Vulnerability of Bridges to Natural Events

Patricia León Malavé[1], Prof. Gustavo Pacheco Crosetti[2], P.E., PhD.

Polytechnic University of Puerto Rico – Undergradute Research Program 2019-2020

[1]Senior student, Civil Engineering Program. [2]Professor, Department of Civil and Environmental Engineering and Land Surveying.

Abstract

This project utilized the HAZUS program and ArcGIS to perform vulnerability assessments on the bridges in Puerto Rico. After conducting earthquake scenarios, the most probable bridge to experience failure or distress was identified and analyzed. It was determined that the HAZUS program and ArcGIS were not fully integrated for different hazard scenarios, and the learning curve in order to use them by novice investigations were steep. A more traditional methodology is suggested to identify high risked bridges, such as merging liquefaction, tsunami, landslide and seismic wave maps together in order to identify the bridges that are located in areas of concurrent high natural hazards, being more likely to be affected by such events.

Introduction

Puerto Rico is an island very susceptible to experience extreme natural events, because so, it is important to be prepared and to have a general knowledge of how the island's infrastructure could behave under such devastating events.

A bridge is an essential path of transportation network to overcome a physical obstacle such as lands of water, elevation, roads and more. Civil engineers follow guidelines and rules to make these structures as safe as possible to civilians, however they are prone to fail (FEMA, 2019).

From 2017 to 2020, Puerto Rico experienced hurricanes (Irma and María), floods, landslides and earthquakes. Many structures completely failed, and entire communities got isolated (see Figure 1). Due to their importance and the consequences of their vulnerability, it is valid to research bridge behavior under different extreme natural events scenarios and identify bridges that are more vulnerable to such events. (Maldonado, 2018). This would bring awareness and a general knowledge of the island's infrastructure and could enhance an emergency plan to avoid structural failures and catastrophes.

Objectives

Evaluate the suitability of the HAZUS software, that can simulate extreme natural events, such as floods, hurricanes, earthquakes, landslides and more, to identify critical bridges in terms of their vulnerability to extreme natural events. If appropriate, contribute to the identification of bridges that may require special attention, maintenance, verifications, and/or improvements to avoid collapse under extreme events.

Figure 1: Fallen Bridge in Corozal, Puerto Rico (Cruzado & Pacheco, 2018)

Methodology

- Investigate bridge infrastructure, components and types.
- Obtain bridge location data suitable to GIS programs
- Study and explore the most typical natural hazards that Puerto Rico is vulnerable to.
- Explore methodology of antecedents.
- Download software program and read user technical manuals (Hazus and ArcGIS).
- Install and setup a dedicated PC with ArcGIS and Hazus
- Upload data to perform a natural event scenario.
  - Simulating a natural event scenario is used to predict how critical infrastructure, such as bridges, might perform. Calculate probabilities of property failure, social impacts, economic loss, resources needed and general outcome of that natural event.
- Run analysis and obtain results
- Interpret results and compare top 3 at risk bridges per scenario as case studies
- Provide an analysis, conclusion and recommendation based on results and outcome.
- Assess if this software is a user-friendly and manageable option to analyze infrastructure in Puerto Rico

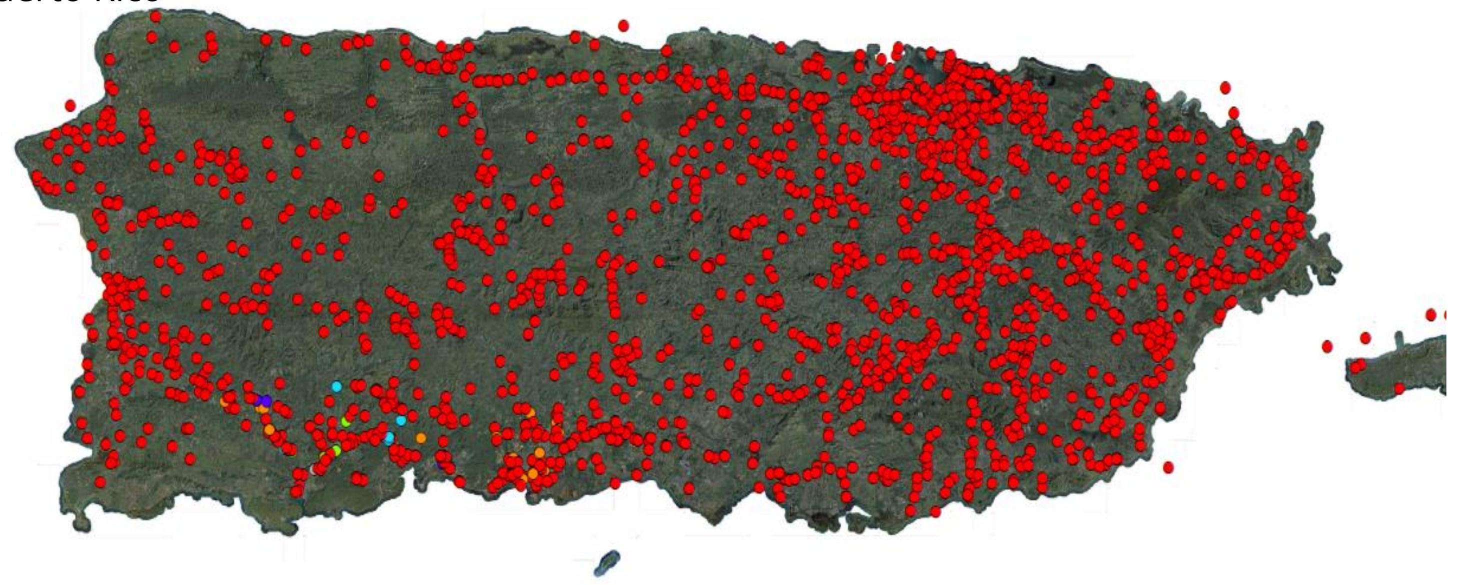

Figure 2: Geolocation of Bridges (Hazus, 2020)

Data

All the bridges in Puerto Rico were plotted to visualize and grasp their locations. Recent earthquakes from January 7-11 from 2020, above 5.0 of magnitude and located in the south west region were evaluated. Controlling these variables provided a more controlled outcome of results and analysis. Using the USGS shakemaps provided by HAZUS, 3 earthquake scenarios were evaluated and the bridges with most probability to experience a type of failure were selected as case studies. Using Google Earth the bridges were located to verify their locations, type of bridge and what they are exposed to, such as highways or rivers.

Table 1: Earthquake Scenarios

Scenarios	**5.6M 11km S of Tallaboa, Puerto Rico**	**5.6 8km SSW of Tallaboa, Puerto Rico**	**5.9 10km SSE of Indios, Puerto Rico**
Bridge Name (ID)	Portugues River (PR001137)	Guayanilla River (PR000223)	Loco River (PR001118)
	Portugues River (PR001060)	Guayanilla River (PR001030)	Yauco River (PR000601)
	PR 2 (PR000233)	Tidal Inlet (PR000874)	PR 2 (PR001806)

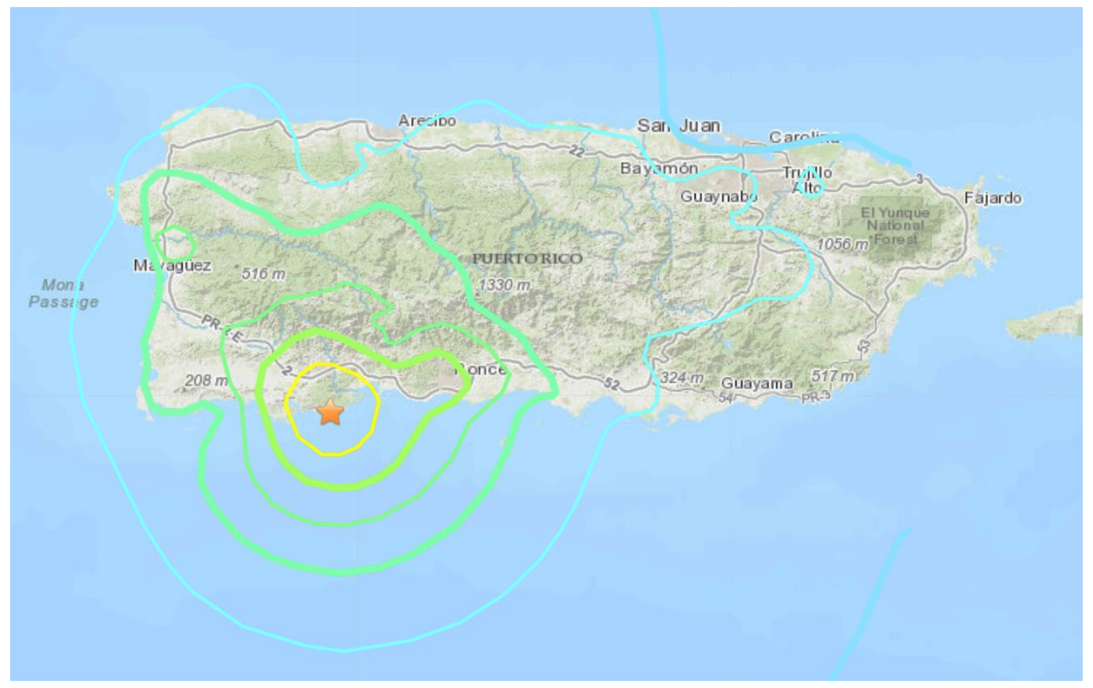

Figure 3: Shake Map (Intensity Countours) of Earthquake 5.9 10km of Indios, Puerto Rico (USGS, 2020)

Analysis and Results

Out of the 3 scenarios ran by HAZUS, it is evident that the bridge that experienced most probability of failure was Loco River from scenario 5.9 10km SSE of Indios, Puerto Rico, with 55.93%. Its specifications, conditions and location make the bridge most prone to distress or failure. The bridge was built in 1941, as a girder bridge to connect two roads over a river. The results seem very reasonable because although the bridge was slightly near the epicenter of the earthquake, it is very exposed to scouring, corrosion, deterioration and other factors that could potentially affect the bridges conditions. Circumstances for bridges from scenario 1 and 2 were also analyzed and effectively, they are as well exposed to collisions, scouring and other factors.

Case Studies

Scenario	Bridge Name (ID)	Probability of failure
5.6M 11km S of Tallaboa, Puerto Rico	Portugues River (PR001137)	0.86%
5.6 8km SSW of Tallaboa, Puerto Rico	Guayanilla River (PR000223)	41.47%
5.9 10km SSE of Indios, Puerto Rico	Loco River (PR001118)	55.93%

Figure 3: Geolocation of Loco River Bridge (Google Earth, 2020)

Conclusion

Although the HAZUS program does not work perfectly for Puerto Rico, it did serve its function to analyze the vulnerability of bridges toward the natural hazard event of earthquakes. Out of the 3 earthquake scenarios, the most vulnerable bridge was highlighted, (Bridge Loco River) and its factors were defined to understand why it was most probable to failure. It is recommended that these bridges be inspected after the earthquakes because they were under distress and could have potential failures, such as cracking or corrosion, for instance. The HAZUS program also identified the social impacts and economic losses that could be expected, which is very useful and brings much awareness to prepare an emergency plan. However, the program did not allow for other natural hazard scenarios to be studied because it was not available for Puerto Rico (such as hurricane hazards), there were incompatibilities between Hazus 4.2 versions, ArcGIS 10.7.1 version, and hazard situations (such as flood Hazards), and the tsunami model for PR had errors.

It was also observed that the learning curve to use the software, and to address the incompatibilities between versions and hazards, were too steep and time consuming. This perception may have been also influenced by the several challenges confronted to carryout the research, such as getting access to the dedicated PC with both software packages installed and waiting for the renewal of ArcGIS license. Additionally, it is considered that an intense guided seminar on ArcGIS and HAZUS at the beginning of the investigation could have been beneficial, together with an accessible help line from both FEMA and ArcGIS. That is why a more traditional methodology is recommended towards performing a vulnerability assessment as a novice investigation, consisting in superimposing GIS data of the different hazards and their intensity (earthquakes, tsunamis, landslides, liquefaction, hurricanes, flooding) and the bridge location, and identify the bridges located in areas of concurrent hazards with high intensity.

Acknowledgments

I would like to thank the program members and professors for allowing me to have such a great opportunity of my academic development. A very special thanks to my mentor, Dr. Gustavo Pacheco for being there along the way with advice and help. Also, Ileana Melendez from the Civil Engineering Department for helping with much technical difficulties and my classmates, friends and family for going through this journey alongside with encouragement and reassurance.

References

Bridge Masters. (2017, Janurary 6). 9 Common Reasons for Bridge Failures. Retrieved from https://bridgemastersinc.com/9-common-reasons-for-bridge-failures/

Cruzado, H., & Pacheco, G. (2018). Structural Damages due to Hurricane Maria. Mega Viernes Civil.

FEMA. (2019, January 14). Earthquake Fast Facts. Retrieved from https://www.fema.gov/earthquake-fast-facts

Kiger, S. A., Salim, H. A., & Ibrahim, A. (2010). Bridge Vulnerability Assessment and Mitigation against Explosions. Iowa State Univerisy .

Maldonado, C. L. (2018, 08 27). Falta taller como loco en los puentes. El Nuevo Día. Retrieved from https://www.primerahora.com/noticias/gobierno-politica/nota/faltatallercomolocoenlospuentes-1299426/