A COMPARISON OF SEISMIC BEHAVIOR BETWEEN SPECIALLY SHAPED COLUMN FRAME STRUCTURE AND RECTANGULAR COLUMN FRAME STRUCTURES

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ABSTRACT :

According to the current Chinese code and technical specification, some frame structures with rectangular columns and specially shaped columns are designed respectively based on the criterion of the same section area, moment of inertia, initial stiffness of the specially shaped frame structure. Using the program of fiber beam-column element based on flexibility method of finite element, nonlinear dynamic analysis is taken to analyze the two types of structures. The response of structures (such as story drift and torsion varying rules) is obtained under the fortification and rare grand motion. Still, the crack and yield rules of the main elements of the structures are compared by analyzing the stress and strain data of section fibers. So the change rules of the nonlinear seismic behavior of the two kinds of structures are obtained and some advices are provided for the seismic design of the specially shaped column structures and revising of the related specifications.

KEYWORDS: specially shaped column; RC frame structure; nonlinear dynamic analysis; fiber model

Introduction

Three-dimensional analyzing method and related software are expected in the analysis of the specially shaped column frame structures due to their spatial mechanical behavior [1]. Recently quasi-static test and vibrating table test of reduced-scale structures are performed in the study of the spatial frame with specially shaped columns [2~5]. Because of the size of the frame, a lot of labors, equipments and money are required in the process of the test, and the study is confined only to a small number of tests. Theoretical researches on the frame with specially shaped columns presently are limited to planar nonlinear analysis or spatial elastic analysis, which reveal some seismic behaviors of the specially shaped column frame structures. Further study of the three-dimensional nonlinear dynamic analysis of the specially shaped column frame structures is expected and is necessary. This paper will analyze the nonlinear seismic behaviors of the RC frame with specially shaped columns and RC frames with conventional rectangular columns under the unilateral horizontal ground excitations. Responses of the structures, the crack and yield rules of the beam and column elements are compared.

1. Analytical model

1.1 Structure model

According to the current Chinese Code for Seismic Design of Buildings (GB 50011-2001) and Technical Specification for Concrete Structures with Specially Shaped Columns (JGJ 149—2006), a regular six-story RC frame with specially shaped columns is designed, which is situated at the area of fortification intensity 7. Subsequently, three RC frames with conventional rectangular columns are designed with their columns respectively based on the criterion of the same section area, moment of inertia of the specially shaped columns or the same initial stiffness of the specially shaped frame structure. The height of the structures is 18 meters, 3 meters each floor. C30 concrete is used. The reinforcement of the structures is designed by the SATWE software according to the code and specification.

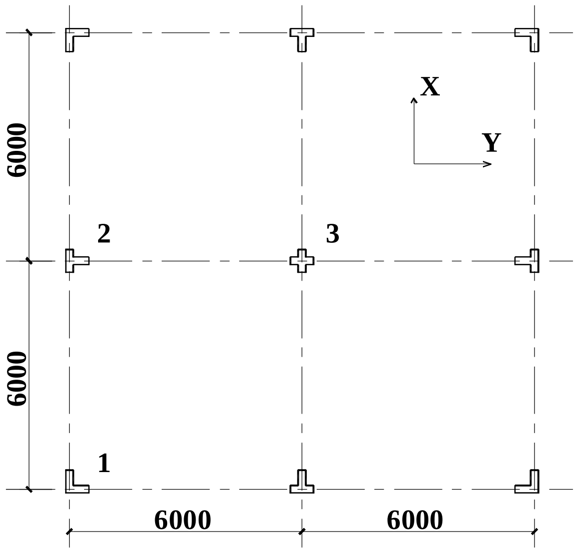


Fig 1 plan view of the structure

The following two criteria are abode by in the design of the RC frames with conventional rectangular columns
1) The two types of frame structures should have the same plane, elevation and so on.
2) Rectangular columns should be located at the same location with the specially shaped columns. The beams of two types of frame structures own the same sectional dimension and the same location. The reinforcement of the beams and columns are satisfied with the code and specification.

Table 1 Dimension of the columns *(mm)

	SS	SR1	SR2	SR3
Conner column	200x500	440x440	400x400	420x420
Side column	200x500	391x458	400x400	420x420
Mid-column	200x600	464x464	447.2x447.2	470x470

*SS,SR1,SR2,SR3 respectively refers to frame with specially shaped columns, frame with rectangular columns of the same moment inertia of the specially shaped columns, the same section area of the specially shaped columns and the same structure initial stiffness of the frame with the specially shaped columns. The illuminations apply to the whole text.

1.2 Period of the structures

Periods of the structures are shown as table 2. The regular frame structure with specially shaped columns and frame structures with conventional rectangular columns are similar with the period. The first and second modes are vibration mode, while the third one is torsion vibration mode. First and second periods of the frame structure with conventional rectangular columns are most close to the one with specially shaped columns.

Table 2 Period of the structures (s)

	SS		SR1		SR2		SR3	
	Period I & II	Period III	Period I & II	Period III	Period I & II	Period III	Period I & II	Period III
natural period	1.060	0.892	1.053	0.927	1.089	0.960	1.058	0.929

The stiffness of the frame SR2 is less than the frame SS because the moment of inertia of SR2 is smaller. Therefore its periods are longer slightly.

1.3 Selecting input earthquake waves

According to the two-frequency domination method [6] and the code, three natural earthquake records (USA00581, USA00676, and USA00707) and one artificial earthquake wave (ACC2) are selected as the input of the earthquake ground motion in the dynamic time-history analysis. Response spectrum analysis and elastic time history analysis are performed by the SAP2000 software. The results show that the earthquake waves selected meet with the requirements of the code.

2.NONLINEAR DYNAMIC RESPONSE ANALYSIS

Using the program of 3D nonlinear seismic response analysis which is developed on the beam-column element of fiber model based on flexibility method of finite element, nonlinear seismic response of the two types of structures is analyzed. In the fiber models, one element is subdivided into several longitudinal fibers. The constitutive relation of the section is derived by integration of the response of the fibers. Shear effect is ignored. Fibers are assumed to follow the uniaxial stress-strain relation. Plane-assumption is used to harmonize the strain of fibers with the displacement of the section. The stiffness matrix of the beam and column elements is derived by the flexibility-based method of infinite element theory. Nonlinear section stress-strain relation is computed by the uniaxial stress-strain relation of the fibers of the particular material. The verification and accuracy of the program have been proved by conventional rectangular columns, specially shaped columns and by the frame structures of the two types of columns [7-11].

Because of the regular structural plane arrangement, the mass and rigidity of the structures in the paper are uniformly distributed, the unilateral ground excitation are input along the X-direction. Thus the response of the structures refers to the X-direction without any special notes.

2.1 Structural response analysis under fortification ground motions

Maximum angle of story drift and maximum torsion angle of the frame structure with specially shaped columns under the fortification seismic motions are shown in table.3 and fig.3.

Table.3 Maximum angle of story drift and torsion angle of the structure SS under the fortification seismic motions

Ground motion	USA00581	USA00676	USA00707	ACC2	average	maximum
Maximum angle of story drift	1/395	1/403	1/364	1/366	1/381	1/364
Maximum torsion angle (radian)	3.79E-18	1.49E-18	3.52E-18	1.31E-18	2.53E-18	3.79E-18

Maximum angle of story drift and torsion angle of the frame structures under the fortification seismic motions are shown in table.4 and fig.2.

Table.4 Maximum angle of story drift and torsion angle of the frame structures under the fortification seismic motions

Frame structures	SS	SR1	SR2	SR3
Maximum angle of story drift	1/364	1/365	1/331	1/362
maximum torsion angle(radian)	3.79E-18	4.08E-18	2.75E-18	2.59E-18

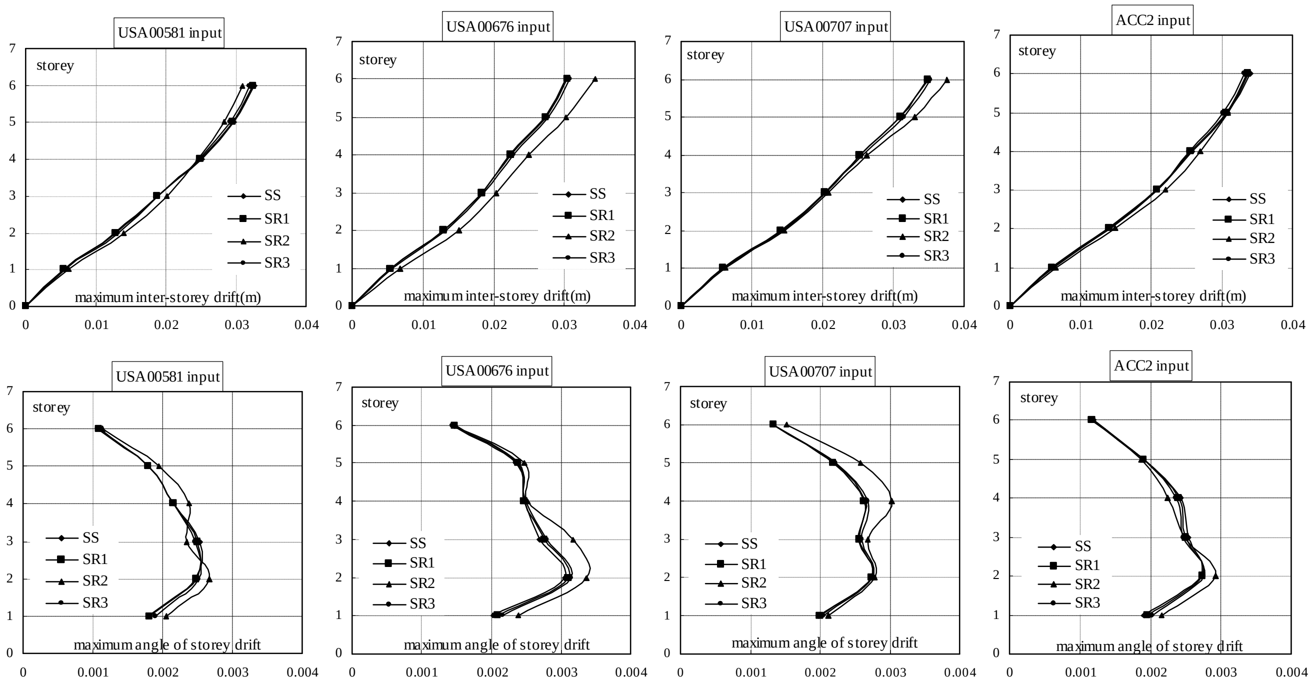


Fig.2 Maximum inter-story displacement and angle of story drift of the structures under the fortification seismic motion

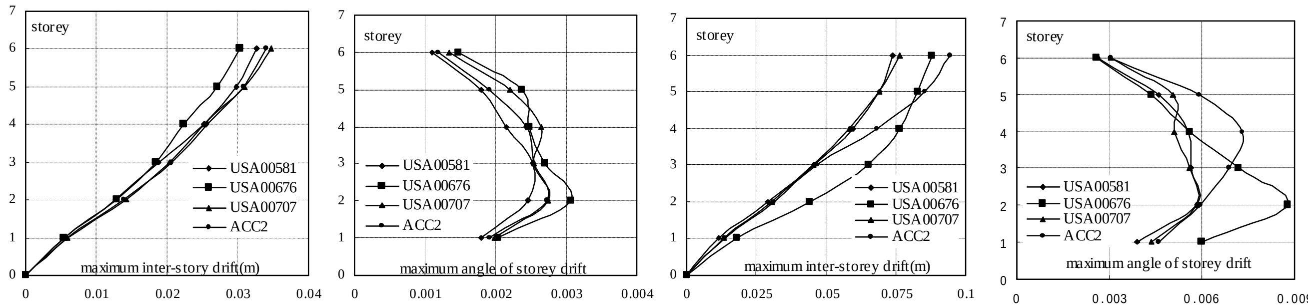
It is shown in the figures and tables above that the maximum torsion angle of the structures are almost zero under the unilateral ground motion and so the torsion effect of the regular frame structures could be ignored; The maximum inter-story displacement of the frame structures occurs at the second floor in general. The displacement of structure SS is very colose to displacement of SR1 and SR3. Displacement of the structure SS2 is obviously different with other structures.

2.2 Structural response analysis under severe ground motions

Maximum angle of story drift and torsion angle of the frame structure with specially shaped columns under the severe seismic motions are shown in table.5 and fig.3.

Table.5 Maximum angle of story drift and torsion angle of the structure SS under rare seismic motions

Ground motions	USA00581	USA00676	USA00707	ACC2	average	maximum
Maximum angle of story drift	1/171	1/114	1/172	1/137	1/144	1/114
Maximum torsion angle（radian）	8.56E-18	2.89E-18	8.51E-18	5.19E-18	6.28E-18	8.56E-18



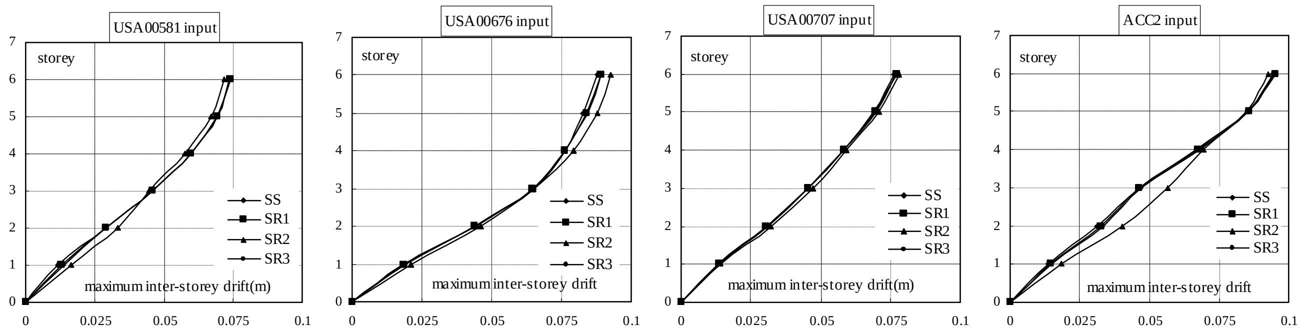
(a) Fortification ground motions (b) Severe ground motions

Fig.3 Maximum inter-story displacement and inter-story drift angle of the structure SS

Maximum angle of story drift and maximum torsion angle of the two kinds of frame structures under the severe seismic motions are shown in table 6 and fig 4.

Table.6 Maximum angle of story drift and torsion angle of the structures under the rare seismic motions

structures	SS	SR1	SR2	SR3
Maximum angle of story drift	1/114	1/117	1/119	1/114
Maximum torsion angle（radian）	8.56E-18	22.8E-18	55.2E-18	30.6E-18



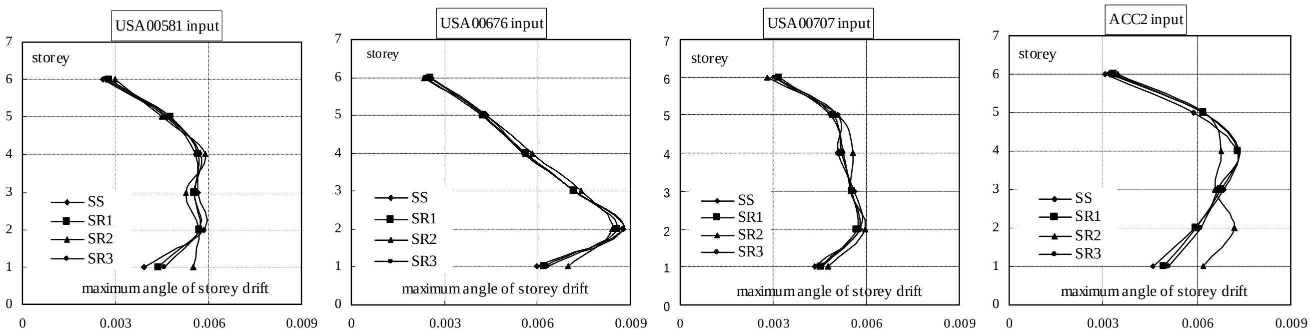


Fig.4 Maximum inter-story displacement and angle of story drift of the structures under the rare seismic motions

Table.7 Maximum fiber strains in beam and column elements of the structures under the rare seismic motions*

Fiber strain		SS	SR1	SR2	SR3
Maximum concrete compressive strain of the columns	Bottom of corner columns	-0.00184[1]	-0.00145[1]	-0.00131[1]	-0.00147[1]
	Bottom of side columns	-0.00236[1]	-0.00177[1]	-0.00205[1]	-0.00188[1]
	Bottom of mid-columns	-0.00309[1]	-0.00229[1]	-0.00265[1]	-0.00233[1]
Maximum steel tensile strain of the columns	Bottom of corner columns	0.00325[1]	0.00309[1]	0.00311[1]	0.00296[1]
	Bottom of side columns	0.00246[1]	0.00226[1]	0.00263[1]	0.00259[1]
	Bottom of mid-columns	0.00256[1]	0.00223[1]	0.00233[1]	0.00233[1]
Maximum concrete compressive strain of the beams	Ends of side beams	-0.00156[2]	-0.00158[2]	-0.00143[2]	-0.00155[2]
	Ends of middle beams	-0.00209[2]	-0.00203[2]	-0.00195[1]	-0.00190[2]
Maximum steel tensile strain of the beams	Ends of side beams	0.00197[1]	0.00196[1.2]	0.00209[1]	0.00196[1]
	Ends of middle beams	0.00245[1]	0.00251[1]	0.00275[1]	0.00254[1]

*' I ' in the "[ ]" indicates the story where the maximum strains occur.

From fig.3~4 and tables.5~7, It is noted that: 1) The maximum inter-story displacement of the frame structures occurs at the second floor in general. The displacement of structure SS is very close to displacement of SR1 and SR3. Displacement of the structure Sr2 is obviously different with other structures under the four rare earthquake excitations.

2) The maximum angle of inter-story drift of the frame structure with specially shaped columns ,of which is 1/114, meets with the elastic-plastic allowance for angles of drift with respect to the code of which is 1/60. The maximum angle of story drift of the frame structure with specially shaped columns are larger than the frame structures with conventional rectangular columns, and the maximum angle of story drift of the frame structures with conventional rectangular columns are more even distributed than that of the frame structure with specially shaped columns.

3) Fiber strain of the beam and column sections: the concrete compressive fiber strains decrease in the order of the mid-columns, side columns and corner columns. The maximum compressive strain of the specially shaped column fibers, of which equals to 0.00309, is 1.3 times of the maximum compressive strain of the rectangular columns. The maximum tensile strain of the corner columns is much more than that of the side columns and mid-columns. The maximum corner column fibers' tensile strain of the frame structure with the specially shaped columns is a little larger that that of the rectangular columns, with the largest ratio to 1.1. As to the strains of the beam fibers, the two kinds of structures almost share the same rules. The maximum concrete compressive fiber strains and the maximum steel tensile fiber strains occur at the first floor or the second floor in general. The concrete compressive strains of the middle beams are larger than that of the side beams. The maximum steel tensile strain of the beam fibers of the frame structure with specially shaped columns equals to 0.00245 and is larger than the yield strain of the steels of which is 0.00194.

3.CONCLUSION

(1) The structural seismic response differences between specially shaped column structure and conventional

rectangular frame structures are not very obvious. Due to the minor moment of inertia compared with the specially shaped columns, the stiffness of the frame with rectangular columns with the same area is inferior to the frame with specially shaped columns.
(2) Even at the unilateral earthquake excitations, the maximum shear force of the bottom corner columns (L-shaped column) perpendicular to the input direction can't be underestimated. The L-shaped corner columns are in the biaxial bending and axial force coupling conditions.
(3) Under the fortification seismic motions, steel of beams and columns does not yield. Under the severe seismic motions, beams at the first and second floor and columns at the first floor of the two types of frame structures yield to some degree. Steel tensile strains of the corner column are much larger that the side columns and mid-columns. Due to the special sections of the specially shaped columns, phenomenon of stress and strain concentration is found obvious. Thus the maximum steel tensile strain of the corner columns and mid-columns of the specially shaped column frame structure are larger than the rectangular columns. The maximum concrete compressive strain decreases in the order of mid-column, side column and corner column. The maximum concrete compressive strain of the specially shaped column frame structure is much larger than the rectangular columns, but is much smaller than the concrete ultimate compressive strain. As to the subsequence of hinge occurrence of the two types of frame structures, beam hinges come first, and accumulate, the hinges rotates to some degree but not severely and the bearing capacity doesn't decrease significantly. The frame structures form a beam-hinge collapse mechanism.
To conclude, the frame structure with specially shaped columns designed by the code in this paper could resist the earthquake effectively as the frame structures with conventional rectangular columns do. The stress-strain concentration of the frame structure with specially shaped columns can't be ignored. Steels at some locations yield severely and the maximum concrete compressive strain of some locations is a bit large at the input of the severe ground excitations which needs recognition in the analysis and design.

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