CFSRC summer symposium

Test Protocol Development and Adaptive Motion Scaling Strategies for Shake Table Testing

Xiang Wang and Amanpreet Singh, UC San Diego

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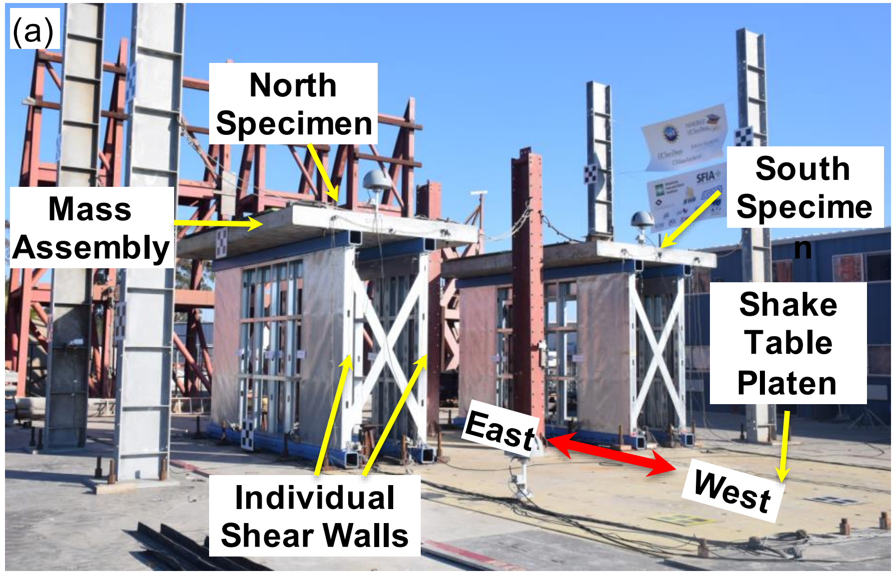
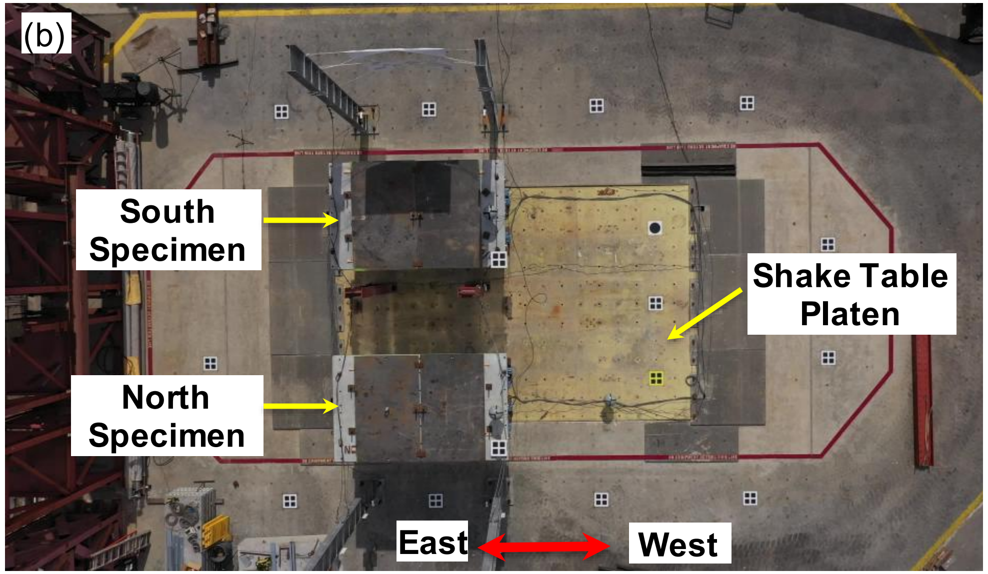
Cold-formed Steel Wall Test Program

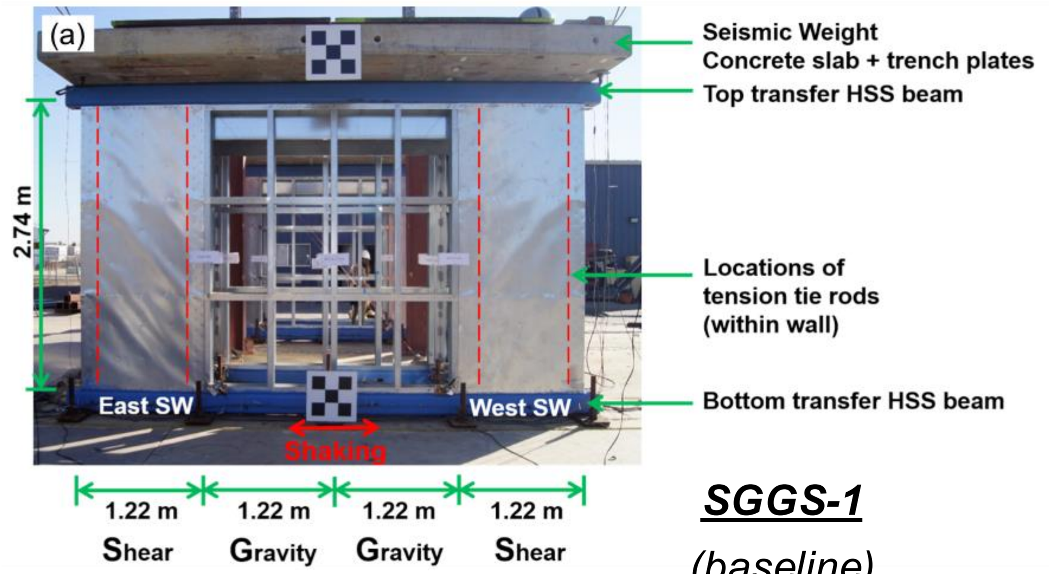
- Shake table testing of eight single-story CFS shear wall assemblies (Fall 2018)
  - disparate lateral force-displacement behavior (due to the differences in installation details)
  - eight test assemblies were tested in four test sequences (two assemblies in each test sequence)
- ***Objective*** for the proposed test protocol**: specimens with different lateral behavior achieve comparable performance targets (damage states) by adjusting motion scale factors to an identical set of seed motions**
  - lateral force-displacement behavior characterization
  - pre-test numerical simulation for motion scale factor determination



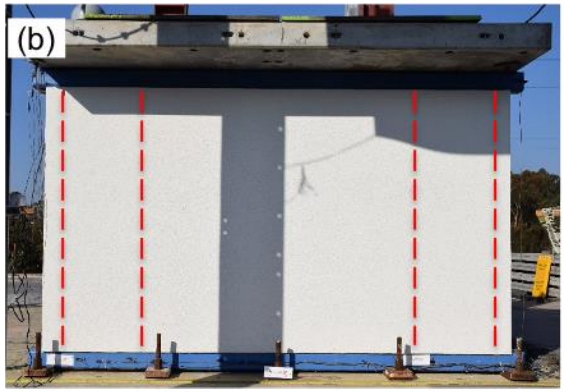


CFS Shear Wall Test Matrix

Test Series	Specimen name	Configuration details	Lateral strength group
1	**SGGS-1 (baseline)**	Symmetric and unfinished, Type I	Baseline
	SGGS-1XS	Symmetric and unfinished, Type I (fastener pattern differed from the baseline specimen)	Baseline
2	**SGGS-1F**	Symmetric and finished, Type I (Type-X gypsum panels attached to wall framing)	Upper-bound
	SGGS-1SB	Symmetric and finished, Type I (composite steel-gypsum panels attached to wall framing)	Upper-bound
3	SGGS-2	Symmetric and unfinished, Type II	Lower-bound
	SGGG-1	Non-symmetric and unfinished, Type I	Lower-bound
4	SWWS-1	Symmetric and unfinished with window opening, Type I	Baseline
	SWWS-2	Symmetric and unfinished with window opening, Type II	Lower-bound



SGGS-1
(baseline)



SGGS-1F
(upper-bound)

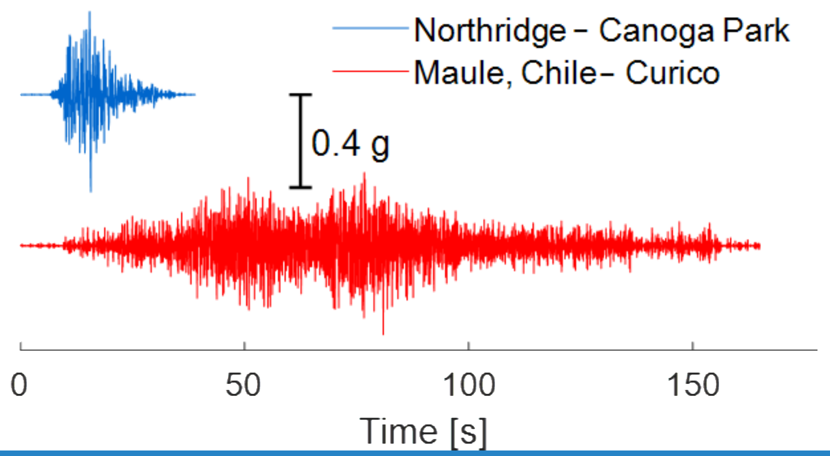
SGGG-1
(lower-bound)

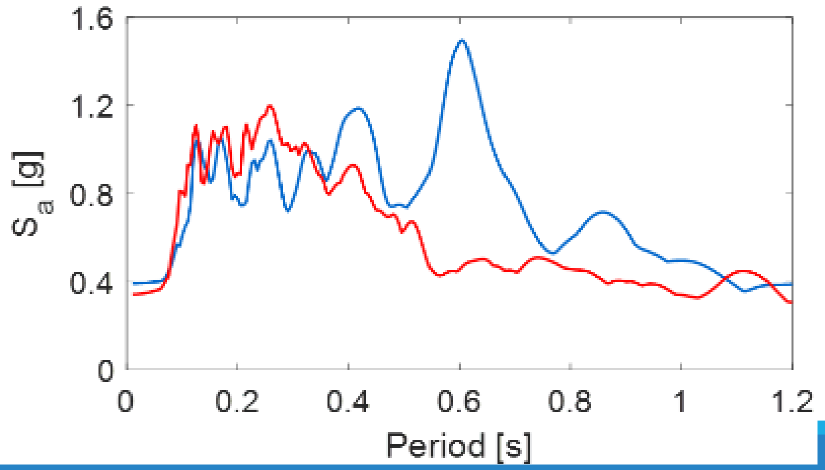
Performance Target Matrix & Seed Motions

- Four different performance target levels (with increasing motion intensity)

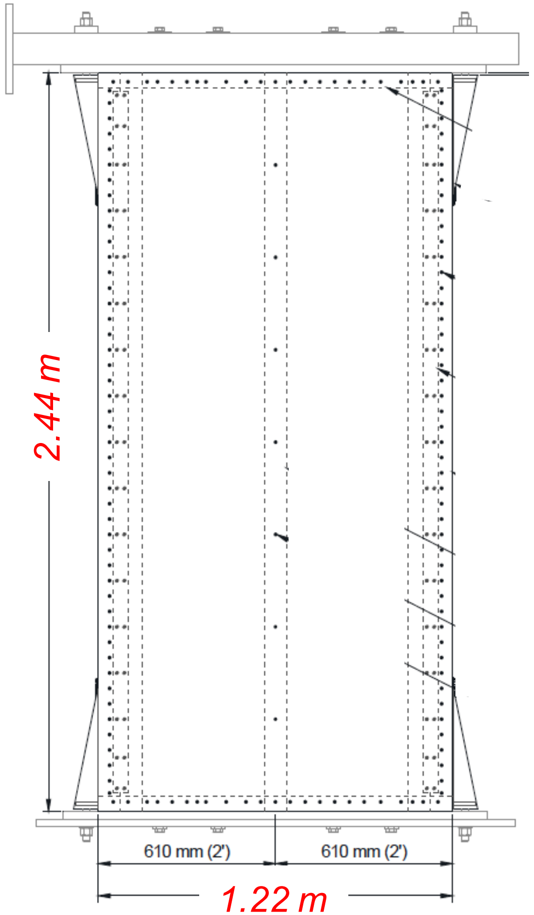
Performance level	Response characteristics	Target force (normalized)	Target drift (normalized)	Damage
Elastic	Linear	20% – 40%	~20%	Minimal damage
Quasi-elastic	Essentially linear	60%~70%	30% – 40%	Minor (cosmetic) damage
Design	Nonlinear	Near peak strength (> 90%)	75% – 95%	Moderate (repairable) damage
Above-design (optional)	Salient pinching	Strength deterioration by >20%	>125%	Continued damage, structural integrity not severely jeopardized

- Two seed motion records (Canoga Park & Curico)

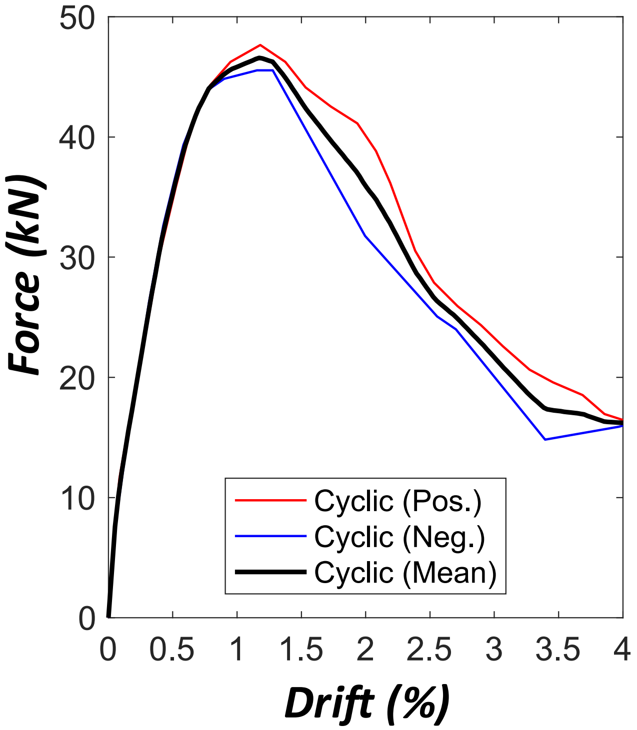




Lateral Force-Displacement Characterization

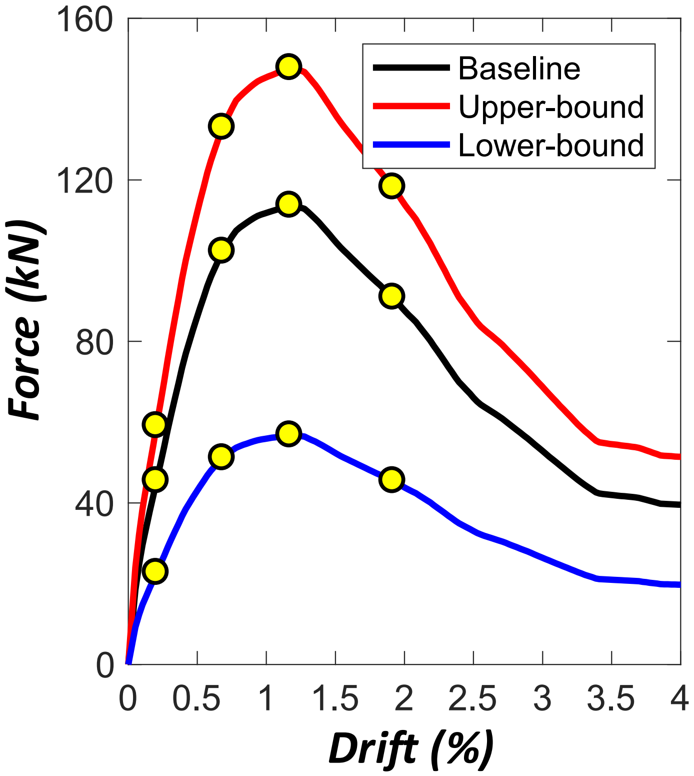


Prototype Specimen (Rizk and Rogers, 2017)



Envelope Response: Prototype Specimen

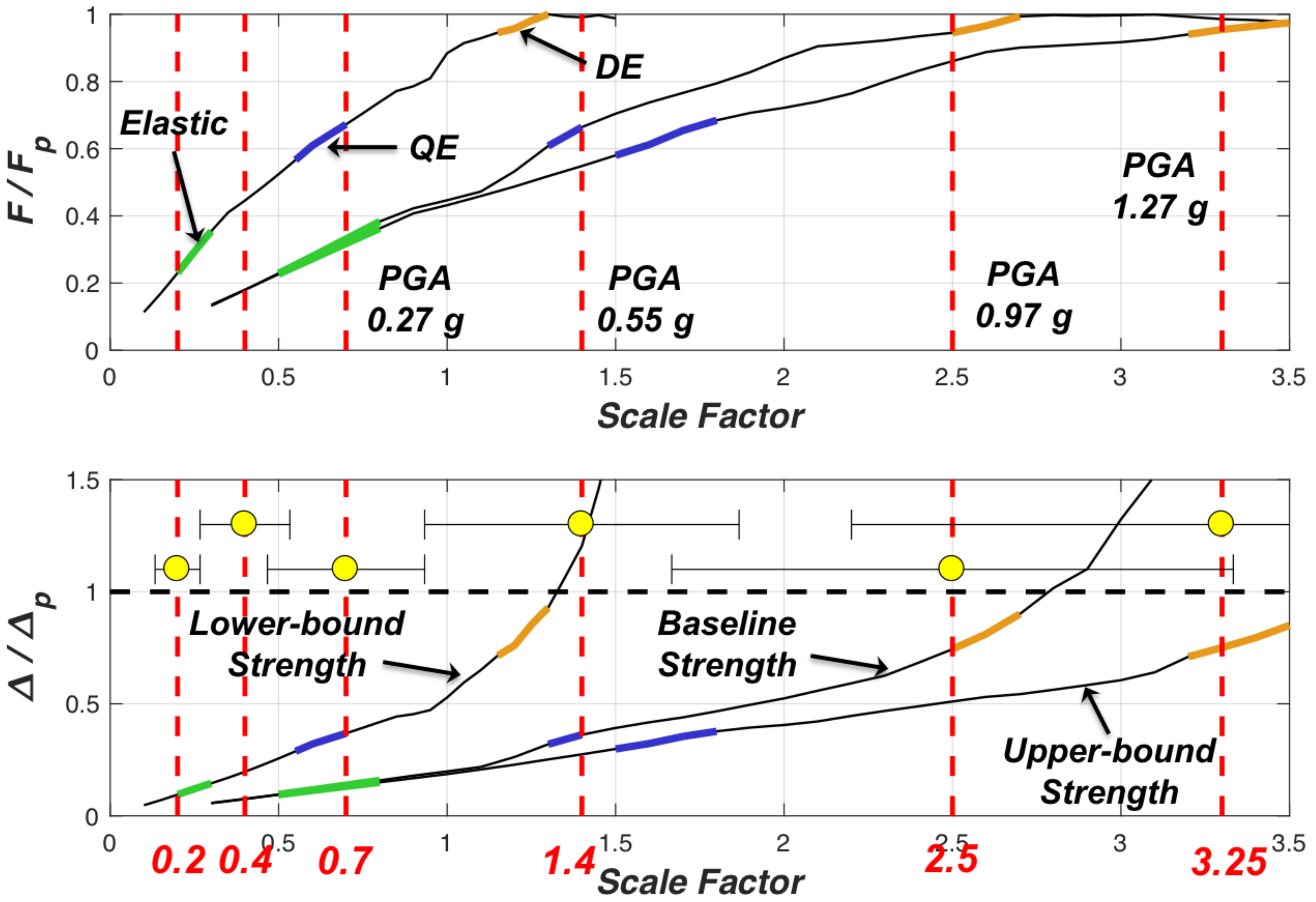
Strength Scaling by Wall Length



Envelope Responses: Representative Wall Specimens

Incremental Dynamic Analysis

- Shear wall test assemblies modeled as ***SDOF*** systems with ***Pinching4*** material in OpenSees
- Envelope (backbone) response defined per McGill test results and lateral strength group
- Hysteretic parameters adopted those suggested by Shamin & Rogers (2013)
- ***5% damping*** considered in dynamic analysis



Test-date Motion Adjustment Procedure

Step 1: Choose an intended performance level and determine the target scale factor SF_{target} based on the seed motion scaling curves

Step 2: Calculate the performance adjustment coefficient SF_1 based on target scale factor SF_{target} and the specific OLI motion training scale factor SF_{OLI} (one of the six pre-selected seed motion scale factors ranging from 0.2 to 3.25):

$$SF_1 = SF_{target} / SF_{OLI} \quad (1)$$

Step 3: Calculate the motion spectra adjustment coefficient (SF_2) based on the actual (or estimated) period of the test specimen at different stages during the earthquake test sequence:

$$SF_2 = \tilde{S}_{a,target} / \tilde{S}_{a,OLI} \quad (2)$$

where $\tilde{S}_{a,target}$ and $\tilde{S}_{a,OLI}$ represent the average spectral acceleration of the scaled seed motion and the OLI motion within the period intervals of interest, respectively.

Step 4: Compute the final motion adjustment coefficient SF_{final}:

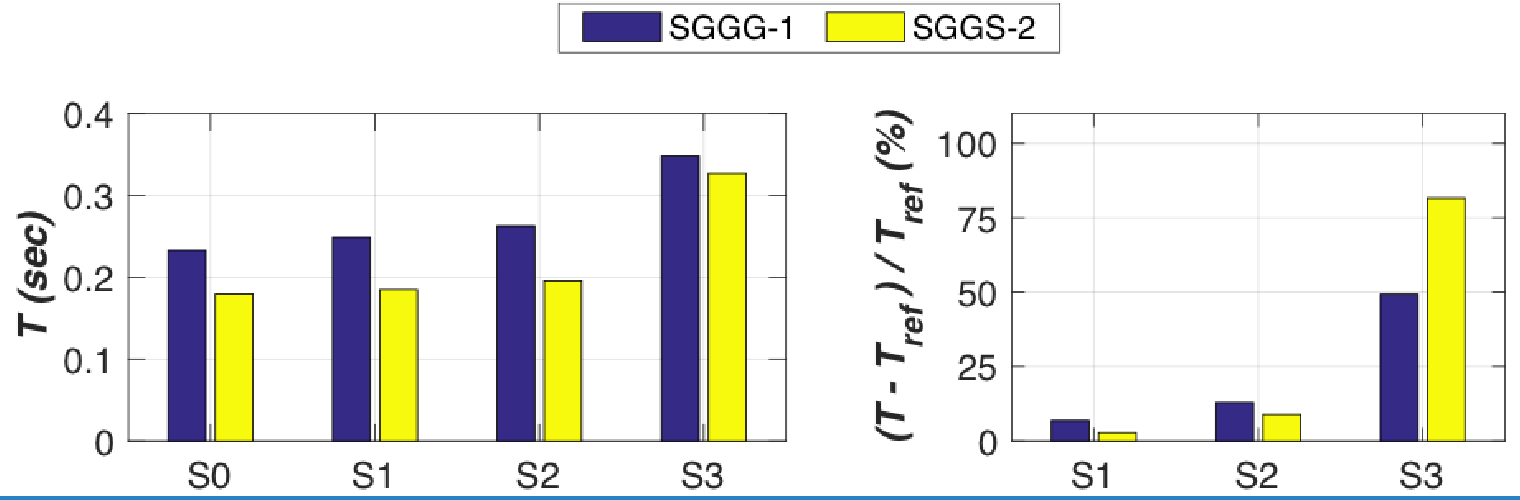
$$SF_{final} = SF_1 \times SF_2 \quad (3)$$

- Consider the discrepancy between ***target*** (commanded) motion and ***achieved*** motion
- Consider the ***dynamic characteristics evolution*** of test specimens during the EQ test sequence

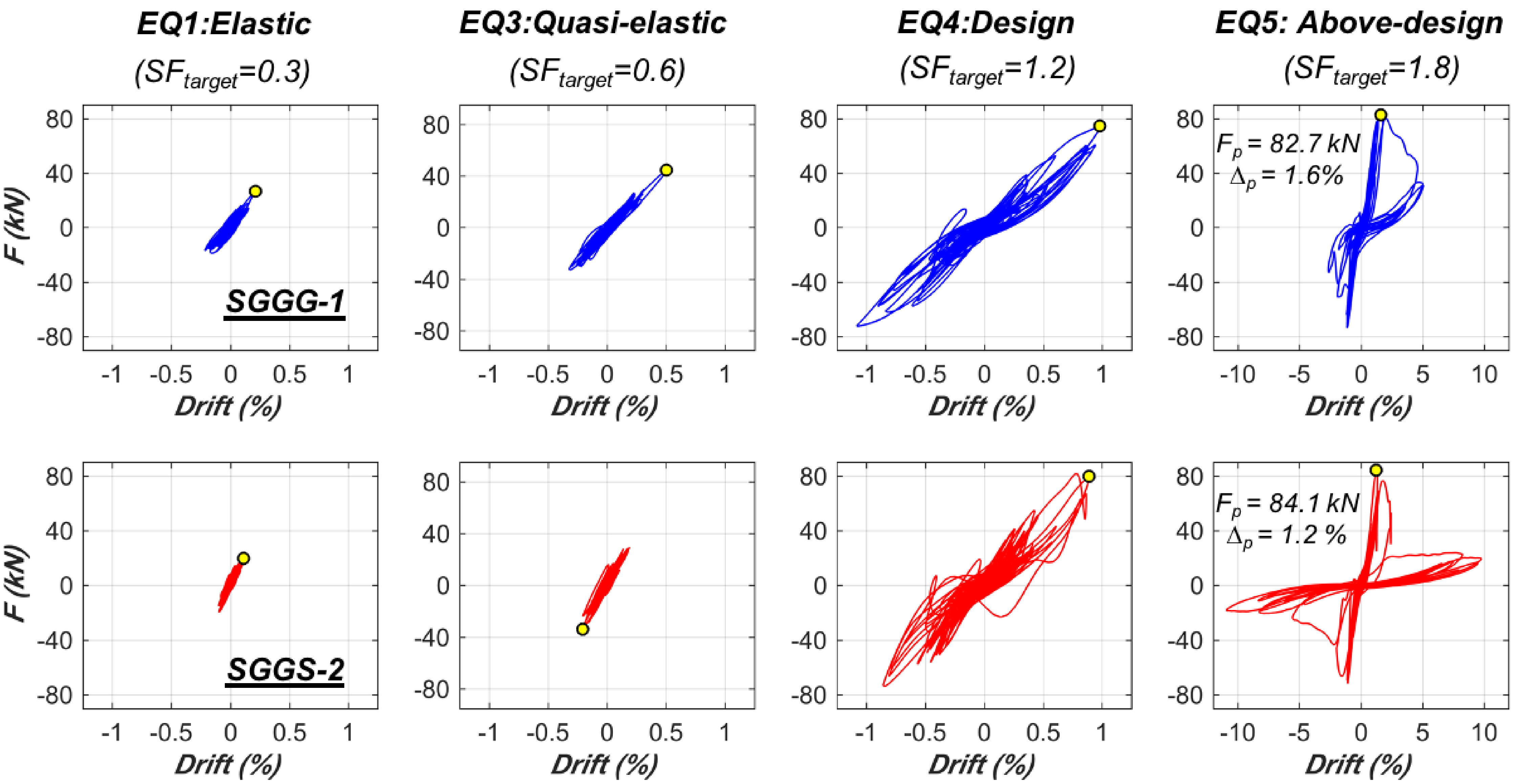
Motion Scaling Strategies Implementation (SGGG-1 & SGGS-2)

Earthquake test	OLI motion	SF_{target}	SF_{OLI}	SF_1	SF_2	SF_{final}	Period interval (sec)	$\tilde{S}_{a,target}$ (g)	$\tilde{S}_{a,OLI}$ (g)
EQ1 Elastic	CNP-196 (40%)	0.3	0.4	0.3/0.4= 0.75	1.17	0.877	0.18 – 0.30	0.346	0.296
EQ2 Elastic	CUR-EW (70%)	0.3	0.7	0.3/0.7= 0.429	1.163	0.498	0.18 – 0.30	0.738	0.635
EQ3 Quasi-elastic	CNP-196 (70%)	0.6	0.7	0.6/0.7= 0.857	1.175	1.007	0.18 – 0.30	0.606	0.516
EQ4 Design	CNP-196 (140%)	1.2	1.4	1.2/1.4= 0.857	1.108	0.95	0.19 – 0.36	1.24	1.12
EQ5 Above-design	CNP-196 (140%)	1.8	1.4	1.8/1.4= 1.286	1.117	1.436	0.31 – 0.48	1.39	1.25

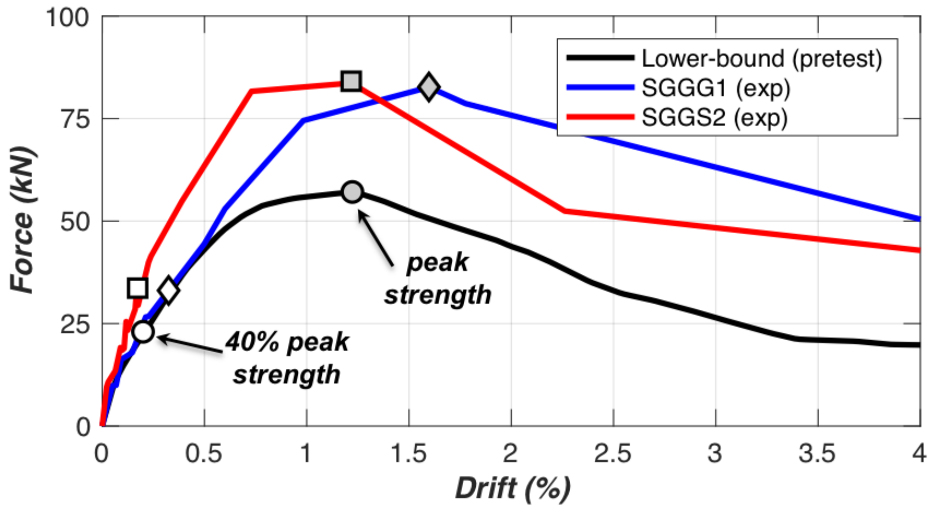
Evolution of the ***dynamic characteristics*** of the test specimens during the test sequence



Achieved Force-Displacement Responses (SGGG-1 & SGGS-2)

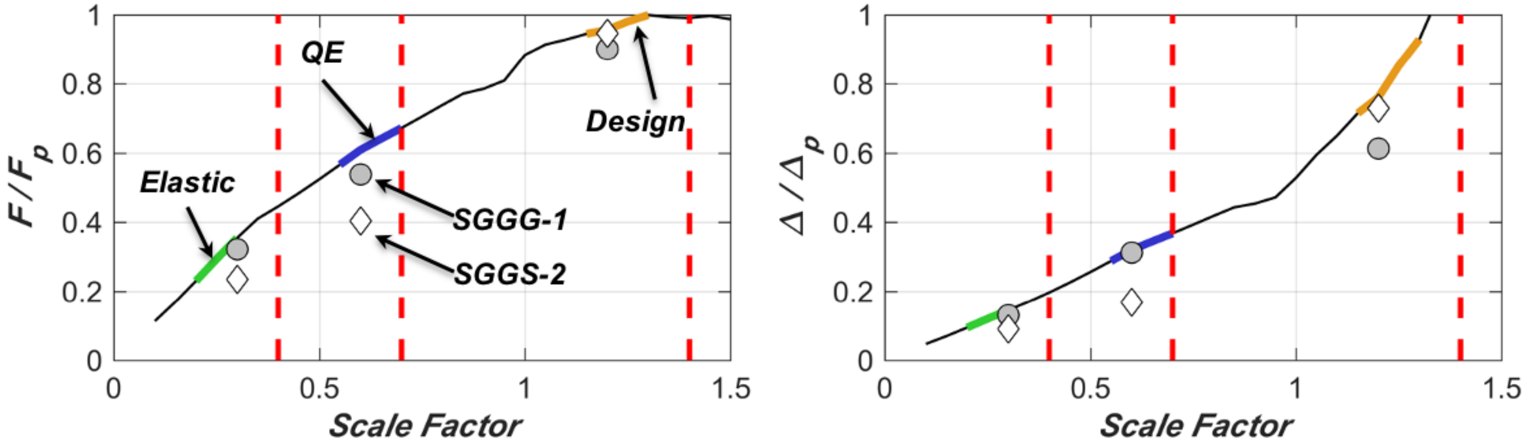


Comparison of Predicted and Achieved Responses (SGGG-1 & SGGS-2)



backbone response comparison

- both specimens attained highly similar peak strength (82–84 kN)
- measured strength is ~40% larger than that derived from the prototype specimen



dynamic response comparison

- achieved force and displacement responses in reasonable agreement with the predicted motion scaling curves.
- ***SGGG-1:*** discrepancies for specimen are limited to 15% at the all performance levels.
- ***SGGG-2:*** discrepancies appear larger at the ***elastic*** and ***quasi-elastic*** performance levels (errors reaching as much as 30-40%)

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