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THE COSTS OF NOT RETROFITTING FROM A COMBINED ENGINEERING, SOCIOECONOMIC AND DEMOGRAPHIC PERSPECTIVE

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Abstract

It is of great research interest to explore paths which reduce the severity of a natural disaster, where the severity of a natural disaster may be quantified as the product of exposure and vulnerability. Thus disaster reduction can be accomplished through decreasing either, or both, the natural hazard exposure and/or the community's vulnerabilities. Communities have both physical and social vulnerabilities, and these are often linked. This study presents an approach at reducing the physical vulnerabilities of two communities through their residential building stock by modeling the social vulnerabilities and demonstrating the link between the two. Household dislocation, critical injuries, fatalities, and posttraumatic stress disorder (PTSD) were used as the vulnerability metrics. Two community-level retrofit plans were explored: one which retrofitted all low-code buildings to code level, and a second which retrofitted all low-code buildings to a high-code level. The retrofit plans were exemplified on two real communities in Los Angeles County, California, USA at the zip code level: 90011 the poorest zip code and 90077 the wealthiest zip code. Census data was used for modeling the social and physical vulnerabilities, including computing morbidity modification factors determined by the product of five socioeconomic and demographic factors for age, ethnicity/race, family structure, gender, and socioeconomic status. The costs of not retrofitting were demonstrated by comparing the vulnerability metrics and associated financial costs of the vulnerability metrics when a community decides to or not to retrofit their residential building stock. The results of the analyses revealed that the cost of not retrofitting was 9 to 446 critical injuries, 14 to 740 fatalities, 143 to 7,157 persons diagnosed with PTSD, and 127 to 1136 households forced to dislocate. Additionally, the results revealed that the financial cost of not retrofitting was US$80 million to US$4.5 billion. These numbers were computed for the poorest zip code for a maximum considered earthquake (MCE) scenario. The ranges are based on the retrofit level (either to code or to high code).

This study quantified a social disaster index (SDI) as the product of exposure and the vulnerabilities. The analyses demonstrated a reduction in the SDI to occur when the physical vulnerabilities were reduced through retrofit. The reduction in SDI also demonstrated the influence of the social vulnerabilities by its great differences in value between the two study communities. There are other options for reducing the severity of natural disasters, including hazard exposure reduction, such as creating programs which offer incentives to households to relocate away from very hazardous regions (fault lines, coasts, floodplains, etc.). Addressing both the hazard exposure and vulnerabilities is likely the best solution for reducing the severity of future natural disasters.

Keywords: Woodframe Buildings, Earthquakes, Social Vulnerability, Household Dislocation, Community Resilience

1. Introduction

It is commonplace for the long term mention of the severity of a natural disaster to be reported in two terms: the financial loss and the number of fatalities. The financial loss is typically reported as the total economic loss or the total insured loss. For example, the 1994 Northridge earthquake reportedly caused US$40 billion in economic loss and 57 fatalities; the 2011 Christchurch earthquakes reportedly caused US$18 billion in economic loss and 185 fatalities; the 2011 Tohoku earthquake and tsunami reportedly caused as much as US$360 billion in economic loss and as many as 28,000 fatalities; the 2014 South Napa earthquake reportedly caused as much as US$1 billion in economic loss and 1 fatality. Based on these reports, one could rank the severity of these four earthquake disasters relative to each other and conclude that the 2011 Tohoku earthquake and tsunami was the most devastating and the 2014 South Napa earthquake was the least devastating. Ranking the 1994 Northridge earthquake relative to the 2011 Christchurch earthquake is less straightforward since the loss is higher for one, but the number of fatalities is higher for the other. This difficulty in comparing the two disasters demonstrates that the severity of a natural disaster is measured by more than the economic and/or insured losses and the fatalities. There are many other short term factors, such as the number of buildings damage, persons injured, and people without access to lifeline or healthcare serves. There are also many other long term factors, such as the number of persons with posttraumatic stress disorder (PTSD), and the number of businesses which closed. In reality, the list of factors which should be used to measure the severity of a natural disaster is practically endless. As researchers, it is important to get ahead of the problem, and thus a major research question has continued to be: How can the severity of natural disasters be reduced? This study focused specifically on earthquake disasters, however the framework is extendable to all types of natural disasters.

To answer this question, one must consider the fact that natural hazards come from nature, but natural disasters are socially constructed. This concept was first presented by [1] who theorized that natural disasters represent a conjuncture of physical and social happenings. A small earthquake occurring in the middle of the ocean, far away from any inhabited land, or ships, and too small to cause a tsunami, does not create a disastrous situation. Natural disasters are the product of exposure and vulnerability, where the vulnerability of a location is both physical and social. With this in mind, a social disaster index (SDI) may be conceptually expressed as

$$SDI_i = (\text{Exposure})_i \times (\sum \text{Physical Vul.} + \sum \text{Social Vul.})_i \quad (1)$$

where i refers to the natural disaster agent, whether an earthquake, tsunami, hurricane, etc.. Thus to reduce the severity of the natural disaster, one of more of the variables on the right hand side of Eq. (1) must be reduced. That is, disaster reduction can be accomplished through decreasing either the natural hazard exposure and/or the community's physical and/or social vulnerabilities. This study presents an approach to reducing the effects of a natural disaster by addressing a subset of both the physical vulnerabilities and the social vulnerabilities, and then uses this information to demonstrate the costs of not planning ahead of time by retrofitting. The physical vulnerabilities are assessed through physical damage on a set of residential buildings, and the social vulnerabilities are assessed through a critical injury rate, a fatality rate, a PTSD diagnosis rate, and a household dislocation rate. The social vulnerabilities are computed by modeling five socioeconomic and demographic variables. The exemplified approach will demonstrate how the severity of an earthquake disaster can be reduced by designing or retrofitting residential structures to higher code levels, but that ultimately an investment is required for reducing both physical and social vulnerabilities in order to achieve resilience.

2. Modeling the Physical Vulnerabilities

A significant portion of economic loss generated by natural disasters is due to damage to residential buildings and housing relocation [2]. For example, as noted above, the 1994 Northridge earthquake caused an estimated US$40 billion in economic loss, approximately US$20 billion of which was due to damage to residential woodframe buildings [3]. Thus, if the physical vulnerabilities of residential buildings can be reduced, then a significant and positive impact should be achieved in reducing the severity of future earthquake disasters. The physical vulnerabilities are simplified in this study to be modeled strictly by the number of buildings with structural damage, whether repairable or not (collapsed).

2.1 Building Archetypes

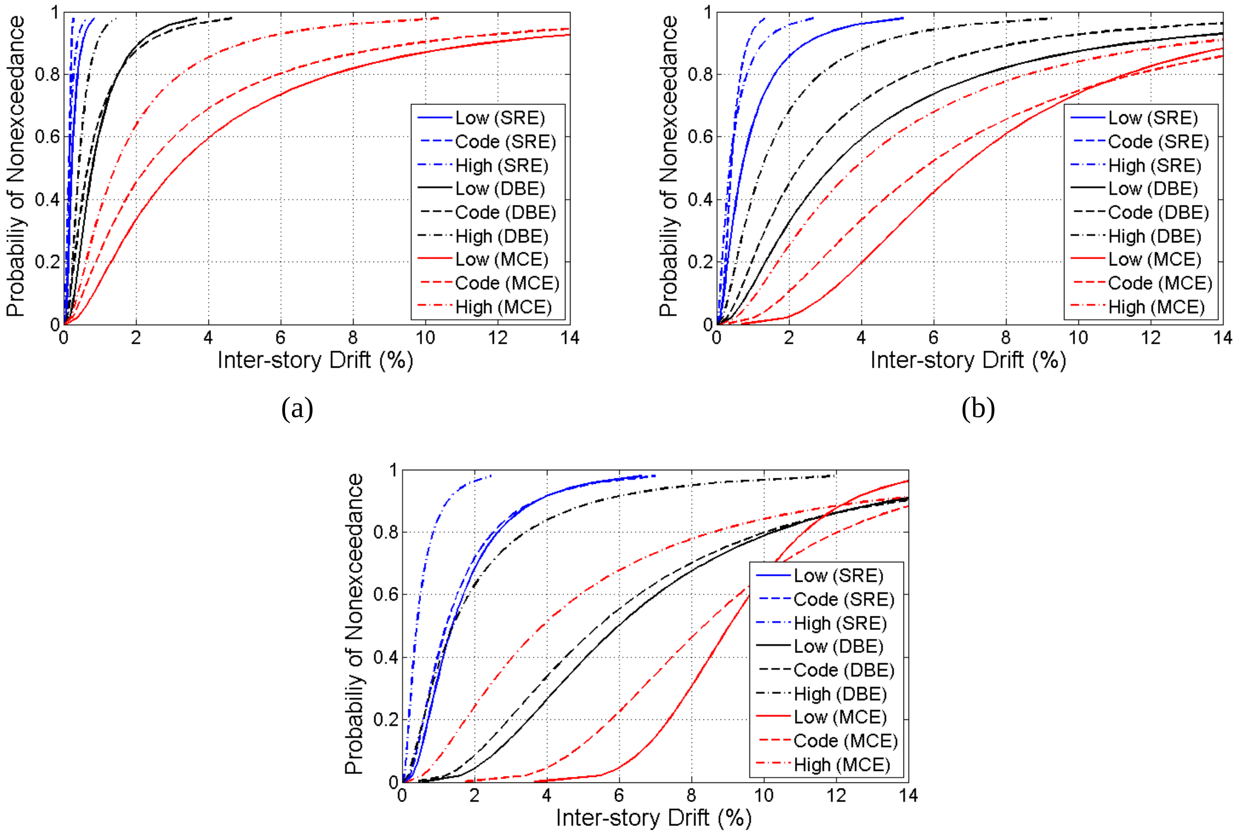
Residential buildings represent substantial investment in the United States, and approximately 90% of residential buildings in the U.S. are light-frame wood construction [4]. To quantify physical vulnerability, the present study modeled residential light-frame wood buildings in an effort to control the size of the analysis while capturing the very common building type. A portion of the woodframe building archetypes designed and modeled in [5] were selected for this study. These included: a one-story single-family dwelling (SFD), a two-story multi-family dwelling (MFD), and a three-story multi-family dwelling. To capture the diversity in age (and thus building code and seismic design standard) of the residential buildings in the United States, the present study adopted three levels of seismic design, namely, a below code level (low), a code level (code), and an above code level (high). To model the below code level, the 1978 National Earthquake Hazard Reduction Program (NEHRP) provisions were used. To model the code level, the 2006 International Building Code (IBC) using American Society of Civil Engineers (ASCE) 7 – 2005 load modeling were used. Lastly, to model the above code level, a performance-based seismic retrofit (PBSR) using the simplified direct displacement design (SDDD) procedure [6] providing superior seismic performance was used. The PBSR was designed to an immediate occupancy limit state defined as not exceeding 1.0% peak inter-story drift given a maximum considered earthquake (MCE) (Sa = 2.5g) with a 50% probability of nonexceedance (PNE). In all cases, the building archetypes were modeled using the seismic hazard for Los Angeles, California, and had a fundamental period of approximately 0.22 seconds. Table 1 provides the descriptions, total floor area, and the initial cost for each of the archetypes used in this study. The initial costs were determined using the new construction cost estimates per unit floor area in [7] multiplied by the total floor area.

Table 1 – Description of Building Archetypes

Archetype Description	Total Floor Area, m^2	Initial Cost (Million USD)		
		Low	Code	High
A1: One-story single-family home	131.0	$0.211	$0.224	$0.259
A2: Two-story three-unit townhome with garages	674.5	$1.176	$1.209	$1.300
A3: Three-story ten-unit apartment building with tuck-under parking	1,269.5	$1.768	$1.796	$1.876

2.2 Building Archetype Seismic Performance

The seismic performance of the building archetypes was measured using a single engineering demand parameter, peak inter-story drift. The archetypes were modeled in SAPWood [8] and subjected to an extensive nonlinear time history analysis which used a suite of 22 biaxial ground motion records [9]. The incremental dynamic analysis results were then used to develop fragility curves for three seismic intensities. These seismic intensities were defined by the spectral acceleration of MCE, including 1/3MCE, 2/3MCE, and MCE, where 1/3MCE is termed the Short Response Earthquake (SRE), and 2/3MCE is also known as the Design Basis Earthquake (DBE). These three seismic intensities were selected in an effort to exemplify the costs of not retrofitting for small, moderate, and large earthquakes. The fragility curves are presented in Fig. 1a, 1b, and 1c for archetypes 1, 2, and 3, respectively.



(c)

Fig. 1 – Archetype Inter-story Drift Fragility Curves: (a) Archetype 1; (b) Archetype 2; (c) Archetype 3

Damage states were defined for four physical damage categories: slight, moderate, severe, and collapse, with corresponding peak inter-story drift values of 1.20%, 2.75%, 5.50%, and 10.0%, respectively, and where shelter-out-of-place is required for the severe and collapse damage states. Using these definitions and the seismic performance of the building archetypes, the probability of household dislocation and the probability of collapse were determined. The 50th percentile values were extracted and are shown in Fig. 2 for all building archetypes at a MCE seismic intensity. Referring to Fig. 2, the one-story SFD has an approximately zero probability of collapse or causing dislocation of the occupants given a MCE event regardless of the design level. The two-story MFD has approximately a 68% and 90% probability of dislocation at a code-level and low-code level design. The two-story MFD has approximately a zero probability of collapse or dislocation when designed to the high-code level. Additionally, Fig. 2 demonstrates that the three-story MFD with a soft first story has a 100% probability of causing dislocation given a MCE event at a low-code level and a code-level design. The 50th percentile collapse probability is 20% for the code level design and approximately 38% at the low-code level design for the three-story MFD. It is important to note that all archetypes have approximately a zero probability of collapse or dislocation when designed to a high-code level. These probabilities will be given a closer look in Section 4.

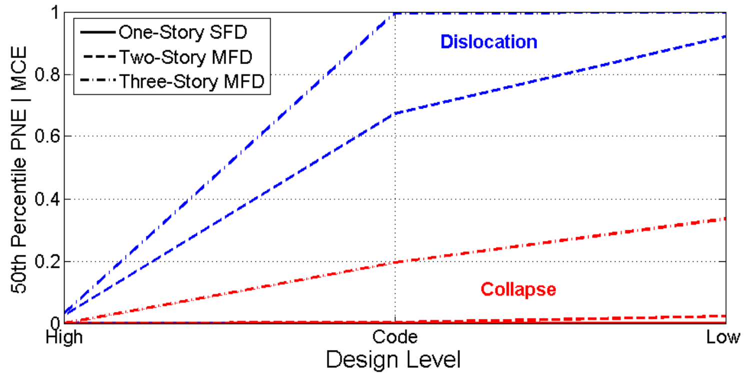


Fig. 2 – 50th Percentile Probability of Nonexceedance of Dislocation and Collapse Given a MCE

3. Modeling the Social Vulnerabilities

The social vulnerabilities were modeled by morbidities and household dislocation, where morbidities include physical injuries, emotional injuries, and fatalities. To constrain the model space, only critical injuries were reported for physical injuries, and PTSD diagnosis for emotional injury. The critical injuries, PTSD diagnoses and fatalities were determined using socioeconomic and demographic (SED) adjustment factors applied to the morbidities determined from building damage alone. Specifically, there were five SED adjustment factors used, namely for the population's age, ethnicity/race, family structure, gender, and socioeconomic status distributions. These five SED variables have been shown to have a significant effect on social vulnerability [10, 11]. Following previous earthquake disasters, the elderly have been shown to be the most vulnerable age group to injury and fatality, attributed to their physiology, living conditions, and a myriad of other factors [12-16]. Ethnic and racial minorities were observed to be more susceptible to physical injury and PTSD following an earthquake [12, 17, 18], likely due to living conditions and minorities having less political power, and lower access to resources. Adults in households with children have been observed to be more vulnerable to PTSD than partnered households [19]. Females, especially in developing countries, have been recorded to be approximately twice as vulnerable to injury, fatality, and PTSD as their male counterparts [16, 20-28]. Low-income households, and households with low education levels were modeled together as (low) socioeconomic status (SES). There two groups have been observed to be the most vulnerable groups to injury, fatality, and PTSD [10, 29]. This fact is due to many reasons, including that households with low SES are generally located in risky areas with lower quality housing which experiences more damage during extreme loadings, and are more likely to be renters. This short list of variables is certainly not the full list of factors which contribute to social vulnerability, and although very important, their intersectionality was not caught in the development of the five factors. The in depth development of the five SED variables into factors for the three morbidity rates (i.e. critical injury rate, fatality rate, and PTSD diagnosis rate) is provided in [5]. These factors act as morbidity modification factors acting on census data. The use of census data makes the community-level analysis community-specific. The factors may be analytically expressed as

$$\mathrm{F_{MR,i}} = \sum \mathrm{f_{MR,sub(j)}} \cdot \mathrm{p_{sub,j}} \tag{2}$$

where $F_{MR,i}$ is the SED factor, i is for each variable (e.g., age, gender, etc.), the MR subscript is for the specific morbidity rate, $f_{MR,sub(j)}$ is a subcategory factor developed from empirical data [5] for each subcategory (e.g., male, female, etc.), j is the number of subcategories for each variable, and $p_{sub,i}$ is the percentage of each subcategory in the community. The factors developed in Eq. (2) act as adjustments to morbidity rates based on building damage alone. The analytical expression for the adjusted morbidity rates (AMR) may be expressed as

$$\mathrm{AMR_{MR,DS}} = (\mathrm{F_{MR,age}} \cdot \mathrm{F_{MR,eth}} \cdot \mathrm{F_{MR,fam}} \cdot \mathrm{F_{MR,gen}} \cdot \mathrm{F_{MR,ses}}) \cdot \mathrm{MR_{MR,DS}} \tag{3}$$

where $AMR_{MR,DS}$ is the adjusted morbidity rate, DS is the damage state, $MR_{MR,DS}$ is the morbidity rate based on building damage alone [30], and $F_{MR,age}$, $F_{MR,eth}$, $F_{MR,fam}$, $F_{MR,gen}$, and $F_{MR,ses}$ are the SED adjustment factors for age, ethnicity/race, family structure, gender and socioeconomic status, respectively, for the specific morbidity rate. $F_{MR,eth}$ and $F_{MR,fam}$ are equal to one for critical injury and fatality. This is due to the lack of data that was available to capture their influence on the morbidity rates, although it is recognized that these variables do influence critical injury and fatality following earthquake disasters. The morbidity rates are dependent on the building damage state; the adjustment factors are independent of the building damage state. The unadjusted morbidity rates and the household dislocation rate for each of the four damage states is provided in Table 2. The rates in Table 2 for critical injury and fatality were adopted from [30]. The unadjusted rate for PTSD diagnosis was set as the severe injury rate from [30].

Table 2 – Unadjusted Rates of the Social Vulnerability Measures per Damage State

Damage State	Critical Injury Rate	Fatality Rate	PTSD Diagnosis Rate	Household Dislocation Rate
1	0.0000005	0.0000005	0.000005	0
2	0.0000003	0.0000003	0.0003	0
3	0.00001	0.00001	0.001	1
4	0.03	0.05	0.2	1

Each morbidity rate has a cost associated with it. For critical injury and PTSD, this includes a treatment cost and a downtime cost. For fatality, this could include many different costs depending on the perspective. The total cost associated with a critical injury and a fatality were set to US$3,170,000 per person and US$4,165,000 per person, respectively. These values were adopted from [31] and adjusted to 2014 dollars. The values are a comprehensive cost used by the U.S. government, and cover the cost of pain, lost quality of life, medical costs, legal costs, lost earnings, lost household production, and more. The cost associated with PTSD was determined as the treatment cost for one year, and the cost of downtime due to absenteeism (the tendency to not go to work) and presenteeism (the tendency to not be productive at work). The cost for treating PTSD for one year was determined as US$5,400 per person based on [32]. The downtime cost of PTSD is less straightforward, and was determined to be a function of the community's average annual income and the severity of damage caused by the earthquake. The number of work loss days per year due to absenteeism was set to six in this study. The number of work cut back days per year was set to 31, with 2 hours of work cut back on each of those days due to presenteeism (see [5] for more information regarding these specific time selections). The specific costs of PTSD will be provided in the case study below.

4. Reducing a Community's Vulnerabilities

To determine the costs of not retrofitting, and the costs of reducing a community's vulnerabilities, the natural disaster index presented in Eq. (1) is applied. The SDI is computed here using a shortened list of variables: the number of households dislocated, critical injuries, fatalities, and PTSD diagnoses. The census data from two actual communities, defined by zip code, are analyzed. The SDI is computed and compared across three situations: the current building stock distribution based on census data, and two community-level retrofit plans.

4.1 Example Communities

Two communities are analyzed in this section. U.S. census data was obtained for two zip codes in Los Angeles County, California: the poorest zip code (90011) and the wealthiest zip code (90077). These two communities were selected due to the differences in socioeconomic and demographic distributions of their populations. The census data used in the analysis from these two zip codes is provided in Table 3. To control the analysis size and in an effort to maintain consistency in comparing the results, the total number of households in the analysis was set to 2,000 for each zip code. Using the mean household size in Table 3, and the 2000 households, the total population size was determined as 9,991, and 5,062 persons for zip code 90011 and 90077, respectively. Using housing statistics from the American Community Survey which operates under the Census Bureau, an approximate distribution of the 9 building archetypes scaled for 2,000 households was determined and is provided in Table 4. Note: to compute the 2,000 households, the values in Table 4 must be multiplied by the number of units in each archetype (1, 3, and 10 for archetypes 1, 2, and 3, respectively), then multiplied by 2,000 and summed for all archetypes. The American Community Survey data used to develop the data in Table 4 is provided in the bottom rows of Table 3.

Table 3 – Community Data

Variable	**Subcategory of Variable**	**90011 (poorest)**	**90077 (wealthiest)**
Mean Annual Income		US$39,043	US$284,834
Mean Household Size		4.57	2.53
Age	(0 – 9 y.o.)	18.8%	11.1%
	(10 – 19 y.o.)	18.7%	12.2%
	(20 – 29 y.o.)	16.7%	8.60%
	(30 – 45 y.o.)	23.5%	13.4%
	(46 – 64 y.o.)	17.6%	30.3%
	(65+ y.o.)	4.60%	24.4%
Ethnicity/Race	White, non-Hispanic	0.60%	84.3%
	Racial/Ethnic Minorities	99.4%	15.7%
Family Structure	Single	59.8%	35.4%
	Partnered	40.2%	64.6%
	Person <18 y.o. in household	62.8%	27.3%
Gender	Female	49.8%	46.8%
	Male	50.2%	53.2%
Socioeconomic Status	Low	52.9%	7.60%
	Moderate	42.1%	16.8%
	Upper	5.10%	75.7%
Year Structure Built	Built 2010 or later	0.20%	0.00%
	Built 2000 to 2009	4.00%	4.60%
	Built Prior to 1999	95.8%	95.4%
Units in Structure	1-Unit detached	46.1%	88.4%
	3 or 4 Units	10.9%	1.10%
	10 to 19 Units	4.60%	0.00%

The morbidity modification factors determined from Eq. (3) above were 3.67, 3.65, and 8.87 for critical injury, fatality, and PSTD for 90011, and 2.14, 2.15, and 2.37 for 90077, respectively. These factors will effectively amplify the morbidity rates computed by building damage alone. From these numbers, it is clear that 90011 is more socially vulnerable than 90077, and therefore scenario analyses will likely result in higher morbidity rates.

4.2 Earthquake Scenario-Analysis

Prior to reducing the vulnerabilities, a scenario-earthquake analysis must be conducted so that the present state of vulnerabilities can be determined. Once the current vulnerabilities are known, improvements and reductions can be made. The three seismic intensities used in the previous section were applied as the scenario-earthquake analyses here (1/3MCE, 2/3MCE, and MCE). This provides a comparison of the vulnerabilities at a wide range of earthquake intensities, and can help identify whether solutions with higher initial costs are warranted if the seismic hazard probability of an area is low, and historical data only indicates small earthquakes have occurred in the past.

Table 4 – Housing Distribution Data

Archetype	90011 (poorest)	90077 (wealthiest)
A1-Low	32.4%	92.0%
A1-Code	1.35%	4.44%
A1-High	0.09%	0.00%
A2-Low	7.66%	1.14%
A2-Code	3.14%	0.06%
A2-High	0.00%	0.00%
A3-Low	3.24%	0.00%
A3-Code	0.14%	0.00%
A3-High	0.00%	0.00%

4.3 Community-Level Retrofit Plans

To reduce the vulnerabilities, and therefore the SDI, two community-level retrofit plans were explored. The first plan retrofitted all low-code buildings to code level. The second plan retrofitted all low-code buildings to the high-code design level. These three archetype distributions are termed “No Retrofit”, “Code Retrofit”, and “High Retrofit”, respectively, herein. The costs associated with retrofitting each archetype from low-code to code, low-code to high-code, and code to high-code are provided in Table 5. The retrofit costs for retrofitting from low-code to code and low-code to high-code were determined from two sources [33, 34]. Costs per m^2 of floor area were determined from the referenced studies and multiplied by the total floor area of the three archetypes. The cost of retrofitting from code to high-code was determined by subtracting the retrofit cost per m^2 for low-code to code from the retrofit cost per m^2 for low-code to high-code, and then multiplying this value by the total floor area of each archetype. The benefits of retrofitting from code to high code are not demonstrated in the analyses here due to brevity, nevertheless, this improvement in design level is not to be considered arbitrary in any way.

Table 5 – Description of Building Archetypes

Archetype Description	Retrofit Cost (USD)		
	Low to Code	Low to High	Code to High
A1: One-story single-family home	$12,690	$47,940	$35,250
A2: Two-story three-unit townhome with garages	$65,340	$246,840	$181,500
A3: Three-story ten-unit apartment building with tuck-under parking	$95,274	$359,924	$264,650

4.4 Results

The results presented in this section provide only the 50th percentile values for brevity under the assumption that strict values can be more impactful when discussing losses, however this is not meant to be misleading since the uncertainty is not demonstrated. The total number of dislocated households were determined for the two communities at the three seismic intensities (see Fig. 3). Fig. 3 demonstrates the high level of inequity between the two communities. A DBE scenario caused over three times as many households to dislocate in 90011 (poorest) as a MCE scenario did in 90077 (wealthiest). Although evident in Table 4, Fig. 3 helps point out the major difference in physical vulnerability that more socially vulnerable communities have created by their lower quality housing stock. Notice that 3.65% of the building stock in 90011 is the soft-story building (A3), whereas 90077 has none of these buildings in its community. For both communities, the SRE caused zero households to dislocate, and similarly did the DBE for 90077.

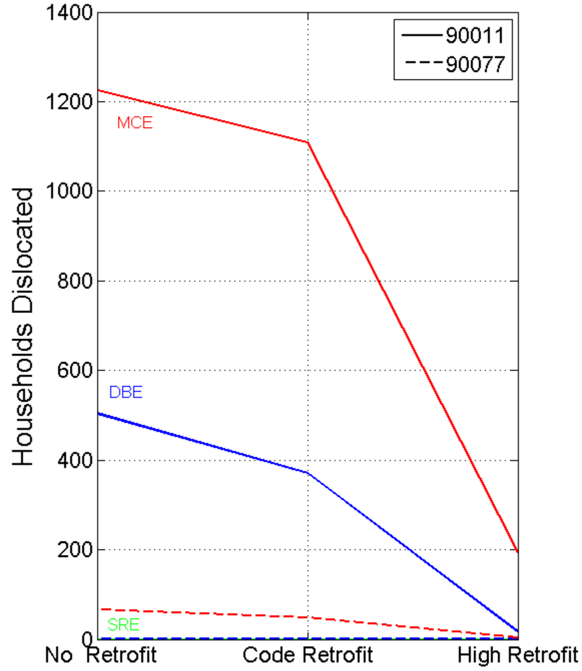


Fig. 3 – Number of Households Dislocated (50th Percentile)

The SDI was computed for the two communities for their initial building stock and both community-level retrofit plans, and is provided at MCE in Table 6. Additionally, the different metrics used in this study to compute the SDI are provided in Table 6. Table 6 helps demonstrate the high level of difference in vulnerability between the two communities. Due to the high vulnerability associated with 90011 in their building stock and in their socioeconomic and demographic distributions, each morbidity and number of households dislocated are at least one order of magnitude larger than 90077 at all three retrofit levels. Table 6 shows that the SDI reduced from 10615 to 10347 and 2013 for 90011 when the low code buildings were retrofitted to code and high-code, respectively. Similarly, the SDI reduces from 183 to 133 or 14 for 90077 when the low code buildings were retrofitted to code or high code, respectively.

Table 6 – SDI and Vulnerability Counts for MCE

Analysis	Community	Critical Inj.	Fatalities	PTSD	Household Disl.	SDI
No Retrofit	90011	499	829	8062	1225	10615
	90077	11	18	87	67	183
Code Retrofit	90011	491	816	7931	1109	10347
	90077	8	13	64	48	133
High Retrofit	90011	94	157	1569	193	2013
	90077	1	1	8	4	14

The vulnerability counts were taken a step further to determine the associated cost of each metric, as well as the cost of building repair. The analytical model for determining the cost of household dislocation and building repair are provided in [5]. Table 7 provides the cost breakdown for critical injury, fatality, PTSD, household dislocation, building repair, and retrofit. The last column in Table 7 provides the total cost caused by a MCE scenario by summing all of the other tabulated costs. The detailed costs are only provided for MCE here. Table 8 provides the retrofit cost versus the total loss for all three seismic intensities for the two communities for the initial building stock and the two retrofit plans. In this case, the total loss does not include the cost of the retrofit. Table 8 helps demonstrate that although there is no retrofit cost associated with the initial building stock, major losses were still experienced during moderate sized earthquake rupture events. The total loss at MCE was greatly reduced by retrofitting, justifying the initial cost. Table 8 also demonstrates that for a wealthy community with low social vulnerability, a low hazard probability, and a history of only experiencing small earthquakes, the high cost of retrofitting may not be justified. If larger earthquakes are a concern, then retrofitting is still the best option since it will significantly reduce the number of morbidities and households forced to dislocate.

Table 7 – Total Costs (USD) of Not Retrofitting for MCE

Analysis	Comm.	Critical Inj.	Fatalities	PTSD	Household Disl.	Retrofit	Bldg. Repair	Total Cost
No Retrofit	90011	1.58E9	3.45E9	1.26E8	4.48E6	-	2.26E7	5.18E9
	90077	3.49E7	7.50E7	1.35E6	3.93E5	-	2.58E6	1.14E8
Code Retrofit	90011	1.56E9	3.40E9	1.24E8	3.71E6	2.67E7	1.83E7	5.13E9
	90077	2.54E7	5.41E7	9.97E5	2.81E5	2.48E7	1.86E6	1.07E8
High Retrofit	90011	2.98E8	6.54E8	2.44E7	6.57E5	1.01E8	3.77E6	1.08E9
	90077	3.17E6	4.17E6	1.25E5	1.37E4	9.38E7	9.03E4	1.01E8

Table 8 – Total Loss versus Retrofit Cost (USD)

Analysis	Comm.	Retrofit Cost	Total Loss (SRE)	Total Loss (DBE)	Total Loss (MCE)
No Retrofit	90011	0	1.25E5	8.37E8	5.18E9
	90077	0	0	1.10E6	1.14E8
Code Retrofit	90011	2.67E7	9.34E4	6.05E8	5.11E9
	90077	2.48E7	0	0	8.26E7
High Retrofit	90011	1.01E8	1.56E4	2.53E7	9.81E8
	90077	9.38E7	0	0	7.57E6

5. Discussion and Conclusion

Table 1 demonstrated that the initial cost and retrofit costs required for achieving a higher seismic performance is not significantly more than the initial cost of a below-code level building. Fig. 1 – Fig. 2 demonstrated the significant improvement in seismic performance (reduction in peak inter-story drift) that can be achieved by designing to a higher code level. These numbers should help encourage communities to retrofit their buildings. Table 4 and Fig. 3 point out the major difference in physical vulnerability that often houses the most socially vulnerable groups of people. Identifying vulnerability hotspots by taking approaches like those demonstrated here is important for effective and efficient planning and recovery purposes.

A 1.3% and 28% reduction in total loss was achieved by retrofitting 90011 and 90077 to code level, respectively, for a MCE scenario. An 81% and 93% reduction in total loss was achieved by retrofitting 90011 and 90077 to a high code level, respectively, for a MCE scenario. These percentages demonstrate the need to build buildings and retrofit buildings to seismic design levels higher than what is specified in the code in regions of high seismicity. The cost of not retrofitting was demonstrated in Tables 6 – 8. Table 6 more importantly demonstrates the mean cost of not retrofitting being 8 to 405 critical injuries, 13 to 672 fatalities, 131 to 6,493 persons diagnosed with PTSD, and 116 to 1,032 households forced to dislocate. Table 7 demonstrates the financial cost of not retrofitting was US$50 million to US$4.1 billion. These numbers are for 90011 for a MCE scenario, and the ranges are based on the retrofit level (either to code or to high-code).

Only damage states which caused structural damage were included in this study. It should be noted that nonstructural damage causes tremendous financial loss, and the majority of the $20 billion of damage caused to residential woodframe buildings during the 1994 Northridge earthquake was caused by nonstructural damage. Similarly, minor, moderate, and severe injuries were not considered here, but typically comprise the majority of injuries and are by no means to be considered negligible.

This study reduced the SDI by reducing the physical vulnerabilities through retrofit and demonstrated the influence of the social vulnerabilities. There are other options for reducing the severity of natural disasters, including hazard exposure reduction, such as creating programs which offer incentives to households to relocate away from very hazardous regions (fault lines, coasts, floodplains, etc.). Addressing both the hazard exposure and vulnerabilities is likely the best solution for reducing the severity of future natural disasters. The results of this study can be used for community-level planning for an earthquake disaster.

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