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No Longer Just a Research Idea - Rocking Technologies as a Practical Approach to Achieving Functional Recovery

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ABSTRACT

Despite progress made in the development of building codes that protect lives, communities continue to face costly and sometimes lengthy recoveries following major earthquakes. For example, after the 2011 Christchurch Earthquake, the central business district was cordoned off for several years and approximately 70 % of the building stock was demolished. The Christchurch experience highlights the limitations of traditional earthquake-resistant design practice that relies on damageable structural "fuses". The present surge of interest in designing for post-earthquake functionality has created the opportunity for innovative approaches to be brought into the mainstream of structural design. Rocking structural systems are designed with deformable connections that minimize structural damage and offer a cost-effective solution to recovery-based design. Their feasibility has been demonstrated through extensive peer-reviewed research and implementation in buildings and bridges. This special session explores the question: *what is hindering wider implementation of rocking technologies*? Industry experts will discuss past research and successful implementations of rocking technologies and introduce coordinated research efforts to characterize the lifecycle benefits of rocking systems over conventional systems. Panelists will provide perspectives on the development of design guidelines and standards; technical knowledge gaps; socioeconomic considerations; and challenges that need to be addressed to motivate wider implementation.

Introduction

Earthquake-resistant buildings have traditionally been designed like an electrical circuit. Given an overload (strong earthquake), predetermined fuses (structural elements) of the building will be damaged and require repair (Figure 1a). In some cases, damage is severe enough that the building is permanently deformed and may need to be demolished. As a result, communities affected by major earthquakes often face costly and sometimes lengthy recoveries. For example, the central business district in Christchurch, New Zealand had to be cordoned off for several years due to extensive damage resulting from the 2011 Christchurch Earthquake, and approximately 70 % of the building stock was demolished, including many newly designed structures [1].

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The Christchurch experience demonstrated that societal expectations for the performance of the built environment do not match the objectives set by current seismic design codes [1]. With the recent publication of the NIST SP-1254 Functional Recovery Report [2] and the NIST SP-1224 Immediate Occupancy Report [3], NIST researchers are leading efforts to advance recovery-based design objectives that prioritize post-earthquake building functionality in addition to occupant safety. The report recommends that new buildings be designed to support acceptable functional recovery times following a major earthquake. However, designing buildings for limited earthquake damage and rapid recovery using conventional construction practices may not be economical or feasible; therefore, it is prudent to revisit emerging approaches that have potential to deliver the desired performance.

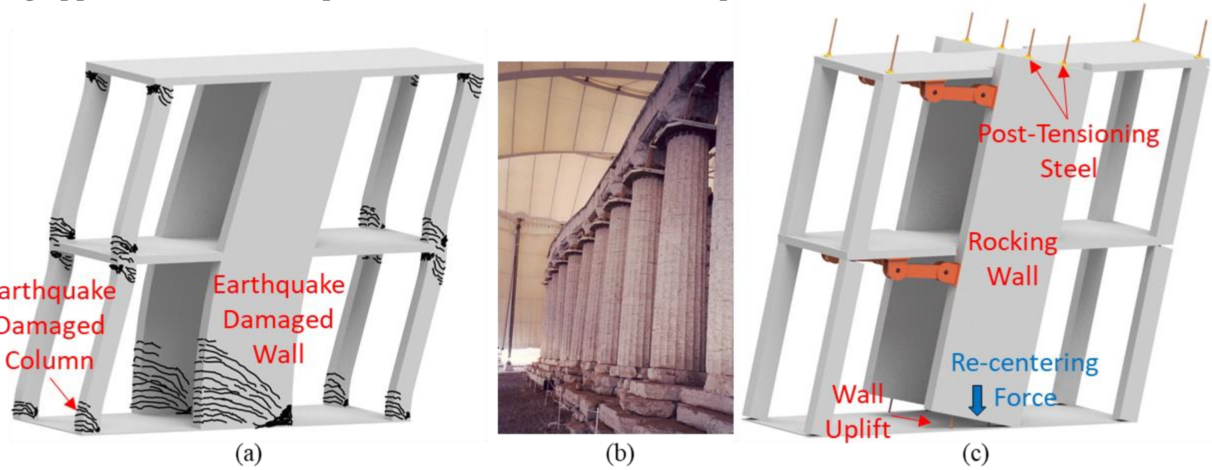

Figure 1. (a) Seismic Response of Conventional Reinforced Concrete Building; (b) Rocking Columns in the Epikoureios Apollo Temple at Bassai [4]; and (c) Seismic Response of Building with Rocking Walls

Rocking Structural Systems

Rocking structural systems that have been proven as earthquake protective mechanisms in ancient civilizations (e.g., Figure 1b) can be implemented to limit damage and preserve building functionality, while also ensuring occupant safety, offering a potentially inexpensive solution for earthquake-resistant construction that better aligns with societal expectations. In rocking systems, the elements (e.g., columns and walls) are designed to uplift once the resistance provided by their self-weight is exceeded (Figure 1c). The ingenuity of the system is that the uplifting behavior protects the rocking elements from damage. In addition, the system utilizes gravity to re-center, preventing permanent deformation while providing stable earthquake resistance. Researchers have developed economical rocking technologies that use post-tensioning steel (Figure 1c) to supplement the system's gravity resistance without the need for excessively large and heavy columns or walls. Rocking systems have been implemented in a small number of buildings with little or no additional cost as compared to conventional systems (e.g., [5]). Despite extensive peer-reviewed research demonstrating their feasibility, wider implementation of rocking systems has been hindered, presumably due to a lack of knowledge, experience, technical design guidelines, and other factors. To promote the next generation of earthquake-resistant construction, there is a need for documented cost-benefit analyses demonstrating the value of rocking systems.

Rocking has been investigated by numerous researchers over the last few decades. Research on rocking and self-centering systems is extensively summarized in a recent literature review by Zhong and Christopoulos [6]. This review highlights applications to bridges and the design and retrofit of new and existing buildings utilizing a variety of construction materials including steel, reinforced concrete, masonry and timber. The state-of-the-art for designing select rocking systems has also been highlighted in the scientific literature [7] and initial design guidelines and standards have been developed for some of these systems [8, 9].

This special session includes seven short presentations and a panel discussion that provide a snapshot of research on rocking systems in buildings and discuss challenges to wider implementation including the need for design guidelines and standards to promote uptake by the engineering profession. The presentation speakers and topics are as follows:

- **Christopher Segura and Matthew Speicher, NIST**: Research efforts at NIST to evaluate the technical and socioeconomic benefits of rocking, self-centering systems
- **Greg Deierlein, Stanford University**: Research on controlled rocking of steel braced frames and a researcher perspective on hurdles to wider implementation
- **Nicos Makris, Southern Methodist University**: Benefits of gravity to control rocking and the role of the rotational inertia in rocking structures
- **David Mar, Mar Structural Design**: The case for rocking systems – cost-benefits and successful implementations
- **Stefano Pampanin, Sapienza University of Rome**: Towards a practical implementation of low-damage systems to enhance community resilience
- **Georgios Tsampras, University of California San Diego**: Practical approaches for connecting elements in rocking systems
- **Lydell Wiebe, McMaster University**: New Zealand design guide – success and challenges of implementing rocking

Opportunity for Change

The National Institute of Standards and Technology (NIST) became the lead agency for the National Earthquake Hazard Reduction Program (NEHRP) in 2004. Since then, NIST has led and funded earthquake-related research on numerous topics, one of which is an effort to advance the use of performance-based seismic design (PBSD) methodologies. Along with the Federal Emergency Management Agency (FEMA) and the National Science Foundation (NSF), the federal efforts supporting PBSD have produced a wealth of new knowledge and tools to design buildings to perform better during earthquakes. However, given the renewed recognition of the importance of post-earthquake functionality in addition to life safety, great benefit may be had by shepherding low-damage technologies into the mainstream of engineering practice.

A new research initiative at NIST is underway to "bridge the gap" between research and practice for low-damage technologies, with the first push looking into rocking systems. In collaboration with industry leaders, NIST researchers are conducting seismic performance evaluations on a set of archetype buildings designed with conventional earthquake-resistant structural systems (e.g., concrete shear walls) and, alternatively, with low-damage rocking systems (e.g., post-tensioned rocking walls). By applying advanced seismic performance tools (e.g., FEMA P-58 [10], SP3 software [11]), the NIST research will compare earthquake recovery metrics (repair cost and time, casualty rate, likelihood of a red tag designation, and reparability) for the conventional and low-damage systems to evaluate the lifecycle benefits of rocking systems. Findings of this research will be used to demonstrate the potential benefits of wider implementation of rocking systems as an effort to further promote earthquake resilience. It is envisioned that dissemination of this research and other such efforts will encourage earthquake engineering professionals to initiate the development of design guidelines and standards which will help motivate wider use of low-damage earthquake-resistant construction technologies.

Conclusions

With an understanding of the potential consequences of future damaging earthquakes, the earthquake engineering community is beginning to evaluate options for, and the feasibility of, designing buildings with a focus on post-earthquake recovery in addition to occupant safety. For some earthquake-resistant construction applications, rocking structural technologies are an economical solution that can limit earthquake damage and enable rapid recovery of building function following a major earthquake. This session brings together industry experts to discuss the path towards wider implementation of state-of-the-art rocking technologies in new and existing buildings. The session provides a high-level overview of major research efforts related to rocking structures, as well as successful implementation in buildings prone to strong earthquake shaking. To bridge the gap between research and implementation, sessions speakers and panelists will also discuss ongoing, coordinated research efforts intended to pave the way for the development of design guidelines and standards that will support the next generation of earthquake-resistant construction.

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