Applied Mechanics and Materials *Online: 2012-12-13*
ISSN: 1662-7482, Vols. 256-259, pp 2673-2676
doi:10.4028/www.scientific.net/AMM.256-259.2673

Analysis on dynamic failure behaviors of steel double-layer grids supported by circumjacent steel columns used in a sports center under disaster earthquake waves

W. W.LI [1, a], H. W. LI [1, b]*

[1] Department of Civil Engineering, Taiyuan University of Technology79,
Yingzexi Street, Taiyuan, 030024, China

[a]08.li.wei@163.com, [b]lhwtut@126.com (corresponding author),

Corresponding author ,Prof.,Email:lhwtut@126.com

Key words: Strong earthquake action, steel double-layer grids, Elasto-plastic dynamic response, Plastic hinge, Seismic performance

Abstract: In this paper, the analysis is carried out under EL-centro wave with SAP2000, and the appraisal results on their anti-failure performances are presented based on the plastic-hinge theory. In the analyses, the geometric and material nonlinear effects are considered simultaneously. The plastic development level of the rods, the deformed shape and the failure type and the ductility are estimated. The results show that the failure model of the structure under the earthquake wave action is the complicated combination of strength failure and elasto-plastic dynamic local buckling in deferent areas of the structure; Its critical failure peak acceleration of EL earthquake wave when applied in X directions is 747gal, which is 1.87 times more than the official seismic fortification level of 8 degree (major earthquake, 0.4g) and can be served as earthquake victim shelter in the area of 8 degree seismic fortification; Its displacement ductility coefficient is12.14,which shows the structure owns good energy dissipation capacity.

1. Introduction

Double-layer grids with their structural advantages and good seismic performance are widely used in large span buildings in China. Previous recent disastrous earthquakes show that the large span public buildings were used as earthquake shelters and disaster relief headquarter sites [1]. So the large span public buildings newly designed are gradually required to have the function of earthquake shelters. In order to work safely during disastrous earthquakes, the structures of these buildings are required to be designed under strong earthquake action larger than the official seismic major fortification earthquake level. Therefore the appraisal method on their anti-collapse performances under strong earthquake action is needed to be studied. In this paper, the elasto-plastic dynamic analysis on dynamic failure behaviors of steel double-layer grids supported by circumjacent steel column used in a gymnasium with the function of earthquake victim shelter under disaster earthquake is carried out and appraisal results on their anti-failure performances are presented under strong earthquake action based on the plastic-hinge theory [2].

2.Analysis Model

A sports center is shown in Fig.1. Its cornice elevation level is 10.45 m. Its roof structure is a double-layer grids with square on square pyramids supported by circumjacent steel columns. Its main grid size is 3mX3m, its grid height is 2.5 m. The structure is designed firstly according to the current national standards with official seismic fortification level of 8 degree (0.2g) and site classification of type Ⅲ, design reference period of 50 years, design characteristic period of ground motion of 0.45 s. Its peak ground acceleration for the small and the major earthquake is respectively 70 gal and 400gal[3].The damp is taken as Rayleigh with the damping ratio 0f 0.02 or 0.05 for elasticity or elasto-plasticity. The material adopts bilinear elastic-plastic material model with the density 7850Kg/m3, elasticity modulus 2.06Gpa, tangent modulus 6.18GPa, the Poisson ratio 0.3, and the yield strength 235MPa. The top chord cross section sizes are amongφ60X3.5,φ89X4 andφ102X4, the lower chord cross section sizes are amongφ60X3.5,φ89X4 andφ102X4, the web member cross section sizes areφ60X3.5,φ70X4,φ89X4,Connecting rods areφ219X8;columns are H400X400X13X21； and column bracing areφ351X8.The nonlinear analysis on the spatial truss under EL-Centro wave is carried out with plastic hinge method by SAP2000. The generalized force-displacement relation for the plastic hinge defined in the members of the structure is defined according to **FEMA356**[4].

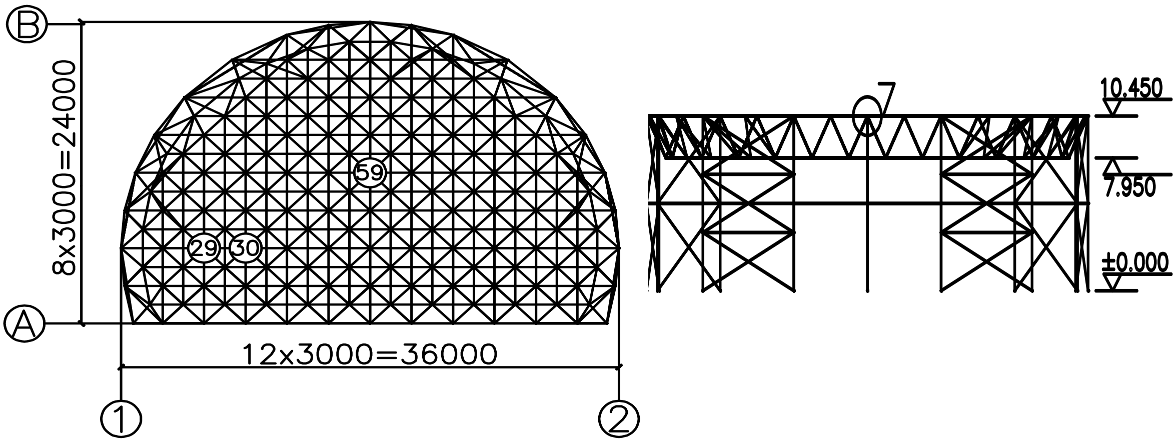

Fig. 1 Structure layout
(The number and the signs those shown in this figure are feature nodes)

3.Results and Analysis

Nonlinear time history calculations on the model are carried out by SAP2000 with El-Centro wave chosen as earthquake wave applied in X direction. The initial condition for each time-history calculation is the deformed state of the structure under the whole dead load and the half snow load. Many calculations with different peak value of the input earthquake wave applied to the structure designed according to the official Seismic fortification level(shorted as SFL) are carried out to find two limit conditions for the structure. The first is the elastic limitation; the second is critical failure state. The failure model is shown in Fig.2. The relationship curves between the maximum displacement response of feature nodes and peak ground acceleration (shorted as PGA) are respectively shown in Fig.3. The time history displacement response of the characteristic node is shown in Fig.4,Fig.5.The number and the distribution of the plastic hinge in different PGA are provided in Tab.1. The number and the distribution of the plastic hinge in 747gal are provided in Tab.2. Displacement ductility coefficients of the structure are listed in Tab.3.

Tab. 1 The number and percentage of plastic hinges in EL-Centro wave

Critical PGA (gal)	Plastic hinge number and proportion (%)					Total percentage (%)
	B-IO	IO-LS	LS-CP	CP-C	C-E	
352	—	—	—	—	—	—
353	2(0.2)	—	—	—	—	0.2
400	7(0.8)	2(0.2)	—	—	—	1.0
560	10(1.2)	5(0.6)	—	—	4(0.4)	2.2
570	12(1.4)	6(0.7)	—	—	5(0.5)	2.6
745	14(1.7)	19(2.3)	—	4(0.5)	62(7.6)	11.7
747	18(2.2)	16(2)	—	6(0.7)	70(8.6)	13.5
748	—	—	—	—	—	—

Note 1:. “—”indicates that no plastic hinge.

Tab.2 The plasticity development level in 747gal

Plastic hinge stage	Number of plastic hinges				
	top chord	lower chord	web members	columns	column bracing and connecting rods
B-IO	4	6	5	3	—
IO-LS	8	1	7	—	—
LS-CP	—	—	—	—	—
CP-C	1	1	4	—	—
C-E	18	9	43	—	—
Total percentage (%)	3.87	2.04	7.27	0.34	—

Note 2:. “—”indicates that no plastic hinge.

Tab. 3 Displacement ductility coefficients

Critical PGA (gal)	Node number	Absolute displacement (mm)	Yield displacement ratio
353	59	18.25	1.000
570	29	143.2	7.85
747	30	221.6	12.14

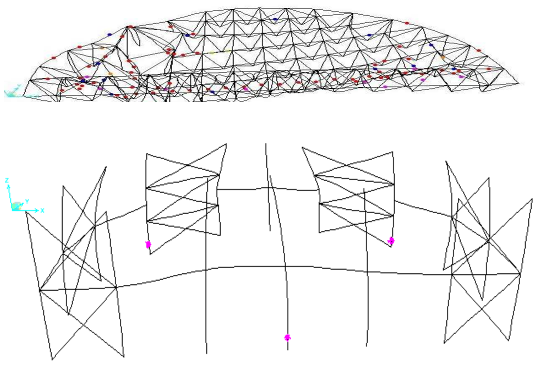

Fig. 2 The failure mode and the plastic hinge distribution

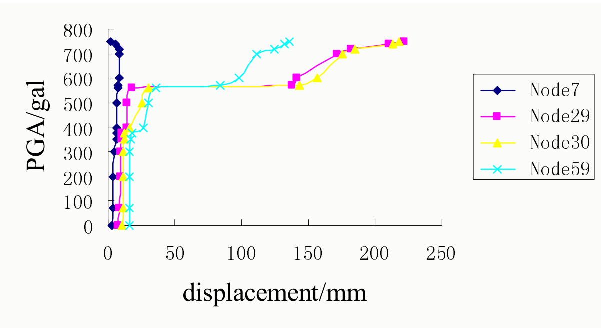

Fig. 3 The displacement of the feature node of the roof structure and the support structure - the PGA curve

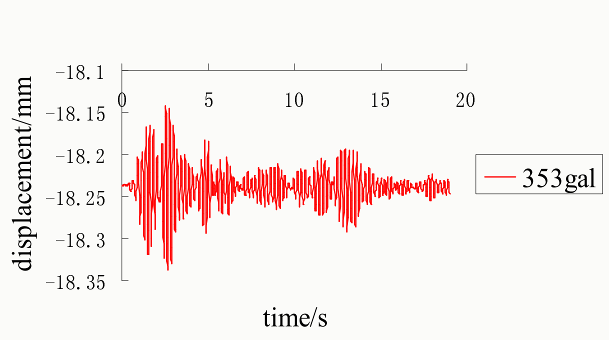

Fig. 4 Disp. time history curves of Node 59

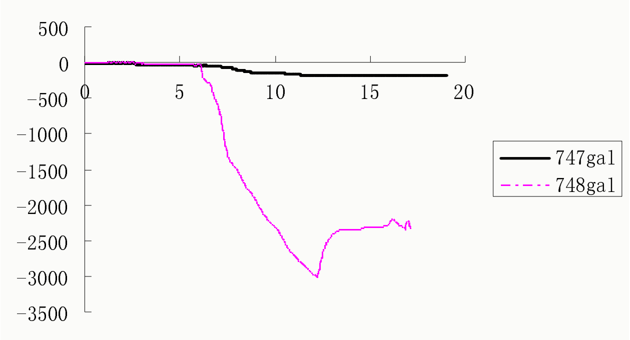

Fig. 5 Disp. time history curves of Node 29

According to Tab.1~4 and Fig.2~5, the results can be concluded as follows:

The elastic limitation PGA for three direction input is 353gal. It is much larger than the PGA of the official SEL for small earthquake (70gal).

According to the B-R criterion [5] [6], the failure model of the structure under the earthquake wave action is the complicated elasto-plastic dynamic local buckling in deferent areas of the structure. The critical PGA for this direction input is 747gal. It is much larger than the PGA of the official SEL for major earthquake (400gal).

The displacement ductility coefficient is 12.14 for the roof structure, and the ratio of its bars with plastic hinge appearing for ultimate critical state is only 13.15% when EL earthquake waves applied on the structure, the development of the plastic hinges is not sufficient.

When its critical failure peak acceleration of EL earthquake wave when applied in the directions of X, all the members in the E stage are compression failure.

All results about show the structure have some deformed capacity and energy-dissipation capacity before collapse under earthquake.

4. Conclusions

The failure model of the structure under the earthquake wave action is the complicated elasto-plastic dynamic local buckling in deferent areas of the structure; When the structure reached its failure critical limit, the development of the plastic hinges is not sufficient and only 13.15% of the rods enter into their plastic stage; The ratio of its maximal failure node vertical displacement and its short span is 1/110, which can meet the need for flexible non-structural attachment; The ratio of its maximal failure node horizontal displacement and its columns is 1/305; Its critical failure peak acceleration of EL earthquake wave when applied in the directions of X is 747gal, which is 1.87 times more than the official seismic fortification level of 8 degree (major earthquake, 0.4g) and can be served as earthquake victims shelter in the area of 8 degree seismic fortification; Its displacement ductility coefficient is 12.14 for the roof structure, which shows the structure owns some energy dissipation capacity.

Acknowledgements

This project is financially supported by National Natural Science Foundation of China (50878137); Key Project Foundation of Shanxi Province (20080321086) and Shanxi Province Foundation for Scholar Returned From Abroad (2009-26).

References

[1] H.W. Li, H.S. Zhao, Y.J. Zhao: Study on Planning for the Indoor-earthquake-shelter in City and Town. (Advanced Science Letters), USA, 2011,Vol. 4, pp.2654–2665.
[2] Civil King Software Technology Co., Ltd. China institute of Building Standard Design & Research. Usage Guide to Structure Analysis Program SAP2000 Chinese Edition [CP] (China communications press, China, 2006),p.460.
[3] GB50011-2010(2010 edition) Code for seismic design of buildings[S]. (China architecture & building press, Beijing, 2010).
[4] FEM 356 The Seismic Rehabilitation of Buildings[S]. Federal Emergency Management Agency,2000.
[5] S.S. Zhao and C. Xin: Dynamic stability of grid structure[M] (Beijing, Science Press,1999).
[6] H.W. Li, J.X. Li, F. Zhi, F. Ma and D.Q. Qin: Proceedings of the 6th International Conference on Computation of Shell and Spatial Structures IASS-IACM (Cornell University, Ithaca, NY, USA, May 28-31, 2008).