Performance of typical buildings designed according to the US codes subject to the CI.CCC record of M7.1 Ridgecrest Earthquake

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Three typical buildings (a seven-story reinforced concrete (RC) frame, a 20-story shear wall tall building and a 37-story steel braced-frame) designed according to the US codes were selected to check the performance of structures subject to the CI.CCC station record of the M7.1 Ridgecrest Earthquake (Figure 1). The finite element models are established using fiber beam element and multi-layer shell elements, which is introduced in Lu et al. (2013). The results are listed as follows:

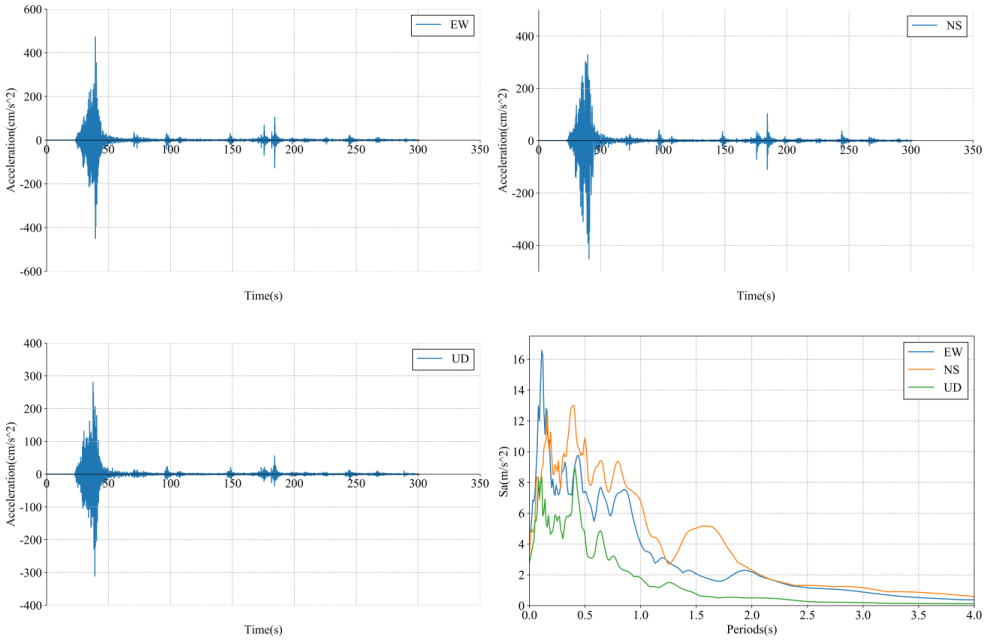


Figure 1 Ground motion of Station CI.CCC (Data from CESMD, 2019)

1. Seven-story RC frame

The frame has seven stories. The height of the ground story is 6.0 m. The heights of the other stories are 4.5 m. The layout of the frame is shown in Figure 2. The design parameters are shown in Tables 1 to 4. It is designed by ARUP.

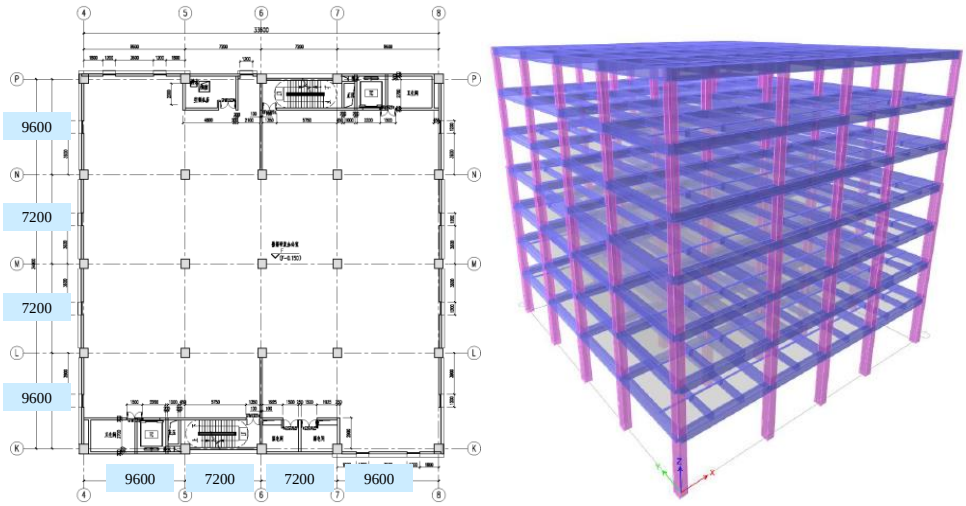


Figure 2 Layout of the seven-story RC frame

Table 1 Design parameters of the seven-story RC frame

Design parameters	Value	Design parameters	Value
Risk category	Ⅱ	Site Class	E
I_e	1.0	S_s	1.125g
Seismic Design Category	D	S_1	0.45g
Structural type	Special Moment Frame	T_L	8 s
ρ	1.0	F_a	0.9
R	8.0	F_v	2.4
C_d	5.5	Damping Ratio	5%

Table 2 Sections of the seven-story RC frame

Components	Section (mm)
X side beam	F1~4: 600×800 / F5~7: 500×800
X internal beam	F1~4: 600×800 / F5~7: 500×800
Y side beam	F1~4: 600×800 / F5~7: 500×800
Y internal beam	F1~4: 600×800 / F5~7: 500×800
Internal columns	F1~2: 800×800 / F3~4: 700×700/ F5~7: 600×600
Side / Corner columns	F1~2: 800×800 / F3~4: 700×700 / F5~7: 600×600
Secondary beam	F1~7: 400×550
Slab	F1~6: 120/ F7: 180

Table 3 Materials of the seven-story RC frame

	Components	Materials
Concrete	Columns	5000Psi (f_c'=34.5MPa)
	Beams	4000Psi (f_c'=27.6MPa)
	Slabs	4000Psi (f_c'=27.6MPa)
Steel		A615Gr60 (f_y=413.7MPa)

Table 4 Vibration periods of the seven-story RC frame

Vibration modes	Periods (s)
1st x-mode	2.086
1st y-mode	2.024
1st torsion-mode	1.915

The 3-directional ground motions in Figure 1 were inputted and the nonlinear time history analysis was conducted. The inter-story drift of the seven-story RC frame is illustrated in Figure 3 and the plastic-hinge distribution is shown in Figure 4. The maximum value of the inter-story drift is 1/37 (5th story in the y-direction). A lot of plastic hinges are found on the columns and beams.

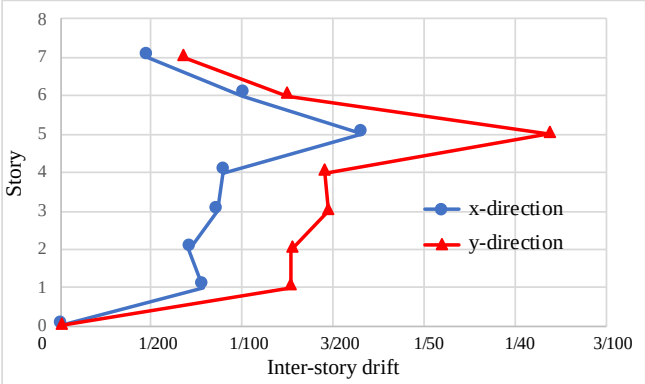


Figure 3 Inter-story drift of the seven-story RC frame

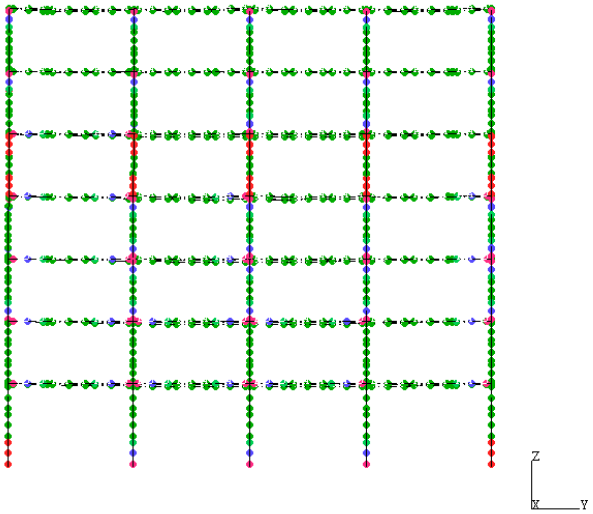
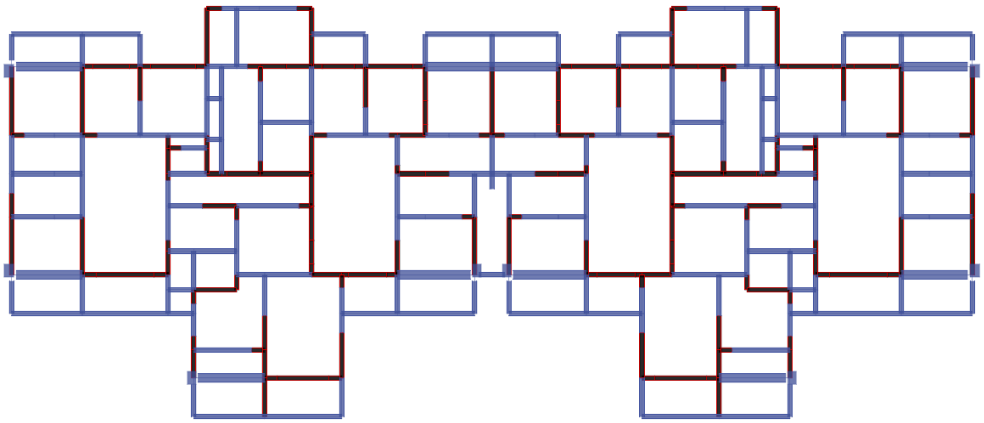


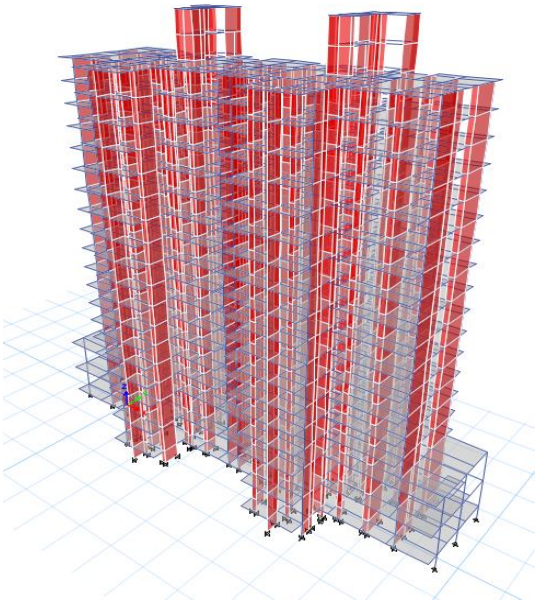
Figure 4 Plastic hinge distribution of the seven-story RC frame

2. 20-story shear wall tall building

The shear wall tall building has 20 stories. The heights of the ground and second stories are 4.2 m and 4.5 m, respectively. The heights of the other stories are 2.9 m. The layout of the building is shown in Figure 5. The planar section is 54.4 × 17.8 m. The design parameters are shown in Tables 5 to 7. It is designed by ARUP.



(a) Planar view



(b) Perspective view

Figure 5 Layout of the 20-story shear wall tall building

Table 5 Design parameters of the 20-story shear-tall tall building

Design parameters	Value
Risk Category	Ⅱ
Seismic Importance Factor, I_e	1.0
Seismic Design Category	D
S_s	1.147g
S_1	0.516g
F_a	1.041
F_v	1.500
R	5.0
Site Class	D
C_d	5.0

Table 5 Sections of the 20-story shear-tall tall building

Components	Section (mm)
Beam	Beam 1: 300×500 / Beam2: 300×400 / Beam 3: 300×450
Column	Col. 1: 500×600/ Col. 2: 400×600/ Col. 3: 500×500/ Col. 4: 450×600/ Col. 5: 700×400
Wall	300
Slab	Slab 1: 100 / Slab 2: 120 Slab 3: 150 / Slab 4: 200

Table 6 Materials of the 20-story shear-tall tall building

Components		Materials
Concrete	Column	F1~8: 6000Psi / F9~12: 5000Psi/ F13~18: 4000Psi
	beam	4000Psi
	Wall	F1~8: 6000Psi / F9~12: 5000Psi / F13~18: 4000Psi
	Slab	4000Psi
Steel		A615Gr60

Table 7 Vibration periods of the 20-story shear-tall tall building

Vibration modes	Periods (s)
1st x-mode	2.274
1st y-mode	1.911
1st torsion-mode	1.780

The 3-directional ground motions in Figure 1 were inputted and the nonlinear time history analysis was conducted. The inter-story drift of the 20-story shear wall tall building is illustrated in Figure 6 and the damage distribution is shown in Figure 7. The maximum value of the inter-story drift is 1/112 (19th story in the y-direction).

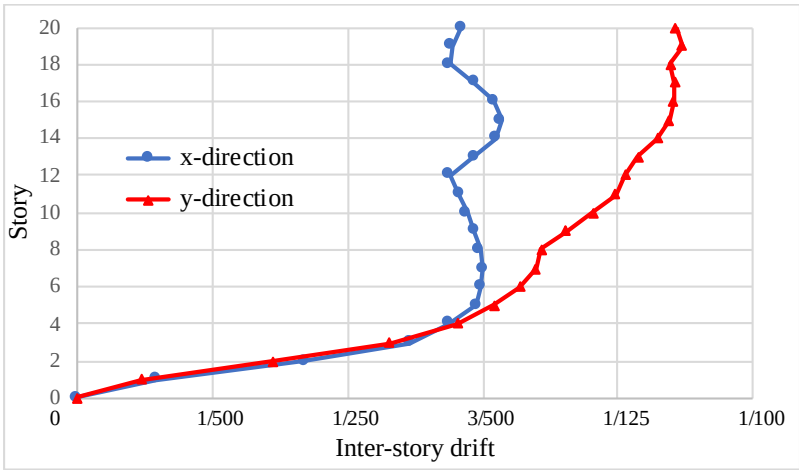


Figure 6 Inter-story drift of the 20-story shear wall tall building

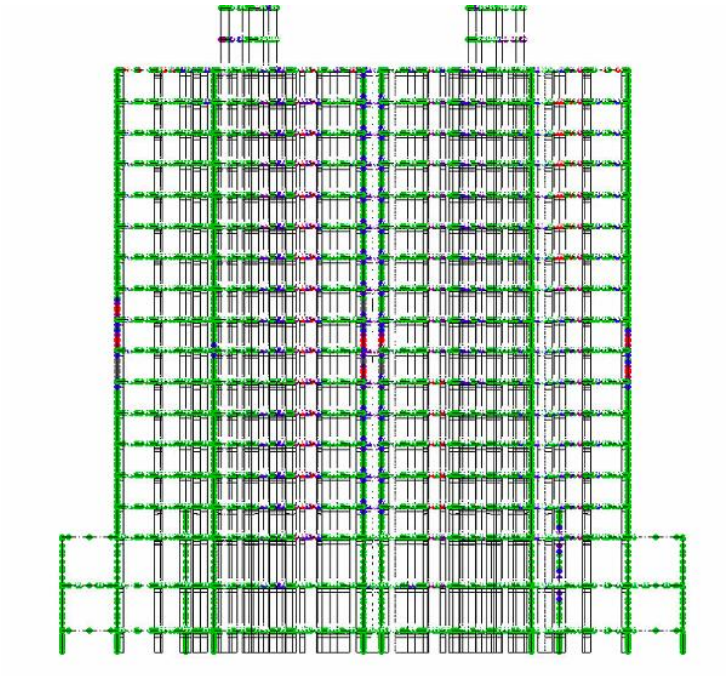
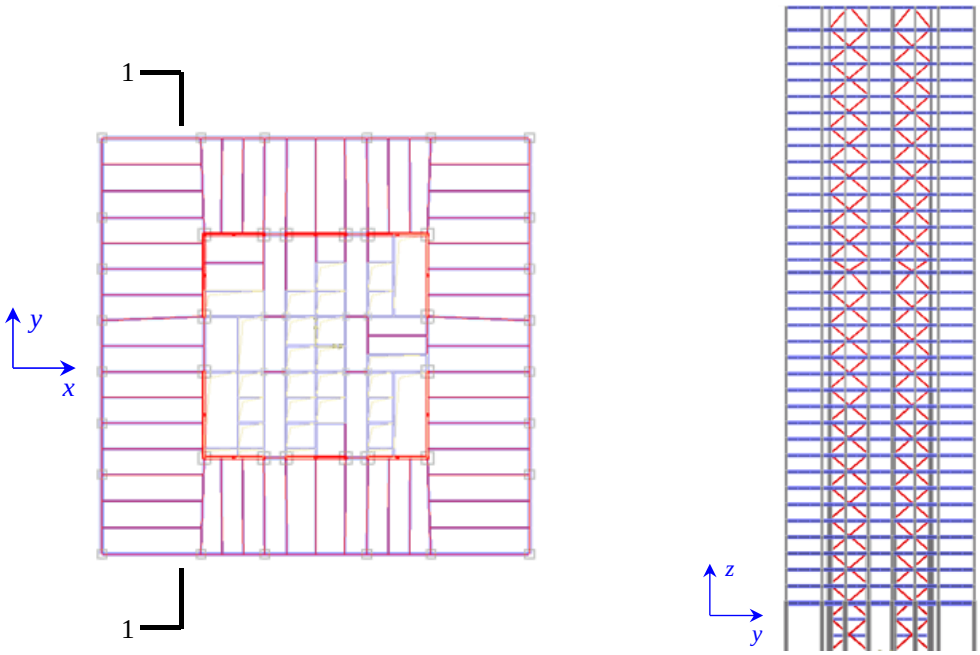


Figure 7 Damage state of 20-story shear wall tall building

3. 37-story steel braced-frame building

The steel braced-frame building has 37 stories. The heights of 1st to 3rd stories are 6 m. The heights of the other stories are 4.2 m. The layout of the frame is shown in Figure 8. The planar section is 48 × 48 m. The design parameters are shown in Tables 5 to 7. It is designed by SOM.



(a) Plane view (b) 1-1 section view

Figure 8 Layout of the 37-story steel braced-frame building

Table 9 Design parameters of the 37-story steel braced-frame building

Design parameters	Value
Risk Category	Ⅱ
Seismic Importance Factor, I_e	1.0
Seismic Design Category	D
S_s	1.037g
S_1	0.273g
F_a	1.085
F_v	1.854
R	7.0
Site Class	D
C_d	5.5

Table 10 Sections of the 37-story steel braced-frame building

Components	Section (mm)
Beam	Beam 1: 785×384×20×34 / Beam 2: 780×267×17×30 / Beam 3: 780×267×17×30 / Beam 4: 757×267×14×19 / Beam 5: 599×178×10×13 / Beam 6: 455×153×8×13 / Beam 7: 404×141×7×11 / Beam 8: 310×102×6×9 / Beam 9: 617×230×13×22 / Beam 10: 780×267×17×30 / Beam 11: 455×153×8×13
Column	F1: Col. 1: 1270×1270×89 / Col. 2: 762×762×38 / Col. 3: 610×610×51 F2~F3: Col. 1: 1016×1016×89 / Col. 2: 762×762×38 / Col. 3: 610×610×51 F4~F13: Col. 1: 1016×1016×70 / Col. 2: 635×635×38 / Col. 3: 533×533×51 F14~F19: Col. 1: 762×762×57 / Col. 2: 635×635×38 / Col. 3: 457×457×38 F20~F25: Col. 1: 762×762×57 / Col. 2: 635×635×25 / Col. 3: 457×457×38 F26~F37: Col. 1: 508×508×38 / Col. 2: 635×635×25 / Col. 3: 381×381×32
Brace	Brace 1: 305×305×25 / Brace 2: 254×254×19 / Brace 3: 229×229×19 / Brace 4: 203×203×19
Slab	Slab 1: 110 / Slab 2: 120

Table 11 Materials of the 37-story steel braced-frame building

	Components	Materials
Concrete	Slab	4000 Psi
Steel	Column / beam / brace	ASTM A992 (H-shaped steel): 345 MPa; A500, GR. B (hollow square steel): 345 MPa

Table 12 Vibration periods of the 37-story steel braced-frame building

Vibration modes	Periods (s)
1st x-mode	7.34
1st y-mode	6.18
1st torsion-mode	4.84

The 3-directional ground motions in Figure 1 were inputted and the nonlinear time history analysis was conducted. The inter-story drift of the 37-story steel braced-frame building is illustrated in Figure 9 and the damage distribution is shown in Figure 10. The maximum value of the inter-story drift is (33 story in y-direction). Some plastic deformations in the braces are found on the top zone of the building.

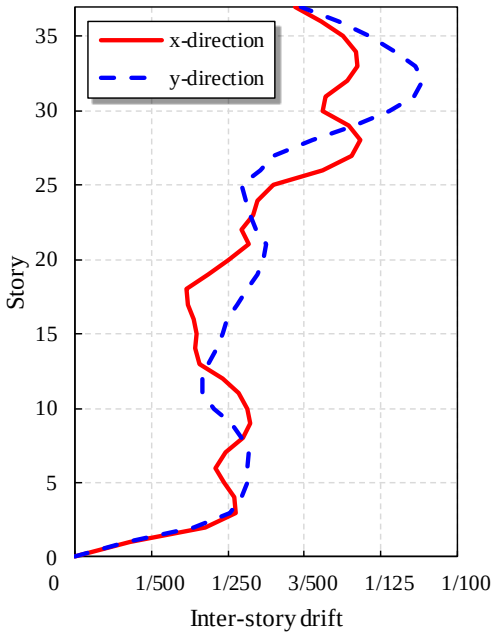
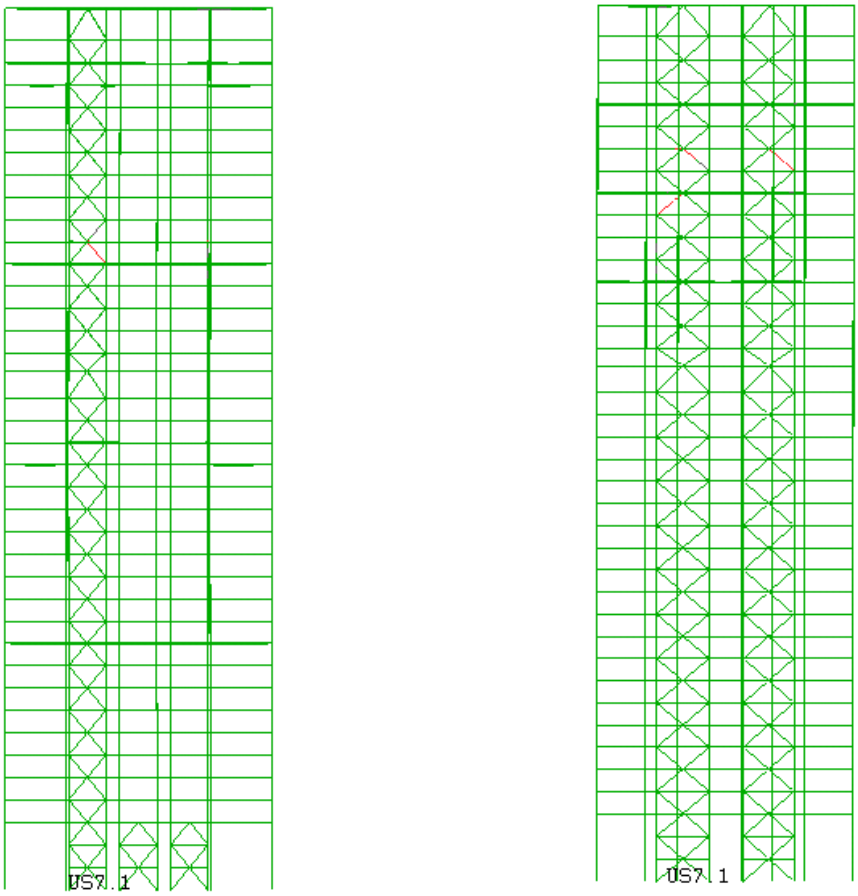


Figure 9 Inter-story drift of the 37-story steel braced-frame building



(a) x-direction (b) y-direction

Figure 10 Damage distribution of the 37-story steel braced-frame building

References:

CESMD, 2019. https://strongmotioncenter.org/

Lu X, Lu XZ, Guan H, Ye LP, Collapse simulation of reinforced concrete high-rise building induced by extreme earthquakes, Earthquake Engineering & Structural Dynamics, 2013, 42(5): 705-723.