RECENT RISK EVALUATION AND DISASTER MITIGATION STUDIES FOR BRIDGE STRUCTURES AT LANAMME-UCR

UNIVERSIDAD DE COSTA RICA

LanammeUCR

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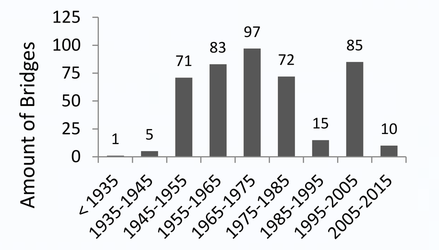
SEISMIC VULNERABILITY EVALUATION OF BRIDGES IN THE NATIONAL ROAD NETWORK

Objectives

The main goal of this research project is to identify vulnerability characteristics of local bridge structures in the Costa Rican National Road Network. To achieve this purpose other further objectives were necessary:
- Create a detailed bridge inventory database
- Determinate bridge fragility families
- Calculation of each individual fragility curves for different damage levels according to site soil conditions, seismic hazard zone, fragility families and particular structural conditions

Introduction

Past earthquake experience of Limon 1991 (7,7 M_W) and Samara 2012 (7,6 M_W) earthquakes revealed poor seismic performance of bridge structures. Damage was mainly attributed to the lack of seismic protection components and design considerations, and to soil liquefaction. In Costa Rica the use of the United States AASTHO norm is the common practice, these norms introduced relevant changes for seismic design from 1975 and 1990. Many important bridge structures in Costa Rica were constructed before 1975 and there is a need to evaluate their seismic vulnerability in order to prioritize seismic retrofit works, renewal needs and to rapidly identify possible weakened structures after an earthquake occurred.



Construction period of bridges in the detailed inventory

Partial Collapse of Chirripó River Bridge in 1991 (insufficient seat length)

Methodology

For the vulnerability assessment using fragility curves the following steps were performed:
1) Review of the 1440 bridge units in the National Road Network. Adequate information for fragility description was found for 582 bridges with 13 different structural types (USA NBI classification was used)
2) Definition of structural fragility families applicable for Costa Rica based on the US Federal Highway Association FHWA proposal
3) Calculation of each bridge fragility according to local conditions and characteristics (soil type, material, span number, skew, etc)
4) Determination of possible bridge seismic damage level
5) Validation of the results with past earthquake data, in particular for Samara where reliable ground motion records are available

Results

For the obtained inventory, 12 different fragility families were proposed, the details are shown in table 1. For each family, a base mean spectral acceleration is associated with different degrees of damage (Slight/Moderate/Severe/Complete). With this table and local conditions, individual fragility curves are computed for all damage levels. For each damage curve, mean spectral accelerations are stored. With this acceleration database, results for expected damage can be assessed for any earthquake scenario (ex: fig. 1).

Table 1. Seismic fragility groups and amount of bridge units per group

Group	Structural Description	NBI Class	Design	Bridge Units
MS1	Multi-column simple support	101-106, 301-306, 501-506 309 y 310	Before 1975	140
MS2	Multi-column simple support	101-106, 301-306,501-506 309 y 310	Seismic	42
MVC1	Single column, box girder	205,206, 605,606	Before 1975	4
MVC2	Single column, box girder	205,206, 605,606	Seismic	2
MCC1	Continuous concrete	201-206 601-607	Before 1975	19
MCC2	Continuous concrete	201-206 601-607	Seismic	11
MCA1	Continuous steel	402-410	Before 1975	11
MCA2	Continuous steel	402-410	Seismic	7
CUSA	Single span, simp. support	All		318
OP	Other	207, 413*, 622		24
PM1	Mayor bridge L_{max}^{t} > 150 m	All	Before 1975	0
PM2	Mayor bridge L_{max} > 150 m	All	Seismic	4

Conclusions and ongoing works

Bridge fragility functions had been successfully calculated for the vulnerability assessment of bridge structures in the Costa Rican National Road Network. Validation works are currently performed with data from the Samara earthquake, this validation includes bridge in-situ inspections due to the inappropriate seismic damage data available. Vulnerability assessment for all the national road bridge stock is considered to be possible with the help of statistical analysis of available detailed data.

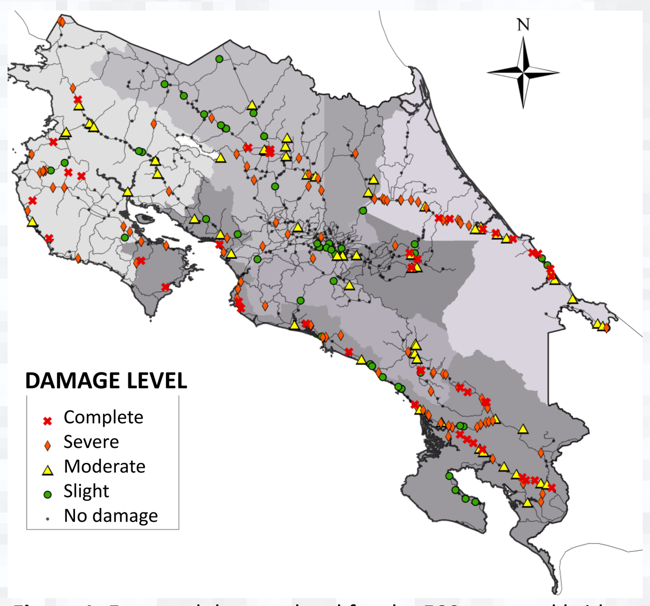


Figure 1. Expected damage level for the 582 assessed bridges for a 50% probability of occurrence and Costa Rican seismic zones (PGA ranges from 0,24 to 0,49 %g)

PROTOCOL PROPOSED FOR SAFETY POST-EARTHQUAKE BRIDGE STRUCTURE INSPECTIONS IN COSTA RICA

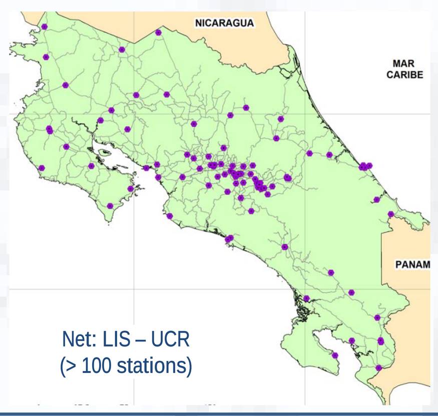
Objectives

The main goal of this proposal is to define a protocol for post-earthquake safety inspection of bridge structures. To attain this goal, further activities will be accomplished:
- Bridge inventory database and seismic vulnerability assessment
- 3 Bridge Inspection procedures and bridge seismic damage characterization (includes training program)
- Definition of bridge importance
- GIS interface and real-time bridge inspection prioritization list

Introduction

Earthquake hazard is of major concern in Costa Rica, a single strong event can significantly affect all the national territory; a recent example was the Samara earthquake in 2012 (7,6 M_W) . Bridge function after a seismic event is of strategic importance for emergency actions. Bridge damage status must be assessed prior to operate again after an event. In Costa Rica there is no clear rigorous inspection procedure to evaluate seismic damage in order to decide if normal traffic can be permitted, should be restricted or prohibited. Actual damage description is ambiguous and subjective, in particular for moderate and low damage levels of damage which difficults decision making. Furthermore, inspection teams are allocated in basis to epicenter distance and damage reports, not including vulnerability characteristics. Nowadays, the wide distribution of accelerometer stations allows reliable estimation of ground motion intensities at most of the bridge locations, this info can be used to predict damaged bridges and improve efficiency in bridge inspection prioritization.

LIS-UCR accelerometer distribution in the National territory. 20 stations more will be installed close to important bridges or low coverage areas



Methodology

The protocol consists of the development of procedures, databases, activities and inspection formularies in 3 steps (fig. 1):
1) Pre-event: Activities include definition of bridge vulnerability, damage characterization, inventory, development of inspection formularies (training), bridge importance definition (fig. 2), validation, and diffusion (National Emergency Agency, Local Gov.)
2) Emergency: Seismic acceleration data arrival from LIS Network, computation and deliver prioritization list for probable damaged bridges and bridge importance information. Local Government or Emergency committees perform basic safety inspections.
3) Post-event: Bridge condition inspection or detailed inspection if required by structural engineers, protocol calibration activities.

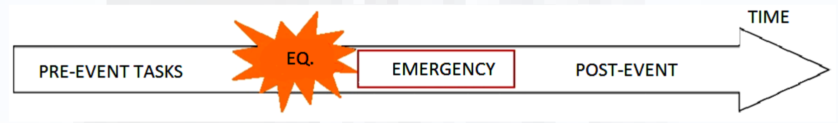


Figure 1. Seismic Emergency activity sequence as defined in the proposal

Current Results

Current results include: estimation of seismic vulnerability of bridge structures by means of fragility curves, the development of a bridge inventory including exact location of bridges and verification of the data, the elaboration of inspection formularies for seismic damage characterization and different assessment levels, the relevance determination of bridges (fig. 2). Currently, the calibration of the proposal with the data collected for the Samara Earthquake is carried out. Diffusion and training activities are programmed for next year.

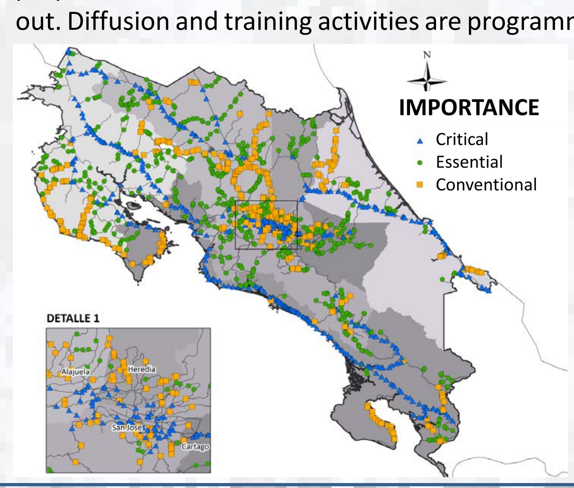


Figure 2. Economic and logistic importance determination for bridges in the National Road Network (total 1440 units)

LAHAR HAZARD MODEL FOR RECENT TURRIALBA VOLCANO ERUPTIONS

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Objectives

The main objective of this study is to evaluate the lahar potential to reach bridge structures in the National Road Network. Further objectives are:
- Use and calibration of the USGS LAHARZ procedure for estimation of the lahar`s potential
- Raise public awareness of lahar as an event that can affect bridge structures

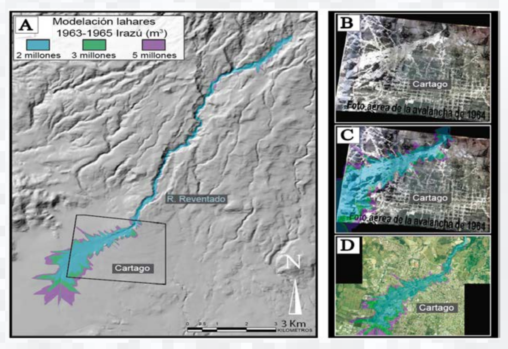
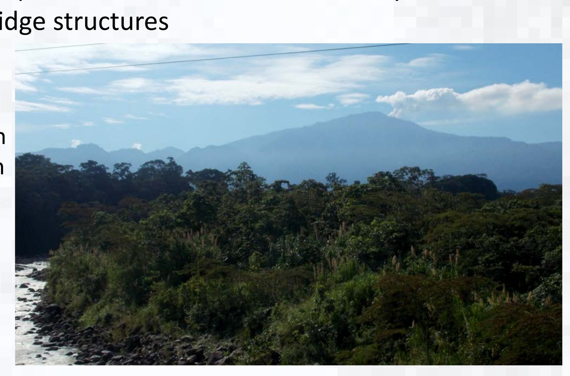


Figure 1.LAHARZ calibration for expected volume of material by analysis of 1963 Irazú Volcano lahar event

Introduction

Lahar risk is not new in Costa Rica, a lahar in 1963, during the Irazú Volcano eruptions, destroyed more than 300 houses and caused 20 fatalities close to the city of Cartago. Recently, lahars triggered by the 2009 Chichona (6.2 M_w) earthquake on the north flange of Poás Volcano produced heavy damage. Since 2011, the Turrialba Volcano is increasing its activity. This year only, the consequence of these eruptions brought disruption in several occasions to the main airport in the country and had constantly raised alerts in the areas adjacent to the volcano. Due to the past experience and the actual volcanic activity, this study was performed to estimate how likely is for a lahar to reach important bridge structures

Turrialba volcano eruption during a bridge inspection at the Toro Amarillo river, Guápiles, Limón 11.2014



Calibration and Results

In order to attain reliable outcomes, the LAHARZ parameters were obtained by calibration of results with the 1963 Irazú Volcano lahars event in order to estimate adequate possible lahar material events. Comparison of GIS results and 1963 event aerial photos is shown in fig. 1. LAHARZ main variables are computed from the topographic model and the expected volume so, with the Irazú data, results can be estimated for the Turrialba volcano, taking into account that both volcanoes share similar characteristics. The position of the lahar`s ignition point is triggered by a topographic condition algorithm. In fig. 2, results for a 2, 3 and 5 million m^3 of material events are shown. For a 5 million m^3 event, the lahar is estimated to reach 41 bridges, 12 of them on the principal communication roads to the Caribbean coast.

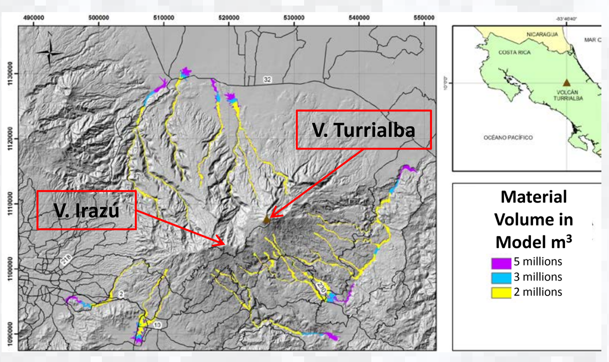


Figure 2. GIS results for 2, 3, and 5 million m^3 events

METHOD FOR VULNERABILITY ASSESSMENT OF CULVERT STRUCTURES

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Objectives

To develop a vulnerability assessment method for culvert structures. Other objectives include:
- Evaluation of structural vulnerability
- Evaluation of site conditions vulnerability
- Provide an evaluation method for government authorities

Introduction

Both natural and anthropological causes had increased the culvert risk to fail during heavy rain periods. Traffic disruptions due to overtopping, embankment erosion or culvert damage is common in the Costa Rican National Road Network. In particular for urban areas, the impermeabilization of terrains by new urban developments, the reduction of the creek hydraulic section and the waste accumulation are important aspects that increment the vulnerability to suffer damage. Due to this fact, a methodology is presented here for the assessment of culvert structures. The proposed method was applied for 27 important culvert structures located in the main urban developed area of the country.

Culvert overtopping in Maria Aguilar river and land use change comparison for San José city center

Methodology

The method for vulnerability condition assessment focuses on two main aspects: the site condition and the structural vulnerability. Under these two main features other variables are considered and evaluated according to a weighing factor. Aspects considered are:
- Site Condition: Average daily transit, flood historical records, creek basin, water entrance angle, foundation terrain properties, obstructions and material in the nearby basin slopes
- Structure vulnerability: Culvert windwalls, headwalls, floor slab, curtain and the road embankment over the culvert

The total vulnerability condition is calculated for ranges of 0-25 Low, 26-50 Moderate, 51-75 High and 76-100 Very High. The structural vulnerability is 40% and site conditions are 60% of the total weight.

Results

The culvert vulnerability assessment results are shown in fig. 1 for the 27 analyzed structures. This Outcome concludes that more than 50% of the analyzed structures presented High or Very High vulnerability to experience damage or service disruptions if actual conditions are maintained. Recommendations were presented to the National Road Administration and local governments to mitigate vulnerable aspects.

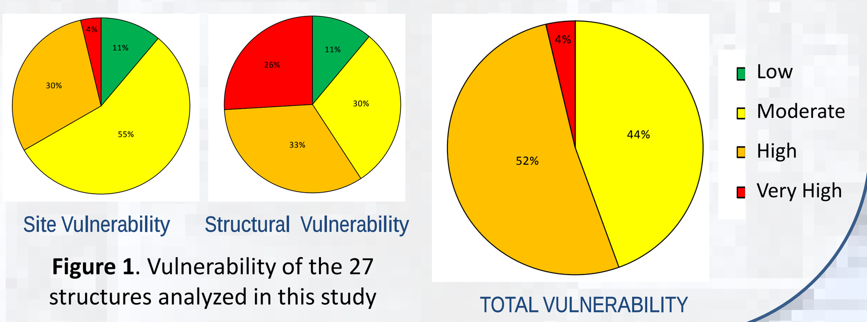


Figure 1. Vulnerability of the 27 structures analyzed in this study

OTHER RESEARCH INTERESTS

According to previous damage experience in Costa Rica, research in the area of natural hazards in the Bridge Unit is intended to intensify in:

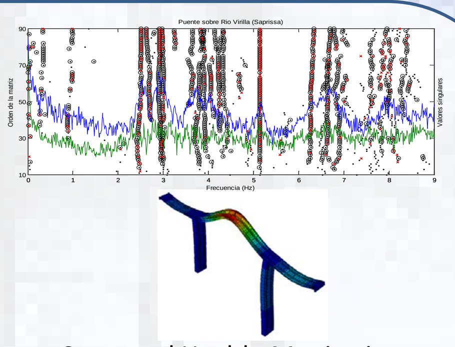
- Assessment of bridge substructures structural vulnerability to seismic liquefaction hazard
- Vulnerability of bridge substructures to scour damage (suitable assessment procedure to be applied to the National Road Network and unknown foundation inspection methods)

Severe scour damage at Turrialba river bridge (07/2015) and liquefaction damage in the 1991 Limón earthquake

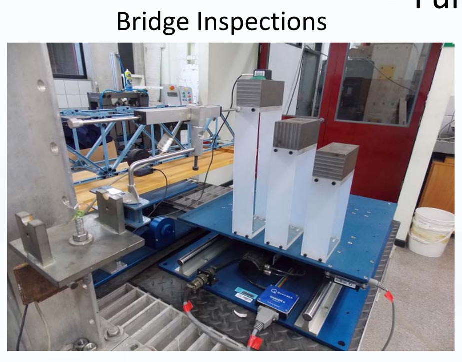
BRIDGE UNIT TEAM AND FURTHER ACTIVITIES

Bridge Inspections

Further activities of the Bridge Unit include:
- Bridge inspections: inventory, condition and detailed
- Structural health monitoring and structural analysis
- Educational: bridge contest and lab. testing, academic shaking table.
- Full scale test of bridge components



Structural Health Monitoring



Small Scale Shaking Table Test

Bridge Unit Team

Current Full Scale Bridge Component Test