NARLabs
國家實驗研究院

近斷層地震作用下具有軟弱底層之建物的受震反應

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May 29, 2018

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Outlines

1. Introduction
2. Simulation of the Shaking Table Test
3. Seismic Analysis of the Building with a Soft/Weak Bottom Story
4. Conclusions

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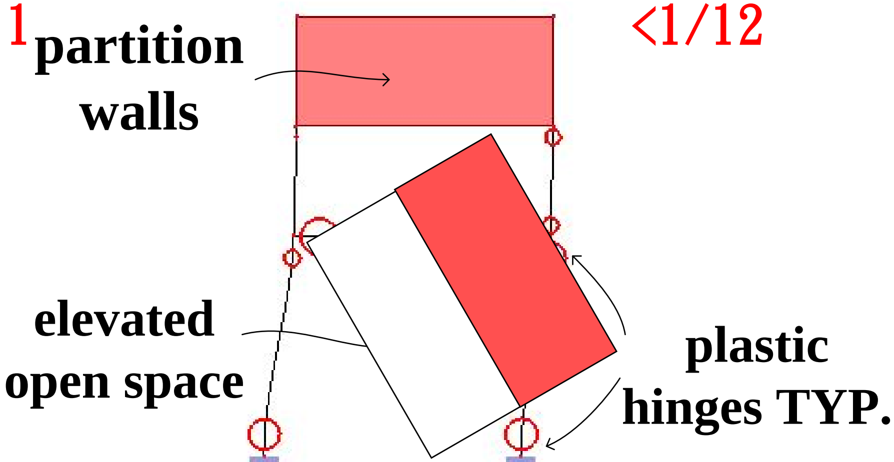
Buildings with Soft/Weak Bottom Stories

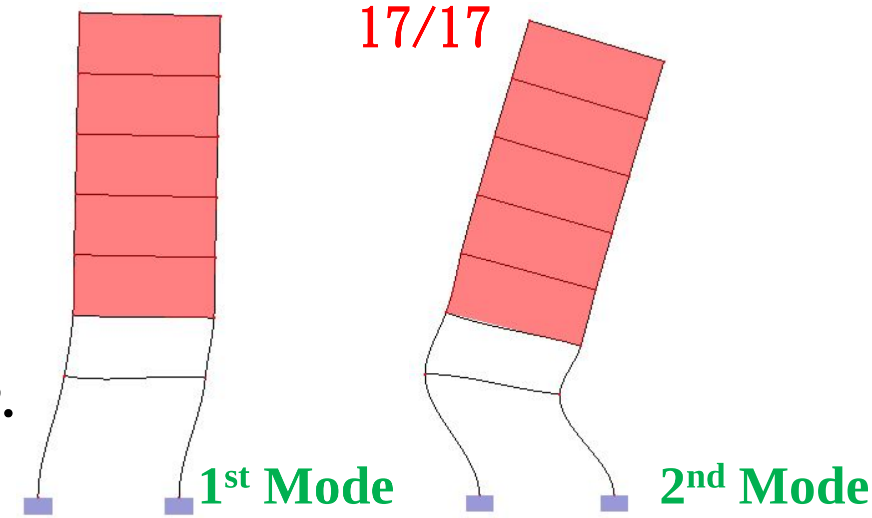
Building collapse is the most disastrous seismic damage.

sit down (統帥飯店) kneel down (雲門翠堤) lie down (維冠大樓)

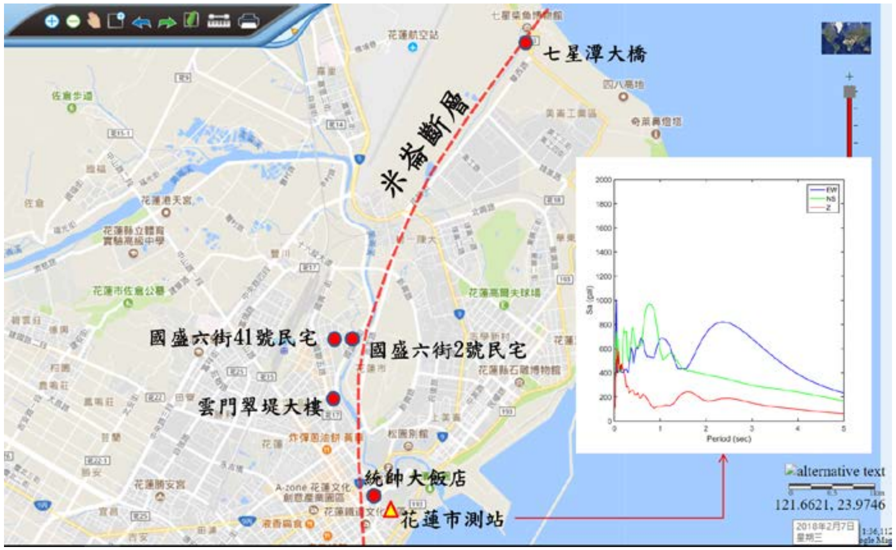
2/11 <1/12 17/17



Collapse mechanism



Near-Fault Ground Motions



At the NCREE Tainan lab, an 8 m × 8 m 6-degree-of-freedom tri-axial shaking table with a 250-ton payload was established to simulate near-fault ground motions.

	Horizontal Axis	Vertical Axis
Stroke	±1.0 m	±0.40 m
Velocity	±2.0 m/sec	±1.0 m/sec
Acceleration	±0.75 g (250 ton)	±0.5 g (250 ton)
	±1.4 g (100 ton)	±0.8 g (100 ton)
	±2.5 g (bare table)	±3.0 g (bare table)
Overturning moment	500 ton-m (bi-axial X-Z)	
	1000 ton-m (uni-axial)	

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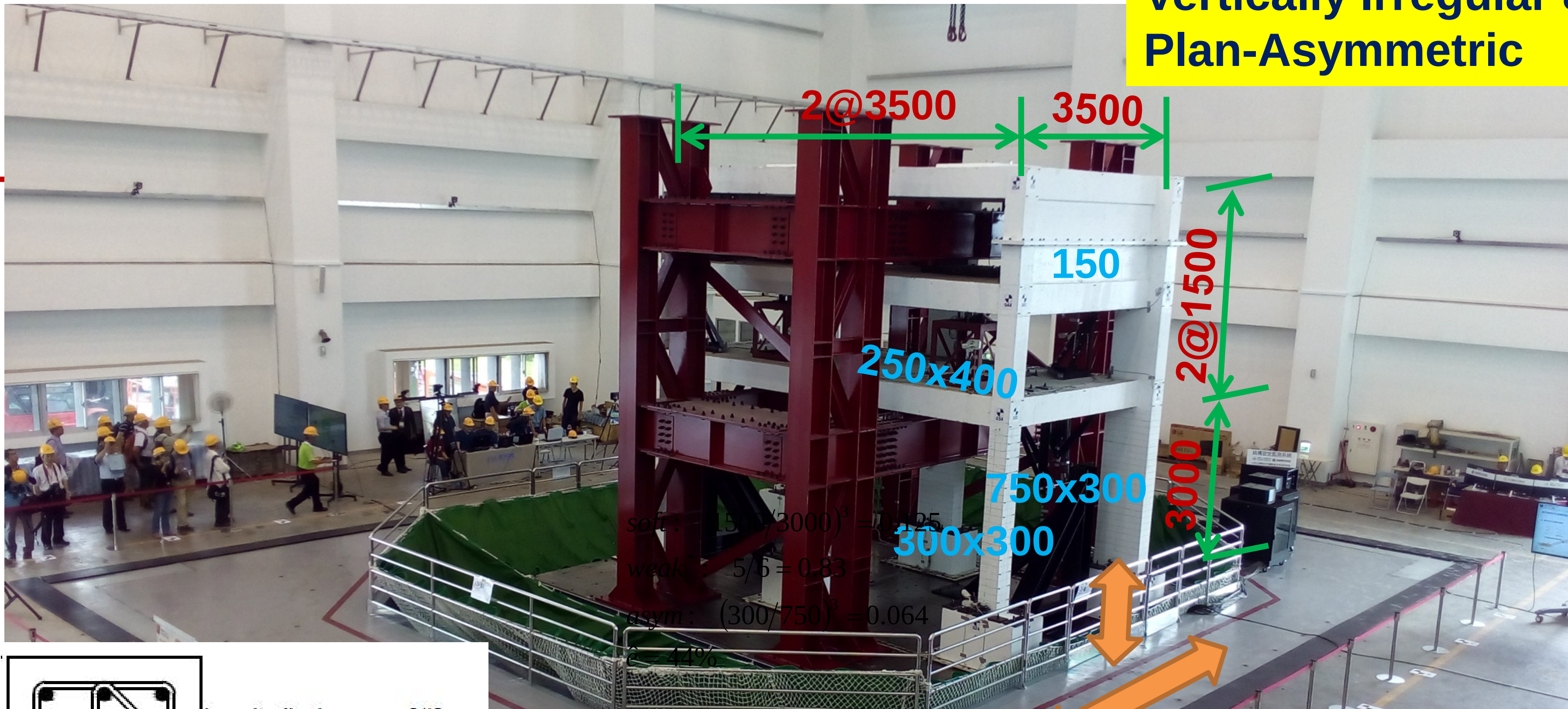
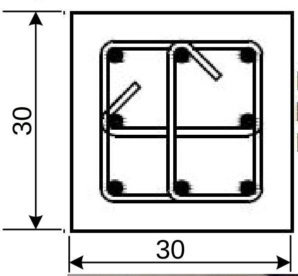
Vertically Irregular & Plan-Asymmetric



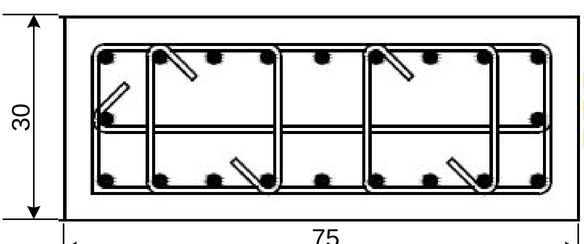
7/28 elastic levels:
TCU052 (350 gal),
CHY047 (420 gal)

8/9 inelastic levels:
TCU052 (800 gal),
TCU052 (1000 gal)



Longitudinal : 8#6
End Transverse : #3@12
Middle Transverse : #3@25

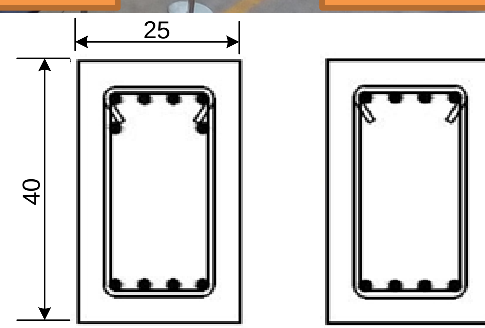
Column C1



Longitudinal : 20#6
End Transverse : #3@12
Middle Transverse : #3@25

Column C2

unit: cm



Longitudinal: 10#6
Transversal: #3@15

Longitudinal: 8#6
Transversal: #3@25

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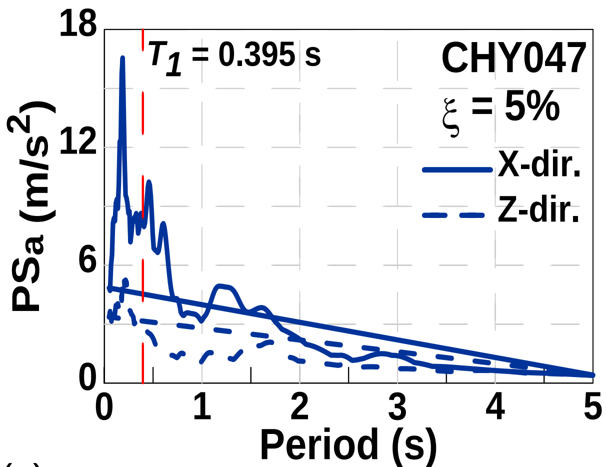
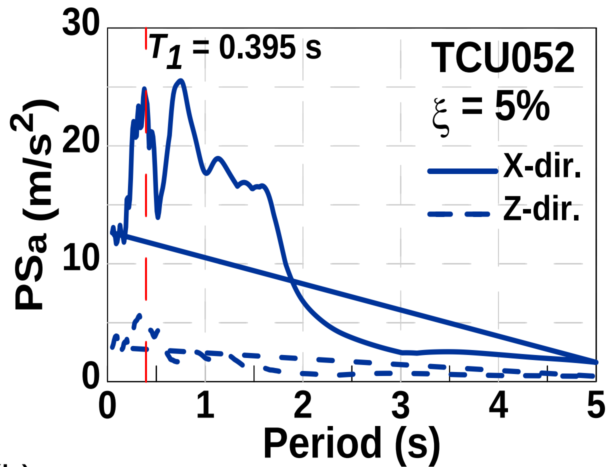
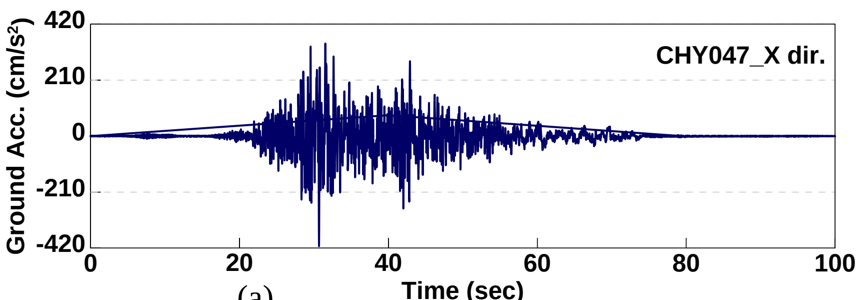
Input Ground Motions



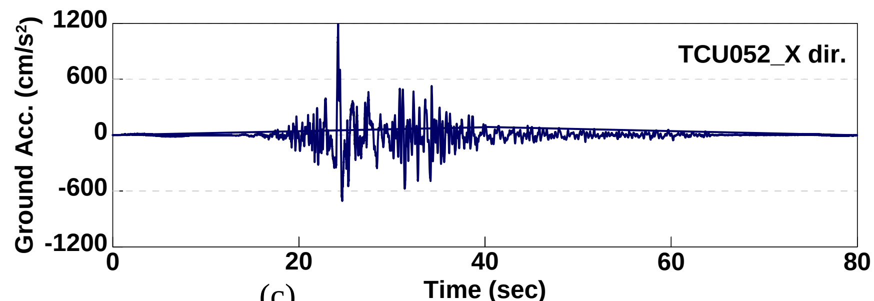
(a)



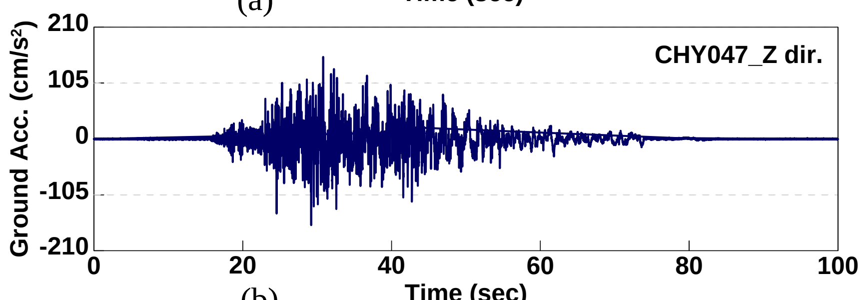
(b)



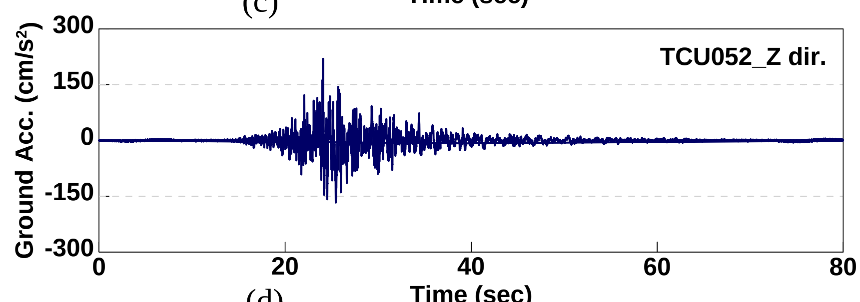
(a)



(c)

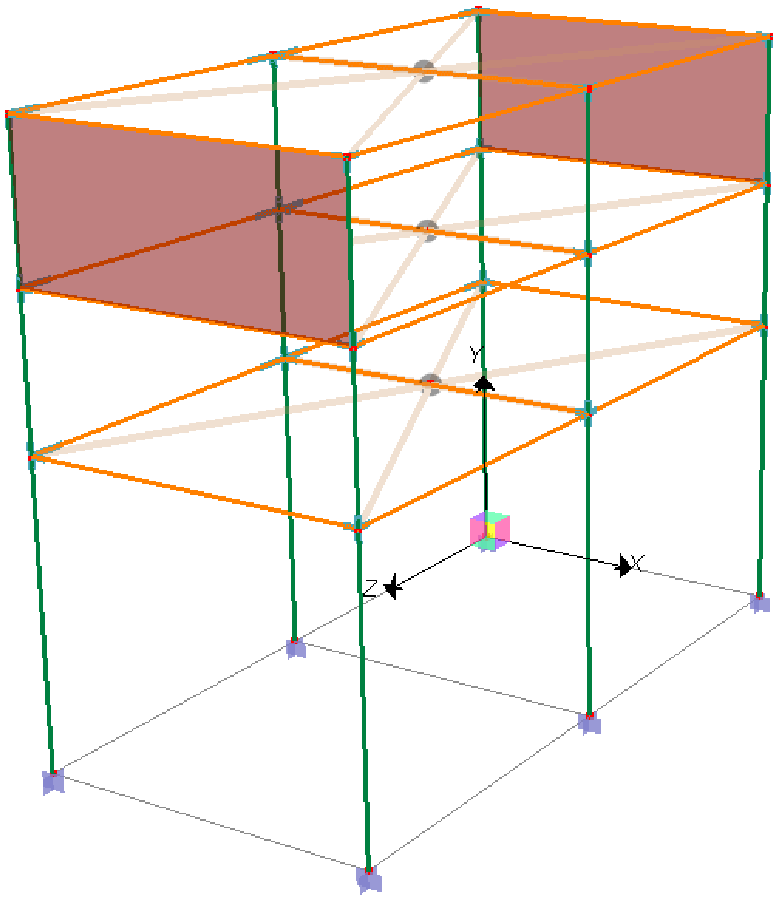


(b)



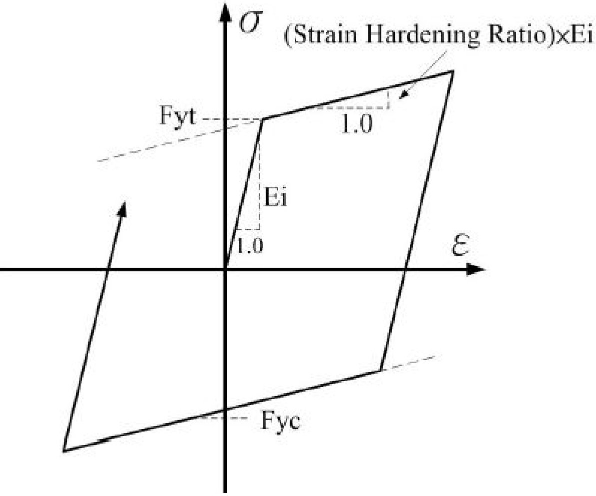
(d)

PISA3D Model



1. Rigid diaphragms with lumped mass.
2. Consider P-Δ effects , without rigid end zones.
3. Beam-column elements with plastic hinges at the ends of the elements.
4. Elastic panel element for the RC walls.
5. Employ degrading materials for columns and bilinear materials for beams.

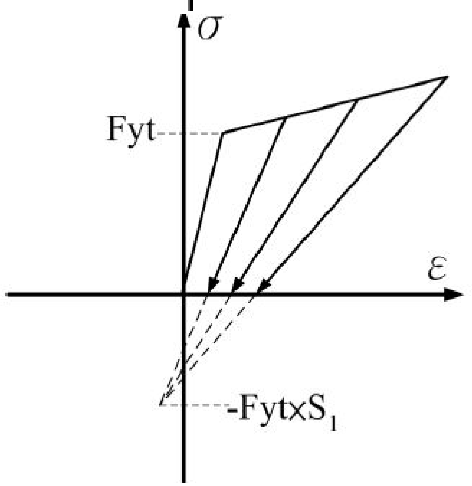
PISA3D Model

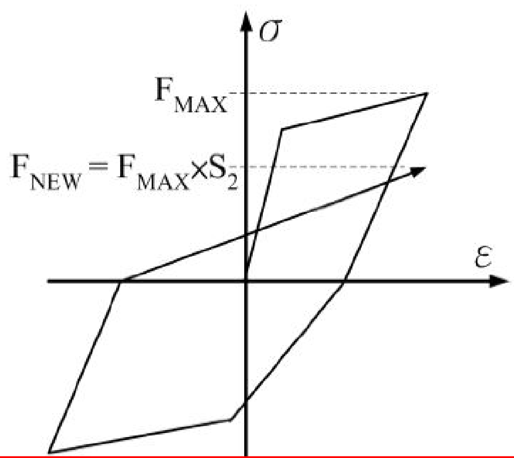


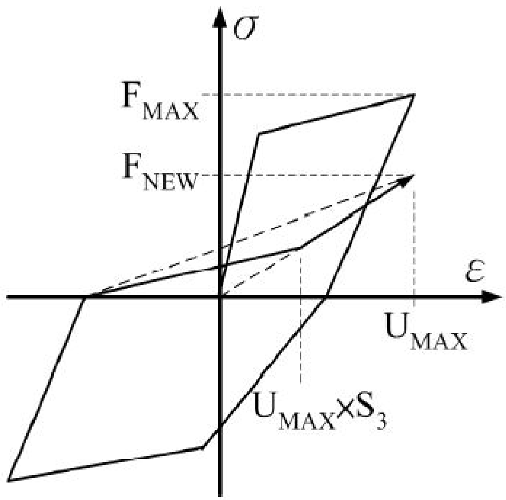
Command:

Material Bilinear Tag? Ei? SHR? fyt? fyc? Nu?

Bilinear material





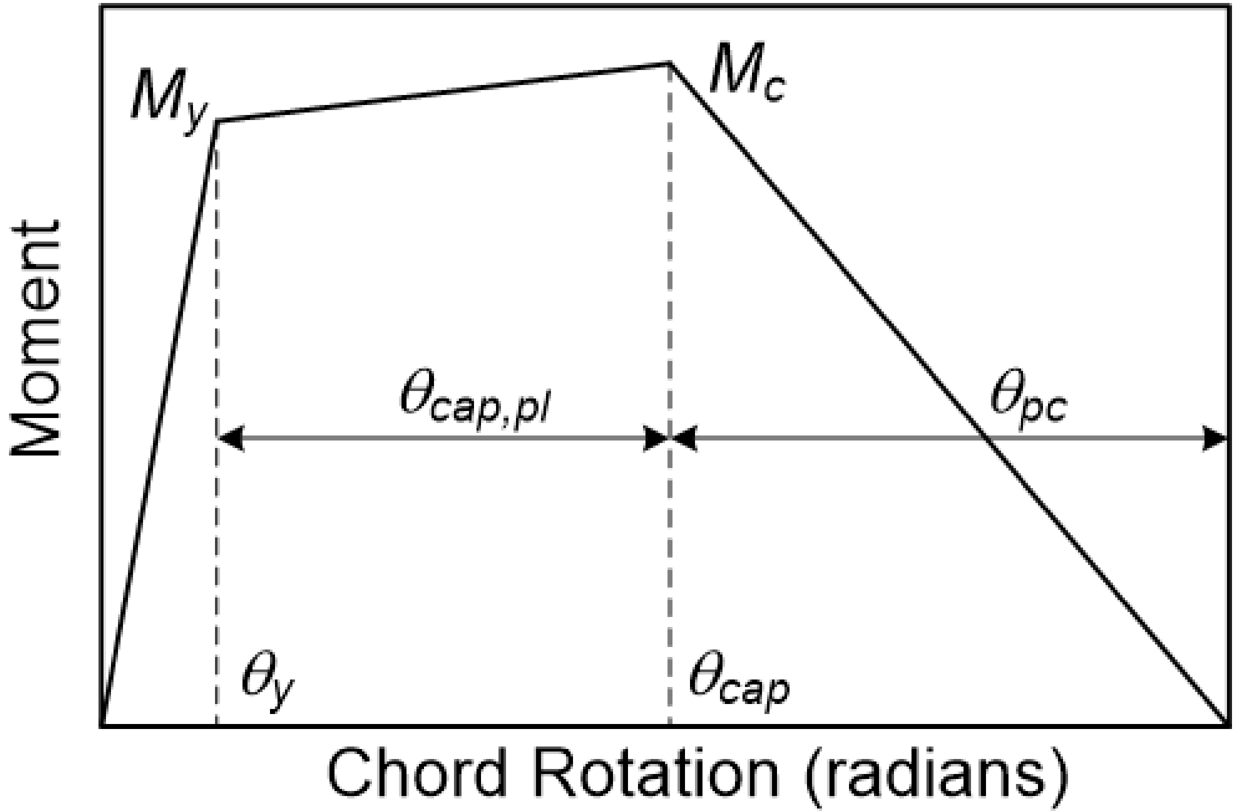


Degrading material

Command:

Material Degrading Tag? Ei? fyt? fyc? SHR+? SHR-? FStiff1? FStren1? FPinch1?

BV? FStiff2? FStren2? FPinch2? Nu?



Panagiotakos TB, Fardis MN (2001) Deformation of reinforced concrete members at yielding and ultimate. *ACI Structural Journal* 98(2):135-148.

Ibarra, L.F., Medina, R.A., Krawinkler, H. 2005. Hysteretic models that incorporate strength and stiffness deterioration. *Earthquake Engineering and Structural Dynamics*; 34: 1489-1511.

Haselton, C.B., Liel, A.B., Lange, S.T., Deierlein, G.G. 2007. Beam-column element model calibrated for predicting flexural response leading to global collapse of RC frame buildings. *PEER* 2007-03

Construction of Backbone Curves

ϕ_y = (CASE I, CASE II)$_{min}$

CASE I

$$\phi_y = \frac{f_y}{E_s(1-k_y)d}$$

$$k_y = (n^2A^2 + 2nB)^{1/2} - nA$$

$$A = \rho + \rho' + \rho_v + \frac{N}{bdf_y},$$

$$B = \rho + \rho'\delta' + 0.5\rho_v(1+\delta') + \frac{N}{bdf_y}$$

$n = E_s/E_c$

CASE II

$$\phi_y = \frac{\varepsilon_c}{k_y d} \approx \frac{1.8f_c'}{E_c k_y d}$$

$$k_y = (n^2A^2 + 2nB)^{1/2} - nA$$

$$A = \rho + \rho' + \rho_v - \frac{N}{\varepsilon_c E_s bd} \approx \rho + \rho' + \rho_v - \frac{N}{1.8nbdf_c'},$$

$$B = \rho + \rho'\delta' + 0.5\rho_v(1+\delta')$$

$n = E_s/E_c$

Construction of Backbone Curves

$$\frac{M_y}{bd^3} = \phi_y\left\{E_c\frac{k_y^2}{2}\left(0.5(1+\delta')-\frac{k_y}{3}\right)+\right.$$

$$\left.\frac{E_s}{2}\left[(1-k_y)\rho+(k_y-\delta')\rho'+\frac{\rho_v}{6}(1-\delta')\right](1-\delta')\right\}$$

$$\theta_y = \phi_y\frac{L_s}{3}+0.0025+a_{sl}\frac{0.25\varepsilon_y d_b f_y}{(d-d')\sqrt{f_c'}}$$

f_y and $f_{c'}$ are in MPa

Construction of Backbone Curves

- Plastic rotation capacity:

$$\theta_{cap,pl} = 0.12(1+0.55a_{sl})(0.16)^{v}(0.02+40\rho_{sh})^{0.43}(0.54)^{0.01c_{units}f'_c}(0.66)^{0.1s_n}(2.27)^{10.0\rho}$$

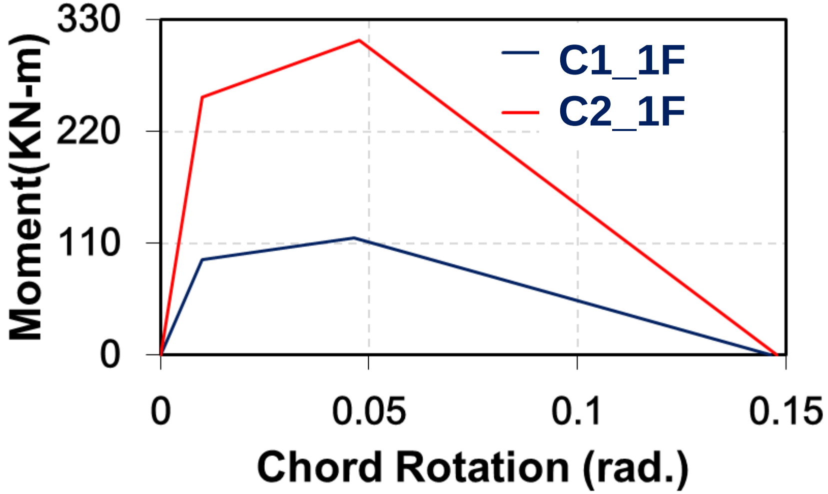
- Post-capping rotation capacity:

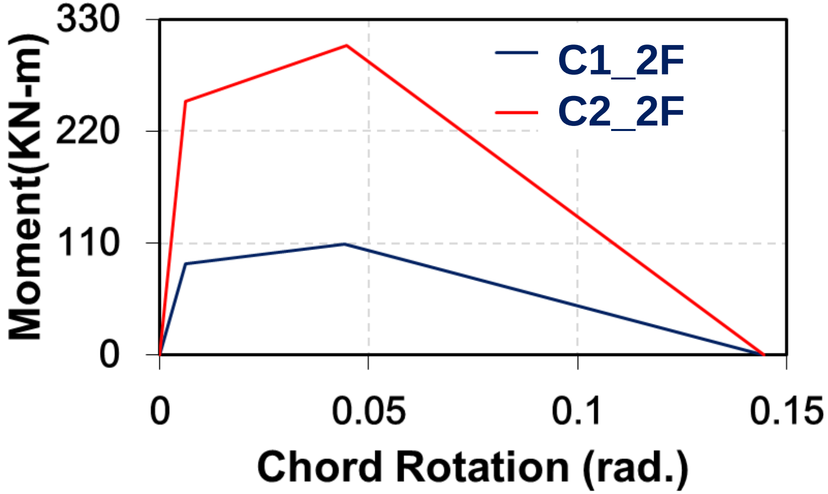
$$\theta_{pc} = (0.76)(0.031)^{v}(0.02+40\rho_{sh})^{1.02} \leq 0.10$$

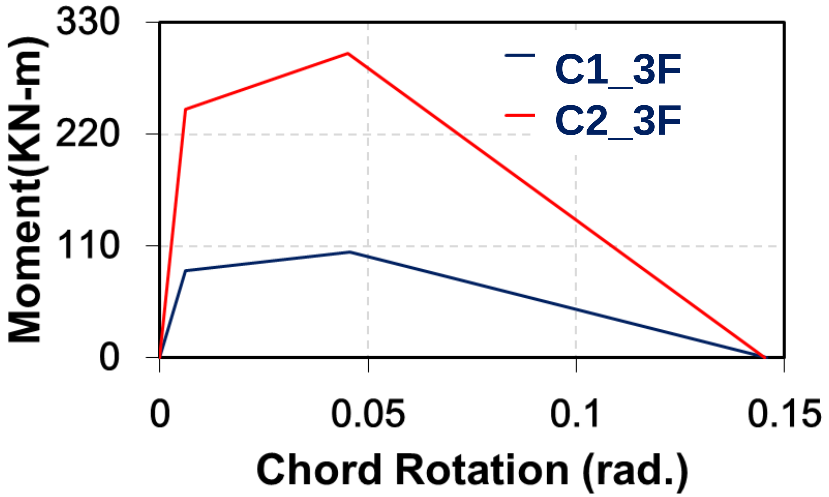
- Capping strength:

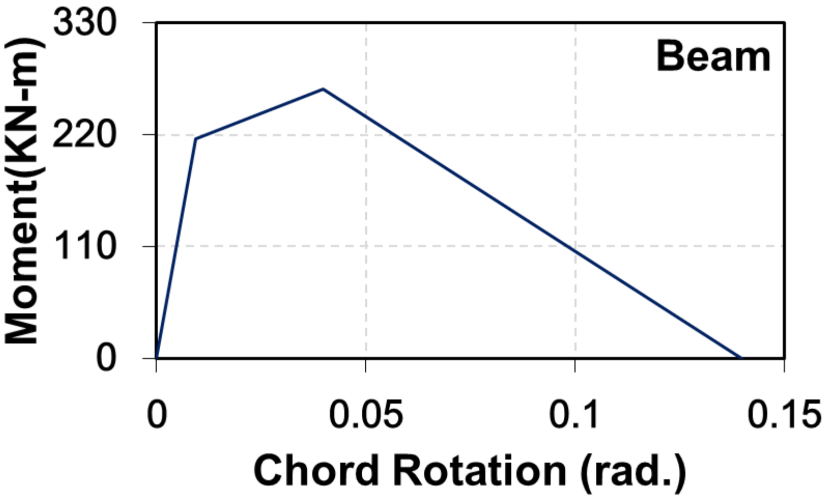
$$M_c / M_y = (1.25)(0.89)^{v}(0.91)^{0.01c_{units}f'_c}$$

Construction of Backbone Curves









ACI 318-95:

$0.35E_cI_g \quad for \quad beams \,\&\, walls$

$0.7E_cI_g \quad for \quad columns$

FEMA 356 (2000):

$0.5E_cI_g \quad when \quad P/(A_g f_c') < 0.3$

$0.7E_cI_g \quad when \quad P/(A_g f_c') > 0.5$

Elwood and Eberhard (2006):

$0.2E_cI_g \quad when \quad P/(A_g f_c') < 0.2$

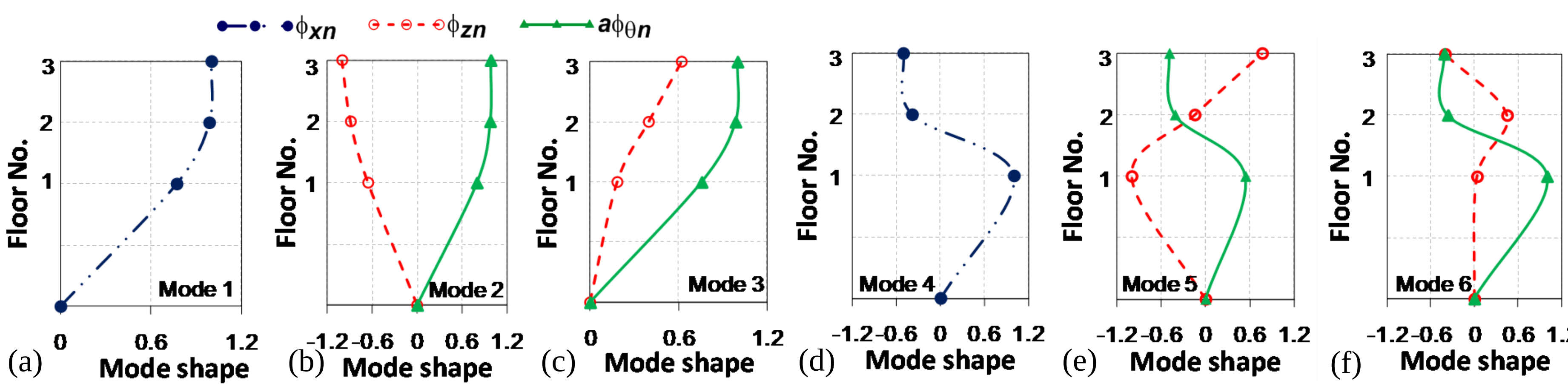
$0.7E_cI_g \quad when \quad P/(A_g f_c') > 0.5$

The effective rigidity of the cracked member to yielding is, on average, approximately 20% of that of the uncracked gross section E_cI_g (Panagiotakos and Fardis 2001).

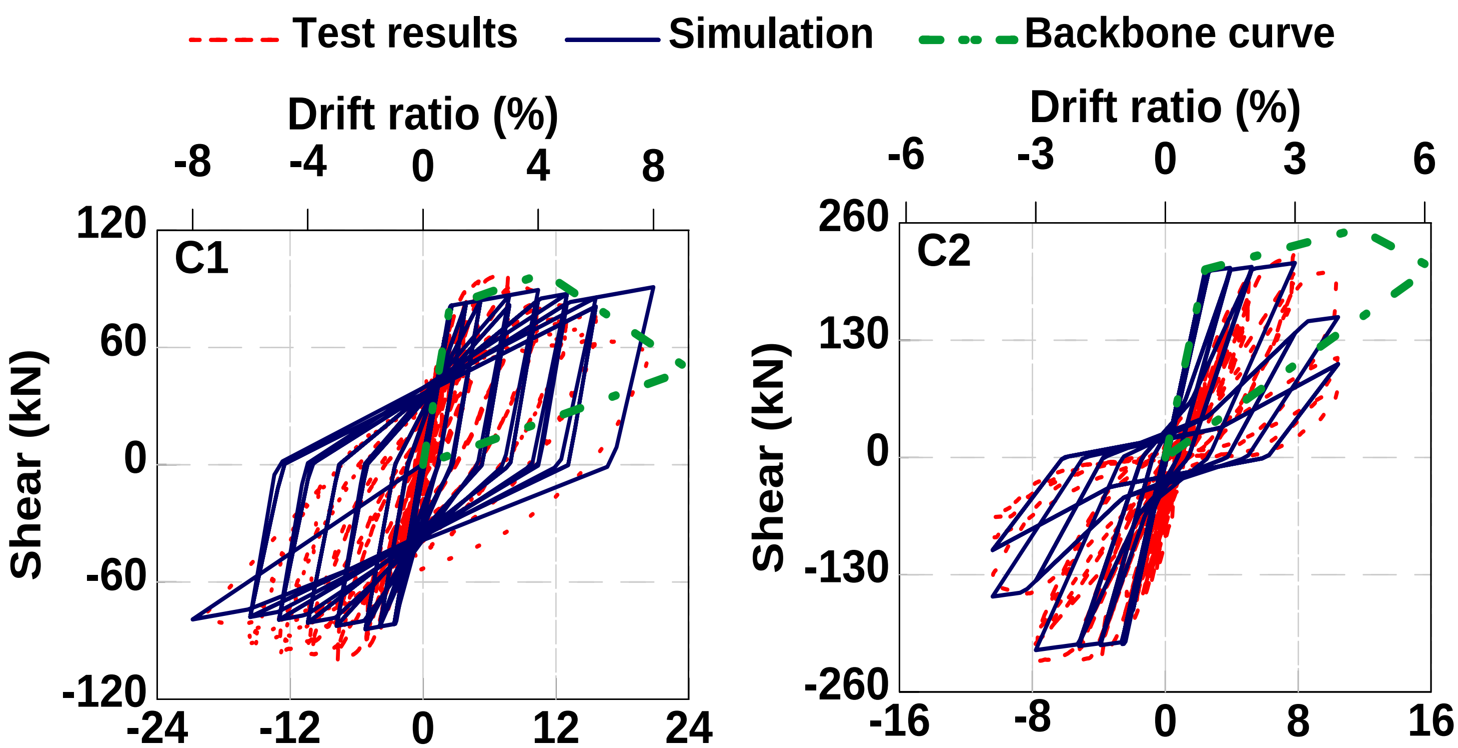
Element	Location	θ_y (rad.)	θ_{cap} (rad.)	θ_{pc} (rad.)	M_y (kN-m)	M_c (kN-m)	$P/(A_g f_c')$	EI_{eff}/EI_g
Column C1	1F_ext.*	0.0099	0.0484	0.1	87.97	107.33	0.033	0.287
	1F_int.*	0.0101	0.0464	0.1	94.50	114.87	0.065	0.302
	2F_ext.	0.0061	0.0455	0.1	85.50	104.47	0.021	0.224
	2F_int.	0.0062	0.0442	0.1	89.61	109.23	0.041	0.232
	3F_ext.	0.0061	0.0463	0.1	83.22	101.82	0.010	0.219
	3F_int.	0.0061	0.0456	0.1	85.29	104.23	0.020	0.223
Column C2	1F_ext.	0.0099	0.0486	0.1	247.29	302.44	0.013	0.320
	1F_int.	0.0100	0.0478	0.1	253.88	310.03	0.026	0.326
	2F_ext.	0.0062	0.0452	0.1	244.75	299.50	0.008	0.253
	2F_int.	0.0062	0.0446	0.1	249.32	304.78	0.017	0.257
	3F_ext.	0.0062	0.0455	0.1	242.71	297.15	0.004	0.252
	3F_int.	0.0062	0.0452	0.1	244.75	299.50	0.008	0.253
Beam	Beam	0.0093	0.0397	0.1	216.33	264.98	0	0.441

Modal Properties

Mode n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
T_n (s)	**0.395**	0.330	0.192	0.071	0.070	0.045	0.023	0.017	0.011
x-trans.(%)	98.63	0	0	1.38	0	0	0	0.0004	0
y-trans.(%)	0	64.89	28.33	0	5.21	0.59	0.59	0	0.005
z-rot.(%)	0	32.85	64.61	0	0.44	1.87	0.49	0	0.005



Hysteretic Loops of Single Column Test

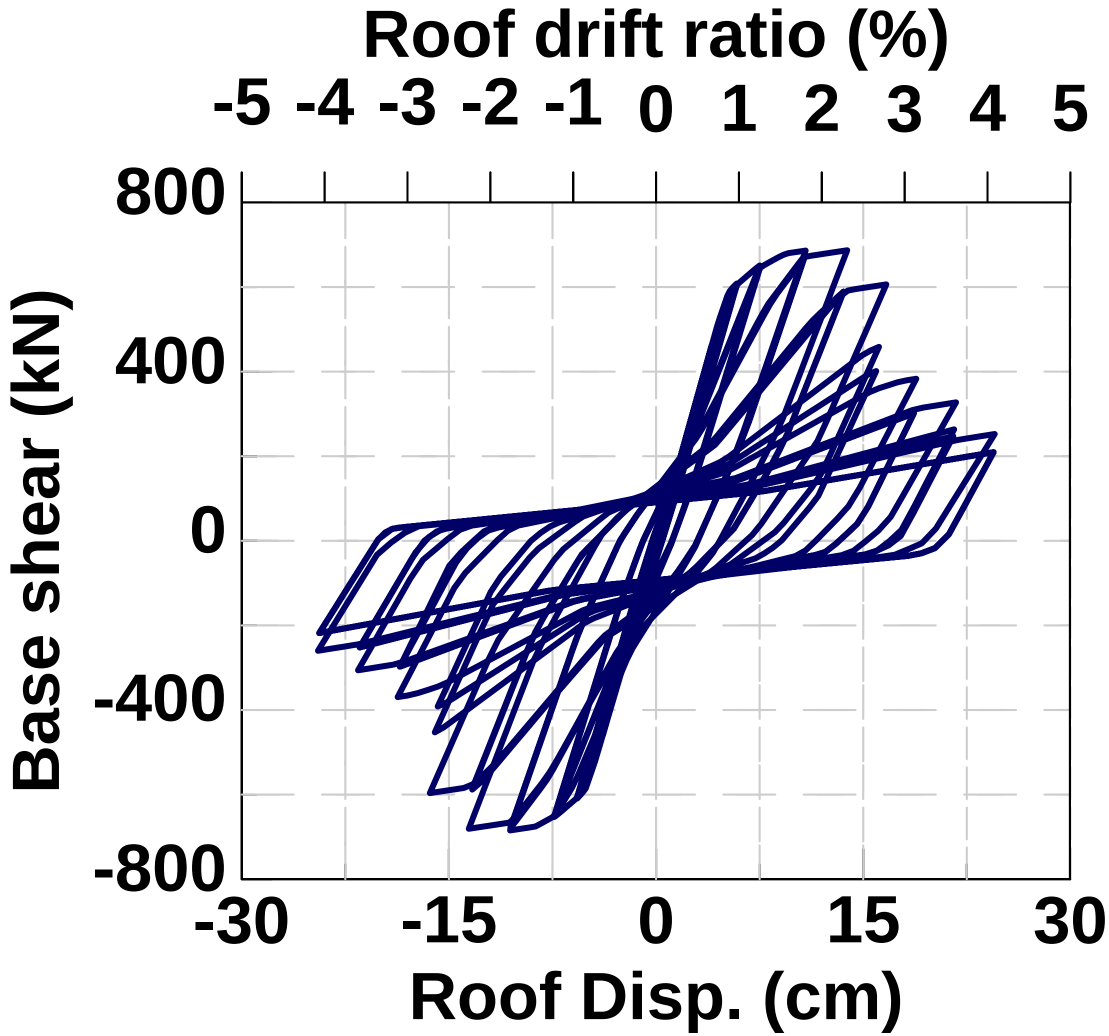


(a) (b)

S1 = 20, S2= 1, S3 = 1,
BV =1.5,
S1'= 20, S2'= 0.95, S3' = 1

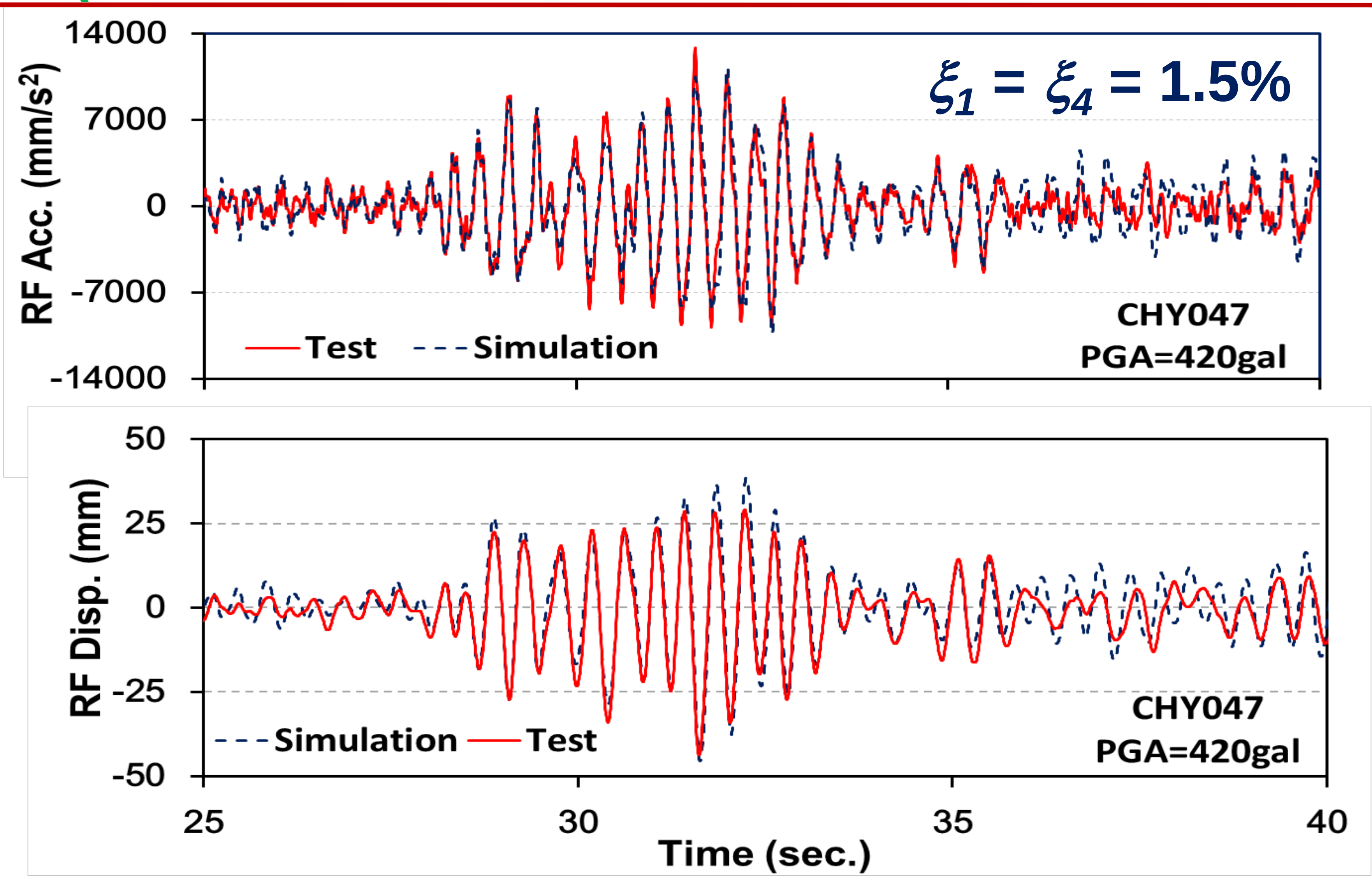
S1 = 1, S2= 0.99, S3 = 0.3,
BV =1.5,
S1'= 1, S2'= 0.7, S3' = 0.3

Cyclic Pushover Curve

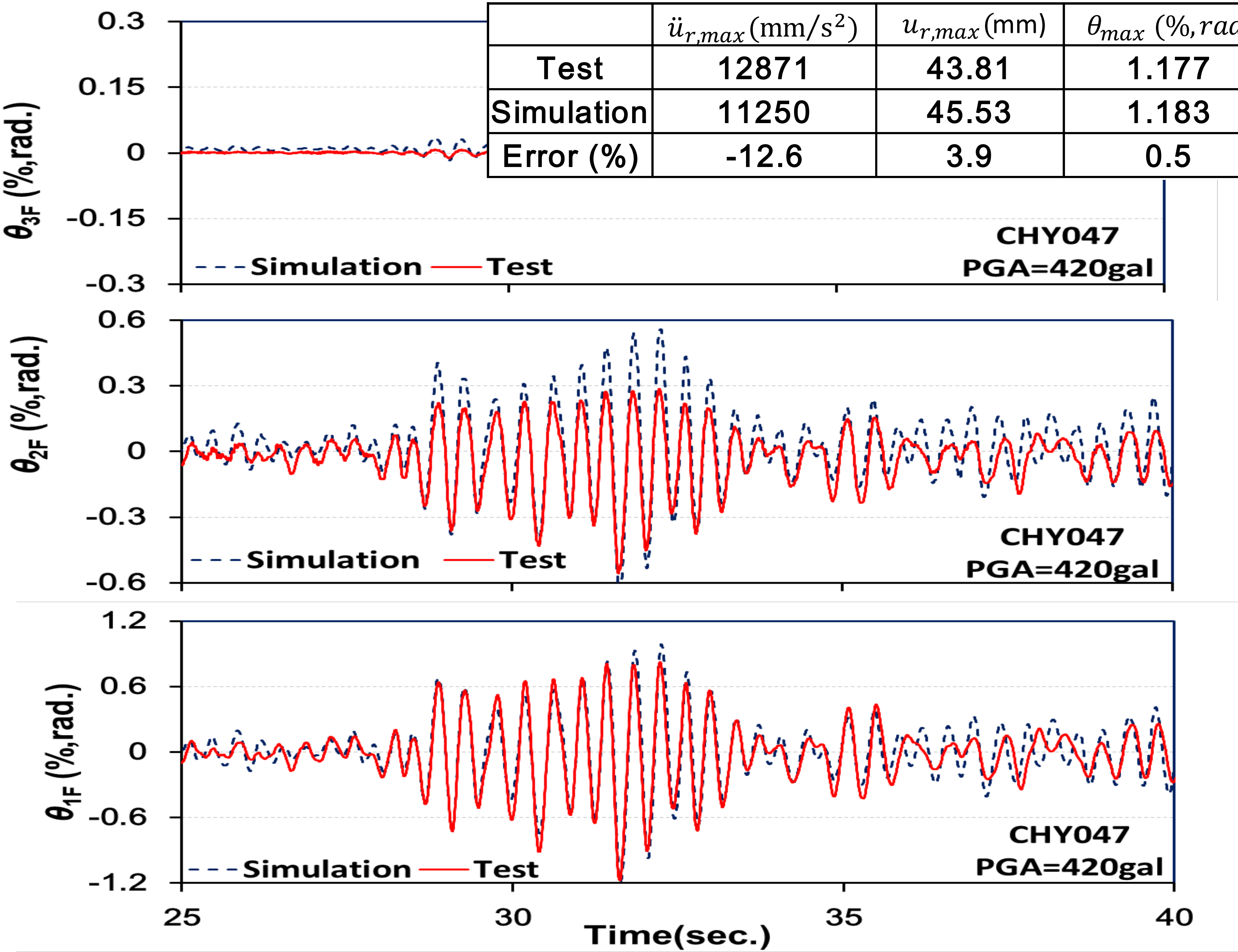


CHY047

(PISA3D Analysis Time for CHY047 = 61.5 sec)

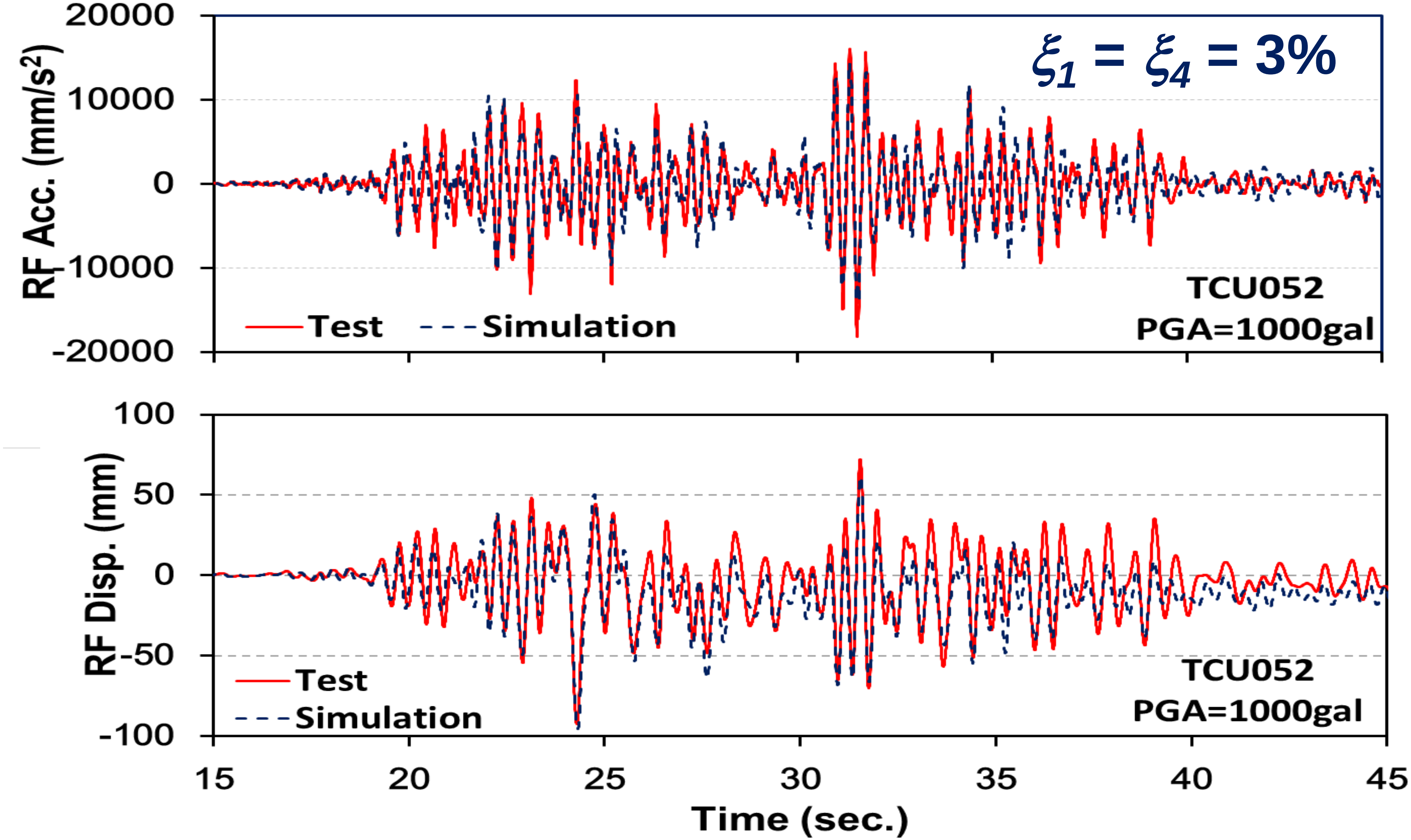


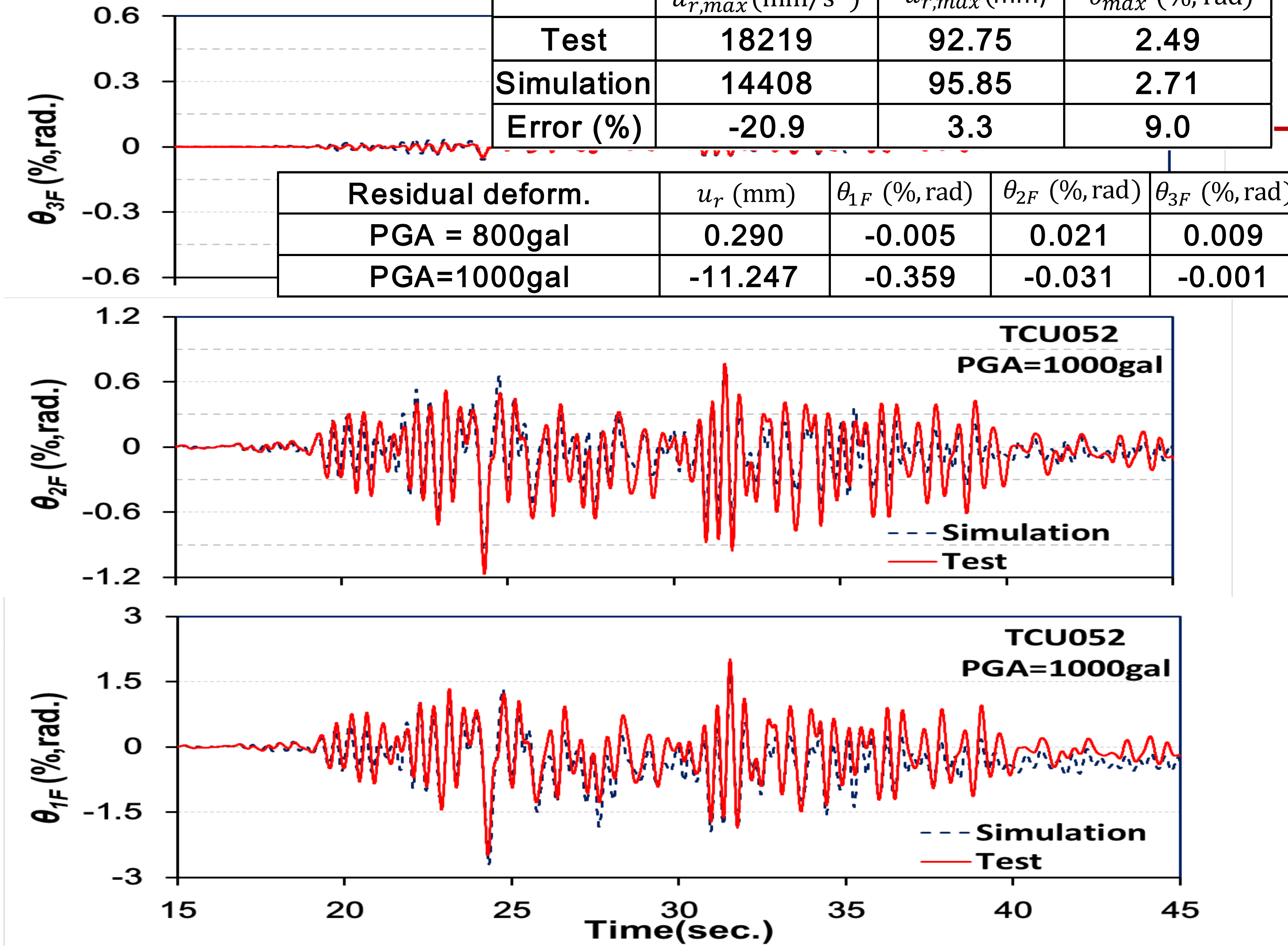
	$\ddot{u}_{r,max}$ (mm/s^2)	$u_{r,max}$ (mm)	θ_{max} (%, rad)
Test	12871	43.81	1.177
Simulation	11250	45.53	1.183
Error (%)	-12.6	3.9	0.5



TCU052

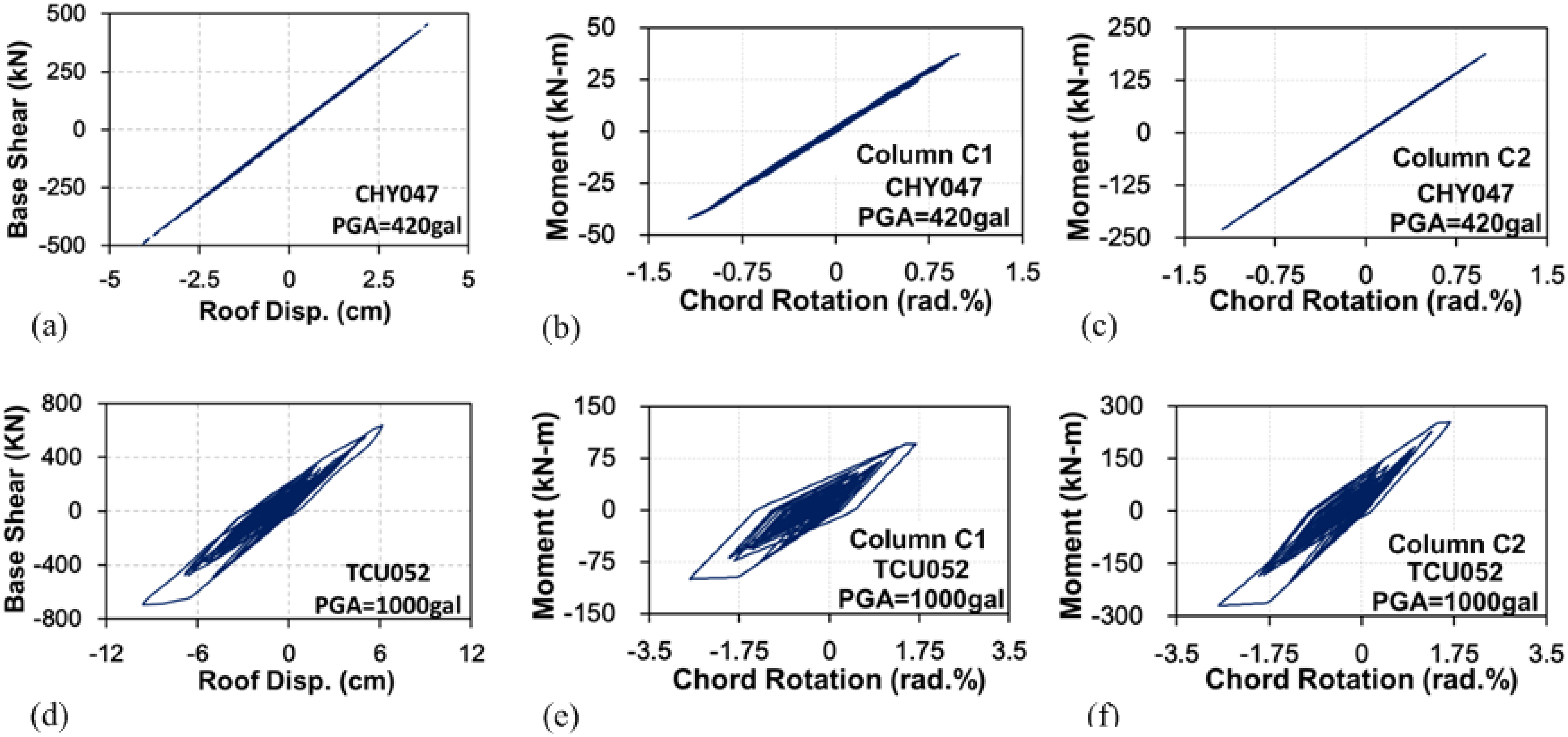
(PISA3D Analysis Time for TCU052 = 50.5 sec)

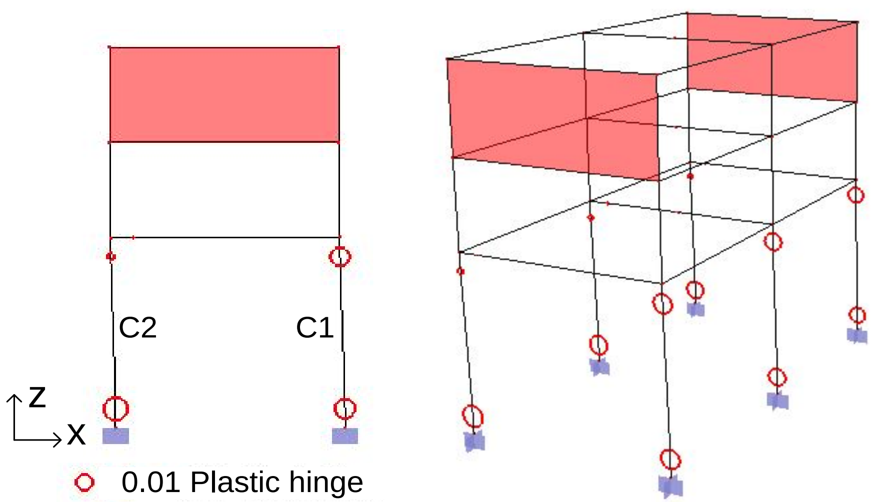




	$\ddot{u}_{r,max}$ (mm/s^2)	$u_{r,max}$ (mm)	θ_{max} (%, rad)
Test	18219	92.75	2.49
Simulation	14408	95.85	2.71
Error (%)	-20.9	3.3	9.0

Residual deform.	u_r (mm)	θ_{1F} (%, rad)	θ_{2F} (%, rad)	θ_{3F} (%, rad)
PGA = 800gal	0.290	-0.005	0.021	0.009
PGA=1000gal	-11.247	-0.359	-0.031	-0.001

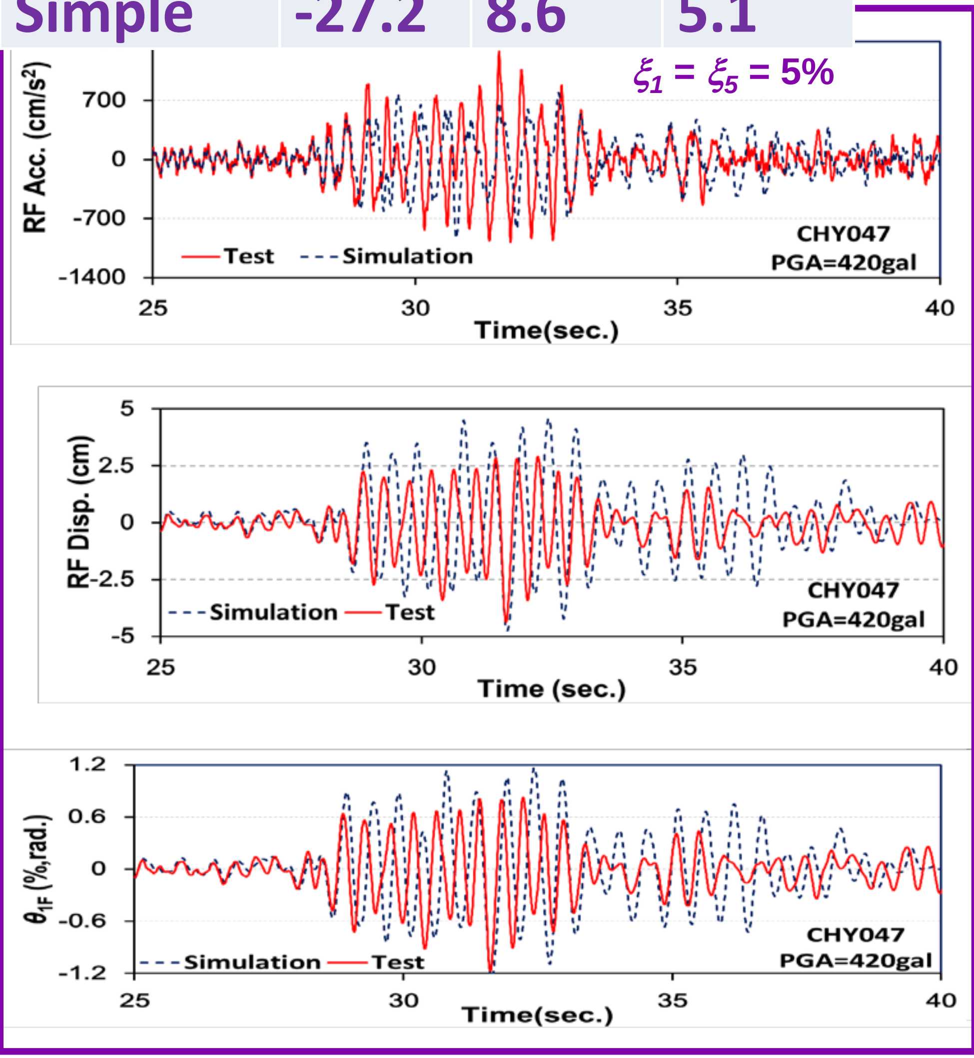

Base Shear (kN)
Roof Disp. (cm)
CHY047
PGA=420gal
(a)
Moment (kN-m)
Chord Rotation (rad.%)
Column C1
CHY047
PGA=420gal
(b)
Moment (kN-m)
Chord Rotation (rad.%)
Column C2
CHY047
PGA=420gal
(c)
Base Shear (KN)
Roof Disp. (cm)
TCU052
PGA=1000gal
(d)
Moment (kN-m)
Chord Rotation (rad.%)
Column C1
TCU052
PGA=1000gal
(e)
Moment (kN-m)
Chord Rotation (rad.%)
Column C2
TCU052
PGA=1000gal
(f)

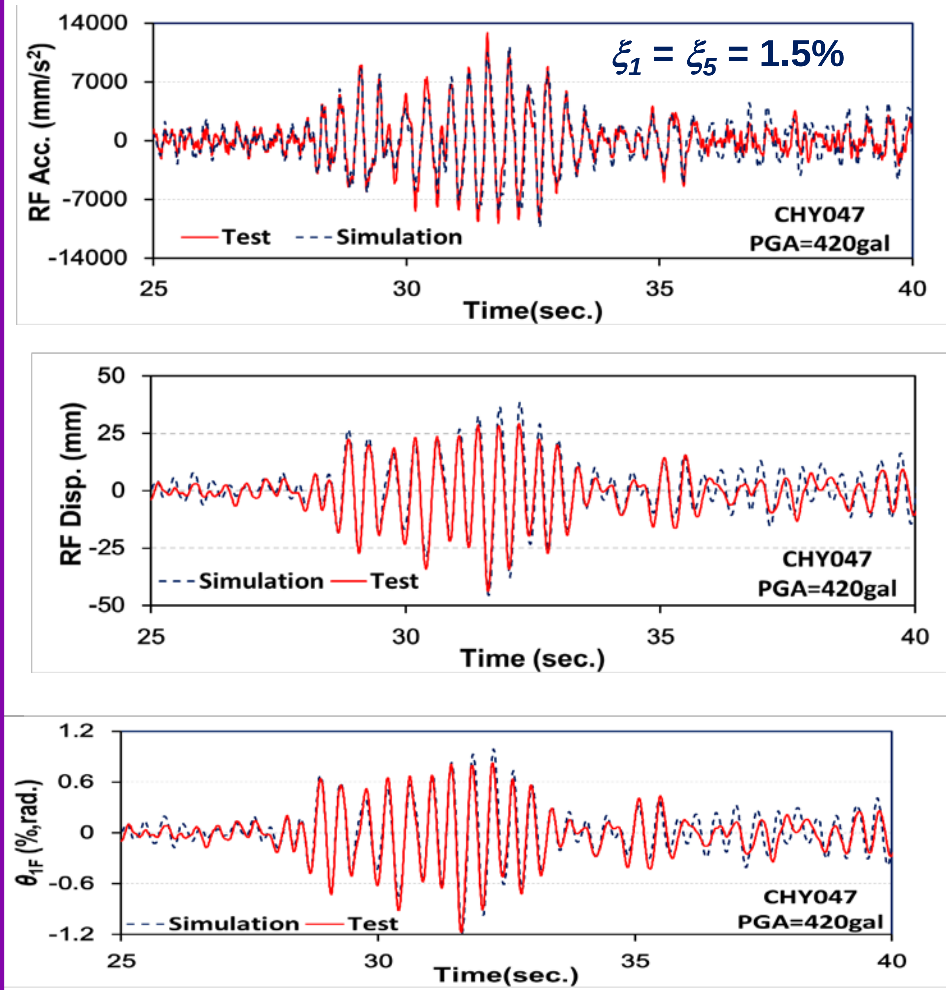

C2
C1
Z
X
0.01 Plastic hinge

(a) (b)

Error (%)	$a_{r,max}$	$u_{r,max}$	θ_{max}
Precision	-12.6	3.9	0.5
Simple	-27.2	8.6	5.1

lation (CHY047)

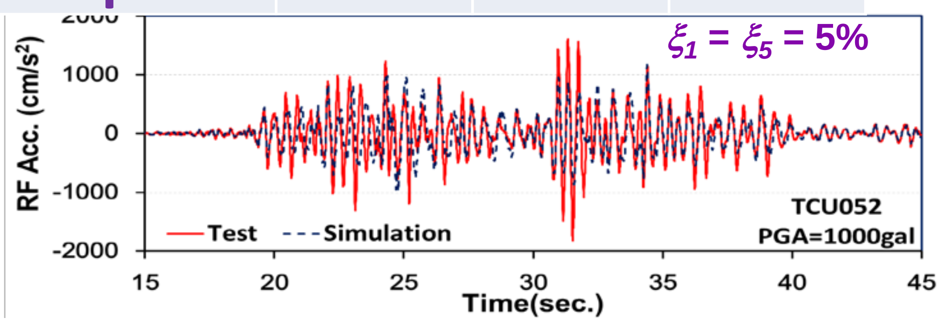


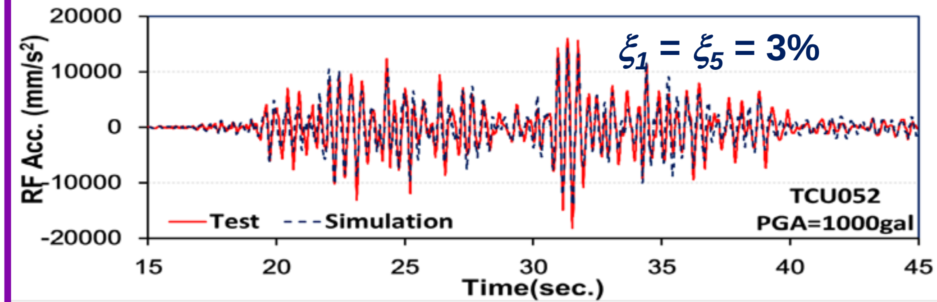


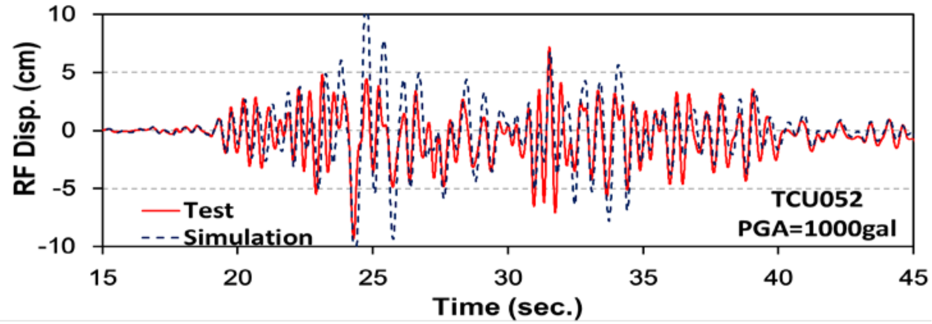
$EI_{eff} = 0.2E_cI_g$ (T_1 = 0.51 sec)

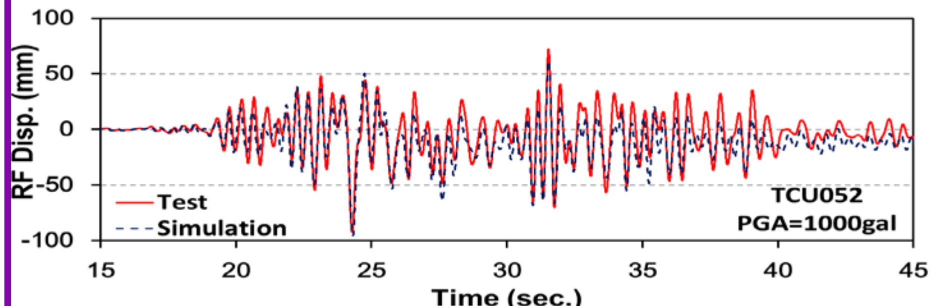
…lation (TCU052)

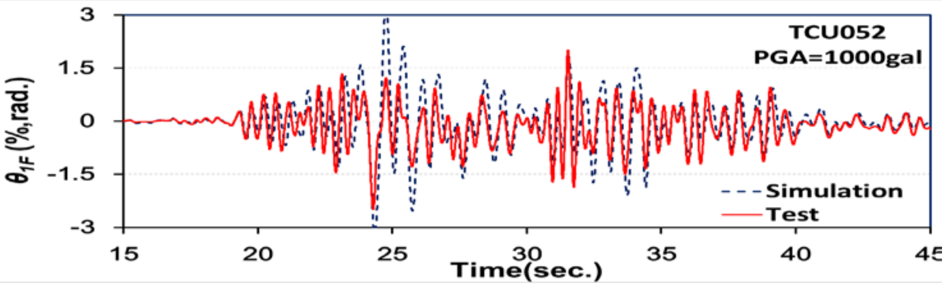
Error (%)	$a_{r,max}$	$u_{r,max}$	θ_{max}
Precision	-20.9	3.3	9.0
Simple	-35.3	29.9	32.6

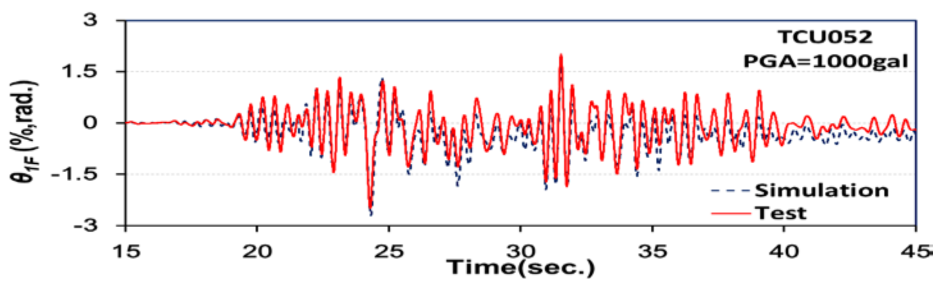












$EI_{eff} = 0.2E_cI_g$ (T_1 = 0.51 sec)

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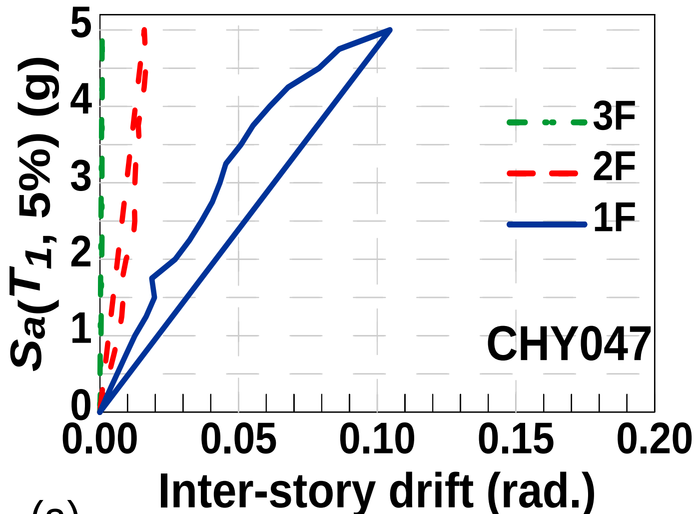
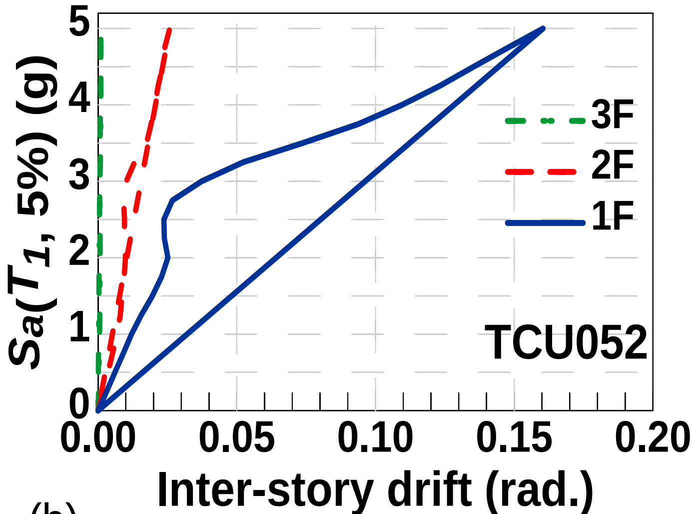
Incremental Dynamic Analyses



(a)



(b)

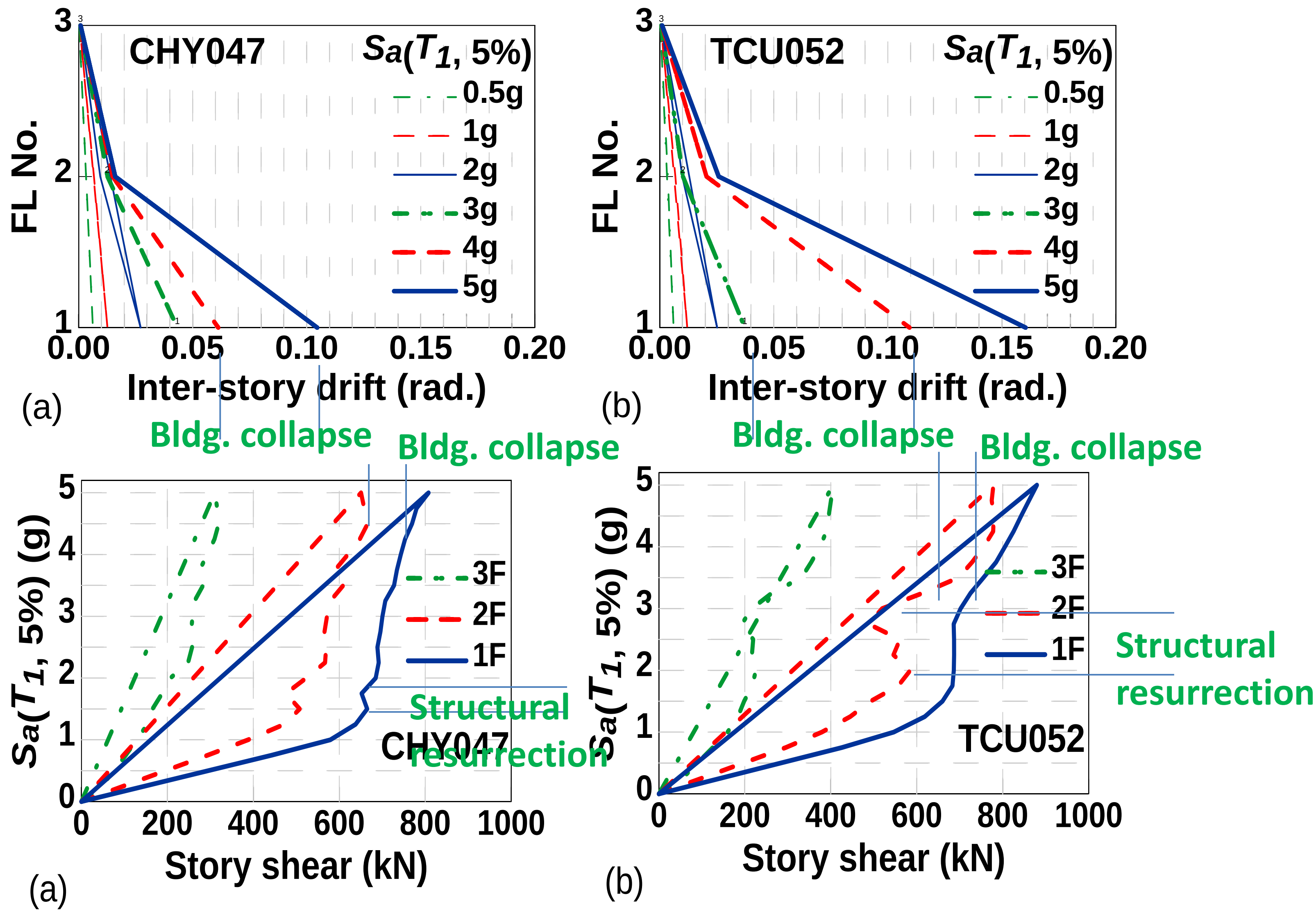
‘**Structural resurrection**’ occurs while $S_a(T_1, 5\%)$ increases from **1.5 g to 1.75 g** and from **2.0 g to 2.5 g** for CHY047 and TCU052, respectively.

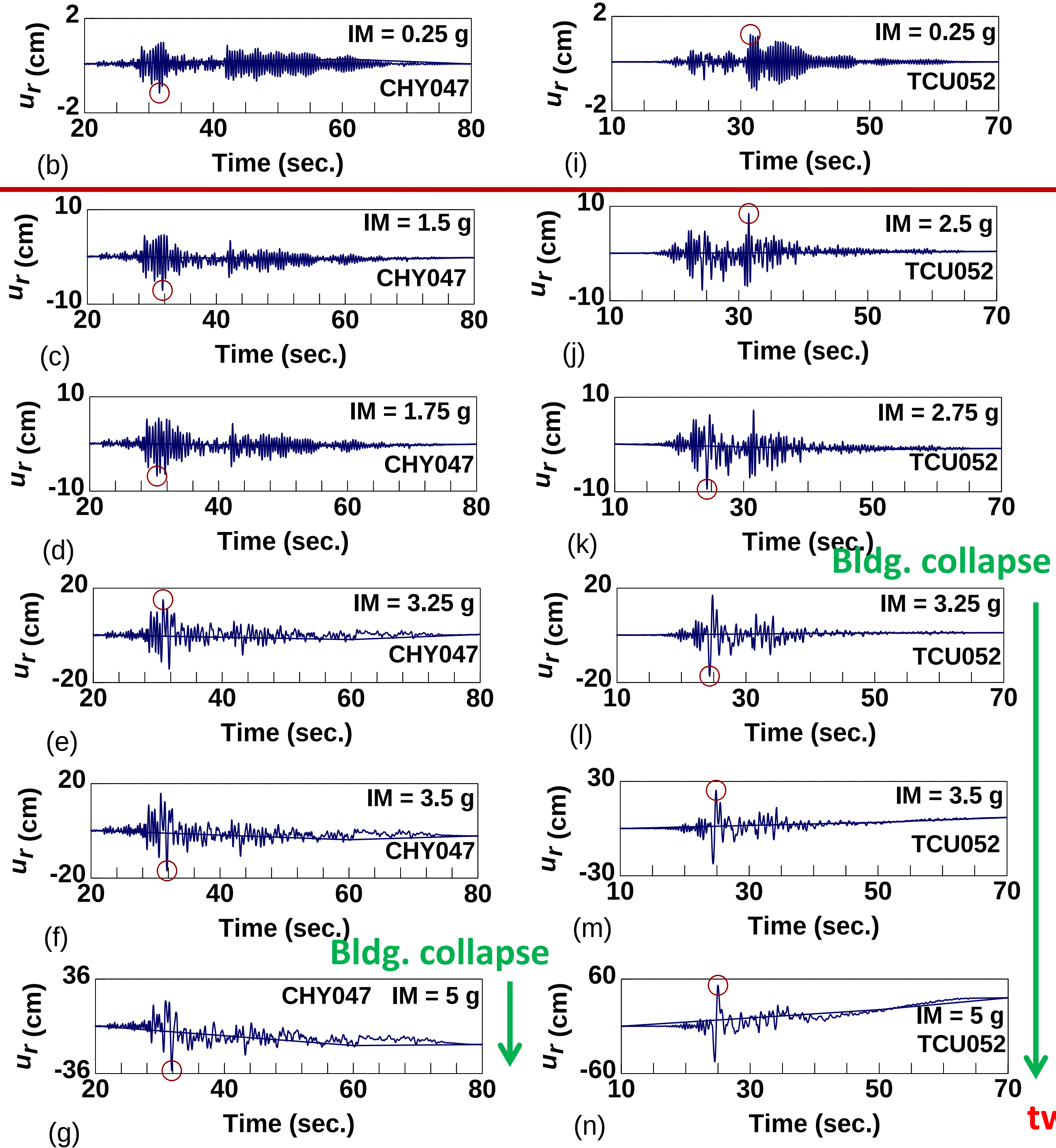
Taking the tangent slope of an IDA curve equal to **20% of its initial slope** as the indicator of **building collapse** (i.e., **limit-state Collapse Prevention**), the three-story building is collapsed at $S_a(T_1, 5\%)$ = **4.75 g and 3.25 g** under the excitations of CHY047 and TCU052, respectively.

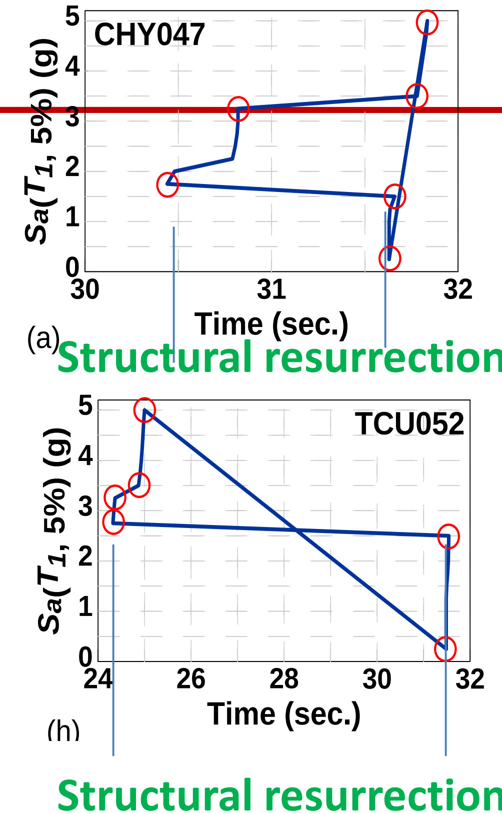
4.2.2.2.1 Collapse Prevention Performance Level

The Collapse Prevention structural performance level is defined as the post earthquake damage state in which the structure is on the verge of experiencing partial or total collapse. Substantial damage to the structure has occurred, potentially including significant degradation in the stiffness and strength of the lateral-force-resisting system, large permanent lateral deformation of the structure, and, to a more limited extent, degradation in the vertical-load-carrying capacity. However, all significant components of the gravity-load-resisting system must continue to carry their gravity-load demands. The structure may not be technically or economically practical to repair and is not safe for re-occupancy; aftershock activity could credibly induce collapse. (FEMA-350 2000)

Effects of Near-Fault Ground Motions

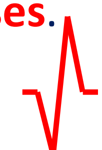




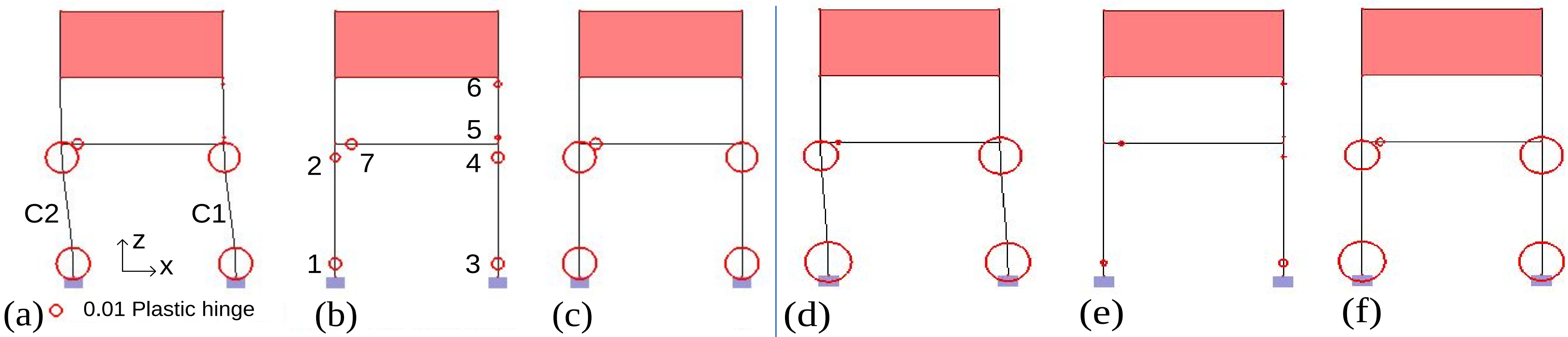


The characteristic of near-fault ground motions — **fling** and then destroy the structure by **large displacements** and **velocity pulses**.

two-side spike



Snapshot of the deformation and the distribution of plastic rotations

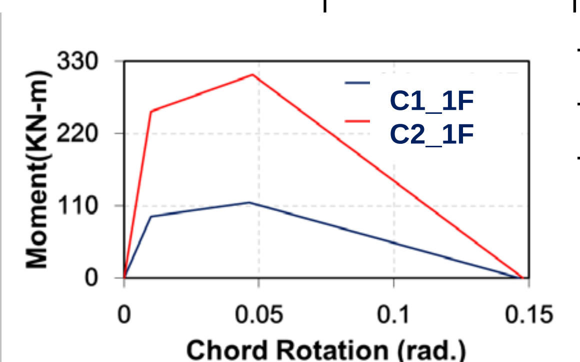


CHY047 scaled to $S_a(T_1, 5\%)$ = **4.75 g**

TCU052 scaled to $S_a(T_1, 5\%)$ = **3.25 g**

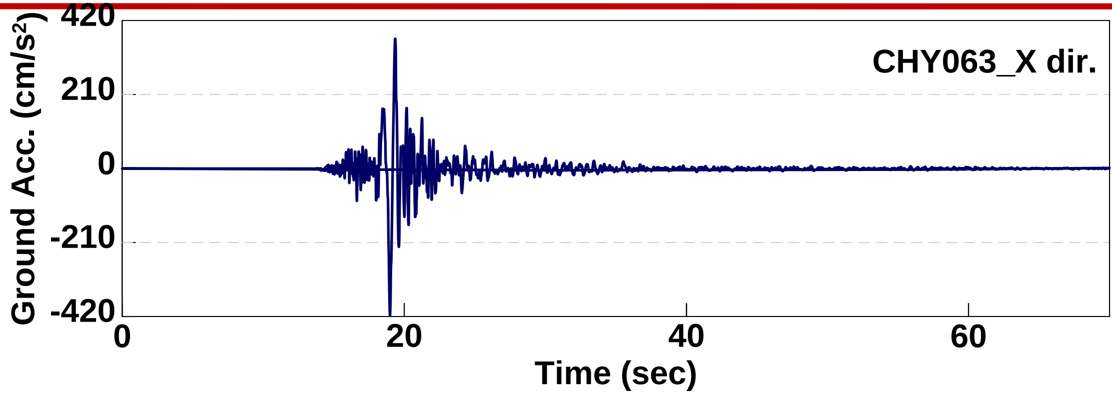
Plastic rotations (%, rad.)

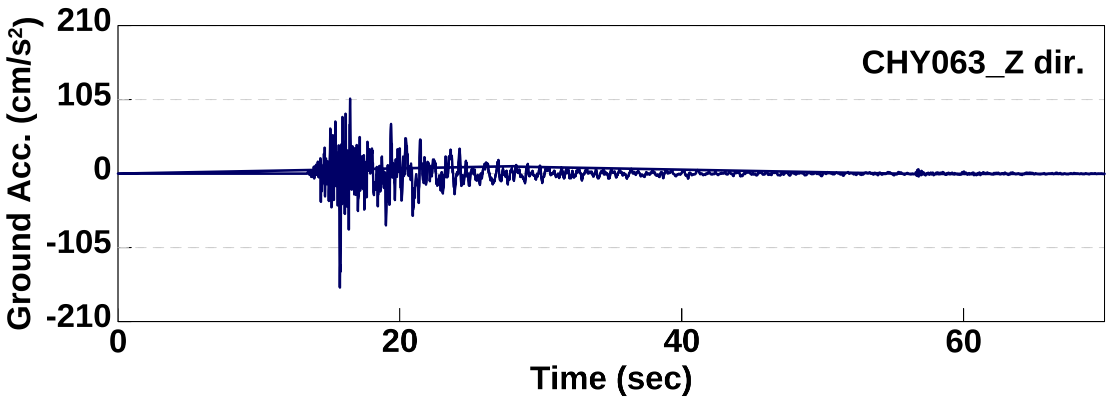
Shaking	State	Location						
		1	2	3	4	5	6	7
CHY047 (IM = 4.75 g)	Peak roof disp.	-2.86	-2.76	-2.84	-2.65	0.25	0.14	0.90
	Positive envelope	1.02	0.75	1.04	1.00	0.39	0.56	0.91
	Negative envelope	**-2.86**	**-2.76**	**-2.85**	**-2.65**	0	0	-1.02
	Peak roof disp.	-3.59	-2.63	-3.44	-3.28	0	-0.04	0.37
	Positive envelope	0.48	0	0.67	0.28	0.09	0.32	0.37
	Negative envelope	**-3.59**	**-2.63**	**-3.44**	**-3.28**	0	-0.04	-0.66

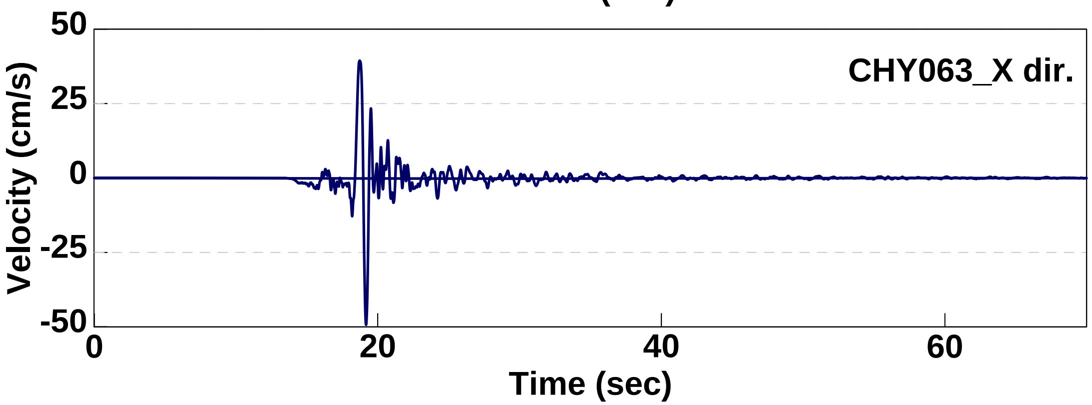


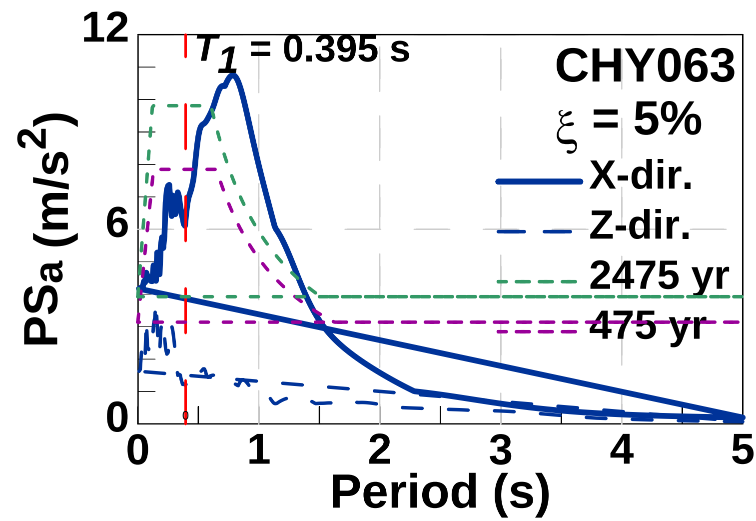
$S_a(T_1, 5\%)$ = 3.25 g of TCU052 is indeed an **incipient intensity** causing the collapse of the numerical model.

Feb. 6, 2016 Meinong Earthquake









永康市 第二類地盤

$S_s^D = 0.8$, $S_1^D = 0.4$

$S_s^M = 1.0$, $S_1^M = 0.55$

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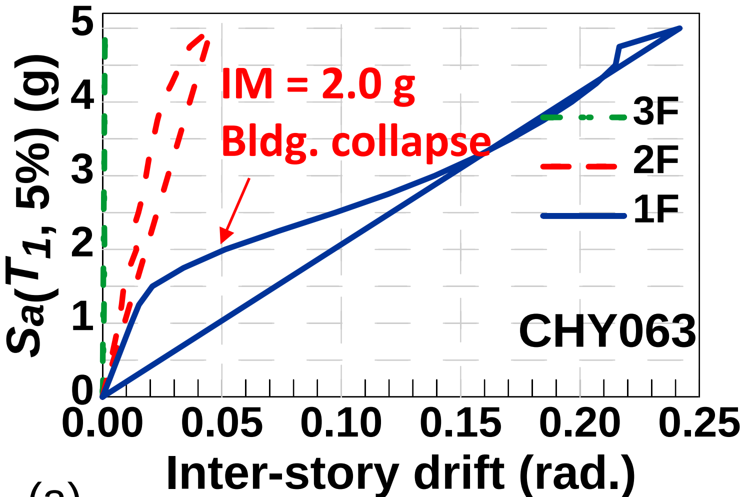
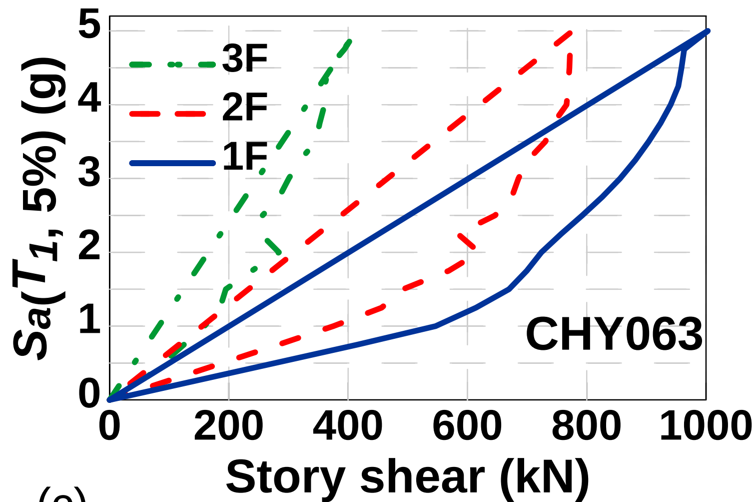
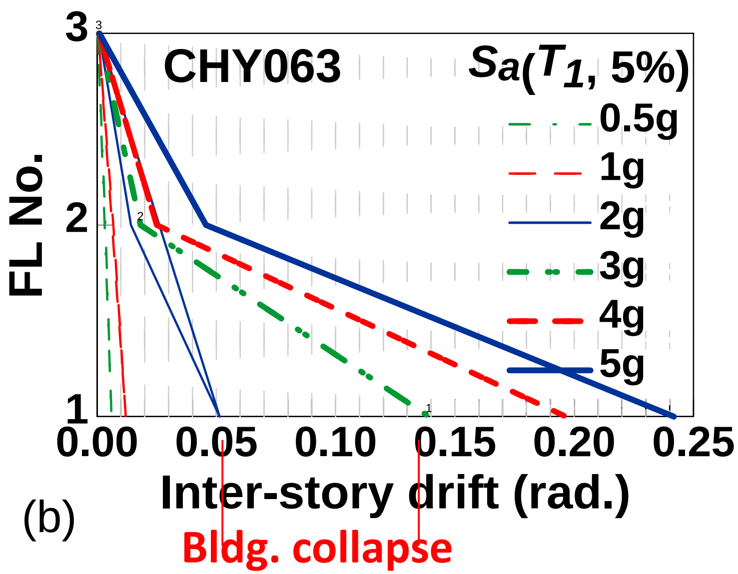


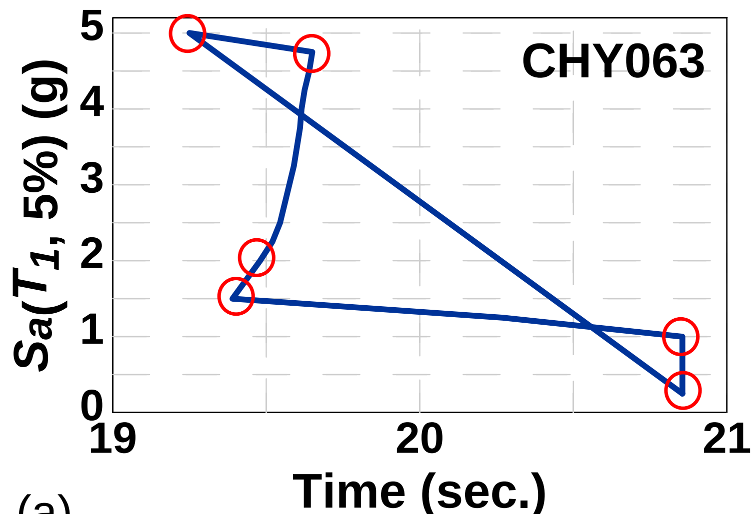
(a)



(c)



(b)



(a)

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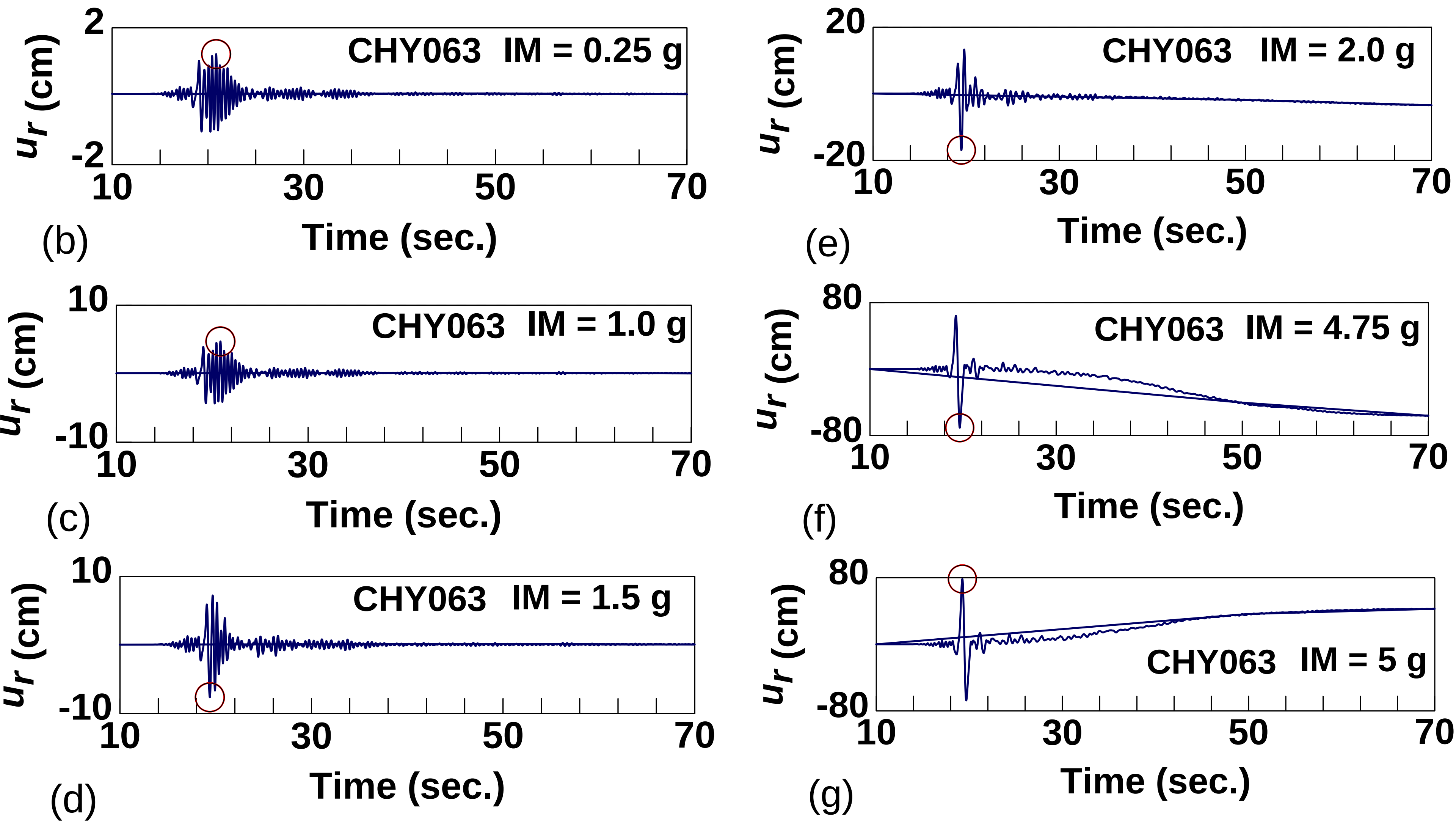
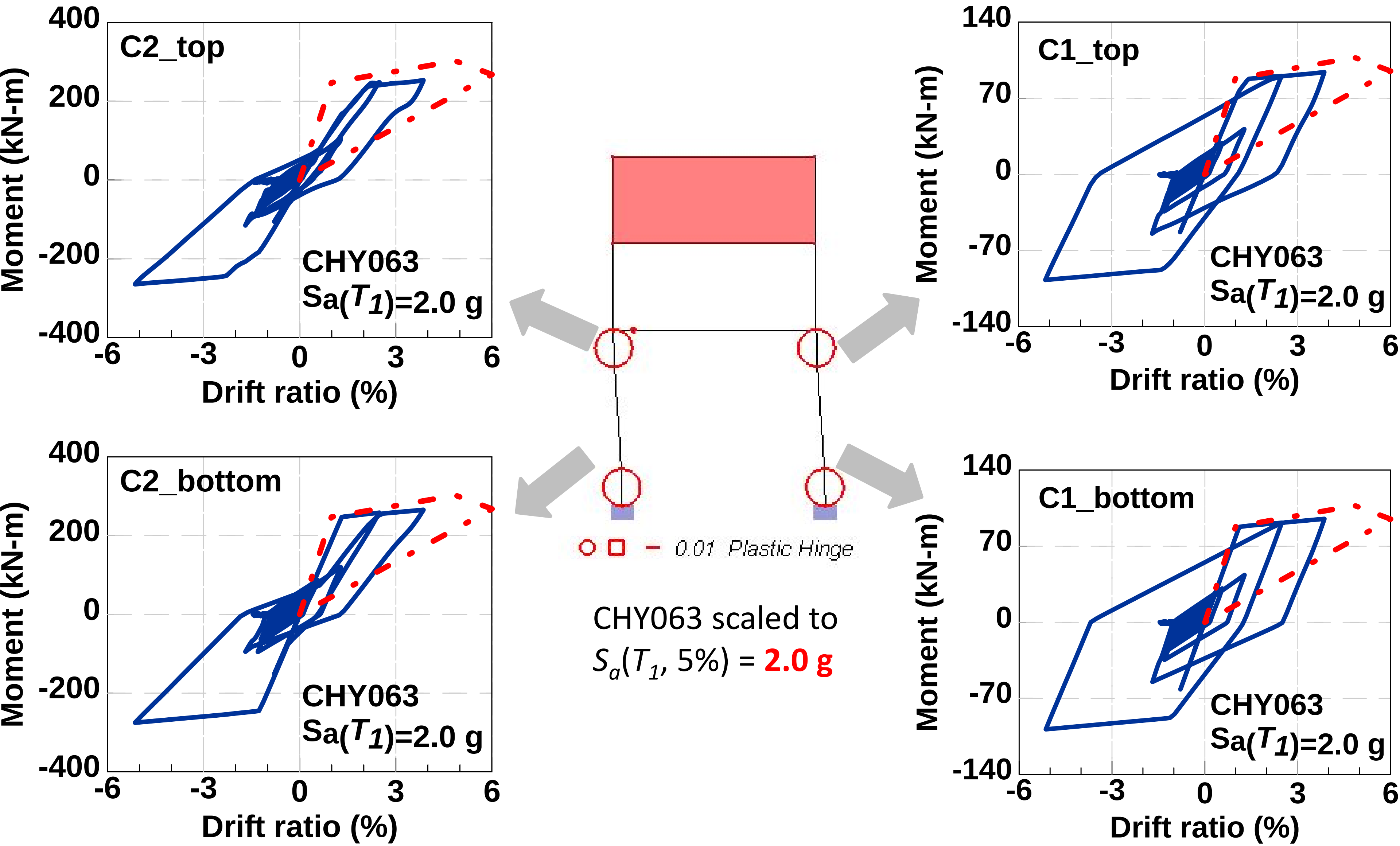


Feb. 6, 2016 Meinong Earthquake



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Outlines

1. Introduction
2. Simulation of the Shaking Table Test
3. Seismic Analysis of the Building with a Soft/Weak Bottom Story
4. Conclusions

Conclusions

1. The common practice, which simply adopts $0.2EI_g$ for all beams and columns, results in over three-fold errors of the estimated peak IDRs.
2. In terms of the incipient IM causing the building collapse, the near-fault ground motion TCU052 clearly poses more severe threats on the 3-story building than the far-field ground motion CHY047.
3. Among the three examined ground motions, CHY063 is the most devastating for the building.

Conclusions

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4. The 'structural resurrection' accompanies the decrease of the story shears; and signal a significant transition of the point in time when the peak displacement of the numerical model occurs.
5. Using the tangent slope of an IDA curve equal to 20% of its initial slope as the indicator of building collapse appears appropriate for the examined ground shaking cases.
6. Under near-fault ground shaking, the characteristic of one two-side spike was observed in the disp. response histories of the collapsed building.

Thank you for your attention!