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# PREPARING A REGION FOR EARTHQUAKE DISASTERS – THE SAN DIEGO - TIJUANA EARTHQUAKE SCENARIO PROJECT

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## Abstract

The San Diego-Tijuana Earthquake Scenario Project was initiated by the Earthquake Engineering Research Institute (EERI) San Diego Chapter starting in 2013. Spurred by previous scenario studies and consideration of the cross-border interdependence in the greater San Diego-Tijuana region, EERI sponsored a series of meetings, presentations, and a workshop leading to the organization of a scenario project team in 2015.

A U.S. and Mexico-based team of engineers, geologists, researchers, and public officials are working collaboratively on the project. The scenario project team has recognized the opportunity to investigate the cross-border vulnerability from a M6.9 earthquake scenario on the Rose Canyon Fault. While the postulated earthquake fault rupture terminates off-shore at the U.S.-Mexico border south of San Diego, rupture directivity toward Tijuana amplifies the ground shaking and resulting damage on the Mexican side of the border. The earthquake scenario project utilizes recent advances in the understanding of seismic hazards in the greater San Diego-Tijuana region. A regional seismic hazard and vulnerability study is being conducted utilizing the all hazards loss estimation tool "HAZUS," to quantify the expected earthquake losses.

The key objective of the scenario is a "call to action" for regional earthquake preparation and mitigation that will positively affect the entire region on both sides of the border, ultimately providing an opportunity to improve the region's earthquake awareness, preparedness, public policy, disaster resilience, and earthquake risk management programs.

This paper describes the project objectives, organizational effort, technical approach to the hazard and vulnerability study loss modeling, multidisciplinary cross-border collaboration of the project team and stakeholders, and benefits to improve the disaster resilience of the San Diego-Tijuana region.

*Keywords: Earthquake Scenario; Hazard and Vulnerability Assessment; HAZUS; Fault; Losses; Loss Modeling; Regional Earthquake Prepareness; Cross Border*

## 1. Introduction

Earthquake disaster preparedness can take many forms and involve many different players in the community, from architects and engineers teaching post-disaster safety evaluation classes [1], to earth scientists providing seminars on regional seismic hazards, to building officials implementing seismic safety provisions through our building codes, to emergency managers and public officials organizing and preparing our communities for the inevitable future earthquake. These activities and a myriad of others help to inform and prepare our communities and make them more resilient to these potentially catastrophic events.

Earthquake scenario development allows the earthquake engineering community, elected officials, and public policy makers to stretch their thinking by asking "what if" questions considering a credible set of earthquake parameters and expected impacts and losses to a region. Authored by local experts, the earthquake scenario highlights vulnerabilities in the region's communities, buildings, and critical infrastructure, and identifies potential socio-economic consequences, to ultimately underscore the need for clear, effective, and consistent planning recommendations to our region's public policymakers, elected officials, and the general public.

The final product of this effort will be an earthquake scenario report that describes the scenario earthquake, ground shaking and secondary hazards, possible effects on lifeline structures, transportation facilities, buildings and critical facilities, as well as the potential social and economic impacts. The report will include recommendations for resiliency planning to help the region prepare for and respond to future earthquakes.

This paper presents the organizational efforts and objectives of the San Diego-Tijuana Earthquake Scenario Project to enhance the disaster resilience of the greater San Diego, California and Tijuana, Mexico region. It details the work progress thus far, which includes definition of a Scenario Earthquake and preliminary engineering evaluation of the building stock in San Diego and Tijuana to estimate expected physical damages. Efforts to analyze the social and economic implications of the scenario are just initiating. Therefore, only future work in this area will be presented.

The study area includes all of San Diego County and the Tijuana Region with a regional population of 4.9 million (2012). San Diego County is 4,526 square miles with a population of 3.2 million (2013) with the City of San Diego having a population of 1.35 million in the scenario path. Coastal cities north and south of the fault rupture will be impacted.

## 2. Scenario Background

The first Earthquake Planning Scenario for San Diego, California and Tijuana, Mexico was published in 1990 titled "*Planning Scenario for a Major Earthquake, San Diego-Tijuana Metropolitan Area*," prepared by the California Geological Survey (CGS) as Special Publication 100 [2]. This scenario included the San Diego and Tijuana metropolitan areas, and was designed for international planning where significant earthquake damage could occur on both sides of the border. The scenario covered San Diego County, from Oceanside on the north, to Alpine and Ramona on the east, and south to the international border. The scenario also covered from Tijuana at the international border, southward to Rosarito, Baja California, Mexico. In 1990, the scenario estimated 3.8 million residents in the planning area; 2.3 million residents in San Diego County, and approximately 1.5 million residents in Tijuana.

At the time of this 1990 scenario study, there were no "active" faults as defined by the State of California within the City of San Diego. By 1991, the State had enough data to map the first "active" fault zones in San Diego. Over the last 25 years, significant research has changed the knowledge of fault locations, history, and the potential for earthquake hazards in the San Diego and Tijuana regions. Hence, the importance for updating this scenario.

A similar effort was undertaken in the city of Tijuana in 1998 called Risk Assessment Tools for the Diagnosis of Urban Seismic Risk (RADIUS) project, which was implemented by the United Nations as part of the International Decade for Natural Disaster Reduction (IDNDR) initiative. Tijuana was one of nine cities where the program was implemented [3]. The objectives of the RADIUS project in Tijuana were [4]: to develop an earthquake damage scenario for the City of Tijuana; to create a risk management plan for the City of Tijuana, including a timeline for its application; to increase seismic awareness in the community, government and stakeholders; and to formalize and institutionalize the effort so that future mitigation plans are possible.

## 3. Project Objectives

The overarching objective is to conduct an updated regional seismic scenario study to serve as a risk communication tool for stakeholder groups and the public and as a risk mitigation planning tool for regional policy makers, planners, developers and businesses. The project is intended to foster discussion and cooperation among organizations and experts involved in earthquake planning and response spanning across international borders to increase the region's seismic preparedness and resilience. The Scenario Report will provide recommendations to policy makers to improve building codes and will inform government, business and industry about vulnerabilities and opportunities to plan for disaster in order to facilitate faster recovery.

## 4. Organizational Effort

The M6.9 San Diego-Tijuana Earthquake Scenario project was first envisioned in 2013 by a group of engineers, geologists and researchers in the Earthquake Engineering Research Institute's (EERI) San Diego Chapter. Spurred by previous earthquake fault studies in the San Diego region, earthquake scenario projects in other communities, and the interdependence of both the U.S and Mexican communities in the greater San Diego-Tijuana region, a series of meetings, presentations, and a day-long workshop led to the organization of a scenario project binational team in 2015 (Fig. 1).

Fig. 1 – A Preliminary Planning Workshop at UC San Diego in January 2015 demonstrated regional interest and led to establishment of the Executive Steering Committee.

The project team is headed by a 12-person steering committee made up of researchers, geologists, engineers, and public officials. Three working groups were formed to coordinate volunteers in performing the key research, investigation, and analysis. They are:

- Working Group 1 – Earth Science
- Working Group 2 – Buildings, Lifelines & Infrastructure
- Working Group 3 – Social & Economic Impacts

Expertise of the project team members includes research, education, seismology, emergency management, geotechnical engineering, civil engineering, structural engineering, architecture, and planning.

This working group organization model, shown in Fig. 2, is based on EERI's Guidelines for Developing an Earthquake Scenario [5] and on past scenario studies, e.g. the 2008 ShakeOut Scenario ([6] and [7]) and the Seattle Scenario study (2005) [8]. Working Group 1 focuses on "Earth Science" and initiated the binational effort by selecting and defining the scenario earthquake as part of the geo-hazards evaluation. Working Group 2 focuses on "Engineering" aspects and is studying building and infrastructure inventories and vulnerabilities to estimate the expected physical damage from the scenario earthquake. Working Group 3 focuses on "Social Science" and will estimate impacts on social and economic systems. Finally, the project will focus on defining recommended "Policy" measures, including actions that if applied today could reduce earthquake losses in the future.

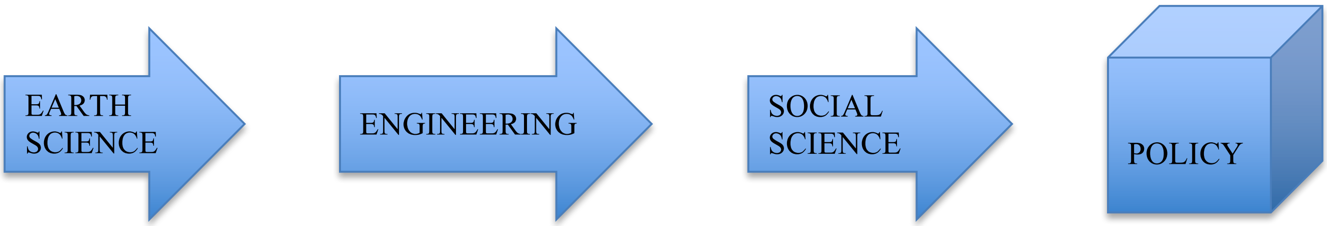



Fig. 2 – Project Team Workflow Model.

## 5. Initial Earth Science Findings

The update for the San Diego-Tijuana Earthquake Planning Scenario is utilizing three categories to determine the "Earth Science" Hazards: The *Scenario Earthquake*, *Earthquake Shaking*, and *Earthquake Secondary Hazards*.

### 5.1 Scenario Earthquake

To update the San Diego and Tijuana Earthquake Planning Scenario, it was necessary to select a scenario earthquake. Experts were brought together to discuss all available information, from fault trenching studies to the latest scientific findings, to decide on a credible earthquake for this region. For planning purposes, the scenario earthquake should be close to population centers, create economic impacts, and be evaluated so that we can make changes now to avoid significant future consequences.

The scenario earthquake and fault rupture location were selected to occur on a portion of the mapped Rose Canyon Fault Zone that bisects the City of San Diego, as shown in Fig. 3.

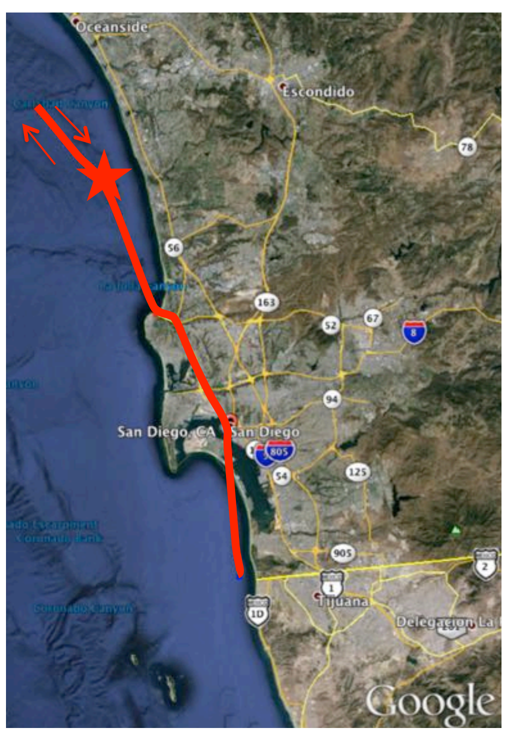


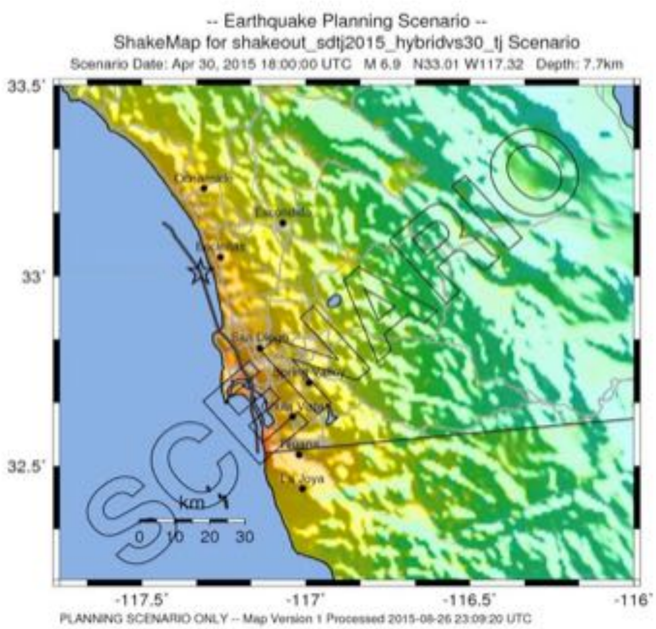

Fig. 3 – Map of Earthquake Scenario Fault Rupture.

The Rose Canyon fault zone is a right-lateral strike-slip system. The scenario earthquake starts with a unilateral rupture beginning off shore near Carlsbad in northern San Diego County, rupturing southeastward onto land at La Jolla. The rupture continues southeast within the Rose Canyon Fault Zone through Old Town San Diego and bisecting downtown San Diego, and then continues south crossing San Diego Bay, back on land at Coronado, then further south rupturing the Silver Strand fault within the Rose Canyon Fault Zone. From Coronado, the rupture continues south in the Pacific Ocean parallel to the coastline, terminating at the International border with Mexico.

The scenario earthquake was selected with a magnitude of 6.9, a depth of 7.7 kilometers, a rupture length of 69 kilometers, and a maximum horizontal slip of 2 meters. The rupture includes directivity towards Tijuana, Mexico. The red star on Fig. 3 locates the earthquake source and the red line indicates the extent of fault rupture. The recurrence interval for the fault was estimated at 1,000 years, with a 2-millimeter yearly slip rate.

## 5.2 Earthquake Shaking

With an updated Scenario Earthquake, the next step is to obtain the ground motions at sites around San Diego and Tijuana. Knowing ground motion intensity allows predictions for shaking and damage to buildings and lifelines. The magnitude of the earthquake, the distance from the fault, and the soil conditions affect the ground motions. The United States Geologic Survey (USGS) assisted and generated their ShakeMap® series to estimate shaking variations throughout our region. The ShakeMap series includes seismic intensities and peak ground motions. The ground motions include acceleration, velocity and spectral response at three periods: 0.3, 1.0 and 3.0 seconds. The USGS incorporated new and updated data for the Velocity from the Surface to 30 meters (Vs30) [9]. The Center for Scientific Research and Higher Education (CISESE) at Ensenada, Baja California, Mexico produced new Vs30 data for Tijuana and the California Geological Survey (CGS) provided updated Vs30 data for San Diego. The results of the ShakeMap series relate to intense earthquake shaking and damage near the population centers of San Diego and Tijuana. The ShakeMap intensity graphic presents Modified Mercalli data where warmer colors correlate to areas of greater damage (Fig. 4).




| PERCEIVED SHAKING | Not felt | Weak | Light | Moderate | Strong | Very strong | Severe | Violent | Extreme |
|---|---|---|---|---|---|---|---|---|---|
| POTENTIAL DAMAGE | none | none | none | Very light | Light | Moderate | Mod./Heavy | Heavy | Very Heavy |
| PEAK ACC.(%g) | <0.05 | 0.3 | 2.8 | 6.2 | 12 | 22 | 40 | 75 | >139 |
| PEAK VEL.(cm/s) | <0.02 | 0.1 | 1.4 | 4.7 | 9.6 | 20 | 41 | 86 | >178 |
| INSTRUMENTAL INTENSITY | I | II-III | IV | V | VI | VII | VIII | IX | X+ |

Scale based upon Worden et al. (2012)

Fig. 4 – USGS Intensity ShakeMap.

After the ShakeMap series were complete, the USGS was able to generate a Prompt Assessment of Global Earthquakes for Response (PAGER) (Fig. 5), an automated system created and operated by the USGS. PAGER reports are generally available within 30 minutes of a significant earthquake, and provide estimates for the impact of the earthquake to the region. These impact estimates assist to inform emergency responders, government, aid agencies, and the media of the scope of the potential disaster. In addition to direct alert notifications, PAGER provides important supplementary information, including comments describing the dominant types of vulnerable buildings in the region, exposure and fatality reports from previous nearby earthquakes. In some cases, PAGER includes a summary of regionally specific information concerning the potential for secondary hazards, such as earthquake-induced landslides, tsunami, and liquefaction, which will be noted if data exists based on past earthquakes in the region.

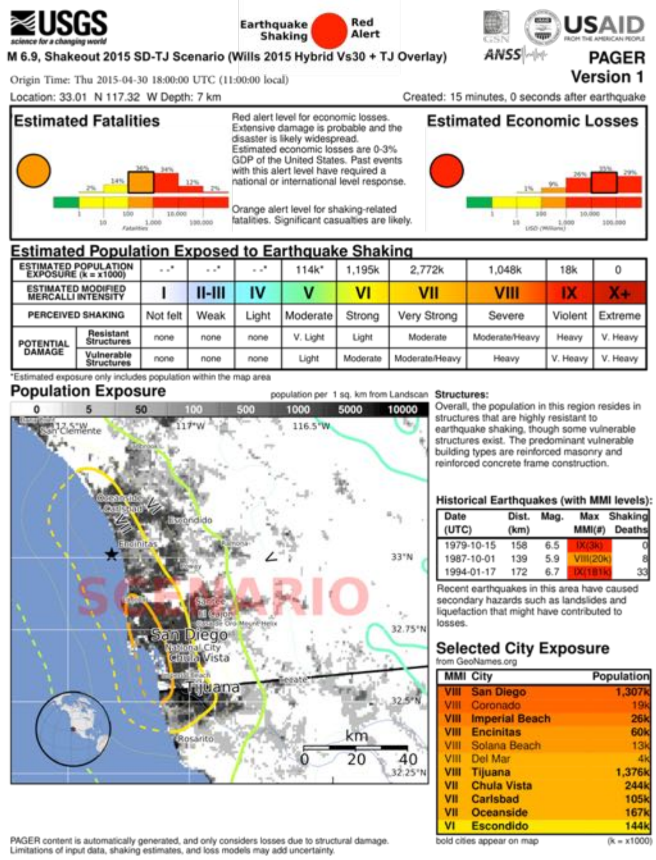



Fig. 5 – USGS PAGER report for the proposed scenario earthquake.

As shown on PAGER, the estimated fatalities for this scenario are an **Orange** alert, which is issued for estimates of up to one thousand fatalities, or one billion dollars in losses. PAGER shows the estimated economic losses for this scenario as a **Red** alert, which is issued when either fatalities or losses are predicted to exceed one thousand fatalities or one billion dollars in losses. This preliminary PAGER estimate for the updated scenario earthquake does create significant damage and risk for the San Diego and Tijuana regions warranting significant consideration in the planning efforts. Damage estimates and losses due to the scenario earthquake will be significantly refined as part of Working Group 2 efforts (see Sections 6 and 7 below).

## 5.3 Earthquake Secondary Hazards

The Earth Science group is currently working on identifying known earthquake fault strands that may have direct surface rupture, and defining the secondary hazards that can be triggered by the scenario earthquake in San Diego County and the Tijuana region. Existing maps will be utilized to create hazard maps that combine data north and south of the border. These maps are planned to show areas susceptible to secondary hazards.

Additional graphics will be utilized to show vulnerable areas. Photographs will be included showing earthquake damage that has occurred after similar damaging earthquakes.

To analyze direct surface rupture, the group will identify the specific fault strands that may have surface displacement and postulate the sense and amount of surface displacement. It is anticipated that most of the surface rupture will be focused along the main trace of the Rose Canyon Fault, and additional surface rupture might be distributed in the downtown San Diego graben and the San Diego International Airport areas.

The secondary hazards analysis is planned to include liquefaction and groundwater depth, landslides (on-shore and off-shore), tsunamis, seiches, and aftershocks. Aftershocks are important as they create additional shaking that can damage weakened structures, necessitate evacuations, endanger rescue workers, and undo efforts to restore and rebuild after an earthquake.

## 6. Technical Approach to Loss Modeling

The scenario loss estimation methodology is to overlay the ground shaking intensities and secondary hazards defined by the Working Group 1 (Earth Sciences) over the building and infrastructure inventory and vulnerability mapping defined by the Working Group 2 (Building & Infrastructure) in order to estimate the expected damages, casualties, and economic losses across the San Diego-Tijuana region. This loss assessment effort led by the Working Group 2 faces unique challenges due to the binational context of the regional study and the divergent building stocks and infrastructure systems on each side of the border. The general approach employed is to utilize the HAZUS loss assessment tool in combination with local expert specialty groups focused on select subsets of the buildings and infrastructure to generate more refined regional loss estimates. The implementation strategy engages parallel groups on each side of the international border to develop and refine their respective building and infrastructure inventories, prepare their separate loss assessments, and then to combine their findings into an integrated regional earthquake loss model capable of capturing the potentially far reaching local and international socio-economic impacts. Fig. 6 shows the flow chart for HAZUS being used in this analysis [10].

On the San Diego side, the loss modeling tracks the path of previous scenario studies conducted in Utah for the Wasatch Fault (2015) [11], in Northern California for the Hayward Fault [12], in Southern California for the Great Shakeout (2008) [6] and [7], and in Washington State for the Seattle Fault (2005) [8]. The depth and detail of the scenario study will be contingent upon funding and resources available but the general structure is similar to that of preceding studies. HAZUS provides default inventories for San Diego's buildings and infrastructure systems with default fragilities and vulnerabilities based on national economic and census statistics, and local inventory projections. The San Diego team is working to enhance that HAZUS default data in several ways to improve its accuracy.

First, the general building stock representing the great majority of buildings in the County can be enhanced from the HAZUS default dataset. HAZUS estimates default building inventories in each San Diego County census tract based on economic and population census data and assigns occupancies and valuations based on national statistics. The Scenario team can refine that inventory based on updated tax accessor's data to reflect more accurate building square footage totals and values, and more accurate distributions among occupancy and structure types. In the Southern California Shakeout scenario, similar data enhancement techniques resulted in 20% to 40% increases in building square footages and values and in more accurate distributions of the inventory to different occupancy and structure types compared to HAZUS default values [6].

Second, the Scenario team is cataloging Unreinforced Masonry (URM) buildings to assess them individually using the HAZUS Advanced Engineering Building Model (AEBM). The team is also considering inventorying other seismically vulnerable building groups such as non-ductile concrete frames, pre-Northridge steel moment frames, soft story buildings, and tilt-up buildings. These other buildings may not be catalogued as part of this study but could be added for future updates as data become available.

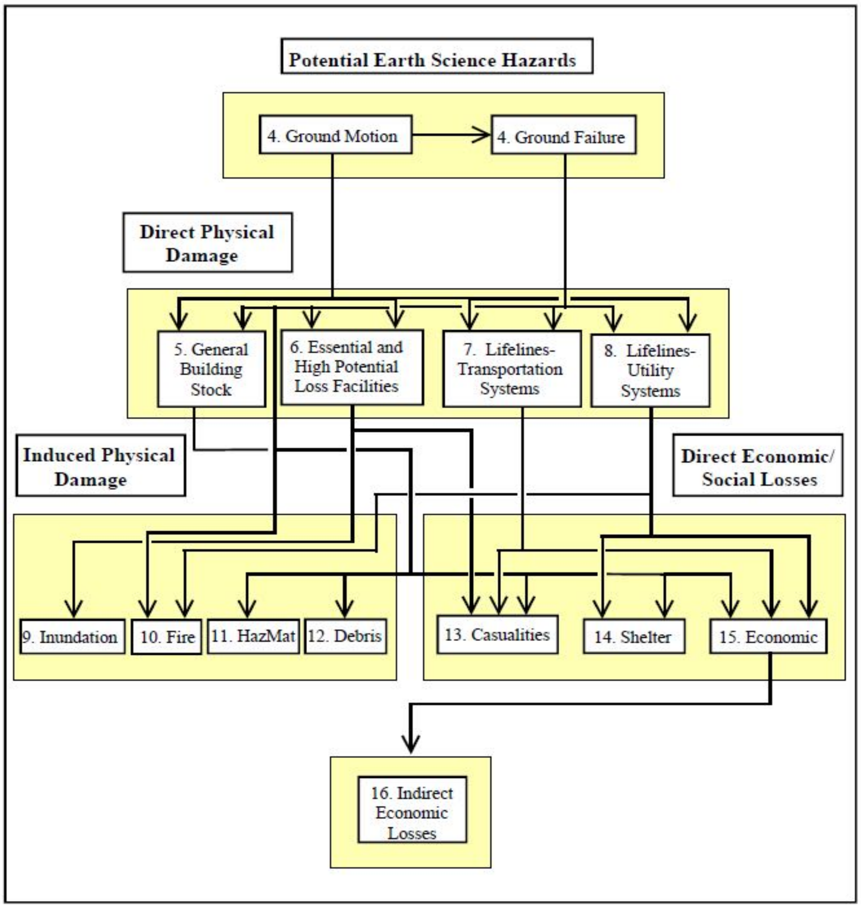



Fig. 6 – Flow Chart for HAZUS Earthquake Module [16].

Third, the Scenario team is enhancing the essential facilities inventories. The initial effort is to replace default HAZUS inventories with updated ones based on local SanGIS data, school district records, California hospital records, and City records for police and fire stations. The intent is to utilize these enhanced inventories to run more accurate Essential Facility module assessments. An individual building assessment using the AEBM module, similarly to what has been described above for URM buildings, could be run at a later date for the essential facilities stock.

Fourth, the team is identifying key stakeholders and establishing subgroups of experts to collect and map inventory and vulnerability data for lifeline, transportation, and other infrastructure systems. These expert groups will then utilize the ground shaking and secondary hazard maps developed by Working Group 1 to conduct special studies and assess the probable damages to infrastructure systems.

On the Tijuana side of the study, HAZUS default data south of the border does not exist. The team is using a GIS-based methodology to adapt the HAZUS earthquake model for global applications [13]. The Mexican team is working through CICESE and local engineering groups and stakeholders to assemble an inventory of buildings and infrastructure from multiple separate data sources, and to develop appropriate vulnerability characteristics for the different structural types (Fig. 7). One of the challenges is to define applicable structural building classifications that account for the different structural types and construction practices in Tijuana (Fig. 8), and account for the significant variability in the fragility curves. Empirical fragility curves are being developed to fit the unique Tijuana building typologies. The Mexican team is capitalizing on the connections developed through the RADIUS project; this project has evolved into a strong and influential local professional community, allowing for information sharing at all levels: private, public, academic, etc.

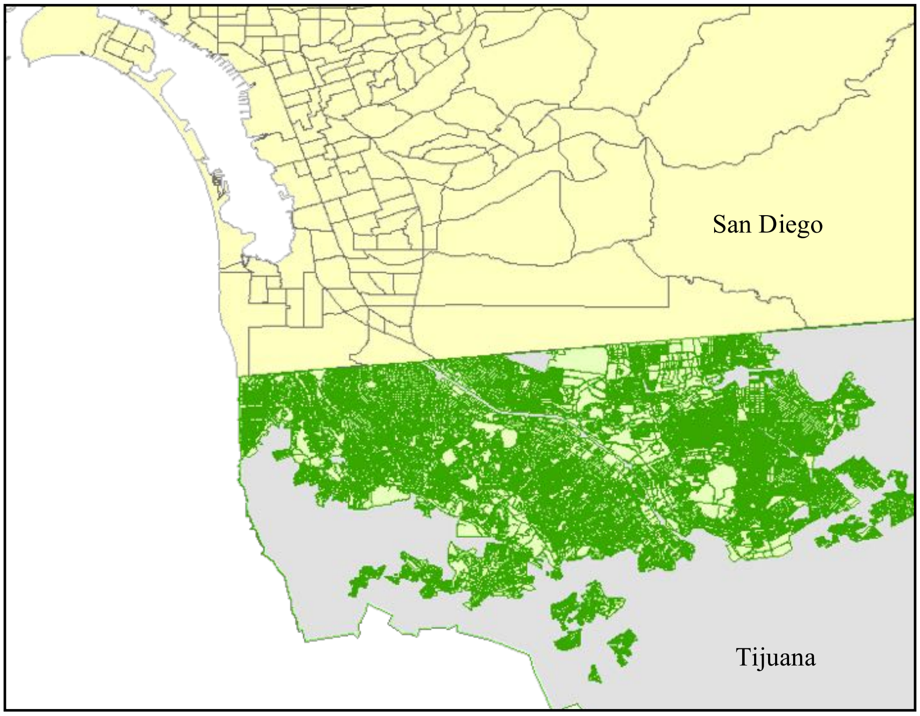



Fig. 7 – Implementing HAZUS Earthquake Loss Estimation for Global Applications. Green areas indicate regions of Tijuana that are being enhanced with aggregated data like population, demographics, and general building stock values.

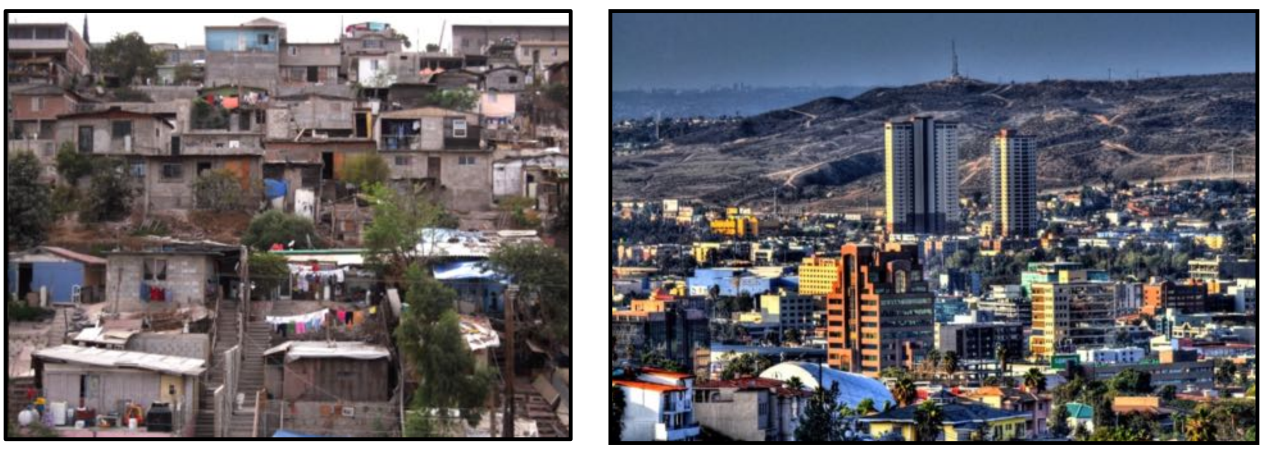


Fig. 8 – Tijuana Mexico building type samples.

The two Building & Infrastructure subgroups are working in parallel on each side of the border, collaborating and coordinating regularly to share expertise and ultimately to assure a common basis for loss assessments. The two teams will construct and run their HAZUS models separately, enabling each to focus on their unique building stocks and infrastructure inventories, while comparing general quantities of inventory and estimates of damage across the border. The two separate models will allow each team to update their models in the future as additional data become available and as local inventories change. Each side will be able to address their separate jurisdictions with mitigation policy recommendations and respond to separate local requests.

The results of the two separate damage assessments can then be manually combined to provide a comprehensive regional loss picture that can be used by the Socio-Economic Impact work group to evaluate potential broad regional consequences, mitigation strategies, and emergency response strategies.

## 7. Initial Buildings & Infrastructure Findings

The ShakeMap generated by Working Group 1 was imported into preliminary HAZUS assessments for San Diego and PAGER assessments for the San Diego-Tijuana region. These preliminary assessments indicate broad swaths of damage concentrated along the Rose Canyon Fault zone, extending from La Jolla and Del Mar in North County San Diego, through the heart of downtown San Diego, and through the South Bay cities of National City, Chula Vista, San Ysidro, Coronado and Imperial Beach, and across the Tijuana river basin. Preliminary economic loss estimates range from a high probability of tens of billions of dollars to a lower probability of hundreds of billions of dollars. Casualty estimates range from the hundreds to the thousands, as illustrated in the PAGER report.

The preliminary HAZUS model also demonstrates high damage probabilities, particularly for URM (Fig. 9) and non-ductile concrete frame buildings, along the Rose Canyon fault as it bisects the major city centers between La Jolla and Tijuana. In this figure, red indicates high probability for damage while green indicates low probability. The model shows significant damage to schools, hospitals, and other essential facilities along the fault zone.

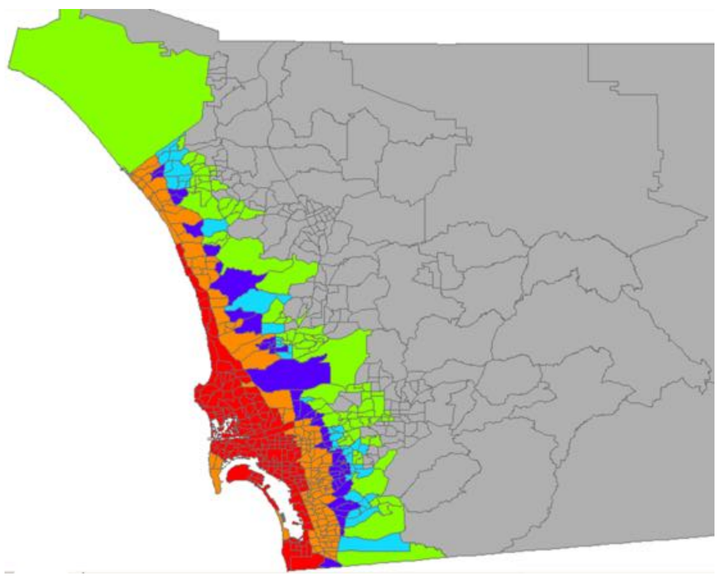


Fig. 9 – Relative Probability of at least Moderate Damage in URMs.

These loss estimates will be considerably refined as the building and infrastructure inventories are updated and the San Diego and Tijuana damage assessment models are completed. The combined San Diego and Tijuana loss estimates will be provided to Working Group 3 (Socio-Economic Impacts) to assess the broader social, economic, and community consequences.

## 8. Socio-Economic Impacts

Disasters disrupt people's lives, damage the structures they live in and work in, and damage the economies of their families and communities. Earthquakes affect infrastructure, water and sewer lines, roads, bridges, buildings and dams. They can cause fires, flooding and landslides, and displace people. Following an earthquake, many people will immediately need temporary housing, clean water, and food, while others will need medical service. Hospitals need supplies, and police and fire will need civil order and the communication channels to maintain it. The already marginalized communities become further disadvantaged and the homeless population potentially explodes with a need to shelter many more people. Being better prepared for an earthquake, by thinking through what is going to happen, will reduce the social impacts, human casualties, and costs of recovery when disaster strikes ([14], [15], and [16]).

Efforts related to Working Group 3 (Socio-Economic Impacts) have just initiated. Work will be divided into the different categories for Social and Economic Impact evaluation related to Building damage, Transportation Lifeline damage and Utility Lifeline damage. Damage to each of these systems will have potentially widespread impacts on residences and businesses with potential home and work dislocations, utility service interruptions, business interruptions, civic and governmental disruptions, health, education and welfare systems disruptions, and general economic loss and disruption. Trade, industry, and tourism will be significantly disrupted. Economic losses in terms of direct damage losses and business interruption losses will be crippling. The mission of Working Group 3 is to identify and measure these social, cultural, and economic consequences, to explore response strategies, and to recommend advanced planning and mitigation measures.

### 8.1 Information Objectives

The final report for the scenario project will provide Social and Economic Information Objectives that describe the loss of service (operations) to the public, the types of services lost, the employees and contractors out of work, the population without service, and the cascading effects and interdependencies that are associated with an earthquake event. The objective is to inform the public, policy makers, and business planners, of the risk and loss potential to their communities through Public Impact Narratives, which show how the earthquake will impact people's lives. This approach was successful in Washington State for the Seattle Fault [8].

The Information Objectives will describe the types of financial loss in terms of operational expense, staff salaries, licenses, certifications and contractual services. Structural losses to the building include the cost to repair, restore or replace. Financial loss also includes all of the non-structural equipment, materials and resources that are inside and outside of the building. There is also a loss of revenue in rents, contracts and fees, and mission essential functions that need to be identified, short term, mid-term and long term. The scenario report will inform business contingency planning and community planning measures that can be taken to reduce loss.

## 9. Conclusions

The scenario report will describe the impacts expected from a M6.9 earthquake on the Rose Canyon Fault in terms of casualties, damage, losses, and disruption. The Scenario objective is to spur action by highlighting the potential risks and identifying preparation and mitigation measures that San Diego and Tijuana can take now to reduce catastrophic impacts after the inevitable earthquake occurs.

The Scenario team is currently pursuing geologic, structural engineering, and social science studies on both sides of the border to define the geologic hazards, catalog the building and infrastructure inventories, predict the potential physical damages, and estimate the socio-economic consequences. The team is investigating the cross-border economic and social interdependencies and is identifying collaborative opportunities and organizations. We will be developing a technical report of our study and will use a set of Public Impact Narratives to illustrate the potential earthquake impacts on individual lives, community activities and governmental functions. The Scenario study is expected to shed new light on both the current vulnerabilities and the opportunities of collaborative planning and response.

The San Diego and Tijuana communities will better understand how and where their population will be impacted and will be better prepared to collaborate, respond to local needs, and share regional resources. The San Diego-Tijuana Region will also have at its disposal a broad collective database to help measure potential losses, plan for mitigation and recovery, and facilitate cross border communication and cooperation. This database will provide rich graphic inventory and demographic information that will serve as a resource for future research, planning, and disaster recovery in the San Diego–Tijuana Region.

## 10. Acknowledgements

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