INTERSECTION OF EARTHQUAKE ENGINEERING WITH THE DIGITAL AGE: APPLICATIONS TO RESILIENCE

I. Almufti1 N. Paul2 M. Mieler3 J. Lee4 and B. Carter5

ABSTRACT

In the past few years, an exponential increase in computational power has enabled seismic engineers to undertake significantly more complex analyses or to investigate more iterations in the same amount of time. This allows further insight into seismic behavior, including parametric studies to ascertain the sensitivity of building performance to certain parameters. At the same time, digital skills which were once the domain of only software engineers have begun to penetrate the field of earthquake engineering. This paper will present a web-based portfolio risk assessment tool developed by the authors to virtually simulate thousands of earthquake scenarios across building portfolios to calculate losses utilizing a database, calculation engine, and front-end app to interact with the results. The computational efficiency of various platforms typically used for enabling risk assessments will be compared. The purpose of the paper is to demonstrate how new digital technology can be leveraged to undertake complex problems in seismic engineering and improve upon current methods for risk assessment.

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1Associate, Arup, San Francisco, CA, 94105 (email: ibrahim.almufti@arup.com)
2Risk Analyst, Arup, San Francisco, CA, 94105 (email: nicole.paul@arup.com)
3Risk Analyst, Arup, San Francisco, CA, 94105 (email: michael.mieler@arup.com)
4Risk Analyst, Arup, San Francisco, CA, 94105 (email: ji-su.lee@arup.com)
5Engineer, Arup, San Francisco, CA, 94105 (email: ben.carter@arup.com)

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Applications to Resilience

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In the past few years, an exponential increase in computational power has enabled seismic engineers to undertake significantly more complex analyses or to investigate more iterations in the same amount of time. This allows further insight into seismic behavior, including parametric studies to ascertain the sensitivity of building performance to certain parameters. At the same time, digital skills which were once the domain of only software engineers have begun to penetrate the field of earthquake engineering. This paper will present a web-based portfolio risk assessment tool developed by the authors to virtually simulate thousands of earthquake scenarios across building portfolios to calculate losses utilizing a database, calculation engine, and front-end app to interact with the results. The computational efficiency of various platforms typically used for enabling risk assessments will be compared. The purpose of the paper is to demonstrate how new digital technology can be leveraged to undertake complex problems in seismic engineering and improve upon current methods for risk assessment.

Introduction

The proliferation of new technology, computer science skills, and computational power has begun to make a profound impact on the seismic engineering industry. While the dawn of this new digital age has widespread application to multiple tasks (e.g., rapid automation of seismic analysis for performance-based seismic design purposes), this paper will focus on applications to seismic risk and resilience assessments. The paper will describe how the authors have leveraged advances in digital capabilities to develop a platform for streamlining the seismic risk assessment of large building portfolios. The benefits of the digital platform and the underlying framework for improving the accuracy and efficiency of risk assessments will be presented. Finally, a case study demonstrating the application on a large university campus will be shared.

Current Approach to Portfolio Seismic Risk Assessments

In order to perform portfolio seismic risk assessments, it is standard practice to use the FEMA HAZUS [1] software and methodology. It is widely accepted in the industry, however there are several key limitations to HAZUS. These limitations are particularly true for assessing the risk of

1Associate, Arup, San Francisco, CA, 94105 (email: ibrahim.almufti@arup.com)
2Risk Analyst, Arup, San Francisco, CA, 94105 (email: nicole.paul@arup.com)
3Resilience Analyst, Arup, San Francisco, CA, 94105 (email: michael.mieler@arup.com)
4Risk Analyst, Arup, San Francisco, CA, 94105 (email: ji-su.lee@arup.com)
5Engineer, Arup, San Francisco, CA, 94105 (email: ben.carter@arup.com)

smaller building portfolios, where the performance of individual buildings is important. Some of these limitations include:

1. HAZUS is primarily meant to provide a generalized basis for producing averaged losses over a very large population of buildings (thousands). It is therefore necessarily rudimentary in the characterization of predicted building demands, expected damage, and consequences. For that reason, the technical manual states that the results for individual buildings may not be reliable [1].

2. The predicted estimates for building downtime is crude (e.g. the downtime is the same regardless of building type or size) and there is no distinction between different downtime recovery states (i.e. the estimated downtime is for full recovery rather than the time required to achieve re-occupancy and/or functionality, which are more important). This could significantly hamper contingency planning efforts.

3. In terms of mitigation, there is not a technically sound basis for revising the building vulnerability functions to account for retrofits, which could hinder the ability to quantify the risk reduction across the portfolio (including consideration of past retrofits) and associated cost-benefits.

4. The characterization of ground motion is relatively simplistic and does not account for spatial variability or multiple sources.

**Proposed Approach to Portfolio Seismic Risk Assessments**

There is value in performing a more rigorous seismic risk assessment since it will ultimately provide more tangible benefits in the longer term. This approach largely relies on building-specific risk assessments based on the recently released FEMA P-58 approach [2]. FEMA P-58 is the outcome of a 10-year study that is meant to provide significant refinement to the HAZUS approach. It uses a vast library of fragility functions to relate the expected building movements to the expected extent and severity of damage to each type of building component (structural and non-structural) and in turn relate the damage to casualties, repair cost, and repair time. The repair cost and repair time estimates are based on a rigorous study by a cost estimator and represent significant improvements over the HAZUS values. The REDi downtime method [3] is then overlaid on the FEMA P-58 analysis to calculate specific downtime recovery states including the time required to re-occupy and/or regain functionality in the building. This is important for determining business interruption or the amount of space that is fit for residential occupancy immediately after an earthquake. The portfolio risks are estimated by undertaking hundreds to thousands of realizations which each represent a single earthquake scenario impacting the portfolio of buildings at the same time.

In addition, the FEMA P-58 approach importantly enables the identification of specific component types that are driving the losses. For example, it may indicate that a few types of buildings or components (e.g. ceilings, partitions) consistently contribute greatly to the losses. The effects of retrofits can be included by modifying the building movement estimates and/or the fragility curves for specific components. By weighing whether these are easily mitigated (based on cost, time, and intrusiveness), this information could be utilized in developing targeted resilience strategies via cost-benefit analysis.
Web-based Portfolio Risk Platform

In order to enable the proposed approach, Arup developed a bespoke cloud-based web platform comprising a central database, risk computation engine, and user interface. This platform is used to streamline a wide range of tasks, including managing data from myriad sources (including building data gathered in the field from physical inspections), developing and reviewing loss models for each building, performing virtual earthquake simulations to assess seismic risk, rapidly visualizing and sharing results among members of the project team simultaneously, and automating the production of important deliverables.

In the current workflow, the central database (NoSQL) serves as a single source of truth, storing all building information, hazard data, exposure data, and all other relevant information for undertaking the risk assessment. The true power of the central database was only unlocked after the platform was hosted on the cloud (i.e., AWS server). This allowed all team members to have simultaneous access to the most current version of the data. In addition, team members with knowledge of backend scripting could also add and modify data rapidly and simultaneously (though we are currently implementing the ability to populate and edit the database through the front-end user interface described below). Figure 1 shows the project workflow to undertake the risk assessment and the system architecture of the digital platform.

![Figure 1. Diagram of the project workflow and system architecture.](image)

User Experience

While the central database and improved risk engine (based on FEMA P-58 and REDi) have greatly improved efficiency, the front-end user interface most dramatically transformed the workflow, providing valuable data insights and enhanced capabilities. The user can dynamically generate maps, charts, and tables to compare building information and risks at the portfolio level as well as dig deeper to identify the most vulnerable components at the individual building level.
(for example). It has helped slice through a mountain of data and facilitated better quality control, which has resulted in more confidence in the accuracy of the risk analyses and, ultimately, more insightful recommendations for the client. Most significantly, the front-end user interface enables team members without a strong programming background to interact with the data in ways that were previously not possible, resulting in improved quality of results and deliverables. Because the interface runs on a standard web browser, it also facilitates inter-office collaborations as the tool can be easily shared with staff in other locations via a simple web link.

**Computational Efficiency**

Initial versions of the risk assessment workflow were based on custom Microsoft Excel spreadsheets (used for individual building assessments only) and over time have evolved to the digital platform described above. The new digital platform was initially hosted on a local server, but there was value in terms of computational efficiency and distribution/shareability to host it on the cloud. Figure 2 below shows the time it takes to run 1000 earthquake realizations across a portfolio of 50 buildings, using different tools. The power of the new tools enables robust processing of thousands of virtual simulations quickly and efficiently. This allows greater ability to capture uncertainty (using more realizations) and more flexibility to re-analyze.

![Figure 2. Progress of computational efficiency.](image)

**Case Study: University of British Columbia, Vancouver**

Arup was appointed by the University of British Columbia, Vancouver (UBC) to undertake a seismic risk assessment for nearly 330 existing buildings on their campus and develop a resilience strategy which includes physical intervention and operational preparedness measures [4]. The assessment involved developing a loss model for each building and subjecting it to thousands of simulations to estimate casualties, repair costs, and downtime across a range of
earthquake intensities. Results from the assessment were used to identify unsafe buildings, develop targeted mitigation strategies to reduce earthquake losses and downtime, and undertake cost-benefit analysis to inform the university where investment made most sense. Figure 3 shows the web-based portal of UBC’s building stock.

The user can use the tool to query and filter the building stock on campus based on certain building properties (such as construction age, structure type, or number of stories). Key parameters about the building stock (including total area) are summarized and dynamically linked to the filters. This is useful to understand the general exposure of the campus. Each of the markers denoting a building are linked to an individual building page that stores information such as images, on-site evaluation notes, engineering demand parameters (EDPs), and losses. The EDPs and losses are calculated within the back-end of the digital platform. In addition, the extent and severity of damage to components within each building are identified. The downtime is calculated using the REDi method, where the repair schedule is optimized through by a greedy optimization and synchronous allocation algorithm.

Figure 3. User interface showing UBC’s building stock

Conclusions

New technology is pervasive in today’s world. It has driven the recent expansion of our economy and produced new tools and services at a rapid pace. For the most part, this new technology has not been leveraged in the engineering industry as effectively. The following are lessons learned from our experience:
1. Digital applications such as the one discussed in this paper require significant expertise to develop. The person (or people) responsible should have experience with full-stack development and multiple scripting languages.

2. Initial investment for digital applications is often significant and may be hard to justify on a small project, but the bones of the application can be easily repurposed on other projects or efforts, making the initial expenditure well worth it.

3. The use of platforms with front-end user interfaces is powerful because it enables all team members to view and interact with the data in a consistent manner that does not necessarily require programming knowledge.

4. However, there needs to be at least one individual monitoring the data, doing constant Q/A checks as new data is added, and flagging the appropriate people where there are inconsistencies. That individual needs scripting knowledge and awareness of different data types.

References


