USAID/OFDA PREPARE PROGRAM FOR COSTA RICA

H. Kit Miyamoto¹, Amir SJ Gilani², and Tsutomu Nifuku³

ABSTRACT

The PREPARE (Preparing Rescue and Emergency Personnel to Ameliorate the Response to Earthquakes) program, for a disaster risk reduction (DRR) and disaster risk management (DRM) program in San José, Costa Rica started in 2015 and its first phase was completed in early 2017. The program was implemented with financial support from USAID/OFDA. The targeted beneficiaries include an estimated 470,000 residents of San José. The goal of PREPARE is to provide national and municipal DRR institutions with a clearer picture of the probable impact of an earthquake, and to assist them to meet their goals to reduce fatalities and lessen the social and economic impact of future earthquakes. In the Phase I component, seismic risk assessment for the built environment was conducted. This program used the OpenQuake platform from the Global Earthquake Model (GEM) to estimate the expected values of number of fatalities, injuries, structural damage, post-earthquake building tag distribution, and debris volume for a (500-year) earthquake scenario. As part of this phase, rigorous data collection was undertaken to classify the building types and distribution of buildings in the target area. The data collection, performed electronically, employed the FEMA 154 type methodology (i.e., rapid visual survey to identify various building characteristics such as structural type, material, configuration, soil, etc.), and accounted for the local construction. Monte Carlo simulations with 10,000 realizations were conducted and the data was aggregated to compute the seismic risk for the city and to identify the zones most vulnerable to the earthquakes due to large pool of weak buildings, high seismicity, large population, or a combination of factors. Analysis showed that high fatality rates (order of 1%), large percentage of damaged buildings (6% tagged yellow or red) and high ratio of physical damage (over 40%) would be expected. The results from this phase is being utilized to develop a post-earthquake damage assessment program, allocate resources for risk reduction and developing a risk management plan with the goal of developing more resilient cities.

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USAID/OFDA PREPARE Program for Costa Rica and Colombia

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The PREPARE (Preparing Rescue and Emergency Personnel to Ameliorate the Response to Earthquakes) program, for a disaster risk reduction (DRR) and disaster risk management (DRM) program in San José, Costa Rica started in 2015 and its first phase was completed in early 2017. The program was implemented with financial support from USAID/OFDA. The targeted beneficiaries include an estimated 470,000 residents of San José. The goal of PREPARE is to provide national and municipal DRR institutions with a clearer picture of the probable impact of an earthquake, and to assist them to meet their goals to reduce fatalities and lessen the social and economic impact of future earthquakes. In the Phase I component, seismic risk assessment for the built environment was conducted. This program used the OpenQuake platform from the Global Earthquake Model (GEM) to estimate the expected values of number of fatalities, injuries, structural damage, post-earthquake building tag distribution, and debris volume for a (500-year) earthquake scenario. As part of this phase, rigorous data collection was undertaken to classify the building types and distribution of buildings in the target area. The data collection, performed electronically, employed the FEMA 154 type methodology (i.e., rapid visual survey to identify various building characteristics such as structural type, material, configuration, soil, etc.), and accounted for the local construction. Monte Carlo simulations with 10,000 realizations were conducted and the data was aggregated to compute the seismic risk for the city and to identify the zones most vulnerable to the earthquakes due to large pool of weak buildings, high seismicity, large population, or a combination of factors. Analysis showed that high fatality rates (order of 1%), large percentage of damaged buildings (60% tagged yellow or red) and high ratio of physical damage (over 40%) would be expected. The results from this phase is being utilized to develop a post-earthquake damage assessment program, allocate resources for risk reduction and developing a risk management plan with the goal of developing more resilient cities.

Introduction

The PREPARE program intends to develop a new disaster risk reduction (DRR) and disaster risk management (DRM) program in the canton of San José, Costa Rica. The multiyear program, with financial support from the United States Agency for International Development/Office of U.S. Foreign Disaster Assistance (USAID/OFDA), includes cooperation and support of local Costa Rican partner organizations. The targeted beneficiaries are the citizens of the canton of San José.

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who live in zones that are at high risk for future earthquakes. The PREPARE program aims to provide national and municipal DRR institutions with a clearer picture of the probable impact of an earthquake. The program also wants to help these institutions meet their goals of reducing casualties and lessening the socioeconomic impact of future earthquakes. The overarching PREPARE objectives are: i) to strengthen earthquake-response planning and preparedness of national and municipal DRR institutions in San José (Costa Rica); and ii) to strengthen the risk management policy and practice of national and municipal DRR institutions for a reduction in fatalities, injuries, financial costs, and economic disruptions. This objective fits within the OFDA Policy and Planning subsector and the Capacity Building and Training subsector.

Three main PREPARE components are to be implemented during three phases: i) Assess seismic hazards and seismic risk to determine the probabilistic damage to building structures and probable fatalities among the residents in each municipality; ii) Analyze earthquake scenarios based on the findings from risk assessments; review plans, policies, and practices for the response, including rapid damage assessments and debris management, and iii) Implement DRR training activities based upon a review of the results of the earlier phases. The aim is that after completing the PREPARE program, the partner organizations will have gained knowledge for conducting seismic risk assessments and analyzing earthquake scenarios, and will continue to improve their DRR and DRM capacity in the future. The findings have been reviewed and discussed with key stakeholders including local planning agencies and academia. This paper focuses on Phase I of the project.

Phase I description

The canton of San José, Costa Rica, is in a high seismic zone and is at high risk for damaging earthquakes. The 1991 Mw 7.8 Limón Earthquake resulted in 50 fatalities and caused collapse of many buildings. Many of the newer buildings in the San José have been constructed using modern seismic codes, are well constructed, and meet high seismic. The canton also houses numerous older structures that are not well built, especially in poorer neighborhoods.

The risk assessment algorithm used the following parameters as input: (1) design-level seismic hazard; (2) citywide exposure data, including structural properties and number of occupants; (3) building fragility for the common building types; and (4) consequence functions, relating the number of fatalities, structural damage, and debris volume to the building damage state. The seismic hazard parameters were based on the recent studies that characterized the seismicity of key Central American cities [5].

Exposure model

The exposure model (incorporating the number and type of buildings, building footprint, and occupants) was developed through a statistical methodology by using available census data and the field survey of buildings [1] and [2]. In the statistical process, building typologies and homogeneous development patterns (described in the following sections) are associated with each other and the building exposure distributions according to its typology in each zone were developed with occupant information. The generated exposure model was then used as input for OpenQuake. The key data for the target area is presented in Table 1. Figure 1 presents key factors for the exposure model.
Table 1. Key statistics for the canton of San José

<table>
<thead>
<tr>
<th>Political divisions</th>
<th>Buildings</th>
<th>Occupants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrios</td>
<td>Districts</td>
<td>No.</td>
</tr>
<tr>
<td>196</td>
<td>11</td>
<td>85,800</td>
</tr>
</tbody>
</table>

Figure 1. Components of the exposure model

Zones for surveyed buildings

The canton of San José was divided into zones based on the 7 development patterns; see Table 2. The target area was divided into 654 polygons according to the development types; see Figure 2.

Table 2. Development patterns

<table>
<thead>
<tr>
<th>Pattern</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Open space</td>
</tr>
<tr>
<td>2</td>
<td>Informal</td>
</tr>
<tr>
<td>3</td>
<td>Industrial</td>
</tr>
<tr>
<td>4</td>
<td>Single family</td>
</tr>
<tr>
<td>5</td>
<td>Urban</td>
</tr>
<tr>
<td>6</td>
<td>High urban</td>
</tr>
<tr>
<td>7</td>
<td>Commercial</td>
</tr>
</tbody>
</table>
Building typology curves

Buildings in the canton of San José were categorized into eight construction types based on the lateral-force-resisting system (LFRS) and the construction material. Seven of the construction types were further subdivided into two groups based on the number of stories. The resulting 15 building types are listed in Table 3. Fragility curve for these building types was then developed and used in seismic risk analysis.

Table 3. Building typology that was used in analysis

<table>
<thead>
<tr>
<th>Type</th>
<th>LFRS and material</th>
</tr>
</thead>
<tbody>
<tr>
<td>01 &amp; 02</td>
<td>Nonengineered light structure</td>
</tr>
<tr>
<td>03 &amp; 04</td>
<td>Unreinforced masonry</td>
</tr>
<tr>
<td>05 &amp; 06</td>
<td>Confined/reinforced masonry</td>
</tr>
<tr>
<td>07 &amp; 08</td>
<td>Reinforced concrete moment frame</td>
</tr>
<tr>
<td>09 &amp; 10</td>
<td>Reinforced concrete shear wall</td>
</tr>
<tr>
<td>11 &amp; 12</td>
<td>Steel moment frame</td>
</tr>
<tr>
<td>13 &amp; 14</td>
<td>Steel braced frame</td>
</tr>
<tr>
<td>15</td>
<td>Unreinforced masonry informal area</td>
</tr>
</tbody>
</table>

Building exposure inventory

2,575 building assets were developed through the statistical process described above and included in the exposure pool. Each asset contains multiple buildings (i.e., total number is then 85,800) and corresponding occupants but one building type. All assets representatively reflect the building environment of San Jose and are distributed over the target area through the exposure development process. The exposure inventory was obtained by using satellite imagery, available census data and development patterns and supplemented by field surveys of 576 buildings. The spatial distribution of those surveyed buildings is shown in Figure 3.

Figure 3. Geographic distribution of surveyed buildings
Fragility and Damage Functions

The fragility curves for the 15 building types were based on data from FEMA Hazus ([3] and [4]), which is a natural hazard analysis tool established by FEMA. The fragility curve consists of earthquake intensity and occurrence probability of damage state in order to express building seismic capacity by damage probability. FEMA Hazus provides PGA fragility curves according to building types and height, however those fragility curves have to be modified to use for other environment and country because the curves were originally developed for the U.S. FEMA Hazus prepares the modification procedure and this project followed the procedure and adjusted the fragility curves to match with San Jose environment. The adjustments accounted for the spectral shape, average magnitude [5], site class [6], soil amplification factor, and epicentral distance.

Figure 4 presents the sets of plots for the various DS fragility curves for the low rise buildings. The figures were generated by using the San José-modified parameters of fragility curves.
Risk assessment procedure

The probabilistic risk assessment used Monte Carlo simulations (MCSs). To obtain convergence in results, 10,000 MCSs were performed. The risk analysis procedure was as follows (Figure 5). The procedure for each building and for each of the MCS runs involved selecting a scenario earthquake and using the fragility and exposure data to run OpenQuake engine, determine the DS distributions, and then by using the consequence functions (fatalities, structural damage, and debris volume) and the obtained DSs, compute structural damage, fatality, and debris volume. The expected values for each structure were then computed and aggregated for the city.

Figure 5. Process flow using the OpenQuake risk engine

Figure 6 presents MCS outcomes for a sample building. For this particular building, out of 10,000 simulations, approximately 1,400, 800, 2,350, 3,600, and 1,850 outcomes fall into the No Damage, Slight, Moderate, Extensive, and Complete damage states, respectively.

Figure 6. Distribution of MCS outcomes for a sample building

Earthquake seismic risk analysis results

Geographical distribution of seismic risk

The graphical distribution of findings from probabilistic risk analyses are presented in Figure 7, which presents the spatial distribution of structural damage, fatalities, and red-tagged buildings and debris volume, respectively. In the figures, the color distribution indicates the expected
intensity of each consequence. The data from these maps can be used to identify the barrios that are most susceptible to earthquake losses, which can then be prioritized for allocation of resources for seismic retrofit and earthquake preparedness. In particular:

- The distribution of fatalities in barrios differs significantly for daytime and nighttime earthquake scenarios. This difference is attributed to citizens’ commuting to work from their households during the day. As such, it is imperative that both cases be considered for risk planning.

- Depending on the consequence parameter (fatality, damage, debris) chosen, various barrios show increased vulnerability. However, certain barrios appear to be vulnerable for multiple risks. For example, see the barrio circled in the figures. Such barrios may need extra attention when planning risk mitigation and preparedness programs.

**Figure 7. Spatial distribution of seismic risk consequences**

Aggregated results

Table 1 presents the exposure data for the studied area. The canton of San José is home to
approximately 352,000 (nighttime) to 472,000 (daytime) occupants and has nearly 85,800 buildings. It is important to keep these numbers in mind when reviewing the aggregated data.

The anticipated physical damage to the built area that is subject to the design-level earthquake is listed in Table 4. Note that approximately 60% of the buildings would be yellow- or red-tagged. The damage area is nearly 42% of the total building area, and the earthquake could result in over 4,940,000 m$^3$ of debris or approximately 350,000 truckloads (based on 14 m$^3$ per truckload). The anticipated fatalities from a design-level earthquake are listed in Table 4. The area could experience close to 3,000 fatalities, which is nearly 0.7% of the population of the canton.

<table>
<thead>
<tr>
<th>Damage</th>
<th>Daytime fatalities</th>
<th>Nighttime fatalities</th>
<th>Yellow-tagged</th>
<th>Red-tagged</th>
<th>Volume, m$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>Area, m$^2$</td>
<td>%</td>
<td>No.</td>
<td>%</td>
</tr>
<tr>
<td>42%</td>
<td>11,350,000</td>
<td>0.64%</td>
<td>3,000</td>
<td>0.76%</td>
<td>2,700</td>
</tr>
</tbody>
</table>

**Conclusions**

Experience from past and recent earthquakes in Central and South America has shown that extensive damage affects the entire built environment, resulting in loss of life and causing physical damage that can be a significant portion of the country’s GDP. Within Central America, San José—the capital and the major economic center of Costa Rica, with a population of approximately 450,000—is the subject of this report. The analysis results show that:

- The number of buildings that are expected to be yellow-tagged (moderately damaged) or red-tagged (severely damaged or collapsed) is estimated at about 51,000 structures, or approximately 60% of the building stock.
- Depending on the time of event, approximately 3,000 fatalities (for an estimated rate of 0.7%) is anticipated.
- The generated debris volume of 4,940,000 m$^3$ or 350,000 truckloads is significant and must be accounted for.

The high physical damage and fatality rates from an earthquake that are computed point to the need for development of a risk mitigation program. Results of the findings were presented to stakeholders and the project report (Spanish) was distributed to various agencies to provide information about the potential earthquake consequences, the need to take action, and to assist in development of such program. As part of such a program, it is recommended that the following strategies should be implemented:

- To mitigate risk, provide a seismic strengthening program for key structures that are identified as having the most risk because of their inherent structural vulnerability and density of occupants.
- To prepare for risk, establish a damage assessment program for earthquake hazard. It is critical to train and certify engineers and to establish logistics. Such a program will improve response and recovery efforts after major earthquakes.
- To inform about the risk, establish communication and public outreach programs. It is critical to communicate results and the abovementioned recommendations. Communities should be informed about earthquake risk and risk reduction methods.

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References


