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VIRTUAL REALITY OF EARTHQUAKE GROUND MOTIONS FOR EMERGENCY RESPONSE

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Keywords: Ground Motions, Performance-Based Earthquake Engineering, Building Information Modeling, Virtual Reality, Emergency Response, Earthquake Early Warning.

Abstract. *Ground motions interface earthquake science and engineering to advance understanding of seismic hazards and risk. Virtual reality provides an attractive tool to extend knowledge of the research community to a larger audience. This work visualizes emergency response under extreme motions, in the CAVE of the MARquette Visualization Laboratory. The visualization (a) displays ground motions (from the science community), (b) inputs these motions to structural models (from the engineering community) and illustrates the resulting responses, (c) translates structural responses to damage states of building elements, (d) creates a virtual room subjected to the perception associated with such earthquake shaking, and (e) introduces the human element of emergency response in this immersive environment. Building upon previous work on earthquake simulations, performance-based earthquake engineering (PBEE), building information modeling (BIM), and earthquake awareness, this study integrates elements of PBEE and BIM within the CAVE environment to provide visual information for decision making. Real-time or near real-time information via earthquake early warning (EEW) and structural health monitoring (SHM) further facilitates response within a limited time frame. As advanced technologies contribute to the future of community resilience, visualization plays an emerging role in connecting earthquake science, engineering, and policy.*

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1 INTRODUCTION

Ground motion definition is the link between seismic hazard and structural response, the first two elements of performance-based earthquake engineering. Site- and structure-specific ground motion selection is enabled by improved ground motion prediction and considerations of important seismic parameters for nonlinear dynamic analyses [e.g., 1-6]. Ground motion databases are growing, with denser instrumentations to provide more empirical recordings (e.g., PEER NGA database), physics-based and broadband simulations [e.g., 7-12] that are facilitated by high performance computing, and breakthroughs in geophysical understanding that push the frontiers of simulations to the high-frequency range (e.g., high-F project). Structural models are also evolving with enhanced accuracy and complexity to capture important structural behaviors such as structural collapse, cumulative damage and "in-cycle" strength and stiffness degradation [e.g., 13-15]. In the past decade, significant progress has been made in the performance-based earthquake engineering framework to interpret structural performance results in terms of structural response, damage, and loss [e.g., 16-17]. At the same time, Great ShakeOut Earthquake Drills (www.shakeout.org) are extending beyond California to improve earthquake preparedness, with over 24.9 million and 26.5 million participants worldwide in 2013 and 2014 respectively, and continue to grow over the years. The advancements in hazard characterization, structural modeling, performance interpretation, and emergency preparedness offer a unique opportunity to integrate these fields to complete the loop of earthquake science, engineering and policy to reduce risk.

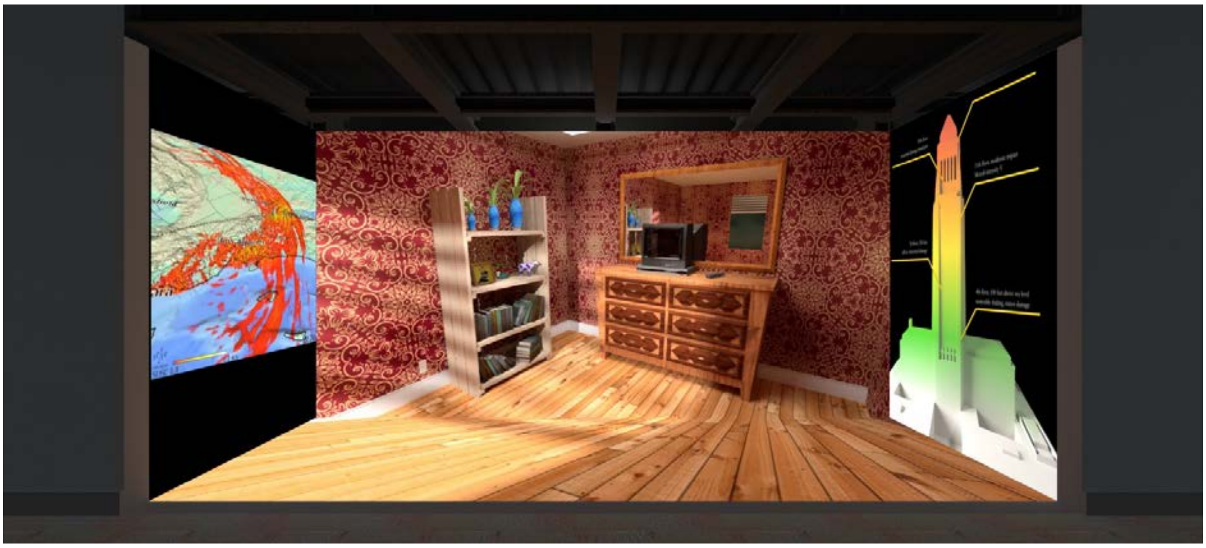

Figure 1: Visualizing Emergency Response Under Extreme Motions: Illustrative CAVE visualization of SCEC M8 (example video from [9]) earthquake simulations (on the left side wall), responses of a structural model (on the right side wall), a virtual room in the site- and structure-specific shaking environment (on the extra-wide front wall), and an emergency response participant (on the floor) to immerse in the interactive space.

This work in the Multi-Hazard Sustainability Research Group (www.HazSus.org) is a first step of a pilot study which aims to visualize emergency response under extreme motions, in the CAVE of the MARquette Visualization Laboratory (www.eng.mu.edu/vizlab). The visualization

- displays ground motions (from the science community)
- inputs these motions to structural models (from the engineering community) and illustrates the resulting responses
- translates structural responses to damage states of building elements

- creates a virtual room subjected to the perception associated with such earthquake shaking
- introduces the human element of emergency response in this immersive environment

This study builds upon previous work on earthquake simulations, performance-based earthquake engineering, building information modeling, and earthquake awareness.

2 BASIC SETUP OF VIRTUAL REALITY

The basic setup of the CAVE is illustrated in Figure 1, with earthquake science on the left, structural engineering on the right, and building information modeling in the middle, all of which facilitate "human-CAVE interaction". In the earthquake simulations, a marker "You are here" can be placed at the site of interest where site-specific ground motions can be obtained. These motions are used as seismic loading to the structure of interest whose dynamic responses, such as story drifts and floor accelerations, can be displayed. The specific floor and room that represents the immediate environment can then be located and modeled as a virtual environment, with nonstructural elements such as partition walls, as well as content such as the dresser, mirror, TV, and bookshelf with books and vases shown in Figure 1. The floor extension from the virtual room model creates a real space that allows additional items, such as a desk and an emergency kit, to be placed inside the CAVE. The emergency response participant can practice in this space what ShakeOut participants do with earthquake drills.

3 RUPTURE TO RAFTERS TO RESPONSE

This "Visualized ShakeOut" completes the cycle of "Rupture to Rafters to Response". The level of virtual shaking and corresponding actions depend on the site-specific motions, structural characteristics, and building elements of interest. Performance-based earthquake engineering (PBEE), which links seismic hazard to structural response, damage and loss, can be used to visualize emergency response under varying levels of motions. The input ground motions may come from extreme yet rare events such as those from the ShakeOut simulations [11], or more frequent events with lower intensity levels, which can be obtained from the PEER NGA database recordings, or a range of motions from the SCEC CyberShake simulations [12]. PBEE evaluates structural performance under frequent to rare earthquakes (Figure 2a). The structure can be modeled using OpenSees, and nonlinear dynamic analyses performed to estimate responses such as displacements and accelerations (Figure 2b).

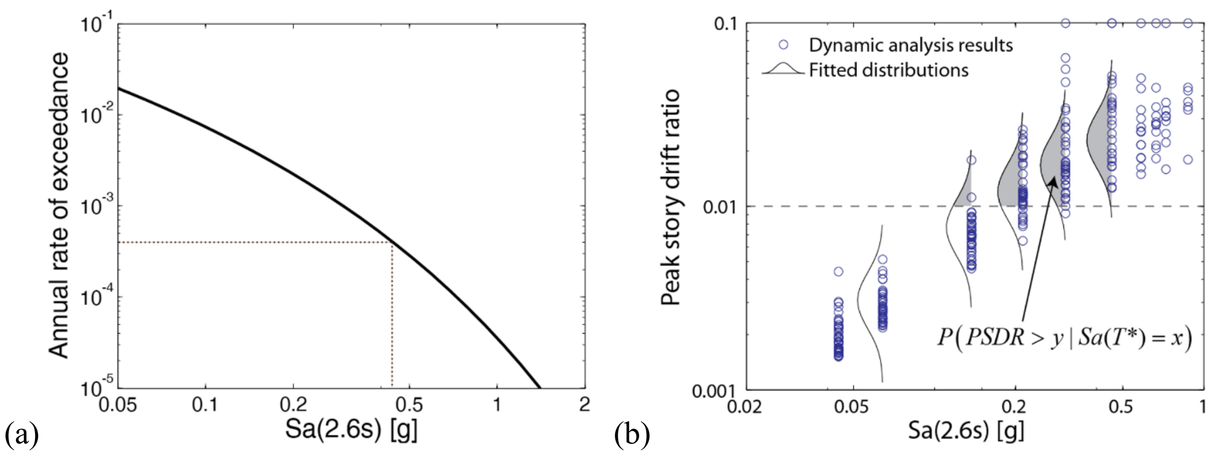

Figure 2. (a) Seismic hazard curve and (b) structural response given a range of ground motion intensity levels. [18]

The PBEE software package Performance Assessment Calculation Tool (PACT), developed as part of the ATC 58 project [17], provides fragility functions which quantify distributions of damage states conditional on structural responses (i.e., thresholds of displacements and accelerations that trigger various damage states of structural elements, non-structural elements, and content of the building). These PBEE fragility functions can be applied to the building information modeling (BIM) that is appropriate for the room (Figure 3), e.g., books shifting, vases falling, and mirror cracking. Green, yellow and red tags that indicate various states and actions (analogous to post-earthquake tagging of buildings or USGS Prompt Assessment of Global Earthquakes for Response, PAGER, earthquake.usgs.gov/data/pager) can be used to guide emergency response and aid decision making.

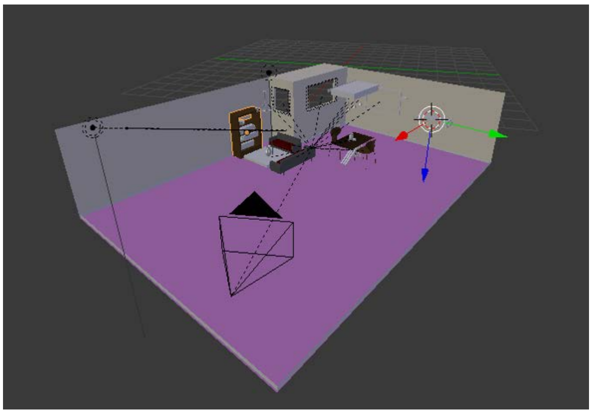

Figure 3. Room model created in Blender before implementation of earthquake excitation and component fragility scripts in Unity.

The illustrative examples utilized existing ShakeOut simulations [11] and extended the high performance computing-facilitated M8 simulations [9] to the Marquette CAVE virtual reality. Rupture to Rafters to Response builds upon advancements in several fields, including ground motion simulations, performance-based earthquake engineering, high performance computing, visualization, and earthquake preparedness. Through this work, site- and structure-specific ShakeOut scenarios were developed that customized the immediate shaking environments (e.g., residential vs. hospital settings) for the general public.

4 CONCLUDING REMARKS

Virtual shaking was created in a room model that integrated elements of ShakeOut simulations, performance-based earthquake engineering (PBEE), and building information modeling (BIM) within the CAVE environment using game engines to visualize emergency response. Similar to flight simulators that train pilots, such virtual shaking can provide muscle memory for potential emergency response participants regarding the expected level of shaking and damage to inform decision and response before an earthquake hits.

In the future, earthquake simulations and structural responses would be obtained real-time or near real-time, via earthquake early warning (EEW) and structural health monitoring (SHM). Predictive models and sensor networks combined provide earthquake information across time scales. The upcoming California EEW system may include smart phones with geotagging features and earthquake countdowns. Sensor readings from various building elements can also provide data about structural responses, which can be integrated to update the structural model. The CAVE participant can then utilize such information together with visual depictions of earthquake rupture, propagation, and building response, to simulate emergency response under various scenarios with time limits (Figure 4). This work is a start to such efforts, with potential applications for the Great ShakeOut Earthquake Drills worldwide and the Earthquake Early Warning system in California to reduce risk. As advanced technologies contribute to the future of community resilience, visualization plays an emerging role in connecting earthquake science, engineering, and policy.

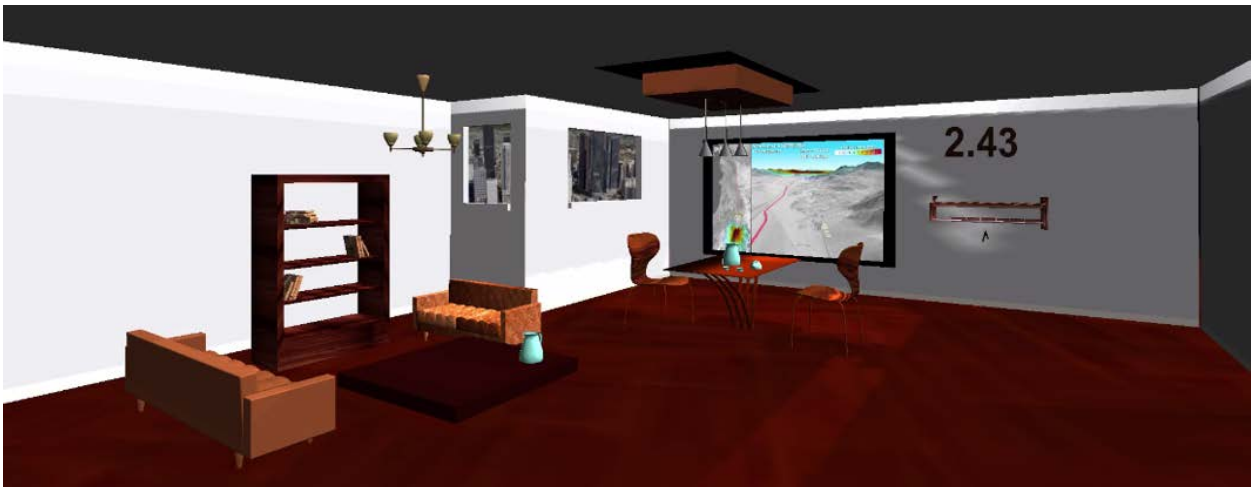

Figure 4. Content developed in Unity for the CAVE visualization of a virtual room subjected to earthquake excitation, with countdown features to simulate early warning and emergency response.

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