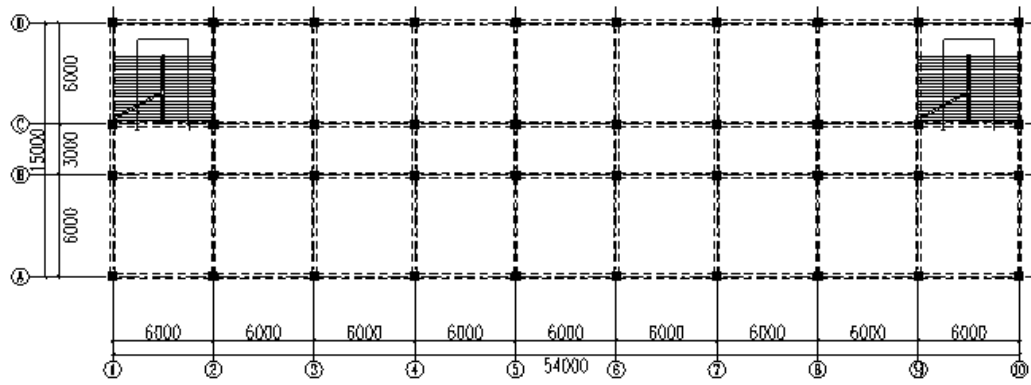
Two models are designed and the seismic-performance of the models in elastic-phase is calculated by adopting base shear method and mode-superposition response spectrum method.

Model 1(M-1) is a 12-story cast-in site reinforced concrete frame structure, of which the first floor is 3.5m and the rest are 3.0m. The column section is 800mm×800mm; only frame beams are laid whose sections are 250mm × 500mm; the floor thickness is 120mm. The concrete strength grade of columns is C35 and that of beams and slabs is C30; the model does not include the staircase and imaginary surface treatment is taken for the stairwell slab with thickness of 0 which is used to transfer loads.

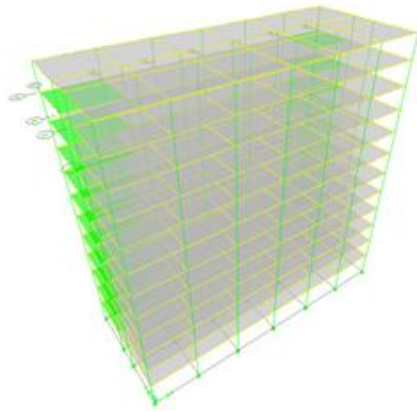
In the Model 2 (M-2), on the basis of M-1, the Y-axis inter-layer cross stair ramp is set with platform beam and platform slab in the middle to simulate stairs, the slab thickness is 120mm.

In the simulation analysis, the membrane element is selected for level floor, the shell element is selected for stair ramp, the space bar element is selected for beam and column; the translational and rotational degrees of freedom of three directions at the bottom of models are bound to be fixed.

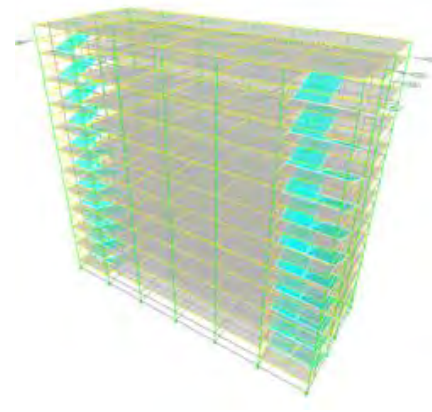
Plan diagram and three-dimensional diagram are shown in Figure 1.



(a) Plan diagram



(b) three-dimensional diagram of model 1



(c) three-dimensional diagram of model 2

Fig. 1 Details of Computer Models

Calculation Condition

The standard value of live load is 2.0kN/m^2 . Seismic fortification intensity is 7 degree ($0.10g$), classification of design earthquake is first group and construction site category is class II ($T_g=0.35s$); the structural seismic-performance of the models is analysed and calculated by base shear method and mode-superposition response spectrum method, which are recommended by “Code for Seismic Design of Buildings”, and the floors are assumed infinite rigidity in its own plane.

Result and Analysis

Computational Results Comparison of Base Shear Method

(1) Under the condition of Y directional earthquake excitation (Q_y), the vertical distribution curves of floor displacement, interlayer displacement angle and floor stiffness along structure models are shown in figure 2~4; the maximum values of floor displacement, maximum interlayer displacement angle, maximum floor shear, maximum floor stiffness and maximum floor overturning moment are showed as Table 1.

Tab. 1 Max of Story Response under Q_y -case of Models

Model name	the maximum values of floor displacement [mm]	maximum interlayer displacement angle	maximum floor shear [N]	maximum floor overturning moment [N·mm]	maximum floor stiffness [$\text{N}\cdot\text{mm}^{-1}$] (Q_y)
M—1	33.9949 (12f)	1/813(3f)	1.543 E+06 (1f)	4.087 E+10(1f)	7.271 E+05(1f)
M—2	20.0404 (12f)	1/1116(1f)	3.242 E+06(1f)	8.083 E+10(1f)	2.981 E+06(3f)

Note: The number in () indicates the floor that the value belongs to.

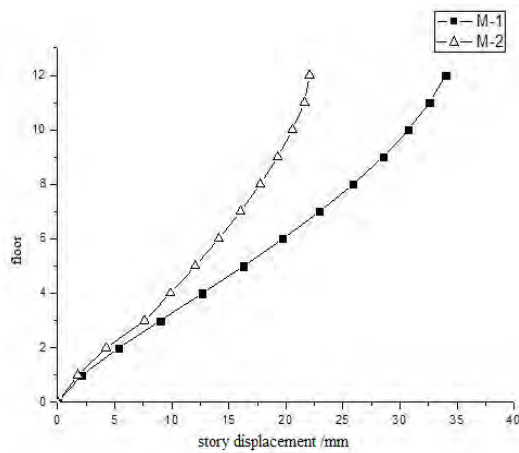


Fig. 2 Story Displacements of Models

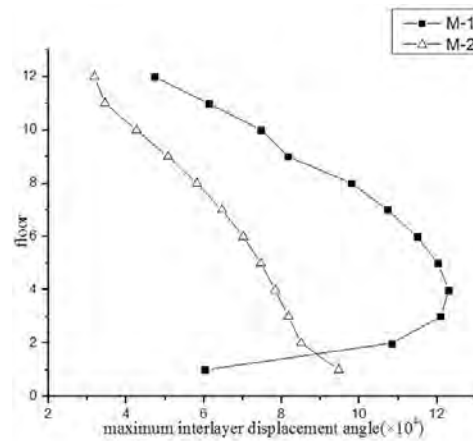


Fig. 3 Story Drifts of Models

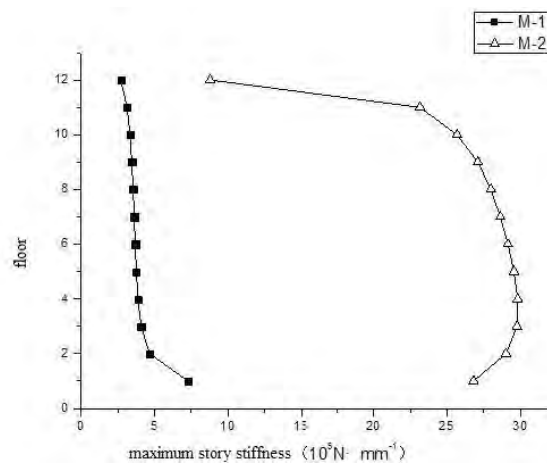


Fig. 4 Story Stiffnesses of Models

It can be seen from Table 1 and Fig 2 to 4:

1) The floor lateral displacement of the model with staircase (M-2) is obviously smaller than that of the model without staircase (M-1), and the lateral displacement curve makes the transition to Shear-Flexural type.

2) Both of the maximum interlayer displacement angle in each model are within the maximum limit value specified by “Code for Seismic Design of Buildings” (1/550), but the vertical distribution curves of interlayer displacement angle and floor stiffness along structure model with staircase are very different from those along structure model without staircase.

3) The maximum floor shear (base shear) and maximum floor overturning moment (base overturning moment) of model 2 are much higher than that of model 1.

(2) In the Qy case, each model’s section shear value of the second floor stairwell frame column along Y-axis direction (②×④) is shown as Table 2.

Tab. 2 Shears of Column under Qy-case of Models

Model name	shear value of the second floor along Y-axis direction [N]	
	top half column section	top half column section
M—1		31821
M—2	23475.12	34088.62

It can be seen from Table 2: The section shear value of the stairwell frame column of model 2 changes largely from that of model 1, which leads to take adequate strengthening measures to ensure the safety of stairwell columns when the stairwell is designed.

The Calculation Results Comparison with Respond Spectrum Analysis

Ritz vector method is taken to make vibration mode analysis in order to consider the effect of dynamic load on structure dynamic performance; the calculated number of vibration mode is 12, and the results show that the vibration mode participation mass of each model is over 90% of the structure total mass; the respond spectrum in “Code for Seismic Design of Buildings” is adopted, CQC rule is selected as vibration mode combination method and SRSS rule is selected as direction combination method[7].

In the respond spectrum case, the periods and mass participation factors of the top 5 vibration modes (U_x , U_y respectively is participation factor along X, Y direction of the global coordinate and R_z is that around Z-axis direction) are shown as table 3~4.

Tab. 3 Periods and Mass-ratios of Mode(1~ 5) for M—1

Model	Period/s	U_x	U_y	R_z
Mode- 1	1.94023	80.21	0.00	0.00
Mode- 2	1.37786	0.00	79.48	0.00
Mode- 3	1.16522	0.00	0.00	79.89
Mode- 4	0.44806	0.00	0.00	0.00
Mode- 5	0.42345	9.92	10.72	0.00

Tab. 4 Periods and Mass-ratios of Mode(1~ 5) for M—2

Model	Period/s	U_x	U_y	R_z
Mode- 1	1.47257	79.46	0.24	4.16
Mode- 2	1.37786	0.20	83.20	0.01
Mode- 3	1.16522	4.03	0.00	79.18
Mode- 4	0.44806	9.01	0.00	0.35
Mode- 5	0.42345	0.03	9.68	0.00

It can be seen from Table 3~4:

(1) The first vibration mode period of the model with staircase (M-2) is significantly shorter than that of the model without staircase (M-1).

(2) In the model 1, the top 2 vibration modes are both mainly in the form of translation, and the third vibration mode is mainly in the form of torsion; In the model 2, the torsion participation factor of the first vibration mode has a slight increasing trend compared with that of model 1, whose reason is that the involved staircase leads to structural vibration mode's change and torsion effect's appearance.

(3) In the respond spectrum case, each model's vertical distribution curves along structure of floor displacement, interlayer displacement angle, floor shear and floor stiffness and so on are shown in Fig 5~7; The maximum values of related parameters shown in Table 5.

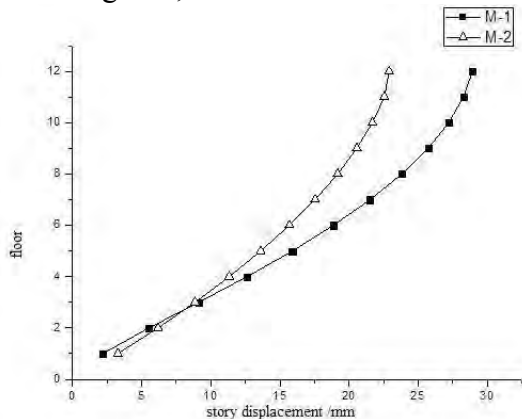


Fig. 5 Story Displacements of Models

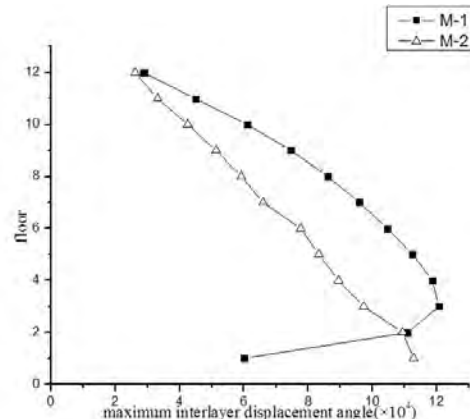


Fig. 6 Story Drifts of Models

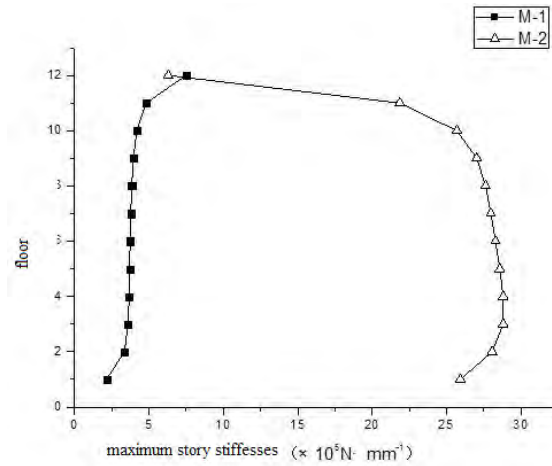


Fig. 7 Story Stiffnesses of Models

Tab.5 Max of Story Response under Spectrum-case of Models

Model name	the maximum values of floor displacement [mm]	maximum interlayer displacement angle	maximum floor shear [N]	maximum floor overturning moment [N·mm]	maximum floor stiffness [N·mm ⁻¹] (Qy)
M—1	28.9192(12f)	1/829(3f)	3.123E+06(1f)	3.535E+10(1f)	7.474E+05(1f)
M—2	22.8906(12f)	1/872(1f)	3.440E+06(1f)	8.095E+10(1f)	2.806E+06(3f)

Under response spectrum conditions, each model's section shear value of the second floor stairwell frame column along Y-axis direction (②×D) is shown as Table 6.

Tab. 6 Shears of Column under Spectrum-case of Models

Model name	shear value of the second floor along Y-axis direction [N]	
	top half column section	top half column section
M—1		34093.71
M—2	41542.39	141637.20

It can be seen from Table 6: the section shear value of the stairwell frame column of model 2 changes largely from that of model 1, that is, the column section maximum shear value of model 2 is about three times of that of model 1 due to stair landing's existence of model 2, and in the model 2, and the shear value of column's top segment is very different from that of column's bottom segment, the difference is approximately up to about 200%, the staircase support effect of model 2 leads to enormous additional stress caused by stairwell frame column's suffering impact under the earthquake action, and probably the frame column will be seriously damaged.

Conclusion

Several conclusions have been reached based on the above calculation models designed for this analysis:

(1) Stairs have a significant contribute to the structural lateral stiffness, the integral lateral stiffness increases much in the direction along the ladder arranged, lateral curve transits to shear-moment deformation curve.

(2) Staircase involved in the overall calculation may make the original structure mainly in the form of translation larger torsion, and the staircase can't be considered easily as a general support only providing the lateral stiffness, the internal forces of staircase itself and stairwell column are greatly influenced by structural changes in the overall performance, hence taking fully consideration of staircase in design and adopting scientific and rational measures to ensure the safety of staircase as a major evacuation passageway in the early time of earthquake.

(3) When staircase is taken consideration into structural overall calculation, the analysis result may be greatly influenced by the simplified model and calculation method, In the current case that there is no specific provision on how staircase participates in the overall structural analysis and calculation, it's suggested that a model with staircase (M-2) should be adopted in the seismic design and spectrum analysis should be used in the earthquake action calculation.

Experimental study on the reinforced concrete structure with staircase should be done in the future due to the complexity of earthquake action and structure response as well as the limit of calculation software, hence revealing the seismic performances of the whole structure and partial stairwell more objectively and fully and providing more reasonable and feasible technical advice for the structural design.

Acknowledgement

In this paper, the research was sponsored by the Education department of Liaoning Province (Project No. L2013201).

References

- [1]GB 50011- 2001 Code for Seismic Design of Buildings (2002 edition) [S].
- [2]JG J3- 2002 Technical specification for concrete structures of tall building [S].
- [3]GB 50011- 2001 Code for Seismic Design of Buildings (2008 edition) [S].
- [4]CAO Wan-lin, PANG Guo-xin, LI Yun-xiao. The Test Research on Elastic Floor Rigidity of Frame with Staircase[J].World Information on Earthquake Engineering,1996(2):29-32.
- [5]CAO Wan-lin, PANG Guo-xin, LI Yun-xiao. Research on Elastoplastic Performance of Frames with Staircases[J].World Information on Earthquake Engineering,1996(3):52-56.
- [6]CAO Wan-lin, HU Guo-zhen, ZHOU Ming-jie, et al. Test Research on Performance of Interactions Between RC Frames and Staircases[J].Engineering Mechanics,1999,16(S2):23-26.
- [7]Civil King Software Technology Co.,Ltd, China building standard design and Research Institute. ETABS Chinese version of the User Guide[M]. Beijing: China Building Industry Press,2004.