QUANTIFY EARTHQUAKE DISASTER AND AFFECT DISASTER RESPONSE POLICY TO IMPROVE CITYWIDE RESILIENCY

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Abstract

To mitigate the social and economic impacts of a major earthquake and to accelerate the recovery process, the PREPARE Program is currently being implemented in Costa Rica, Colombia, El Salvador and Mexico. The program, funded by USAID's Office of U.S. Foreign Disaster Assistance (USAID/OFDA), articulates earthquake disaster risk in selected cities to assist government disaster risk management officials to be better prepared to respond. Exposure models, earthquake hazard, and fragility data are used to perform probabilistic simulations and create GIS maps illustrating projected levels of damage to the built environment - the distribution of red-, yellow- and green-tagged buildings, anticipated volume of debris, number of casualties/heavy injuries and number of internally displaced persons (IDPs) in each district of the cities. Public agencies and first responders working with the program improve earthquake response preparedness by addressing identified obstacles for post-disaster recovery. Scalable building damage assessment and debris management programs are being developed forming public policy and engineering practice. Following the 2017 Central Mexico Earthquake, a Detailed Damage and Reparability Assessment methodology was developed to help train and guide local engineers on conducting such assessments. The methodology includes the quantification of damages and determination of repair techniques for corresponding types of damage. This work also highlighted the need to institutionalize damage assessment methodologies prior to disasters for a prompt post-disaster response. These initiatives assist in recovery following a disaster and thus enhance community resiliency.

Introduction

The hardship of earthquake affected populations is either prolonged, or eased, by the decisions and actions taken in the immediate post-disaster moment. If well-prepared, cities and national government authorities are in a better position to implement critical decisions in the wake of a crisis. The ability to rapidly assess the disaster situation, effectively mobilize resources, and initiate critical response activities is a great responsibility that often burdens affected civil and government agencies. Great earthquake disasters are rare but have significant consequences for a community. This poses a dilemma for planning agencies: how can a community be adequately prepared to respond to a future large-scale disaster of a magnitude they have never previously encountered?

In late 2015, the United States Agency for International Development (USAID) Office of U.S. Foreign Disaster Assistance (USAID/OFDA) initiated a program titled Preparing Emergency Personnel to Ameliorate the Response to Earthquakes (PREPARE program) for selected cities in four countries (Costa Rica, Colombia, Mexico, and El Salvador). The program uses the seismic hazard and building typology, building fragilities, and exposure population data augmented by field surveys, to define the cities' seismic risk. The objective is to provide municipal authorities with the tools necessary to plan for the probable impact of an earthquake on their municipality. The first site for implementation was San José, Costa Rica, and the findings are described in this paper. The probabilistic earthquake disaster simulation served as both a benchmarking tool to assess current earthquake response procedures, policies and plans, and as a political advocacy tool to address identified stumbling blocks for post-disaster recovery. Two such response planning gaps that were identified were the development and institutionalization of: i) a scalable post-disaster building damage assessment program for Costa Rica, and ii) a post-disaster debris management plan.

Following the 2017 Central Mexico Earthquake, volunteer engineers conducted rapid damage assessments of the affected buildings in Mexico City and found that more than 4,000 buildings in the city were assessed as “doubtful.” Detailed Damage and Reparability Assessment (DDRA) methodology and a training curriculum to help train and guide national engineers in determining the fate of these buildings was developed to assist in recovery planning. Although Mexico City experienced a large earthquake in 1985, many non-retrofitted pre-1985 buildings remain in the city, and they performed the poorest in the 2017 earthquake.

The successful implementation of the PREPARE program in Costa Rica provides a path for other countries vulnerable to earthquakes and stressed the importance of pre-event preparation and planning. Such observations and the importance of pre- and post-earthquake planning was further confirmed by the recent experience in Mexico City; the aftermath of the earthquake highlighted the need to train engineers for damage assessment and to advance efforts to institutionalize scalable post-disaster damage assessment programs *prior* to future earthquake disasters in other Latin American countries.

Earthquake Disaster Simulation for San José, Costa Rica

Overview. As the capital, San José, Costa Rica—situated in high seismic zone—constitutes an important number of buildings including national and municipal government administration buildings, hospitals, schools, commercial areas and residential neighborhoods. The buildings fall into two categories: i) newer buildings that are well-constructed using modern seismic codes, and thus anticipated to perform satisfactorily during earthquakes, and ii) older structures that are not well built (especially in poorer neighborhoods), and informal settlements and slums that are vulnerable to earthquake damage. **Error! Reference source not found.** is a map that indicates the boundaries of the canton of San José. The municipality/canton of San José, including its 11 districts, was the focus of the risk study.

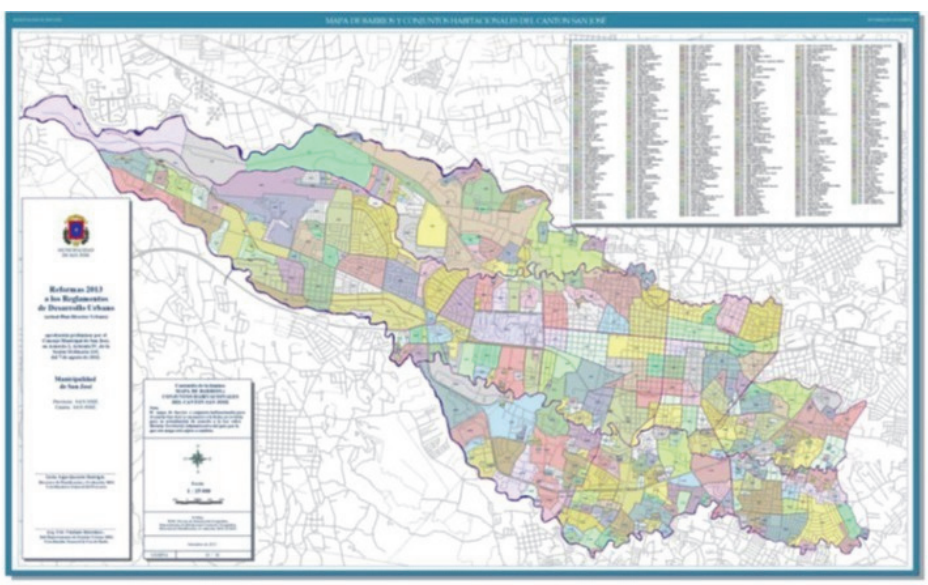

Figure 1. Boundaries of the canton of San José.

Probabilistic Seismic Risk Analysis of the Canton of San José. A risk study for the subject study area was undertaken using seismic hazard data, demographic data and building data to build an exposure model for the locality. Both daytime and nighttime earthquake scenarios were considered. Fifteen building were identified from satellite imagery and field surveys ranged from low-rise non-engineered and unreinforced masonry buildings, to the taller steel frame or reinforced concrete wall. Next, the canton of San José was subdivided into distinct homogenous zones that accounted for the distribution of building types and land use. Data files provided by the municipalities contained satellite imagery, city census data, development patterns, and land-use maps, and were used to configure these zones. Examples of zonal classification included informal, industrial, single family residential, urban, and commercial. Field surveys were conducted on a percentage of buildings in each zone. The Global Earthquake Model (GEM) (GEM, 2016) was used to perform probabilistic risk assessment. GEM provides a set of tools and models for hazard and risk analysis including the GEM Inventory Data Capture Tools (IDCT). The exposure model for the project is presented in Table 1.

Table 1. Exposure Data

No. of buildings	*Built area, km^2*	*Occupants (daytime)*	*Occupants (nighttime)*
85,800	26.9	472,000	352,000

The seismic risk assessment process (Figure 2) is a probabilistic method that used the Monte Carlo simulation. For San José, 10,000 realizations were carried out to ensure convergence of results. For each building, and each simulation, a ground motion parameter was selected; the probability of each damage state was obtained based on the seismic input and building fragility functions, and key consequences (fatality, damage, building tag, debris) were computed. The process was repeated and the expected value for each building was obtained. The process was then repeated for all buildings and data was aggregated.

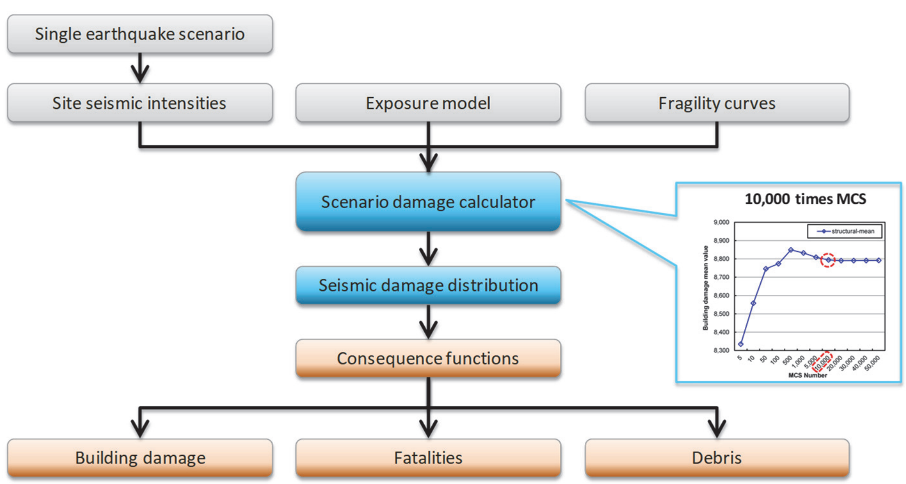

Figure 2. The process and outputs at each state of the probabilistic risk analysis.

Results. Key findings from the probabilistic seismic risk analysis are presented in Table 2. Note the following: i) approximately 60% of the city's building stock, or 50,500 buildings, is expected to be either severely damaged/collapsed (red-tagged) or moderately damaged (yellow-tagged); ii) approximately 3,000 fatalities, or close to 0.7% of population, is anticipated; and iii) 4,940,000 m^3 of debris volume must be removed. Figure 3 is a map showing the projected distribution of red, yellow and green-tagged buildings in the canton of San José. As depicted on the map, a neighborhood near the northwest of the study area is highly vulnerable to earthquakes and could experience a large number of fatalities and building collapse. Figure 4 depicts the volume of anticipated earthquake-related debris.

Table 2. Expected Vales of Earthquake Risk for the Canton of San José

Structural damage		*Fatalities daytime*		*Fatalities nighttime*		*Yellow-tagged buildings*		*Red-tagged buildings*		*Debris volume*
%	km^2	%	Number	%	Number	%	Number	%	Number	m^3
42%	11	0.64%	3,000	0.76%	2,700	33%	28,000	26%	22,500	4,940,000

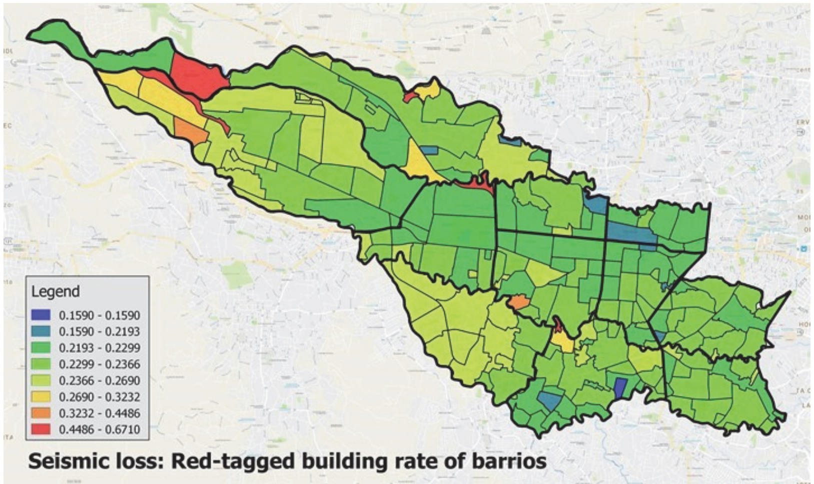

Figure 3. The projected distribution of red, yellow and green-tagged buildings in San José.

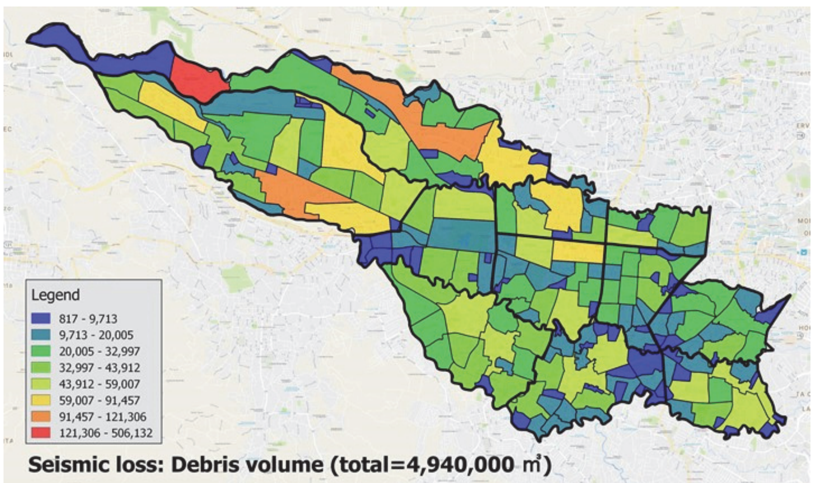

Figure 4. Spatial distribution of debris following an earthquake for San José.

The expected values of earthquake risk for the San José municipalities provided the city officials, first responders/Urban Search and Rescue (USAR) and the fire brigade with an understanding of what they may face in the event of a large earthquake. The extent of possible damage surprised city officials and disaster management authorities since in recent history, no large earthquakes have affected dense urban centers of the country. The seismicity of the locality in relation with vulnerabilities of the built environment highlighted the need to strengthen disaster risk reduction and earthquake preparedness measures and to formulate a response to a fundamental question: *Does the damage forecast match the city's earthquake response planning?*

Damage Assessment Program and Debris Management

Damage Assessment. In the aftermath of a natural disaster, an important task is to conduct a timely damage assessment. According to Costa Rica's national disaster management framework, municipalities have the responsibility to take the lead in post-disaster damage assessments within the boundaries of their jurisdiction, while working in close coordination with the National Commission for Risk Prevention and Emergency Attention (CNE) and relevant ministries. The Ministry of Housing and Human Settlement (MIVAH) in Costa Rica also shares responsibility for post-disaster damage assessments by being the responsible authority for carrying out assessments for housing. Within six weeks after a disaster, the responsible authorities are required to submit their estimates of damages along with estimates of costs to the CNE through the Center for Emergency Operations (COE). This requires quick mobilization of building surveying teams trained and authorized to enter the damage zones to collect the data and conduct building damage evaluations. As part of the PREPARE program, a Rapid Damage Assessment (RDA) Technical Working Group (TWG) was formed under the MIVAH including senior engineering staff of the municipality of San José, the University of Costa Rica's Department of Civil Engineering, the Technical Advisory Committee (CAT) of the CNE and Costa Rica's national Association of Engineers and Architects (Colegio Federado de Ingenieros y Arquitectos - CFIA), to address following needs:

- **Standardized post-disaster RDA methodology for houses**. In Costa Rica's recent disaster experience, various building assessment methodologies were applied across different agencies, which resulted in data sets that were difficult to consolidate. Under the RDA TWG, a RDA methodology including a building assessment form was developed for earthquakes and hurricanes.
- **Training tools for building inspectors and their mobilization.** The TWG also developed a RDA manual for building inspectors, which serves as a guide to train engineers and other qualified technical specialists in the standardized RDA methodology. An online training course and certification examination for building inspectors is now also being developed based on this manual. The TWG established an eligibility criterion for building inspectors. Through the Association of Engineers and Architects (CFIA) and the University of Costa Rica, an outreach campaign was conducted to inform engineers and architects from the private sector and academia on the training and certification program. Costa Rica's national disaster management framework has a provision that allows for the mobilization of volunteers to support large-scale post-disaster damage assessments through the CFIA. Under this newly established RDA certification/mobilization program, the CFIA will support the MIVAH in maintaining the roster of certified volunteer engineers and architects, and ensure sustainability of the training program by serving as a training center.
- **Data Management.** A RDA App consisting of an online version of the damage assessment form was created using an open-source software called ToolBox. This App is accessible by certified building inspectors for their use in the field. The data inputted into the App can be uploaded to a server managed by the MIVAH. This online data management system automates the data collection process and minimizes human resource needs for the manual inputting of the data. Systems to manage and process the damage data for official use were also developed under the PREPARE program, while maintenance of the systems have officially been handed over to the MIVAH.

In 2019, a drill will be organized whereby government staff of engineers alongside certified volunteer engineers and architects from academia and the private sector will be mobilized as building inspectors to test the technical, operational and data management procedures and systems.

Post-disaster debris management planning. The risk analysis concluded that nearly 5 million cubic meters of debris could be generated from an earthquake in the canton of San José. In the absence of a post-disaster debris management plan, this kind of information raised multiple questions among disaster management authorities, planners and other key stakeholders and initiated a new conversation. With the Municipality of San José in a leading coordination role, a wide group of stakeholders including the CNE, the Costa Rica Firefighters, the Social Security (CCSS), the Costa Rican Institute of Electricity (ICE), the Ministry of Public Works and Transportation (MOPT), the Ministry of Public Health, the National Laboratory of Materials and Structural Models of the University of Costa Rica (LanammeUCR), the Chamber of Construction (CCC), and the MIVAH, amongst others, were engaged in a year-long planning process to identify core priority areas for the removal, management and disposal of post-disaster debris. As a group, it was decided that a first attempt of an advanced draft strategy and legal framework should be focused on the canton of San José, as a pilot project, but with the aim of expanding it to the whole metropolitan area. The resulting strategic guidelines defined the organizational structures, coordination mechanisms, processes and the actions for three relevant moments after a disaster: a) the emergency, b) the early recovery, and c) the long-term recovery. The institutions responsible for overseeing specific actions and the timeline for their implementation was also outlined in the strategic document with the aim of developing a more thorough post-disaster management plan in subsequent years. In November 2017, the strategic framework was formally adopted by municipality of San Jose. This ongoing work has the potential to significantly reduce the economic, social and environmental impacts of an earthquake disaster, bringing the city back to normality in a shorter period.

Figure 5. Discussions on damage assessments.

Figure 6. Meeting for management of debris.

Response to 2017 Central Mexico Earthquake

Overview. At midday on September 19th, 2017, a magnitude 7.1 earthquake struck central Mexico killing more than 400 people, collapsing 44 structures, and damaging more than 5,000 structures. Soon after this event, RDAs of buildings in earthquake-affected areas were carried out mainly by volunteer national engineers. However, because no formal guidelines existed to investigate and address unsafe structures, or to assist owners, many buildings identified as unsafe were not further assessed for repair or demolition. To address this deficiency, USAID/OFDA and Miyamoto International developed the Detailed Damage and Reparability Assessment (DDRA) methodology tailored to the Mexican building environment, and established an exercise curriculum for Train-the-Trainers (ToT). The goal of the ToT was to help train and guide national engineers who may not be familiar with the seismic repair and strengthening methods required to conduct extensive DDRAs. The methodology includes: i) quantification of damages, ii) decision to repair or demolish, iii) recommendation for further action, iv) repair techniques suitable for local construction, and v) assistance to complete DICTAMEN, a legal document for damaged building assessment in Mexico.

DDRA development. DDRA is conducted to determine the safety and reparability of earthquake damaged buildings following a RDA executed immediately after an earthquake. Buildings determined as “Unsafe” or “Uncertain Safety” during the RDA (i.e., questionable for repairable or demolish) require a more comprehensive engineering assessment. The DDRA process is shown in Figure 7. Damage status and reparability of buildings should be evaluated by structural engineers, and the methodology is based on a thorough visual inspection from outside and/or inside of buildings. The damage status is classified as “Inspected” “Restricted use” or “Unsafe,” and the reparability status is categorized as “Later repair”, “Immediate repair” or “Demolish.” For repairable buildings, a further engineering evaluation is necessary to determine repair design and construction work planning. The DDRA document is a reference to make decisions for post-earthquake recovery operations and is intended to be used by structural engineers involved in restoration activities for damaged buildings. Supportive information and basic techniques to repair structural damages were also prepared for typical damage scenarios observed on earthquake-affected buildings in Mexico. In addition to damage and reparability sections, the DDRA contains an assistive component to collaborate with city officials by completing DICTAMEN.

ToT execution. The training curriculum, ToT, is established for the DDRA and focuses on senior structural engineers who are expected to teach this methodology to other engineers by additional training sessions (i.e., multiplier training plan), and those trained engineers are anticipated to conduct DDRA. The curriculum consists of both in-classroom instructions and field activities. The first day is used for in-classroom learning about DDRA procedure, modern engineering and seismic design, repair techniques, visual examples, judgement of unstable building, and field safety. The second day is used to do field exercises at two damaged buildings through comprehensive visual inspection. In coordination with national engineering associations, two two-day ToT workshops were conducted in Mexico City in November 2017 as shown in Figure 8 and Figure 9. During these workshops, approximately 40 experienced structural engineers and government officials participated in the ToTs.

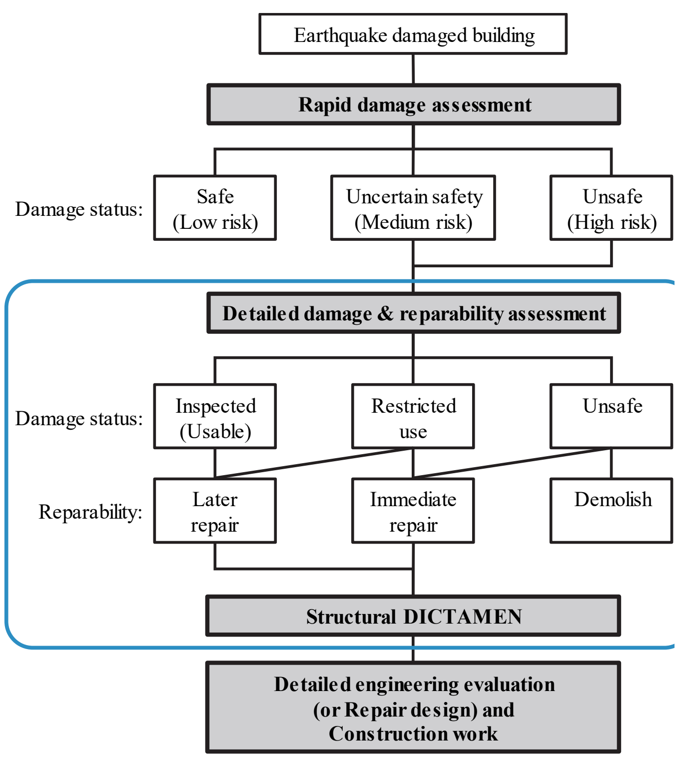

Figure 7. Seismic damage assessment flow.

Figure 8. Classroom instruction.

Figure 9. Field practice.

Capacity building. Based on the developed DDRA methodology and knowledge transfer during the ToTs, the national engineering associations were able to manage this system independently, building local capacity at many levels. They have since trained several hundred engineers who effectively carried out this critical activity for post-disaster recovery in Mexico City, as well as other heavily affected cities within the country. The targeted beneficiaries of the program were citizens of Mexico City and engineers and officials involved in the post-earthquake tasks. However, similar programs can be applied to other cities in Mexico to strengthen the urban capacity of disaster resiliency.

Discussions

Due to success of the USAID/OFDA PREPARE program in Costa Rica, the program is now also being implemented in Colombia, Mexico and El Salvador. Using science and engineering tools such as probabilistic risk analysis supports disaster management officials, planners and decision-makers in their ability to "imagine the disaster situation" and act and plan accordingly (Meguro, 2003b). A critical component of effective disaster management reduction programs is strengthening inter-agency and public-private networks and collaboration.

Following an earthquake disaster, many government agencies and actors are required to work alongside each other, but have had little opportunity to do so *prior* to the disaster. Disaster risk reduction programs that use scientific data translated into meaningful matrixes for a broader group of decision-makers can engage multiple stakeholders and provide them with a shared understanding of disaster risk and mitigation priorities.

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