Probabilistic Seismic Loss Assessment of Retrofitted Public Schools and Modern Buildings in Peru

Dr. Sandra Santa Cruz

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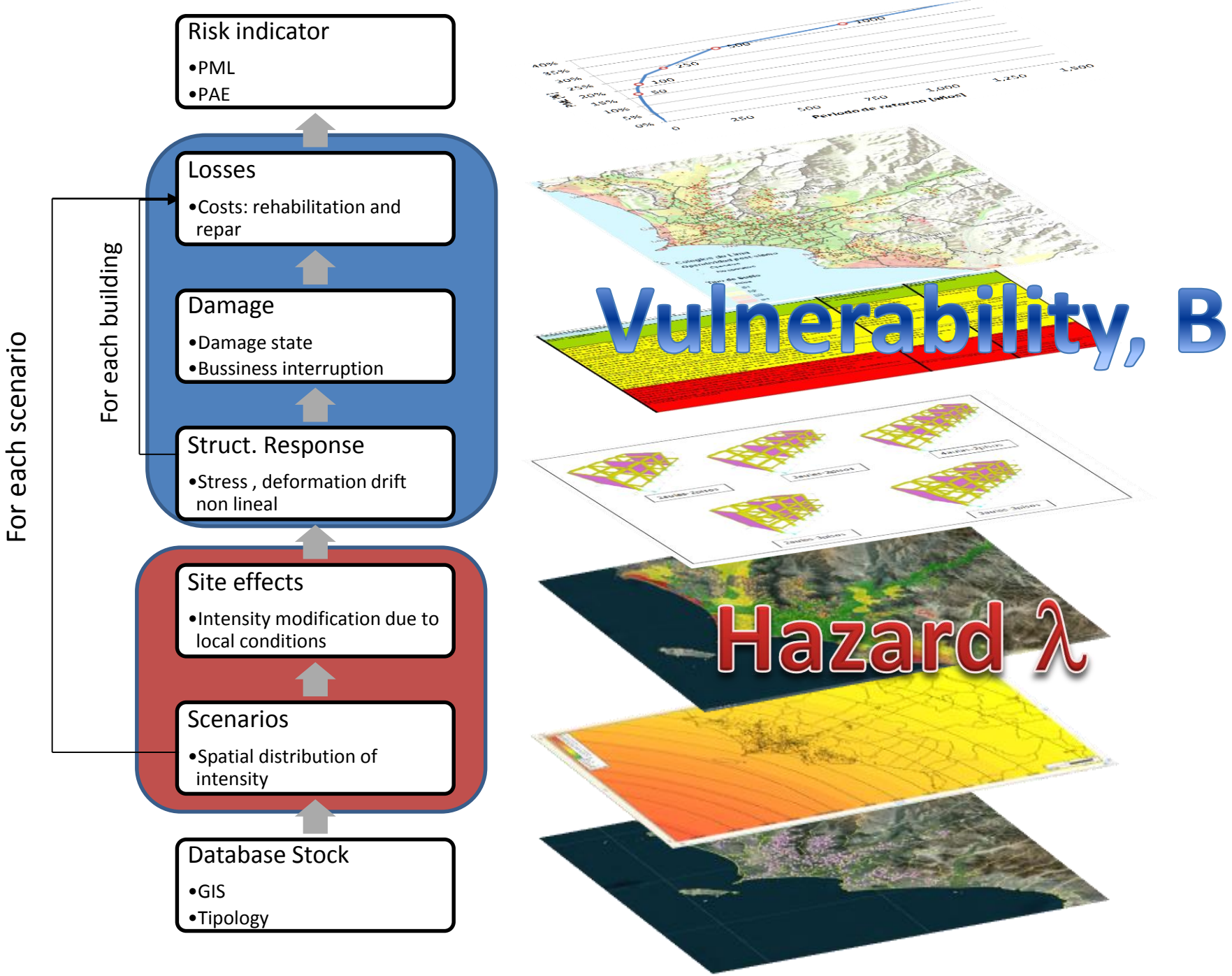
CIENCIACTIVA
Becas y Co-financiamiento de Concytec

Disaster Risk Management Group for Low-Cost Public Facilities and Housing (GERDIS)

PONTIFICIA UNIVERSIDAD CATÓLICA DEL PERÚ

GERDIS-PUCP has focus on public seismic loss assessment of public infrastructure and low-cost housing since 2014 with the financial support of CIENCIACTIVA and DGI-PUCP

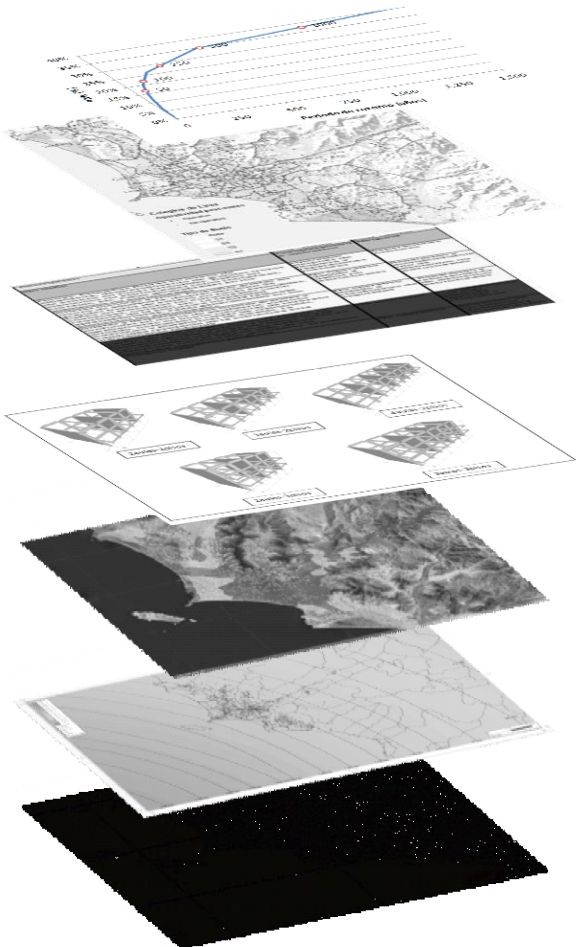
Typical Building	Posible Damage in Past Events	Exposure
 School built before 1997	  Short column failure	School buildings built before 1997 Costa 10 262 Sierra 22 954 Selva 7 101 Total 40 317 *Fuente: MINEDU- 2003* 12000 edificios tipo 780 Pre
 Low-cost departments and houses	 Non ductile failure	There is no available statistics


Risk indicator
•PML
•PAE
Losses
•Costs: rehabilitation and repar
Damage
•Damage state
•Bussiness interruption
Struct. Response
•Stress , deformation drift non lineal
Site effects
•Intensity modification due to local conditions
Scenarios
•Spatial distribution of intensity
Database Stock
•GIS
•Tipology
For each building
For each scenario
Vulnerability, B
Hazard λ

Probabilistic approach

Risk indicator

- PML
- PAE



Expected annual loss, PAE and Probable maximun loss, PML associated to a return period, *Tr*

$$PAE = \sum_{i=1}^{Nf} \int_{Moi}^{Mui} -\frac{d\lambda_i}{dM} E\left[B_j / M, Ri\right] dM$$

Hazard

Vulnerability

$$\frac{1}{Tr} = \nu(PML) = \sum_{i=i}^{Nf} \int_{Moi}^{Mui} -\frac{d\lambda i}{dM} \Pr(B > PML / M, Ri) dM$$

Probabilistic evaluation of seismic risk of schools in the city of Lima

Objectives:
To estimate probable losses in education infrastructure

Sandra Santa Cruz, Juan Palomino

Partially founded by World Bank

A-PRE-B

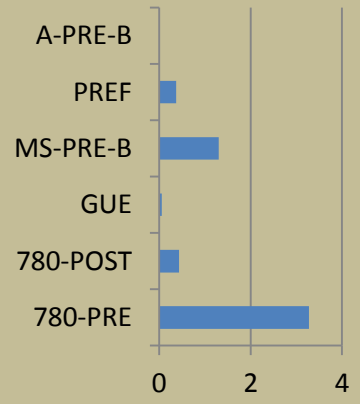
PREF

MS-PRE-B

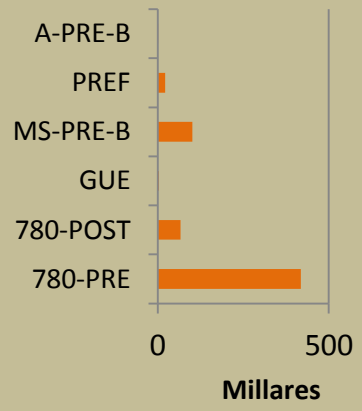
GUE

780-POST

780-PRE

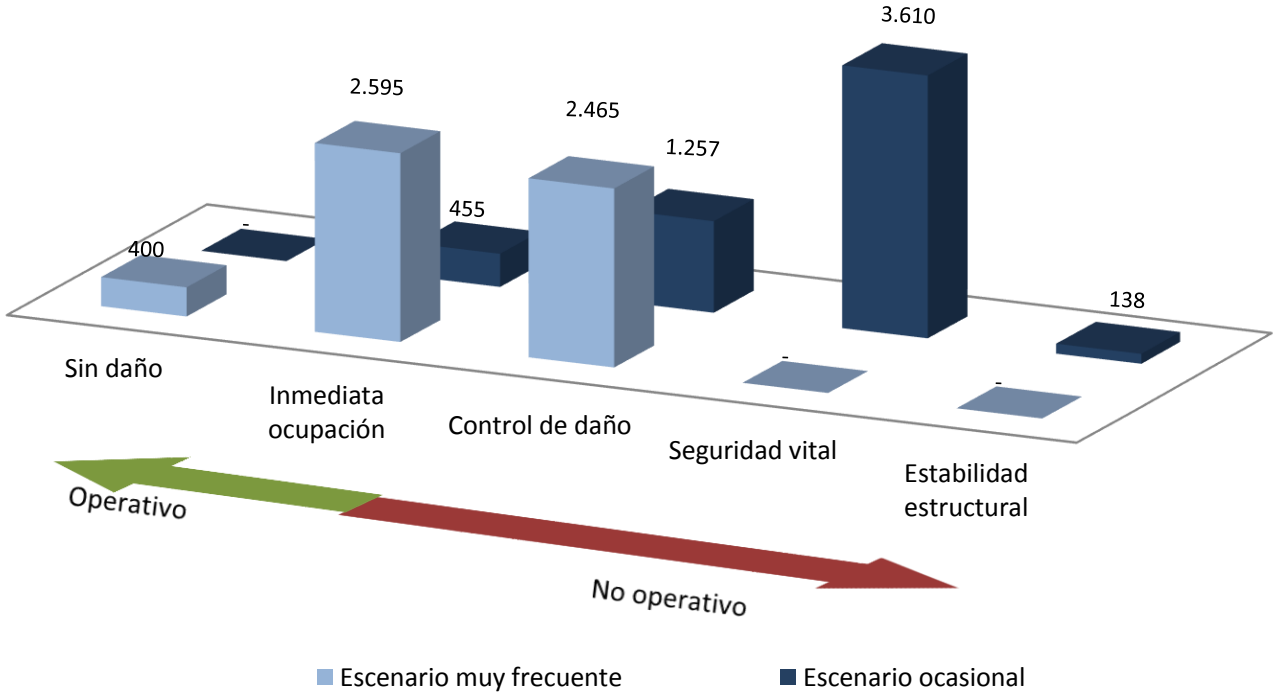


Número de edificaciones



Número de alumnos

After an occasional event, (similar to Pisco, 2007) 92% of schools will be non –operative



Escenario	Intensidad en la Ciudad de Lima (PGA en gals)	Periodo de retorno
Muy frecuente	70-100	10 años
Ocasional	200-250	75 años

Most of the schools are in high risk due to its structural system

Tipo	Valor de Reposición (millones de nuevos soles)	% del total	PAE (miles de nuevos soles)	% del total	PAE promedio (al millar)
A-PRE-B	S/. 5	0%	S/. 223	0%	49.4
GUE	S/. 17	1%	S/. 812	2%	47.3
MS-PRE-B	S/. 255	18%	S/. 11,181	24%	43.9
POST-780	S/. 152	11%	S/. 239	1%	1.6
PRE-780	S/. 937	66%	S/. 32,703	70%	34.9
PREF-PRE-B	S/. 47	3%	S/. 1,431	3%	30.2
TOTAL	**S/. 1,413**	100%	**S/. 46,590**	100%	33.0

Zona	POST	PRE	GUE	MS-PRE-B	A-PRE-B	PREF-PRE-B
I	1.2	30.7	38.6	38.0	49.4	27.7
II	2.0	40.7	53.4	49.7	-	32.7
III-IV	3.2	53.3	72.7	66.1	-	38.0

PROPOSED UPDATE TO THE NATIONAL BUILDING REGULATION TO INCORPORATE INCREMENTAL RETROFITTING TO SCHOOL INFRASTRUCTURE TYPE 780 BUILT BEFORE 1997

Objectives:

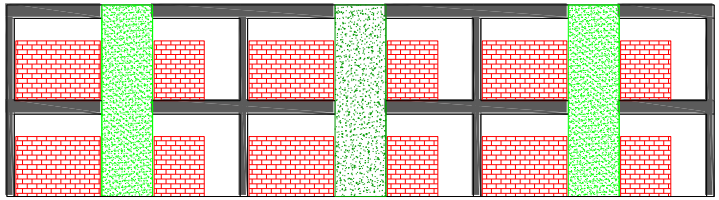
- Performance evaluation of three retrofitting options
- Guidelines for analysis, design and construction of thrre retrofitting options

Team PUCP: Alejandro Muñoz, Sandra Santa Cruz, Nicola Tarque, Gladys Villa García, Gustavo Loa, Pamela Ramírez.
Team UNI: Carlos Zavala, Miguel Diaz, Miguel Estrada, Mary Criss Suarez

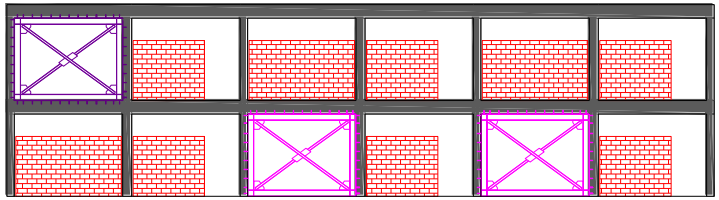
Partially founded by World Bank and CIENCIACTIVA. Universidad de los Andes

Three incremental retrofitting projects were analyzed

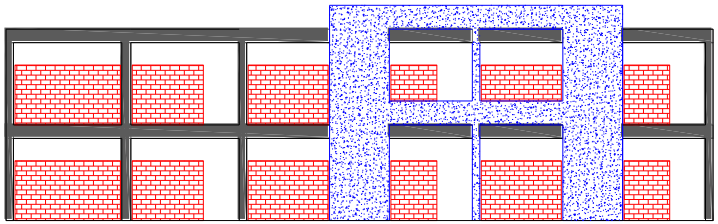
MARM

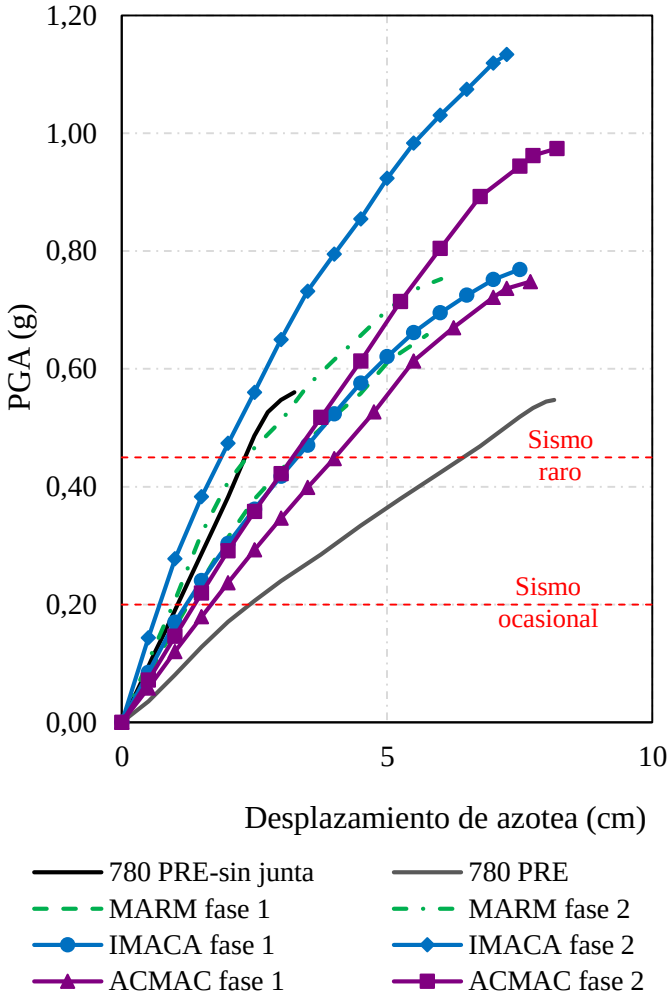


ACMAC



IMACA

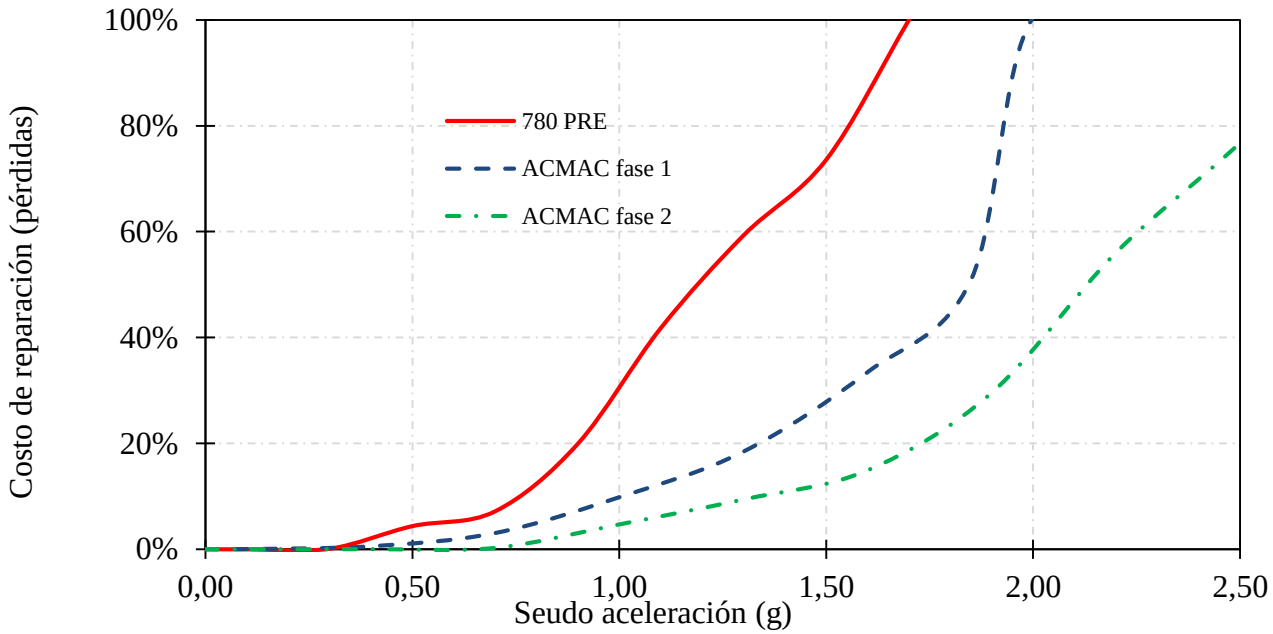




Performance objectives for two phases of intervention

Tipo 780 Pre Estructura esencial		Estado de daño				
		Operacional	Funcional	Seguridad de vida	Prevención al colapso	Colapso
Nivel de intensidad sísmica	Sismo ocasional TR = 75 años PGA = 0.20 g	2	1			
	Sismo raro TR = 450 años PGA = 0.45 g		2	1		

Expected losses are reduced in moderate to severe earthquakes

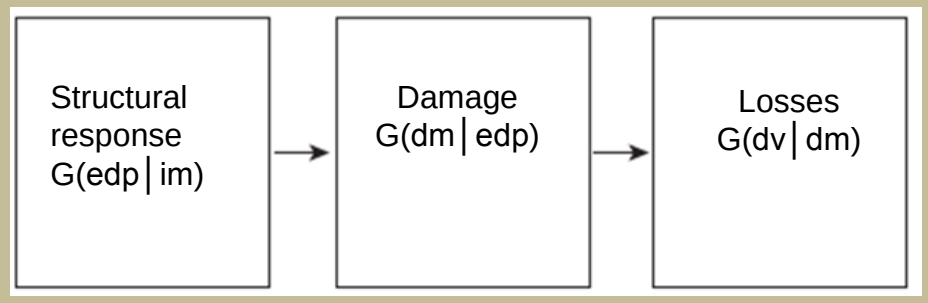


Seismic performance analysis of typical school buildings built after 1997

Objectives:
To estimate the vulnerability function of typical public school buildings in Peru built after 1997

Paper presented in 16WCEE Jan 2017 Santiago de Chile

Sandra Santa Cruz, Nicola Tarque, Mauro Niño, Roberto Chacón e Israel Paz



$$E[dv|im] = \int_{edp} E[dv|edp]dG(edp|im)$$

Losses were estimated from repair cost of concrete and masonry elements

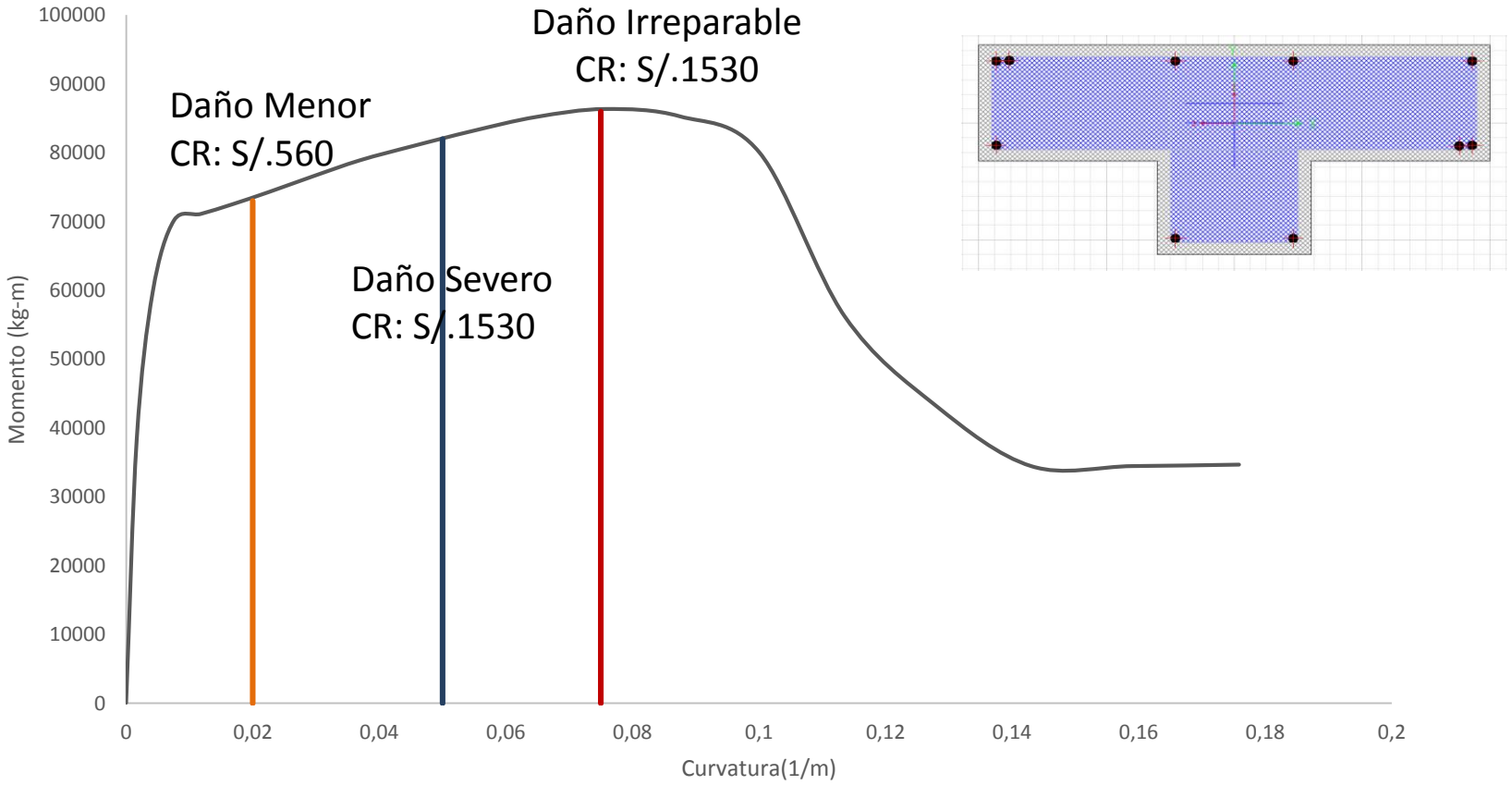
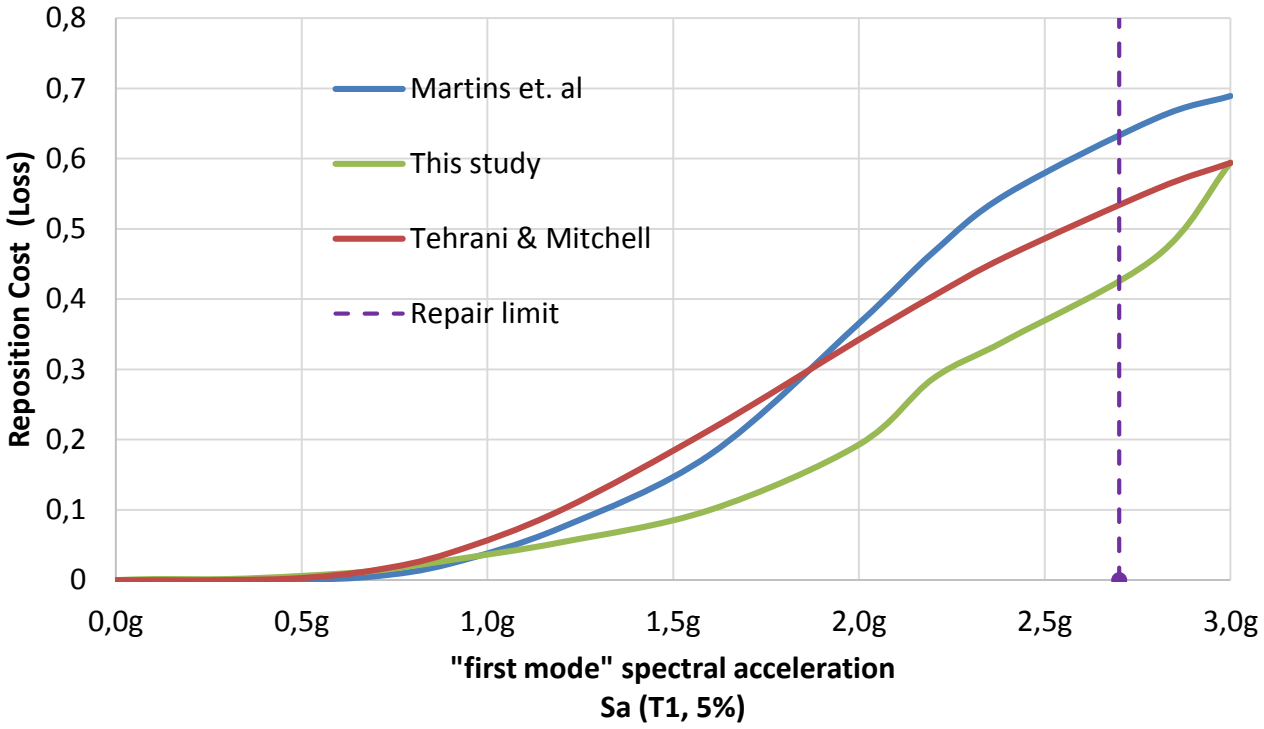


Diagrama momento curvatura de la columna T

CR: Costo de Reparación

Vulnerability function

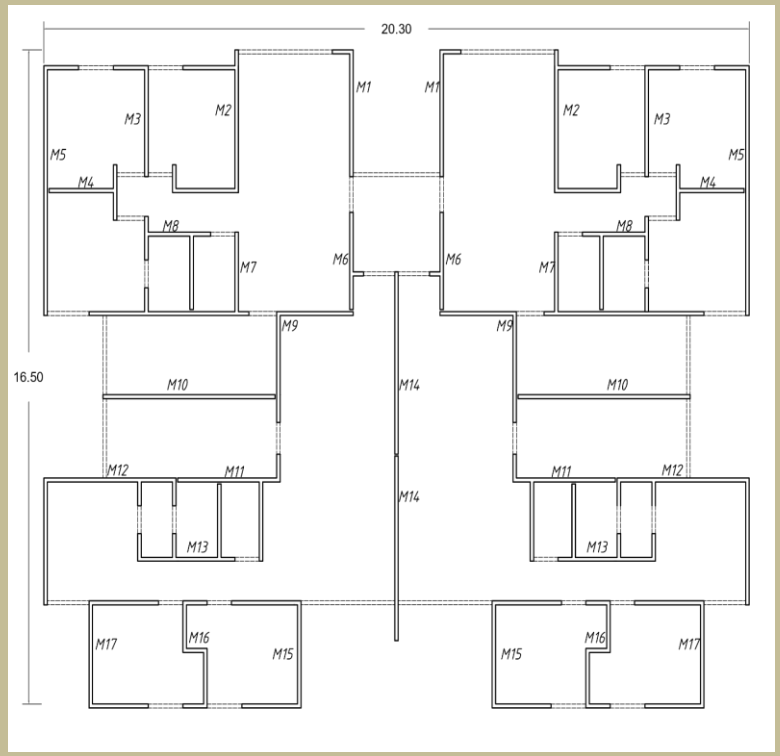


Seismic vulnerability of building with walls with limited ductility en the coast of Peru

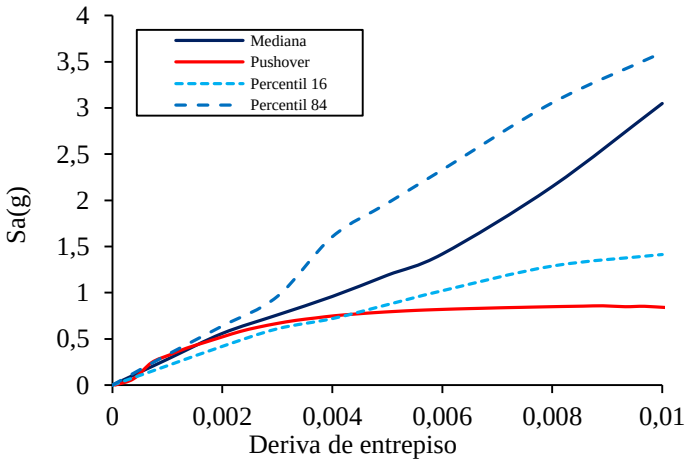
Objectives:

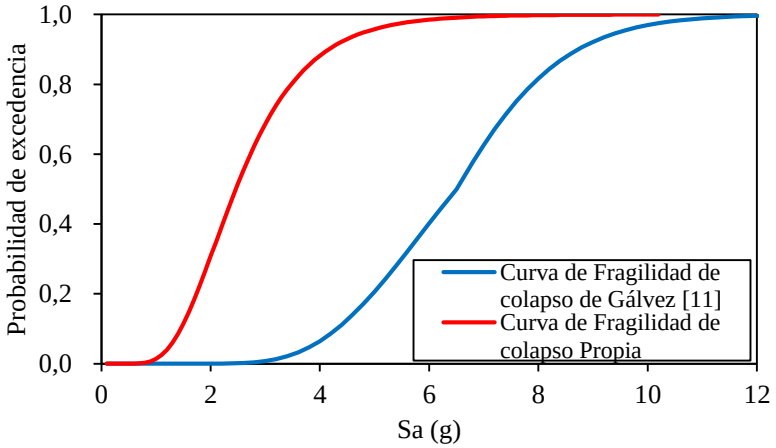
Performance evaluation of building based on thin shear walls (limited ductility shear walls)

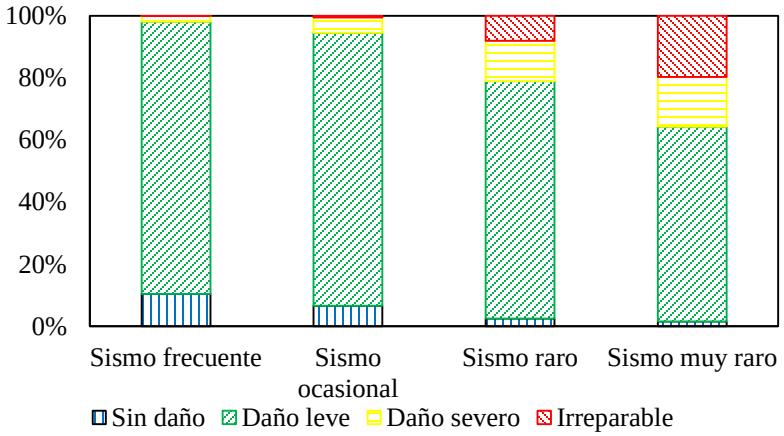
Alejandro Muñoz, Sandra Santa Cruz, César Reyes

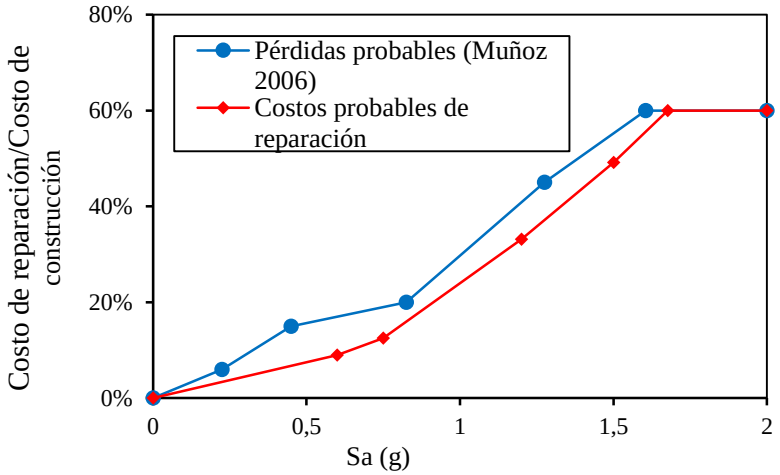


Expected loss for a occasional event is 10% and 20% for rare event









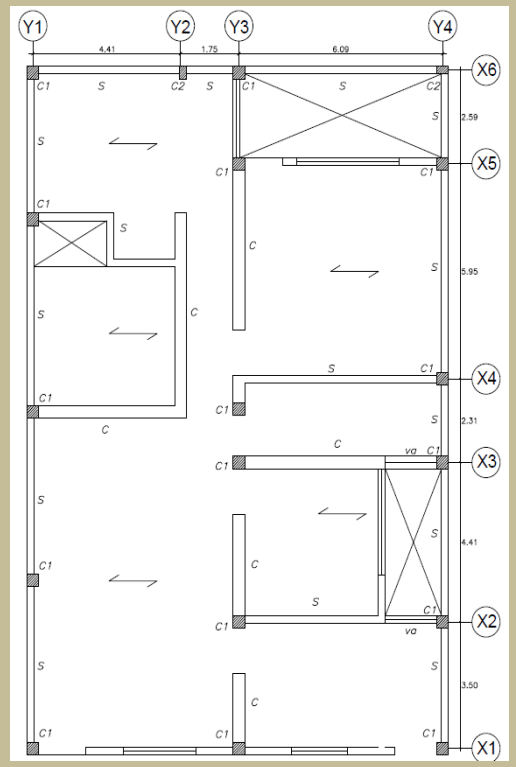
Simplified evaluation of vulnerability functions of confined masonry houses self-built in Lima

Objectives:

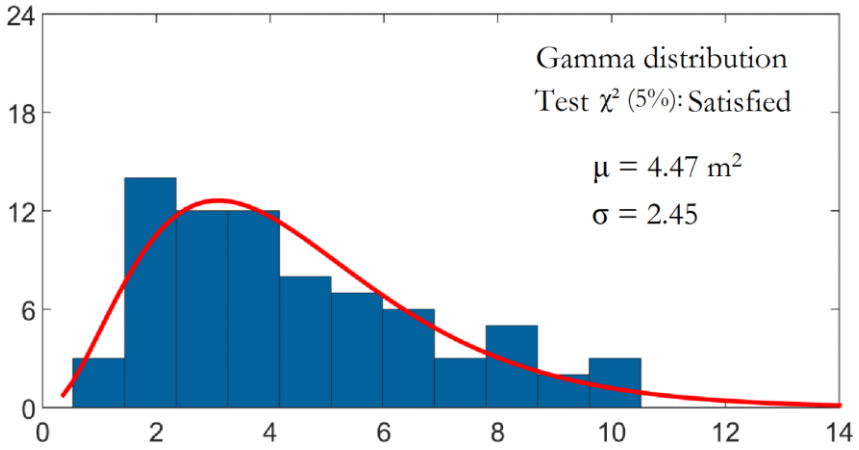
Performance evaluation of self-built Confined Masonry houses

Nicola Tarque, Holger Lovón

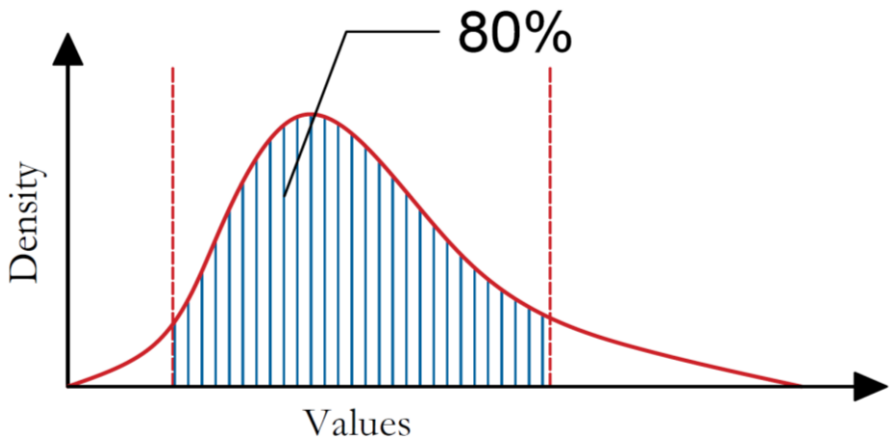
Partially founded by CIENCIACTIVA



We use a probabilistic model to characterize the number of walls in buildings



Área de muros confinados en la dirección: Y-Y



Porcentaje de probabilidad que cubre el truncamiento

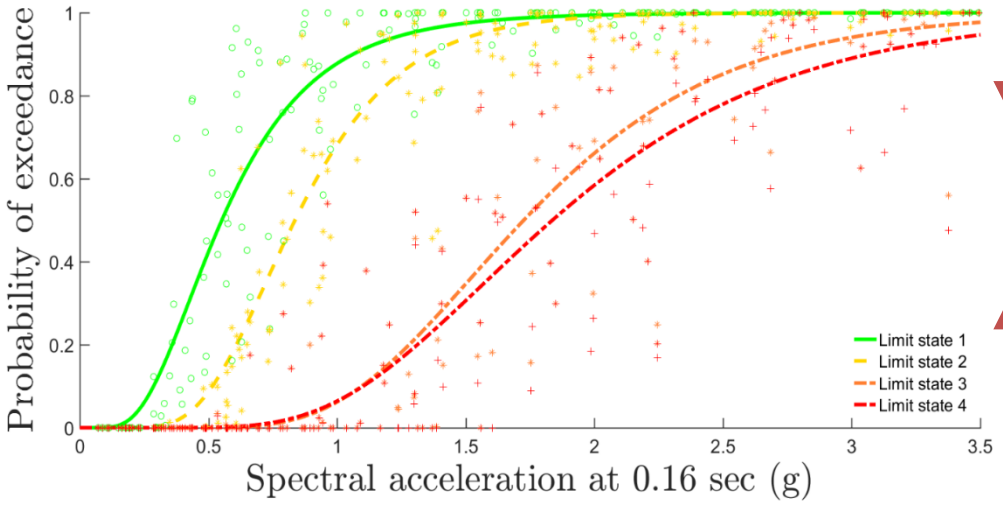
Las funciones de probabilidad deben ser truncadas con el fin de evitar valores improbables, o que no representen la población estudiada.

De acuerdo a la actividad sísmica en la costa del Perú, un sismo “raro” tiene una intensidad de 1.125g Sa

Para esta intensidad se interpretarán los resultados:

Curvas de fragilidad en Sa para viviendas de 1 piso

R^2=0.93

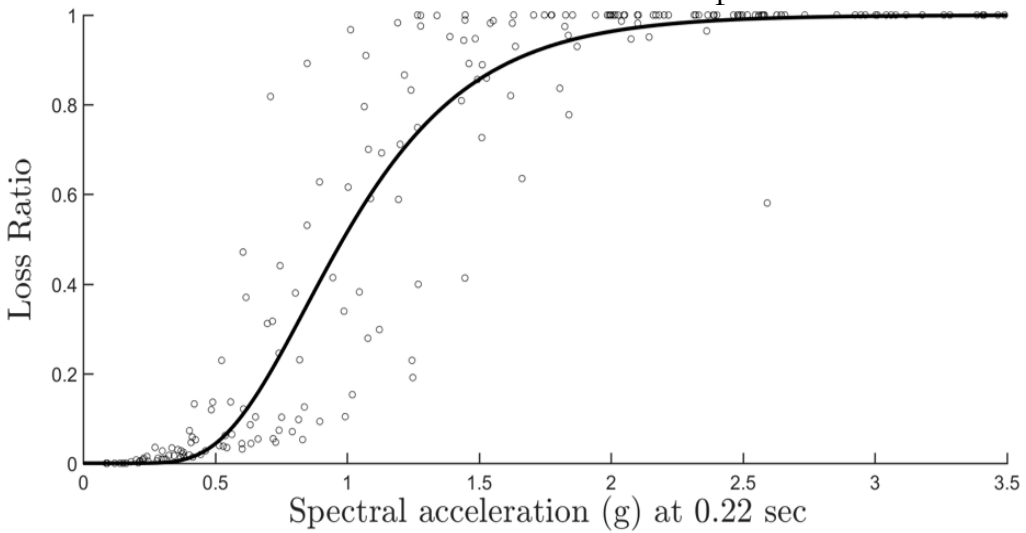


- 11% de viviendas en colapso
- 0 % de viviendas en estado de daño 3
- 12 % de viviendas en estado de daño 2
- 60 % de viviendas en estado de daño 1
- 17 % de viviendas sin daño

De acuerdo a la actividad sísmica en la costa del Perú, un sismo “raro” tiene una intensidad de 1.125g Sa

Para esta intensidad se interpretarán los resultados:

Curvas de vulnerabilidad para viviendas de albañilería confinada de 2 pisos



Se espera 72% de ratio de daño. Esto significa que el costo de reposición de las viviendas de albañilería confinada autoconstruidas de 2 pisos será aproximadamente el 72% del costo original.

QUANTIFICATION OF LOST MATERIAL STOCK IN BUILDINGS AFTER AN EARTHQUAKE - A CASE STUDY OF CHICLAYO, PERU

Objectives:

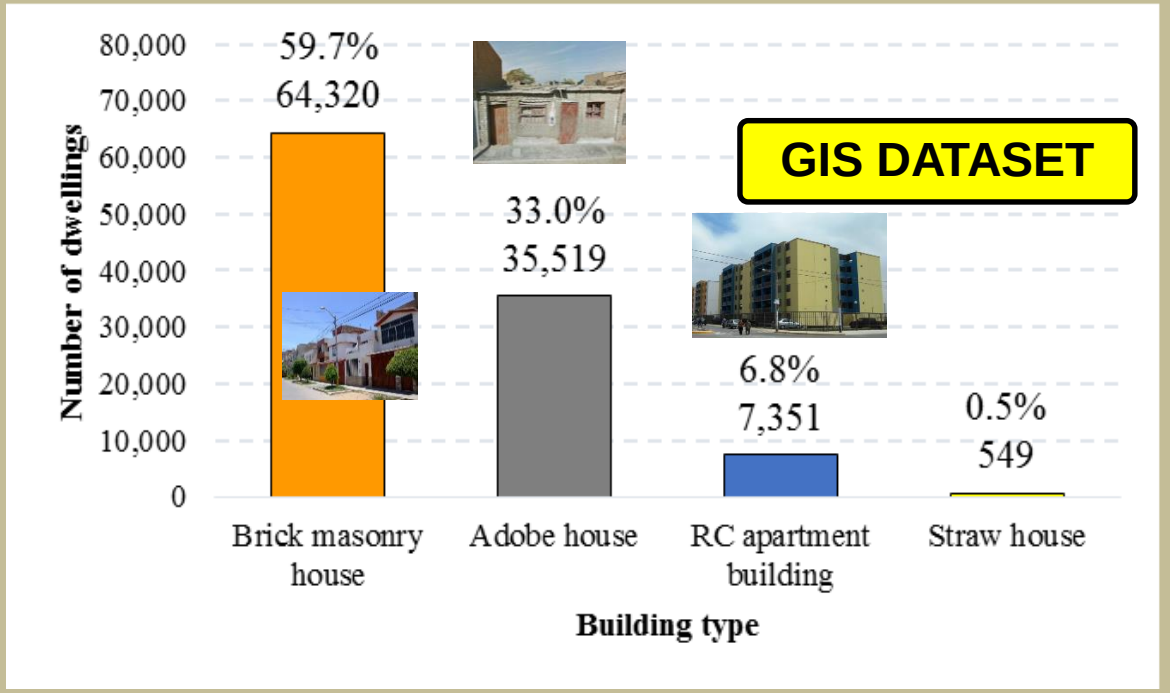
1. Classify the building inventory
2. Calculate the building material stock
3. Asses the seismic risk of the buildings
4. Estimate the material losses in the city

Ramzy Kahhat, Sandra Santa Cruz, Carlos Mesta

Partially founded by CIENCIACTIVA

Type of dwelling

Predominant material on walls



Building types in Chiclayo city (INEI, 2007)

The material stock (MS) in buildings is calculated using a bottom-up approach

NUMBER OF DWELLINGS

- ✓ Census statistics for housing

✖

GROSS FLOOR AREA (m^2)

- ✓ Cadastral maps
- ✓ Google Street View tool

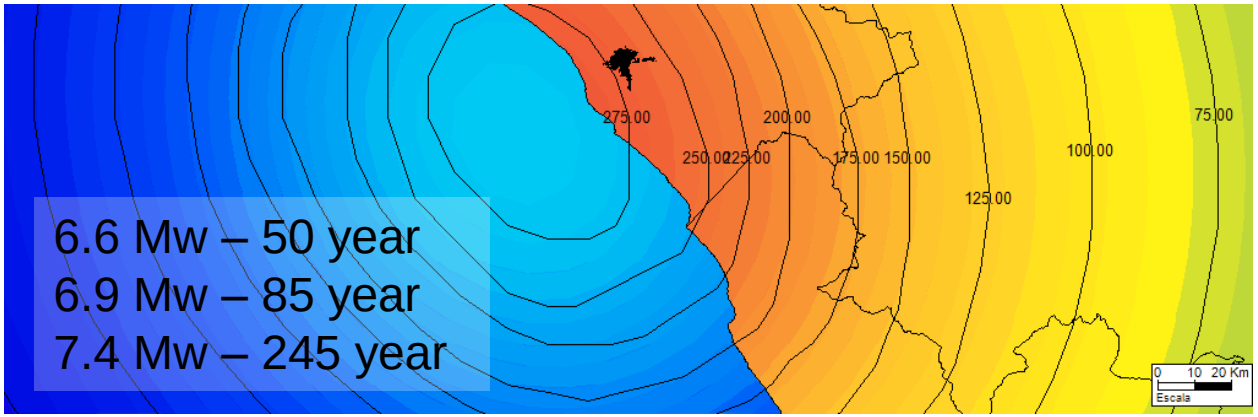
✖

MATERIAL INTENSITIES (kg/m^2)

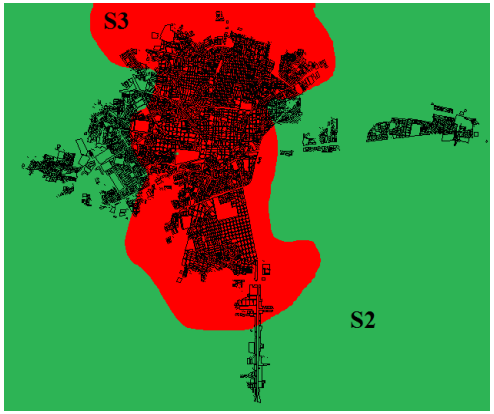
- ✓ Construction plans & budgets
- ✓ On-site investigation
- ✓ Expert opinion
- ✓ Literature

= **MATERIAL STOCK IN BUILDINGS (kg)**

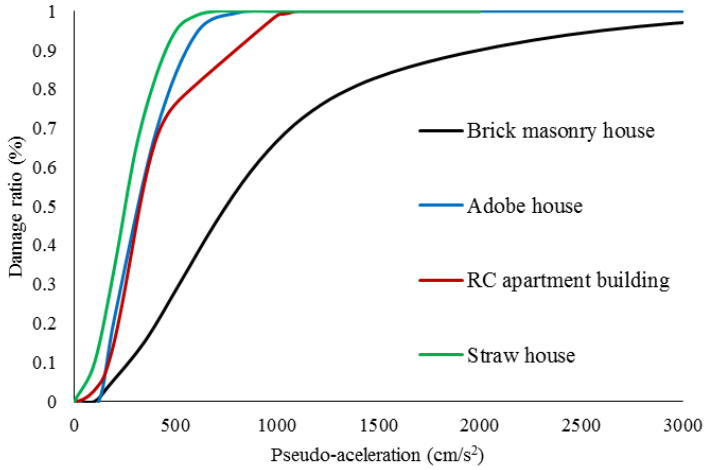
The seismic risk assesment is performed using CAPRA-GIS, in order to estimate the structural damage of the buildings



Seismic scenarios (IGP, 2013)



Soil types (INDECI, 2003)



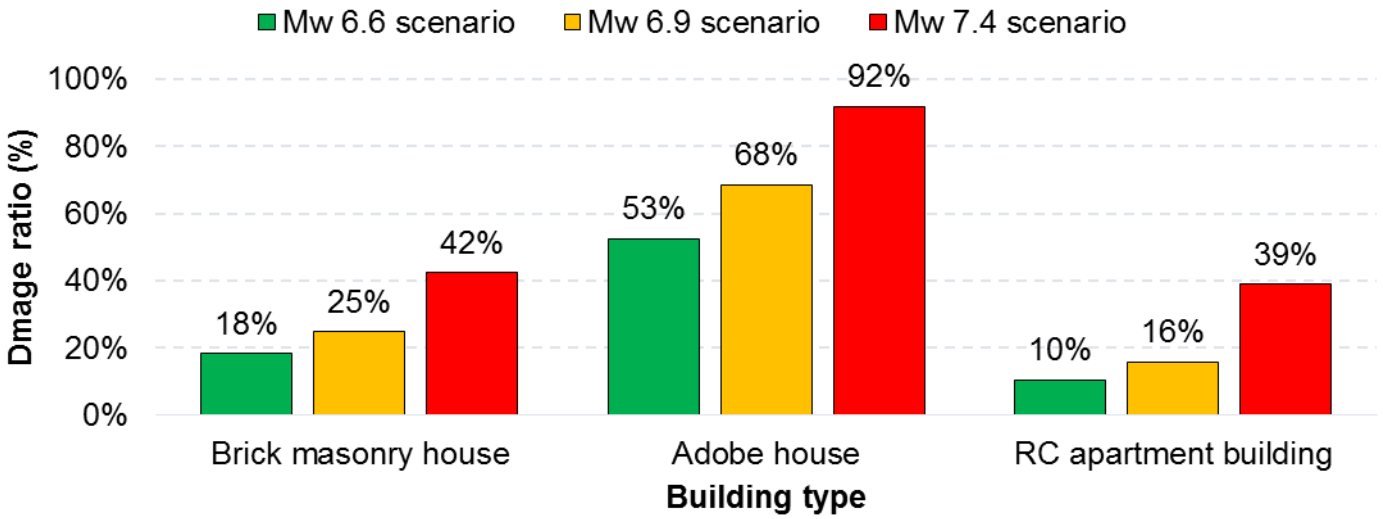
Vulnerability functions (PUCP, 2014)

CAPRA
Probabilistic Risk Assessment Program

DAMAGE RATIO

Slight	: 0% - 5%
Moderate	: 5% - 25%
Extensive	: 25% - 65%
Complete	: 65% - 100%

The seismic risk assessment resulted in values of damage ratio by building type and seismic scenario



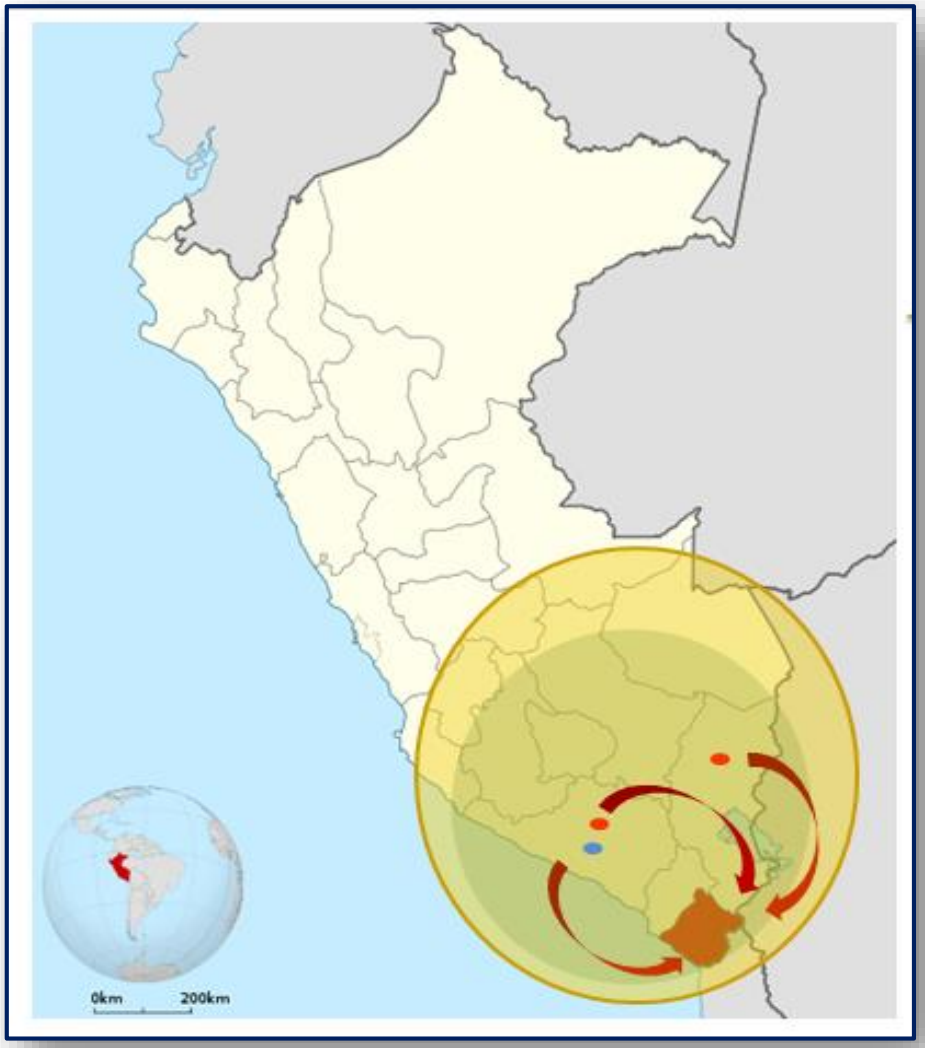
Average values of damage ratio by building type and scenario

DEVELOPMENT OF A METHODOLOGY TO CHARACTERIZE AND QUANTIFY DEBRIS GENERATION AFTER A SEISMIC EVENT: A CASE STUDY OF TACNA, PERÚ

Objectives:

Ramzy Kahhat, Sandra Santa Cruz, Samy García

Partially founded by CIENCIACTIVA



Distribution of materials from other regions to Tacna

Domestic Importation of construction materials from production location to Tacna

"Cementera YURA"

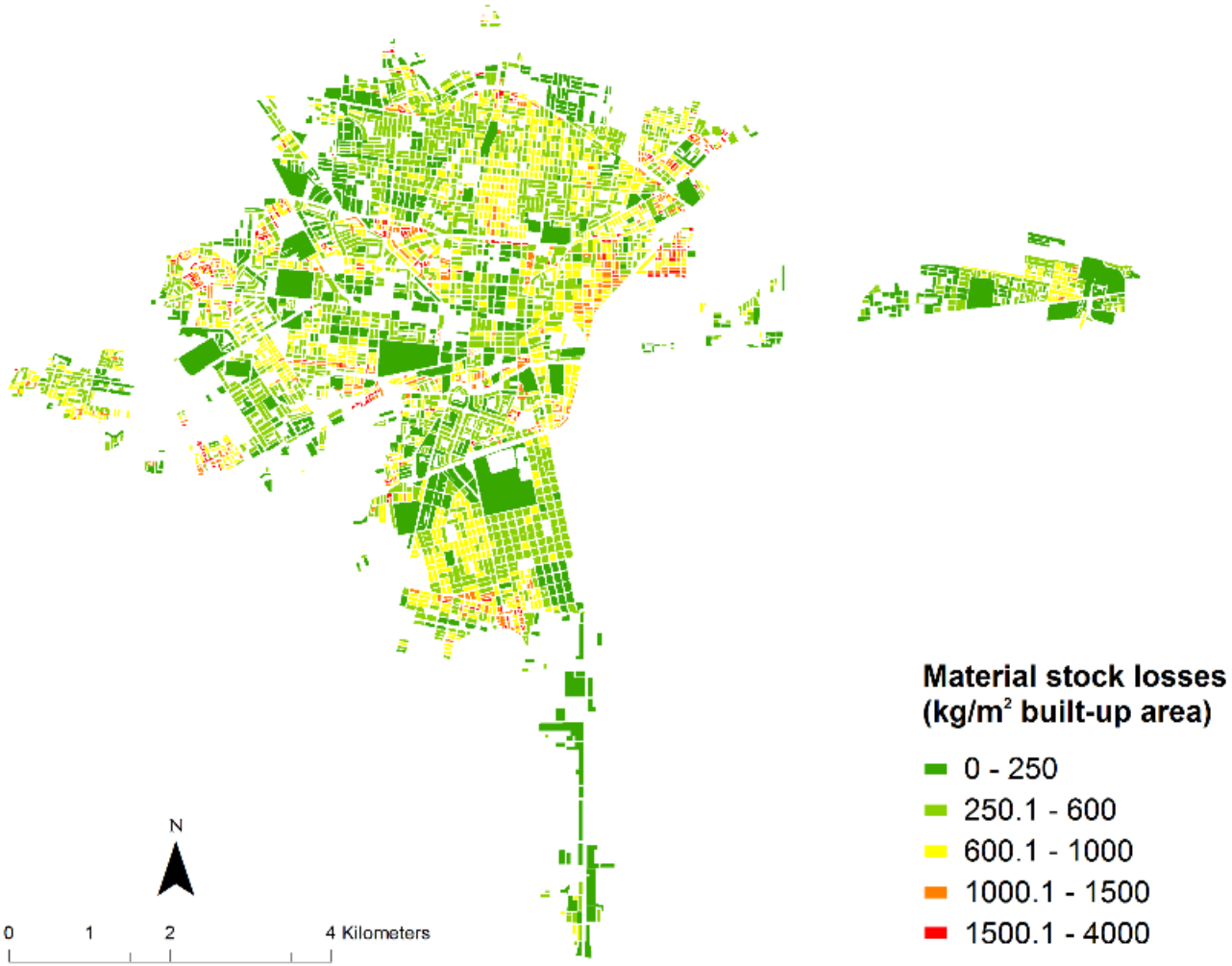
" Aceros Arequipa"

Maximum annual production of material

5600000 Ton. "Cementera YURA"

1259500 Ton. " Aceros Arequipa"

The most affected zones trought the city due the concentration of debris can be identified on the map



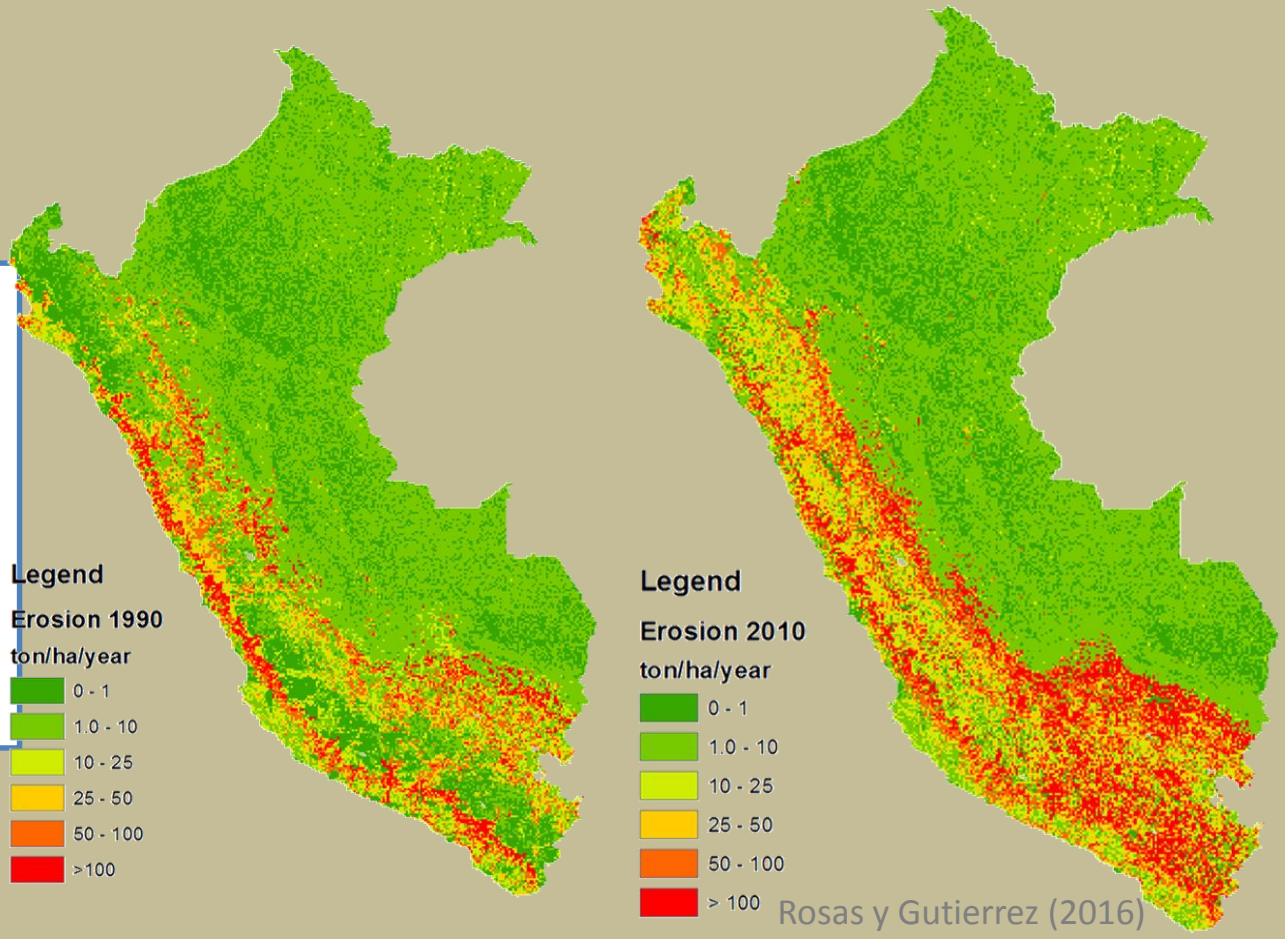
Spatial distribution of MS losses for Mw 7.4 scenario

Quantification of hidric erosion in Peru and its enviromental costs

Objectives:

Ronald Gutierrez, Miluska Rosas

Partially founded by CIENCIACTIVA

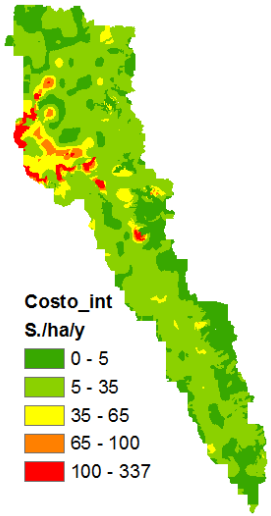


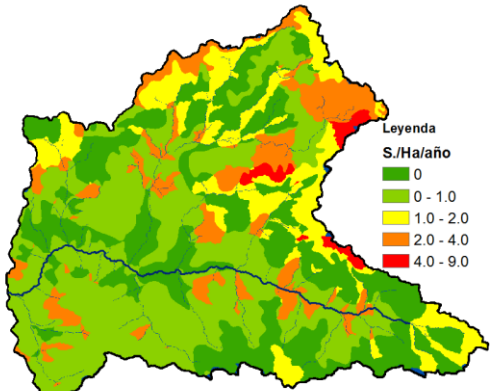
Rosas y Gutierrez (2016)

Las pérdidas económicas por erosión de suelos

- **Off-site:** cuantificación económica de movimiento de tierras
  - Excavación del material: 1.35 $ / m^3
  - Transporte de material: 3.0 $ / m^3
- **On-site:** costo de la pérdida de K y P en función al costo del fertilizante.

CUENCA	Costo ON-site $USD / año	Costo OFF-site $USD / año	Costo Total $USD / año	Costo unitario $USD/ Ha/año
Río Santa	5.2 x 10^6	7.2 x 10^6	**12.4 x 10^6**	11.9
Río Jequetepeque	0.12 x 10^6	427.2 x 10^6	**427.3 x 10^6**	1 288





Conclusions

- We have obtained vulnerability functions for public schools, retrofitted schools and low-cost houses and departments.
- For an rare event Sa 1.125g
  - Modern schools 7.5%
  - Retrofitted schools (first stage) 9.8%
  - Schools pre 1997 41%
  - Limited ductility shear walls 21%
  - Masonry houses 72%

- Expected anual losses in retrofitted schools pre 1997 could be reduced from 3% to 0.16% approximately
- CAPRA software was used to estimate losses and debris due to earthquakes.
- Erosion generates losses up to 1 288 $USD/ Ha/year

Thank you