EVALUATING POLICIES BY SIMULATING LARGE SCALE REGIONAL SEISMIC RESPONSE

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ABSTRACT

As urbanization occurs it becomes increasingly important to continually work towards increasing a region’s resilience to natural disasters. This project attempts to develop a computational workflow to gauge how a policy could potentially influence a region’s resilience. Two programs, UrbanSim and a Regional Seismic Response Simulator, and ground motions developed by the United States Geological Survey are all utilized in an attempt to create this workflow. The outputs from each simulation includes building status, economic loss, and people displaced. As an example, a scenario in which a required retrofit of vulnerable buildings is proposed and its effects on damage, post hazard, are assessed. The hazard is defined as a 7.4 magnitude earthquake along the Hayward fault in the San Francisco Bay Area. Further, limitations and suggested advancements are discussed.

INTRODUCTION

It is projected that 66% percent of the global population will live in urban areas by the year 2050 [United Nations]. As urbanization occurs it becomes increasingly important to continually work towards developing and redeveloping communities that are more resilient to natural disasters. Policies and building codes attempt to mitigate damage by requiring structures to behave more predictably when subjected to natural disasters. When considering a particular policy, being able to simulate and visual how structures in the region respond and the economic loss associated with structural damage can lead to better recovery and mitigation decisions.

Producing a computational model capable of simulating post hazards conditions could also aid in preparing relief efforts post disaster. Currently, there is no framework that allows policy makers to preemptively assess hazard mitigation efforts through the use of simulations.

This report attempts to identify vulnerable structures within the Bay Area after a major earthquake and then runs a simulation where a policy is enacted that would require a mandatory retrofit to previously identified vulnerable buildings. Two programs, UrbanSim [Waddell, 1998] and a Regional Seismic Response Simulator [Lu], and ground motions developed by the United States Geological Survey Haywired Scenario [USGS] are all utilized in an effort to create a workflow. The metrics use to compare outputs from various simulations include building status, economic loss, and people displaced.

METHODOLOGY

While this framework could hypothetically be applied to any region to evaluate various policies, for this project the Bay Area is the defined region and an earthquake is chosen as the hazard of interest. Input information on ground motions and building stock is gathered from the Haywired Scenario and UrbanSim, respectively. This information was integrated and then run through the Regional Seismic Response Simulator, which outputs regional building status, economic loss, and people displaced. The baseline simulation represents a do-nothing scenario. Next, a sample policy, of a required retrofit, was used to demonstrate the framework's capabilities. To represent a required retrofit previously labeled red and yellow tagged buildings have their seismic response reduced by 20% in the next iteration of the simulation. Lastly, each output was then visually represented in UrbanSim. Figure 1 is a flowchart that depicts the overall workflow.

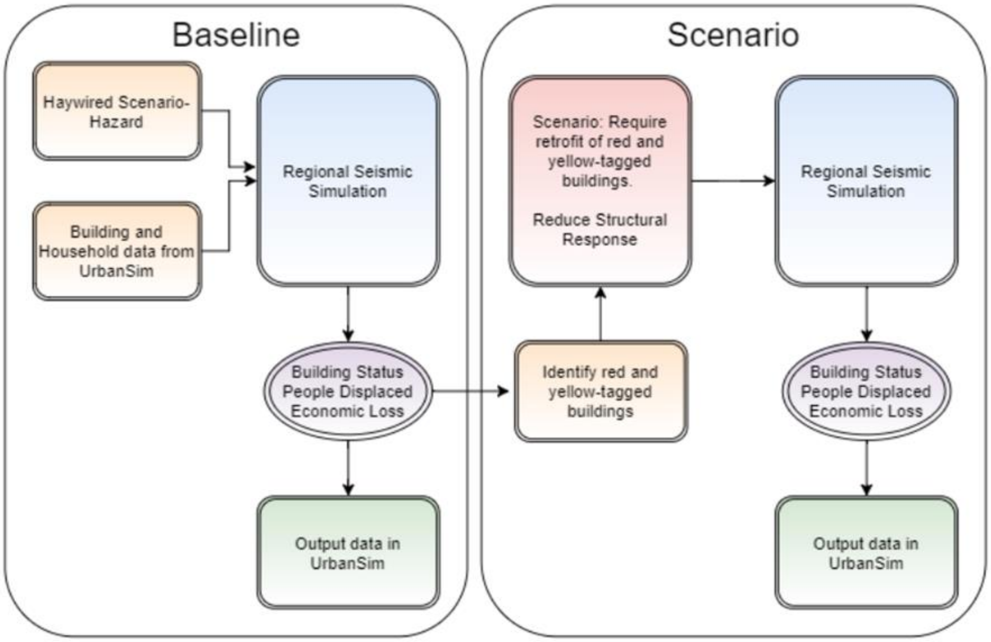

Figure 1: Flowchart of overall methodology.

It has been estimated that there will be a magnitude 6.7 or greater earthquake in the Bay Area within the next 30 years [Field, 2008]. The model earthquake was chosen to occur along the Hayward fault as the Hayward fault has the highest probability of producing an earthquake within the Bay Area in that time span [USGS]. The USGS has produced ground motions representing a 7.4 magnitude earthquake erupting along the Hayward fault, which is referred to as the Haywired Scenario. Ground motions, given in accelerations, were obtained in the north-south, east-west, and vertical direction. Unique ground motions are represented by stations in a two kilometer grid and each building was integrated with ground motions defined by the station it is located closest to.

UrbanSim was used to obtain access to extensive building data throughout the Bay Area, as well as to visually represent the output data. UrbanSim, designed by Paul Waddell, is an open source simulation platform used for analyzing urban development. While this model was initially designed to describe the interactions between land use, transportation, environmental plans, and policy change, this report takes advantage of the large amounts of data from business establishment files, Census, and GIS overlay that is already integrated for the Bay Area model. The data that is integrated within the program uses information gathered from 2010 [Waddell, 2013]. This project also takes advantage of UrbanSim's visualization capabilities to compare the output data from the baseline and policy scenario.

Table 1: Model Building Type defined by Hazus [FEMA].

No.	Label	Description	Height			
			Range		Typical	
			Name	Stories	Stories	Feet
1 2	W1 W2	Wood, Light Frame (≤ 5,000 sq. ft.) Wood, Greater than 5,000 sq. ft.		All All	1 2	14 24
3 4 5	S1L S1M S1H	Steel Moment Frame	Low-Rise Mid-Rise High-Rise	1-3 4-7 8+	2 5 13	24 60 156
6 7 8	S2L S2M S2H	Steel Braced Frame	Low-Rise Mid-Rise High-Rise	1-3 4-7 8+	2 5 13	24 60 156
9	S3	Steel Light Frame		All	1	15
10 11 12	S4L S4M S4H	Steel Frame with Cast-in-Place Concrete Shear Walls	Low-Rise Mid-Rise High-Rise	1-3 4-7 8+	2 5 13	24 60 156
13 14 15	S5L S5M S5H	Steel Frame with Unreinforced Masonry Infill Walls	Low-Rise Mid-Rise High-Rise	1-3 4-7 8+	2 5 13	24 60 156
16 17 18	C1L C1M C1H	Concrete Moment Frame	Low-Rise Mid-Rise High-Rise	1-3 4-7 8+	2 5 12	20 50 120
19 20 21	C2L C2M C2H	Concrete Shear Walls	Low-Rise Mid-Rise High-Rise	1-3 4-7 8+	2 5 12	20 50 120
22 23 24	C3L C3M C3H	Concrete Frame with Unreinforced Masonry Infill Walls	Low-Rise Mid-Rise High-Rise	1-3 4-7 8+	2 5 12	20 50 120
25	PC1	Precast Concrete Tilt-Up Walls		All	1	15
26 27 28	PC2L PC2M PC2H	Precast Concrete Frames with Concrete Shear Walls	Low-Rise Mid-Rise High-Rise	1-3 4-7 8+	2 5 12	20 50 120
29 30	RM1L RM1M	Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms	Low-Rise Mid-Rise	1-3 4+	2 5	20 50
31 32 33	RM2L RM2M RM2H	Reinforced Masonry Bearing Walls with Precast Concrete Diaphragms	Low-Rise Mid-Rise High-Rise	1-3 4-7 8+	2 5 12	20 50 120
34 35	URML URM M	Unreinforced Masonry Bearing Walls	Low-Rise Mid-Rise	1-2 3+	1 3	15 35
36	MH	Mobile Homes		All	1	10

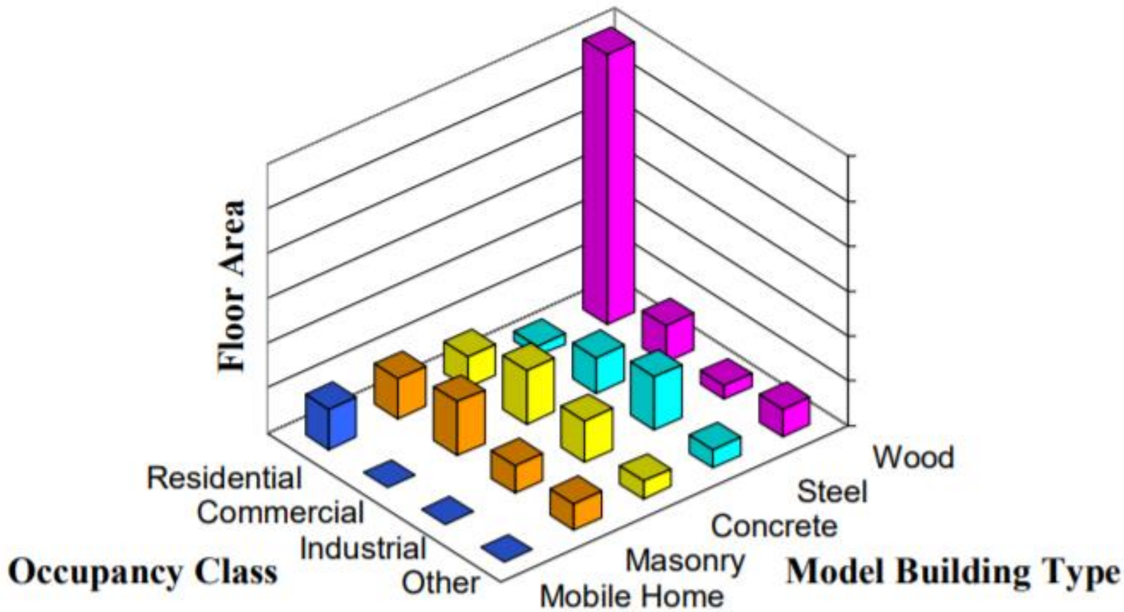

Figure 2: Model Building and Occupancy Class Relationship [FEMA].

Using information provided by UrbanSim on each building it was then necessary to infer each individual building's structural type. Hazus-MH is a natural hazard loss and risk analysis tool developed by the Federal Emergency Management Agency (FEMA), which is why it is considered a valid source regarding structural information. Figure 2 and Table 1 were acquired from a Hazus-MH building model manual. The most common structural types used for this project, W1, URM, RM1, RM2, S1, S2, C1, C2, and C3, are defined in Table 1. Figure 2 was used as a reference when developing the logic to determine a building's structural type. Information on building story height, function, and year of construction were all used to narrow down potential structural type. Table 2 represents the logic behind the MATLAB code that was developed to assign each building a structural type. Once the data was integrated and formatted properly, it was sent to a large scale seismic simulation program.

Table 2: Tabulated form of logic behind structural classification program

Year Built	Story Number	Function	Structural Type
≤1900	Any	Any	Choose Randomly Between: W1, URM, RM1, RM2
>1900	1 to 3	Residential	W1
		Commercial	Choose Randomly Between: W1, S1, S2, C1, C2, C3, RM1, RM2
		Industrial	Choose Randomly Between: S1, S2, C1, C2, C3, RM1, RM2
		Other	W1
	4 to 7	Residential	Choose Randomly Between: W1, S1, S2, C1, C2
		Commercial	Choose Randomly Between: W1, S1, S2, C1, C2
		Industrial	Choose Randomly Between: S1, S2, C1, C2
		Other	Choose Randomly Between: W1, S1, S2, C1, C2
	8+	Any	Choose Randomly Between: S1, S2, C1, C2

The other program used was a large scale Regional Seismic Response Simulator, developed by Xinzheng Lu and graduate student Xiang Zeng from Tsinghua University. This program runs through each building of the collection of 1.8 million buildings within the Bay Area, subjects them to their corresponding a ground motion and provides information on the damage of each structure and the associated economic loss. The percentage of overall structural damage was then associated to a building status. If a building acquired more than 30% structural damage it would be labeled red-tagged, in between 10% to 30% damage is labeled yellow-tagged, and less than 10% would be considered green-tagged. Given the building status and information from UrbanSim on how many households reside in each building, it was then possible to aggregate information on how many people could be displaced if this hazard were to occur. Knowing how many households are displace it was possible to create a post earthquake visual representation within UrbanSim and identify what regions experience the majority of the damage.

There were multiple assumptions made throughout the course of this project. It was assumed that all of the buildings were regular shaped, such that the overall building square footage divided by the stories would be equal to the planar square footage, a value necessary to input into the seismic simulator. For simplification, all the building structural types are generalized building models, which might not adequately represent the actual building's response. Also, this report assumes that aggregated data concerning building information from 2010 is still a valid representation of the Bay Area in 2017. Lastly, the required retrofit scenario assumes that every red and yellow tagged building from the baseline scenario is retrofitted and will experience an across the board 20% reduction in building response.

RESULTS

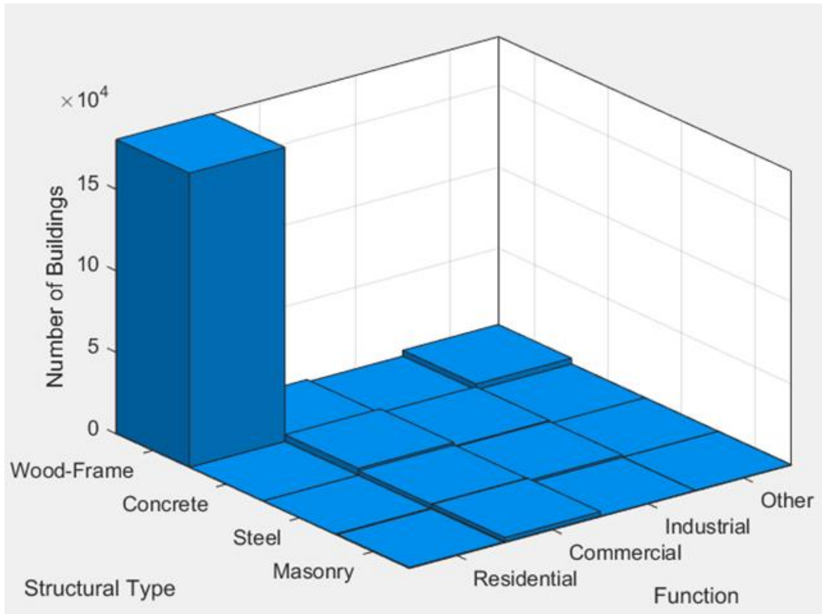

Figure 3: Distribution of 200,000 assigned structural types in the Bay Area

Due to time constraints, the assignment of building classification was the only aspect of the project completed. Figure 3 is a graph of a sample size of 200,000 buildings that was used to visual the distribution. The majority of structures land in the residential, wood-frame category; commercial buildings have a mostly even distribution across all structural types; industrial buildings appear to be more likely to be steel or concrete structures; and other buildings are primarily wood-frame structures. Ground motions and household data were also obtained, but have not yet been integrated with building data.

Figure 4: An example of a graph that UrbanSim is capable of creating

Results concerning building status, economic loss, and people displaced are expected for both the baseline and the required retrofit policy scenario. Figure 4 is an example of how the output information can be represented. Producing these graphs would make it easier to analyze the output data. By comparing graphs for the baseline and policy scenario it is possible to evaluate if a policy is effective or not. Calculations can be made concerning the economic incentive to enact said policy. This kind of information could be helpful to urban planners, engineers, policy makers, among others.

DISCUSSION

The MATLAB code developed to assign structural type appears to be an adequate starting point for the overall framework. The graph of the distribution, Figure 3, mostly agrees with the graph or relationships developed by FEMA, Figure 2. Since the graph was obtained using only the first 200,000 buildings in the data file, it is advized that a graph for the distribution of all 1.8 millions structures in the building file be compiled. A comparison of the results produced by both simulations could provide insight into a policy's effectiveness. If the results are similar to the baseline, a potential policy could be deemed ineffective. If the results are signifcantly different a policy maker could push to get the given policy enacted. Another possible option is if the cost of housing displaced people greatly out weighs the cost to retrofit buildings, the government might choose to subsidize retrofits in an effort to save money in the long run.

UrbanSim is already used to evaluate transportation policy, but it shows potential for harnessing this overall framework into a natural hazard model within the software. UrbanSim models individual households, jobs, buildings, and parcels and the choices made by individual households, businesses, real estate developers, and agents interactions through choice models. Statistical models, supply and demand accounting, and transition and relocation models are used to simulate agents acting in the system. Using the agents and models that are already in place, the program could potentially be tailored to simulate both response and recovery. While an earthquake in the Bay Area is the hazard used in this report, this framework could also be applied to other regions and has the potential to be agmented to represent other natural disasters; such as hurricanes, tornadoes, and tsunamis.

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