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Earthquake early warning application to buildings

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ABSTRACT

In California, United States, an earthquake early warning system is currently being tested through the California Integrated Seismic Network (CISN). The system aims to provide warnings in seconds to tens of seconds prior to the occurrence of ground shaking at a site; since the system broadcasts the location and time of the earthquake, user software can estimate the arrival time and intensity of the expected S-wave. However, the shaking experienced by a user in a tall building will be significantly different from that on the ground. This paper provides a method to develop engineering applications in earthquake early warning system using Performance-based Earthquake Engineering framework. An example is included to estimate the characteristics of shaking that can be expected in mid-rise to high-rise buildings. Potential engineering applications (e.g. elevator control) for buildings based on the prediction of building shaking level are also addressed.

1. Introduction

Earthquake Early Warning (EEW) is undergoing a rapid development worldwide with enhanced interest coming after the recent major destructive earthquakes, e.g. the 2008 Wenchuan earthquake in China, the 2010 Haiti earthquake and the 2011 Tohoku earthquake in Japan. Most regions in Japan are covered by a public earthquake warning broadcast network operated by the Japan Meteorological Agency (JMA) [1,2]. Development and testing regarding EEW systems are being performed in China, Mexico, Taiwan, various countries in Europe, and in California where an EEW system, called the California Integrated Seismic Network (CISN) *ShakeAlert*, is currently being developed (http://www.cisn.org/eew/CISN_page.html). *ShakeAlert* combines outputs of three distinct early warning algorithms that are based on different theories: namely τ_c-P_d on-site algorithm [3,4], Earthquake Alarm Systems (ElarmS) [5], and Virtual Seismologist (V-S) [6]. Fig. 1 demonstrates a sample user interface of the CISN ShakeAlert System. Detailed information can be found in Böse et al. [7]. In addition, a Smartphone version of such system is currently under development [8].

EEW systems typically provide estimation of earthquake magnitude, epicenter location and warning time to their users, as well as the estimation of intensity measure (*IM*) at the user's location [9]. However, often a user of such system will be residing in a building. The shaking experienced by a user in a tall building will be significantly different from that on the ground and this shaking can change significantly from one building to another and also from one floor to another. During the M9 Tohoku earthquake in Japan on 2011, ground motions were amplified by a factor of 3.5 at the roofs of some of the tall buildings in Tokyo metropolitan area [10]. This paper aims to address this issue and suggests a robust and fast method to predict the characteristics of shaking that can be expected in mid- to high-rise buildings. The computation involved in the proposed decision-making is simple enough that could be handled by a Smartphone, which could possibly extend the coverage for earthquake early warning through cellular networks. Users of the EEW system are expected to receive a message including expected shaking level in case of an earthquake, and such information has shown to be capable of mitigating panic and confusion [11]. Potential engineering applications for buildings based on the prediction of building shaking level are also addressed.

2. Background

The information provided by EEW may be used by decision makers to perform appropriate emergency response. The decision may involve a complicated tradeoff between the potential costs of missed alarms and false alarms due to uncertainties in EEW estimation. As the warning time is usually very short, ranging from a few seconds to a minute or so, an automated decision-making approach is needed. Such automation is commonly based on a cost-benefit framework. Several researchers have addressed the need of a complete end-to-end framework (from seismic hazard warning information to loss models for decision making) in earthquake early warning applications based on Pacific Earthquake Engineering

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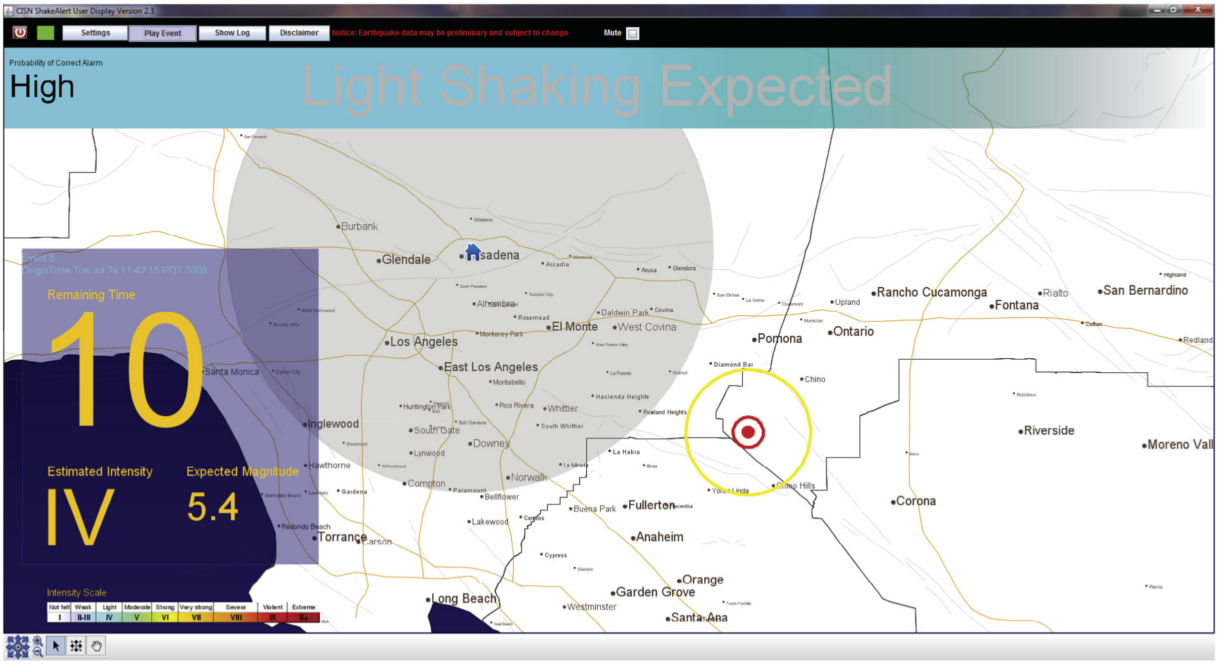

Fig. 1. Sample of the CISN ShakeAlert user interface.

Research Center's (PEER) Performance-based Earthquake Engineering (PBEE) methodology [12–14]. This idea is known as the Performance-based Earthquake Early Warning (PBEEW) [15]. Fig. 2 shows the general structure of decision making with PBEEW. Choice of ground motion model, structural model, fragility model, and loss model for decision-making can be customized depending on the specific context of an application or users' demands. In this paper, the focus will be on building-specific EEW applications. A combination of structural and fragility models are used to extend the ground shaking prediction from EEW to an early warning of building shaking intensity.

Existing ground motion models include Ground Motion Prediction Equations (GMPE) and physics-based three-dimensional ground motion simulation models. For example, the CyberShake [16] project developed physics-based model that allows simulation of ground motion time-series at a specific site in Southern California. The advantage of a physics-based approach over GMPE is that the ground motion response explicitly captures earthquake rupture and wave propagation effects. Results from Graves et al. [16] indicate that when a physics-based model is utilized in seismic hazard analysis, the hazard level is higher for some sites compared to that given by a conventional GMPE, due to the incorporation of rupture directivity and basin response effects. However, a significant amount of computational effort is involved in the physics-based approach. On the other hand, five sets of GMPEs have been developed as a part of the PEER's Next Generation Attenuation model (NGA) project [17–21]. These GMPEs are attenuation equations in which the site location is parameterized by a relative location with respect to the source (which depends on the fault geometry), the site conditions (e.g. Vs30, the local average of the shear velocity in the upper 30 m) and, in some cases, the local depth of the sedimentary basin [17,19,20]. These parameterizations in the GMPEs are determined by empirical regressions of assumed functional forms given the available data. As opposed to the physics-based method, GMPE just provides a ground motion intensity measure (e.g. peak ground acceleration, spectral acceleration, etc.), and the computational effort involved is considerably reduced. Nevertheless, in the framework to be presented here, results from sophisticated physics-based models could be pre-computed and stored in a database for certain sites to improve prediction accuracy and computational efficiency for real time application.

Estimation of floor vibration response of buildings due to earthquakes has been extensively studied in the past. Three-dimensional finite element structural models can be adopted if detailed documentation of the building plans is available [22]. Similarly, if the dynamic properties of a building, e.g. mode shape, modal

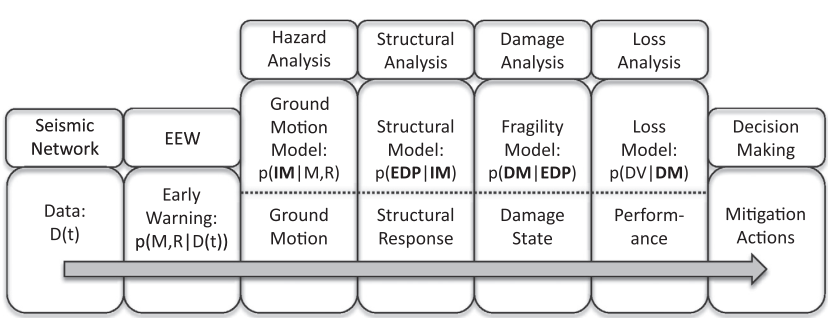

Fig. 2. Information flow of PBEEW. *M* is earthquake magnitude, *R* is epicentral distance from the user's location; *IM* is intensity measure (e.g. *PGA*, *PGV*, S_a); EDP is engineering demand parameter (e.g. floor acceleration, inter-story drift); *DM* is measure of damage; *DV* is decision variable.