Preparing a Region for Earthquake Disasters – The San-Diego-Tijuana Earthquake Scenario Project

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Abstract

EERI, SEAOSD, UCSD and CICESE are collaborating on a San Diego-Tijuana cross-border earthquake scenario study to estimate potential regional socio-economic consequences of a major earthquake on the Rose Canyon Fault. The Scenario team postulates a M6.9 earthquake originating offshore north of La Jolla and propagating south through central San Diego to the international boarder.

The Scenario team comprises three Work Groups, mirrored on each side of the border. WG-1 Earth Science group has defined the expected earthquake and worked with USGS to develop a cross-border ShakeMap of ground shaking intensities. It is studying secondary hazards to map potential surface rupture, liquefaction, tsunamis and landslides. WG-2 Buildings & Infrastructure is utilizing HAZUS to model the built environment and estimate potential physical and economic losses and casualties. It is working with local experts to enhance HAZUS inventories for the general building stock, essential facilities and vulnerable building including URMs, and to assess potential damages to infrastructure and lifelines. WG-3 Socio-Economic Impacts is working with local experts, stakeholders, and emergency response teams to assess potential regional social and economic consequences and emergency response needs.

A special challenge and opportunity of this Scenario project is its cross-border dimension. The project engages CICESE and Mexican engineering expertise to develop HAZUS models for Tijuana buildings and infrastructure, capturing its unique inventory and vulnerability. The cross-border teams are collaborating to develop parallel assessments and to evaluate coordinated emergency response strategies and cross-border economic interdependencies.

The ultimate goal of the Scenario study is to alert the regional community to the potentially devastating consequences of a major Rose Canyon fault zone earthquake and to issue a "call to action" to local governments, planning groups, policy makers, and emergency response teams to begin disaster preparation and mitigation planning with concrete actions to help build a more resilient cross-border regional community.

Keywords: Earthquake Scenario; Risk Assessment; HAZUS; Seismic Resiliency

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 (ATC, 1989), 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 investigate "what if" questions considering a credible set of earthquake parameters and expected losses and impacts 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 and its potential contribution to the seismic safety and 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 were recently initiated, therefore, only the general work plan and goals 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, including nearly 1.7 million residents of Tijuana.

Scenario Background

The first Earthquake Planning Scenario for San Diego, California and Tijuana, Mexico was published in 1990 entitled "*Planning Scenario for a Major Earthquake, San Diego-Tijuana Metropolitan Area*," prepared by the California Geological Survey (CGS) as Special Publication 100 (Reichle, 1990). 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 known "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 seismic risk study was undertaken in the city of Tijuana in 1998 called Risk Assessment Tools for the Diagnosis of Urban Seismic Risk (RADIUS) project, 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 (Villacis et. al., 2000). The objectives of the RADIUS project in Tijuana were (Radius, 1998): 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 stakeholder groups; and to formalize and institutionalize the initiative to better assure its long term implementation.

Project Objectives

The overarching objective of this scenario project is to conduct an updated regional seismic scenario study to serve as a risk identification and 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 on both sides of the international border to improve the region's seismic preparedness and resilience. The Scenario report will provide planning and policy recommendations to help improved building regulations, mitigate seismic hazards in vulnerable buildings, address vulnerabilities in lifelines and infrastructure. It will provide recommendations to help improve emergency response and coordination. It will help identify key post-disaster needs for vital services, public utilities, drinking water, medical care, temporary housing, and community services.

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. Inspired by previous earthquake fault studies in the San Diego region, earthquake scenario projects in other communities, and the interdependence of the U.S and Mexican communities in the greater San Diego-Tijuana region, this group convened a series of meetings, presentations, and a day-long workshop leading to the organization of a binational scenario project team in 2015 (Fig. 1).

Fig. 1 – Preliminary Planning Workshop at UCSD in January 2015 demonstrated regional interest and led to establishment of Project 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.

The working group organization model, shown in Fig. 2, is based on EERI's Guidelines for Developing an Earthquake Scenario (Preuss et. al., 2006) and on past scenario studies, e.g. the 2008 ShakeOut Scenario (Jones et. al., 2008, and USGS, 2008) and the Seattle Scenario study (MacRae et. al., 2006). 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.

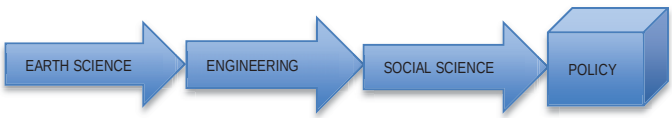

Fig. 2 – Project Team Workflow Model.

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*.

Scenario Earthquake

To update the San Diego-Tijuana Earthquake Planning Scenario, it was first 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. To be useful for planning purposes, the scenario earthquake must be close to population centers, and must create significant physical and economic impacts.

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

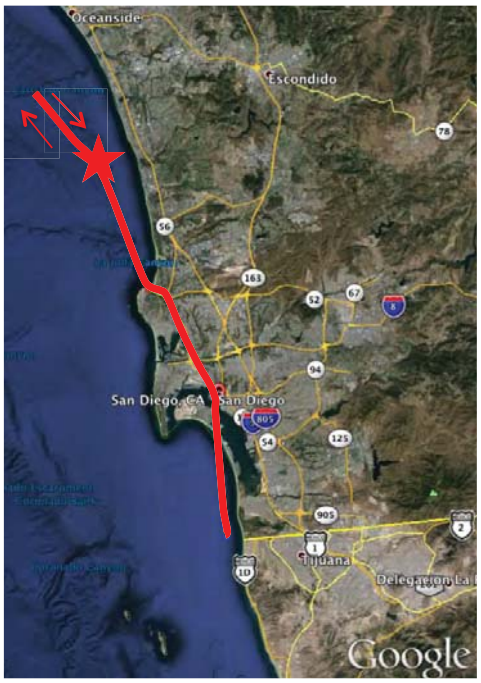

Fig. 3 – Map of Earthquake Scenario Fault Rupture.

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. 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. This type of Rose Canyon Fault Zone event is considered to be the most likely to strike the San Diego and Tijuana population centers, the one to have the greatest regional impact, and, therefore, to be the most appropriate for an earthquake disaster planning scenario.

Earthquake Shaking

With an updated Scenario Earthquake defined, 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 by generating a ShakeMap® series to estimate ground shaking variations throughout the 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 V_{S30}, (Wills, 2015). The Center for Scientific Research and Higher Education (CISESE) at Ensenada, Baja California, Mexico produced new V_{S30} data for Tijuana and the California Geological Survey (CGS) provided updated V_{S30} data for San Diego. The results of the ShakeMap series relate to intense 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).

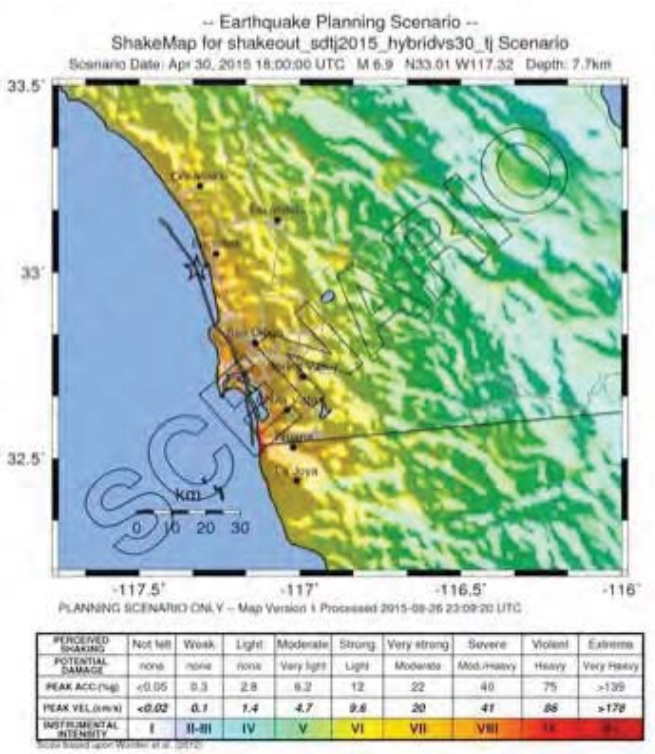

Fig. 4 – USGS Intensity ShakeMap.

After the ShakeMap series were completed, 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 information concerning the impact of the earthquake. These impacts 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 any 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.

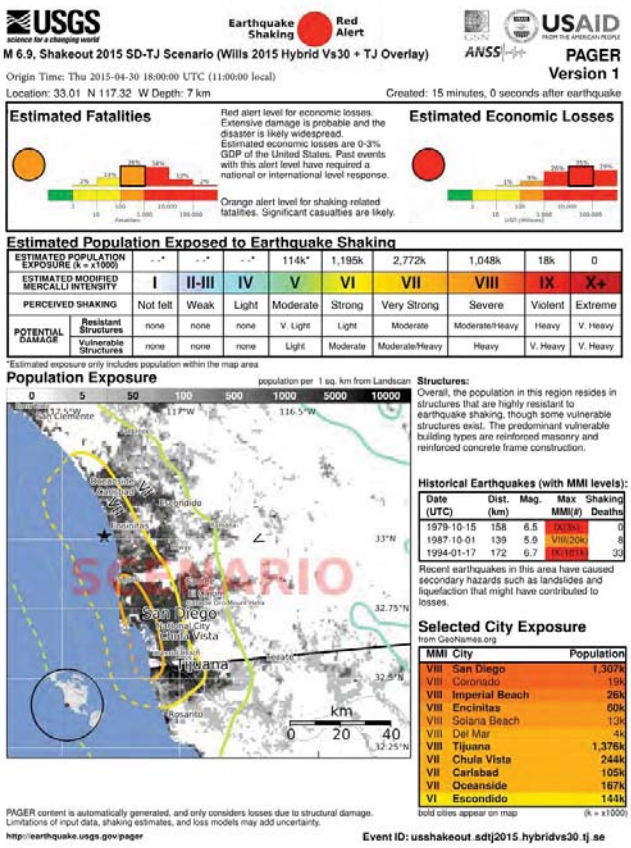

Fig. 5 – USGS PAGER report for the proposed scenario earthquake.

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. 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. Therefore, the updated scenario earthquake does create significant damage and risk for the San Diego and Tijuana regions warranting consideration in the planning efforts. Damage estimates and losses due to the scenario earthquake will be refined as part of Working Group 2 efforts.

Earthquake Secondary Hazards

The Earth Science group is currently working on identifying all known 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.

Building & Infrastructure 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 the two sides 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 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 (Hazus, 2015).

On the San Diego side, the loss modeling tracks the path of previous scenario studies conducted in Utah for the Wasatch Fault (EERI, 2015), in Northern California for the Hayward Fault (EERI, 2005), in Southern California for the Great Shakeout (Jones et. al., 2008, and USGS, 2008), and in Washington State for the Seattle Fault (MacRae, 2006). 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.

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 assessor'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 (Jones et. al., 2008).

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 the current study but could be added for future updates as data become available.

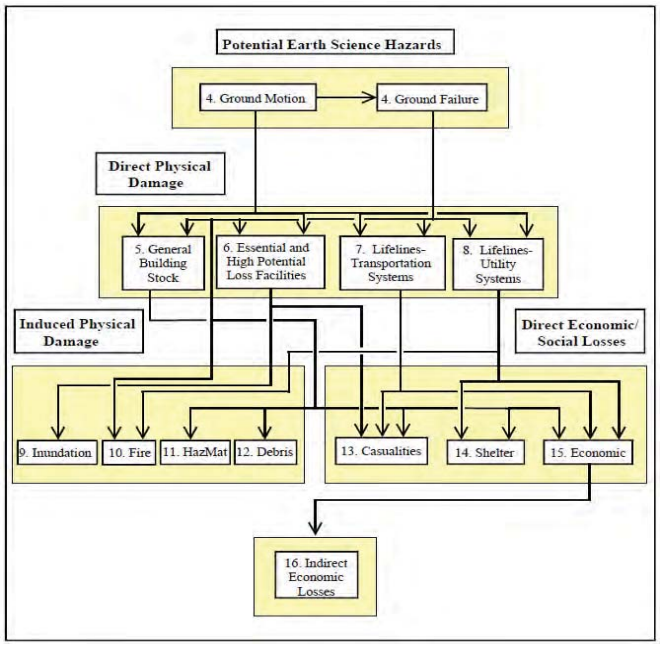

Fig. 6 – Flow Chart for HAZUS Earthquake Module.

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. Key life line systems running across the fault rupture zone and probable liquefaction zones are expected to be hit hardest and contribute the most to utility service disruptions, transportation disruptions, housing and business dislocations, and broader economic and social disruptions.

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 (Hansen, et. al., 2007). 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; that project has spawned a strong and influential local professional seismic risk community, facilitating information sharing at all levels: private, public, and academic.

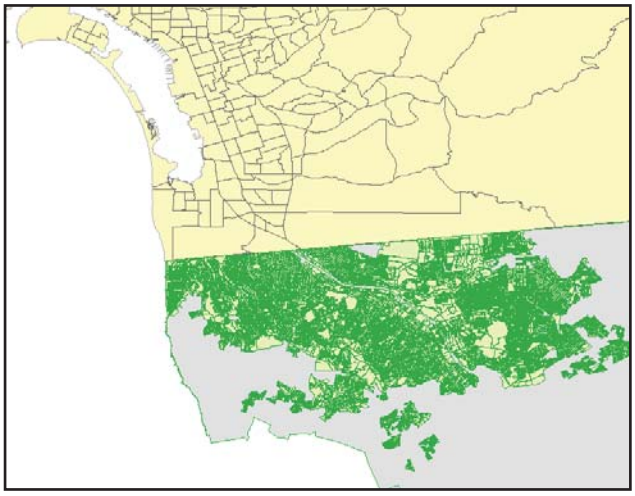

Fig. 7 – Implementing HAZUS Earthquake Loss Estimation for Global Applications. Green areas indicate regions of Tijuana that are being enhanced with aggregated data like population, demographics, and general building stock values.

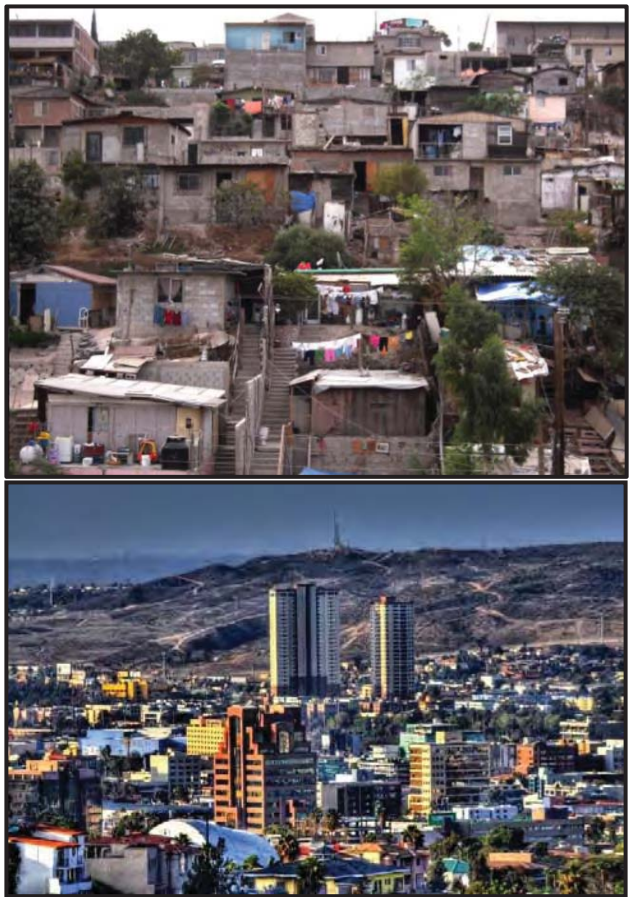

Fig. 8 – Tijuana building type samples.

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 Social & Economic Impact working group to evaluate potential broad regional consequences, border crossing impacts, mitigation strategies, and emergency response strategies.

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 (Figure 5).

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.

The postulated fault rupture zone extending from La Jolla through downtown San Diego is expected to cause heavy damage to key lifeline systems crossing the rupture zone, including transportation systems, the airport, communications systems, and pipelines. This damage is expected to cause major disruptions, particularly to the beach communities west of the fault rupture zone.

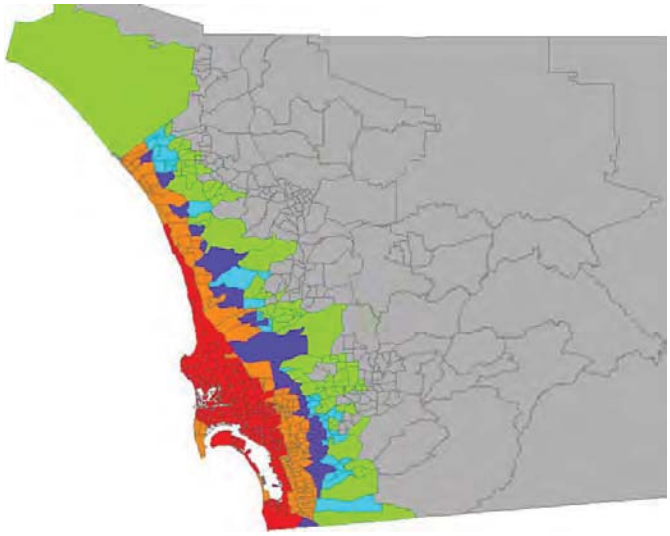

Fig. 9 – Relative Probability of at least Moderate Damage in URMs. Red indicates high probability. Green indicates low probability.

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 (Social & Economic Impacts) to assess the broader social, economic, and community consequences.

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 buildings and infrastructure, water and sewer lines, roads, bridges, dams, ports, airports, and border crossings. They can cause fires, flooding and landslides, and displace people. Disruptions to the international border crossing will cause major economic disruption to the tens of thousands of workers who cross the border every day, to their families and dependents, and to the businesses and industries that depend upon their labors. 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 will become further disadvantaged and the homeless population will potentially explode 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 (NIST, 2015; NIST, 2016; FEMA, 2011).

Efforts related to Working Group 3 have recently initiated. Work will be divided into the different categories for Social and Economic Impact evaluation related to Building damage, Transportation Infrastructure damage, Utility Lifeline damage, and border crossing disruptions. 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 disrupted. Economic losses in terms of direct damage losses and business interruption losses will be potentially crippling. The mission of Working Group 3 is to identify and analyze these social, cultural, and economic consequences, to explore response strategies, and to recommend advanced planning and mitigation measures.

Informational Objectives

The final report for the scenario project will provide Social and Economic Impact analysis and narratives to describe the economic disruptions, infrastructure disruptions, loss of public services, 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 loss analysis and Public Impact Narratives, which show how the earthquake will impact people's lives. This narrative approach was successful in Washington State for the Seattle Fault (MacRae, 2006) and in the Great Southern California Shakeout Scenario (Jones, et al, 2008).

The Informational Objectives will be to describe the types of physical and financial losses and their impacts in terms of reconstruction costs, operational losses, and loss of staff salaries, licenses, certifications and contractual services. Structural losses to the building will trigger costs to repair, restore or replace and will result in business disruption and temporary business relocation. Financial loss will also include loss of non-structural systems, equipment, materials and resources that are inside and outside of buildings. Building losses will result in loss of revenue from rents, contracts and fees, and mission essential functions in the short term, mid-term and long term. The scenario report will help to inform business contingency planning and community planning measures that can be taken to reduce potential losses.

The report will describe the impacts expected from the scenario earthquake 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.

Policy & Planning Recommendations

A chief objective of the scenario study and report will be to develop and present mitigation policy and planning recommendations to help guide both local governments and local businesses prepare for future earthquakes. The Scenario team will review their findings both internally and with community wide stakeholder groups to identify key vulnerabilities in the regional building stock and infrastructure systems. They will identify vulnerable building types and critical life line systems. They will identify key potential social and economic impacts of disruptions to these structures and systems, both locally and in the cross border context. They will assess emergency response needs and existing services. They will review current and potential enhanced collaboration relationships within the emergency response communities on both sides of the border.

The team will collaborate to develop policy recommendations for local governments aimed at long term mitigation programs to abate seismically hazardous buildings including unreinforced masonry buildings, non-ductile concrete buildings, older tilt-up structures, and pre-Northridge steel moment frame buildings. They will consider potential damages to essential facilities and develop recommendations toward developing more redundant and resilient systems. They will study potential disruption of public services and recommend measures to prepare. They will review critical transportation systems and recommend measures to mitigate vulnerabilities. They will consider potential housing, and basic and emergency services needs and recommend planning measures to meet those needs. The goal for these various planning and policy recommendations will be to help the San Diego-Tijuana region become a more resilient community able to better withstand and respond to future earthquakes and other natural disasters.

Summary

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 social and economic consequences. The team is investigating the cross border economic and social interdependencies and is identifying collaborative opportunities and organizations. We will develop 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.

With the Scenario study, 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 model potential disasters, measure potential losses, evaluate mitigation strategies, and plan for mitigation and recovery. It will establish contacts and collaboration relationships to facilitate cross border communication and cooperation. The database will provide a rich graphic inventory of seismic hazards, building and infrastructure inventories, vulnerabilities, and potential damage maps as well as collaboration contacts that will serve as a resource for future research, planning, and disaster recovery in the San Diego–Tijuana Region. The ultimate outcome of the Scenario study will be to contribute to a more seismically resilient regional cross-border community.

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References

ATC, 1989, "ATC 20: Procedures for Post-earthquake Safety Evaluation of Buildings & Addendum", *Applied Technology Council Report* in coordination with California Office of Emergency Services (OES), California Office of Statewide Health Planning and Development (OSHPD) and FEMA, 152 pages.

EERI, 2005, "Scenario for a Magnitude 7.0 Earthquake on the Hayward Fault", *Earthquake Engineering Research Institute*, Oakland, CA, USA, 109pp.

EERI, 2015, "Scenario for a Magnitude 7.0 Earthquake on the Wasatch Fault–Salt Lake City Segment Hazards and Loss Estimates", *Earthquake Engineering Research Institute*, Oakland, CA, USA, 60pp., 2015. https://utah.eeri.org/wp-content/uploads/2015/08/EERI_Scenario_-_FINAL_VERSION_July_16_2015.pdf.

FEMA, 2011, "National Disaster Recovery Framework, Strengthening Disaster Recovery for the Nation".

Hansen, R., and Bausch, D., 2007, "A GIS-based methodology for exporting the Hazards US (HAZUS) earthquake model for global applications". http://www.usehazus.com/docs/gis_global_hazus_paper.pdf, Accessed 01 June 2007, pp 64.

Hazus, 2015, "Hazus-MH 2.1 Technical Manual", Multi-Hazard Loss Estimation Modeling: http://www.fema.gov/media-library/assets/documents/24609.

Jones, LM., Bernknopf, R., Cox, D., Goltz, J., Hudnut, K., Mileti, D., Perry, S., Ponti, D., Porter, K., Reichle, M., Seligson, H., Shoaf, K., Treiman, J. ,and Wein, A., 2008, "The ShakeOut Scenario: U.S. Geological Survey Open-File Report 2008-1150 and California Geological Survey Preliminary Report 25", [http://pubs.usgs.gov/of/2008/1150/].

MacRae, G.A., et al, 2006, "Seattle Fault Scenario – A Decision Making Tool", *Proceedings – 2006 Conference New Zealand Society for Earthquake Engineering (NZSEE)*, Wellington, New Zealand.

NIST, 2015, "Community Resilience Planning Guide for Buildings and Infrastructure Systems", *National Institute of Standards and Technology U.S. Department of Commerce*, Special Publication 1190 v.1 & v.2.

NIST, 2016, "A Conceptual Framework for Assessing Resilience at the Community Scale", *National Institute of Standards and Technology,* NIST GCR 16-001.

Preuss, J. and Godfrey, J., 2006, "Guidelines for Developing an Earthquake Scenario", *Earthquake Engineering Research Institute*, ISBN 1-932884-16-5.

Radius, 1998, "Programa Radius – Tijuana Website (in Spanish)": http://radius-tij.cicese.mx/index.htm.

Reichle, M.S., et al, 1990, "Planning Scenario for a Major Earthquake, San Diego-Tijuana Metropolitan Area", *Special Publication 100, California Department of Conservation,* Division of Mines and Geology, Sacramento, CA.

USGS, 2008, "Effects of a Potential M7.8 Earthquake on the San Andreas Fault, Shake Out Scenario", published as USGS PR 25 and CGS OFR 2008-1150, CA, USA.

Villacis, C., Cardona, C., Tucker, B., 2000, "Implementation of Fast Earthquake Scenarios for Risk Management in Developing Countries", *12th World Conference in Earthquake Engineering*, Auckland, New Zealand.

Wills, C. J., 2015, "Updated Shear Wave Velocity (VS30) data for San Diego County, California". *California Geological Survey*.