Risk Management of Road Networks exposed to natural hazards: A collaborative initiative in Chile

1,2Chamorro A, 1,4Echaveguren T, 1,2Allen E, 1,2Contreras M, 2,3Dagá J, 2,3de Solminihac, H and 1,5Martínez C

1 National Research Center for Integrated Natural Disaster Management (CIGIDEN)
2 Department of Construction Engineering and Management, School of Engineering, Pontificia Universidad Católica de Chile
3 Latin American Center of Economic and Social Policies (CLAPESUC)
4 Universidad de Concepción, School of Engineering, Department of Civil Engineering
5 School of Geography, Pontificia Universidad Católica de Chile

SUMMARY

Chile presents a variety of climatic conditions, morphology and high exposure to natural hazards. This results in a road network highly vulnerable to natural events, such as earthquakes, tsunamis, volcanic eruptions, floods, dry or wet landslides, among others. To date, there is no system in Chile capable of measure objectively risk and resilience of the national road network exposed to the main natural events. The Project “Research and Development of Models to Quantify and Mitigate Risk of the National Road Network affected by Natural Events” is a five-year collaborative initiative led by Pontificia Universidad Católica de Chile and Universidad de Concepción, and partnered by the National Roads Agency of the Ministry of Public Works of Chile MOP, the National Emergency Office of the Ministry of Interior ONEMI and the Association of Public Infrastructure Concessions COPSA. The initiative aims to develop a risk management system for the national road network exposed to natural hazards, in particular seismic, volcanic and hydro meteorological events. This article presents the ongoing project with its primary findings and describes an integrated framework for the development of the risk management system. The framework integrates an interdisciplinary perspective to assess risk of road networks exposed to natural hazards, integrating social vulnerability of exposed population and physical vulnerability of exposed road infrastructure.

Keywords: Road Network, Natural Hazards, Risk Management

INTRODUCTION

Road networks are managed under the assumption of prevailing stresses and strains affecting infrastructure during service life and the natural context where they are located. At the same time, transportation models assign traffic to the road network considering that all links are connected. However, empirical evidence has proven that natural hazards or human-induced phenomena may temporarily or permanently interrupt connectivity between links of road networks.

‘Research and Development of Models to Quantify and Mitigate Risk of the National Road Network affected by Natural Events’ is a five-years project that started on April 2015. The initiate aims to develop a risk management system for the national road network exposed to natural hazards, in particular seismic, volcanic and hydro meteorological events. In a first stage of scientific research, the project focused in the development, validation and application of physical vulnerability models considering the main infrastructure elements of the road network. In addition, cost-effective mitigation strategies were recommended to decrease road risk considering optimization criteria. In an ongoing second stage of the project, social vulnerability and its dependence to critical infrastructure and road network of affected population is addressed, whereas developed models will be integrated in a GIS-based risk management system that will be implemented in the partnering institutions. The second stage also aims to develop an integrated framework that considers both physical and social vulnerabilities in order to manage road networks exposed to natural hazards.

PRELIMINAR RESULTS

The first stage of the project aimed to develop models to quantify physical vulnerability through fragility curves for the main elements of the road infrastructure. The primary results associated to the first stage of this project are:

1. Calibrated vulnerability models for road elements exposed to seismic, volcanic and hydro-meteorological hazards
2. Cost – effectiveness mitigation model to evaluate different strategies in terms of technical and social criteria.
Vulnerability models developed in the first stage considered analytical, empirical and hybrid approach considering historical events in Chile.

As example of models developed in the first stage, the bridge vulnerability model due to volcanic hazards developed under analytical approach. Fig 1 presents the vulnerability, in terms of probability of collapse of exposed bridges.

The ongoing research aims to develop and apply a GIS based risk management systems of road networks considering seismic, volcanic and hydro-meteorologic hazards. The system is based on the vulnerability and mitigation models proposed in the first stage of this project. One of the main objective is to integrate social aspects to the physical risk evaluation.

The methodology to evaluate risk as the mean annual probability of an output variable $\lambda_{DV}$, such as expected travel time or connectivity, consists on the integration of different hazard scenarios based on the total probability theorem expressed in Equation 3.

$$\lambda_{DV}(dv) = \nu \int_{\Omega} \mathcal{P}(DV > dv \mid IM = im) f_{im}(im) \, dvm$$  \hspace{1cm} (3)

Where IM is the intensity of the scenario in all locations, $f_{im}$ is the probability density function of intensities, $\nu$ represent the mean annual rate of natural events and $\Omega$ represents the possible scenarios. This methodology is applied in a road network exposed to natural events.

**INTEGRATED FRAMEWORK FOR RISK MANAGEMENT OF ROAD NETWORKS**

The framework proposed is a comprehensive procedure to assess road network risk to natural hazards by integrating social vulnerability of exposed population and the physical vulnerability of road infrastructure. The framework is developed in a collaborative approach where outcomes of the system should address stakeholders and decision makers such as MOP, COPSA and ONEMI.

The first step in the process is the hazard modelling, which includes the hazard simulations (hazards maps) and the definition of the case study. The second step of the process is the social vulnerability modelling in terms of social dependence to the road network. Physical vulnerability modelling is the third step, which is one of the results of the first stage of the project. The fourth step is the physical risk evaluation in terms of the probabilistic consequences of the system operation. The last step is the integration of both physical and social vulnerabilities. The outputs are social vulnerability, network physical risk and the integrated risk displayed in a GIS platform.

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