Modeling Advances for Numerical Simulation of Existing and Retrofitted Braced Frames

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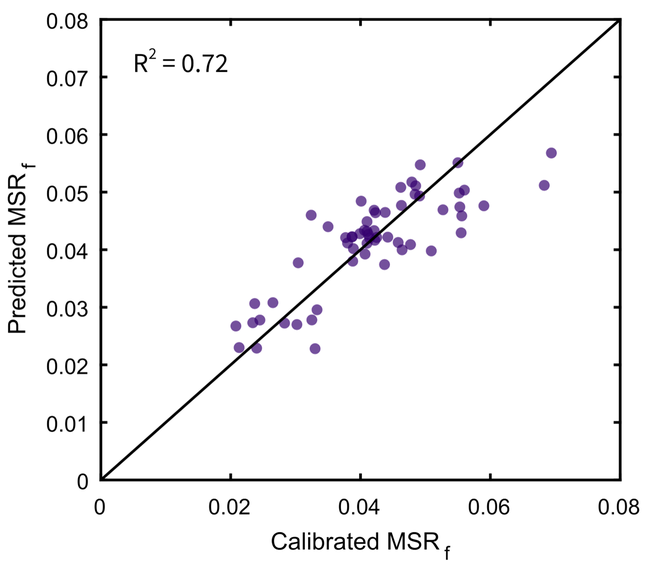
INTRODUCTION

- Substantial inventory of nonductile concentrically braced frames (NCBFs) designed prior to capacity-based and special design provisions (approximately pre-1990)
- Wide variety of brace, connection, and system configurations and deficiencies
- Complex yielding and failure sequences of existing and retrofitted braced frame subassemblages identified in recent experimental research
- **New analytical approaches required to evaluate seismic performance of prototype buildings using OpenSees**

HSS BRACE FRACTURE MODEL

- Maximum strain range fracture model by Hsiao et al. (2013) updated for displacement-based beam-column elements to include additional high b/t test data and account for effects of compression-dominant load histories (e.g., in chevron configuration)

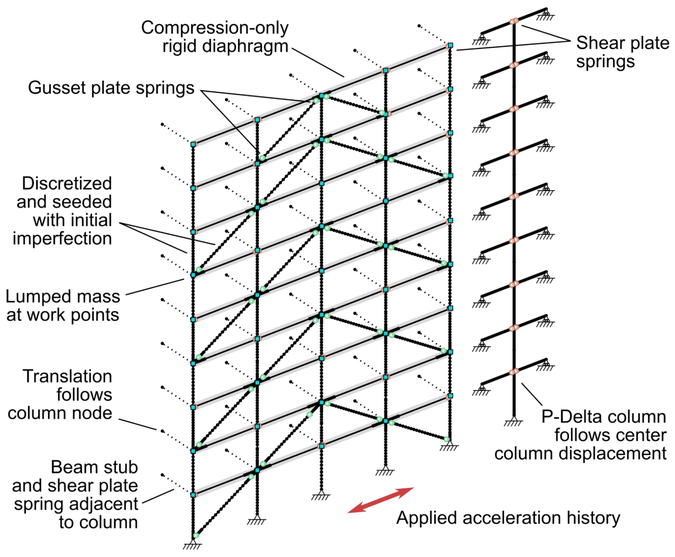


$$MSR_{f,hollow} = 0.554\left(\frac{b}{t}\right)^{-0.75}\left(\frac{L_c}{r}\right)^{-0.47}\left(\frac{E}{F_y}\right)^{0.21}\left(\frac{\delta_{c,max}}{\delta_{t,max}}\right)^{0.068}$$

$$MSR_{f,fill} = 0.0426$$

PROTOTYPE BUILDINGS

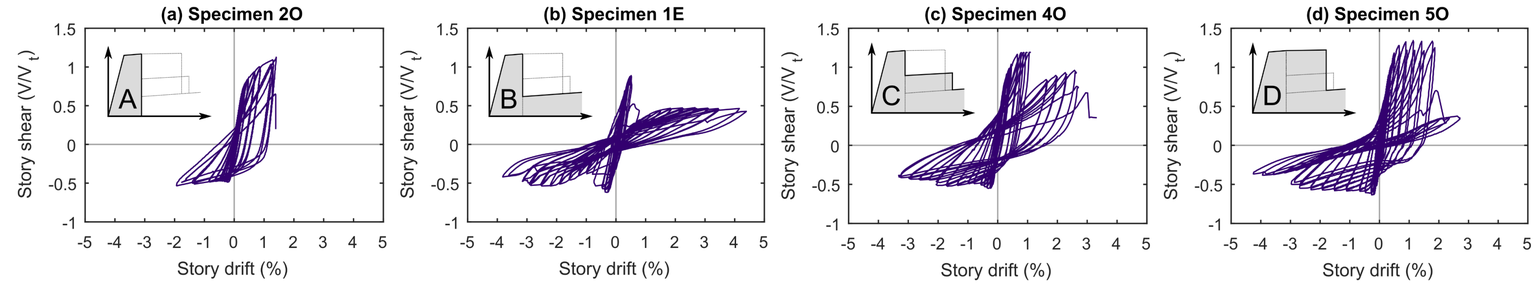
- Prototype NCBF and SCBF buildings designed following the 1979 Uniform Building Code and ASCE 7-16, respectively



CONCLUSIONS

- OpenSees models developed to accurately simulate the nonlinear behavior of existing and retrofitted NCBFs
- Relatively simple retrofit measures are potentially highly effective in mitigating damage
- Ongoing work evaluates the combined effects of component- and system-level deficiencies

GENERALIZED CBF BEHAVIOR TYPES



(a) Specimen 2O
- Premature fracture of brace and beam-to-column connection
- Welded continuous shear plates with strength- and toughness-deficient welds are vulnerable

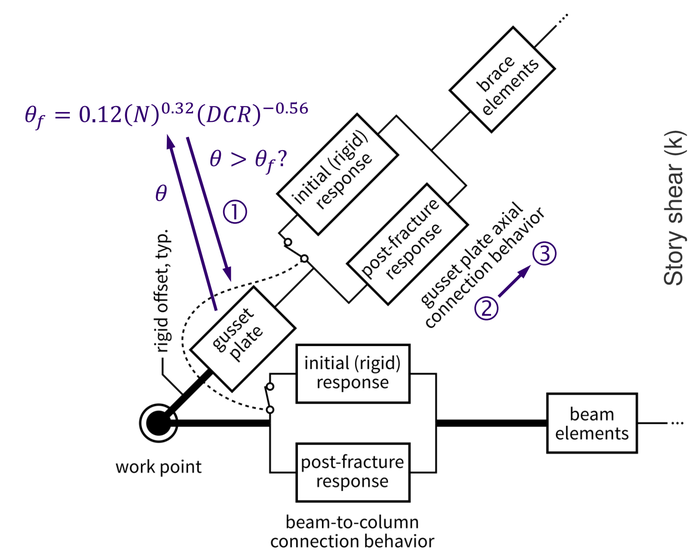
(b) Specimen 1E
- Premature fracture of brace (high b/t) or brace connection (brace-to-gusset or gusset-to-frame)
- Post-fracture resistance from frame action

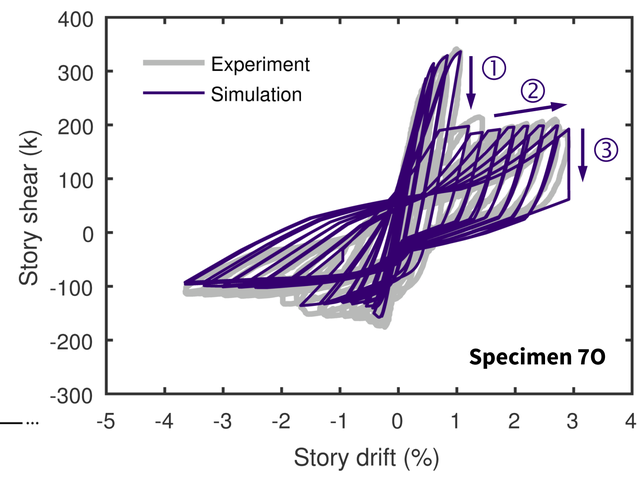
(c) Specimen 4O
- Initial local failure mode due to fracture of gusset-to-beam weld
- Load path to brace maintained through yielding bolted shear plate or double angle gusset-to-column connection

(d) Specimen 5O
- Delayed brace fracture (low b/t)
- SCBF-like behavior
- Achievable through brace replacement and weld reinforcement retrofits

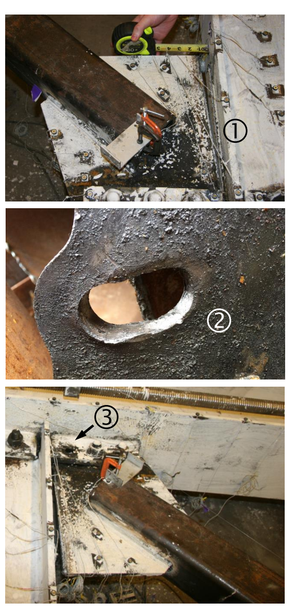
GUSSET PLATE WELD FRACTURE MODEL

- Gusset plate weld fracture model developed using a modified maximum strain range fracture model
- When predicted gusset plate fracture rotation is reached, element removal function is called to achieve Type B or C behavior



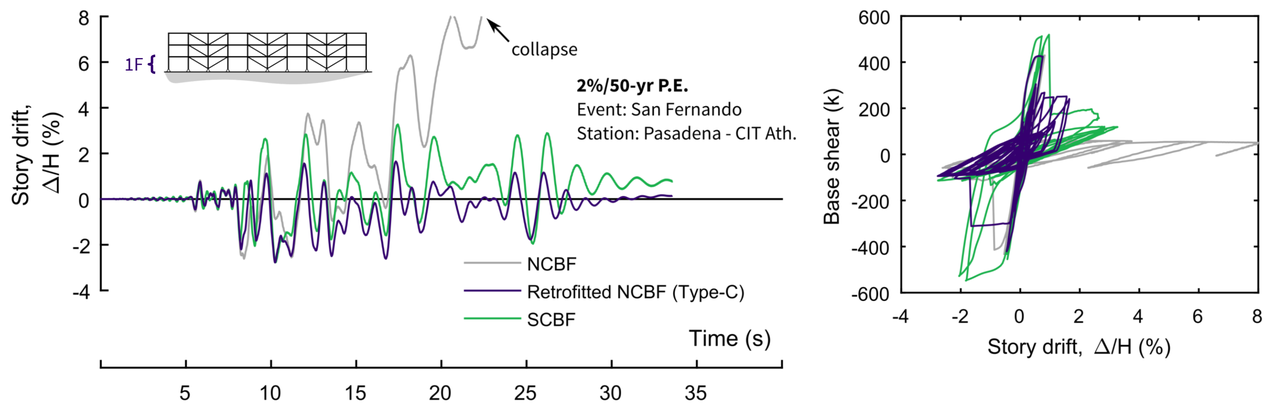


1. (F) Gusset-to-beam weld fracture
2. (Y) Gusset plate bolt-hole elongation
3. (F) Gusset plate bolt fracture

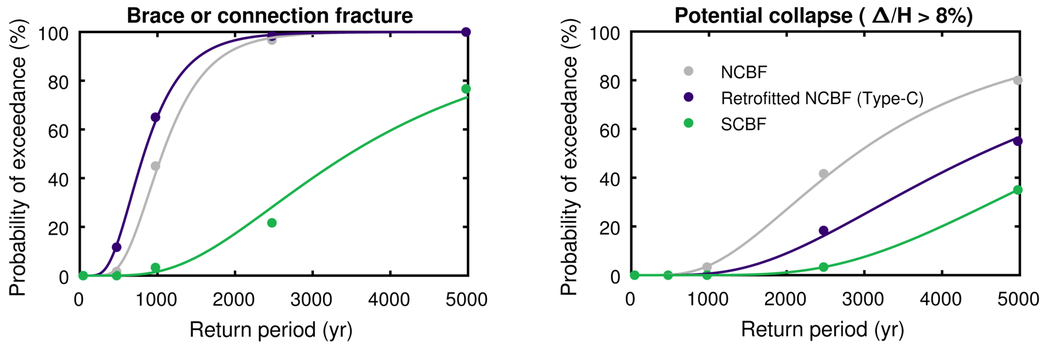


SYSTEM PERFORMANCE EVALUATION

- Evaluation of existing, retrofitted (concrete-filled braces), and new 3-story paired single diagonal CBFs
- Ground motions selected and scaled from NGA-West2 database to match Uniform Hazard Spectrum at 5 return periods



- Lognormal cumulative distribution functions fit as fragility curves for various damage states and used to assess seismic risk under a multiple stripe analysis framework



Building	Probability of potential collapse in 50 years
NCBF	2.00%
Retrofitted NCBF	1.27%
SCBF	0.88%

Note: ASCE-7 targets a 1% probability of collapse in 50 years

REFERENCES

- Hsiao, P. C., Lehman, D. E., and Roeder, C. W. (2013). "A model to simulate special concentrically braced frames beyond brace fracture." *Earthquake Engineering & Structural Dynamics*, 42, 183-200.
- Sen et al. (2017). "Development and evaluation of seismic retrofit alternatives for older concentrically braced frames." *Journal of Structural Engineering*, ASCE, 143(5). <http://dx.doi.org/10.1061/(ASCE)ST.1943-541X.0001738>.

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