NICHOLAS AMBRASEYS
MEMORIAL SYMPOSIUM

His influence on our work in the field of Earthquake Engineering

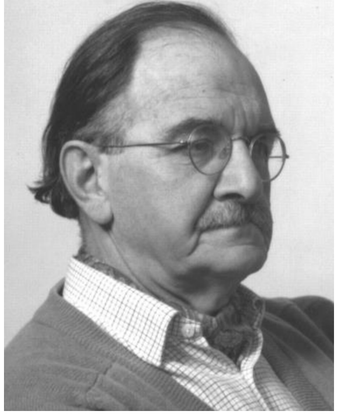
Kypros Pilakoutas

Professor of Construction Innovation

At IC 81-84 BSc, 86-91 PhD, Postdoc

The University Of Sheffield.

Five Adjectives



- **Inspirational**
- **Metoikos***
- **Thinker***
- **Efficient**
- **Pioneering/Innovative**

Why we are here

On Life & who we are

Scholarship/Ethos

Legacy

Out of the box

- *Gentleman**
- *Intelligent*
- *Peaceful*
- *Compassionate*
- *Gentle*

- *Successful*
- *Friendly*
- *Peaceful*
- *Patient*
- *Practical*

- *Famous*
- *Stubborn*
- *Open minded*
- *Impatient*
- *Straightforward*

The University Of Sheffield.

Legacy

Earthquake Engineering Group in Sheffield

Academics:

K Pilakoutas, M Petkovski, I., **Hajirasouliha,** Dr Zuhal Ozdemir and **M. Guadagnini**

PhD Researchers (*Grand-students!*):

Earthquake Engineers

M Frangou, S Kythreoti, N Kyriakides, P Papastergiou, S. Khan, S Ahmad, A Bagheri, R Garcia Lopez, Y Helal, Y Jemma, R Mulyani, R Ahmadi, Y Eljajeh, H C Quintana, W Q Mahdi

Others on FRP, FRC, Concrete and Innovations

27 Completed

The University Of Sheffield.

My Journey

Shake-table tests 1987

Imperial

- Earthquake Prediction!!!! (BSc project)
- Seismic Resistance of RC Walls (PhD)

Sheffield

- **Seismic Strengthening** (PD +)
- Seismic Resistance of substandard buildings
- **Earthquake Risk Assessment and Management**
- Seismic Performance Based Design of Structures

- Concrete Behaviour (*Shear/Punching Shear, Deflections, Ductility*)
- FRP (*Internal Reinforcement and External Strengthening*)
- FRC (*All fibres, including recycled*)
- Construction Innovations *(>30 patents)*

Seismic strengthening

From Field Missions

Poor anchorage & lack of confinement

Pakistan 2005, photo: NESPAK Ltd

Pakistan 2005, photo: NESPAK Ltd

Use of poor quality concrete

North Athens, 1999 photo: EFTU, Imperial College

Inadequate detailing at critical zones

Lack of design/supervision

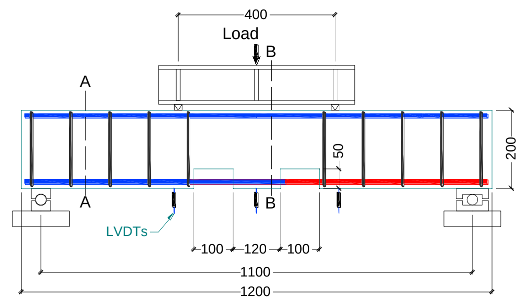
Pakistan 2005, photo: NESPAK Ltd

Lap-Splices

- Lap-spliced beams confined with steel or CFRP

Issues to investigate:

- Lap splice length (10d_b , 25d_b)
- c_c/d_b ratio
- Bar size (12 & 16 mm)
- Type of confinement (nil, steel, CFRP, PTMS)
- Number of CFRP & PTMS layers

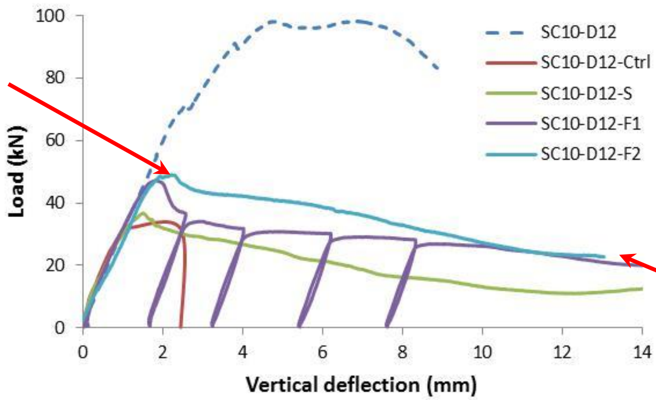


(a) General view

View of beams (Series “S”, splice=10d_b)

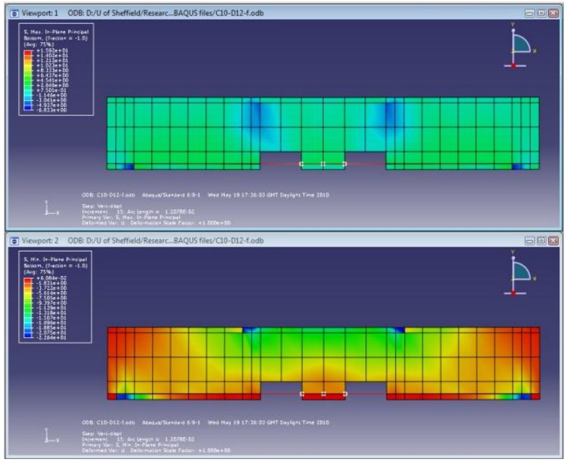
Load-midspan deflection behaviour:

Load (+40%)



Deflection (+50%)

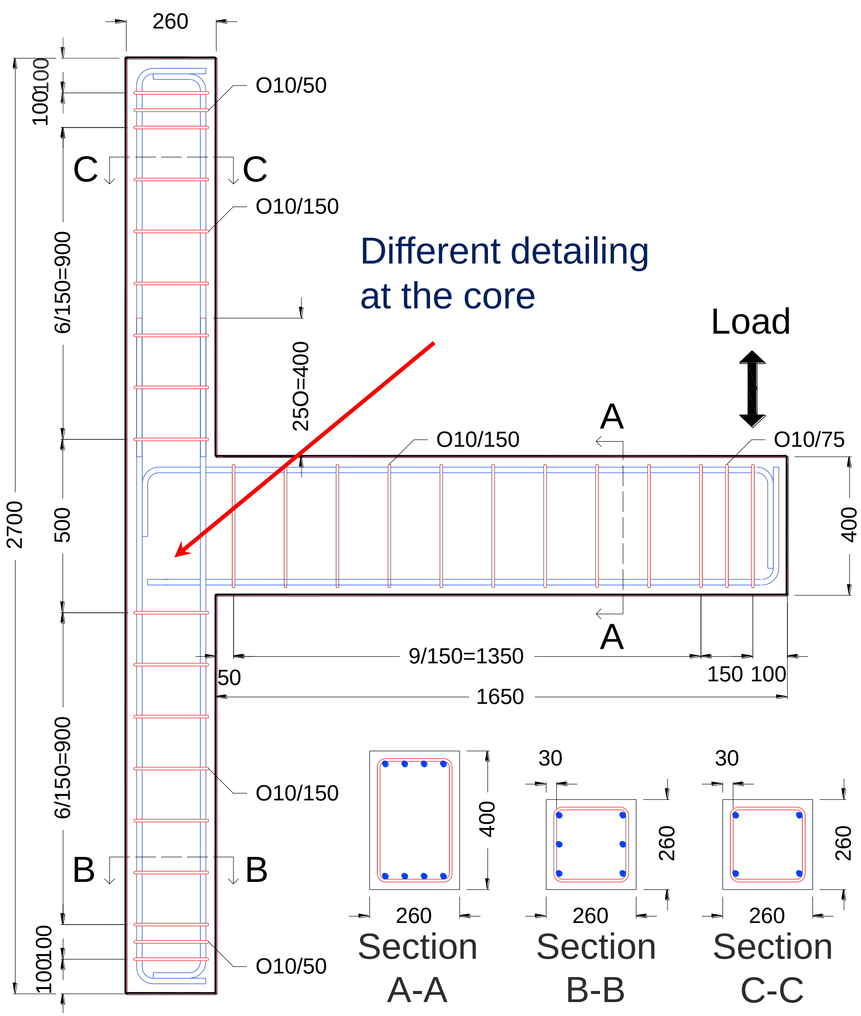
Modelling of beams using ABAQUS®



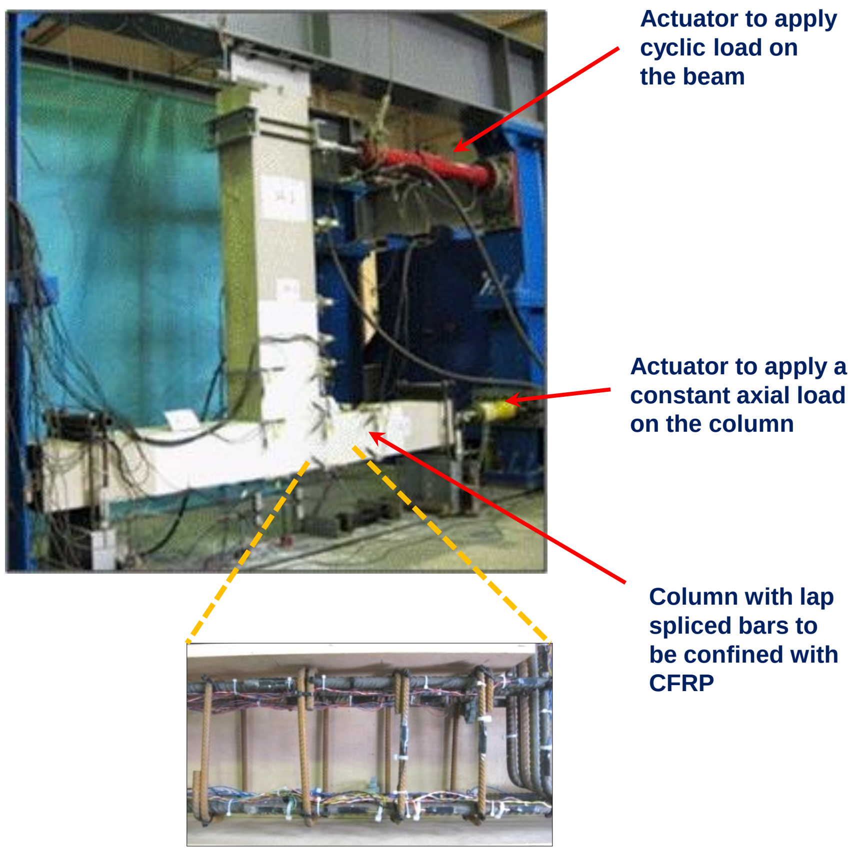
CFRP confinement produces a more desirable failure

Joints

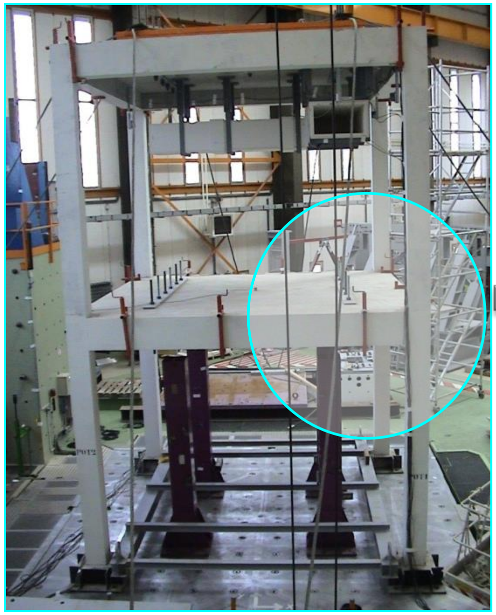
- Full-scale RC beam-column joints strengthened with CFRP composites or PTMS



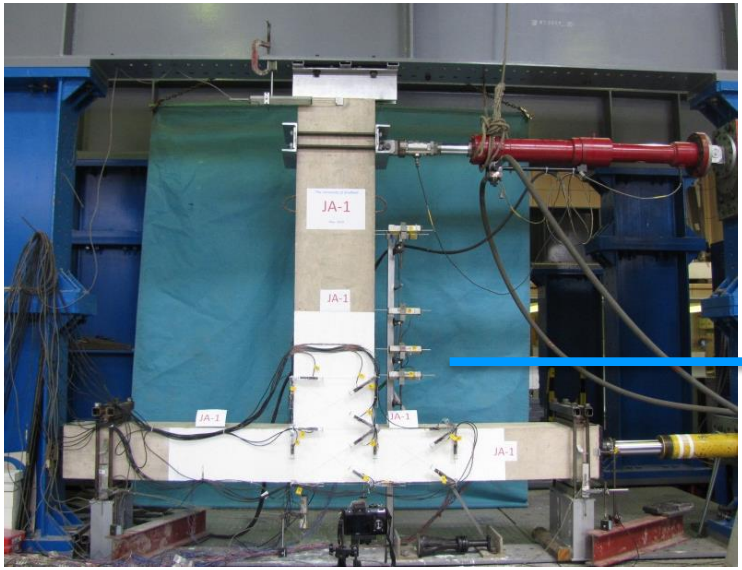
General view of the joint



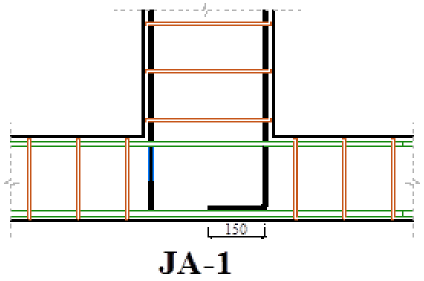
Strengthening of Joints



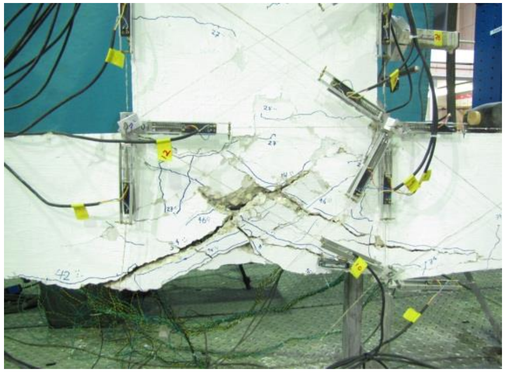
Poorly detailed buildings



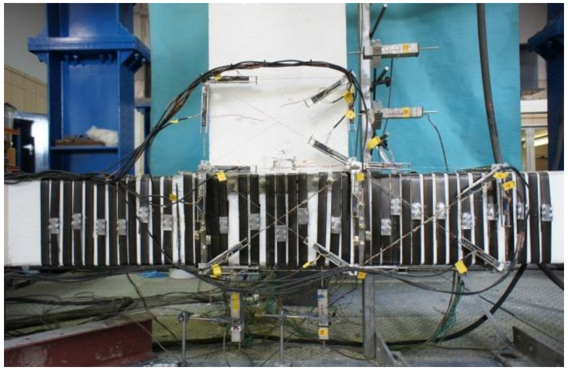
Test Rig



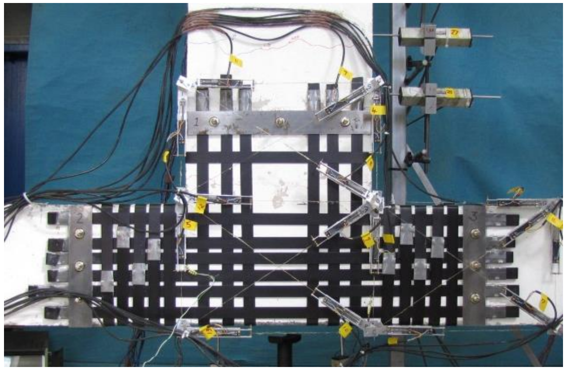
Poor detailing



Shear failure mechanism



Column and Core



Column, beam & core

Strengthening

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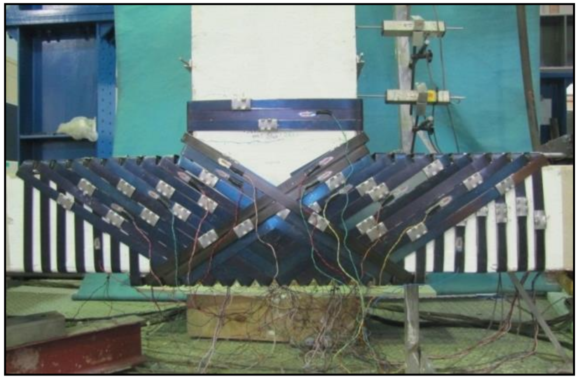
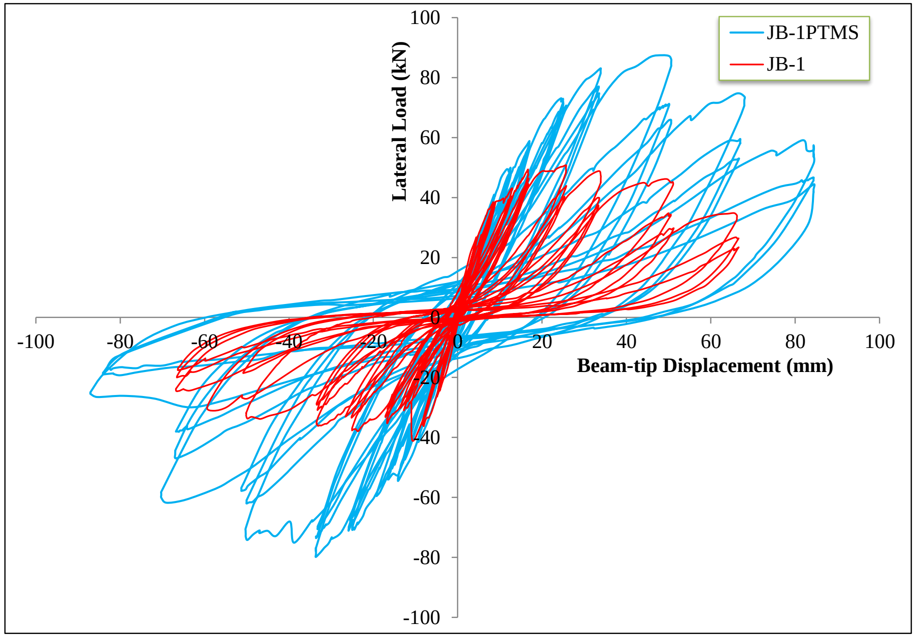
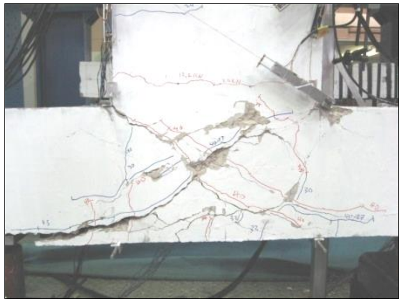
PTMS Joint Strengthening

Scheme 2:

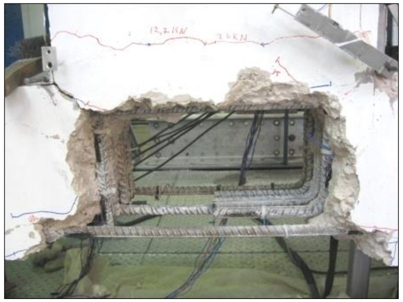




FRP Strengthening



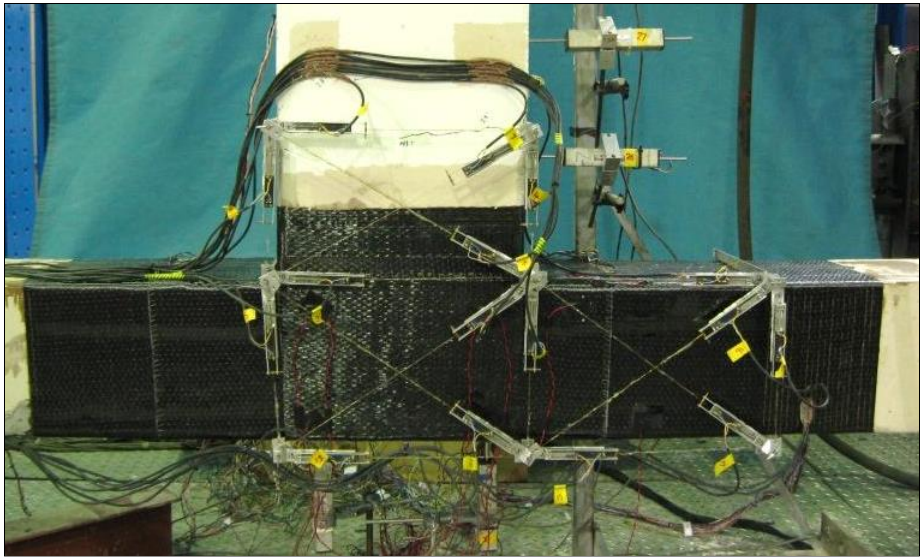
After testing, the core zone suffered severe damage

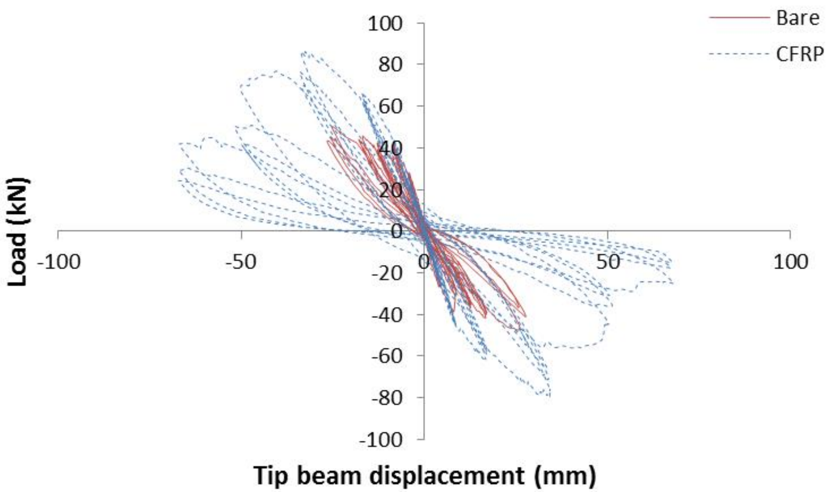


Removal of damaged concrete

Re-casting using high-strength concrete

Strengthening with CFRPS



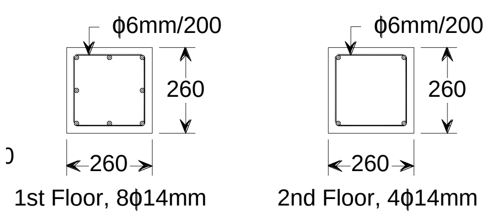


Strengthening of buildings CFRP/PTMS

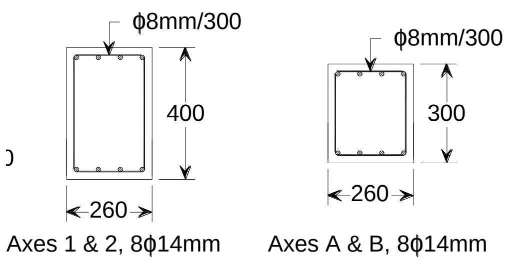
BANDIT building (Part of EU Series project)

Goal: test the effectiveness of PTMS & CFRPs on deficient full-scale RC buildings

- Substandard 3D frame building
- Unidirectional, bidirectional and 3D shake table tests
- H=6.6m, W=4.26m
- Cols. 26×26 cm; beams 26×40 cm (X) and 26×30 cm (Y)
- f_c=26-32 MPa; f_y=526 MPa

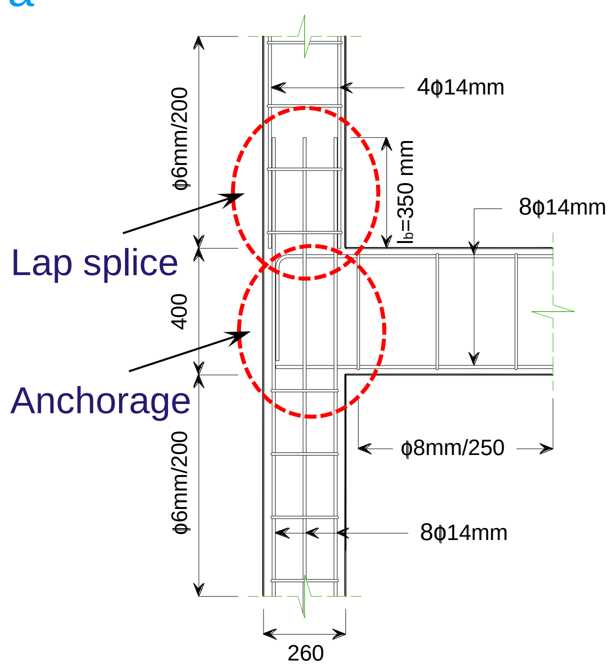


Reinforcement of columns



Reinforcement of beams

(Dimensions in mm)



General view of BANDIT building

Strengthening of buildings CFRP/PTMS

BANDIT building

Test sequence (29 tests in 5 Phases)

Test Phase	Direction of test	PGA (g)	Observations
1 - Bare condition	X axis	0.05	Initial tests to produce damage in X direction
		…	
		0.15 [a,b]	
2 - PTMS-strengthened	X axis	0.05	Tests to verify the effectiveness of the PTMS technique
		…	
		0.35	
3 - PTMS-strengthened	Y axis	0.05	Tests to produce controlled damage in Y direction
		…	
		0.30[b]	
4 - PTMS & CFRP-strengthened	Y axis	0.05	Test to compare PTMS vs CFRP strengthening
		0.20	
		0.30	
		0.35	
5 - PTMS & CFRP-strengthened	Bi-axial	0.10	Tri-axial (XYZ) tests
	Tri-axial	0.10	
		0.20	
		0.30	
		0.35	
		0.40	
		0.50	
		0.60	

[a] Test at PGA=0.15g was repeated due to issues with AZALEE shake table

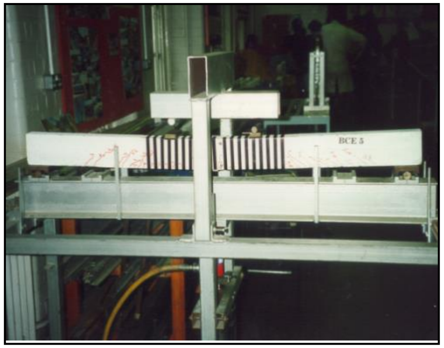
[b] After this test PTMS were removed, cracks resin-injected & spalled/damaged concrete replaced

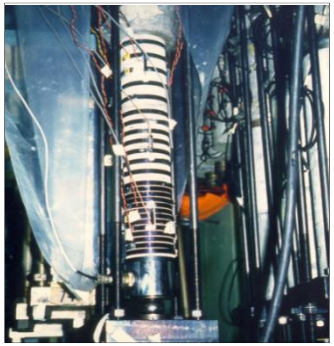
Post-**T**ensioned **M**etal **S**trapping (metal straps + strapping tools)

Strapping tool

Sealing tool

Roll of metal straps



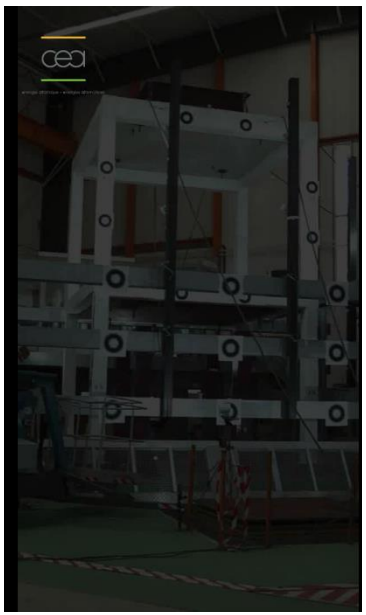


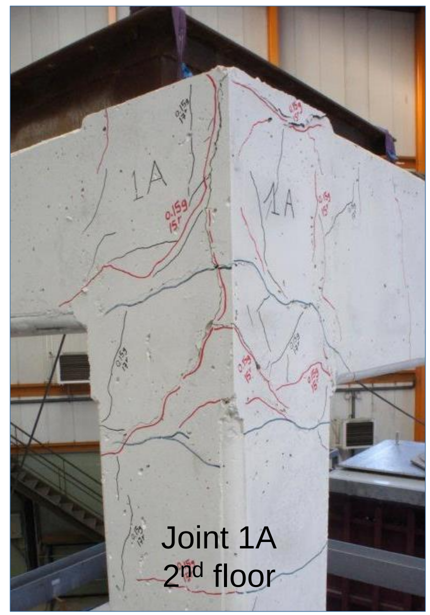
Confinement/ductility

Strengthening of buildings CFRP/PTMS

BANDIT building

Phase 1: tests on bare building (X dir.)





PGA_{max}=0.15 g
Unidirectional test

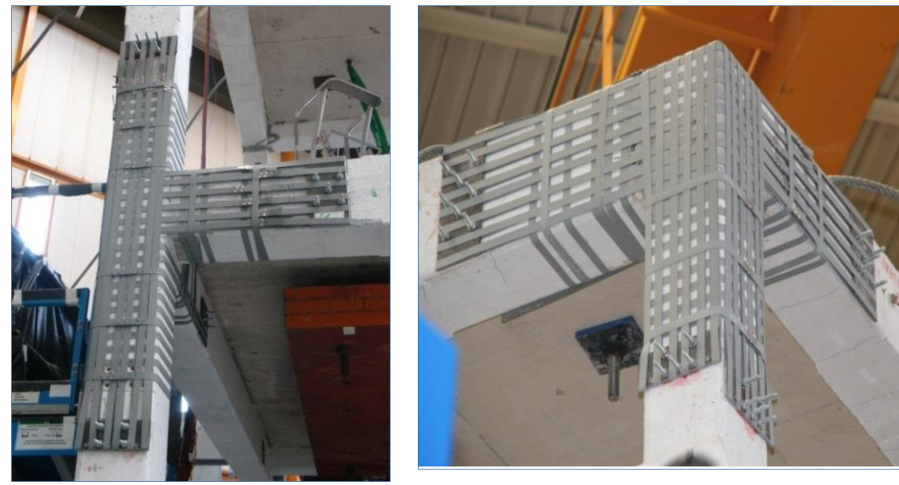
Damage concentrated at 2nd floor joints and columns (cover splitting)

Strengthening of buildings CFRP/PTMS

BANDIT building

Rehabilitation & PTMS strengthening

Crack injection & replacement of damaged concrete



PTMS strengthening of joints

PGA_{max}=0.35 g
Unidirectional test (X dir.)

Strengthening of buildings CFRP/PTMS

BANDIT building

Rehabilitation & CFRP strengthening

Crack injection, replacement of damaged concrete & surface preparation

Orthogonal strengthening of joints

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Strengthening of buildings CFRP/PTMS

BANDIT building

Phases 4 & 5: tests on PTMS+CFRP-strengthened building

PGA_{max}=0.60 g
3D test
Tests were halted because the limits of the table (±125 mm) were exhausted

No major damage; minor damage at beams and columns

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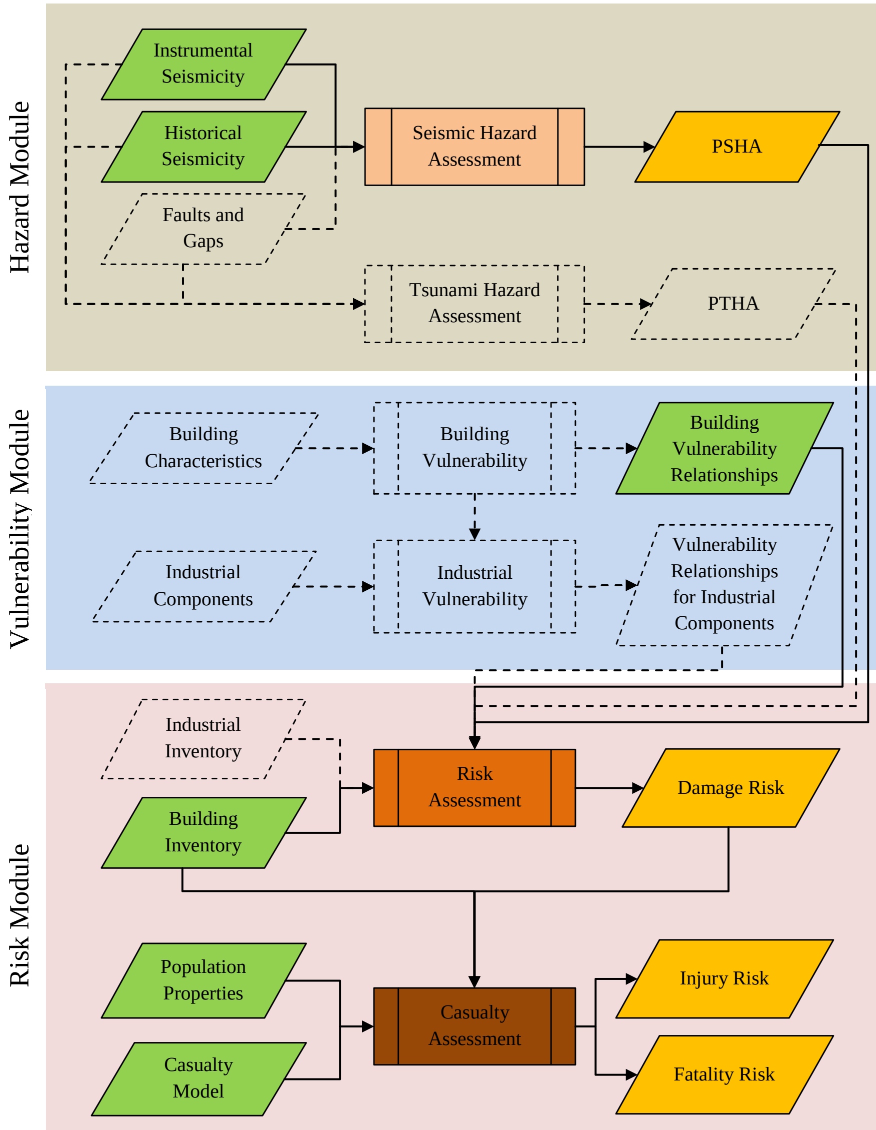
Earthquake Risk Assessment and Management

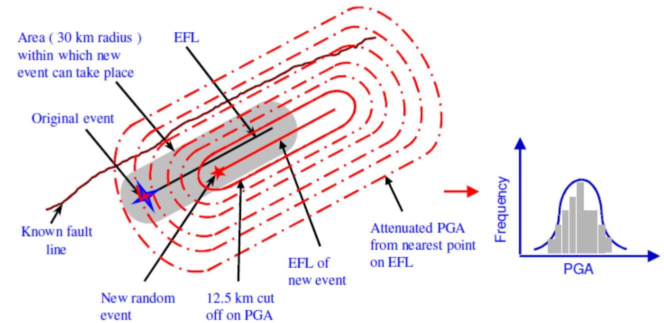
A Framework for Earthquake Risk Assessment In Developing Countries

Earthquake Risk Assessment Framework

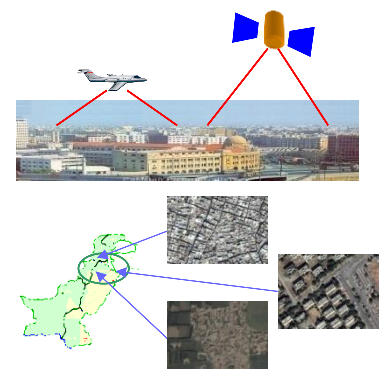
RISK = HAZARD × EXPOSURE × VULNERABILITY × VALUE



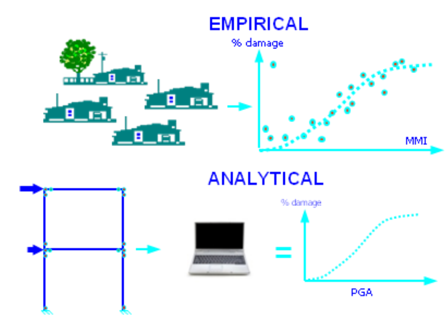
HAZARD



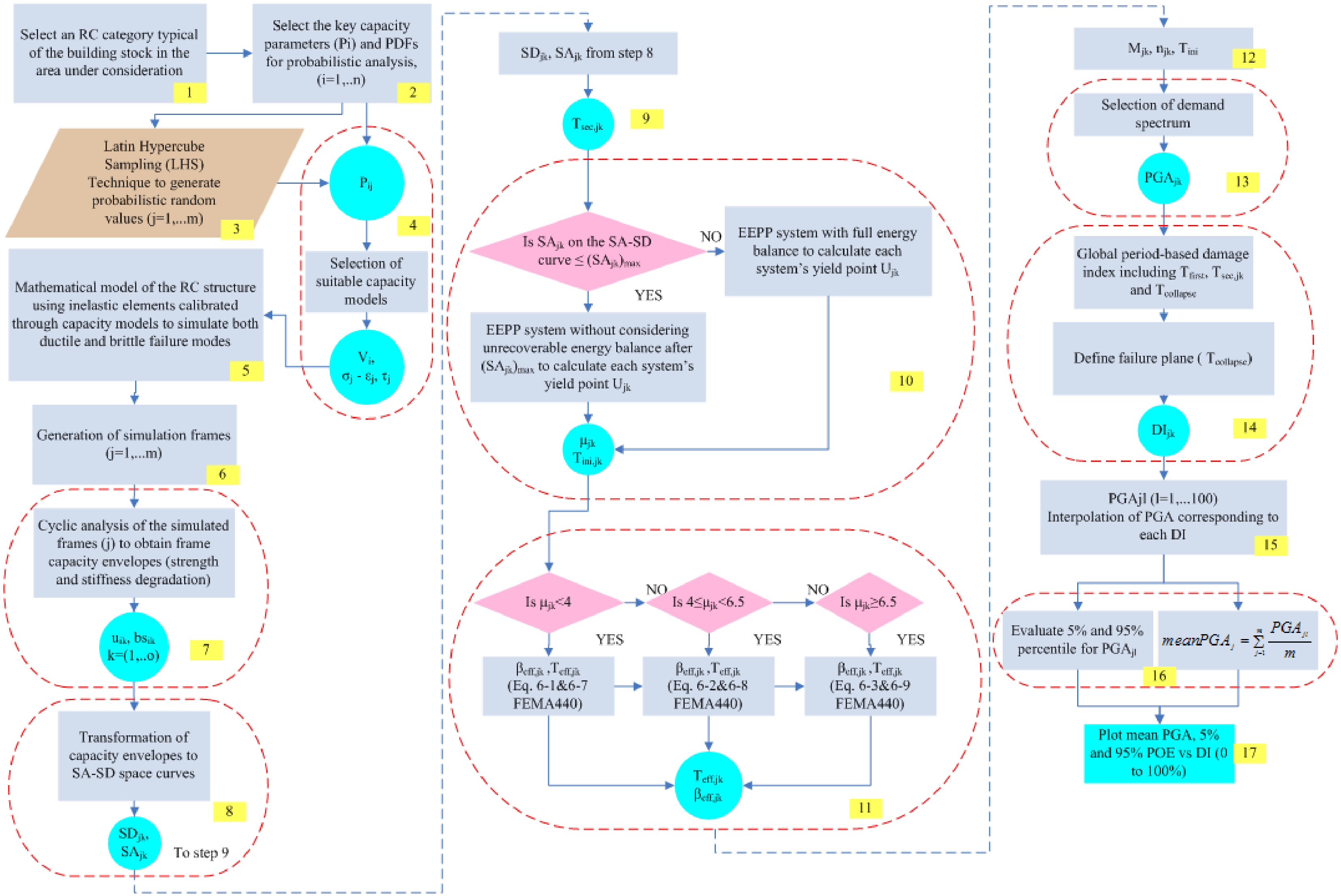
EXPOSURE



VULNERABILITY



Analytical Vulnerability Framework



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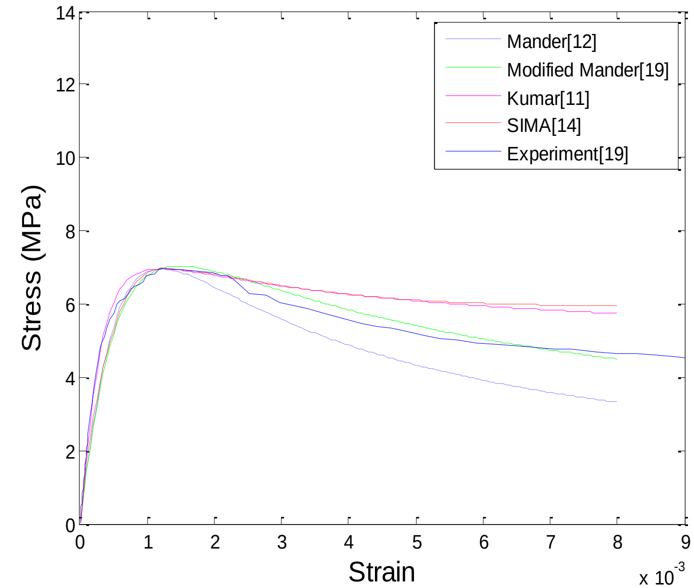
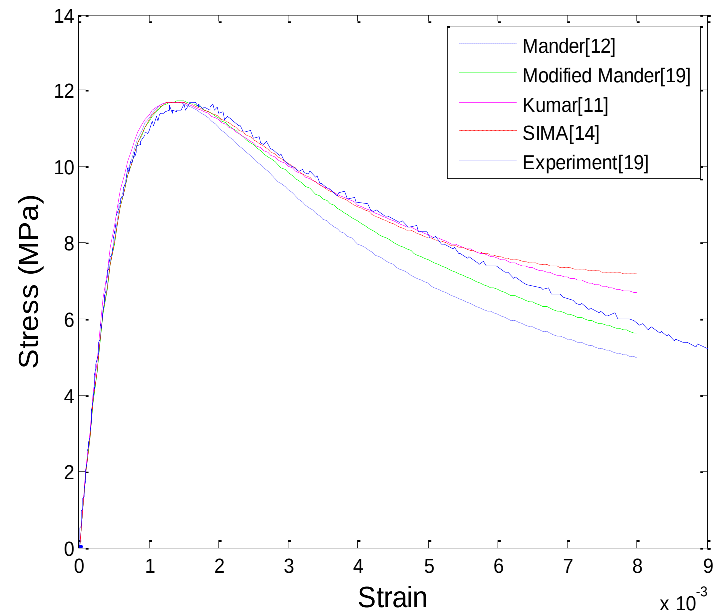
Low Strength Concrete

Strength below 25 MPa
Normally 5-15 MPa

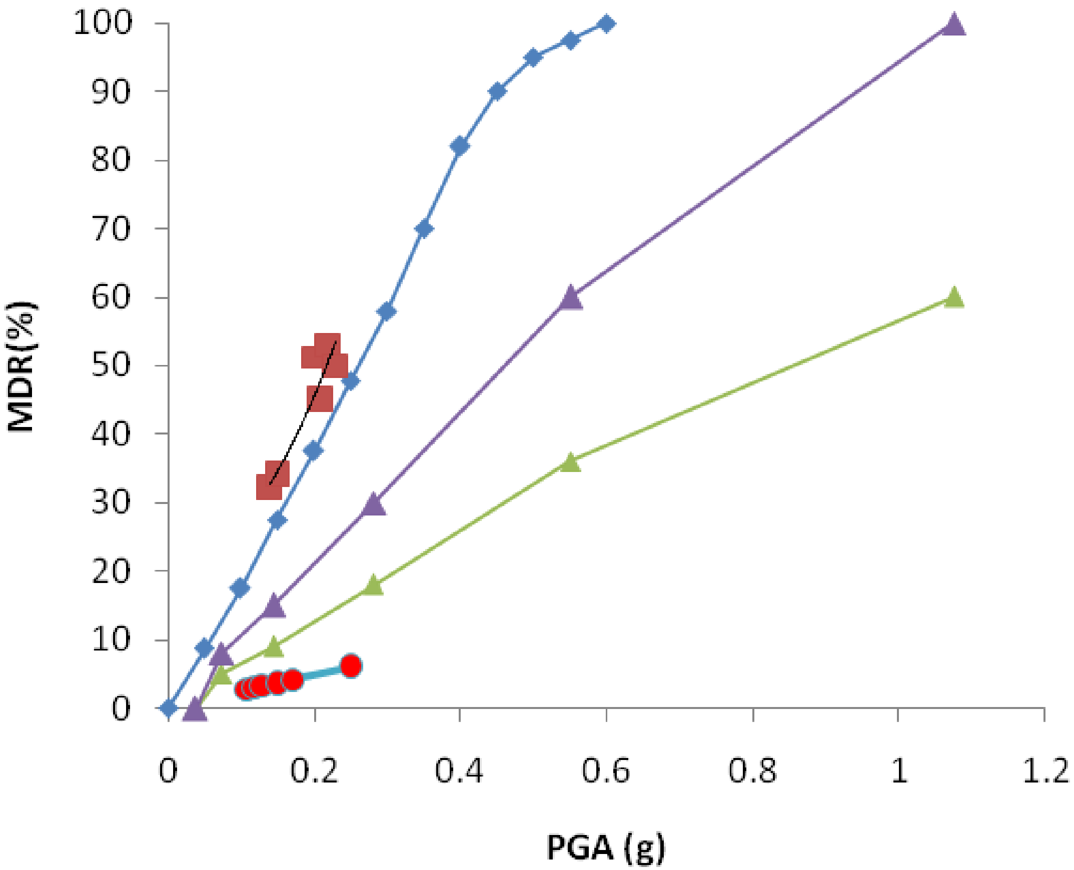
a

b





Vulnerability of Sub-standard buildings



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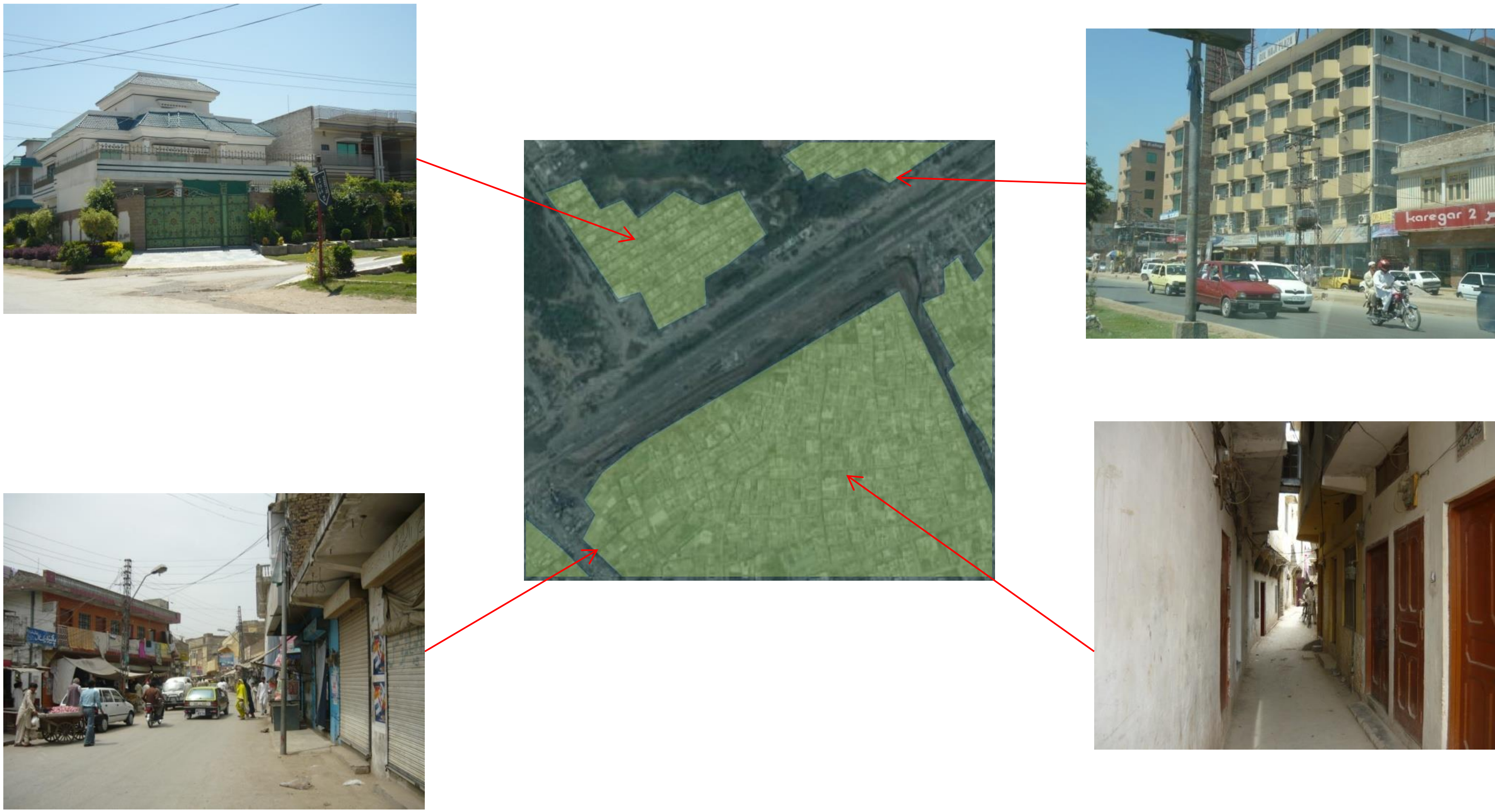
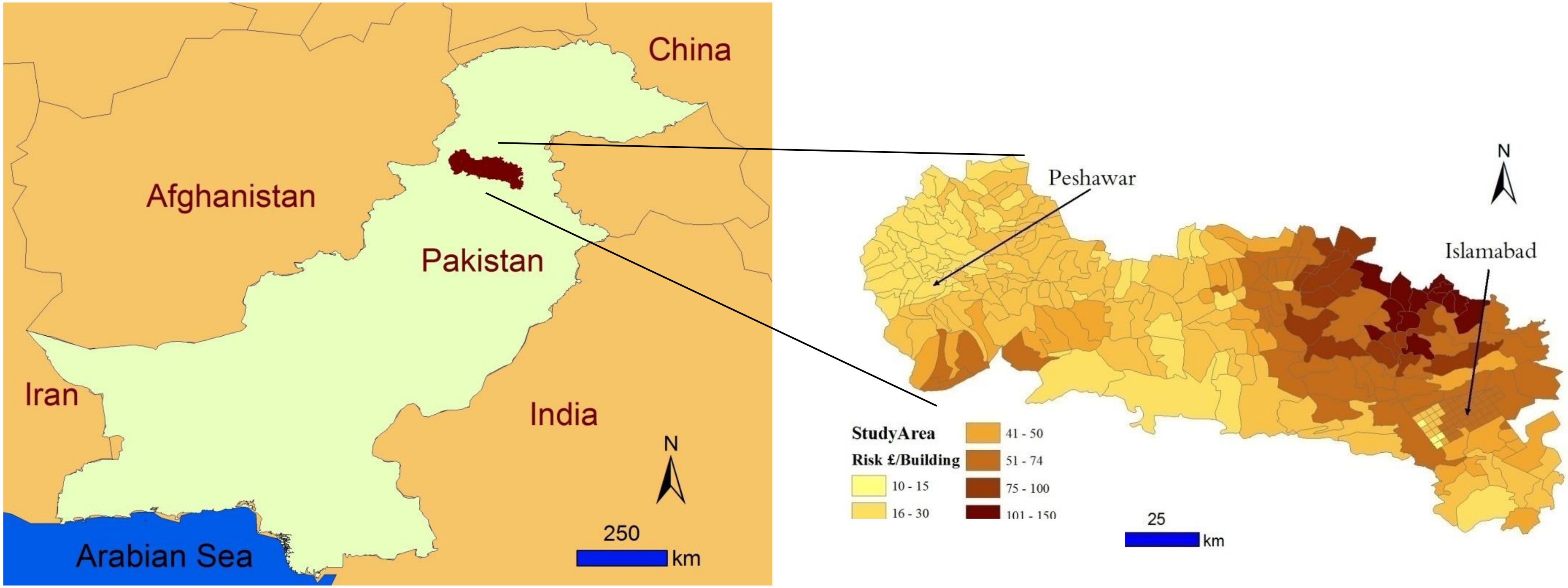
Seismicity Vulnerability Assessment

Satellite Imagery with Minimal Field Sampling



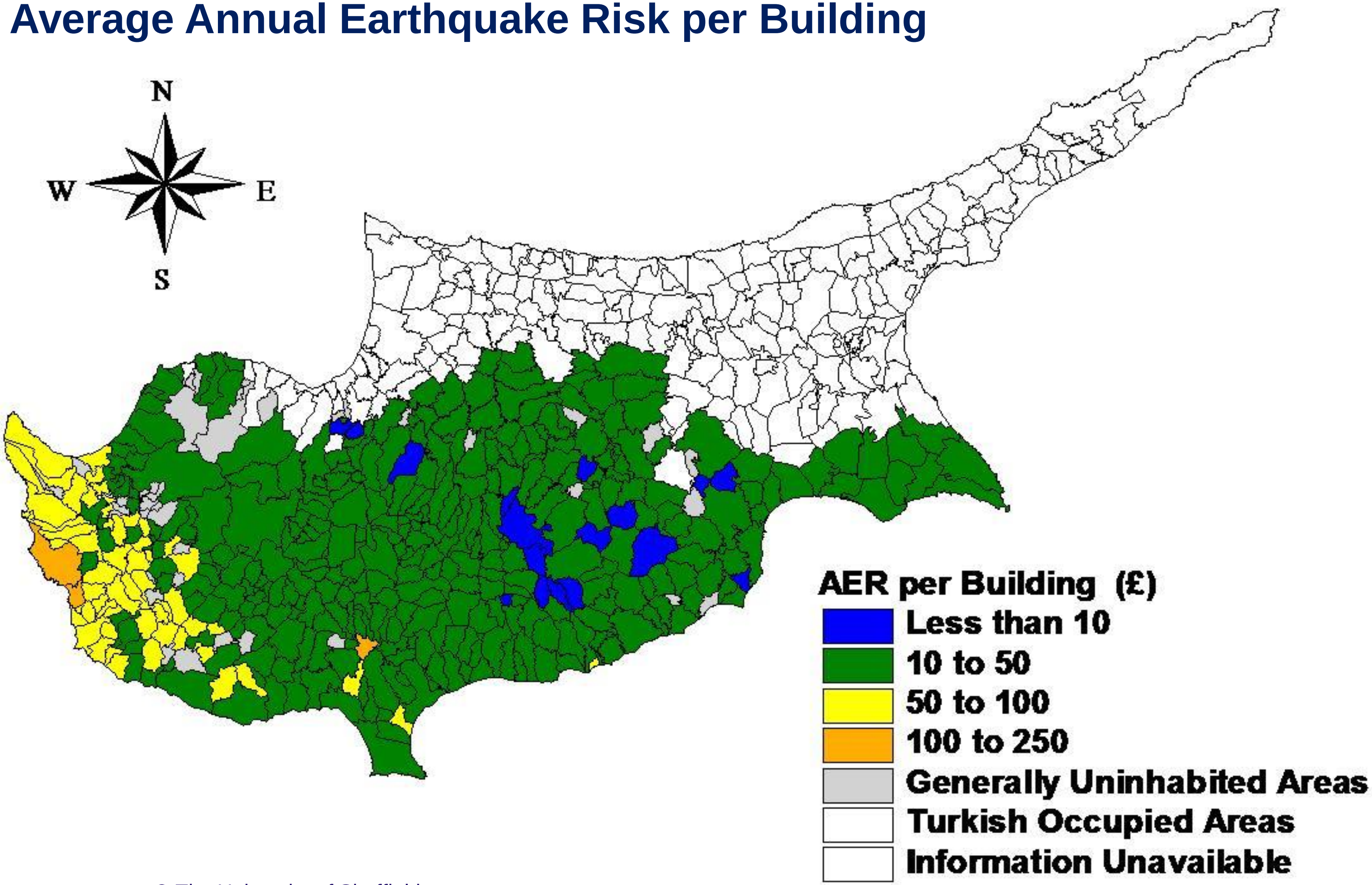
Case Study: Pakistan

Study Area with in Pakistan (2009 figures)

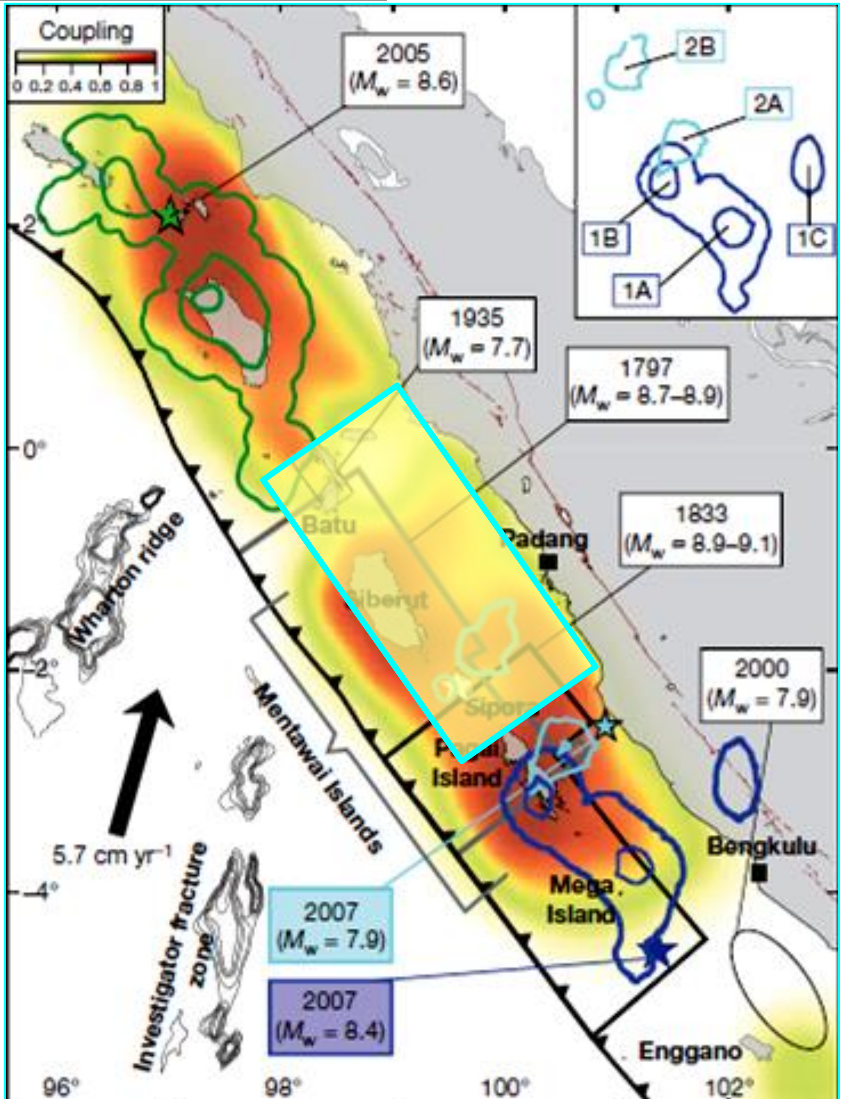


Case Study: Cyprus

Average Annual Earthquake Risk per Building

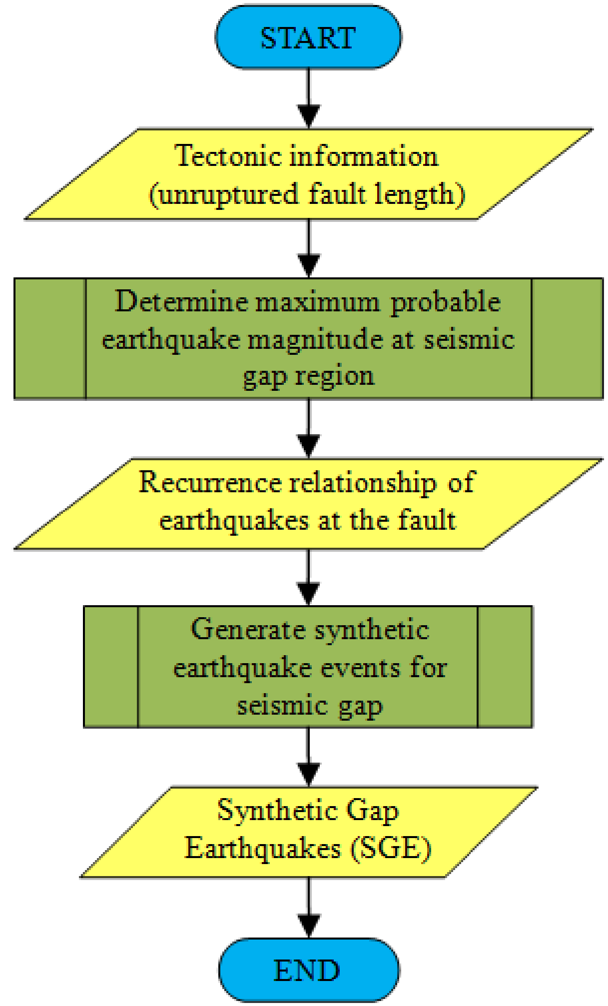


Case Study: West Sumatra



(Konca et al., 2008)

Flow chart to produce Synthetic Gap Events (SGE).



Case Study: West Sumatra

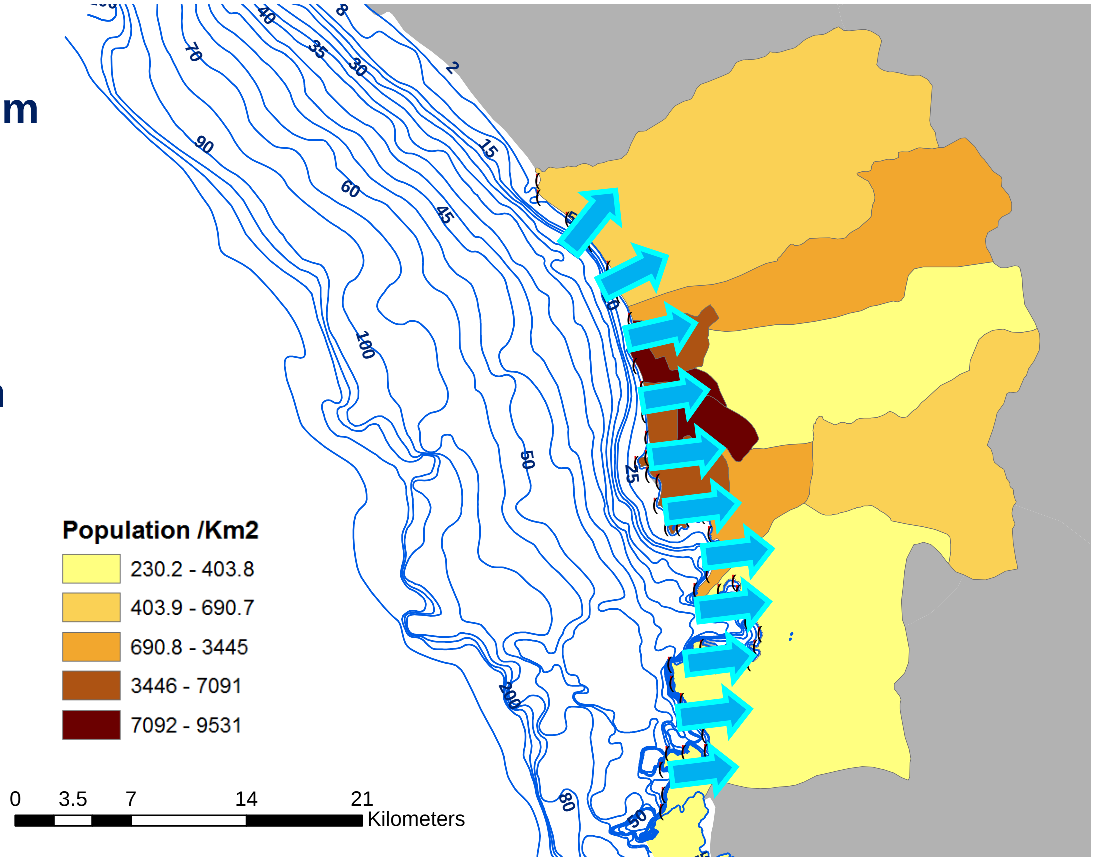
Results

Tsunami Hazard:

- Average tsunami wave height is ~ **5 m**

Inland Penetration:

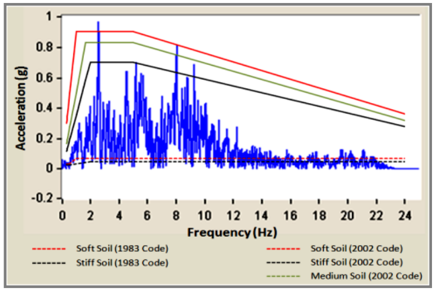
- Smooth terrain : **2.2 km**
- Densely populated buildings: **0.5 km**
- Densely treed landscape: **0.1 km**



Bathymetry and preliminary tsunami hazard analysis for Padang City

Societal Impact

1. Mitigation strategies:
   - *Seismic demands for structures.*
   - *Seismic strengthening of existing building stocks.*
   - *Assessing appropriate locations for tsunami vertical evacuation systems.*
   - *Tsunami evacuation maps.*
   - *Compare mitigation scenarios*
2. Determine premiums for insurance companies.
3. Future town planning to deal with earthquake and tsunami hazards.



The University Of Sheffield.

NICHOLAS AMBRASEYS
MEMORIAL SYMPOSIUM

Lasting influence

on our work

Kypros Pilakoutas