2015 New Zealand Society for Earthquake Engineering
10-12 April 2015, Rotorua, NZ

An Earthquake-Resistant Building System to Reduce Floor Accelerations and Force Responses

Georgios Tsampras[1], Richard Sause[1], Robert Fleischman[2], Jose Restrepo[3]

[1]ATLSS Engineering Research Center, Department of Civil and Environmental Engineering, Lehigh University
[2]Department of Civil Engineering and Engineering Mechanics, University of Arizona
[3]Department of Structural Engineering, University of California, San Diego

Acknowledgements

- National Science Foundation (Award No. CMMI-1135033)
- George E. Brown, Jr. Network for Earthquake Engineering Simulation Research (NEESR) program (Award No. CMS-0402490)
- Dr. Dichuan Zhang, Zhi Zhang, Ulina Shakya, Arpit Nema
- NEES RTMD staff and ATLSS Center staff.

The opinions, findings, and conclusions expressed in this paper are those of the authors and do not necessarily reflect the views of NSF or those acknowledged here.

NEES @ UCSD



NEES @ Lehigh

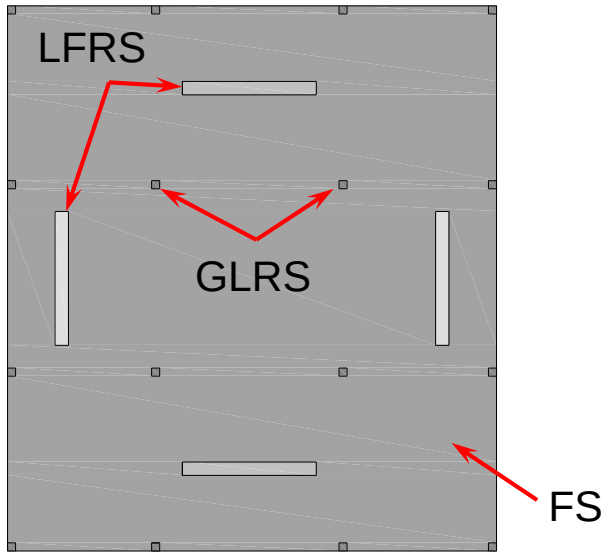


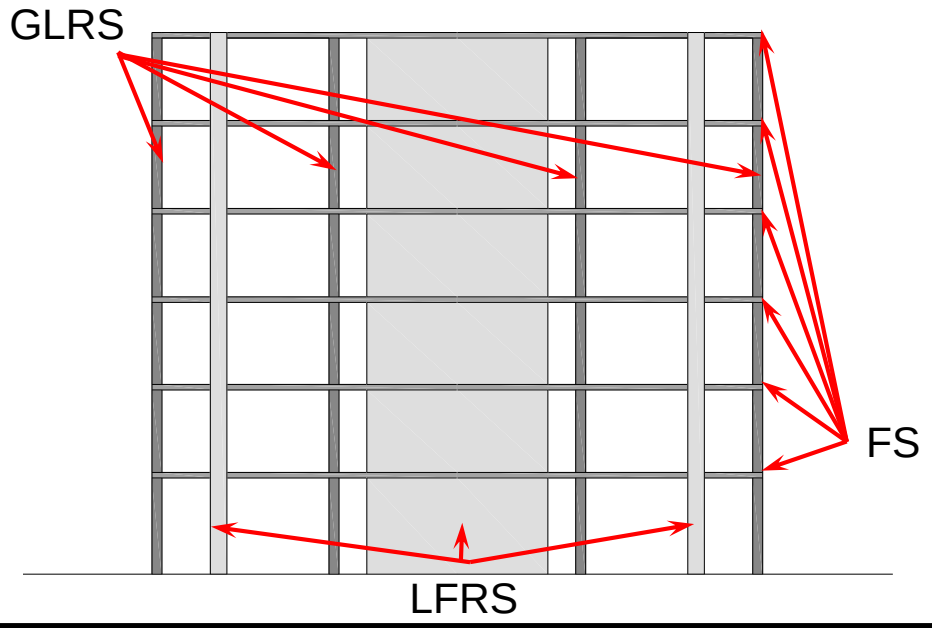
Conventional Building Systems

Three Main Systems

- Gravity Load Resisting System, GLRS
- Floor Systems, FS
- Lateral Force Resisting Systems, LFRS

LFRS assumed to be rigidly connected with the FS

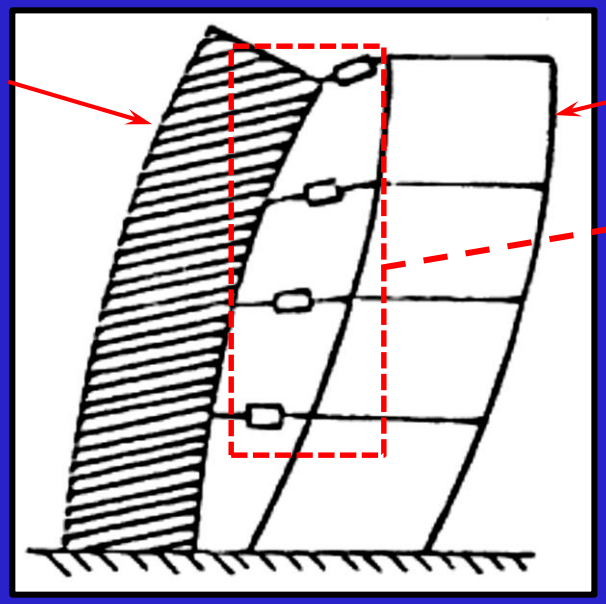




Alternative System Concept



R.I. Skinner, J. Kelly and A. Heine (1975) "Hysteretic dampers for earthquake resistant structures," Earthquake Engineering and Structural Dynamics, pp. 287-296



A building which combines a moment-resisting frame with a central tower may utilize hysteretic dampers if the tower is left separate from the floors and beams. Under lateral loads there would be large relative movements between the tower and the frame, with moderate interfloor translations. Hysteretic dampers may be connected between the tower and nearby floor beams

Alternative System Developed in this Study

Openings in the Floor Systems (FS)

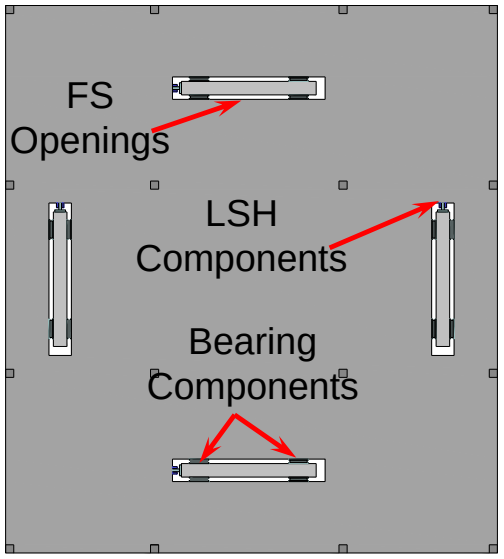
Deformable Connections between FS – LFRS with two types of components:

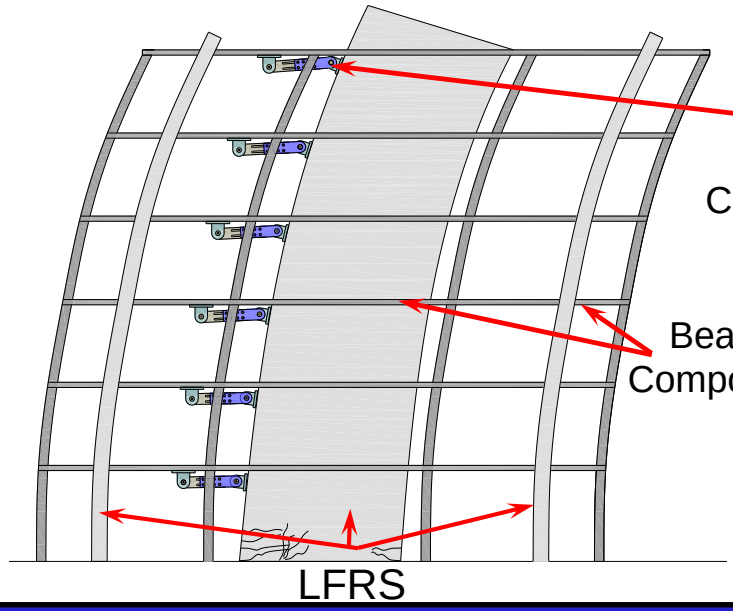
1. Limited-Strength Hysteretic (LSH) components
2. Bearing Components

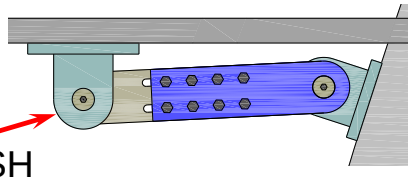
Goal

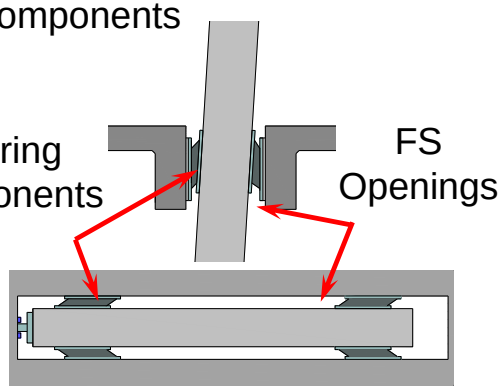
Limit the transferred forces by using deformable connections

Reduce the floor accelerations and force responses





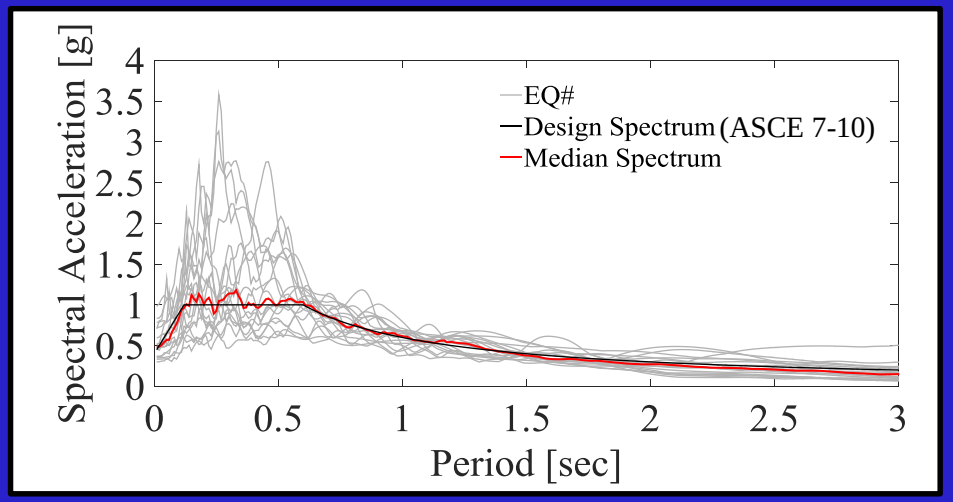




Parametric Numerical Study

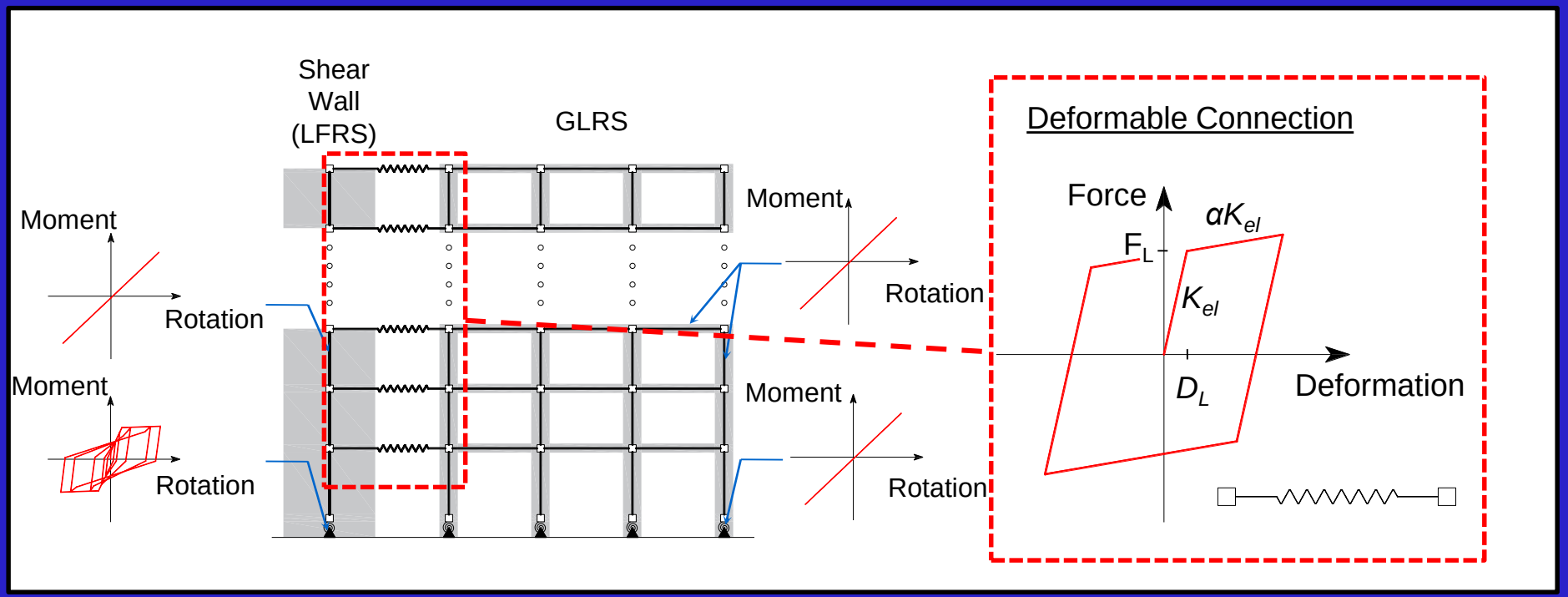
12-story Reinforced Concrete Shear Wall Example Building Structure

Identify Deformable Connection Feasible Design Space

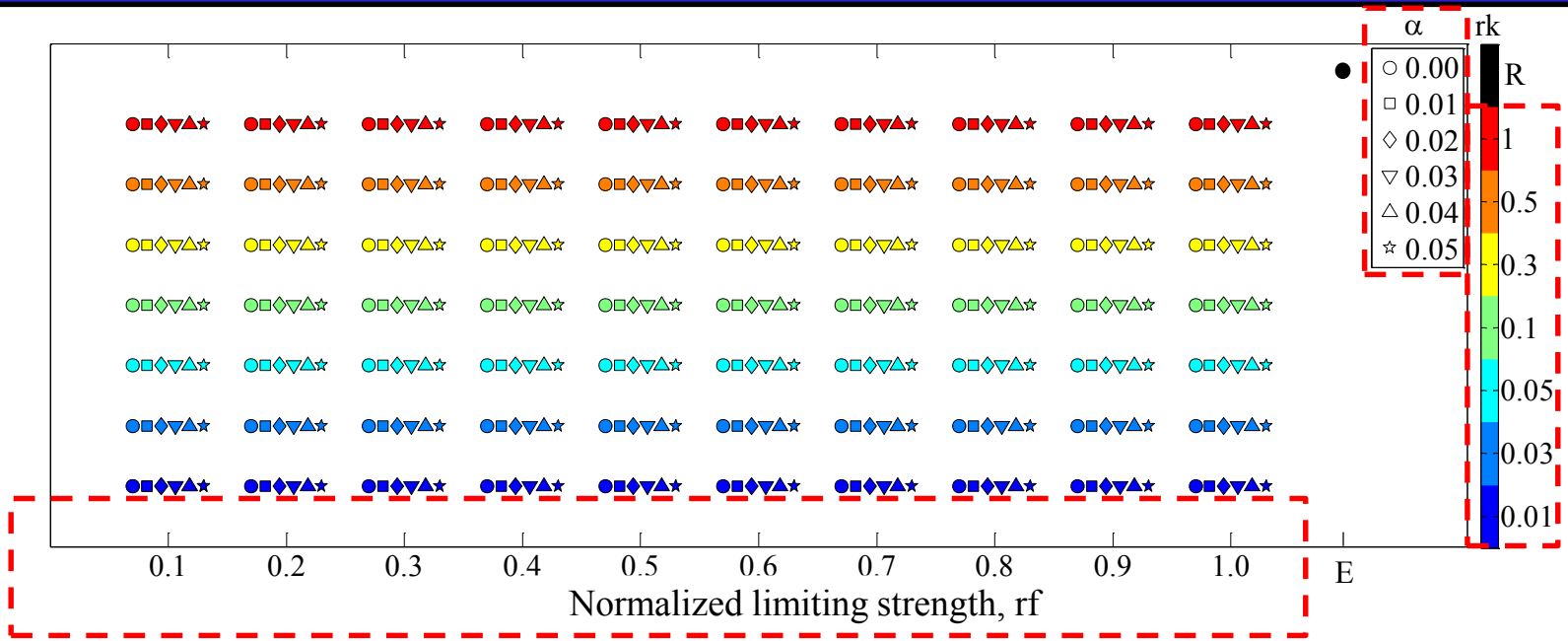


Deformable Connection Parameters

- Limiting Strength, F_L
- Elastic Stiffness, K_{el}
- Post-Elastic Stiffness, αK_{el}



Deformable Connection Parameters Space

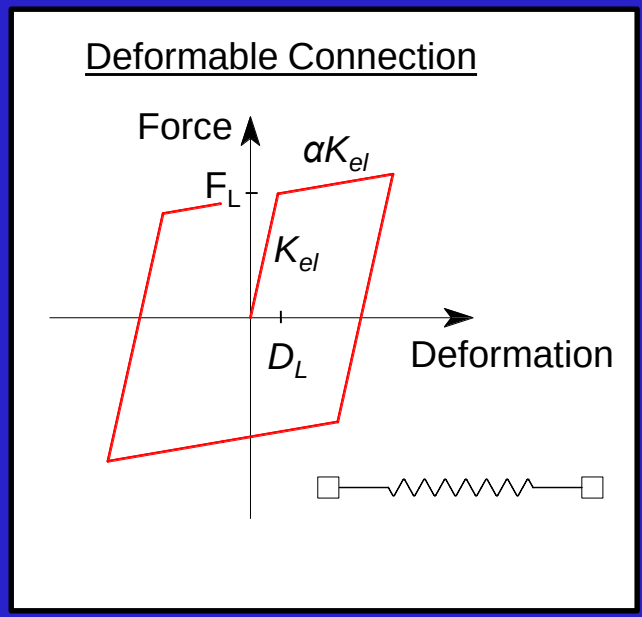


Normalized Deformable Connection Parameters

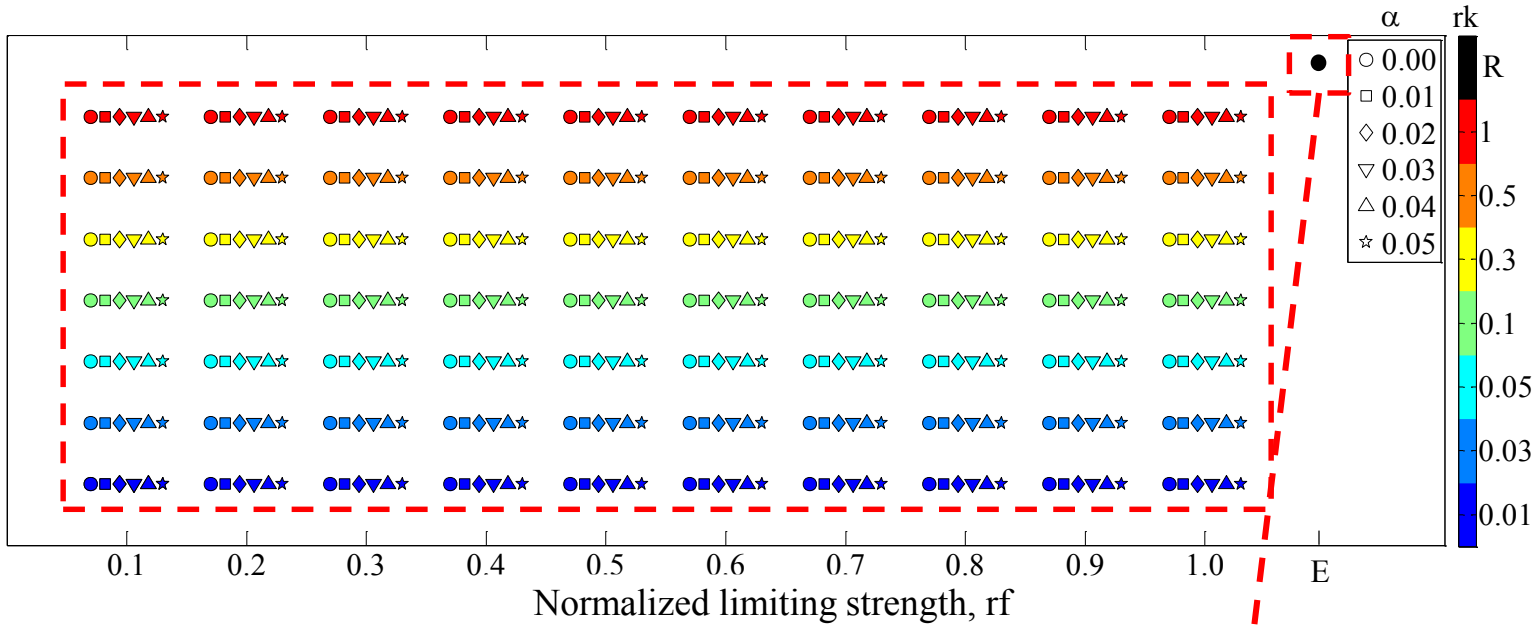
$r_f = 2F_L / F_{px} \in [0.1;0.2;0.3;0.4;0.5;0.6;0.7;0.8;0.9;1]$

$r_k = K_{el} / K_{ref} \in [0.01;0.03;0.05;0.1;0.3;0.5;1]$

$\alpha = \alpha K_{el} / K_{el} \in [0;0.01;0.02;0.03;0.04;0.05]$



Deformable Connection Parameters Space



Normalized Deformable Connection Parameters

$r_f = 2F_L / F_{px} \in [0.1;0.2;0.3;0.4;0.5;0.6;0.7;0.8;0.9;1]$

$r_k = K_{el} / K_{ref} \in [0.01;0.03;0.05;0.1;0.3;0.5;1]$

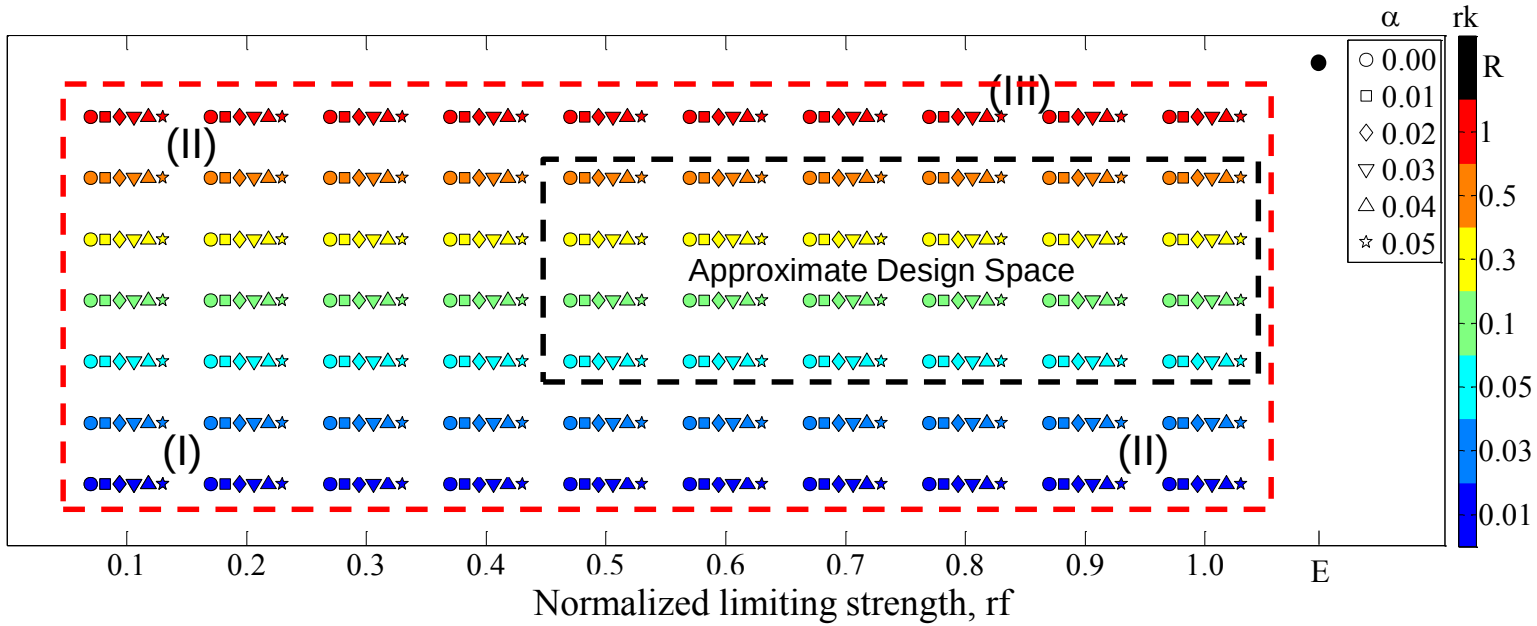
$\alpha = \alpha K_{el} / K_{el} \in [0;0.01;0.02;0.03;0.04;0.05]$

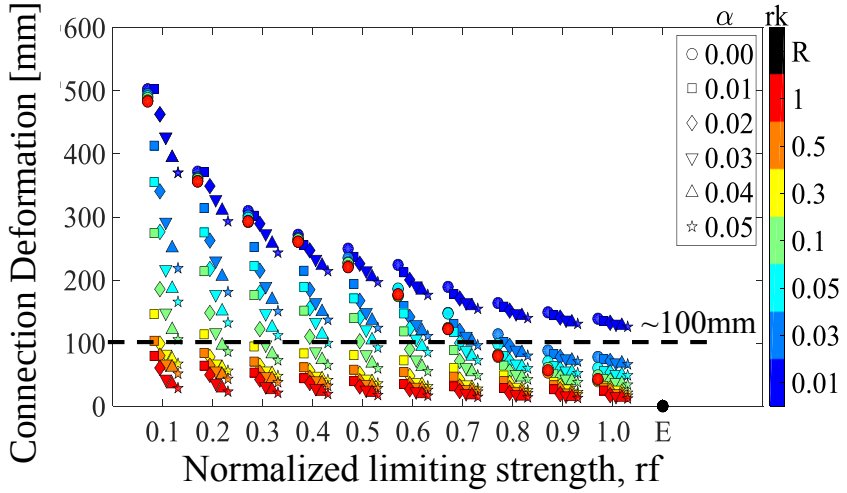
420 Combinations

+

Rigid-Elastic (RE) Connection

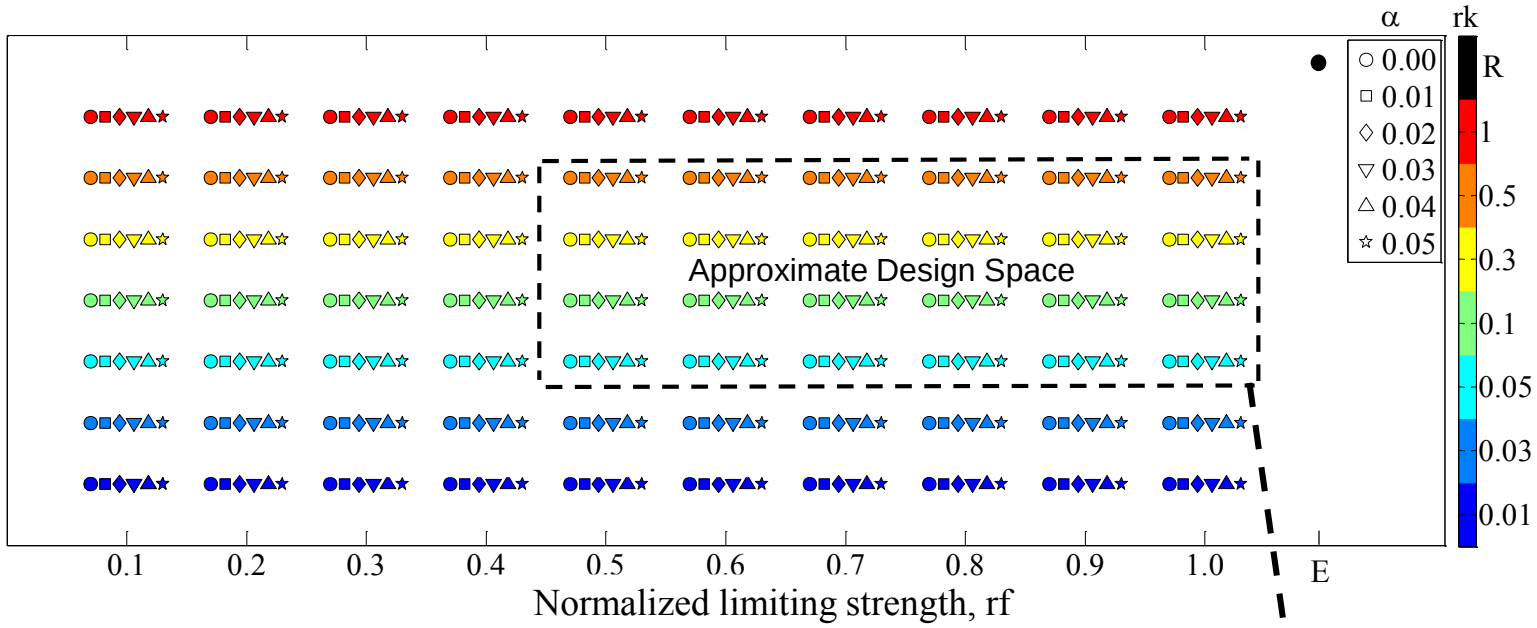
Approximate Design Space

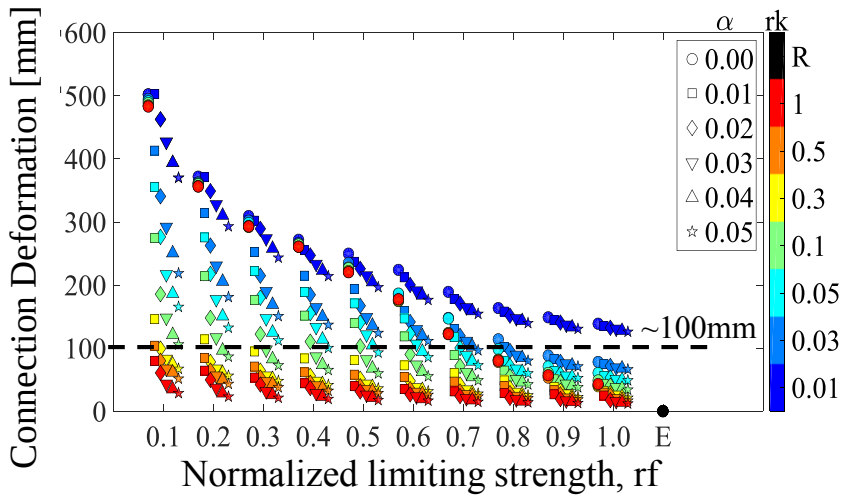


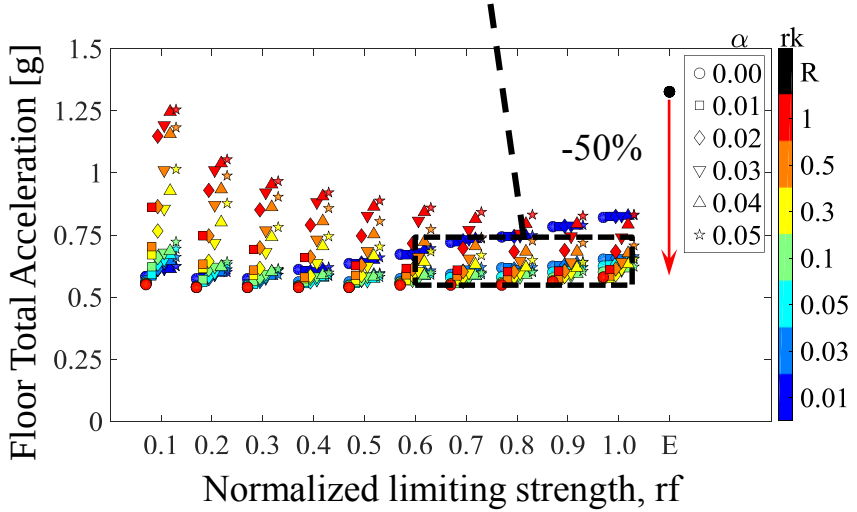


(I) Large Connection Deformation
(II) Difficult to Design F_L & K_{el}
(III) Very High K_{el}

Approximate Design Space



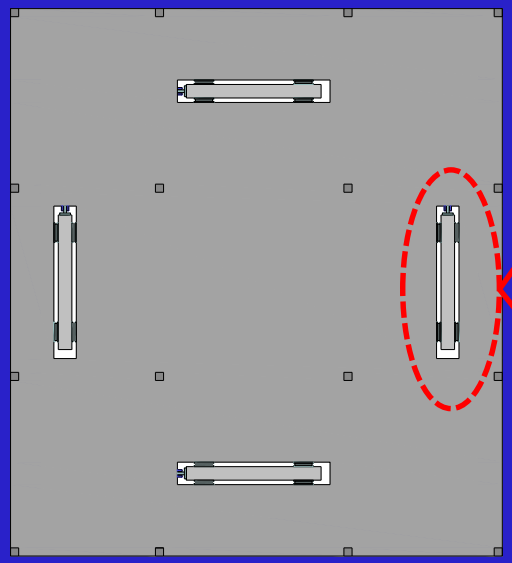


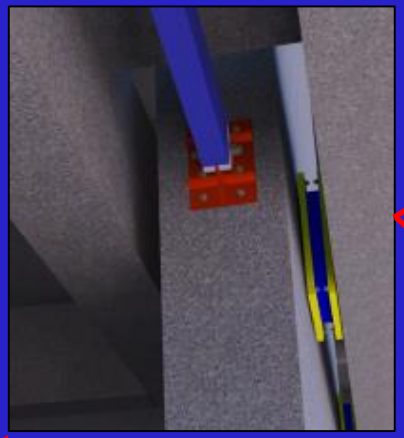


Deformable Connection Components

Combinations of F_L and K_{el} Within the Approximate Design Space

BRB+RB
Deformable Connection

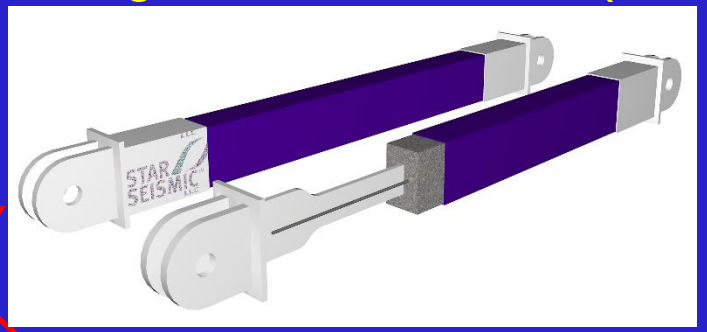




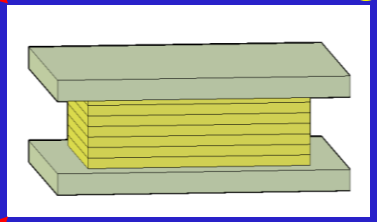
FD+RB
Deformable Connection



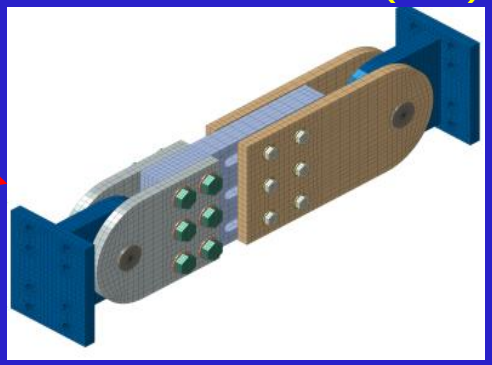
Buckling Restrained Brace (BRB)



Low Damping
Rubber Bearings (RB)



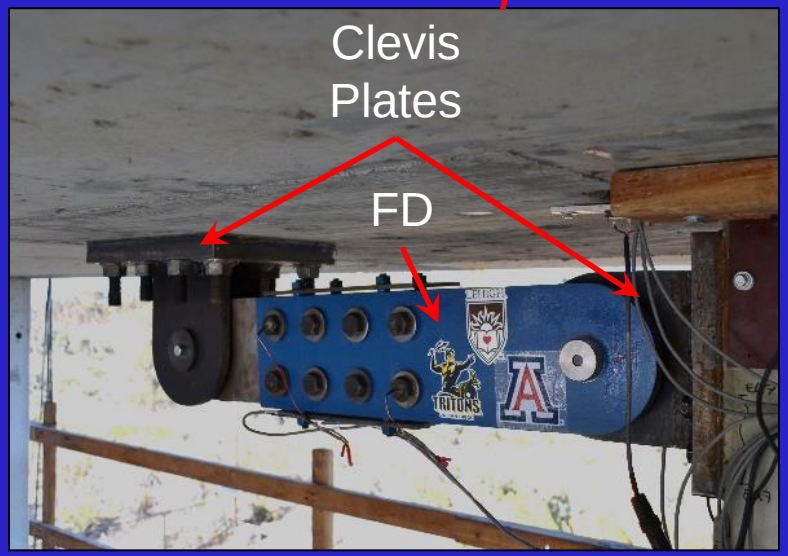
Friction Device (FD)

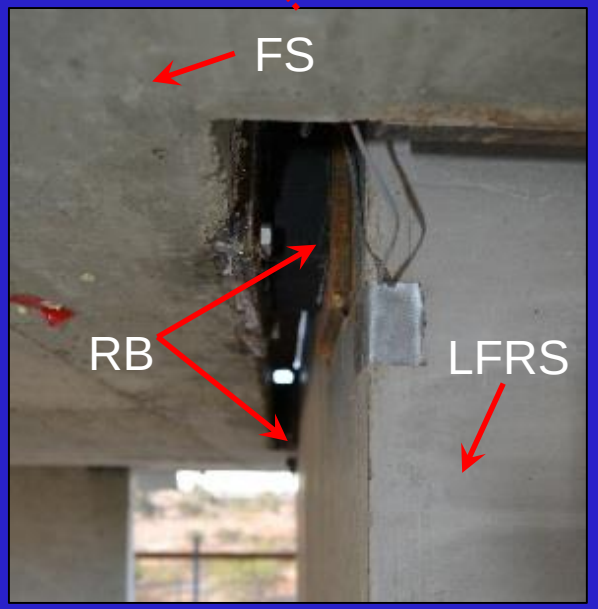


Example Installation of Deformable Connection

Half-Scale 4-story Precast Rocking Shear Wall Structure



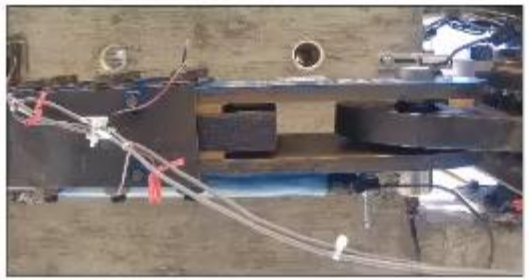




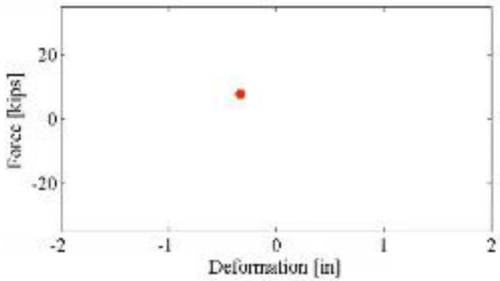
NEES @ UCSD

Example Installation at NEES @ UCSD











THE UNIVERSITY OF ARIZONA UCSanDiego LEHIGH UNIVERSITY

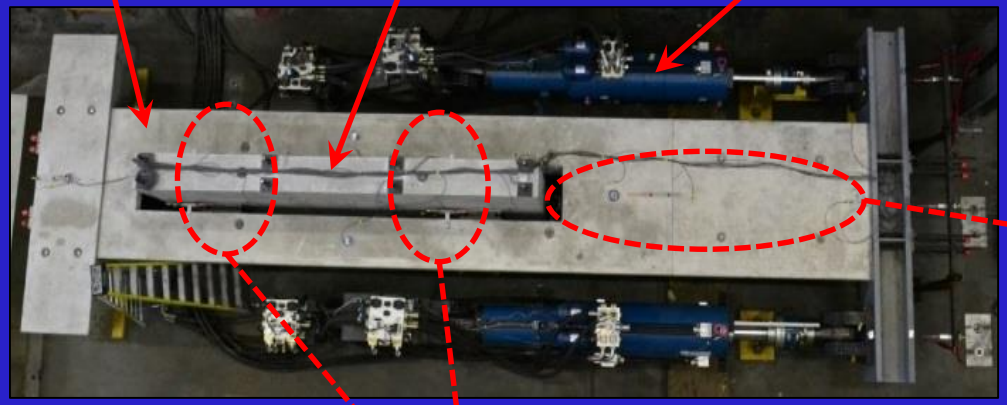
Tests of Full-Scale Deformable Connections

BRB+RB

FS

LFRS

NEES Hydraulic Actuators



BRB



Steel Reinforced RB



BRB



BRB



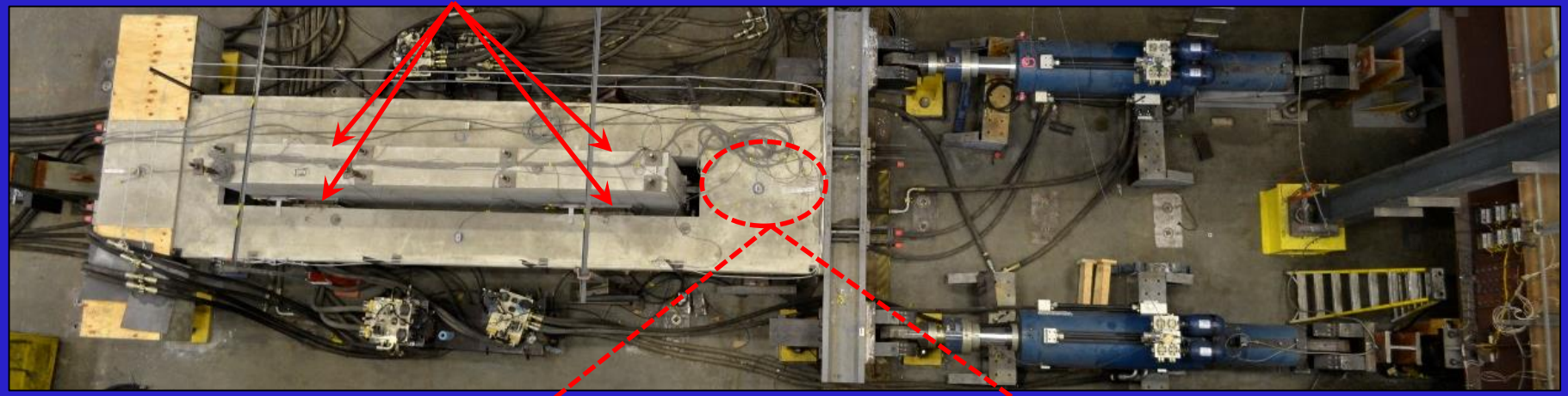
RB



Tests of Full-Scale Deformable Connections

FD+RB

Carbon Fiber Reinforced RB



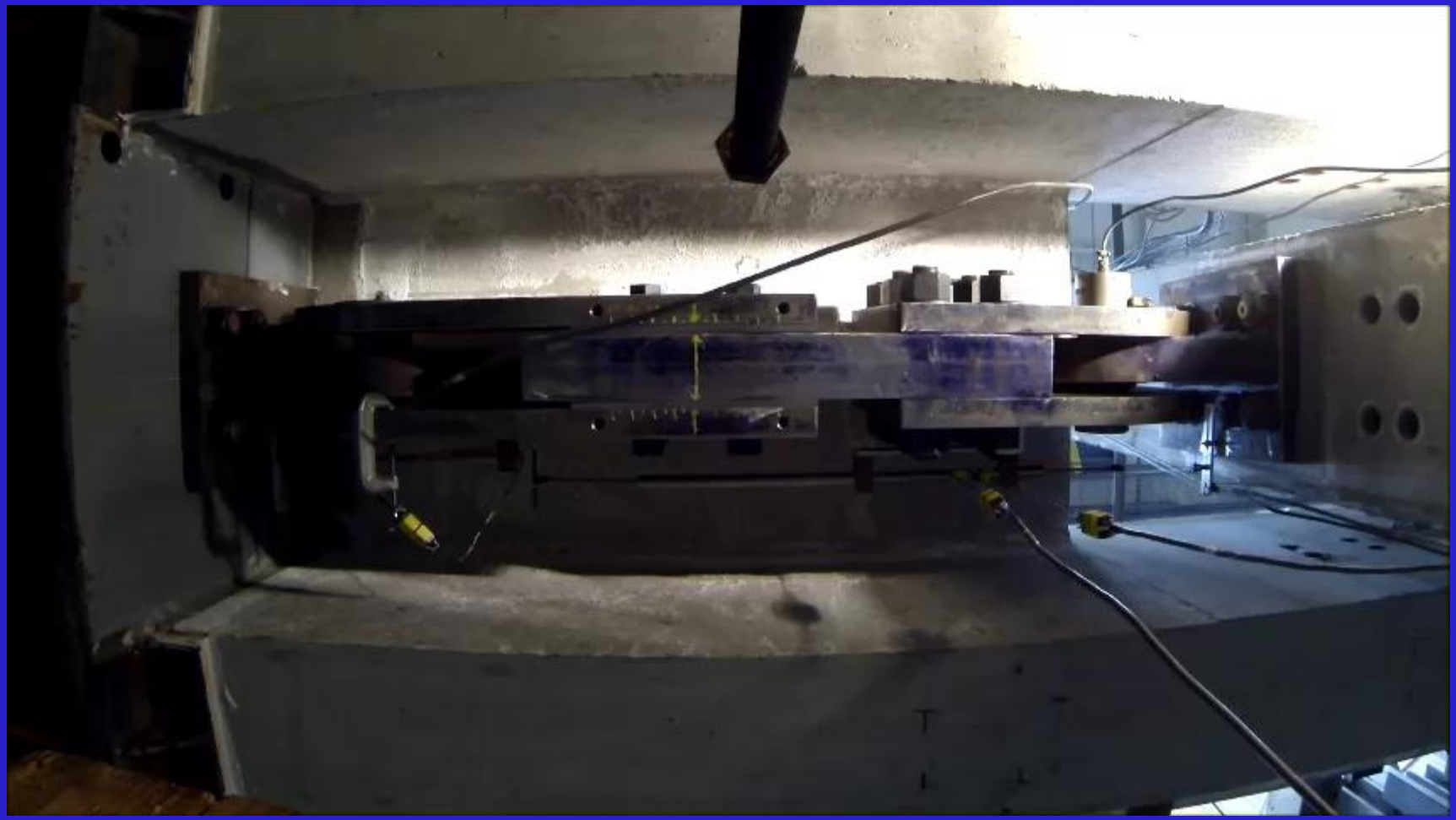
FD



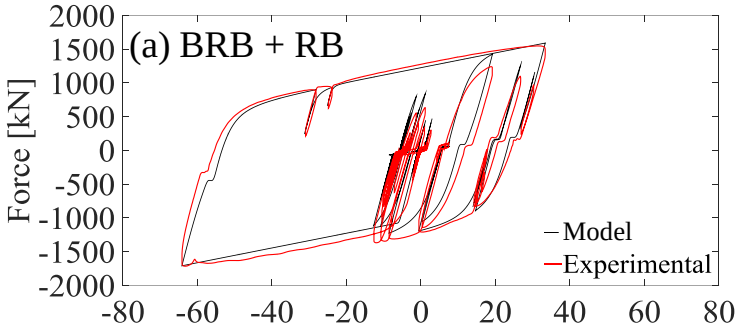


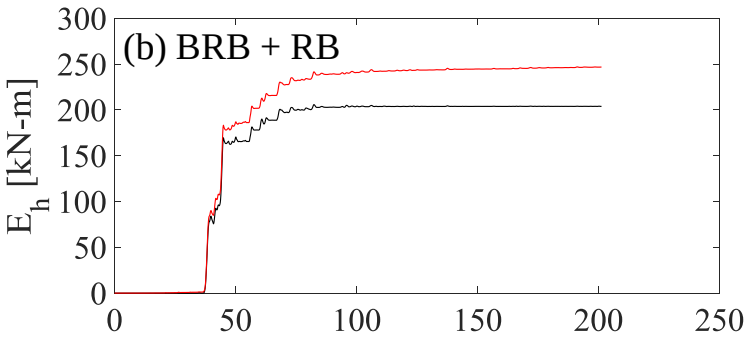
NEES @ Lehigh

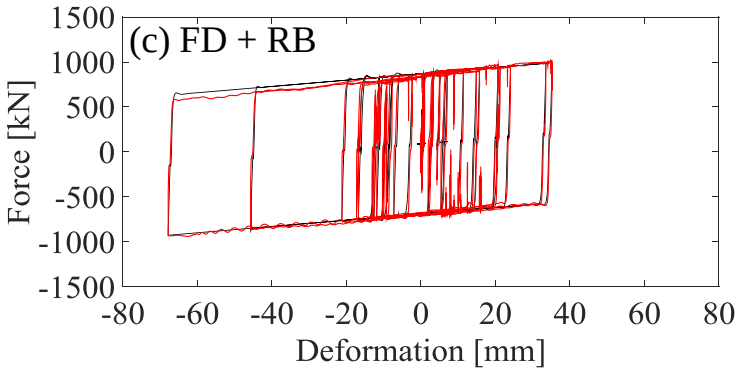
FD

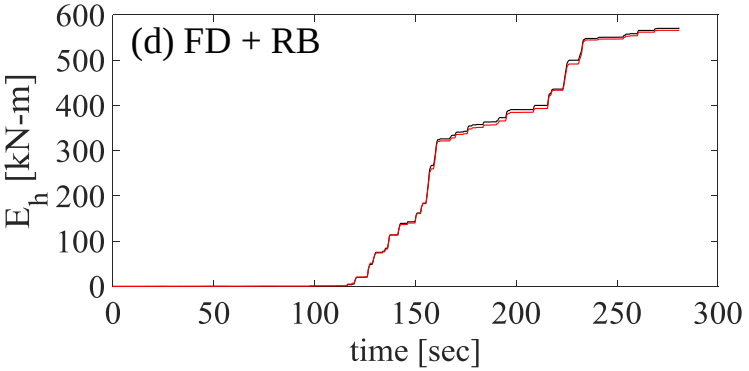


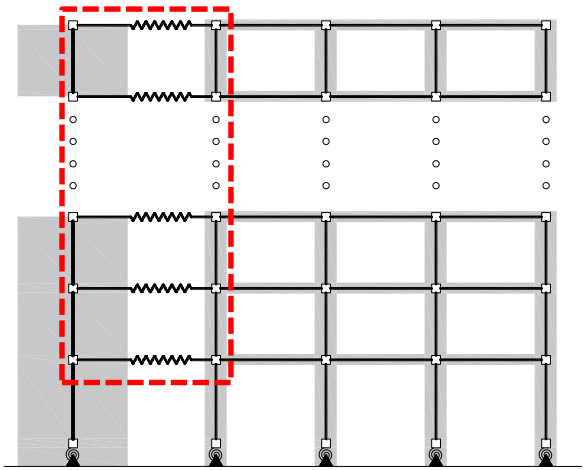
Experimental Results - Numerical Models

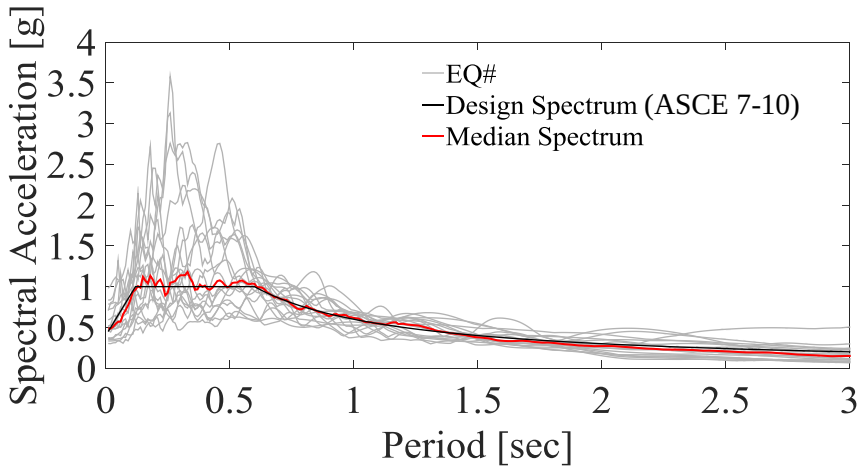






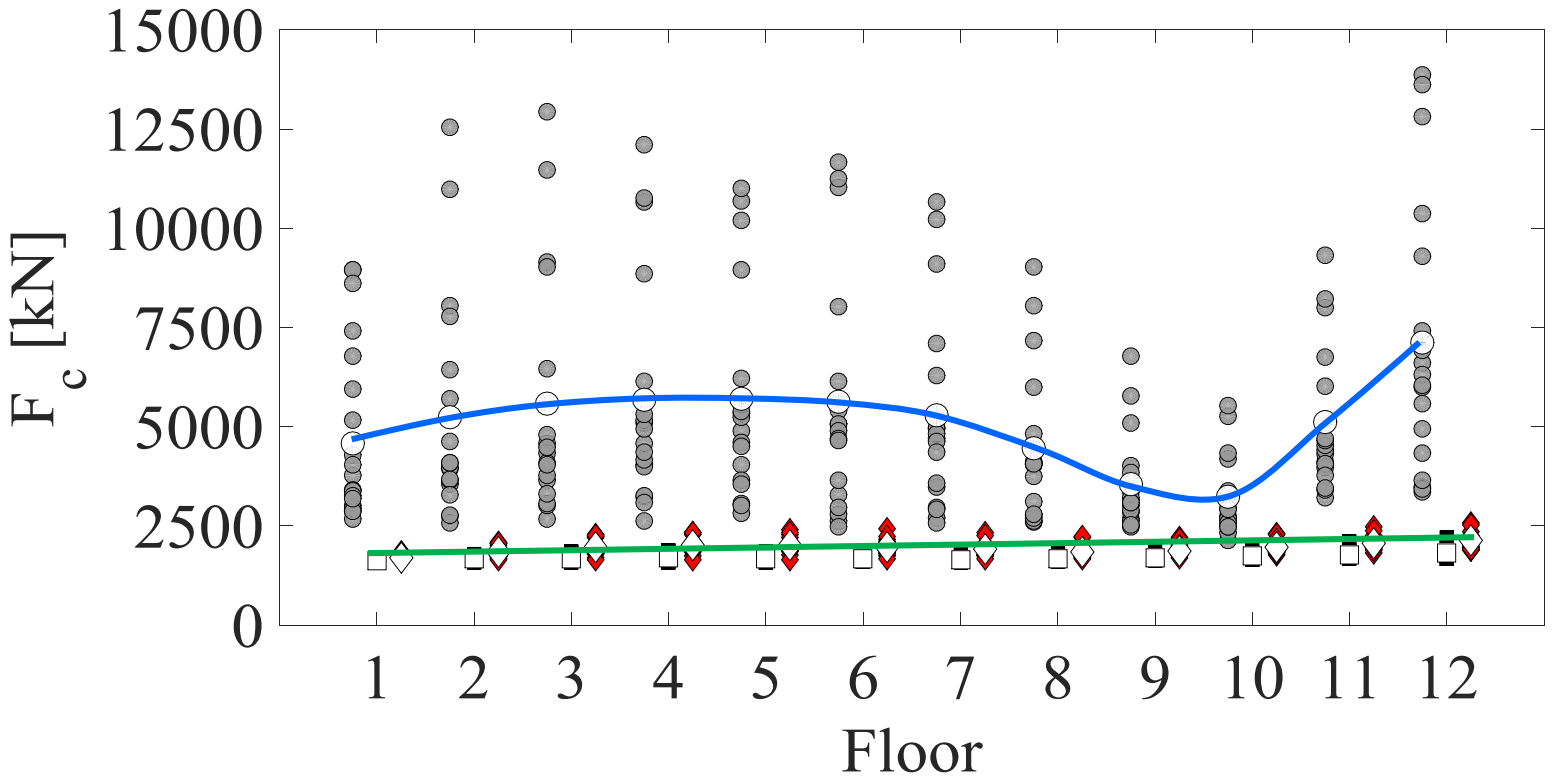






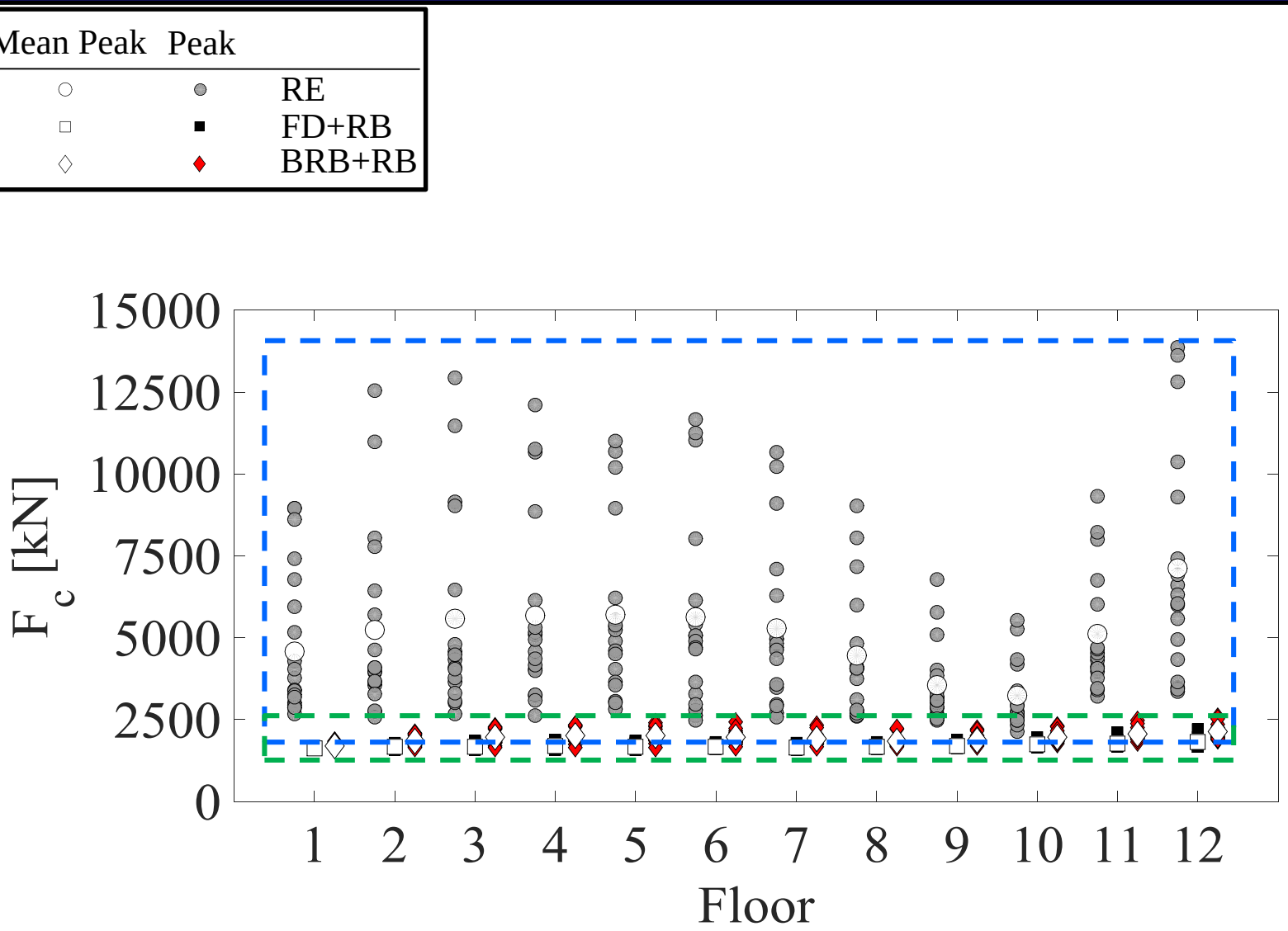
Numerical Simulations Results

F_c: Connection force transferred from FS to LFRS



Numerical Simulations Results

F_c: Connection force transferred from FS to LFRS

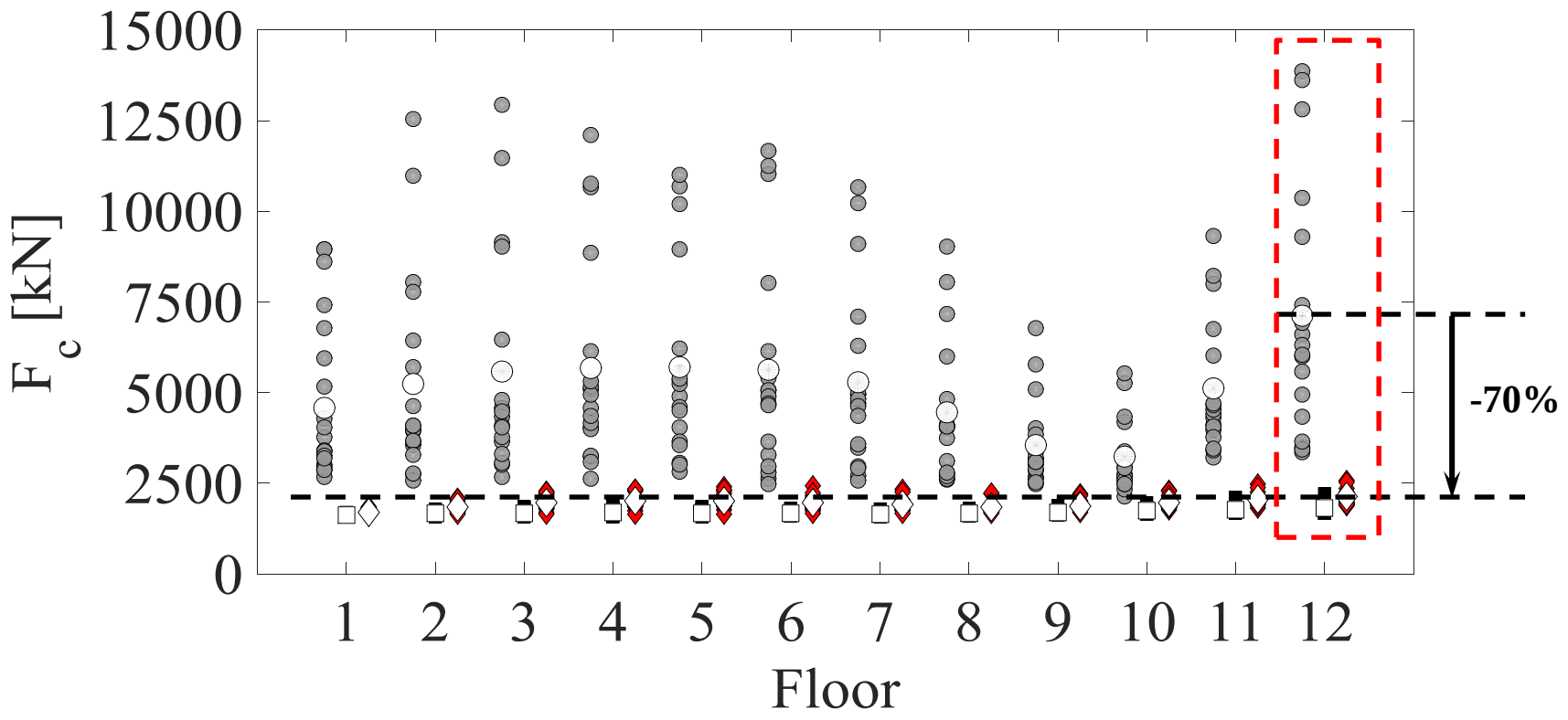


Numerical Simulations Results

F_c: Connection force transferred from FS to LFRS

	Mean Peak	Peak
RE	○	●
FD+RB	□	■
BRB+RB	◇	◆

	μ [kN]	σ [kN]
RE	7100	3500
FD+RB	1800	120
BRB+RB	2100	200

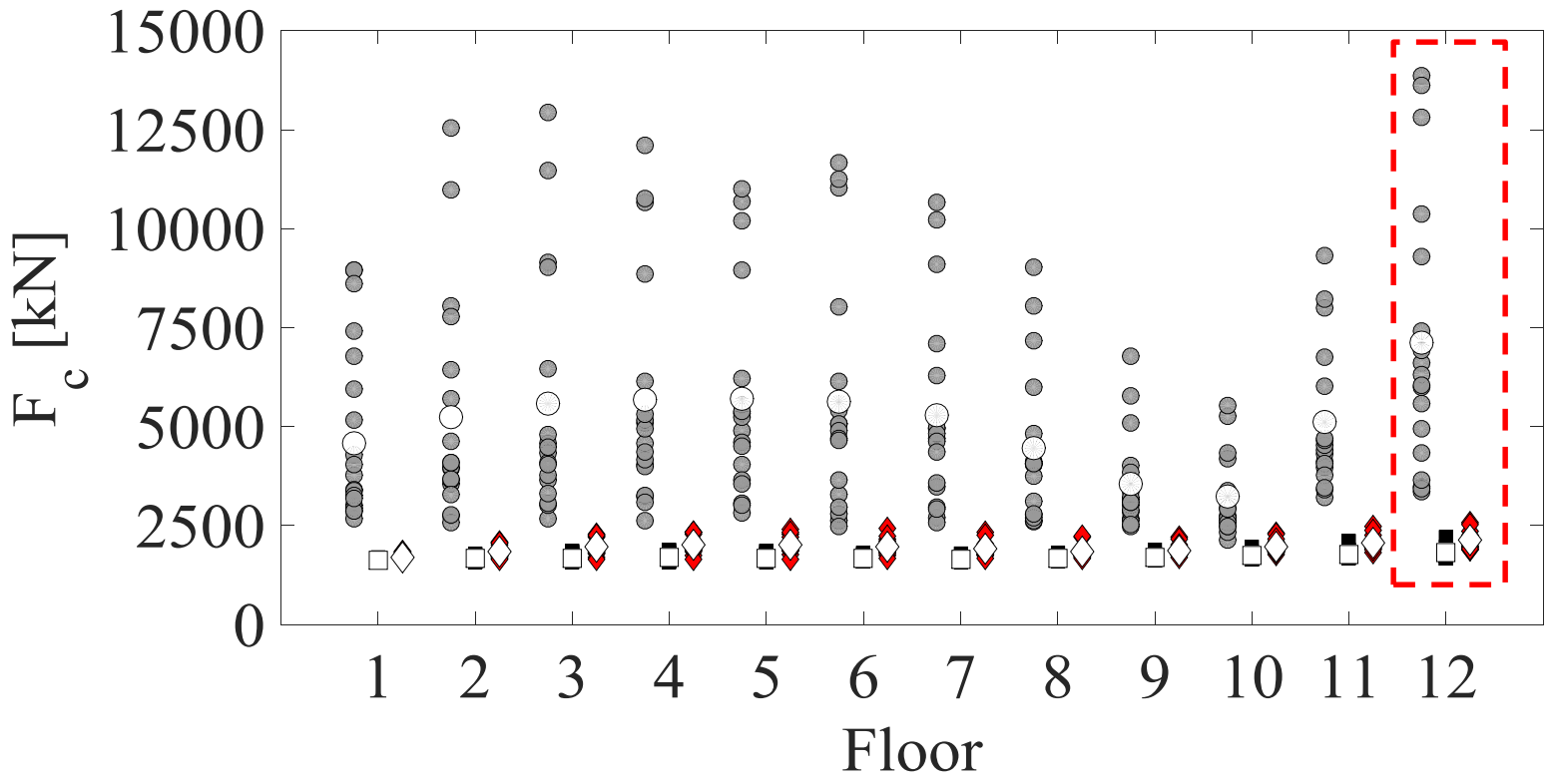


Numerical Simulations Results

F_c: Connection force transferred from FS to LFRS

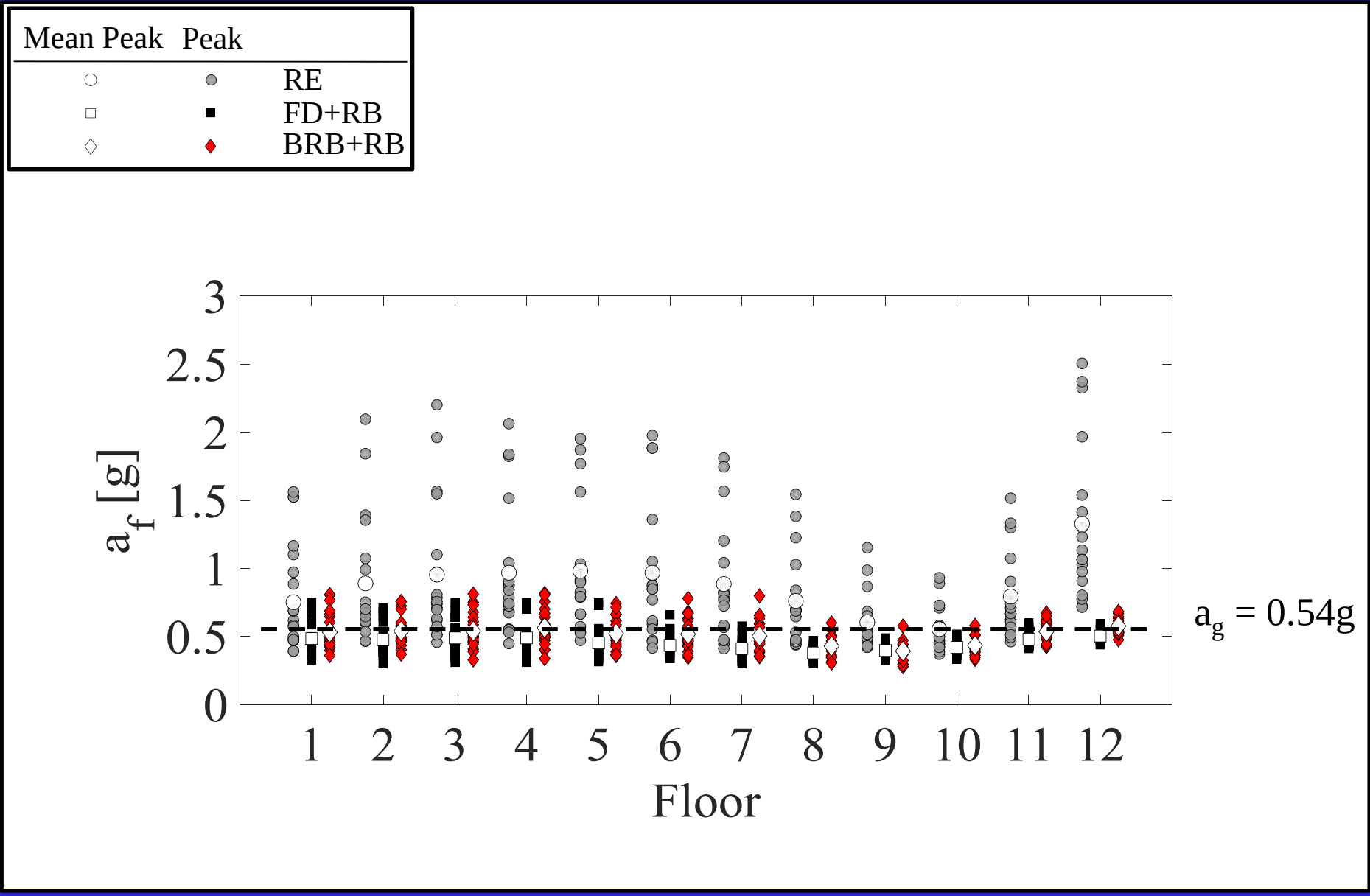
Mean Peak	Peak	
○	●	RE
□	■	FD+RB
◇	◆	BRB+RB

	μ [kN]	σ [kN]
RE	7100	3500
FD+RB	1800	120
BRB+RB	2100	200
	-70%	**-95%**



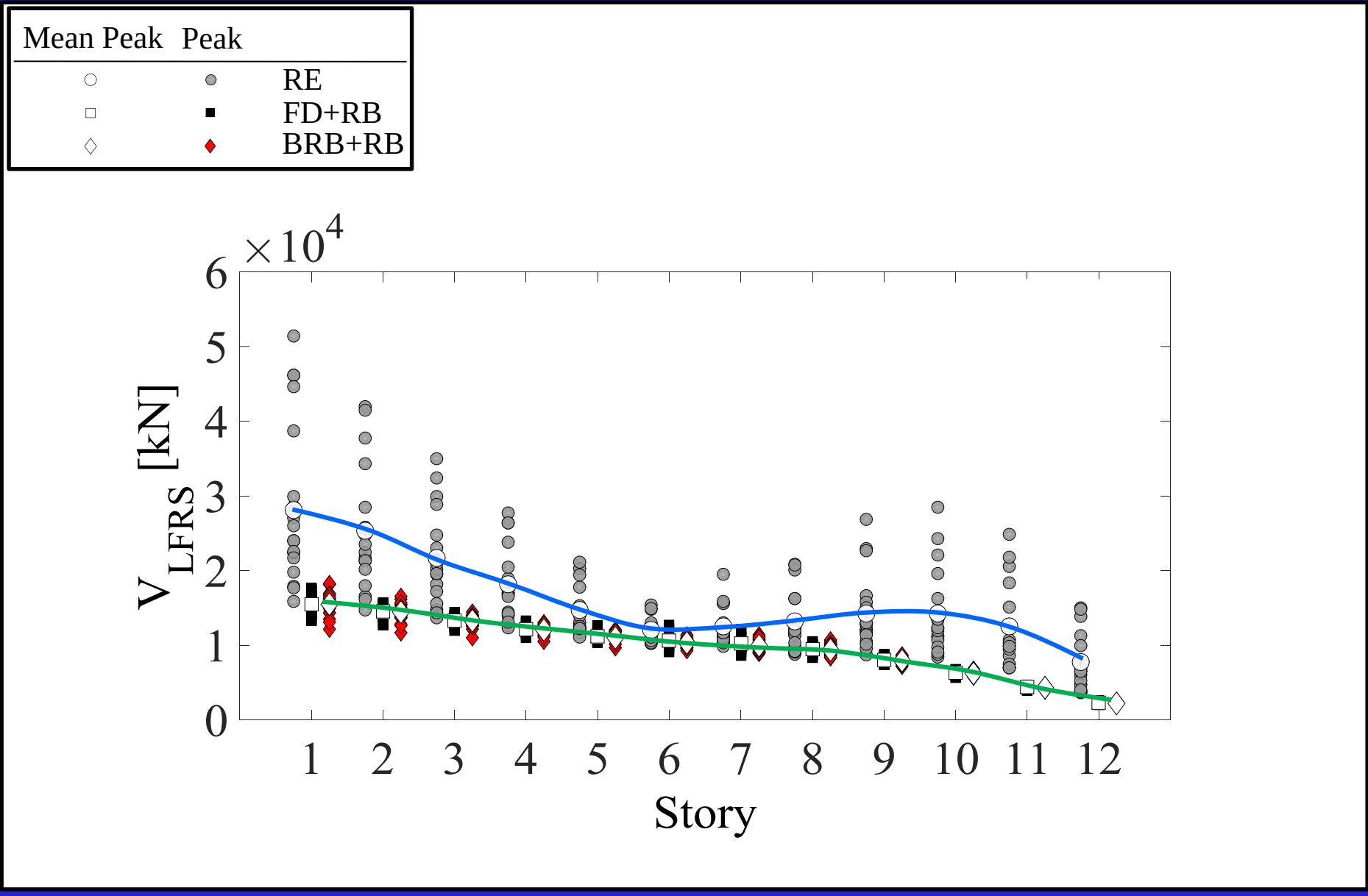
Numerical Simulations Results

a_f: Floor total accelerations



Numerical Simulations Results

V_{LFRS}: LFRS story shear



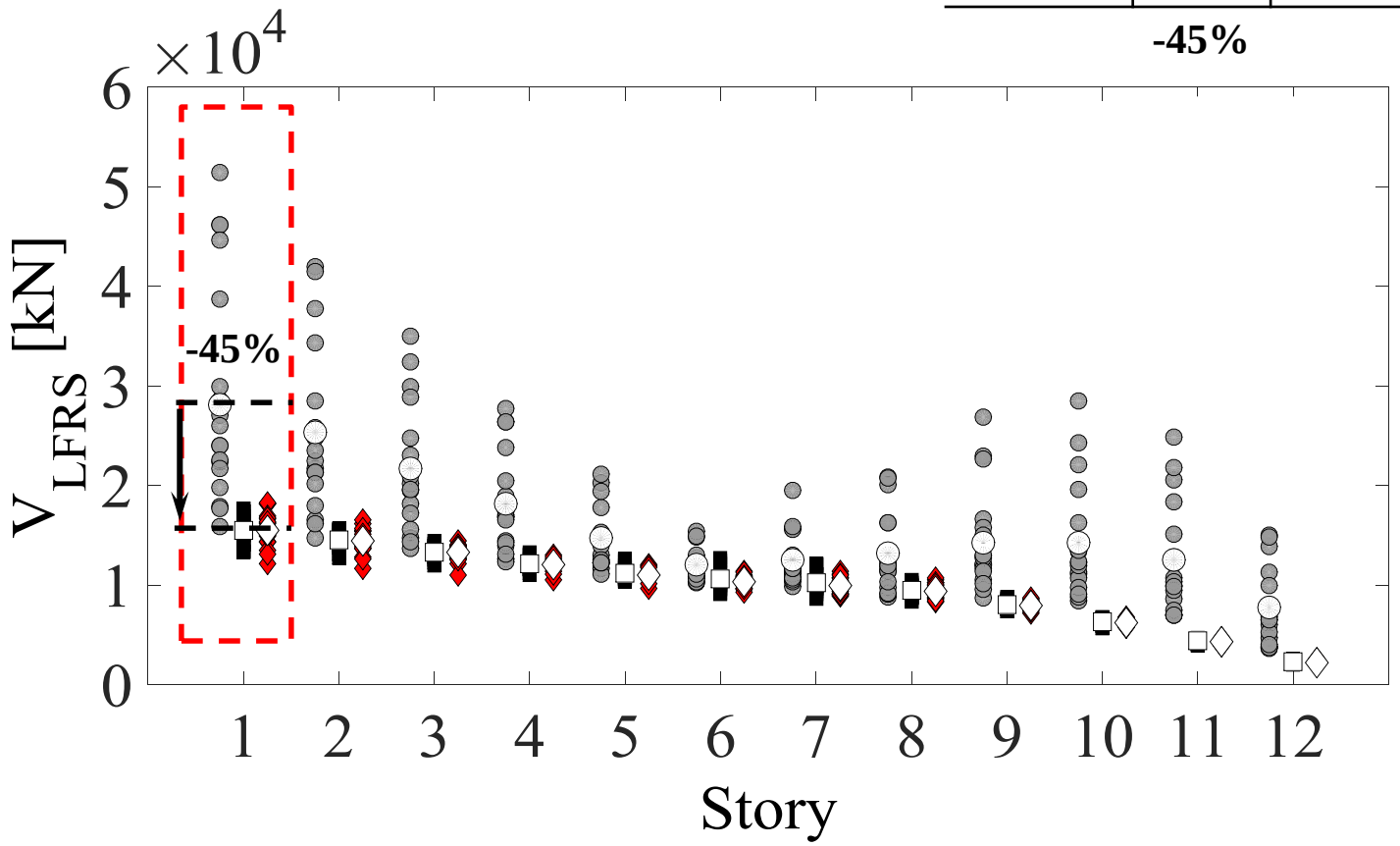
Numerical Simulations Results

V_{LFRS}: LFRS story shear

Mean Peak	Peak	
○	●	RE
□	■	FD+RB
◇	◆	BRB+RB

	μ [kN]	σ [kN]
RE	28000	10400
FD+RB	15500	1300
BRB+RB	15500	1650

-45%

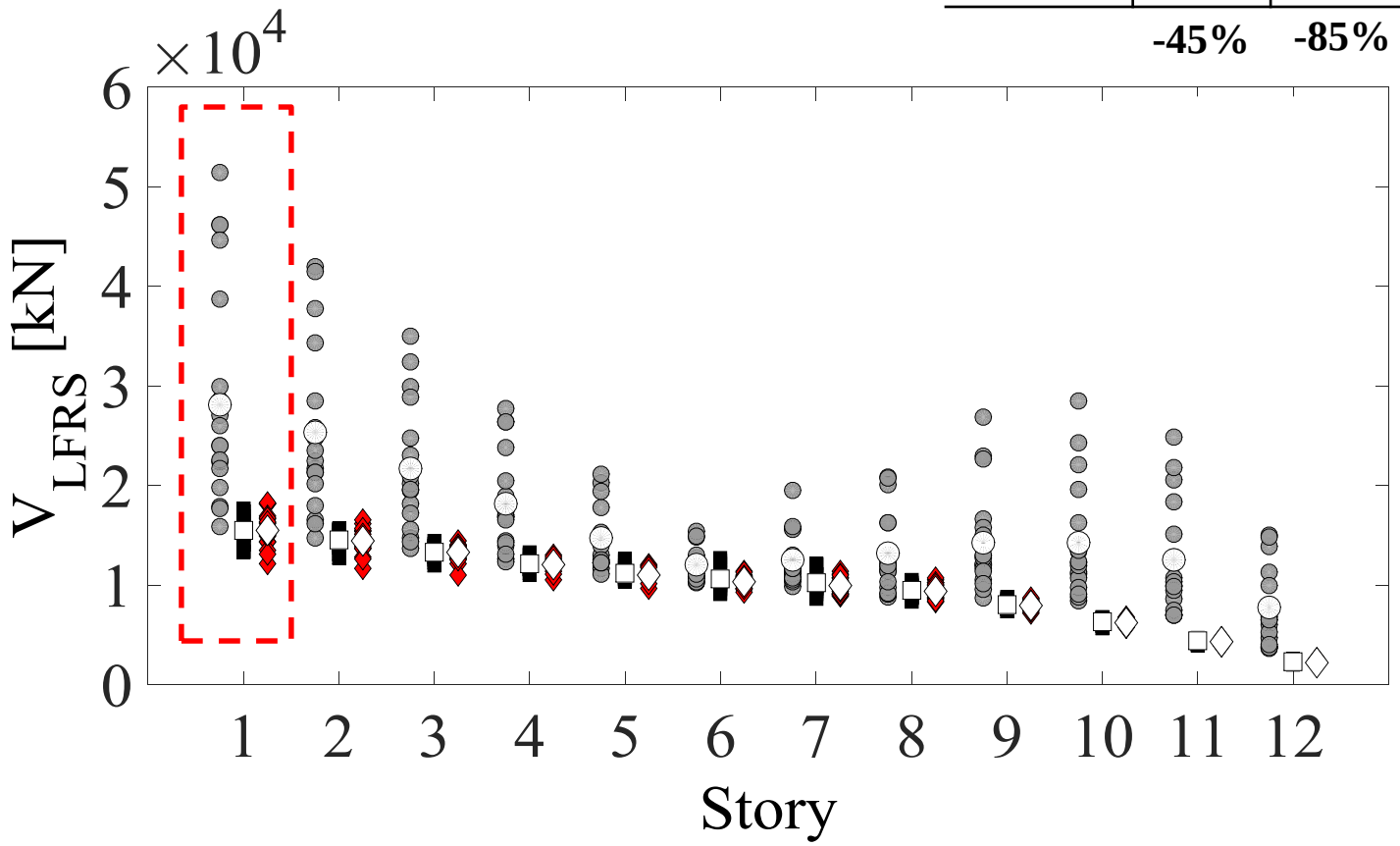


Numerical Simulations Results

V_{LFRS}: LFRS story shear

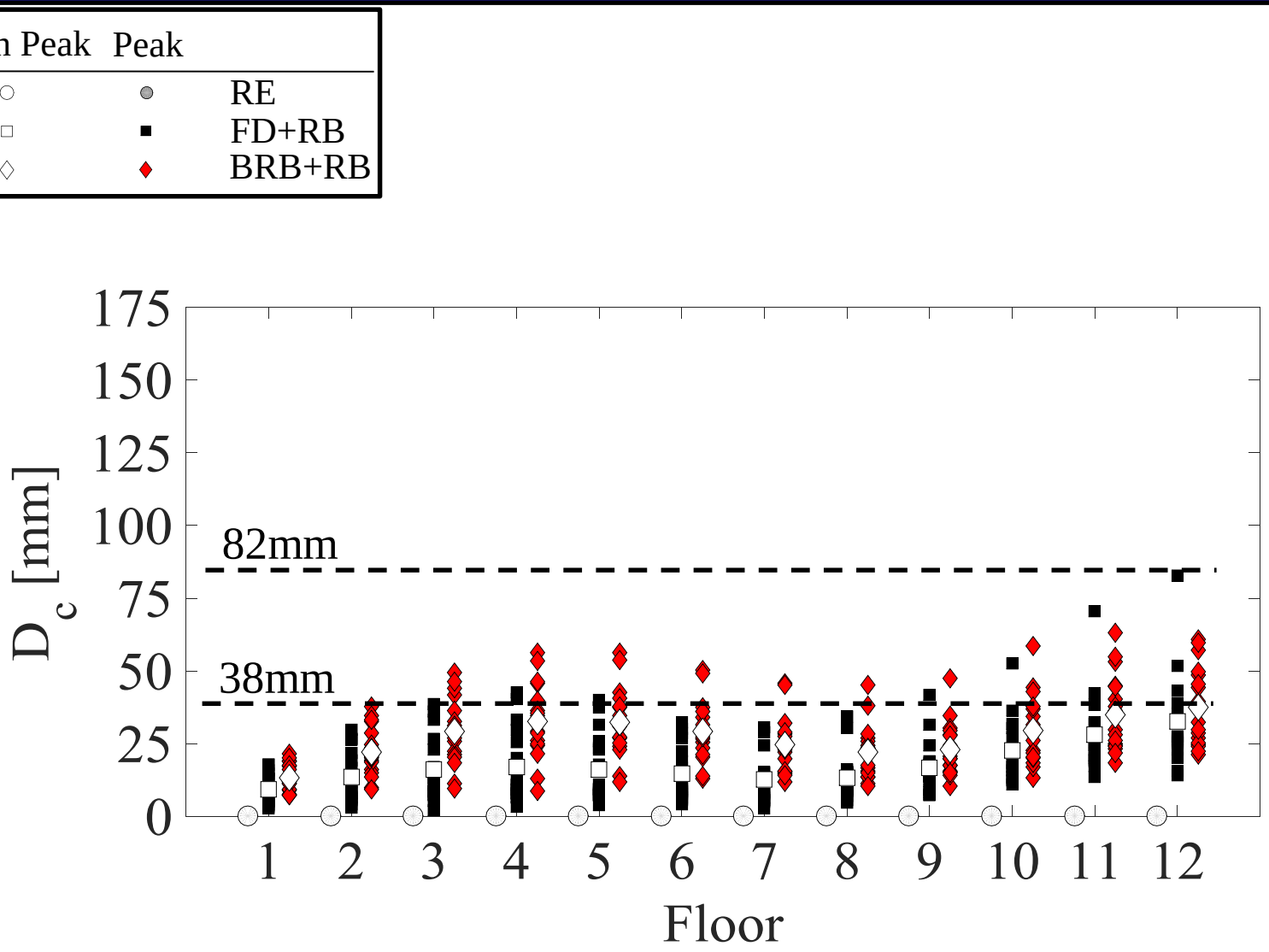
Mean Peak	Peak	
○	●	RE
□	■	FD+RB
◇	◆	BRB+RB

	μ [kN]	σ [kN]
RE	28000	10400
FD+RB	15500	1300
BRB+RB	15500	1650
	-45%	**-85%**



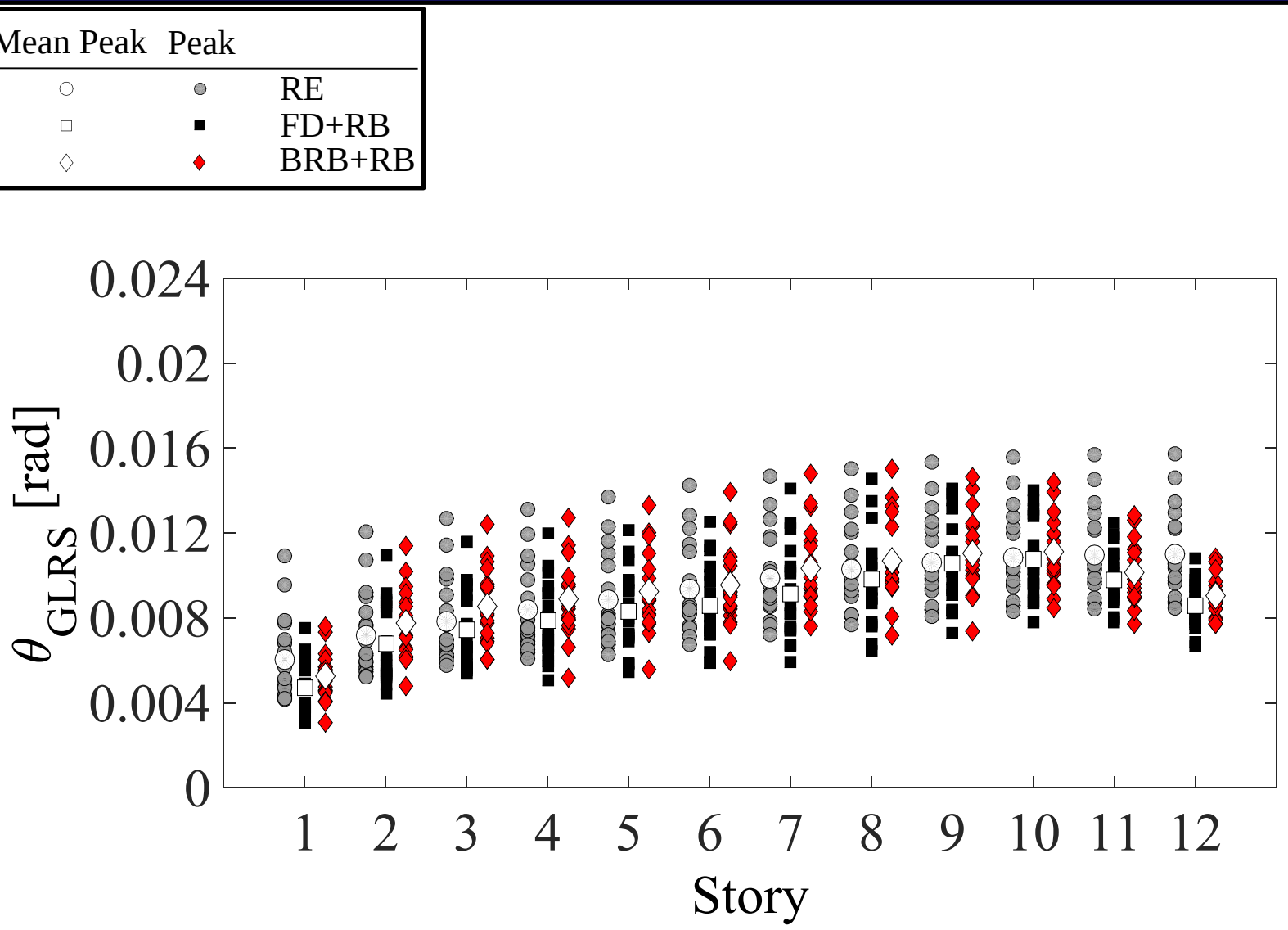
Numerical Simulations Results

D_c: Connection deformation



Numerical Simulations Results

θ_{GLRS}: GLRS story drift



Conclusions

1. An approximate feasible design space for the deformable connections was identified for the example building structure

2. The full-scale BRB+RB and FD+RB deformable connections could be designed and constructed

3. The deformable connections have experimentally validated stable hysteretic response under large deformation

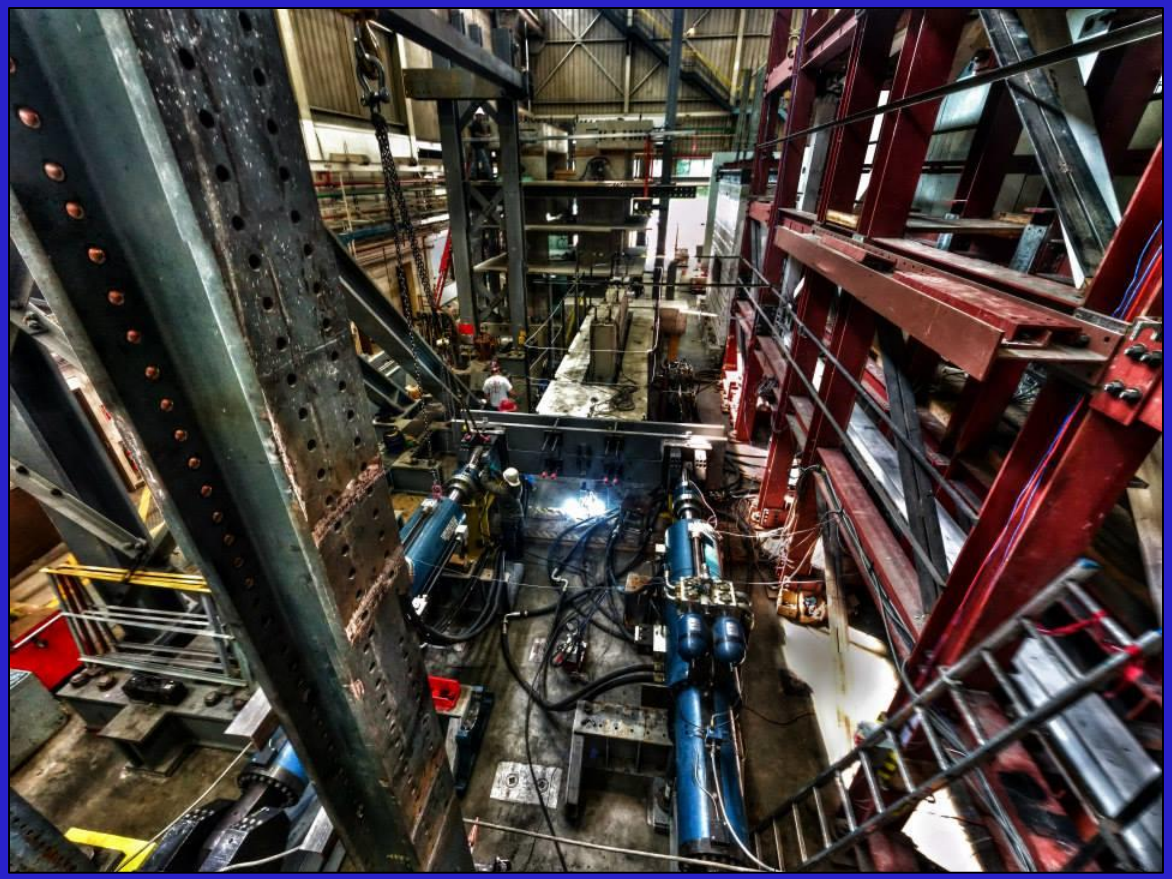
4. The deformation demand of the deformable connections was limited below 40 mm

5. The GLRS story drift was not increased by introducing the deformable connections

6. Limiting the forces transferred from FS to LFRS led to reduction of floor accelerations, and LFRS story shears

7. Significant reduction of the dispersion of the forces transferred from the FS to the LFRS, the floor accelerations, and the LFRS story shears

Questions



NEES @ Lehigh