Seismic Risk Assessment of Human Evacuations in Buildings

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Introduction

Major earthquakes may require people to evacuate immediately from buildings due to other consequential hazards, e.g. fires, landslides, tsunamis, or significant structural damage. During the evacuation, building occupants are exposed to floor accelerations and physical damage of the building, which affects their immediate evacuation response. However, these effects are commonly not modeled, and are not considered when assessing the associated seismic risk of building occupants.
The objective of this work is to develop a probabilistic methodology to assess the seismic risk of building occupants, considering their evacuation behavior inside the building.

General methodology

The effect that future earthquakes would have on the system was quantified by computing its seismic risk. This is achieved by simultaneously considering the rate of different levels of earthquake intensity, $\lambda_{IM}(im)$, and their consequences on the system, $P(OV > ov|IM = im)$:

$$\lambda_{OV}(ov) = \int_{IM} P(OV > ov|IM = im)\,|d\lambda_{IM}(im)|$$

where OV is an output variable to be studied (e.g., number of injured people) and IM is the earthquake intensity measure at the location of the building.

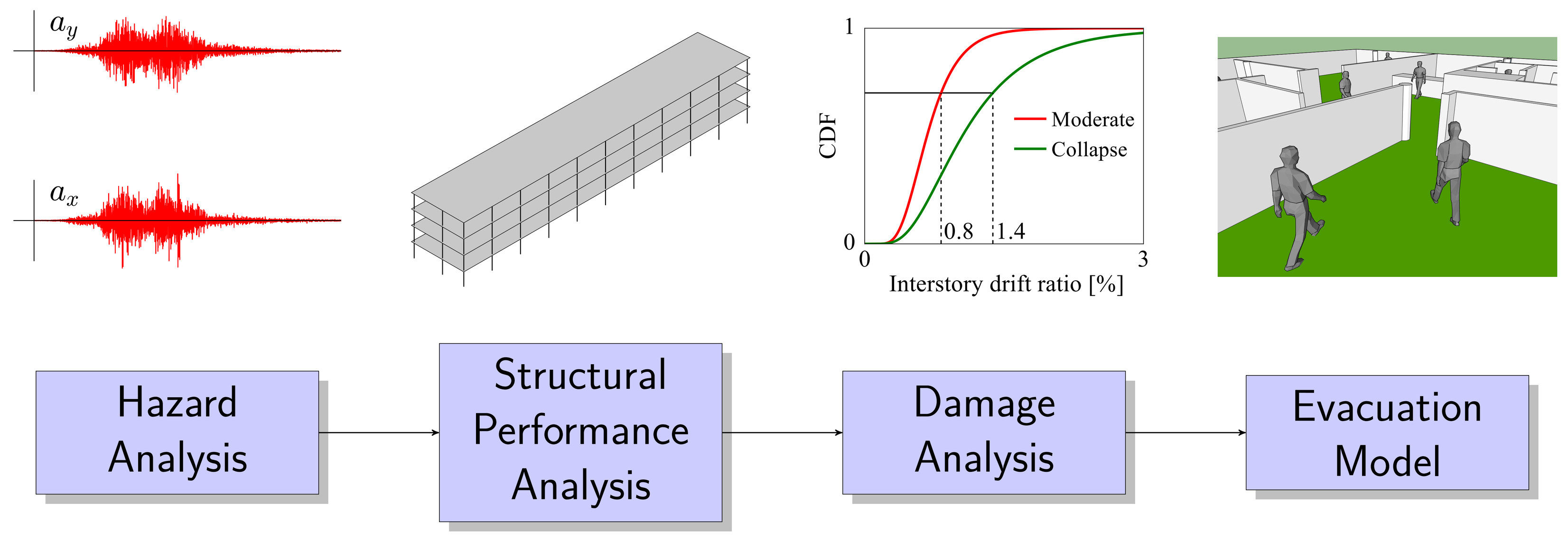

Figure 1: Methodological steps for risk assessment following PEER framework [1].

Ground motion selection

The intensity measure chosen for this study only is the spectral acceleration at the fundamental period of the structure. The spectral accelerations at other periods were computed using a conditional mean spectrum (CMS) [2], as shown in Fig. 2b.

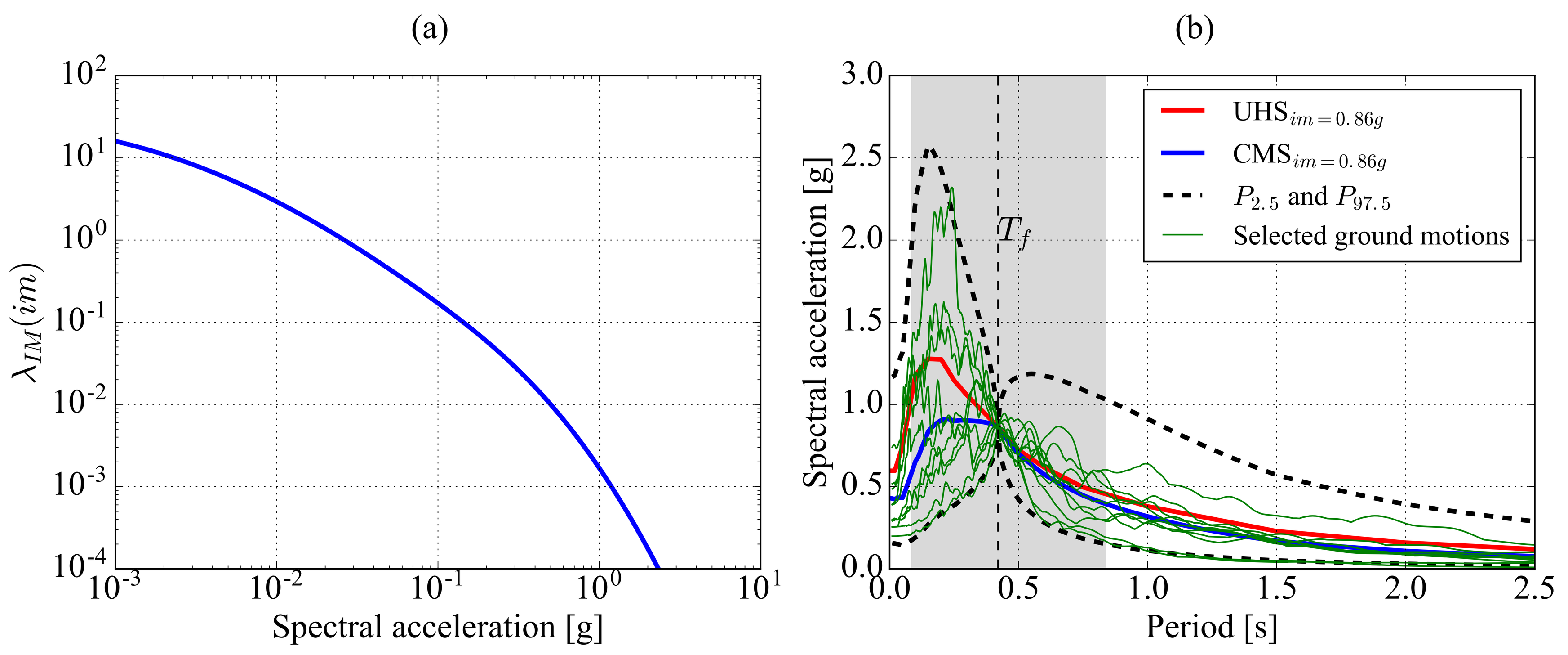

Figure 2: Seismic hazard at the location of the building: (a) hazard curve; and (b) conditional mean spectrum for an intensity of $0.86g$ with associated 2.5th and 97.5th percentiles, and spectra from 10 selected ground motions. The gray area represents the range of periods used for matching.

Building vulnerability

In order to assess the physical damage generated by ground motion, the response of the building in terms of acceleration and displacement was first calculated. This was performed for a four-story reinforced concrete frame testbed building using a model developed in OpenSees. Once the response of the building is computed, fragility curves are used to relate damage on drift- and acceleration- sensitive components with this response.

References

[1] G. G. Deierlein, H. Krawinkler, and C. A. Cornell. A framework for performance-based earthquake engineering. In *Pacific conference on earthquake engineering*, pages 1–8, Christchurch, New Zealand, 2003.

[2] J. W. Baker. Conditional mean spectrum: Tool for ground-motion selection. *J Struct Eng-ASCE*, 137(3):322–331, 2010.

[3] J. Van Den Berg, S. J. Guy, M. Lin, and D. Manocha. Reciprocal n-body collision avoidance. In *Robotics Research*, pages 3–19. Springer, 2011.

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Evacuation modeling

Human evacuation was simulated using an agent-based model that follows the basic steps summarized in Fig. 3. The physical interaction between agents was simulated using the optimal reciprocal collision avoidance principle [3].

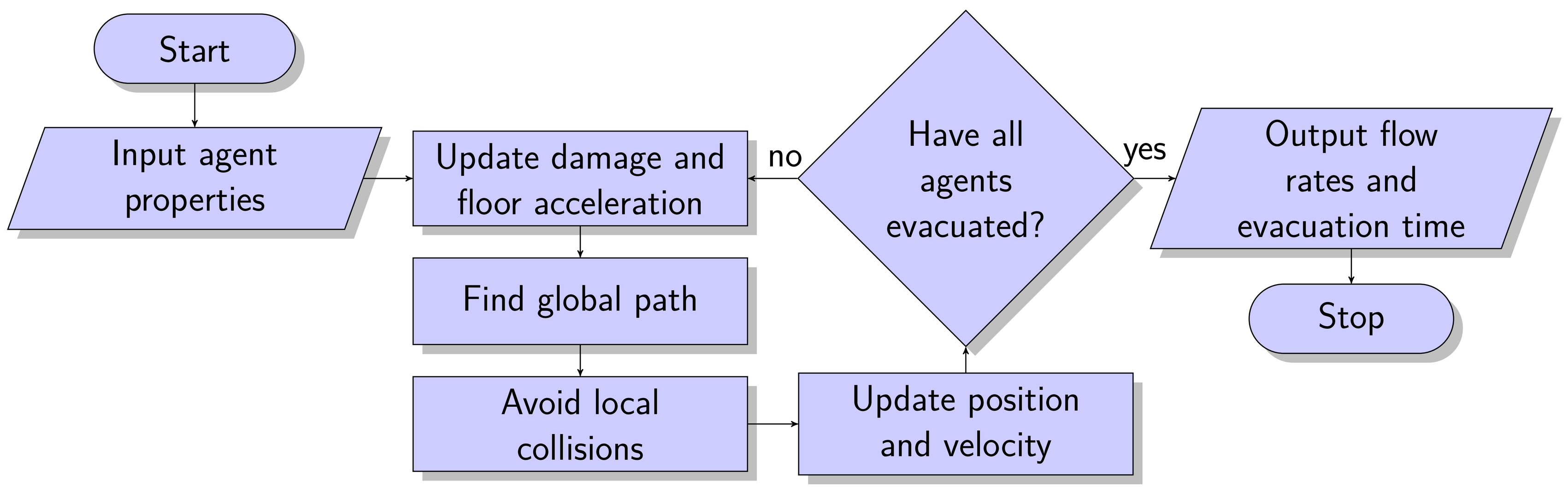

Figure 3: Flowchart of the building evacuation model.

The evacuation model was validated with real evacuation drills carried out in a K-12 school and an office building, with approximately 1500 and 200 evacuees, respectively. The model had an average error of predicting the total evacuation time of only 5.8%. In the model, the response and damage of the building affect the agents by: injuring them due to falling of non-structural components, reducing agent speed when walking on building debris, increasing agent stress level, and impeding movement at certain levels of floor acceleration.

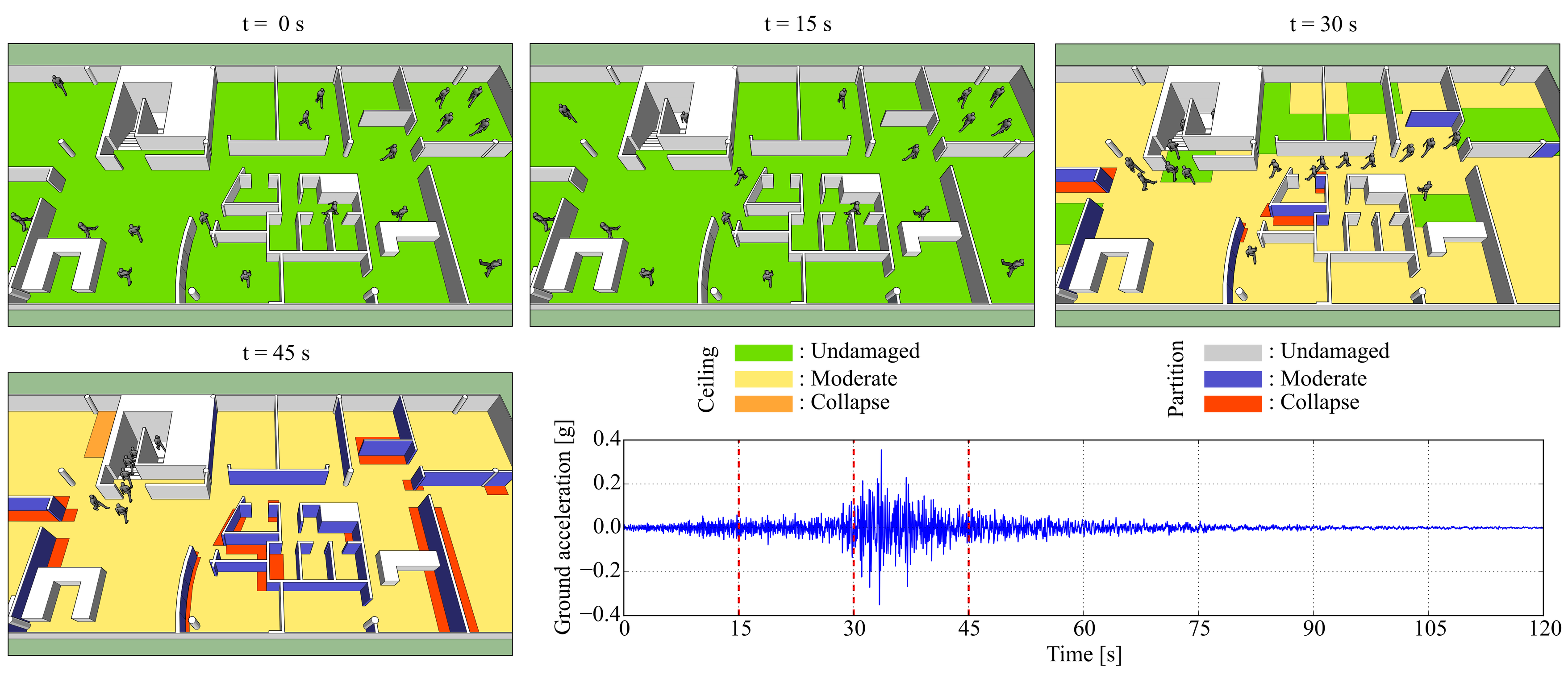

Figure 4: Four snapshots of an evacuation simulation at a section of the fourth floor.

Results

The risk assessment methodology was applied to the testbed building to compute distributions of two output random variables: the accumulated number of injured people and the maximum evacuation time from all earthquakes that occur within a certain time window (shown in Fig. 5).

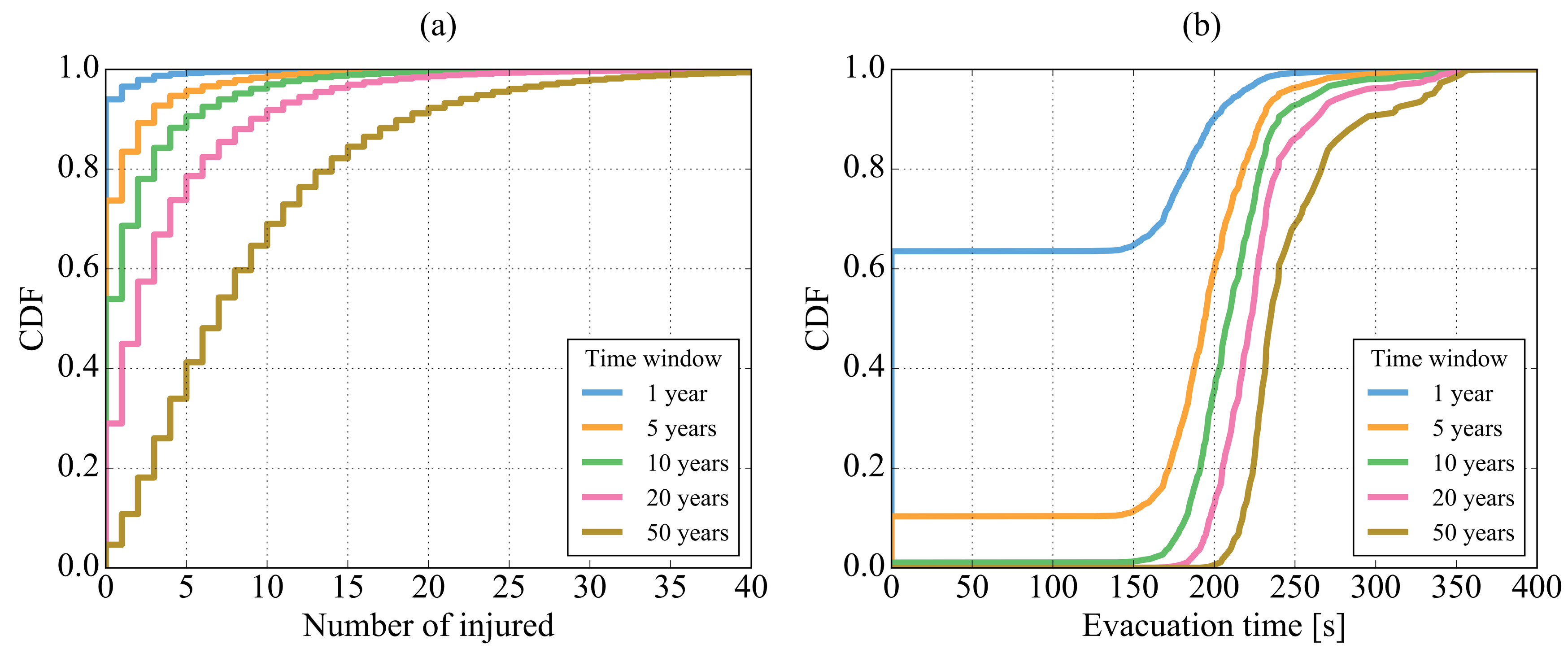

Figure 5: Cumulative distribution functions of (a) accumulated number of injured people, and (b) maximum evacuation time, of all evacuations that occur in different time windows.

Conclusion

The proposed probabilistic methodology enables risk assessment of a variable that can be derived from evacuation simulations, e.g., number of people injured or subjected to a certain level of floor acceleration. All these human variables represent direct effects that earthquakes have on people and are not usually considered when designing infrastructure. Thus, models as the one presented herein can help to prepare and mitigate the eventually critical consequences on building inhabitants as structures are subjected to earthquakes. However, the model can still be improved in several ways, such as considering structural failure and changing evacuation routes due, for instance, to blockage of stairs. Furthermore, reliable computations of human variables are limited to our current state of knowledge on how people are affected by earthquakes. Therefore, more quantitative research should be carried out in this field.

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