The Analysis of Non-Linear Seismic Response between a Collapsed and a serious damage Infilled Frame Structure in Yingxiu Town–the Heavy Disaster Areas of Wenchuan 8.0 Earthquake

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SUMMARY:
On 12 May 2008, a magnitude 8.0 earthquake happened in Wenchuan, Sichuan province, China .It was the most serious earthquake in china since 1949, causing very huge casualties and economic loss. The complex building and the office building of the Yingxiu secondary school in Yingxiu town were designed by the Code for Seismic Design of Buildings of China (GB50011-2001), the seismic fortification intensity of the buildings were both 7 degree. In the earthquake, the complex building collapsed completely, the adjacent office building was serious damaged, but didn't collapse. In the paper, the properties of material nonlinearity were considered ,the nonlinear analysis model of infilled frame structure was established, the time history analysis was used, the main cause of structural destruction was obtained, the influence of the infill wall on the structure was discussed.Therefore ,the results can provide valuable reference for the seismic design of infilled frame structure.

Keywords: Wenchuan earthquake, Infilled frame structure, the analysis of non-linear seismic response, Time history analysis

1. INSTRUCTIONS

On May 12 2008, a magnitude 8.0 earthquake occurred in Wenchuan County, Sichuan Province, China. It was the most serious earthquake in china since 1949, causing very huge casualties and engineering damages to the buildings. The complex building and the office building of the Xuankou secondary school in Yingxiu town were both built in 2005, designed by the Code for Seismic Design of Buildings of China (GB50011-2001); the seismic fortification intensity of the buildings was 7 degree. In the earthquake, the complex building collapsed completely, while the office building was destroyed most seriously, but didn't collapse. It is important to the investigation on theory and engineering

In the paper, the property of material nonlinearity was considered, the nonlinear analysis model of infilled frame structure was established, the time history analysis and nonlinear static analysis were used during inelastic stage, the main cause of structural destruction was obtained, and the influence of the infill wall on the structure was discussed. Therefore, the results can provide valuable reference for the seismic design of infilled frame structure.

2. DESCPITION OF THE BUILDING AND THE ENGINEERING SEISMIC DAMAGE

The complex building and the office building were built in 2005. The concrete grade is: column C30; beam C30; plate C30, the reinforced grade: I-reinforced HPB235, II-class steel HRB335, the floor pillar size is $400 \times 400\,mm$,the filling wall is construct by MU10 hollow block and M5 Mortar. The thickness of the walls is $200\,mm$; the roof and floor are cast-in-place. The basis is individual footing of column; the foundation depth is 3 m^2 . The complex building is the six-storey building with level roof. The area of the complex building is 3618.3 m^2. The height of the first floor is 4.05 m^2, the other is 3.60 m^2. The office building is the four-storey building with level roof. The area of the office building is 1180.44 m^2. The height of the first floor is 4.05 m^2, the height of the second floor and the fourth floor is 3.60 m^2, and the height of the third floor is 3.9 m^2.

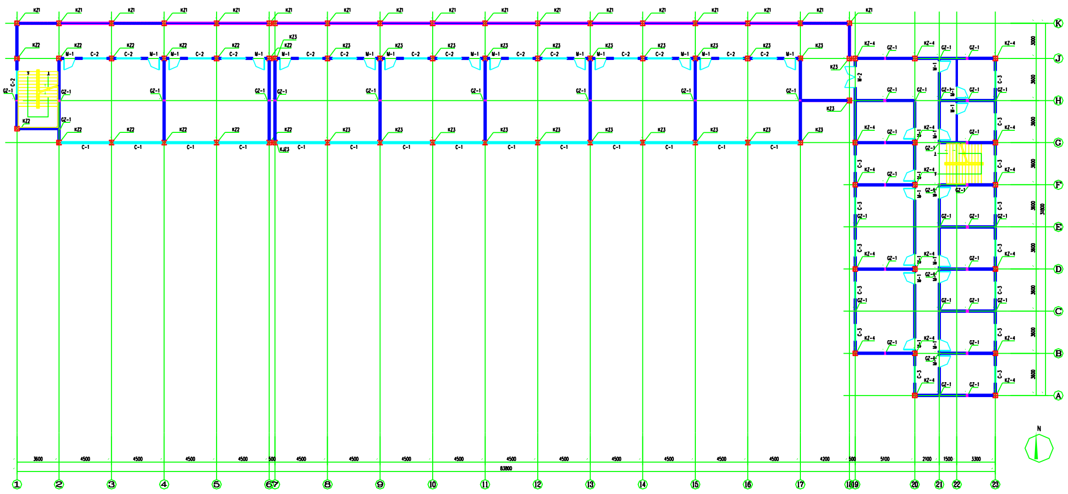


Figure.1 The planar graph of the structure

In Fig.1, the complex building is composed by 1-18 axis and K-G axis; there is a seismic joint between 6 axes and 7 axes. In Fig.3 and Fig.4, the part of 1-6 axis inclined eastwardly, the first story disappeared. In Fig.2, the part of 7-18 axis collapsed completely. [1]

Figure2. The complex building of the Xuankou secondary school(Global)

Figure3. The complex building of the Xuankou secondary school(Local1)

The office building is composed by 19-23 axis and A-J axis. In Fig.5, the main structure of the framework is basically undamaged; the local part of the office building is serious damage by the collision with the complex building that collapsed[1].

3. ESTABLISHMENT OF FINITE ELEMENT MODEL

In the paper, the space finite element model is established by ANSYS. Beam and column is simulated by beam188 element, the filling wall is simulated by link10 element, and the floor slab is simulated by shell63 element. There are 13461 nodes in the model, and the element type and the element quantity are in table1.

Fig4. The complex building of the Xuankou secondary school(Local 2)

Fig5. the office building of the Xuankou secondary school

Table1 classifications of finite element

Component	Element type	Element No.
Beam, Column	beam188	4827
Floor	shell63	6121
Infilled Wall	link10	993

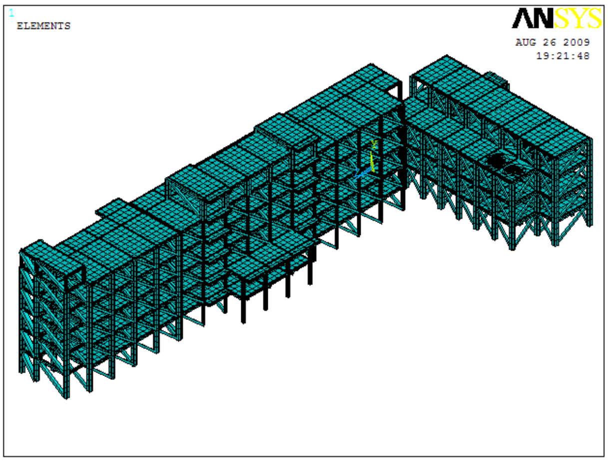


Figure 6. Finite element model

3.1 Treatment of reinforced concrete

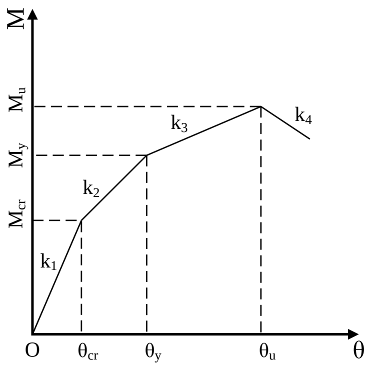
In the paper, the four-line stiffness degradation model is used for the simplification of the restoring force characteristics according to Fig.7. [2] In the model, the restoring force skeleton curve is represent by four lines, the stiffness degradation of reinforce concrete members is considered. The model could reflect the mechanical properties of reinforced concrete members under the action of the periodic reciprocating load.

3.2 Treatment of filling wall

The filling wall is considered as a slant beam which hinged in the frame. The thickness of the slant beam is 200mm.The width is between 1/10 and 1/7 of the length of diagonal of filling wall according to Fig.8. [3] The slant beam only bears pressure.

3.3 Treatment of floor slab

In the paper, the stiffness of floor slab is huge in its own plane, and the stiffness which out of its own plane is very small, could be neglected. [4] Horizontal displacement of vertical members in each floor is transfer by the horizontal rigid motion of the floor slab.



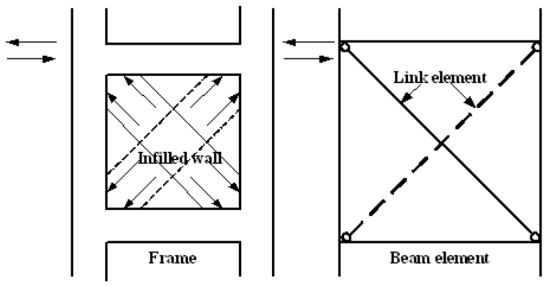


Figure 7. The curve of $M-\theta$

Figure 8. Finite element model of infilled wall

4、STRONG MOTION DATA

In the paper, the strong motion data of Wolong station（31.04N ，103.18E） is used for the time history analysis. The result will be obtained by input the finite element model with the ground motion parameter from ns-trending, we-trending, vertical- trending. The ground motion parameter of 6degree to 10 degree could be obtained by the method of conversion between seismic time history and response spectrum.

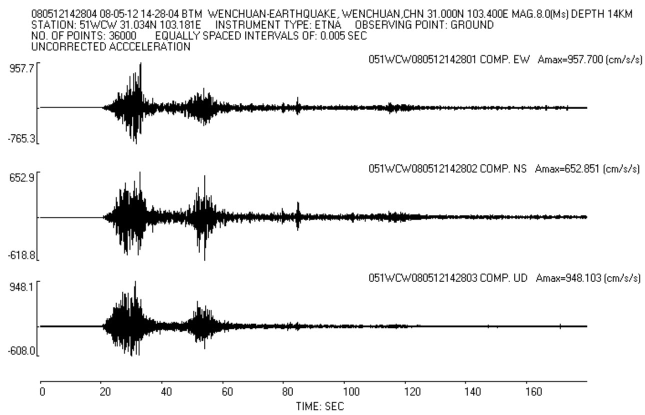


Figure 9. Strong motion data of WoLong

5、RESULT ANALYSIS

5.1、The Story Drift Angle

The story drift angle is adopted for judging the collapse of the structure. [5]The calculation formula is as follow:

$$\left[\theta_{\mathrm{p}}\right] \leq \frac{\Delta u_p}{h} \tag{1}$$

Δu_p – elastic-plastic inter-story displacement

h – height of the story

(1)In Figure.10, the first story drift angle of the 1-6 axis part of the complex building is 0.020587 at 32.310s, exceed the limit value of the elastic-plastic inter-story displacement angle of RC frame structure (1/50) [5],the maximum value is 0.0210024.So the first story collapsed at 32.310s in the earthquake(as Figure.3 and Figure.4);

(2)In Figure.11, the first story drift angle of the 7-18 axis part of the complex building is 0.0201153 at 32.310s, the maximum value is 0.04398; In Figure.12, the second story drift angle of the 7-18 axis part of the complex building is 0.203989 at 33.010s, the maximum value is 0.04004; In Figure.13, the third story drift angle of the 7-18 axis part of the complex building is 0.0200684 at 33.240s, the maximum value is 0.03033; In Figure.14, the fourth story drift angle of the 7-18 axis part of the complex building is 0.0202572 at 33.280s, the maximum value is 0.02355;so the first to the fourth story collapsed in the earthquake(as Figure.1);

(3)In Figure.15, the first story drift angle of the office building is 0.0211061 at 33.27s, and the other time is less than 0.02.Compare with Fig.5, the office building didn't collapse. So the limit value of the elastic-plastic inter-story displacement angle of RC frame structure which is defined by the Code for Seismic Design of Buildings of China (GB50011-2001) maybe relatively small. From Figure.16 to Figure.18, the story drift angles of the second and the third and the fourth story did not exceed the limit value of the elastic-plastic inter-story displacement angle of RC frame structure. So the office building did not collapse in the earthquake (as Figure.5).

5.2、The Reason of the Collision between Complex Building and Office Building

The nodal displacement of the third story of the office building at the place of 19 axes -J axes is defined as δ_{b} . The nodal displacement of the third story of the complex building at the place of 18 axes -J axes is defined as δ_{c}.The width of the seismic joint between 18 axes and 19 axes is 0.1m. If the collision between the complex building and the office building happened, the condition $\Delta\delta = \delta_{\mathrm{b}} - \delta_{\mathrm{c}} > 0.1$ must be satisfied. In Figure.19, the condition $\Delta\delta = \delta_{\mathrm{b}} - \delta_{\mathrm{c}} > 0.1$ happened at 29.19s, the maximum value is 0.20139m.So the complex building and the office building impacts each other at 29.19s (as Figure.4). If the width of the seismic joint is more than 0.20139, the collision will not happen in the earthquake.

5.3、The Internal Force at the time of Collapse

In Figure.20 and Figure.21, the internal force of the 7-18 axis part of the complex building is more than the 1-6 axis part of the complex building and the office building .In X--direction, the maximum value of the internal force is 3400MPa. In Z--direction, the maximum value of the internal force is 5030MPa.

5.4、The Story Drift

In Figure.22 and Figure.23, the story drifts of the complex building and office building are reasonable and with a uniform variation along the height. The variation of the stiffness of each story is uniform. So under strong seismic action, the first story will be the weak story of the two buildings. The maximum value of the complex building's top story is 0.103122m. The maximum value of the office building's top story is 0.0331m.

5.5 、The Influence of the Rate of Filling Wall on Story Drift Angle

In this part, the influence of the rate of the filling wall on the structure will be discussed.The calculation formula of the rate of the filling wall is as follow:

$$\alpha = \frac{\sum F_k}{\sum A} \times 100\% \qquad (2)$$

$\sum F_k$ –the sectionarea of all the filling walls

$\sum A$ – the planearea of all the stories

The rate of the complex building is 4.192%, and its earthquake damage level is collapse; the rate of the office building is 9.288%, and its earthquake damage level is severe damage. So adjusting the rate of the complex building to 9.288% gradually, observe the variation of the rate. In Figure.24, the maximum story drift angle of each story of the complex building gradually decreases with the rate increase from 5% to 9%. The variation is significantly in the first to the third story. The maximum value of the first story decrease from0.04398 to 0.02004, the maximum value of the second story decrease from 0.04004 to 0.01804, the maximum value of the third story decrease from 0.03033 to 0.01322. When the rate reaches at 7%, the variation of the max story drift angle of the fourth story is not significantly, the value decrease from 0.02355 to 0.01172. When the rate reaches at 6%, the variation of the max story drift angle of the fifth story is not significantly, the value decrease from 0.01158 to 0.00451. The influence of the rate on the top story is extremely small; the value decrease from 0.01368 to 0.00977.So the properly increasing of the rate of the filling wall will improve the seismic behavior of the reinforced concrete frame structure under the strong seismic action.

5.6、The Influence of the Intensity on Story Drift Angle

In Figure.25, the maximum story drift angle of each story of the complex building gradually decreases with the intensity decreases from 11 degree to 6 degree. The maximum value of the first story decrease from0.04398 to 0.001736, the maximum value of the second story decrease from 0.04004 to 0.001519, the maximum value of the third story decrease from 0.03033 to 0.001449,the maximum value of the fourth story decrease from 0.02355 to 0.001279， the maximum value of the fifth story decrease from 0.01158 to 0.00057， the maximum value of the top story decrease from 0.01368 to 0.000877.At 9 degree, the maximum story drift angles of each story of the complex building do not exceed the limit value of the elastic-plastic inter-story displacement angle of RC frame structure (1/50). At 6 degree, the maximum story drift angles of each story of the complex building do not exceed the limit value of the elastic inter-story displacement angle of RC frame structure (1/550). So the RC frame structure which is designed by the Code for Seismic Design of Buildings of China (GB50011-2001) with the 7 degree seismic fortification intensity can resist the strong seismic action which is two degrees bigger than its seismic fortification intensity.

6、CONCLUSION

In the paper, the collapse mechanism of the infilled frame structure under the strong seismic action is discussed. Firstly, the story drift angle is adopted for judging the collapse of the structure. The reason of the collapse of the complex building and the office building is given, and the internal force at the time of collapse is given. Secondly, the reason of the collision between complex building and office building is discussed. The reasonable width of the seismic joint is given. Thirdly, the influence of the rate of the filling wall on the structure is discussed. The properly increasing of the rate of the filling wall will improve the seismic behavior of the reinforced concrete frame structure under the strong seismic action. It is signality to the structure such as school and hospital with large bay. Finally, the seismic behavior of the reinforced concrete frame structure which designed by the Code for Seismic Design of Buildings of China (GB50011-2001) under the different intensity is discussed. The structure with the 7 degree seismic fortification intensity can resist the strong seismic action which is two degrees bigger than its seismic fortification intensity.

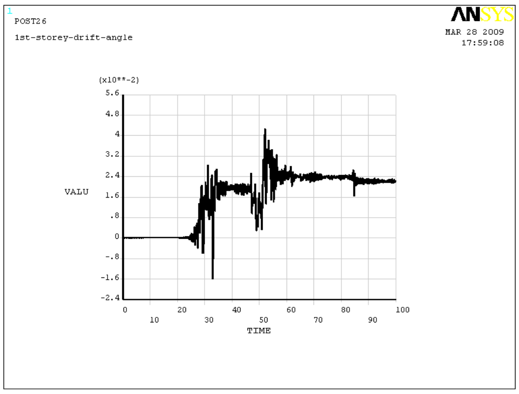


Figure 10. The 1st story drift angle of the complex building（1-6axis1-6axis）

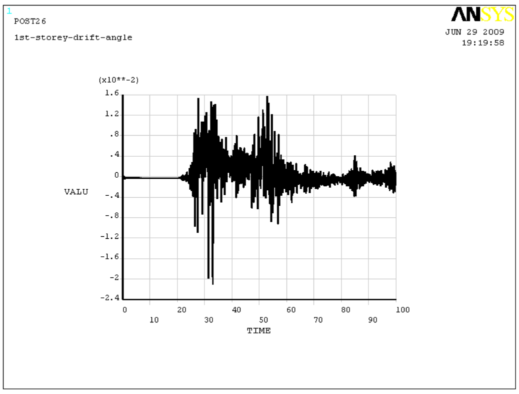


Figure11. The 1st story angle of the complex building (7-18 axis)

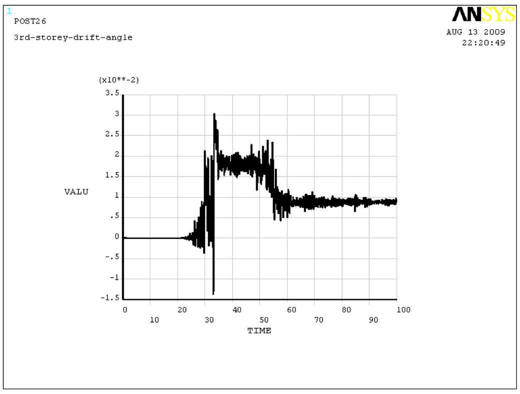


Figure 12. The 2nd story angle of the complex building (7-18 axis)

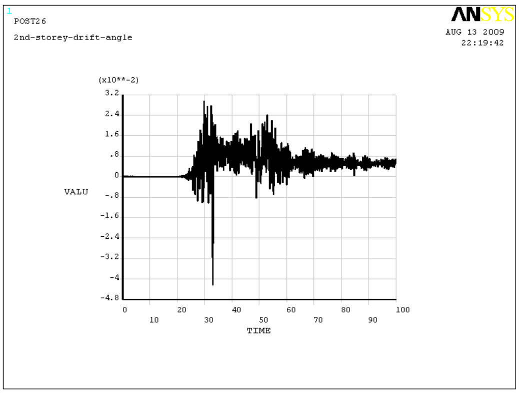


Figure 13. The 3rd story angle of the complex building (7-18 axis)

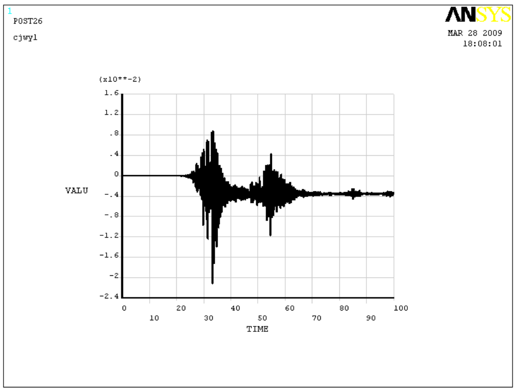


Figure 14. The 4th story angle of the complex building (7-18 axis)

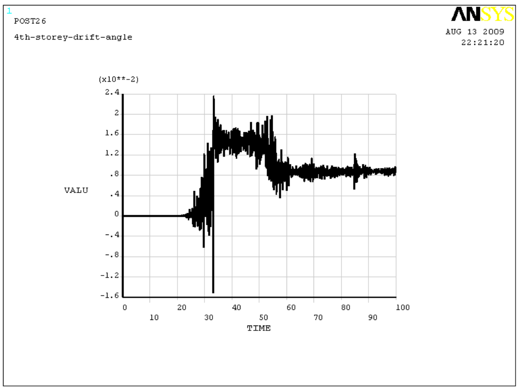


Figure 15. The 1st story angle of the office building

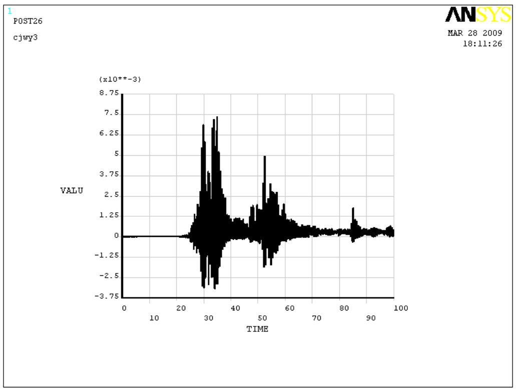


Figure 16. The 2nd story angle of the office building

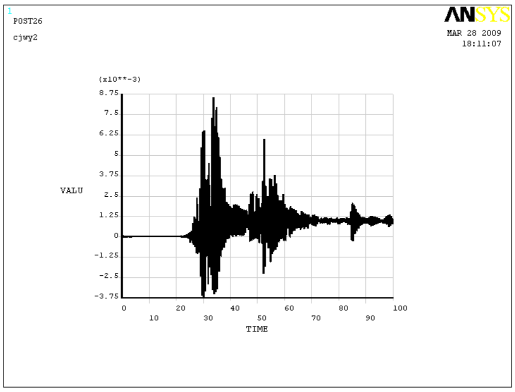


Figure 17. The 3rd story angle of the office building

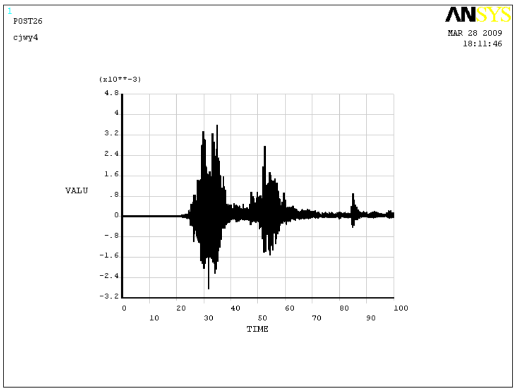


Figure 18. The 4th story angle of the office building

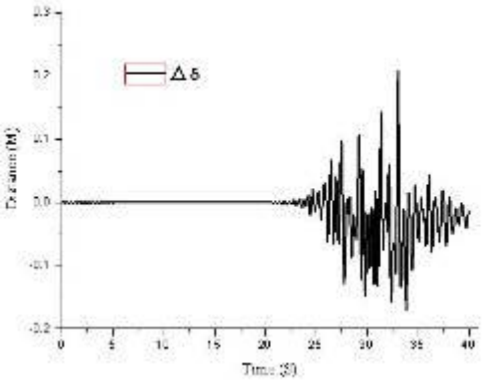


Figure 19. The distance between the office building and the office building

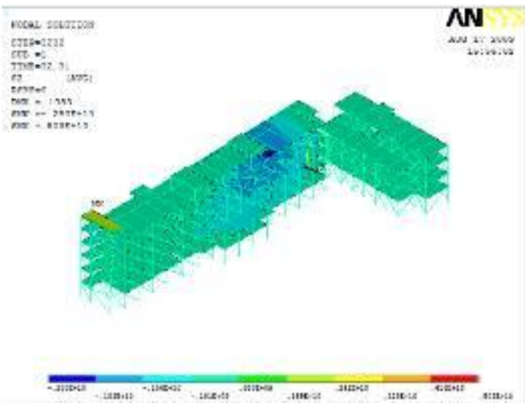


Figure 20. The internal force distribution of the structure in X-direction

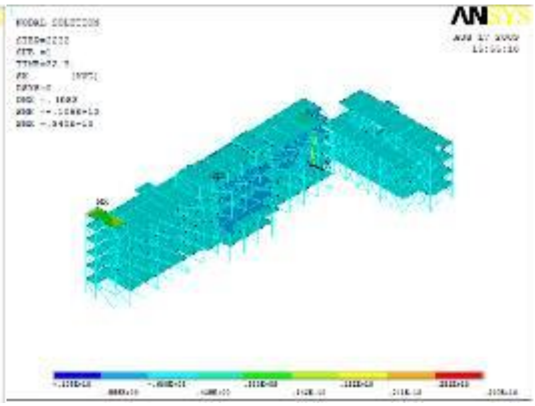


Figure 21. The internal force distribution of the structure in Z-direction

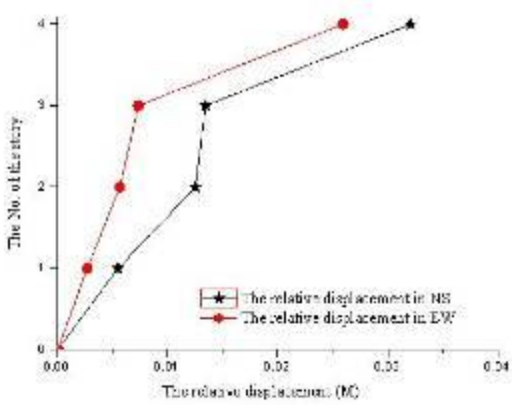


Figure 22. Envelope curves of the relative displacement of the complex building

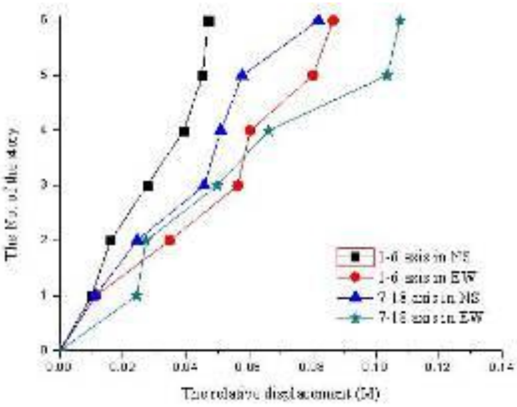


Figure 23. Envelope curves of the relative displacement of the office building

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