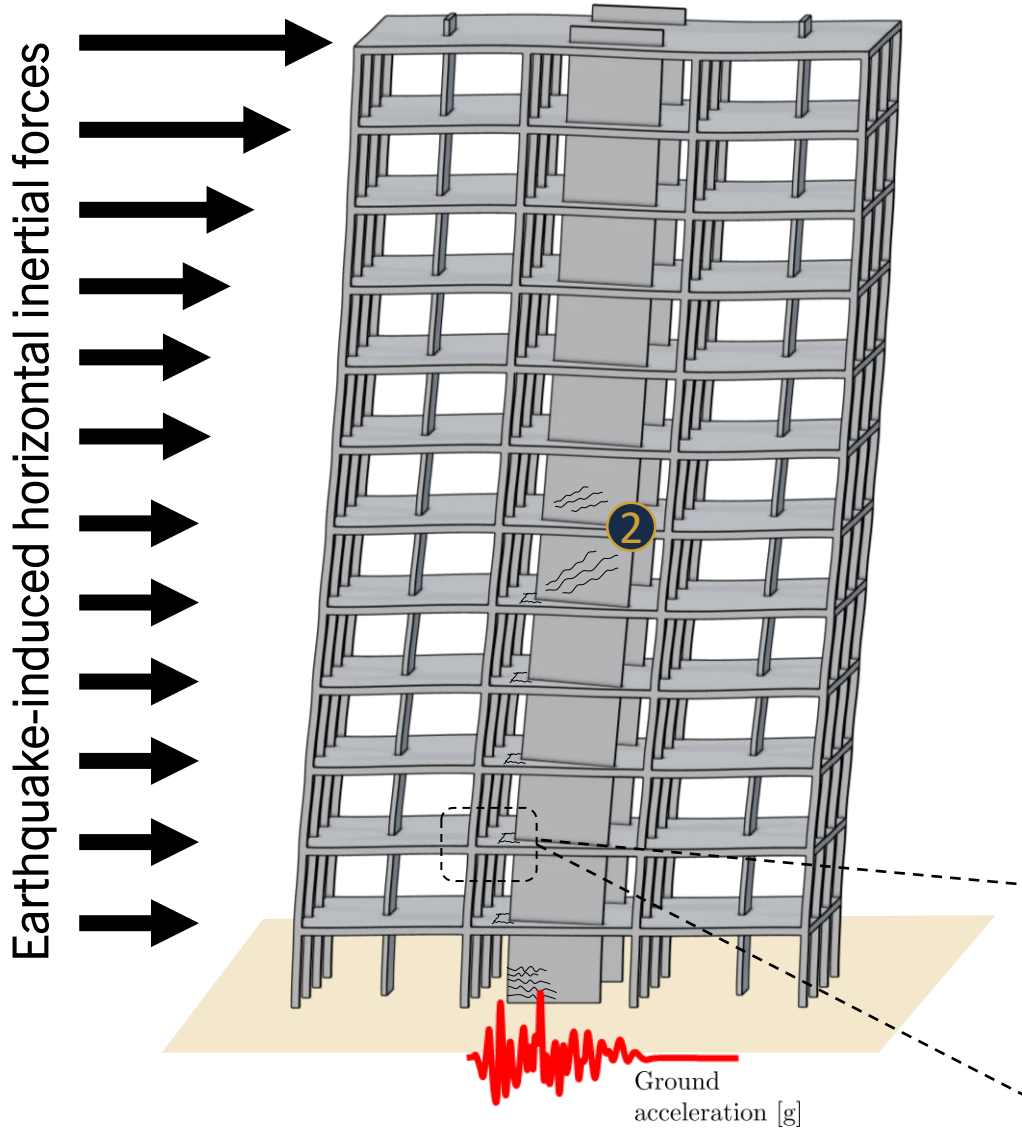
Effects of Uncertainty in the RC Wall Model on Seismic Responses of Buildings with Force-limiting Connections

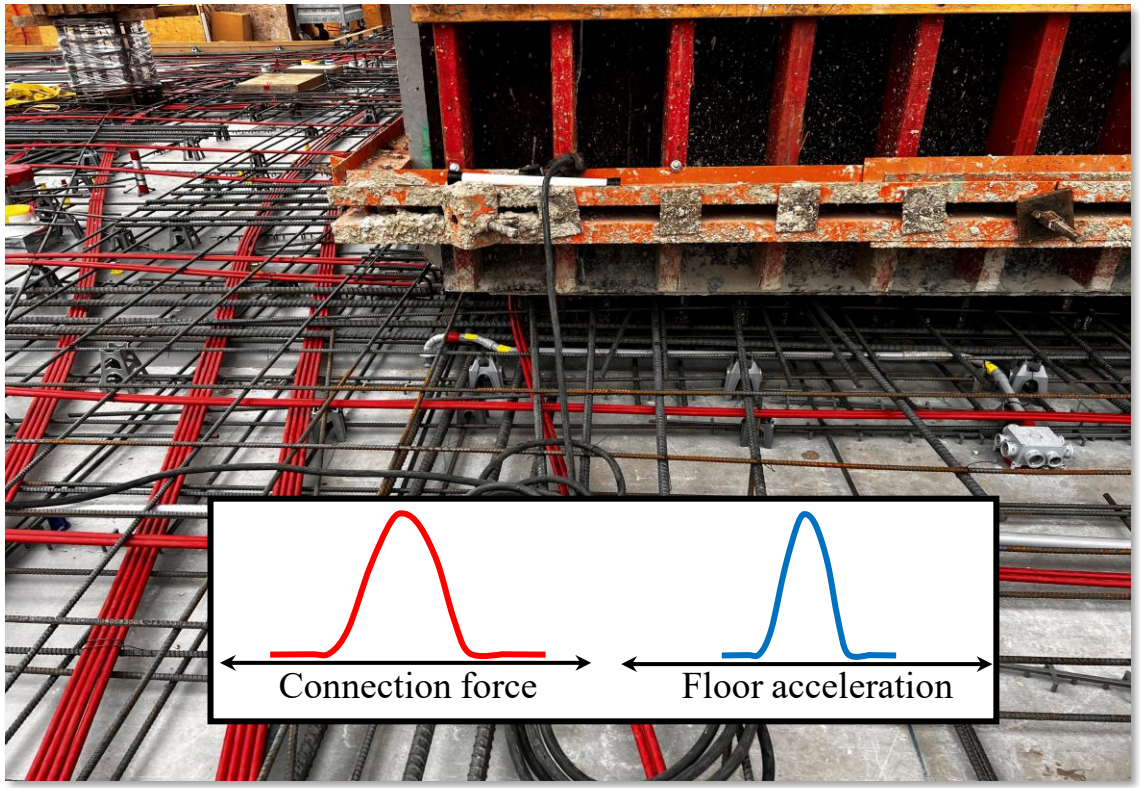
C. Franco Mayorga[1], Georgios Tsampras[2]

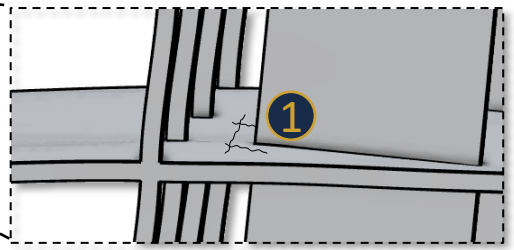
[1]Graduate Student Researcher, University of California San Diego, USA
[2]Assistant Professor, University of California San Diego, USA

Motivation: Diaphragms and their Connections



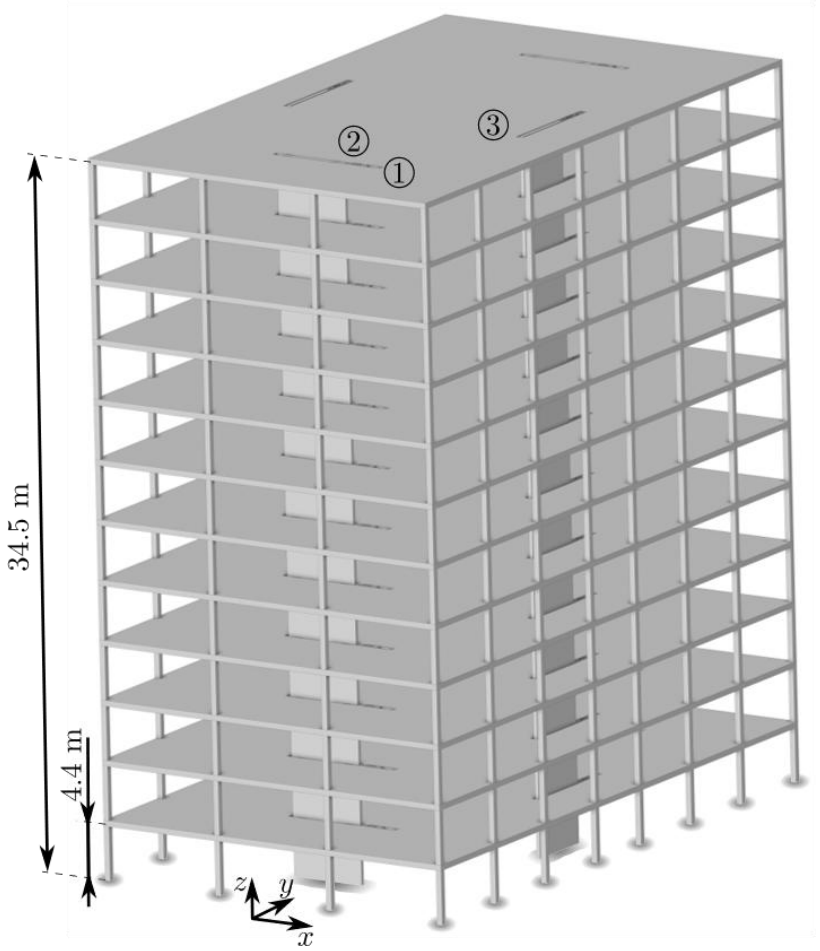
Core wall building construction at UC San Diego

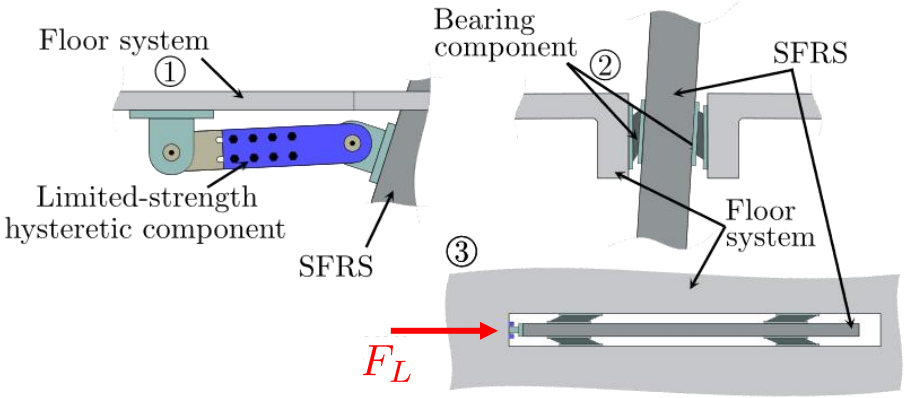


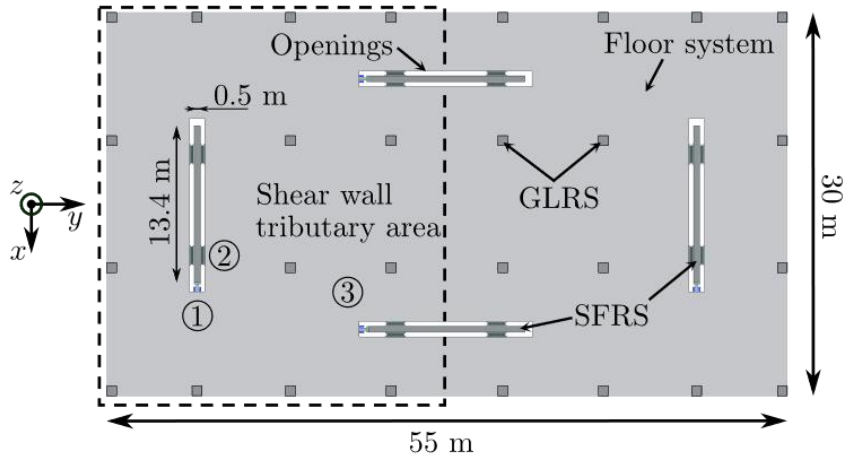


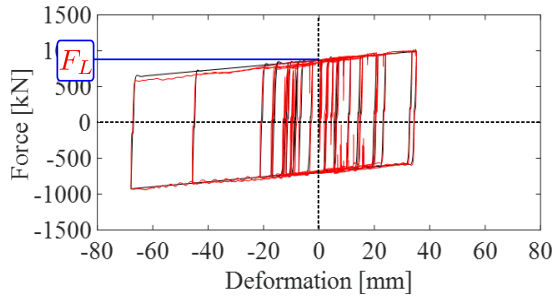
① Kinematic compatibility
② Higher-mode responses

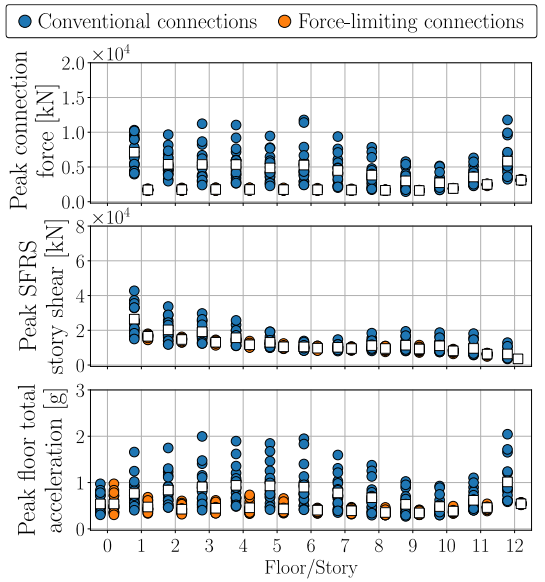
Motivation: Buildings with Force-limiting Deformable Connections







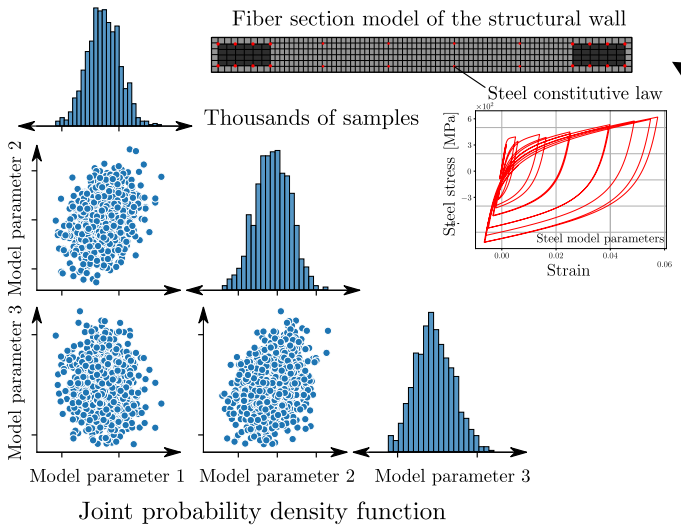


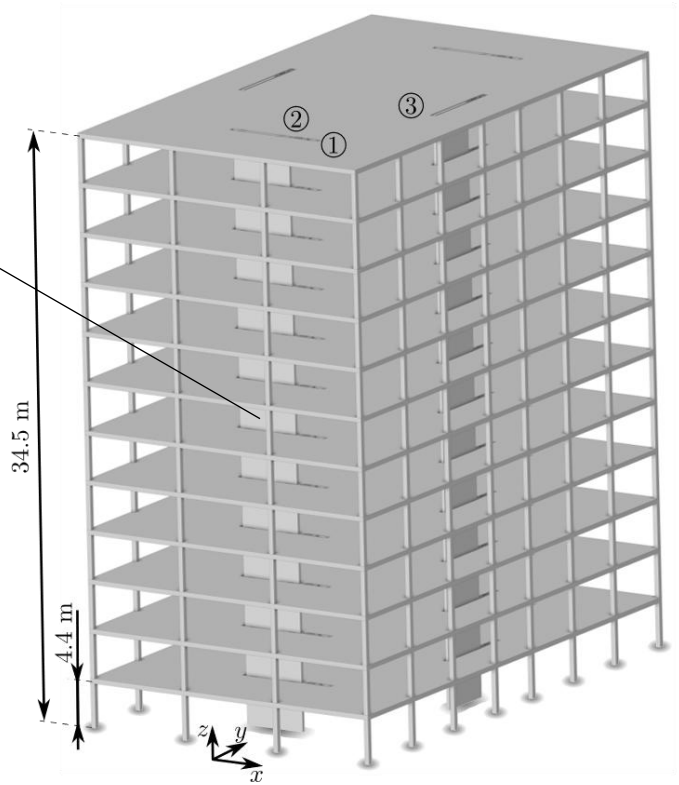


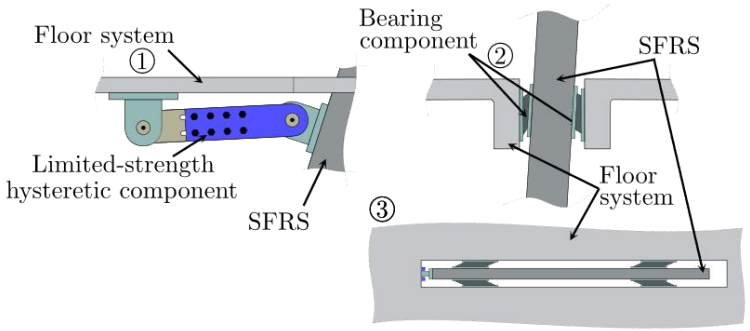
1. Tsampras, G., Sause, R., Zhang, D., Fleischman, R.B., Restrepo, J.I., Mar, D., Maffei, J., 2016. Development of deformable connections for earthquake-resistant buildings to reduce floor accelerations and force responses. Earthquake Engineering & Structural Dynamics 45, 1473–1494. https://doi.org/10.1002/eqe.2718

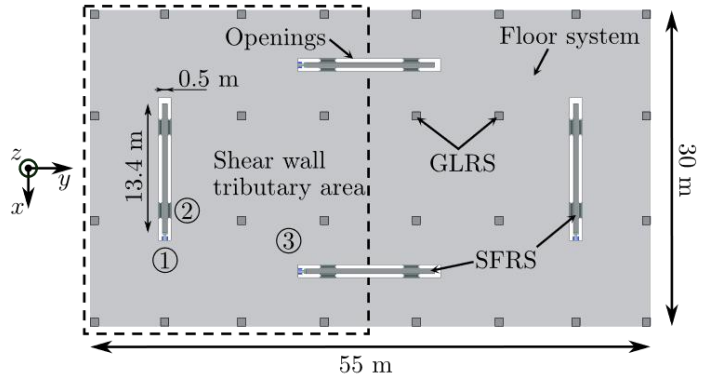
Research Question

How does the **uncertainty** in the **model parameters** of the **constitutive law** of the **RC wall longitudinal reinforcing steel** affect the variability of **seismic responses** of **buildings** with **force-limiting deformable connections**?



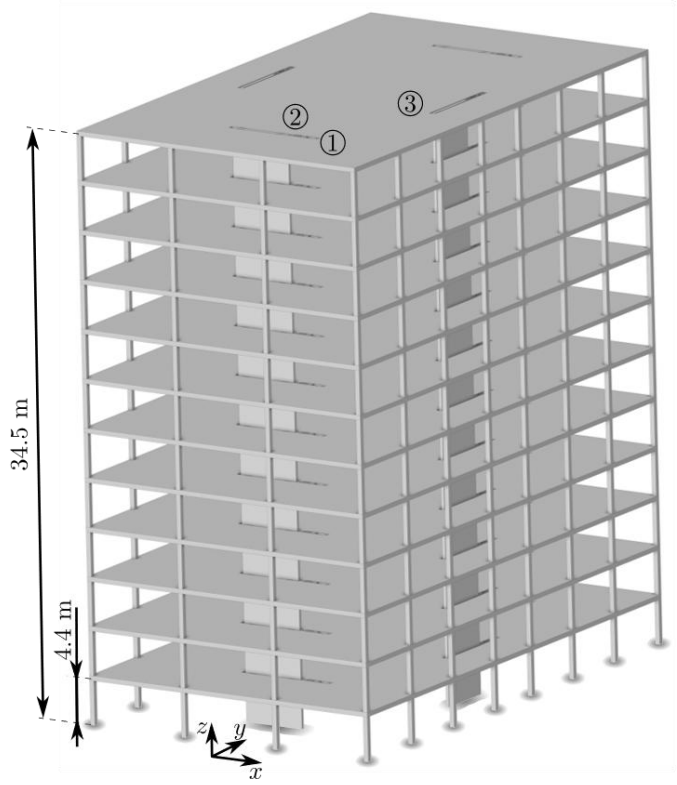


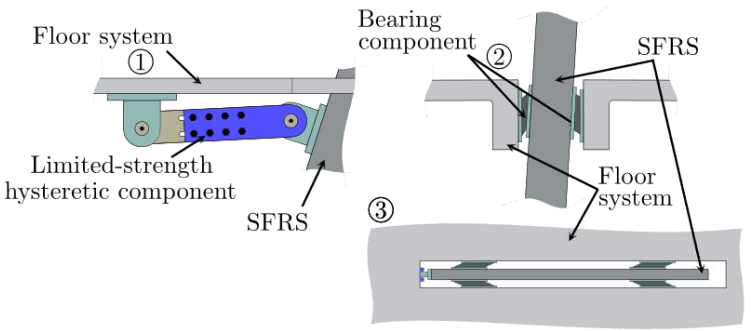


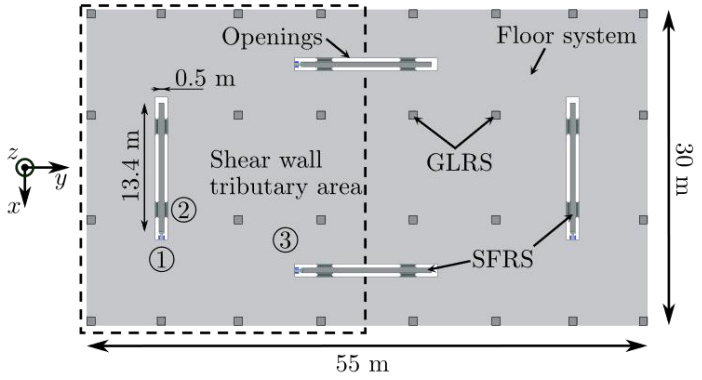


Study Case

Twelve-story building with **force-limiting deformable connections.**







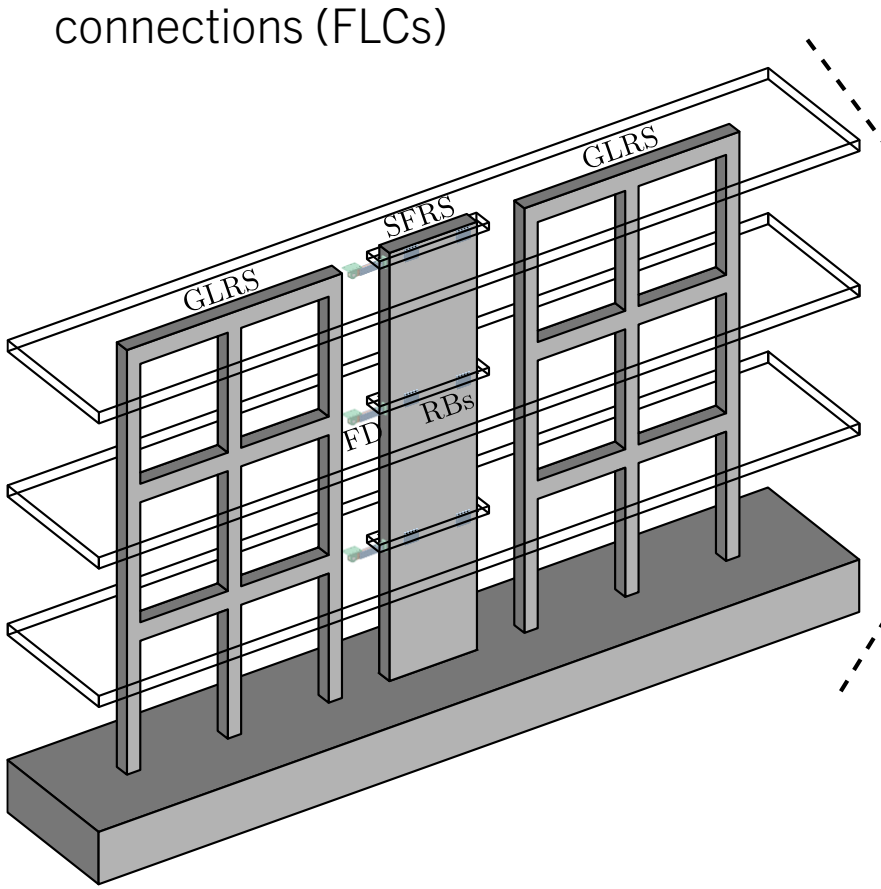
Studied Structural System:

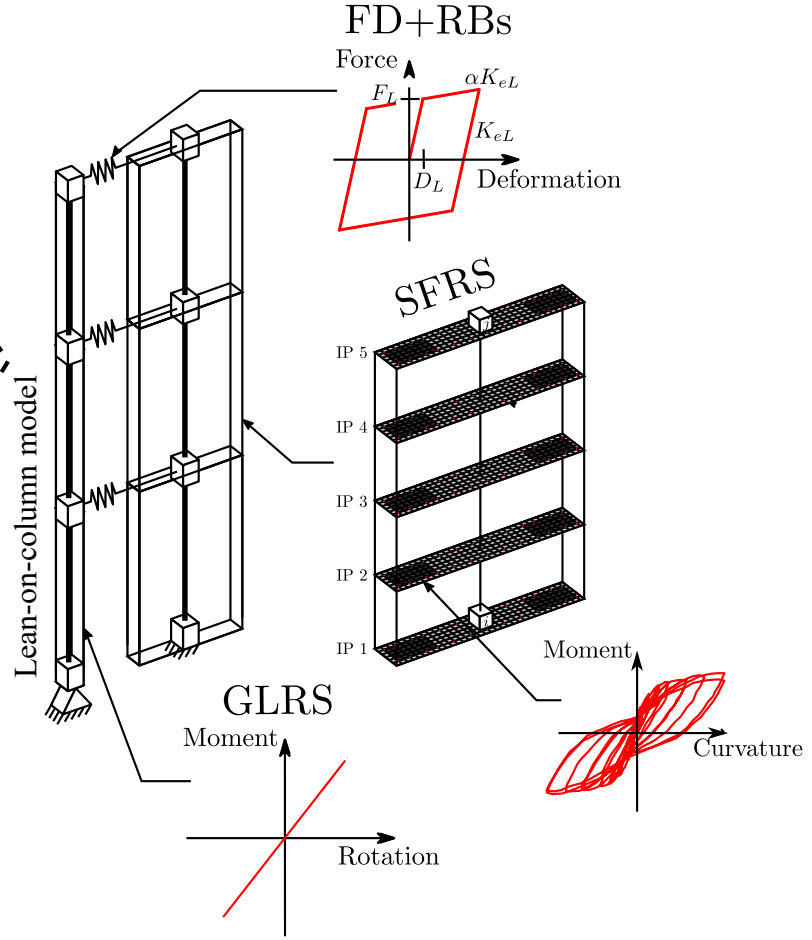
- 12-Story RC building with force-limiting connections
  - 48 friction devices (FDs).
  - 96 rubber bearings (RBs).
- 4 RC rectangular walls as SFRS.
- 28 RC squared gravity columns.
  - 80×80 cm^2 columns in the first seven stories.
  - 55×55 cm^2 columns in higher stories.

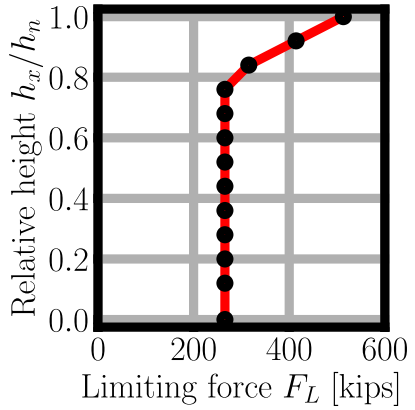
1. Mayorga, C. Franco, and Tsampras G., 2024. Reinforced Concrete Wall Buildings with Force-Limiting Connections: Modeling Effects and Uncertainty Propagation. Earthquake Engineering & Structural Dynamics 53 (4): 1465–91. https://doi.org/10.1002/eqe.4073.

Modeling approach

Gravity-load resisting system (GLRS), seismic force-resisting system (SFRS) , and force-limiting deformable connections (FLCs)







1. Tsampras, G., Sause, R., Zhang, D., Fleischman, R.B., Restrepo, J.I., Mar, D., Maffei, J., 2016. Development of deformable connections for earthquake-resistant buildings to reduce floor accelerations and force responses. Earthquake Engineering & Structural Dynamics 45, 1473–1494. https://doi.org/10.1002/eqe.2718
2. Tsampras, G., Sause, R., 2022. Force-Based Design Method for Force-Limiting Deformable Connections in Earthquake-Resistant Buildings. Journal of Structural Engineering 148, 04022150. https://doi.org/10.1061/(ASCE)ST.1943-541X.0003456

Modeling approach

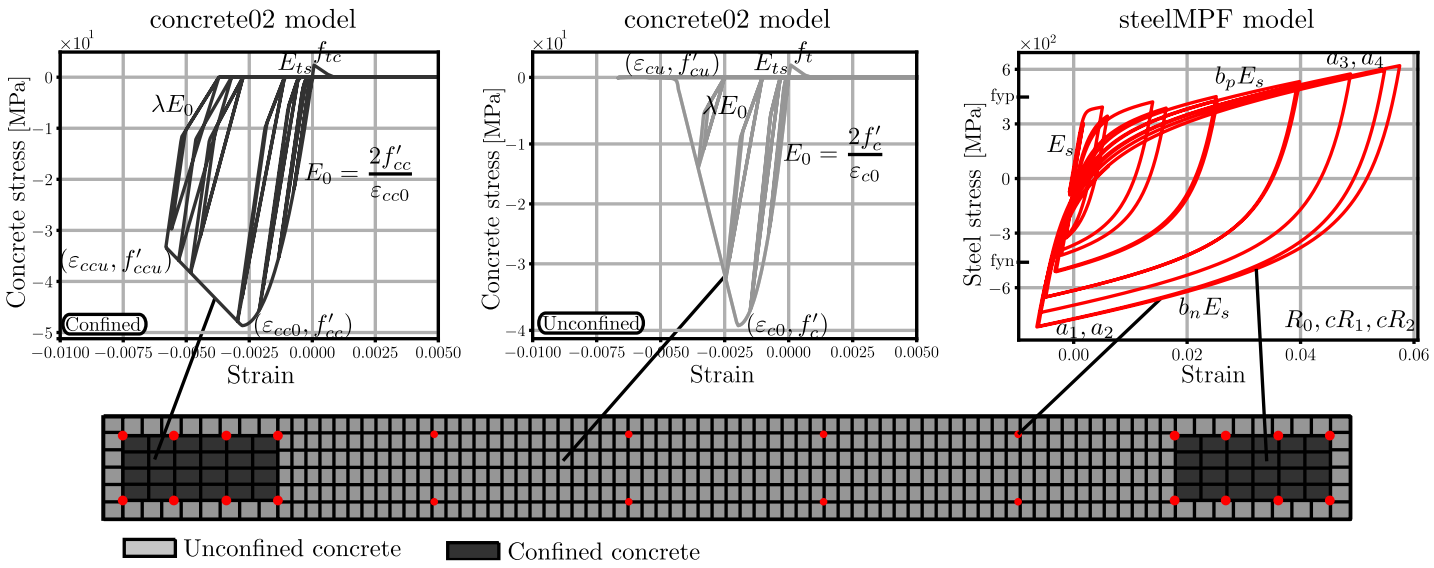
SFRS distributed-plasticity model - Material constitutive laws

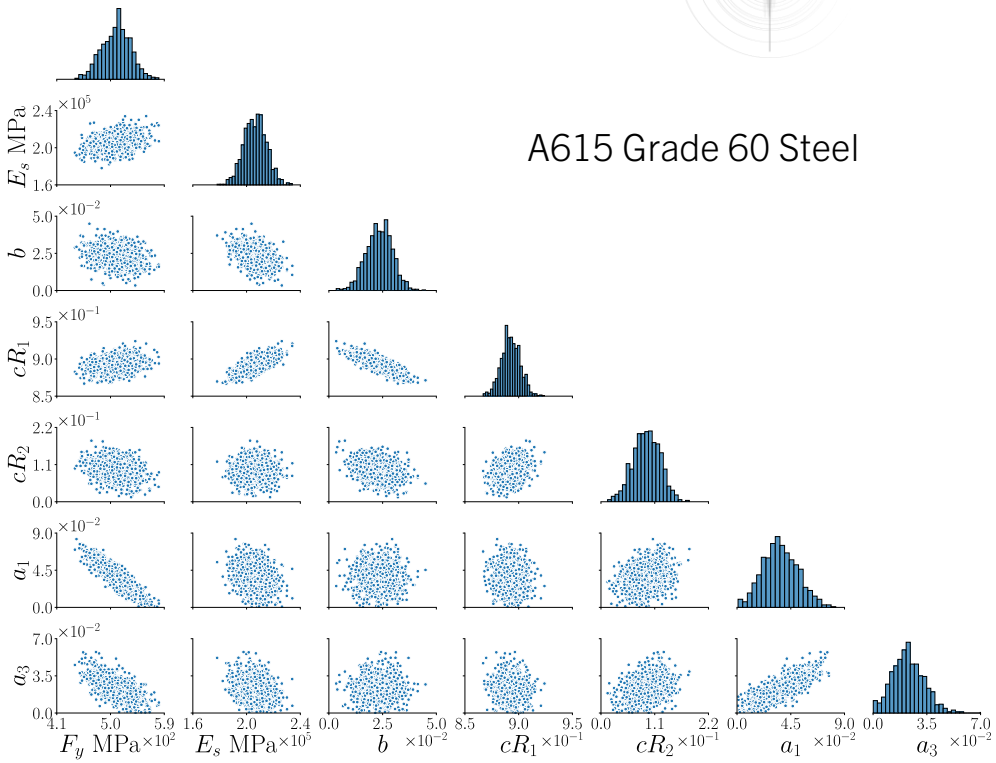
Model parameters of unconfined and confined concrete

- Considered deterministic.

Model parameters of reinforcing steel

- From the joint probability density function proposed by Birrell et al.



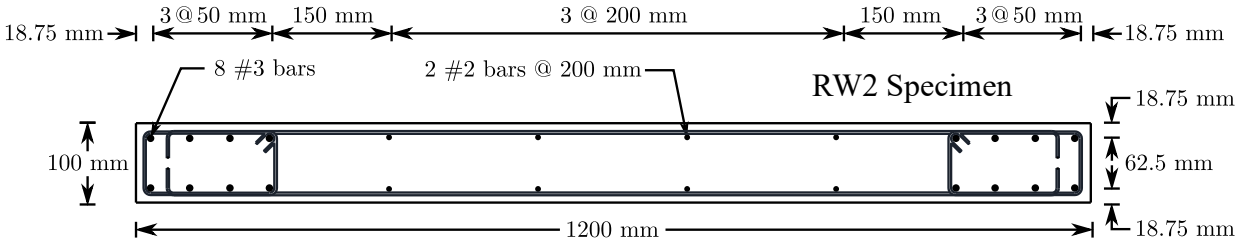


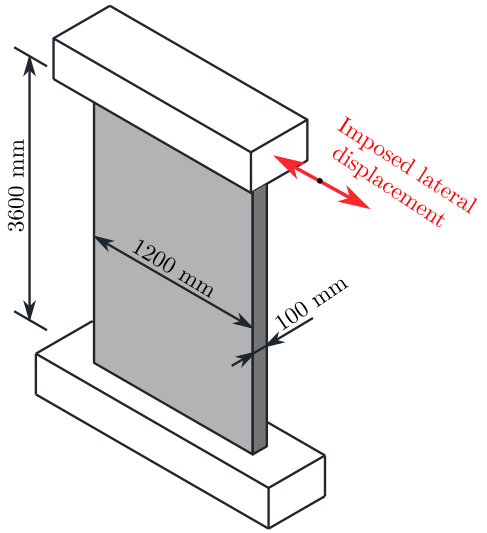
Parameter	Mean	C.o.v. (%)	Correlation matrix
F_y MPa	512.2	5.0	$\begin{bmatrix} 1 & 0.3 & -0.2 & 0.2 & -0.4 & -0.9 & -0.7 \\ & 1 & -0.4 & 0.7 & 0 & -0.2 & -0.2 \\ & & 1 & -0.8 & -0.3 & 0 & 0 \\ & & & 1 & 0.3 & 0 & 0 \\ & Sym. & & & 1 & 0.4 & 0.4 \\ & & & & & 1 & 0.8 \\ & & & & & & 1 \end{bmatrix}$
E_s MPa	206629.0	4.0	
b	0.023	27.0	
cR_1	0.893	1.0	
cR_2	0.093	31.0	
a_1	0.035	45.0	
a_2	0.022	51.0	

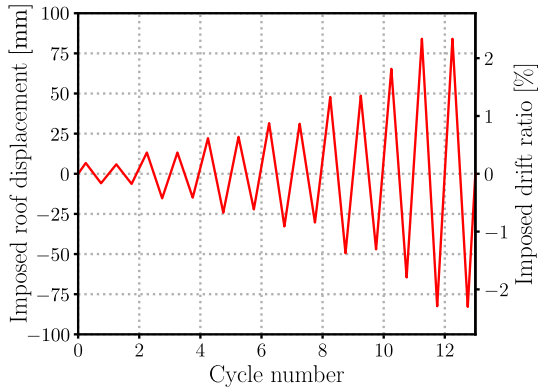
1. Menegotto, M., Pinto, P. E., 1973. Method of Analysis for Cyclic Loaded R. C. Plane Frame Including Changes in Geometry and Non-Elastic Behaviour of Elements under Combined Normal Force and Bending. Proceedings of IABSE Symposium on Resistance and Ultimate Deform Ability of Structures Acted On by Well Defined Repeated Loads 11, 15–22.
2. Yassin, M.H.M., University of California, B., 1994. Nonlinear analysis of prestressed concrete structures under monotonic and cyclic loads. UMI, Ann Arbor, Mich.
3. Coleman, J., Spacone, E., 2001. Localization Issues in Force-Based Frame Elements. Journal of Structural Engineering 127, 1257–1265. https://doi.org/10.1061/(ASCE)0733-9445(2001)127:11(1257)
4. Birrell, M., Astroza, R., Carreño, R., Restrepo, J.I., Araya-Letelier, G., 2021. Bayesian parameter and joint probability distribution estimation for a hysteretic constitutive model of reinforcing steel. Structural Safety 90, 102062. https://doi.org/10.1016/j.strusafe.2020.102062

Modeling approach

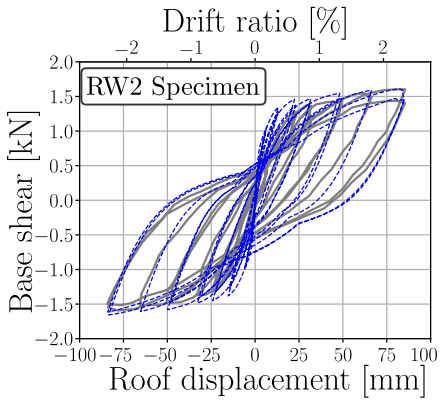
Distributed-plasticity model – Modeling validation





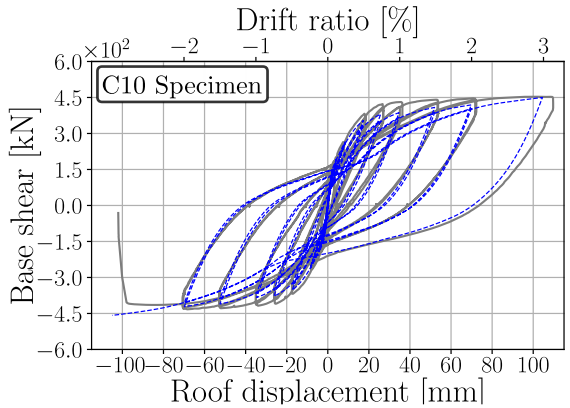


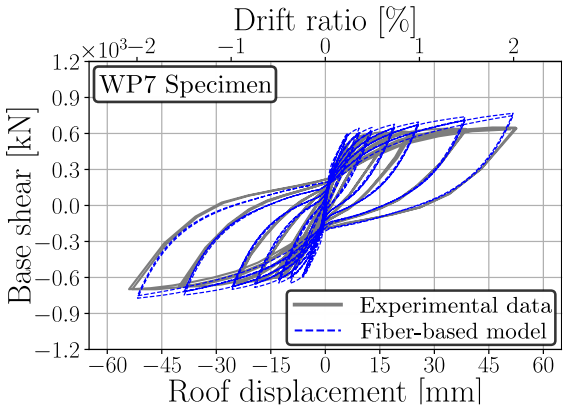
Validation



Parameter	Numerical value
E_s	206.63 GPa
b	0.029
cR_1	0.947
cR_2	0.093
a_1	0.051
a_2	0.022

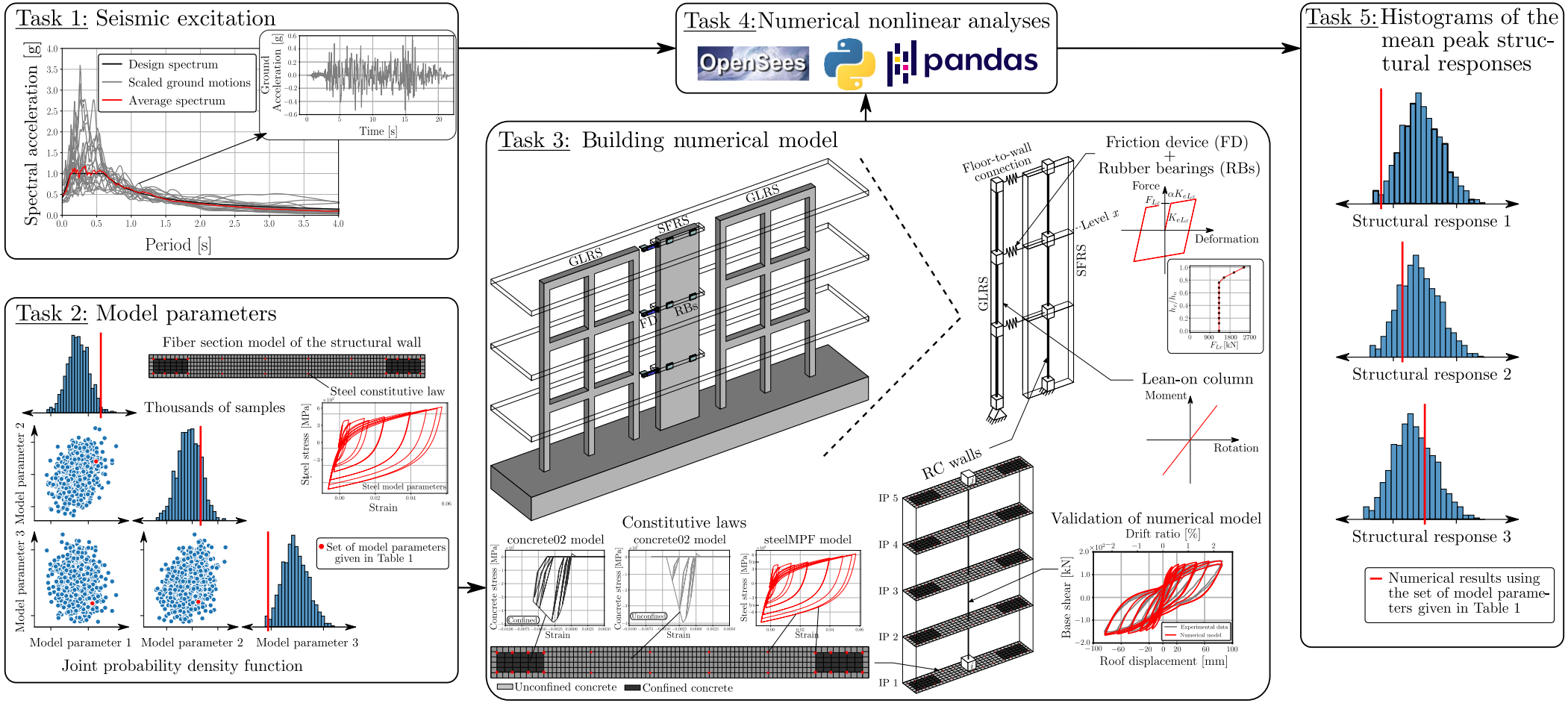
Table 1





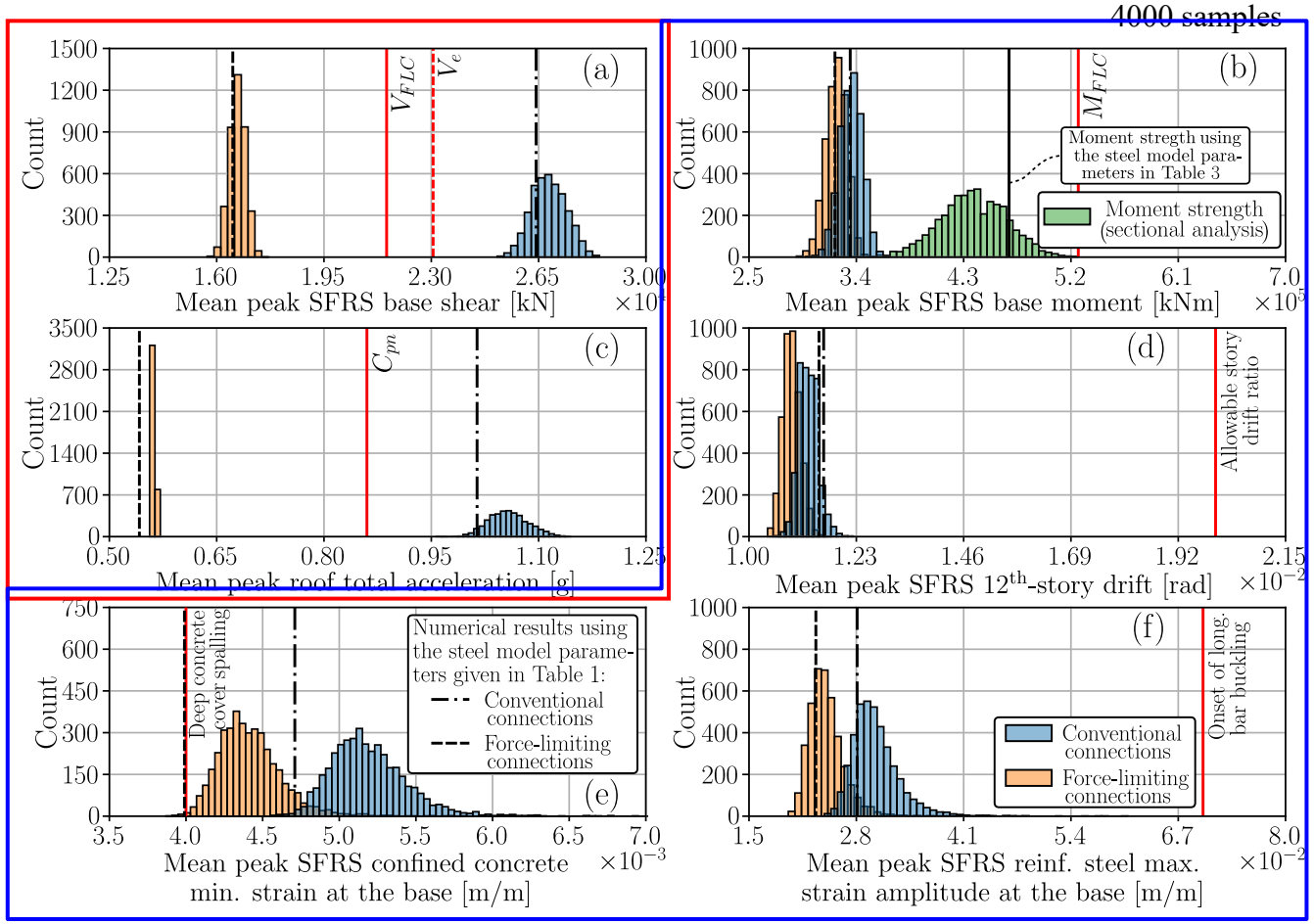
1. Thomsen, J.H., Wallace, J.W., 1995. Displacement-based Design of RC Structural Walls: An Experimental Investigation of Walls with Rectangular and T-shaped Cross-sections. Clarkson University, Department of Civil Engineering.
2. Elwood, K., 2018. University of Auckland High Axial Load Wall Tests. https://doi.org/10.17603/DS2609N
3. Wallace, J., Arteta, C., Segura, C., 2018. NEESR: Seismic Performance of Conventional and Innovative Special Structural Walls. https://doi.org/10.17603/DS2P41P

Uncertainty Propagation Analysis



1. Schuëller, G.I., 2007. On the treatment of uncertainties in structural mechanics and analysis. Computers & Structures, Computational Stochastic Mechanics 85, 235–243. https://doi.org/10.1016/j.compstruc.2006.10.009
2. Birrell, M., Astroza, R., Carreño, R., Restrepo, J.I., Araya-Letelier, G., 2021. Bayesian parameter and joint probability distribution estimation for a hysteretic constitutive model of reinforcing steel. Structural Safety 90, 102062. https://doi.org/10.1016/j.strusafe.2020.102062

Numerical Results: Uncertainty Propagation



Response	Connection case	Mean value	Standard deviation
SFRS base shear [kN]	HSCs	26836.2	559.7
	FLCs	16682.1	260.2
SFRS base moment [kNm]	HSCs	335503.8	9429.2
	FLCs	323121.4	8747.4
Roof total acceleration [g]	HSCs	1.058	0.0273
	FLCs	0.563	0.0014
SFRS 12th story drift [rad]	HSCs	0.0113	0.00020
	FLCs	0.0109	0.00018
SFRS confined concrete minimum strain [-]	HSCs	0.00519	0.00026
	FLCs	0.00442	0.00021
SFRS reinforcing steel maximum strain amplitude [-]	HSCs	0.0304	0.00298
	FLCs	0.0244	0.00213

Response	Connection case	Coefficient of variation
SFRS base shear [kN]	HSCs	2.1%
	FLCs	1.6%
SFRS base moment [kNm]	HSCs	2.8%
	FLCs	2.7%
Roof total acceleration [g]	HSCs	2.6%
	FLCs	0.2%
SFRS 12th story drift [rad]	HSCs	1.8%
	FLCs	1.7%
SFRS confined concrete minimum strain [-]	HSCs	4.9%
	FLCs	4.7%
SFRS reinforcing steel maximum strain amplitude [-]	HSCs	9.8%
	FLCs	8.8%

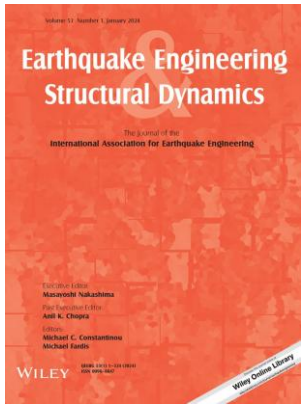
Shear-dominant responses

Flexure-dominant responses

Conclusions

The use of **force-limiting deformable connections** reduces the **mean values** of the **force and acceleration responses** and the **variability** in the **force and acceleration responses** due to the **uncertainty** in the **model parameters** of the **constitutive law** of the **RC wall longitudinal reinforcing steel**.

The reduction in the **variability of the seismic responses** when **force-limiting connections** are included means **higher confidence** in the **response prediction** of buildings with **force-limiting connections**.



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10 April 2024

1. Mayorga, C. Franco, and Tsampras G., 2024. Reinforced Concrete Wall Buildings with Force-Limiting Connections: Modeling Effects and Uncertainty Propagation. Earthquake Engineering & Structural Dynamics 53 (4): 1465–91. https://doi.org/10.1002/eqe.4073.

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The authors acknowledge the Department of Structural Engineering at the University of California San Diego (UCSD), the American Concrete Institute (ACI) Foundation, and the Chilean National Agency for Research and Development (ANID) for their financial support.







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

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Thank you for your attention

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Ministerio de Ciencia, Tecnología, Conocimiento e Innovación
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