Multi-Objective Optimization Approach for Decision-Making: Considering Engineering and Social Variables for Community Level Resiliency

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ABSTRACT

This project develops a community-level mitigation plan for earthquakes by implementing a multi-disciplinary approach to the multi-objective optimization problem via genetic algorithm. The four resiliency objectives considered in the optimization are: (1) minimize the initial cost, (2) minimize the total financial losses, (3) minimize the number of fatalities, and (4) minimize the potential loss in quality of life for the population as a whole. The algorithm presented in this paper considers both engineering and socio-economic variables. The framework ultimately offers a set of optimized solutions for decision makers at the local (or other) government level to mitigate risk within the building stock in their community and can aid decision makers in the allocation of mitigation funds.

Introduction

Earthquakes are one of the most frequently occurring and costly natural hazards in the world, with thousands occurring globally each year. There are also many active faults in the United States. Following several devastating earthquakes in the United States (e.g., 1971 San Fernando, 1989 Loma Prieta, 1994 Northridge, to name a few) significant changes and improvements were made to emergency protocols and disaster preparedness planning and existing building codes. In addition, engineers have developed new performance-based design philosophies, which are still being refined.

The real potential exists for a large devastating earthquake to occur again in the United States which could cause significant damage to the existing infrastructure and widespread community disruption. This seismic hazard potentially: (1) puts many people at risk of death or injury, (2) financially strains individuals, households, businesses, and entire communities, and (3) altogether lessens the quality of life for those affected. Mitigation against disasters can be a difficult task when it comes to deciding where money is best allocated such that it protects the population, the infrastructure, and preserves the quality

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of peoples’ lives. This is especially true considering the pronounced diversity, in both population and building story, of some geographically adjacent communities, and therefore may be an issue that is best addressed by local governments.

**Computational Framework**

The framework presented herein aims to answer two questions. (1) How can local government officials most effectively and efficiently allocate funds to mitigate residential structures against earthquakes? (2) What role does the social and/or economic structure of the community play in the allocation of mitigation funds? These questions are modeled by a multi-objective optimization framework via genetic algorithm by considering the resiliency-based design of woodframe buildings within a community. The objectives considered in the community are the minimization of (1) initial retrofit cost, (2) financial losses, (3) number of fatalities, and (4) loss in quality of life for the population, based on the building retrofit.

Fig. 1 provides a schematic of the framework which initiates with the problem formulation, selection of the region and collection of the specific population data, and defining the seismic hazard level to be considered in the optimization. The framework is intended to be used by decision makers at the local (or other) government level to aid in the allocation of mitigation funds in developing a mitigation plan prior to, or following, an earthquake.

![Diagram of the framework](image_url)

**Figure 1. Framework of the Resiliency-Based Community Design.**

**Socio-Economic and Engineering Variables**

The list of variables which affect community resilience and social vulnerability is extensive. However, based on data availability and comparability, six key socio-economic variables are included in this study: socio-economic status, gender, age, race and ethnicity, household structure, and the built environment. These six variables have consistently been shown in the literature to most influence social vulnerability and a range of pre- and post-disaster outcomes.
Within the presented framework, socio-economic status integrates both educational attainment and annual income of an individual household. Household structure considers whether the household consists of a partnered relationship, and whether children under 18 live in the household. The built environment incorporates the age of the structure (ranging from pre-1970s to current performance-based designs), the quality (whether code compliant or structurally deficient), and the density of the built environment (whether rural or urban).

In addition to the socio-economic variables, a single engineering variable which has been shown to be well-correlated with structural damage for woodframe buildings [5] is considered in the optimization, i.e., inter-story drift. Inter-story drift is a ratio computed as the displacement measured over the height of a single wall or story, divided by the height of that wall or story. Inter-story drift is then used in conjunction with the socio-economic variables described above to quantify damage measures such as the time for and cost of repair, the likeliness of injury and fatality of building occupants, and the likeliness of a building occupant or owner to develop post-traumatic stress disorder. Relationship are developed between inter-story drift both structural and non-structural damage for woodframe buildings based on experimental studies [6-7].

**Decision Variables - Archetypes**

The decision variables within the optimization consist of a set of 35 archetypes. The archetypes represent the design space in the optimization. Seven floor plans makeup the design space, including two one-story single family homes, two two-story single family homes, a three-story apartment building with tuck-under parking, and a four-story multi-unit office building with large open space on the first story. To adequately represent the woodframe building stock that one might encounter today, each floor plan was designed based on each design code starting with the first set of seismic provisions in the United States, and up to current performance-based seismic design, which are in essence state-of-the-art seismic design techniques. The two soft-story buildings were also retrofitted following the FEMA P-807 methodology [8]. After the buildings were designed, extensive nonlinear time history analysis was conducted for each whole structure model in the software program SAPWood [9]. To demonstrate the performance of each of the structures, fragility curves conditioned on inter-story drift were developed. Fragility curves are graphs that demonstrate the probability that a specified limit state is met or exceeded, conditioned on a structural response parameter, i.e., inter-story drift. The fragility curves developed here are then used to develop regional fragilities employed for determining the “individual’s” fitness within the algorithm.

**Genetic Algorithm**

The four resiliency objectives previously discussed are used in a weighted additive function and employed as the fitness function within the genetic algorithm. The genetic algorithm employs the crossover, mutation, and selection operators on the individuals. Here, an individual, or chromosome, represents a woodframe building community. The individual is composed of 70 digits, or 35 two-digit concatenated genes. The genes represent the quantity of each archetype present in that community with a maximum quantity of 99 for each archetype (which can be scaled to represent larger communities). Each generation, the population of individuals is subjected to single-point crossover and mutation, and followed by tournament selection. The
best (non-dominated) solutions (i.e. structural mitigation plans) will be extracted and collected from all generations to form the Pareto-optimal set of solutions. Additionally, weights will be applied to the resiliency objectives and altered for multiple runs so that the full set of Pareto-optimal solutions is obtained. These solutions consist of mitigation plans for the woodframe building stock in the specified community differing by the level of importance weighted on each of the four resiliency objectives. The set of mitigation plans are provided to decision makers for the region being analyzed so that the optimal mitigation plan specific for that region may be selected and used to aid in the allocation of mitigation funds.

**Future Work**

The resiliency-based design framework presented here is still being developed. As such, detailed case studies have not yet been conducted. It is the intention of the authors to conduct several detailed case studies within two earthquake prone regions within the United States, including Los Angeles, California and Memphis, Tennessee. The specific population data for the region of interest will be collected and used in the optimization of a building retrofit plan.

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**References**


