SEISMIC PERFORMANCE OF DISTRIBUTED KNEE-BRACE (DKB) SYSTEM AS A RETROFIT FOR SOFT-STORY WOOD-FRAME BUILDINGS

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ABSTRACT: The seismic performance of the Distributed Knee-Brace (DKB) system was investigated as a retrofit option for weak-story wood-frame buildings. The performance of the DKB system was evaluated numerically using simplified hand calculations and 2D non-linear dynamic analyses. The numerical simulation results were validated using: (1) reversed cyclic tests of two, four-frame, full-scale test specimens each with different knee-brace configurations; (2) dynamic testing of one of the configurations; and (3) slow pseudo-dynamic hybrid simulation of a three-story wood-frame building with the DKB system retrofit. The DKB system proved to be a viable retrofit option for weak-story buildings with acceptable load-deformation characteristics.

KEYWORDS: Knee-brace, wood-frame, weak-story, soft-story, timber, seismic retrofit, FEMA P-807, hybrid test, reversed cyclic, WCTE 2014

1 INTRODUCTION

The recently published U.S. Federal Emergency Management Agency (FEMA) P-807 Guidelines for Seismic Retrofit of Weak-Story Wood-framed Buildings addresses the urgent need to upgrade seismic performance of a large number of existing two-, three- and four-story wood-frame buildings with soft/weak-story deficiency that are prone to first-story collapse during an earthquake. The NEES-Soft Project (“Seismic Risk Reduction for Soft-Story Wood-frame Buildings”), is a five-university, multi-industry, NSF-funded project that has the objectives of (1) enabling performance-based seismic retrofit (PBSR) for at-risk soft-story wood-frame buildings, and (2) experimentally validating the FEMA P-807 retrofit procedure. As part of the validation effort, a number of retrofit options were investigated through testing of sub-assemblages at various participating universities, pseudo-dynamic hybrid simulations of a three story wood-frame structure at the University of Buffalo, and full scale shake table tests of a soft-story four-story wood-frame structure at the University of California, San Diego.

The Distributed Knee-Brace (DKB) system, one of the retrofit options, consists of an array of light wood-frame knee-braced frames spaced to match wall stud spacing. Each frame is formed by connecting an existing floor joist to an existing wall stud with a 2x4 diagonal wood member. Reinforcement of stud and its connections is provided as needed. The performance of the DKB system in this investigation was evaluated numerically using simplified calculations and 2D non-linear dynamic analyses and calibrated with data collected from physical tests.

2 METHODS

The reversed cyclic tests of a 10-ft frame and 20-ft frame DKB system configurations were performed at Cal Poly San Luis Obispo Structural Laboratory using standard CUREE protocol (ASTM E2126 Test Method C). Each test specimen consisted of four knee-braced frames spaced 16” o.c. (Figure 1). Each knee-braced frame was formed by 2x4 wall stud reinforced with another 2x4, 2x10 floor joist and 2x4 knee braces installed between
the stud and joist with blocking located between the knee braces at joist location. The connections and members were designed to ensure a weak link at the knee-brace-to-joist and the knee-brace-to-stud connections.

**Figure 1: DKB system reversed cyclic test set up.**

The slow pseudo-dynamic hybrid simulation was performed at the University of Buffalo NEES facility (NEES@Buffalo). The test specimen was a three story building with a ground floor DKB system retrofit represented numerically using an analytical model and the upper two floors physically loaded using four actuators (Figure 2).

**Figure 2: DKB System slow pseudo-dynamic hybrid test set up (shows physical upper stories with four actuators)**

A mechanistic model to analyse one of the knee-brace frame configurations tested at the Cal Poly San Luis Obispo laboratory was developed within the Buffalo hybrid testing sequence (Figure 3).

**Figure 3: 2D Knee-brace model for 20-ft frame**

It was modelled using an in-house MATLAB® program [1] developed to model the NEES-Soft project full-scale four-story building for the shake table test and to model the three-story building for slow pseudo-dynamic hybrid simulation test. The model is capable of predicting behaviour through collapse and its predictions are closely correlated with test results.

Finally, for dynamic verification of the DKB system performance a shake table test has been scheduled at Colorado State University in September 2013. The specimen is a 10-ft four-frame DKB system (Figure 4).

**Figure 4: DKB System Shake Table Test Set-up**

The shake table test will be conducted to compare the DKB system dynamic response to the results of the pseudo-dynamic hybrid simulation test of the three-story building conducted at the University of Buffalo.

3 **RESULTS**

With drift capacities of 5% at the ultimate force resistance (~ 2200 lbs/frame), the test data from the preliminary, exploratory reversed-cyclic test demonstrates that the DKB system is a viable retrofit option for soft-story wood-frame buildings (Figure 5).

**Figure 5: Hysteresis curve for 20-ft DKB frame**

At the time of authorship of this abstract, the results of the slow pseudo-dynamic hybrid simulation tests are being processed.

4 **CONCLUSIONS**

Primary results of the physical tests performed so far indicate that the DKB system is a viable retrofit strategy for soft-story wood-frame buildings that could potentially eliminate or reduce the need to reinforce the existing second floor diaphragm and/or foundation, commonly required with other retrofit strategies.

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**REFERENCES**