Controlled Rocking of Steel Frames as a Sustainable New Technology for Seismic Resistance in Buildings

Jerome HAJJAR
Professor
University of Illinois at Urbana-Champaign
Urbana, IL, USA
jfhajjar@uiuc.edu

Matthew EATHERTON
Research Assistant
University of Illinois at Urbana-Champaign
Urbana, IL, USA
meather2@uiuc.edu

Gregory DEIERLEIN
Professor
Stanford University
Stanford, CA, USA
ggd@stanford.edu

Xiang MA
Research Assistant
Stanford University
Stanford, CA, USA
maxiang@stanford.edu

Alejandro PEÑA
Research Assistant
Stanford University
Stanford, CA, USA
a2pena@stanford.edu

Helmut KRAWINKLER
Professor
Stanford University
Stanford, CA, USA
krawinkler@stanford.edu

Sarah BILLINGTON
Associate Professor
Stanford University
Stanford, CA, USA
billington@stanford.edu

Summary

During large earthquakes, traditional seismic lateral resisting systems can experience significant damage distributed throughout the structural system, and residual drifts that make it difficult, if not financially prohibitive, to repair. Higher performance systems that allow a structure to be easily repaired after an earthquake represent a more sustainable method of construction. Controlled rocking of steel frames using replaceable energy dissipating fuses is a new technology which virtually eliminates residual drifts and concentrates the majority of structural damage in replaceable fuse elements, thus minimizing the amount of structural elements that require repair or replacement after an earthquake.

A multi-institution, international research project is underway to develop and validate the performance of controlled rocking braced-frame systems. It is expected that the controlled rocking system will offer a high performance, more sustainable alternative to traditional seismic lateral resisting systems.

Keywords: Seismic Force Resisting System, Controlled Rocking, Self-Centering, Flag-Shaped Hysteresis, Structural Fuses, Sustainable Construction, Steel Buildings, Earthquake Resistance.

Impetus

As the structural engineers look to performance based design as a way to enable building owners to choose a desired level of performance, it becomes important to devise structural systems that can deliver higher performance. Clients concerned about life cycle costs, and sustainable construction that uses damage-tolerant seismic technology, will want a structure that is relatively easy to repair after an earthquake. Traditional seismic force resisting systems for steel-framed buildings are designed to experience controlled yielding at selected locations throughout the structure during a large earthquake. Resulting residual drifts and distributed yielding in non-replaceable elements can make buildings difficult, and costly to repair. A logical higher performance goal is to reduce residual drifts and concentrate structural damage in a limited number of replaceable elements.

The Controlled Rocking System

The controlled rocking system is a seismic lateral resisting system for steel-framed buildings that has the ability to self-center after an earthquake and is configured to concentrate the majority of structural damage into replaceable elements. Shown in Figure 1 is one possible configuration of the

https://doi.org/10.2749/222137908796292146

system, which employs the following main components:

1. Steel frames that remain essentially elastic and are allowed to rock about the column bases. As shown in Figure 1, the specially designed column base details permit column uplift and restrain horizontal motion by bumpers or an armoured foundation trough. The configuration in Figure 1 uses two side-by-side frames, though alternative configurations with single frames are possible.
2. Vertical post-tensioning strands provided to provide active self-centering forces. The strands are initially stressed to about half to three quarters of their ultimate strength, so as to permit additional elastic straining when the frames rock. The configuration in Figure 1 employs post-tensioning down the center of the frame; other configurations with strands oriented on the column lines are also feasible.
3. Replaceable energy dissipating elements act as structural fuses that yield, effectively limiting the forces imposed on the rest of the structure. In Figure 1, the fuses are configured as yielding shear elements between the two frames. Other configurations include fuses at the column bases or in inelastic vertical anchors.

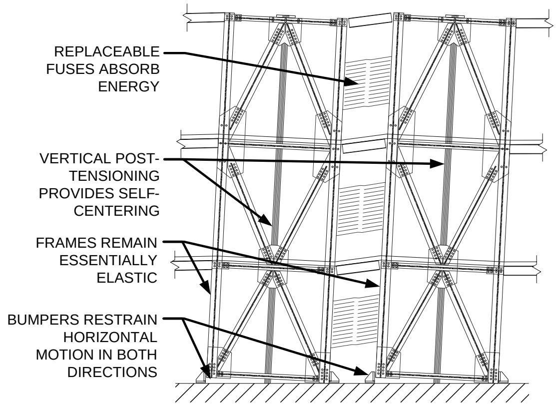

Fig. 1: Controlled Rocking Frame with Replaceable Energy-Dissipating Fuses

Project Phases

The concept design, development, and validation of the controlled rocking system is divided into several phases: 1) Schematic design to define feasible configurations and schematic construction details, 2) SDOF Study to examine the characteristics of the flag-shaped hysteresis loop and study the proportioning of the system, 3) Parametric study using an MDOF model to identify key variables and their effect on the system response, 4) Fuse development through analysis and testing, 5) Large scale cyclic and hybrid simulation tests of the rocking frame, 6) Large scale shake table, and 7) Development of design recommendations to enable practical implementation in practice. Testing is being conducted at Stanford University (item 4), the UIUC MAST-SIM facility (item 5), and the E-Defense facility in Japan (item 6).

Conclusions

Traditional seismic resisting systems that rely on hinging of structural elements can result in residual drifts and distributed structural damage that is difficult and expensive to repair. A proposed alternative to this are self-centering rocking frame systems with replaceable fuses that are relatively easy to repair after an earthquake. Various types of self-centering systems are being researched around the world, each of which has benefits and drawbacks. The controlled steel-braced frame rocking system presented in this paper can virtually eliminate residual drifts while concentrating structural damage in replaceable fuse elements. Analytical studies have been carried out to identify and examine key design variables and demonstrate the viability of the system. Energy dissipating shear fuses have been designed and characterized through testing at Stanford University, and large scale tests at the University of Illinois at Urbana-Champaign and the E-Defense facility in Japan are underway to experimentally validate the rocking system performance.