Research Journal of Applied Sciences, Engineering and Technology 6(11): 1902-1905, 2013
DOI:10.19026/rjaset.6.3802
ISSN: 2040-7459; e-ISSN: 2040-7467
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Submitted: September 22, 2012 Accepted: January 17, 2013 Published: July 25, 2013

Research Article

Response Analysis for Steel Reinforced Concrete Frame Structures under Earthquake Load

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Abstract: In order to understand the whole process of the steel reinforced concrete frame structure from elastic to elasto-plastic cracking gradually, damage until the collapse, the elasto-plastic finite element analysis theory and ETABS structural analysis software were used, then the spatial three-dimensional truss system model of frame structures was established. Based on the analysis of the elasto-plastic response for the frame structure under one-dimensional and two-dimensional earthquake load, the interbedded displacement angle-time curve and horizontal displacement-time curve were obtained. Through the analysis of the model, the sequence of appearance of plastic hinges in the frame structure under earthquake load was cleared and the weak location of the frame structure was detected.

Keywords: Analysis of elasto-plastic response, frame structure, interbedded displacement angle, plastic hinge, steel reinforced concrete

INTRODUCTION

Commonly used structural seismic analysis methods are equivalent to base shear method, model analysis response method and time-history analysis method (Chung *et al*., 2007). The first two belong to the static elastic analysis methods. In order to understand the whole process of the structure from elastic to plastic cracking gradually, damage until the collapse, analysis of elastic-plastic response of structures is done for looking for measures to prevent structural collapse. The study of elastic-plastic time history method experienced from the layer-truss model, plane truss model to the three-dimensional truss system model. Many simplifications are done for the layer-truss model and the plane truss model, so the calculation becomes relatively convenient. However, the ground motion is a multi-dimensional movement when earthquake happens; the action of earthquake on structures is spatial (Geng *et al*., 2012). The structure will bear forces from two directions; in this case, its seismic performance is largely different from that of uniaxial force state (Tao *et al*., 2007). It is very difficult to obtain accurate result of the seismic performance through the plane response (Lu and Jing, 2002; Wu, 2002). Therefore, ETABS software is used to establish the framework of three-dimensional structure of the space truss model, the frame structure is under the elastic-plastic response analysis on the one-way seismic wave and two-way seismic waves, the two sets of data were compared (Lu and Yang, 2012; Xu *et al*., 2011).

Characteristics of resilience: Restoring force is the capacity of restore the deformation; restoring-force characteristic shows the relationship between restoring-force and deformation. Restoring force model is a base of elastic-plastic time history analysis of the structure, generally obtained by test. In accordance with the material properties, component types and loading methods, restoring force model is idealized and then based on the crack, yield and ultimate displacement of structural feature points, hysteretic bone curve is defined. Commonly used restoring force model of concrete structures includes curve type and broken line type. Curve- type restoring force model is a continuous curve, the stiffness changes continuous, closer to the actual project, but more complicated method of calculating stiffness (Li, 1980). Broken line-type restoring force model posed by a number of line segments, the stiffness change is not continuous because of inflection point or mutation, but the stiffness calculation is relatively simple, so it is widely used in practice. For steel reinforced concrete structures, due to the material properties and different types of components, the restoring-force characteristic under major earthquake is very complex. In this study, the calculation of the analysis selected the bilinear restoring force model, as shown in Fig. 1.

METHODOLOGY

Outline of structure frame work: A 20-storey steel reinforced concrete frame structure, floor height of 3 m.

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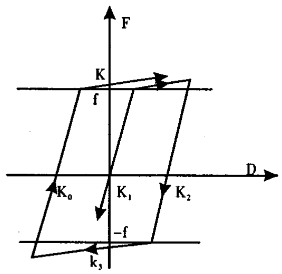

Fig. 1: Restoring force model

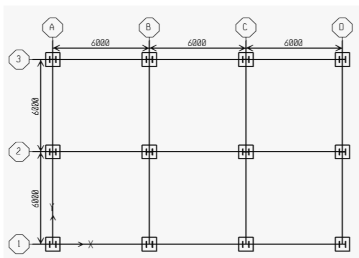

Fig. 2: Plane figure of structure

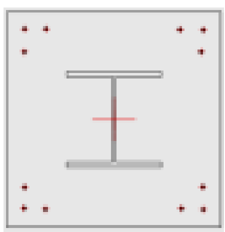

Fig. 3: The cross-section of column

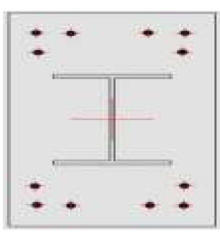

Fig. 4: The cross-section of beam

is established as shown in Fig. 2. The frame structure comply with the design principle of strong column and weak beam, cross-section size of all columns are 900×900 mm and concrete is C50, as shown in Fig. 3; cross-section size of beams are 350×700 mm and concrete is C30, as shown in Fig. 4. Seismic fortification intensity is 7° and site classification is II. ETABS is used to establish a three-dimensional truss element model and a layer-truss model for the analysis of elastic-plastic response.

Selection of seismic wave: According to the construction site classification, design of sub-seismic

Fig. 5: 3-dimensional truss system model

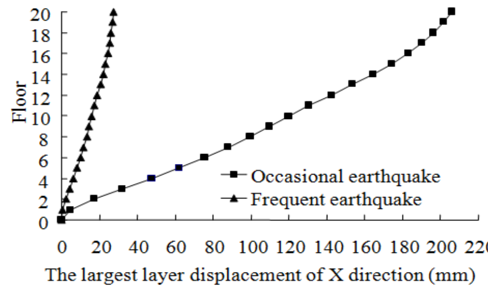

Fig. 6: The largest layer disp. of X direction (mm)

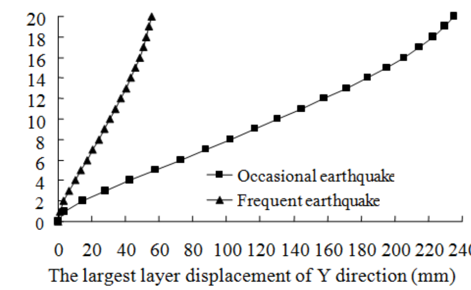

Fig. 7: The largest layer disp. of Y direction (mm)

and site soil, EL-Centro are selected. The peak acceleration is 341.7 gal in north-south and 210.1 gal in the east-west. Two-way seismic waves are used to analyze three-dimensional truss system model, north-south seismic wave is used to analyze layer-truss model.

Analysis of three-dimensional truss system model: Truss system mode is composed of beam element model and column element, as shown in Fig. 5. According to fortification intensity of 7, peak acceleration of the EL-Centro earthquake waves were adjusted. In case of frequent earthquake, the peak acceleration in east-west direction and north-south direction are 42.02, 34.17 gal, respectively; In case of major earthquake, the peak acceleration in east-west direction and north-south direction are 220.61, 222.11 gal, respectively.

Figure 6 and 7 show the largest layer displacement in the X, Y direction respectively. Figure 6 shows the

Table 1: The contrast of seismic response

	Maximum displacement in X direction/mm				Maximum interstorey drift in X direction			
Floor	A1	A2	B1	B2	A1	A2	B1	B2
20	27.4	26.1	206.1	196.2	0.00020	0.00020	0.00152	0.00151
19	26.9	25.6	201.8	192.1	0.00025	0.00025	0.00193	0.00193
18	26.2	24.9	196.6	187.2	0.00031	0.00031	0.00230	0.00236
17	25.3	24.2	190.2	181.6	0.00036	0.00036	0.00271	0.00272
16	24.3	23.4	182.7	175.5	0.00040	0.00040	0.00303	0.00303
15	23.2	22.5	174.1	168.8	0.00044	0.00044	0.00335	0.00334
14	21.9	21.5	164.4	161.3	0.00048	0.00048	0.00360	0.00360
13	20.4	20.4	153.7	153.2	0.00050	0.00050	0.00378	0.00379
12	18.9	19.2	142.2	144.4	0.00052	0.00052	0.00395	0.00395
11	17.4	18.0	130.6	135.0	0.00054	0.00054	0.00408	0.00408
10	15.9	16.6	119.7	125.1	0.00054	0.00054	0.00411	0.00411
9	14.6	15.2	109.7	114.6	0.00054	0.00054	0.00400	0.00406
8	13.2	13.7	99.4	103.0	0.00052	0.00052	0.00394	0.00394
7	11.7	12	88.2	90.4	0.00051	0.00051	0.00386	0.00386
6	10.1	10.2	75.7	76.8	0.00054	0.00054	0.00406	0.00406
5	8.2	8.3	62.1	62.3	0.00056	0.00056	0.00422	0.00422
4	6.3	6.2	47.4	47.2	0.00057	0.00057	0.00430	0.00429
3	4.3	4.2	32.2	31.7	0.00055	0.00055	0.00416	0.00416
2	2.3	2.2	17.2	16.8	0.00046	0.00046	0.00348	0.00348
1	0.6	0.6	4.7	4.5	0.00021	0.00021	0.00159	0.00278

A1: The space truss model under frequent earthquake; A2: The layer-truss model under frequent earthquake; B1: The space truss model under occasional earthquake; B2: The layer-truss model under occasional earthquake

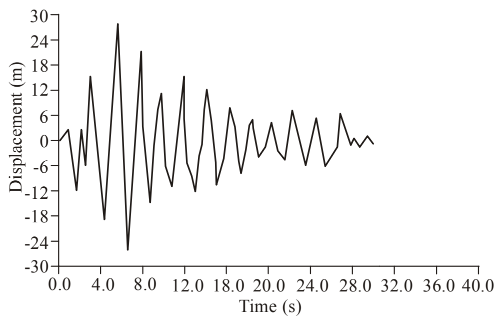

Fig. 8: Time-disp. graph of vertex in X direction

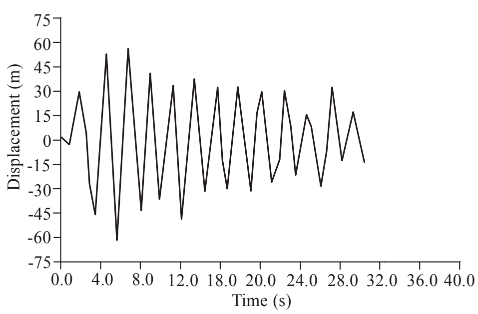

Fig. 9: Time-disp. graph of vertex in Y direction

deformation of framework structure was shear-type under the earthquake, the layer displacement is larger between stories 2, 3, 4, belongs to relative weak layer. As seen from Table 1, in the frequent earthquake, interlayer drift of the structure is less than the allowable elastic interlayer drift index of 1/550; in major earthquake, the interlayer drift is smaller than the elastic-plastic story drift limit of 1/50, meeting the requirements of specification.

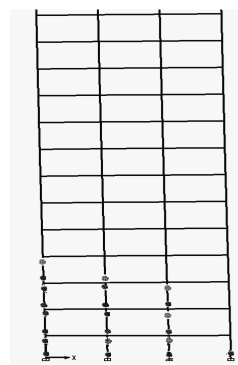

Fig. 10: The plastic hinge of structure

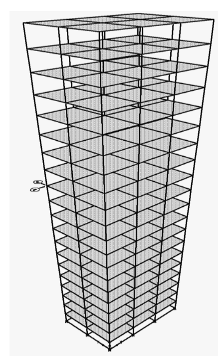

Fig. 11: Layer-truss model

Figure 8 and 9 show the time-displacement graph of the three-dimensional truss system model in the X, Y directions of vertex under the frequent earthquake. The displacement of vertex at 5.5 sec is the maximum and at 12 sec is large; it is in conformity with El-Centro seismic wave.

The plastic hinges of structure are shown in Fig. 10. At about 2.5 sec, plastic hinge firstly happened at the bottom of frame column and then more plastic hinges appeared in order of floor at the end of beams and columns. At last a plastic hinge area is formed and structure is in the state of elastic-plastic deformation.

Analysis of layer-truss model: Figure 11 is the layer-truss model only by the north-south El-Centro seismic waves. The contrast of two types of models is shown in Table 1.

The maximum displacement of vertex in Y direction of the three-dimension truss model is larger than that in the layer-truss model under both of the frequent and occasional earthquakes. The following reasons are included:

- Three-dimension truss model is affected by the two direction seismic waves, but layer-truss model is only affected by single direction seismic wave.
- Under the action of multi-force, its seismic performance will be reduced.
- As a result of uneven weight distribution, the structure will have a reverse effect, thus the displacement increased.

DISCUSSION AND CONCLUSION

In this study, elasto-plastic response of steel reinforced concrete frame structures under earthquake was analyzed with ETABS. Three-dimension truss model and layer-truss model were used. Based on the analysis of the elastic-plastic response under two-directions and one-direction El-Centro seismic waves, the story drift and horizontal time-displacement curve were compared. The response under two-directions El-Centro seismic waves has a coupling effect and causes larger response than that under one-direction. In the design for ultimate limit states of components, the method of calculating the bearing capacity of the two orthogonal directions respectively and stacking is unsafe and it should be considered by the multi-dimensional combined effect of cross-section internal forces. Through the analysis of the model, the sequence of appearance of plastic hinges in the frame structure under earthquake load was cleared and the weak location of the frame structure was detected. It is basically agreement with that of previous study by SAP2000 and ANSYS software.

ACKNOWLEDGMENT

This study was financially supported by Liaoning Provincial Educational Department Fund (L2010412), "Liaoning BaiQianWan Talents Program" Fund (2010921077) and Scientific Research Foundation for the Returned Overseas Chinese Scholars (20086211), Shenyang Science and Technology Plan Fund (F10-205-1-08) and Liaoning Provincial Educational Department Fund (L2010411). The supports are gratefully acknowledged.

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