ASCE 41 versus TEASPA*:

Comparison of Seismic Evaluation Results of RC Frame Buildings Damaged during 2016 Meinong Earthquake, Taiwan

*Taiwan Earthquake Assessment for Structures by Pushover Analysis

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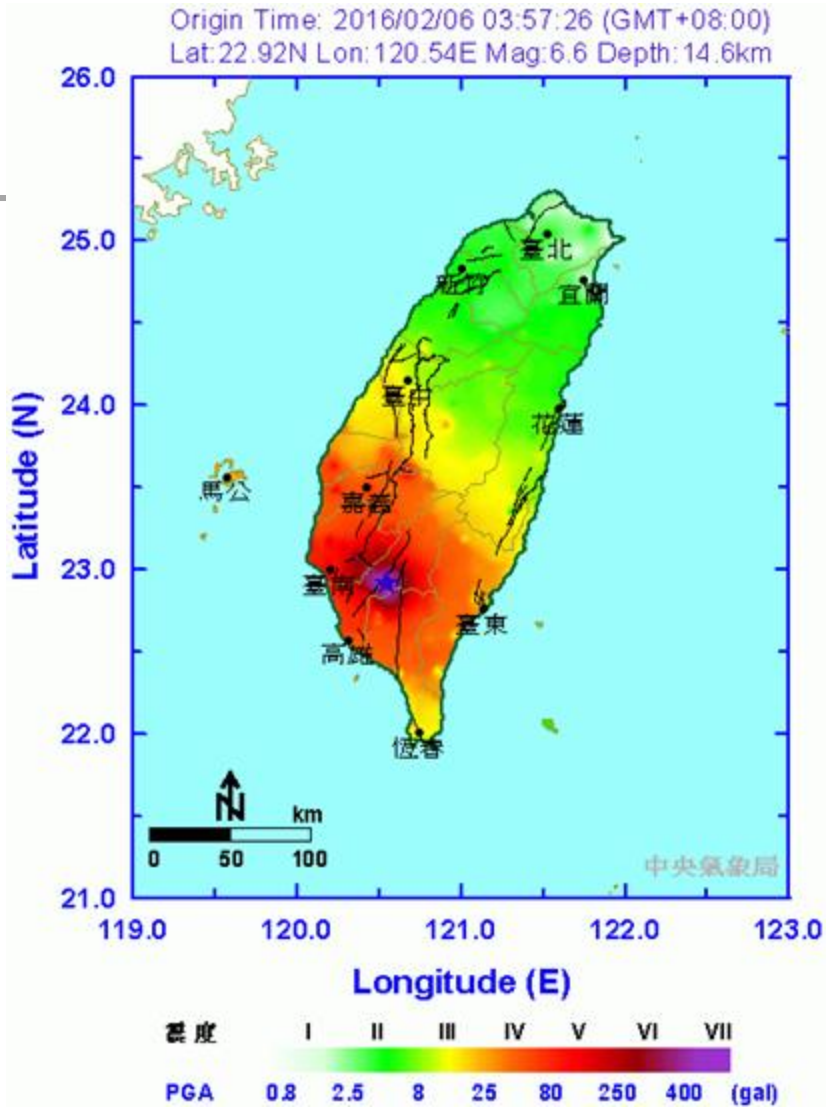
2016 Meinong Earthquake

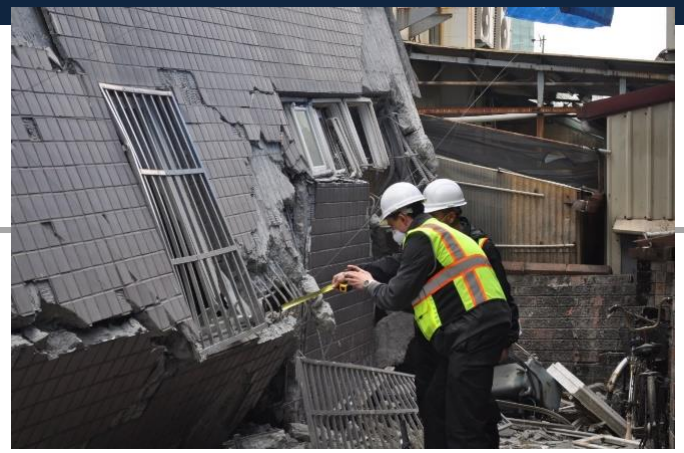
Date and Time	2016/02/06 03:57:26 (UTC+8)
Magnitude (M_L)	6.6
Deaths	117
Injuries	551
Buildings Damaged	Completely Collapse: more than 11 Red Tagged: 288 Yellow Tagged: 328

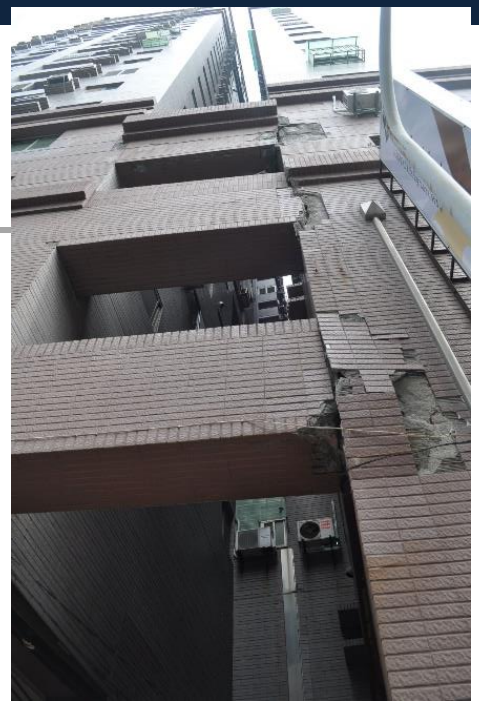
(sources: CWB; Central Emergency Operation Center; NCDR; Construction and Planning Agency, Ministry of the Interior, Taiwan)

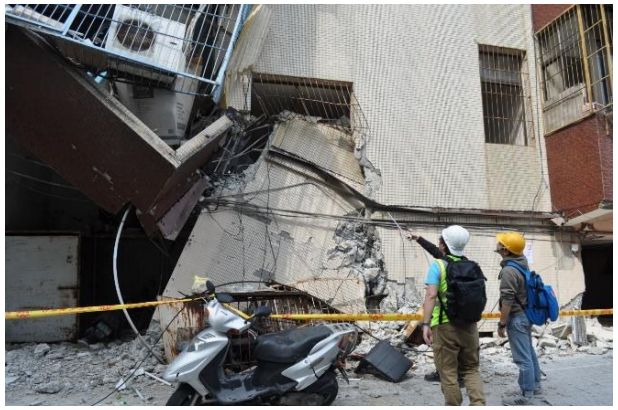


$$1\,gal = 1\,cm/\sec^2 \approx 0.001\,gravity$$

Building Damage

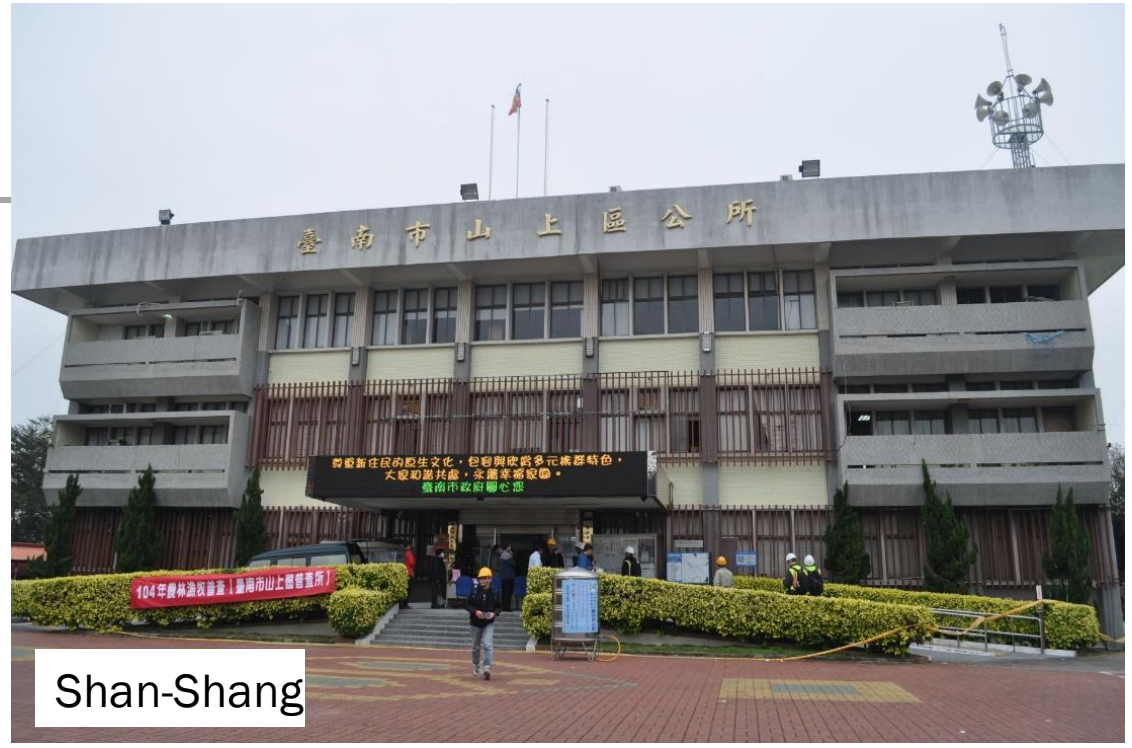






District Office Buildings


Juo-Jhen



Shan-Shang

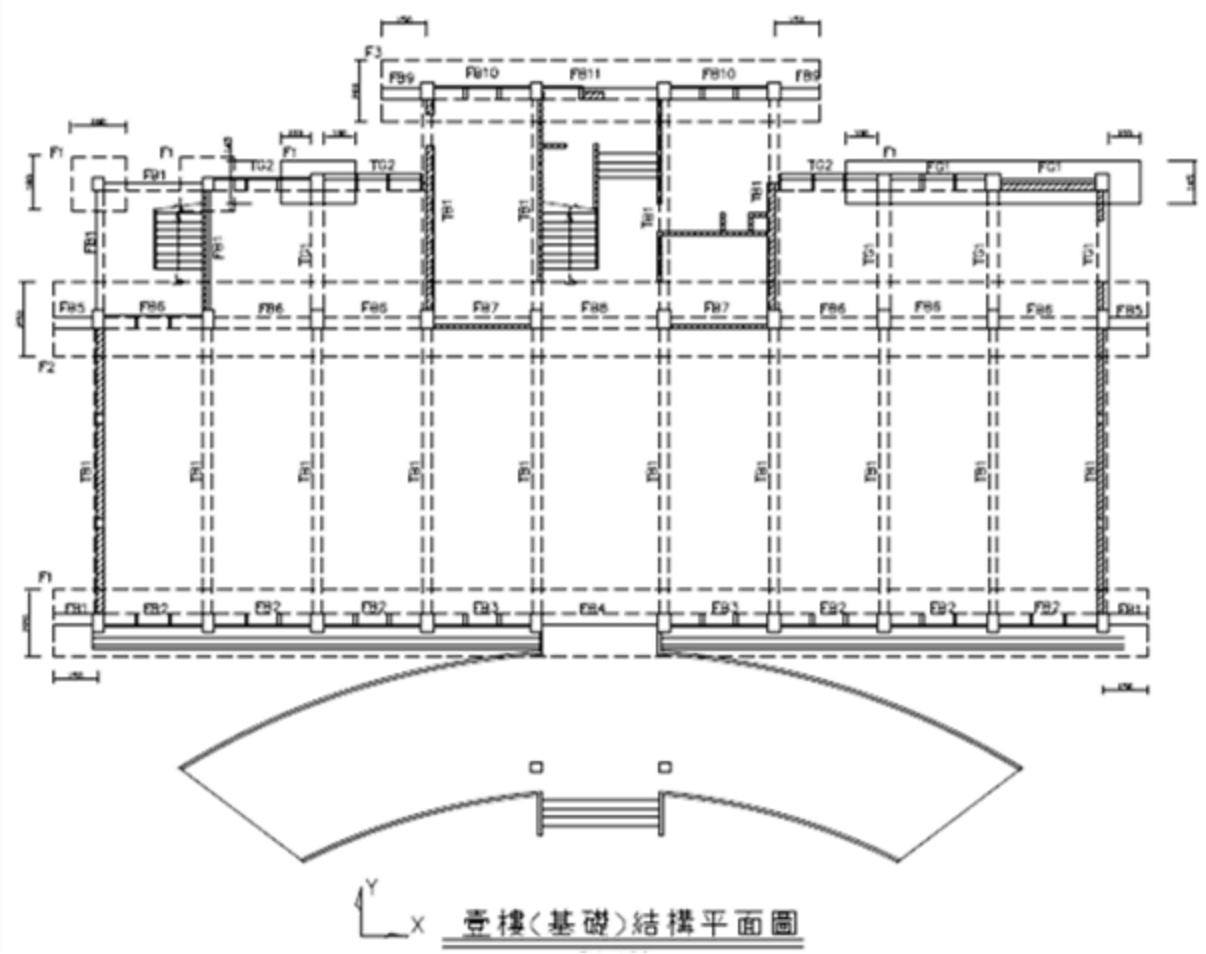

Guei-Ren

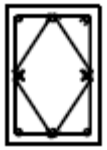
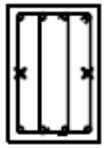
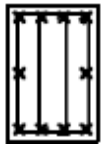
Basic Building Information

District Office Name	Year of Construction /Modification Phase(s)	Building Dimension (Long. × Trans.)	Nominal Material Properties	Observed Structural Performance Level per ASCE 41	Status in 2018
Juo-Jhen	1974/ 1984/ 1998	108.3 ft × 57.4 ft	f_c' = 3,000 psi (RC) f_y = 40 ksi (Reinforcement)	Between Life Safety (LS) and Collapse Prevention (CP)	Retrofitted
Shan-Shang*	1984	108.3 ft × 57.4 ft		Between LS and CP	Demolished
Guei-Ren	1974/ 1988/ 2012**	131.2 ft × 57.4 ft		Immediate Occupancy (IO)	In Use

*This building has a partial basement
**Seismic upgrade

Typical Floor Plan and Column Details

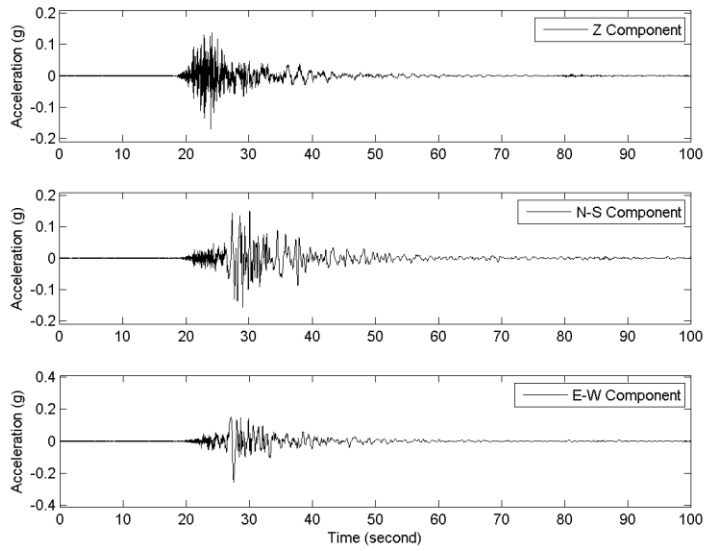


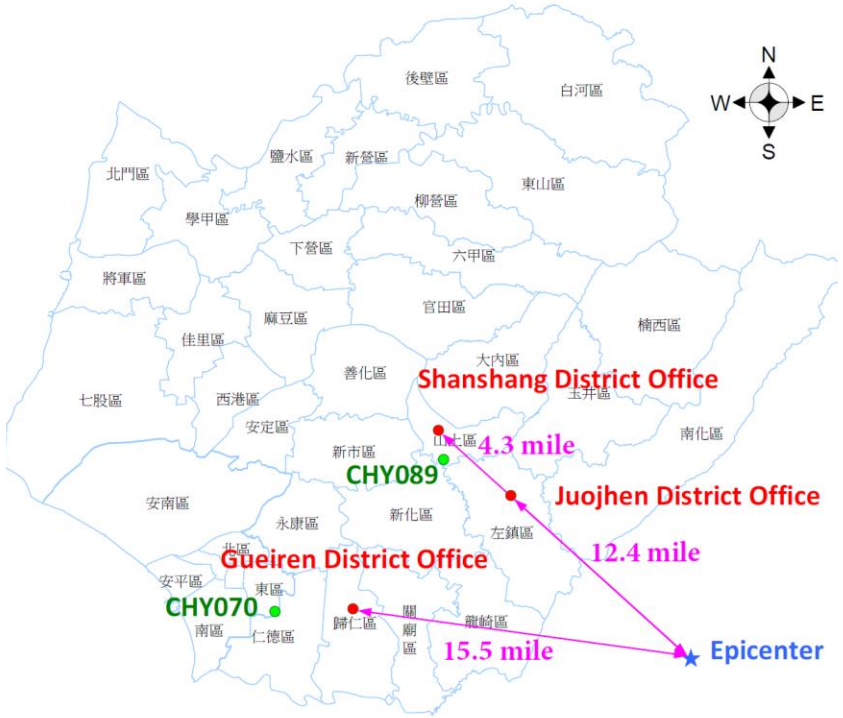
Column Type	C1	C2, C3	C4, C5	C6, C7
Longitudinal Bars				
3F	6-#7 + 2-#6	8-#7 + 2-#6	10-#6	8-#6
2F	6-#7 + 2-#6	8-#7 + 2-#6	4-#7 + 6-#6	
1F	4-#8 + 4-#7	4-#8 + 6-#7	4-#8 + 6-#6	
Tie Bars	#3 @4”~10”	#3 @6”,10”, 6”		#3 @4”~10”
Size	15.7 in × 23.6 in			15.7 in × 19.7 in

1st Floor Plan
(Juo-Jhen District Office Building; source: NCREE)

Ground Motion Records and Seismic Demands

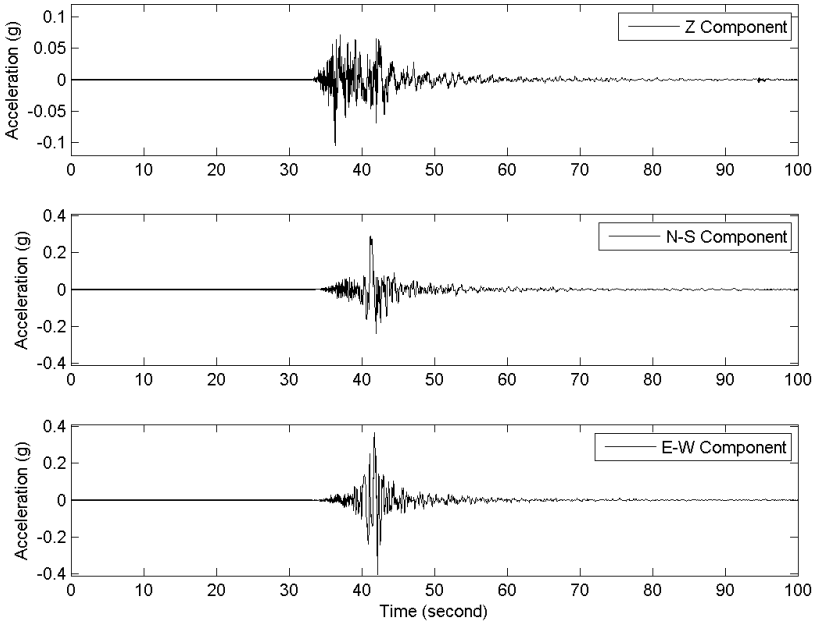
CHY070, Measured PGA:
0.25g(EW), 0.15g(NS), 0.17g(Z)



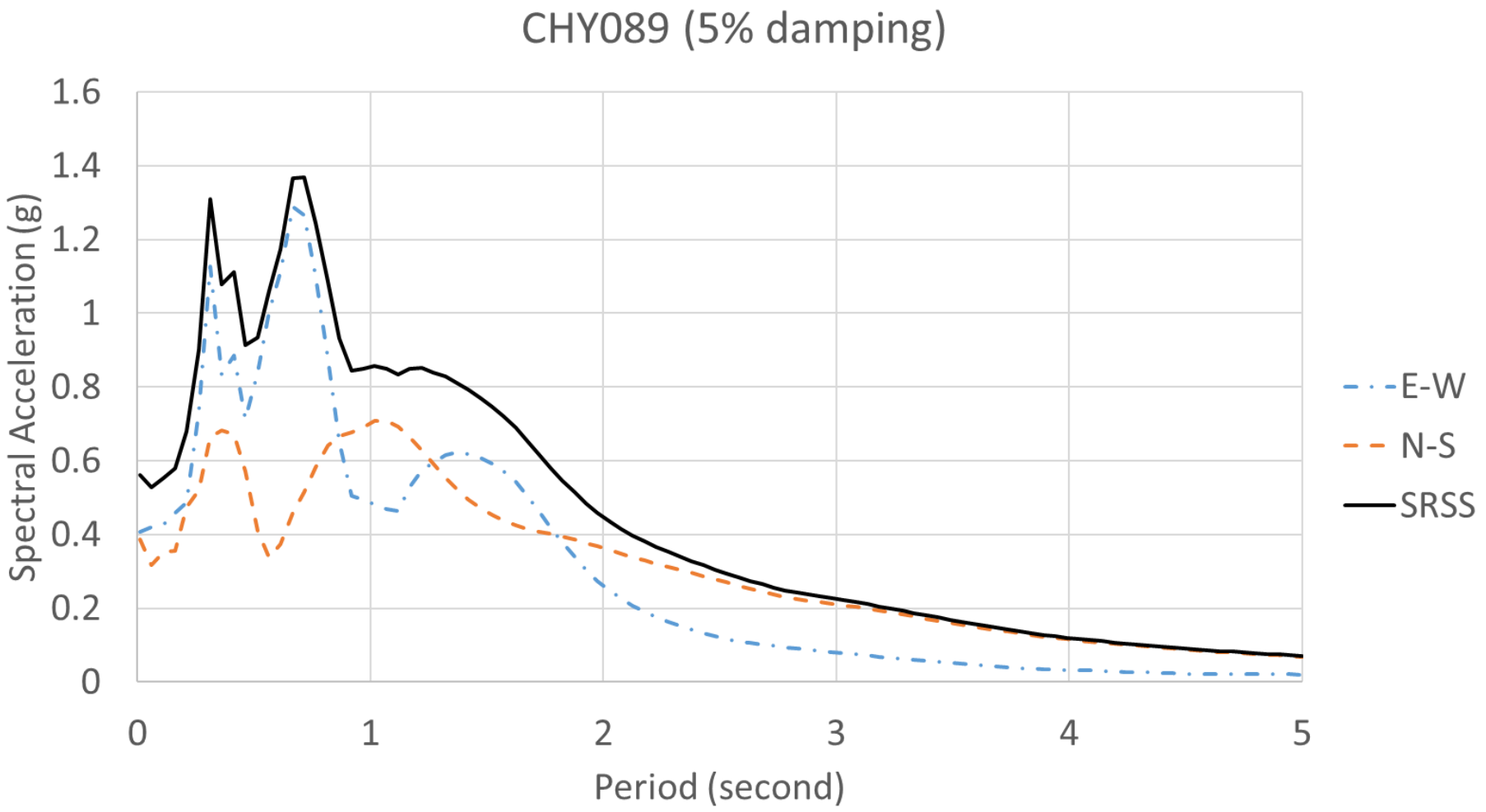


(source: NCREE)

CHY089, Measured PGA:
0.40g(EW), 0.28g(NS), 0.10g(Z)



Response Spectrum (CHY089)



Analysis Summary (ASCE 41, LDP)

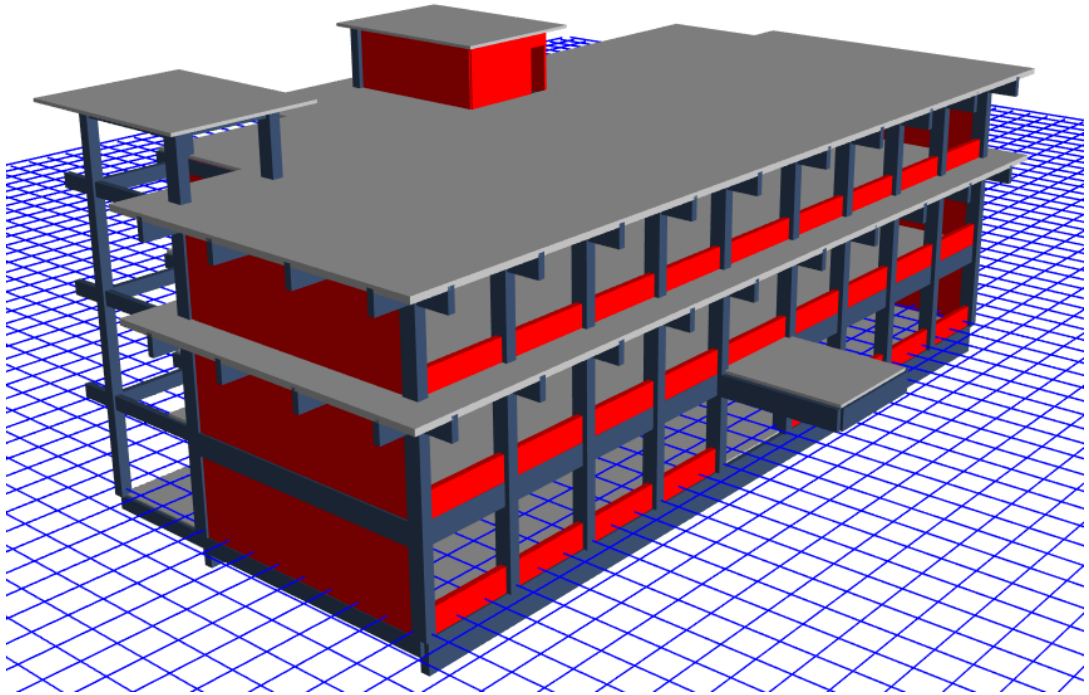
District Office Building	Build Weight (kip)	Periods (second) (Modes 1, 2 and 3)	Spectral Acceleration (g)	LDP in Longitudinal Direction (X-dir.)			
				Base Shear (kip)	Roof Displacement (in.), (Roof Drift)	Max. Column Shear DCR (LS) (Unless Noted Otherwise)	Max. Column Shear DCR (CP)
Juo-Jhen	3,752	0.58, 0.19, 0.19	1.06	3,717	4.31 (1.0%)	2.90	2.74
Shan-Shang	3,100	0.53, 0.19, 0.18	0.93	2,701	3.32 (0.8%)	2.33	2.21
Guei-Ren (retrofitted)	3,667	0.22, 0.21, 0.15	0.68	1,992	0.42 (0.1%)	0.67 (LS) 0.74 (IO)	-

Analysis Summary (ASCE 41, NSP)

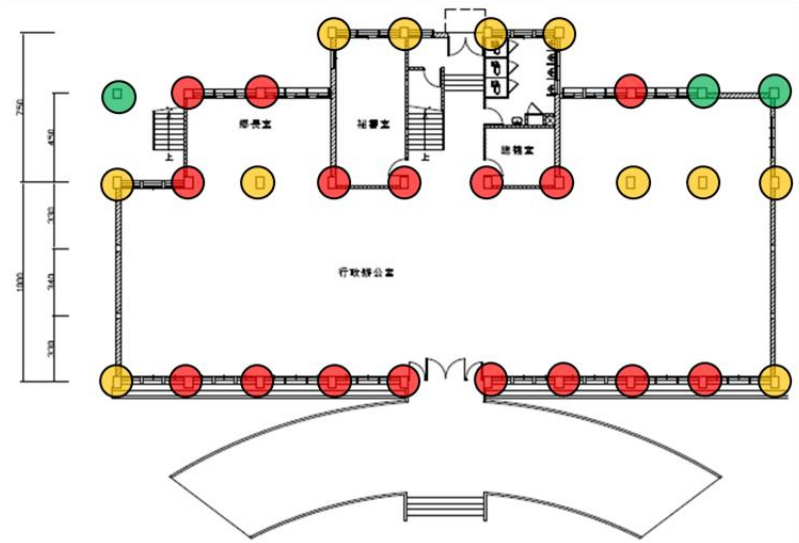
District Office Building	Build Weight (kip) and Height (ft)	NSP in Longitudinal Direction (X-dir.)						
		Effective Periods (second)	Spectral Accel.(g)	ASCE 41 Yield Displacement (in.) and Roof Drift Ratio (%)	Peak Base Shear (kip)	Target Displacement (in.) and Roof Drift Ratio (%) (1)	Displacement where First LS Column Hinge Occurred(in.) (2)	DCR (1)/(2)
Juo-Jhen	3,752 36.4	0.58	1.06	2.10 (0.5%)	2,464	4.39 (1.0%)	3.40	1.29 (LS)
Shan-Shang	3,100 36.4	0.54	0.93	1.87 (0.4%)	2,025	3.33 (0.8*)	3.13	1.05 (LS)
Guei-Ren (retrofitted)	3,667 36.4	0.23	0.68	N.A.*	N.A.*	0.36 (0.08)	1.89	0.19 (LS)

*The building model remains essentially elastic at target roof displacement

Juo-Jhen District Office Building

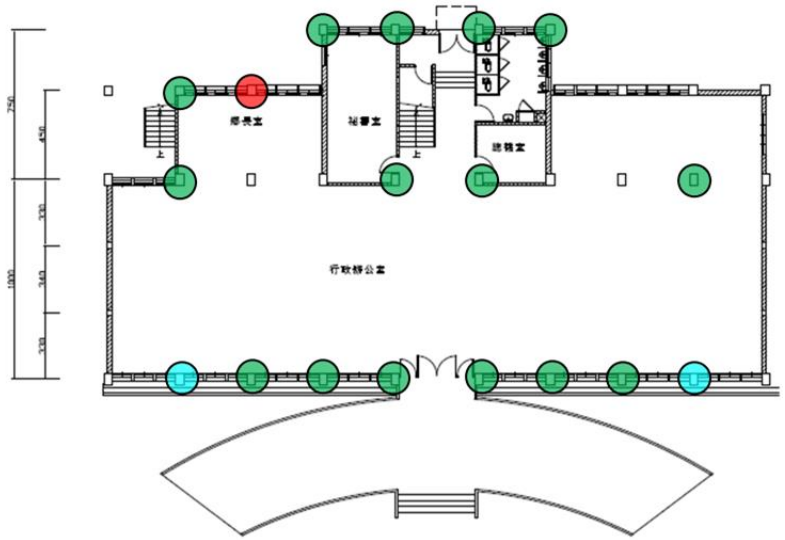


Column Evaluation Results vs Actual Damage Observed (Jho-Jhen District Office)



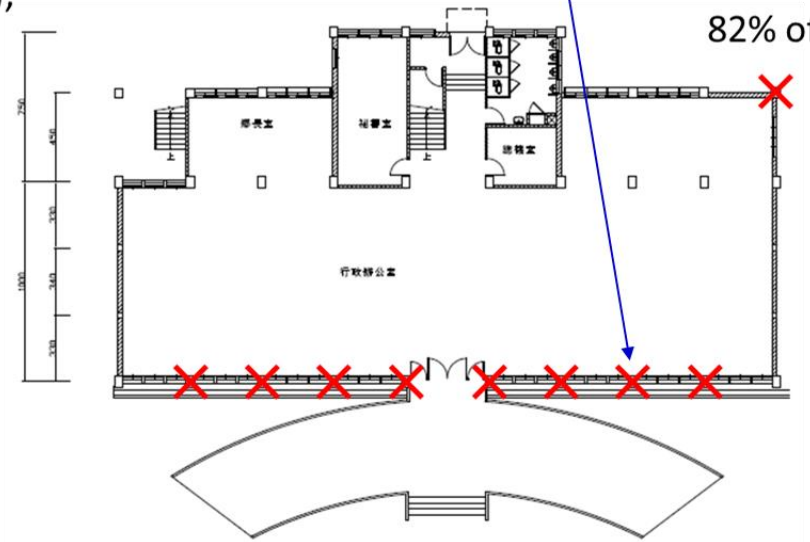
LDP, column shear DCRs (1st floor),
LS performance level

- DCR < 1.0
- 1.0 ≤ DCR ≤ 2.0
- DCR > 2.0



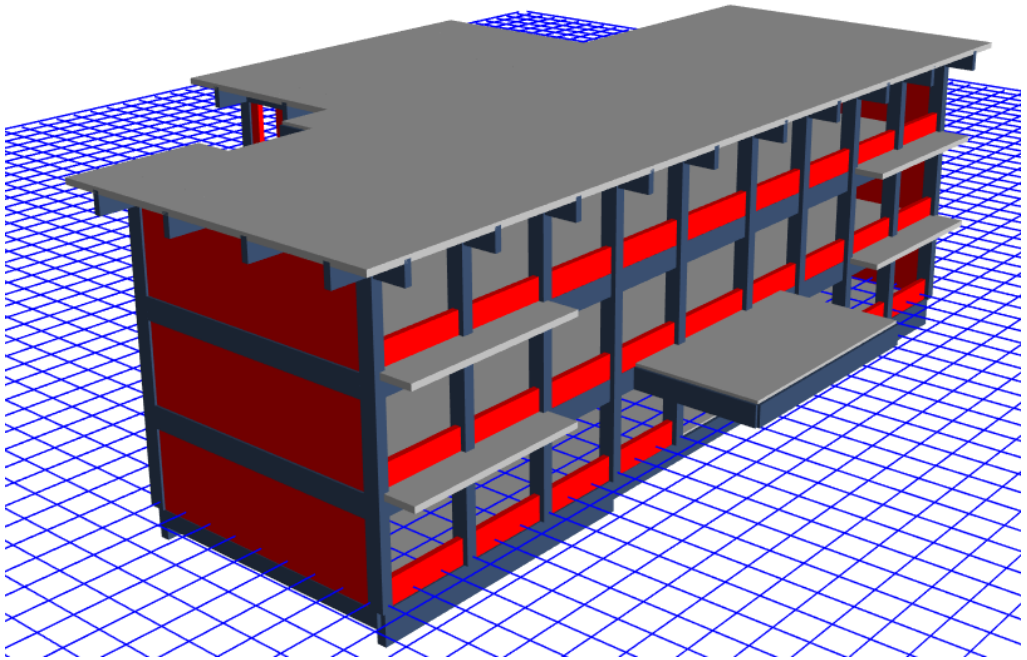
NSP, column hinge distribution (1st floor),
82% of target roof displacement

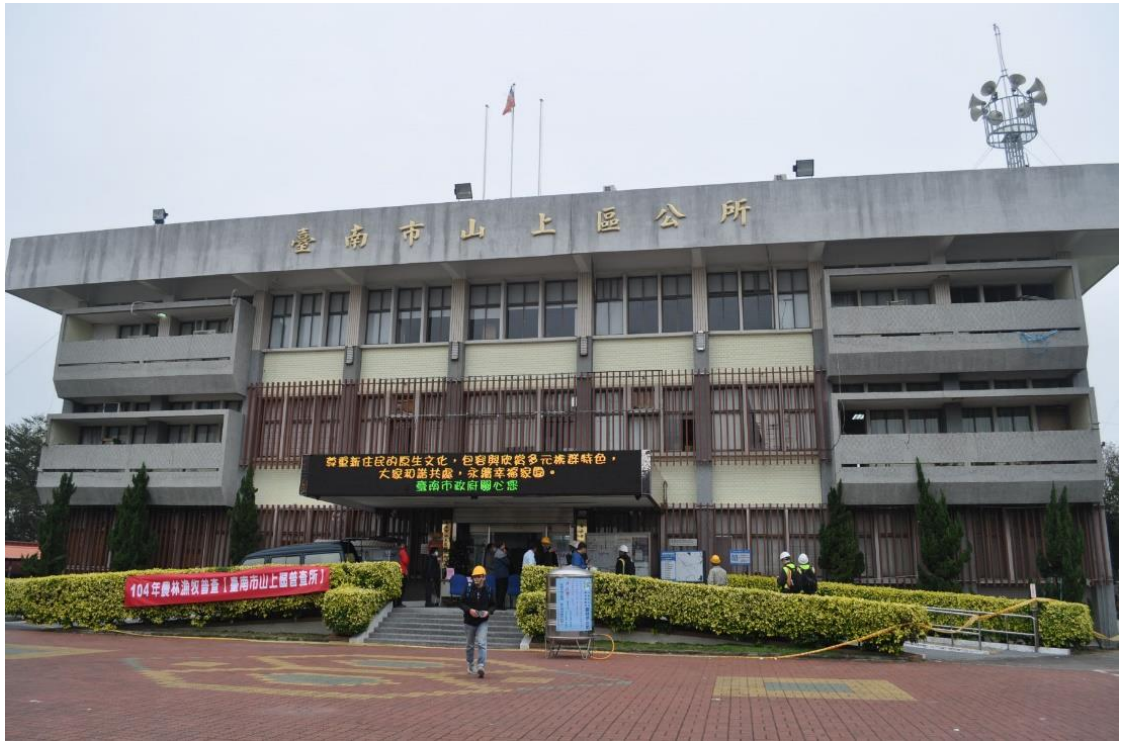
- IO ~ LS
- LS ~ CP
- > CP



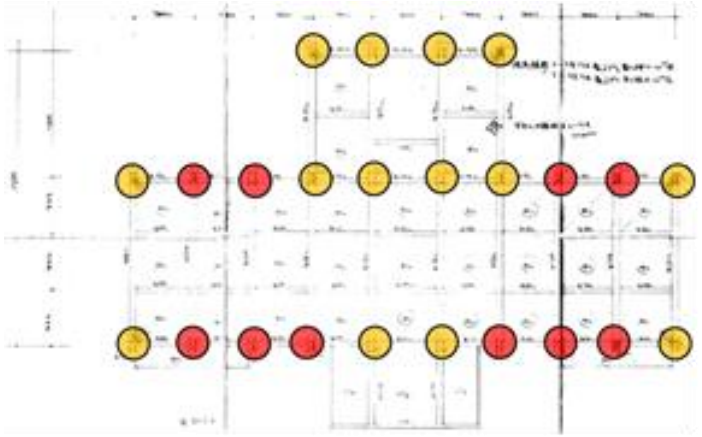
Observed Column Damage during Meinong Earthquake

Shan-Shang District Office Building



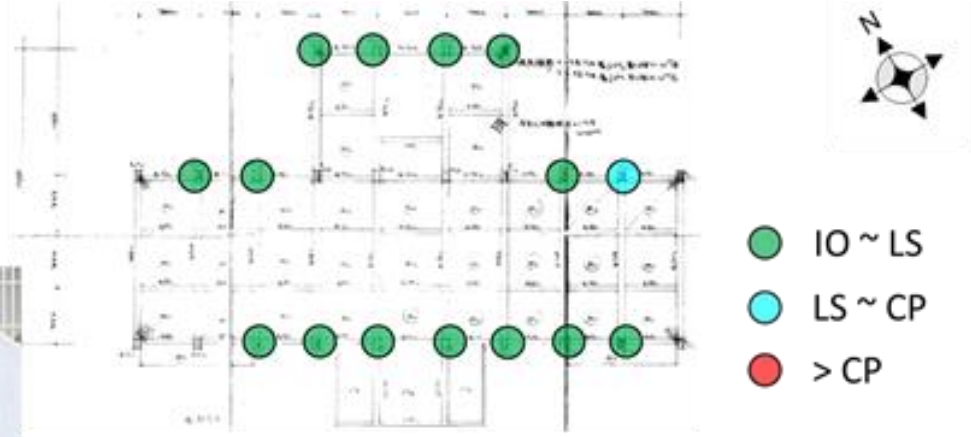


Column Evaluation Results vs Actual Damage Observed (Shan-Shang District Office)



LDP, column shear DCRs (1st floor), LS performance level

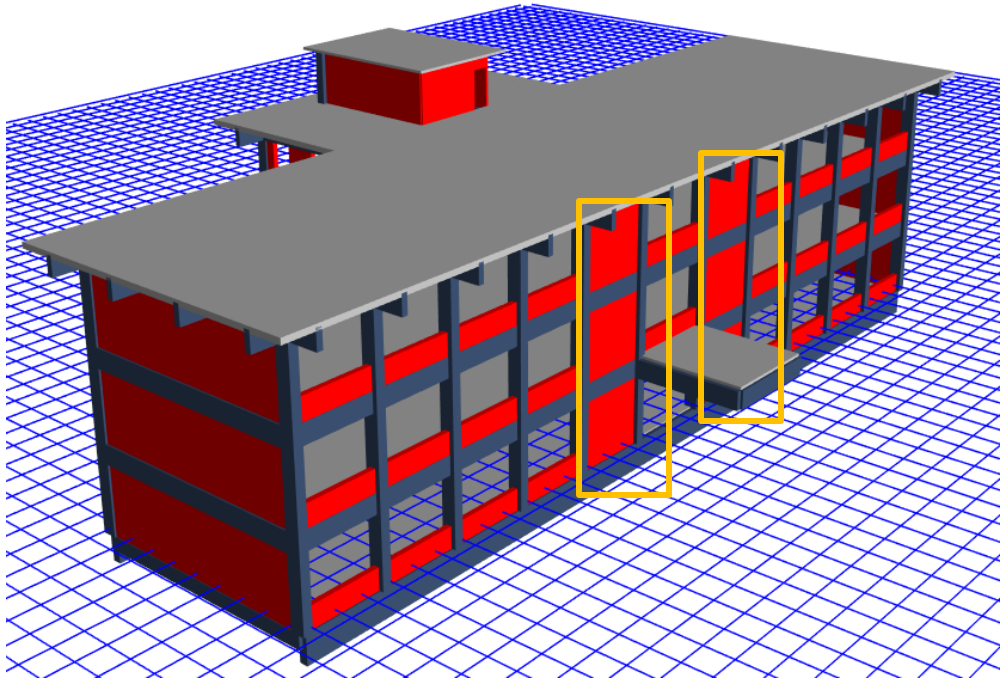
- DCR < 1.0
- 1.0 ≤ DCR ≤ 2.0
- DCR > 2.0



NSP, column hinge distribution (1st floor), 100% of target roof displacement

Observed Column Damage during Meinong Earthquake

Guei-Ren District Office Building (Retrofitted)



ASCE 41-13 LDP

DCR = 0.67 (LS)

DCR = 0.74 (IO)

ASCE 41-13 NSP

DCR = 0.19 (LS)

Taiwan Earthquake Assessment for Structures by Pushover Analysis (TEASPA)

- ATC 40 based approach (capacity spectrum method)
- Performance point (for school buildings) is selected as one of the following points on the capacity curve:
  - Peak base shear
  - 2% roof drift
  - Failure of gravity load carrying components
- Focusing on global building performance

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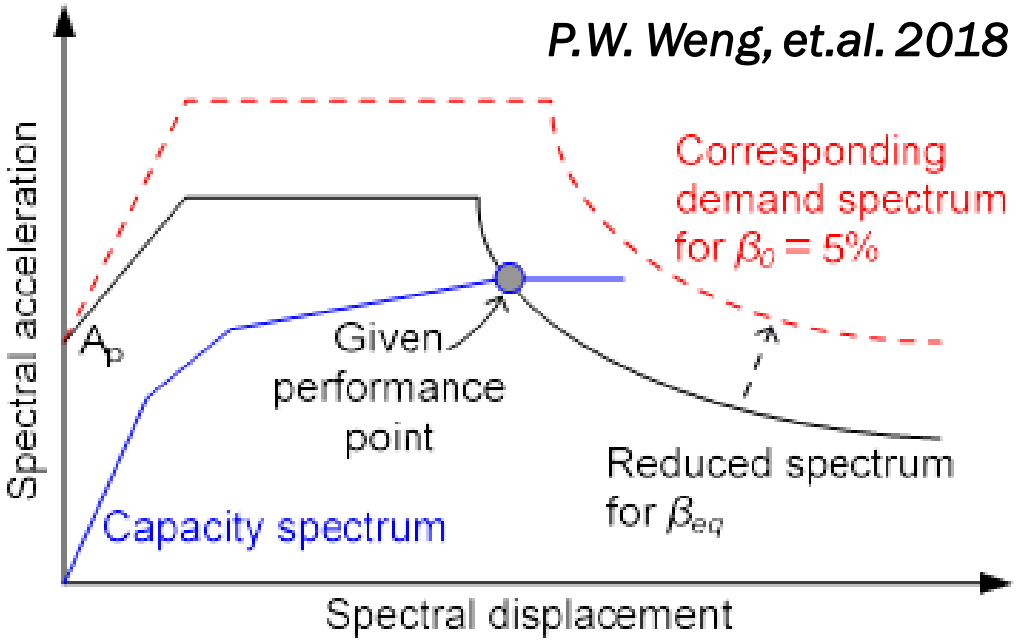
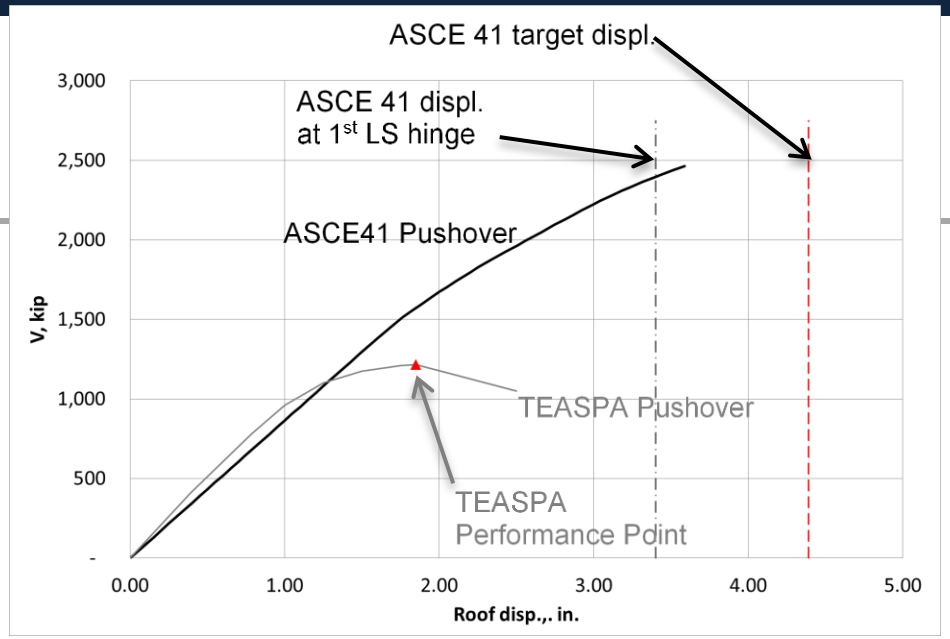


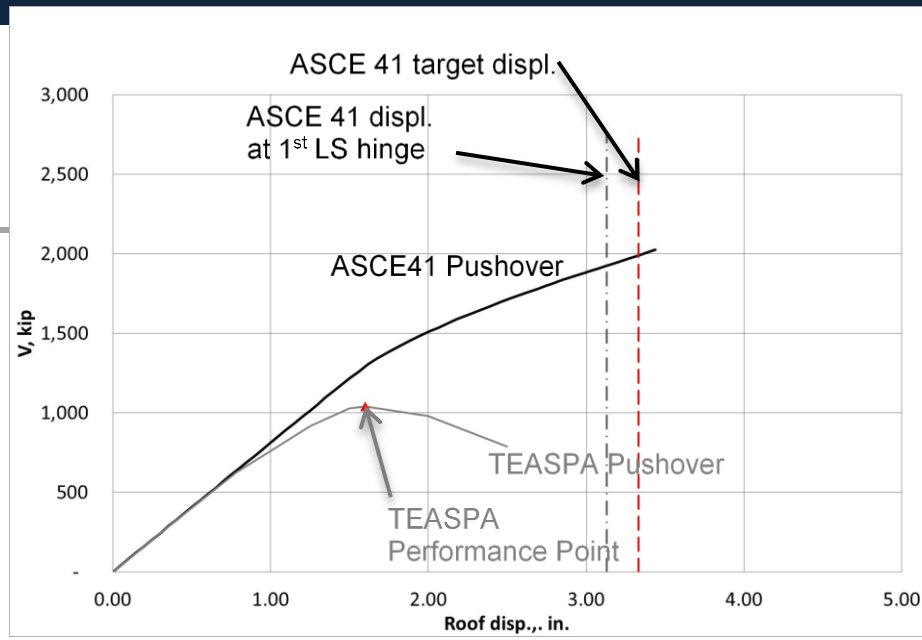
Shan-Shang District Office Building	X direction
Base Shear (tonf)	462
Roof Displacement (cm)	4.05
Seismic Capacity A_p (g)	0.26
Ground Motion Record A_{EQ} (g)	0.40
Capacity-Demand Ratio (CDR)	0.66 (DCR= 1.52)

Retrofit required

ASCE 41 vs. TEASPA

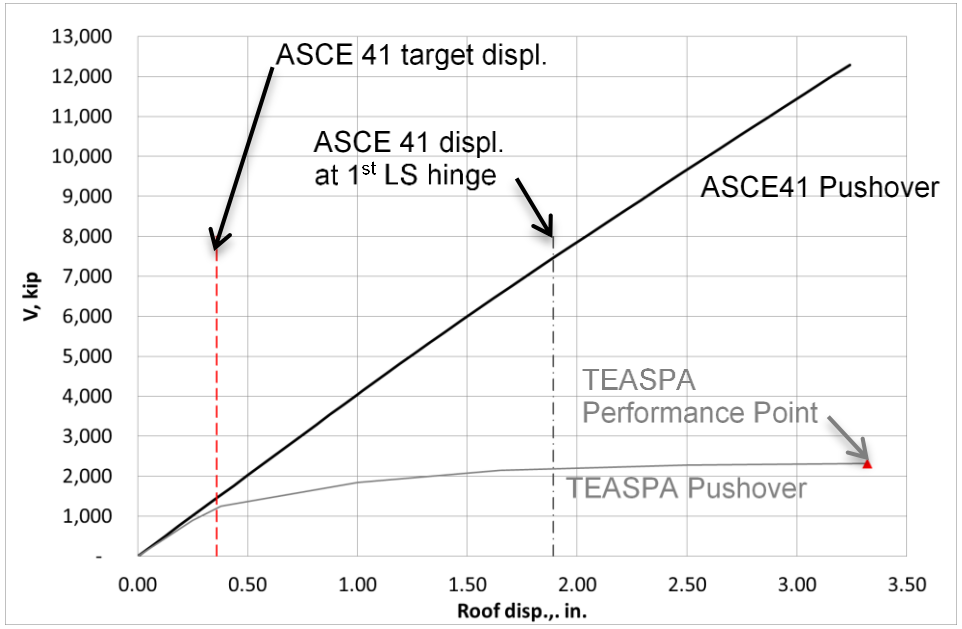


Jho-Jhen



Shan-Shang

District Office Building	TEASPA DCR	ASCE 41 Life Safety NSP DCR
Juo-Jhen	1.54	1.29
Shan-Shang	1.52	1.05
Guei-Ren (retrofitted)	0.40	0.19



Guei-Ren (Retrofitted)

Main Findings

1) ASCE 41 LDP conservatively identified the over-stressed columns
2) ASCE 41 NSP captured the global performance relatively well for all three buildings
3) LDP generally predicted higher DCRs compared to NSP
4) Both ASCE 41 and TEASPA provided reasonable estimations of building performance
5) Significant differences in the calculated strength and deformation capacity from ASCE 41 NSP and TEASPA

Questions?