12th National Conference on Earthquake Engineering
Salt Lake City, Utah
27 June - 1 July 2022

Hosted by the Earthquake Engineering Research Institute

High-Fidelity Testbed Development for Regional Risk Assessment in Alameda, California

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ABSTRACT

Assembling a building inventory for a high-resolution regional seismic risk assessment from publicly available data is a laborious task with several challenges due to the disparate nature of publicly available structural and demographic information. The authors developed an open-source framework for inventory generation and proposed a standardized schema for building inventories. The framework provides templates to automate or greatly facilitate common tasks in data harvesting, merging, and augmentation. This paper illustrates the application of the framework to create a building inventory for the city of Alameda, California, and provides an example of ground shaking and liquefaction-induced damage assessment for the city to illustrate the investigations that are enabled by such high-resolution regional analysis. The inventory-generation framework and corresponding templates, as well as the testbed produced for Alameda, are available at the NHERI SimCenter.

Introduction

Traditional seismic risk assessment methods, such as Hazus [1], rely on clever approximations to be computationally feasible given the resources available at the time of their development. The proliferation of high-performance computing clusters substantially increased the available computational resources and made it possible to replace the approximations from traditional methods with explicit, high-resolution simulations. For example, capacity spectra can be replaced with nonlinear response history analyses, and specific simulations can be performed for each individual building instead of calculating aggregate results at census-block resolution. The high-resolution simulations also enable modeling and propagation of uncertainties in the hazard, building inventory, structural behavior, and consequences of damage.

Although today these simulations are computationally feasible, they can only provide more details about regional risk if they first receive detailed, building-specific exposure and hazard information. Collecting, reviewing, and merging various databases to prepare such input data is not trivial. Regional simulation testbeds have been used in the Natural Hazards Engineering (NHE) community to support researchers and practitioners by providing them sample inputs for disaster simulation in a synthetic [e.g., 2] or actual location [e.g., 3-5]. Such testbeds facilitate benchmarking and verification of models and workflows, support educational efforts, and promote tools and best practices. Despite general consensus about their utility [6], few high-resolution testbeds exist in the community because preparing such data has traditionally been a laborious task with limited guidance available.

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Bassman TJ, Zsarnóczay A, Saw J, Wang S, Deierlein GG. High-Fidelity Testbed Development for Regional Risk Assessment in Alameda, California. *Proceedings of the 12th National Conference in Earthquake Engineering*, Earthquake Engineering Research Institute, Salt Lake City, UT. 2022.

The authors developed a framework for constructing high-resolution testbeds that integrates various methods to collect and merge data from publicly available databases in a US context. Both the framework and its implementation using Python scripts and Jupyter notebooks are open source and publicly available through the NHERI SimCenter [7] to support the development of further testbeds that follow a standardized data schema. This paper presents the application of the method to develop a testbed in the city of Alameda, California.

Alameda is an island city of 78,000 people in the San Francisco Bay Area with a local government interested in better understanding and mitigating the risks it faces from several hazards [8]. The city expanded substantially in the mid-20th century using highly liquefiable artificial fill, which poses a growing threat as its liquefaction potential increases [9] due to a rising ground water table caused by sea level rise [10]. The mostly residential city has several vulnerable structural archetypes, of which some, such as unreinforced masonry and soft-story buildings, have been addressed in part by successful retrofit programs. Alameda's diverse population includes several vulnerable communities that are expected to be disproportionately impacted by a major earthquake and greatly challenged to recover from such a shock without external assistance. In sum, these complex factors comprise an urban environment that the authors believe to be an ideal setting for a regional simulation testbed.

Seismic Hazard

Several tools [e.g., 11] are available to simulate ground shaking intensity over a region in high-resolution. This study emphasizes the importance of including other relevant types of seismic hazards in the risk assessment by demonstrating how considering permanent ground deformation (PGD) due to liquefaction changes the seismic risk in several parts of the city.

We used the approximate method by Wang et al. [12-13] to estimate site-specific vertical settlement and lateral spreading from liquefaction based on three primary inputs: near-surface soil column properties, groundwater table elevation, and peak ground acceleration (PGA). Soil column and groundwater table information is available in several parts of the US from cone penetration test (CPT) data collected by the USGS, such as that shown in Fig. 1(a) for Alameda [14]. This data can often be supplemented by borehole log reports kept in city records that were prepared by geotechnical engineers for city projects or private developments submitted for city approval. We used this information, along with simulated PGA values, to estimate PGD at the soil measurement locations, and employed a spatial interpolation algorithm to then estimate PGD at intermediate points across the island. The resulting maps of PGD and PGA served as inputs to the subsequent steps of the risk analysis. An example of the simulated ground deformation map is shown Fig. 1(b), for which the corresponding ground shaking is a magnitude 7 earthquake scenario based on a rupture on the nearby Hayward fault.

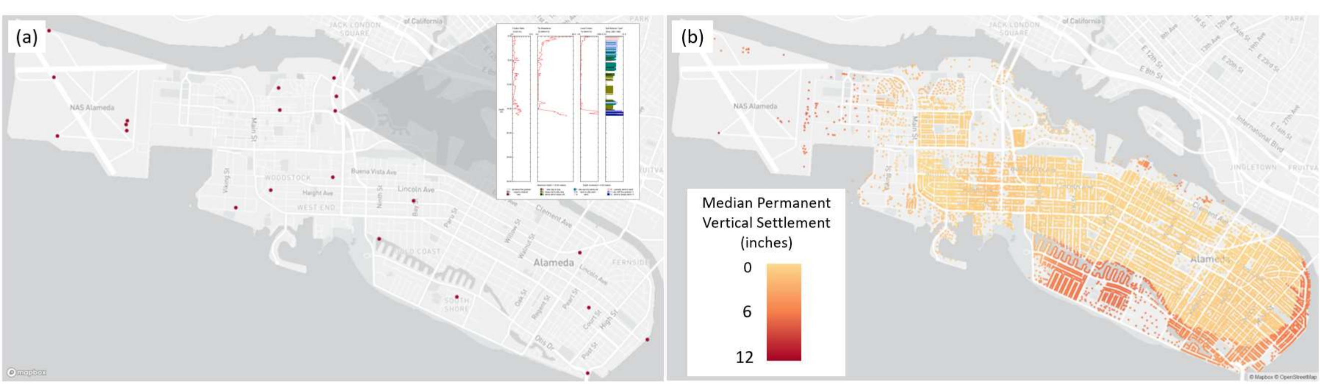

Figure 1. Liquefaction seismic hazard simulation data in Alameda: (a) USGS borehole measurement locations [14]; (b) median estimates of liquefaction-induced vertical settlement from simulations.

Building Inventory Development

Fig. 2 provides an overview of the application of our inventory-generation framework in Alameda. Only publicly available data was used in this study to demonstrate the general applicability of the framework when resources to purchase proprietary building information for entire cities are not available. Alameda, like many other cities, stores its tax assessor data, building permits, and business licenses in a publicly accessible digital format. They also monitor buildings with some known structural vulnerabilities, such as multi-family residential buildings with soft stories, and make the corresponding list of addresses publicly available. Besides these local data sources, we obtained building footprints from OpenStreetMap [15], information on tenure and race from the US Census [16], and other demographic data from the American Community Survey [17] and the American Housing Survey [18]. Finally, we used BRAILS, a machine learning tool developed at the SimCenter [19], to infer additional building information from satellite and streetview images.

Several common challenges in working with publicly available data are represented in the example of Alameda. Although the gathered datasets provide sufficient structural and demographic information, they are heterogeneous in their geographic reference units (i.e., building footprints, addresses, parcels) and data reliability. Redundant fields in different datasets (e.g., number of units based on Census and on tax assessor data) often hold conflicting information. We developed a mapping between footprints, addresses, and parcels to link datasets that are based on different reference units, and an algorithm to assign attributes to buildings footprints based on aggregate information that is only available at lower resolution, such as census blocks or tracts. Conflicting data is handled using well-defined and transparent rules that are specific to each structural and demographic attribute. The framework can use these maps and rules to generate an integrated building inventory with building footprints as a reference unit. More details about the inventory development framework are available in [20].

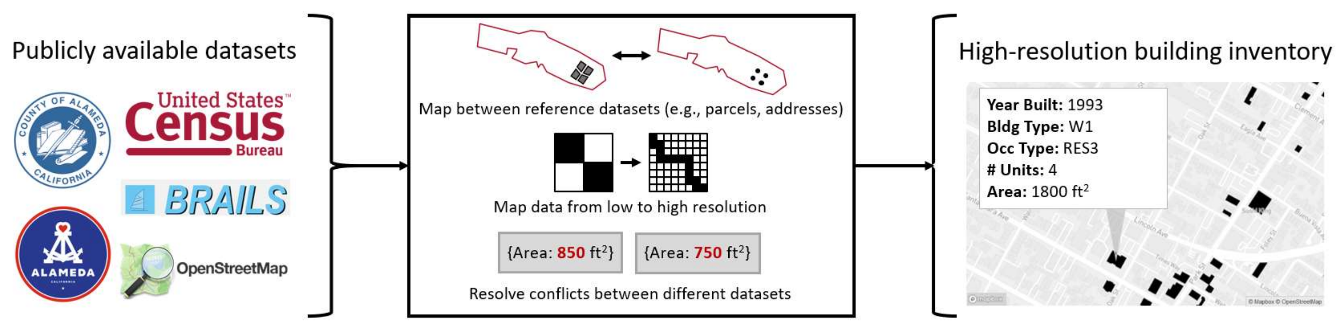

Figure 2. Overview of proposed framework for high-resolution building inventory generation from publicly available datasets.

Illustrative Results

We illustrate the utility of a high-fidelity building inventory and of the consideration of permanent ground deformation alongside ground shaking in regional risk studies using the example of building damage estimation for the city of Alameda. Given the input hazard and exposure data introduced above, we ran a regional simulation using the SimCenter's R2D Tool [21]. The vulnerability of buildings was modeled both with and without considering liquefaction-induced ground deformation, based on the Hazus earthquake methodology. Hazus uses a judgment-based approach for incorporating ground deformation effects into damage estimation. The probability of a shallow-foundation building being in the "Extensive" or "Complete" damage state is increased if the vertical settlement or lateral spreading at the building location exceeds a specified threshold [1].

Fig. 3 compares simulated damage results with the two different approaches. Buildings in areas of high liquefaction susceptibility in the western and southern parts of the island experience moderate or more severe damage more often if liquefaction is considered (Fig. 3b) than in a conventional simulation that uses only ground shaking (Fig. 3a). The maps illustrate not only the importance of considering ground deformation in areas of high liquefaction susceptibility but also some of the benefits of using a high-resolution building inventory. The higher-resolution results provide more precise information about disaster impact and, beyond simply visualizing results in greater detail, enable further building archetype-specific calculations of loss and consequence metrics. Progress towards further mitigation actions, such as retrofit ordinances, may also benefit from information derived from maps such as those in Fig. 3 because the granular knowledge of the city's risk supports more targeted policies.

Figure 3. Simulated damage results for the city of Alameda: (a) based on ground shaking only; (b) also including effects of liquefaction. Color indicates the probability of each building reaching or exceeding "Moderate" damage state, as defined by Hazus [1]. (The presented simulation results estimate the outcome of a scenario earthquake and are not representative of any individual building's seismic performance. To understand the risk of any individual building, please consult with a professional structural engineer.)

Conclusions

This paper introduced a high-fidelity inventory-generation framework to support the next generation of regional natural hazard risk assessment and illustrated the application and advantages of using this framework to prepare a detailed building inventory. The illustrative example also demonstrates the importance of considering liquefaction-induced ground deformations in regional seismic risk assessment for the city of Alameda, California. The inventory-generation framework, its implementation, and the Alameda testbed data are all open source and publicly available to the research community through the NHERI SimCenter. The data availability and challenges are expected to be similar in other US locations, hence, we expect the developed methods to facilitate inventory generation in all studies in a US context. However, additional, location-specific complications might exist and should be anticipated. The open-source nature of the framework encourages contributions from the community to address those problems and gradually generalize the framework.

Acknowledgments

The authors thank Danielle Mieler and colleagues at the City of Alameda who generously supported this study with advice and data, and David Bonowitz for discussions which improved the quality of this work.

This material is based upon work supported by the National Science Foundation under Grant No. 1612843. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Several figures in this paper use map data from Mapbox and OpenStreetMap and their data sources. To learn more, visit https://www.mapbox.com/about/maps/ and http://www.openstreetmap.org/copyright.

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