Impact of earthquake magnitude on the estimation of tsunami evacuation casualties

S. Castro\textsuperscript{1}, A. Poulos\textsuperscript{1}, A. Urrutia\textsuperscript{1}, R. Cienfuegos\textsuperscript{1,2}, J.C. Herrera\textsuperscript{1,3}, J.C. de la Llera\textsuperscript{1,4}

\textsuperscript{1}Researcher, National Research Center for Integrated Natural Disaster Management
\textsuperscript{2}Professor, Dept. of Transport Engineering and Logistics, Pontificia Universidad Católica de Chile
\textsuperscript{3}Professor, Dept. of Hydraulic and Environmental Engineering, Pontificia Universidad Católica de Chile
\textsuperscript{4}Professor, Dept. of Structural and Geotechnical Engineering, Pontificia Universidad Católica de Chile

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The mission of the Research Center for Integrated Disaster Risk Management, CIGIDEN, is to develop, integrate and transfer scientific knowledge and form advanced human capital that contributes to reduce the social consequences of extreme natural events.

Motivation

• Evacuation plans developed in several cities do not consider the effect of the induced earthquake damage.

• Additionally, evacuation models are normally tested for specific scenarios, which lack of the variability in the hazard description.

Objective

Develop an evacuation model considering the earthquake damage and tsunami inundation for several scenarios in order to estimate the effect on the evacuation times and casualties.
Methodology

Start

Ground motion intensity

Location and fragility of building stock

Assess building damage

Compute tsunami generation

Calculate tsunami propagation

Distribute debris on evacuation routes

Assign people to buildings

Compute building evacuations

Time of day

Distribute pedestrians and cars on streets

Compute tsunami inundation

Run evacuation model

Output evacuation times and casualties

Stop
Case study

- Coastal city of Iquique, north Chile (20°13’S, 70°09’W).

- Population of about 180,000 people.

- In 2014 suffered a $M_w$ 8.2 earthquake and a later tsunami.

Figure: Map of Iquique showing the evacuation zone and the area of study.
Case study

- Safety zone is defined with an elevation of 30 m.a.s.l.

- Iquique has the highest motorization rate of Chile: 23.7 vehicles per urban hectare.

- Even though is not suggested, people have evacuated in vehicles in previous earthquakes.

Figure: Evacuation routes and pictures of the streets in a normal day.
Analysis procedure

• Three moment magnitudes are studied: $M_w$ 8.0, $M_w$ 8.5 and $M_w$ 9.0.

• HAZUS is used to compute the amount of debris of each block.

• For each magnitude, 100 PGA maps are performed using a ground motion prediction equation (GMPE).

• Spectral accelerations at 0.3 and 1 second are obtained using a period correlation model.

Figure: Spectral accelerations at 0, 0.3, and 1 second.
Analysis procedure

• For each moment magnitude a tsunami simulation was performed, assuming an uniform slip.

• The Okada model is used to obtain the vertical displacement at the seafloor.

• Propagation and inundation is modeled solving the nonlinear shallow water equations

**Figure**: Tsunami inundation arrival times for magnitudes: a) $M_W$ 8, b) $M_W$ 8.5, and c) $M_W$ 9, when water height reaches 10 cm.
Analysis procedure

• An agent-based evacuation model was developed to represent the movement of the pedestrians and cars.

• The current velocity of each agent is calculated using a collision avoidance algorithm:

\[ v_i^n = \arg \min_{v \in \mathcal{V}_i^r} \| v - v_i^p \|, \forall i \in \mathcal{N} \]

where

\[ \mathcal{V}_i^r = \text{set of possible velocities that ensure that agent } i \text{ will not collide with other agents and obstacles.} \]

\[ \mathcal{N} = \text{set of all evacuating agents.} \]

Animation: Evacuation simulation of a 4-floor building.
Analysis procedure

• Before evacuating the city, people have to evacuate their buildings.

• Evacuation simulations were calculated using typical residential building layouts, changing the number of floors.

• Probabilistic distributions were obtained for the initial and ending times of each evacuation curve.

• In each simulation, these curves are sampled for every building in the city.

Figure: Mean evacuation curves for buildings.
Analysis procedure

• Debris is estimated using the characteristic of each block and distributed randomly around each building.

• Evacuation modeling considers pedestrians and vehicles at the same time.

• A collision avoidance algorithm is used in order to capture the congestion problem.
Results

- $T_{95\%}$: time needed to evacuate the 95% of the population.

- Median evacuation times are practically the same (23.6, 23.8 and 23.8 minutes).

- The worst scenario shows an increment of 63% relative to the median.

*Figure:* Evacuation times for 95% of the population.
Results

• Casualties: people that are reached by tsunami flows with inundation depths of at least 10 cm.

• Casualties could represent injured, dead or people trapped within buildings.

• Number of scenarios with at least one casualty: 1, 19, and 78, for the three magnitudes.

Figure: Tsunami casualties.
Conclusions

• Evacuation modeling is a powerful tool to evaluate the evacuation routes of a city.

• However, without combining the evacuation process with the hazard, the estimation of the evacuation times are underestimated.

• Additionally, using a collection of earthquake scenarios provides a more generally applicable results on the definition of robust public policies.

• Future work should focus on the estimation and characterization of the debris, use more complex slip faults for tsunami generation and reduce the computational times of the simulations.
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  • www.cigiden.cl

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