Seismic Performance Assessment of Pre-1988 Steel Concentrically Braced Frames

PEER Internship Program – Summer 2013

Undergraduate Intern: Mara Minner - University of California, Berkeley
maraminner@gmail.com
Faculty Mentor: Professor Stephen A. Mahin
Post-Doctoral and Graduate Mentors: Jiun-Wei Lai and Barb Simpson
Research Conducted at the University of California, Berkeley

Introduction

Many existing buildings have lateral load-resisting systems utilizing steel concentrically braced frames designed using codes prior to the 1988 Uniform Building Code (UBC, 1988). Due to differences in detailing, as displayed in Figures 1a and 1b, the ductility of NCBFs is considerably lower than that of modern special concentrically braced frames (SCBF). As a result, the seismic safety of older NCBF buildings is likely lower than that of current AISC-compliant SCBF buildings, and older NCBF buildings may be vulnerable to collapse in response to seismic activity. Figures 2-4 display damage to NCBFs after past earthquakes. Performance-based measures are necessary for owners of existing NCBFs to make informed decisions about possible retrofit strategies. This project seeks to analyze the performance of a prototype NCBF building, assessing the expected repair costs, repair time, casualties, and probability of unsafe placarding following various intensities of seismic activity. The results of the analysis are compared to those of an SCBF system.

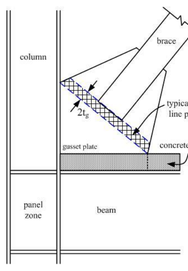


Figure 1a: SCBF connection

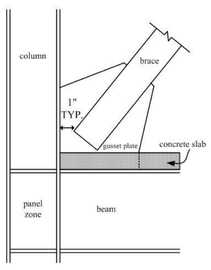


Figure 1b: NCBF connection

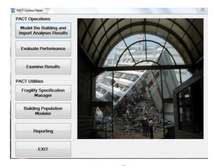
Figure 2: Complete fracture of gusset plate (Lignos, 2011)

Figure 3: Local buckling of square HSS brace (NISEE, 1994)

Figure 4: Global buckling of braces (AIJ, 1995)

Methods

OpenSees → MATLAB → PACT



- **Prototype Building:**

The prototype building design selected for this study is a 3-story office building designed by Troy Morgan (2008) modified to contain four identical NCBFs shown in Figure 5. For comparison, Figure 6 displays the special concentrically braced frame (SCBF) featured in the original design of this prototype building, which is used in the comparison of the building performance of the NCBF and SCBF. Each story is 15 ft in height, and has a rectangular footprint that is 120 ft by 180 ft, with 30 ft bays, shown in Figure 7.

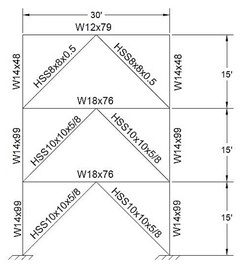


Figure 5: NCBF

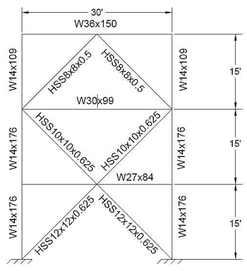


Figure 6: SCBF

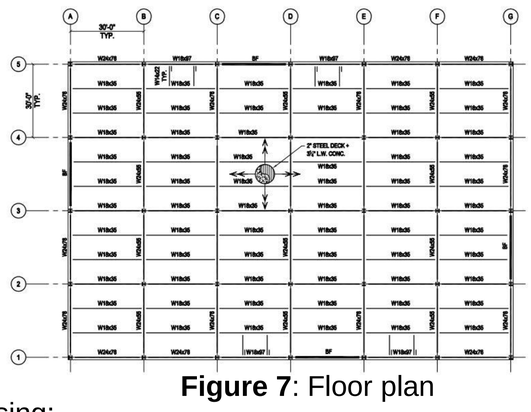


Figure 7: Floor plan

- **2D OpenSees Model:**

A total of 240 dynamic analyses were performed using:

40 Ground Motions

3 Hazard Levels:
- 50%/50 years
- 10%/50 years
- 2%/50 years

2 Earthquake Directions:
- Fault Normal
- Fault Parallel

Story drift ratios, floor velocities, and floor accelerations were recorded. MATLAB was used to post-process the data by extracting peak parameter values and performing a collapse mode assessment.

- **PACT Model:**

The Performance Assessment Calculation Tool (PACT) is a computational tool developed by the Applied Technology Council (ATC) that measures performance in terms of:
- repair and replacement costs
- the probability of incurring casualties
- repair time
- the probability of unsafe placarding (ATC, 2012).

A PACT intensity-based assessment was performed for the NCBF prototype building and repeated for an SCBF system, using the same prototype building but with an SCBF lateral load-resisting system.

Results

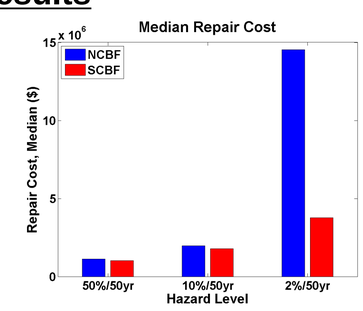


Figure 8: Comparison of repair costs

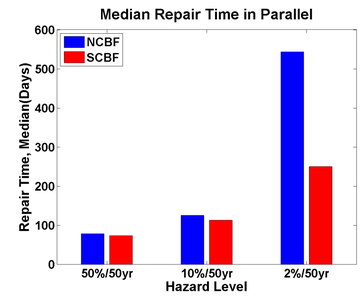


Figure 9: Comparison of repair time in parallel

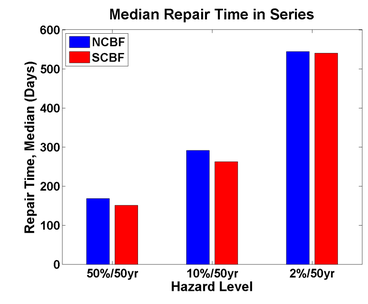


Figure 10: Comparison of repair time in series

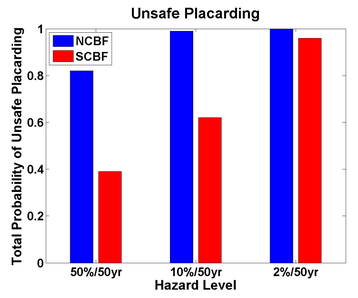


Figure 11: Comparison of probability of unsafe placarding

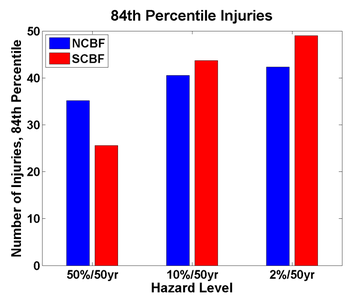


Figure 12: Comparison of injuries

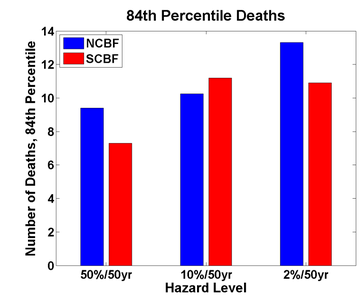


Figure 13: Comparison of deaths

Conclusions

General trends in the PACT results indicate that an SCBF building would generally be expected to outperform an NCBF building in terms of:
- Repair cost
- Repair time
- The probability of unsafe placarding.

Future Work

To continue this research effort, additional PACT analyses can be performed investigating other details of the NCBF system. PACT can also be used to assess the performance of other systems, such as the ordinary concentrically braced frame (OCBF). Additionally, upon completion of an experimental study, retrofit strategies should be explored based on the failure modes that are observed.

Acknowledgements

This research was organized by the Pacific Earthquake Engineering Research (PEER) Center as part of the 2013 Internship Program with financial support provided by the National Science Foundation (NSF). The author would like to thank Professor Stephen Mahin for his invaluable direction and overall geniality during the program. Additionally, the author is deeply grateful for mentors Jiun-Wei Lai and Barb Simpson for their guidance, encouragement, patience, and willingness to answer an interminable number of questions throughout the research process. Much appreciation is likewise directed towards Heidi Tremayne, the coordinator of the PEER Internship Program, for her never-ending effort and commitment to making this program a success.

References

AIJ. (1995). "Reconnaissance Report on Damage to Steel Building Structures Observed from the 1995 Hyogoken-Nanbu Earthquake", Architectural Institute of Japan.

ATC. (2012). "Seismic Performance Assessment of Buildings Volume 1 – Methodology." Applied Technology Council, Redwood City, CA. [electronic version: https://www.atcouncil.org/files/FEMAP-58-1_Volume%201_Methodology.pdf].

Lignos, D. (2011). Tohoku Japan Earthquake & Tsunami Clearinghouse. *EERI*. Retrieved August 15, 2013 from http://www.eqclearinghouse.org/2011-03-11-sendai/2011/08/03/eeri-steel-structures-reconnaissance-group/pgarage-gussetfracture/.

Morgan, T. (2008). "Summary of Design Basis for 3-Story NEES-TIPS Model Buildings." Forell/Elsesser Engineers, San Francisco, CA.

NISEE, e-library. (1994). "Tube fractured due to local buckling." Date Accessed: August 2013. <http://nisee.berkeley.edu/jpg/5074_1631_0641/IMG0027.jpg>.

UBC. (1988). *Uniform Building Code.* International Conference of Building Officials, Whittier, CA.

The PEER Internship Program is funded from a REU Site Award from the National Science Foundation.
More information can be found at http://peer.berkeley.edu/education/internships.html