Study on dynamic failure behaviors of steel double-layer grids(36X42 m)supported by circumjacent steel columns used in a gymnasium under disaster earthquake action

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Abstract. In this paper, the elasto-plastic dynamic analysis on dynamic failure behaviors of steel double-layer grids supported by circumjacent steel columns used in a gymnasium with the function of earthquake victims shelter under disaster earthquake is carried out under EL-centro wave with SAP2000, and the appraisal results on their anti-failure performances are presented under strong earthquake action based on the plastic-hinge theory. In the analyses, the geometric and material nonlinear effects are considered simultaneously based on the plastic-hinge theory. The plastic development level of the rod, the deformed shape and the failure type and the ductility are estimated by plastic hinge principle. 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; When the structure reached its failure critical limit, the development of the plastic hinges is not sufficient and only 16.60% of the rods enter into their plastic stage; The ratio of its maximal failure node vertical displacement and its short span is 1/194, which can meet the need for flexible non-structural attachment; The ratio of its maximal failure node horizontal displacement and its columns is 1/34; Its critical failure peak acceleration of EL earthquake wave when applied in the combination of three directions is890gal, which is 1.9 times more than the official seismic fortification level of 8 degree (major earthquake, 0.2g) and can be served as earthquake victims shelter in the area of 8 degree seismic fortification; Its displacement ductility coefficient is 6.45,which shows the structure owns good energy dissipation capacity.

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 tridimensional truss columns used in a gymnasium with the function of earthquake victims 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].

Analysis Model

A sports practice gymnasium with plane size of 36X42 m and cornice elevation level of 10 m is shown in Fig.1. Its roof structure is a double-layer grids with square on square pyramids supported by circumjacent tridimensional truss columns. Its grid size is 3mX3m, its grid height is 3 m. The gymnasium 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 amongφ127X6,φ89X4,φ76X4andφ60X3.5, the lower chord cross section sizes areφ60X3.5, the web member cross section sizes are amongφ102X4,φ89X4,φ76X4, and the cross section sizes used in the circumjacent steel columns are H600X220X8X10,. The cross section of bracing rods between columns areφ127X6. 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]**.**

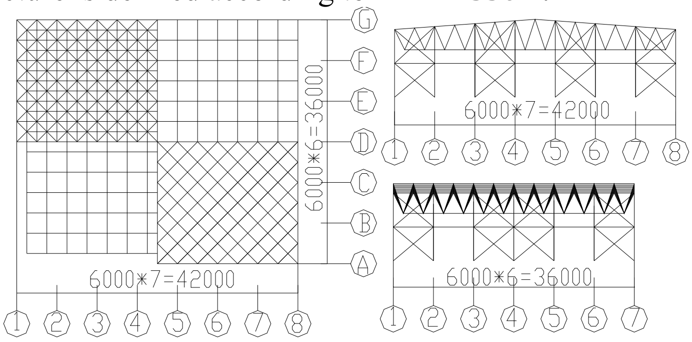

Fig. 1 Structure layout
(The number and the signs those shown in this figure are feature nodes)

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 the combine direction of Y+0.85X+0.65Z. 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 are carried out to find two limit conditions for the structure. The first is the elastic limitation; the second is critical failure state. The plastic hinge distribution and deformed mode for the ultimate state is shown in Fig.2~ Fig.7; Feature node's displacement-PGA carvel is shown in Fig.8. Feature node displacement-time curve in 430gal, 890gal and 891gal is shown in Fig.9~Fig.10.The plastic hinge ratio is respectively shown in Table 1. The number of the plastic hinges and ratio in 890gal are provided in Table 2. Max node displacements of roof and support structure are shown in Table3.

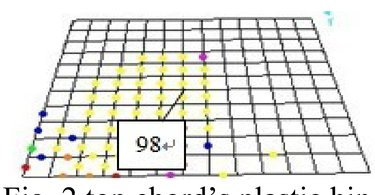

Fig. 2 top chord's plastic hinge

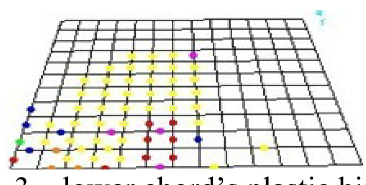

Fig. 3 lower chord's plastic hinge

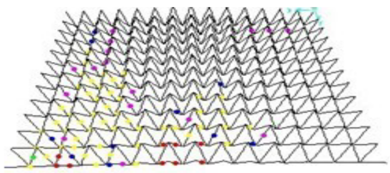

Fig. 4 ventral pole's plastic hinge

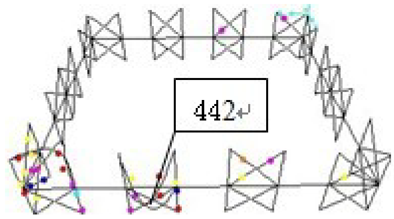

Fig. 5 pillars' plastic hinge

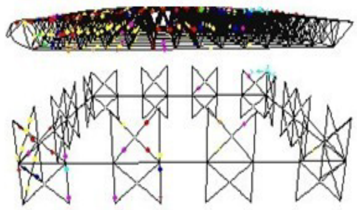

Fig. 6 Deformed model at 890gal

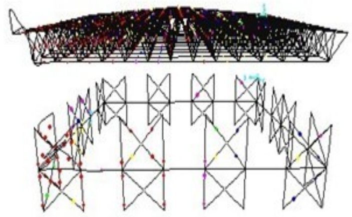

Fig. 7 Deformed model at891gal

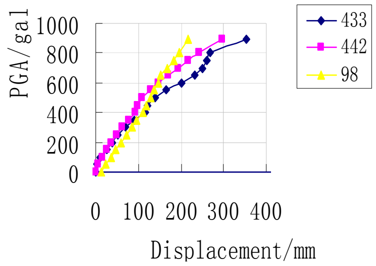

Fig. 8 Feature node's displacement-PGA

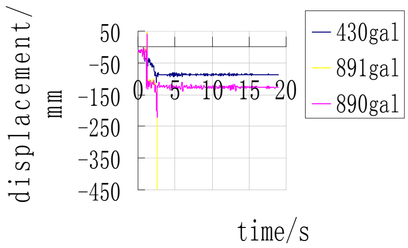

Fig.9 Disp. time history curves of Node98

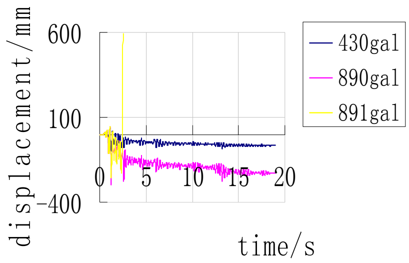

Fig.10 Disp. time history curves of Node442

Tab.1 the number of plastic hinge and ratio in EL-Centro wave

PGA (gal)	Plastic hinge stage（%）					Overall scale（%）
	B-IO	IO-LS	LS-CP	CP-C	C-E	
400	—	—	—	—	—	—
430	1（0.06）	—	—	—	—	0.06
500	7(0.42)	1（0.06）	—	—	2（0.12）	0.60
600	13(0.79)	7(0.42)	—	—	23（1.39）	2.60
700	19(1.15)	13（0.79）	—	—	45(2.73)	4.67
800	25(1.52)	19(1.15)	—	—	72(4.36)	7.03
850	31(1.88)	24(1.45)	—	—	125(7.58)	10.91
890	38(2.3)	31(1.88)	1（0.06）	5（0.30）	199（12.06）	16.60

Tab.2 the number of plastic hinge and ratio in 890 gal

Plastic hinge stage	top chord	lower chord	web members	Substructure
B-IO	11	4	14	9
IO-LS	12	5	10	4
LS-CP	—	—	—	1
CP-C	3	1	1	—
C-E	79	54	47	19

Total percentage（%）	38.32	23.36	26.28	12.04

Notes: "—"indicates that no plastic hinge; The value in the brackets means the percentage of the rods with plastic hinge in all rods. "+"said rods with E plastic hinge are tensile failure. "-"said rods with E plastic hinge are compression failure.

Tab.3 max node displacements of upper and bottom in the structure

PGA （gal）	0	430	700	890
upper rack node's max displacement U3(mm)	11.9	119.4	146.2	217.1
Bottom structure node's max displacement U3(mm)	1.12	113.4	148.2	297.5
U3/L	1/3529	1/352	1/287	1/194
U1/H	1/8929	1/88	1/68	1/34

Notes: This structure has failured in772gal; The value in the brackets means absolute displacement.

Conclusions

According to Tab.1~3 and Fig.2~10, the results can be concluded as follows:

The elastic limitation PGA for three direction input is 430. It is much larger than the PGA of the official SEL for small earthquake (70gal). The critical PGA for this direction input is 890gal. It is much larger than the PGA of the official SEL for major earthquake (400gal).

The displacement ductility coefficient is 6.45 for the roof structure, and the ratio of its bars with plastic hinge appearing for ultimate critical state is 16.60% in 890gal, while the ratio is 25.3% in 772gal, the development of the plastic hinges is sufficient. The ratio of its maximal failure node vertical displacement and its short span is 1/194, The ratio of its maximal failure node horizontal displacement and its columns is 1/34.

When it reaches critical failure PGA in the combination of three directions, all the members in the E stage are compression failures.

According to the B-R criterion [5] [6], the failure model of the structure under the earthquake wave action is the complicated ensemble instability failure.

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

Summary

Its critical failure PGA in the combination of three directions is 890gal, which is 1.9 times more than the official seismic fortification level of 8 degree (major earthquake, 0.2g) and can be served as earthquake victims shelter in the area of 8 degree seismic fortification; Its plastic hinge ratio is16.60% in critical PGA and 25.3% in failure PGA, Its displacement ductility coefficient is 7.6 for the roof structure, which shows the structure owns good energy dissipation capacity.

Acknowledgements

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