5th Summer School workshop INFRARISK-
Analysis and Mitigation of Risks in Infrastructures
15th July 2019, Guimarães

a scoping study for the assessment of historical centres

earthquake risk mitigation of urban cultural heritage assets

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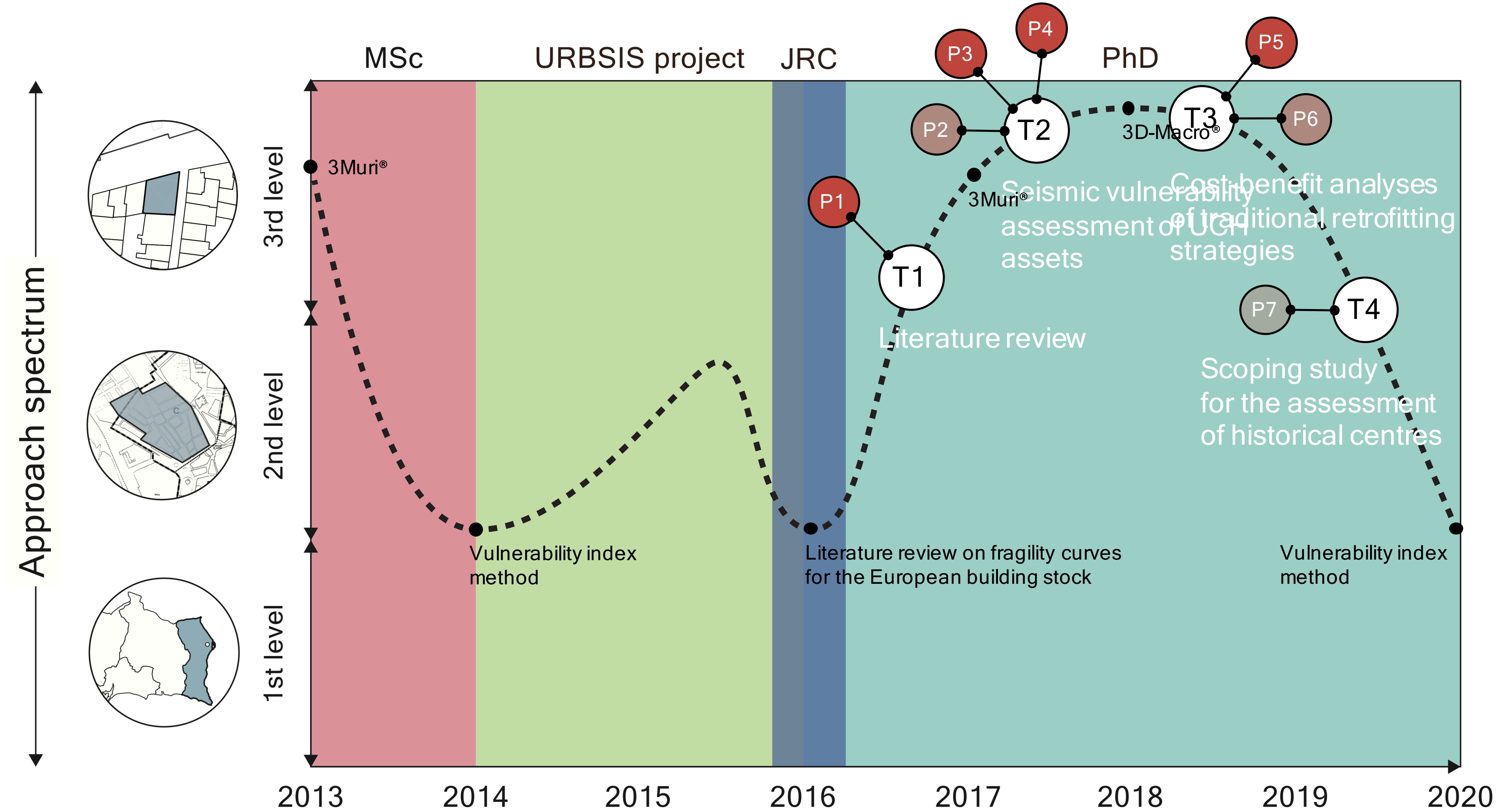
Approach spectrum
1st level
2nd level
3rd level



MSc
URBSIS project
JRC
PhD
Approach spectrum
3rd level
2nd level
1st level
3Muri®
Vulnerability index method
Literature review on fragility curves for the European building stock
Vulnerability index method
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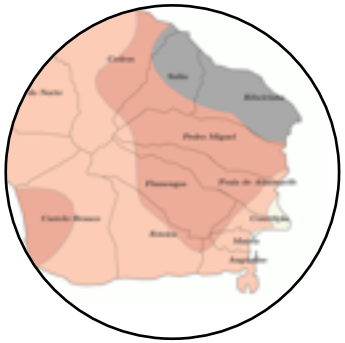
Bernardini et al. (2007) proposed an analytical expression that correlates hazard with the mean damage grade, μ_D, of the damage distribution in terms of vulnerability value:

$$\mu_D = 2.5 \times \left[1 + \tanh\left(\frac{I + 6.25 \times V - 13.1}{Q}\right)\right], \quad 0 \leq \mu_D \leq 5$$

$$V = 0.592 + 0.0057 \times I_V$$

I_v mapping



Intensity map

μ_D mapping

However, the applicability of this analytical expression in countries with limited damage data from real ground motions has been an issue of great controversy.

Moreover, the value adopted for the ductility factor, Q, which describes the ductility of the considered building typology, is also quite arguable.

Main research questions are:

- How could we revert the use of the vulnerability index method by avoiding the use of the European Macroseismic Intensity Scale, I_{EMS-98}?
- How can we take advantage of the potential of simplified numerical models to this aim?
- Is there a correlation between the vulnerability index and the main properties of the capacity curves derived from numerical models and further applied in the scope of the N2 Method?

Parameter		Class, C_{vi} A	B	C	D	Weight, p_i Vicente (2008)	Ferreira et al. (2017)
Group 1. Structural building system							
P1	Type of resisting system	0	5	20	50	0.75	2.50
P2	Quality of resisting system	0	5	20	50	1.00	2.50
P3	Conventional strength	0	5	20	50	1.50	1.00
P4	Maximum distance between walls	0	5	20	50	0.50	0.50
P5	Number of floors	0	5	20	50	1.50	0.50
P6	Location and soil conditions	0	5	20	50	0.75	0.50
Group 2. Irregularities and interactions							
P7	Aggregate position and interaction	0	5	20	50	1.50	1.50
P8	Irregularity in plan	0	5	20	50	0.75	0.50
P9	Irregularity in height	0	5	20	50	0.75	0.50
Group 3. Floor slabs and roofs							
P10	Openings alignment	0	5	20	50	0.50	0.50
P11	Horizontal diaphragms	0	5	20	50	1.00	0.75
P12	Roofing system	0	5	20	50	1.00	2.00
Group 4. Conservation status and other elements							
P13	Fragilities and conservation status	0	5	20	50	1.00	1.00
P14	Non-structural elements	0	5	20	50	0.50	0.75

$$I_v^* = \sum_{i=1}^{14} C_{vi} \times p_i$$

the vulnerability index method

Independent parameters

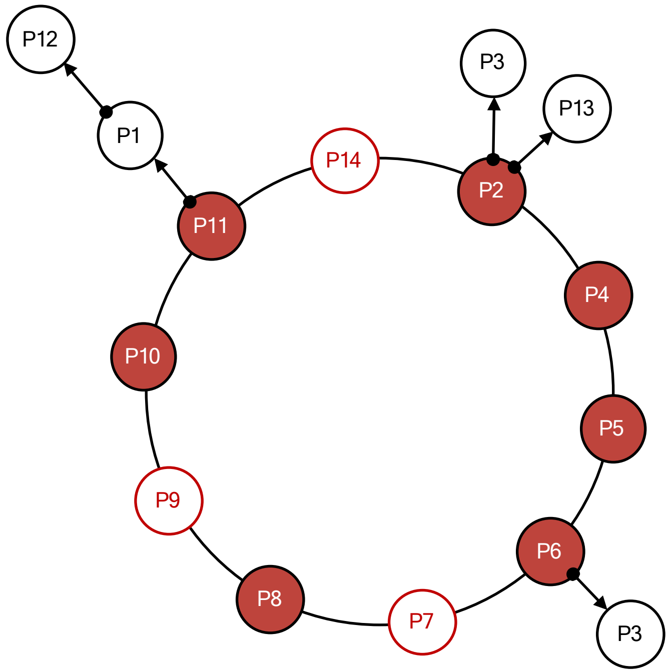
- P2 Quality of resisting system
- P4 Maximum distance between walls
- P5 Number of floors
- P6 Location and soil conditions
- P8 Irregularity in plan
- P10 Openings alignment
- P11 Horizontal diaphragms

Dependent parameters

- P1 Type of resisting system
- P3 Conventional strength
- P12 Roofing system
- P13 Fragilities and conservation status

Disregarded parameters

- P7 Aggregate position and interaction
- P9 Irregularity in height
- P14 Non-structural elements



from I_v to numerical modelling

P2 Quality of resisting system

VI - Stone blocks squared masonry

Class, C_{vi}	Masonry typology	w [kN/m^3]	f_m [N/cm^2]	t_0 [N/cm^2]	f_{tm} [N/cm^2]	E [N/mm^2]	G [N/mm^2]	Cracked stiffness
A	VI max	22	607.4	8.9	30.4	3300	1100	1.00
B	VI min	22	429.6	6.7	21.5	2000	667	0.83
C	I max	19	148.1	2.4	7.4	700	233	0.67
D	I min	19	74.1	1.3	3.7	345	115	0.50

Italian code (CM 2018)

I - Disorganized irregular stone masonry

Assumptions:

- The mechanical properties assumed for each typology (adopted from the Italian code) are assumed to match those of both rural and urban stone masonry typologies of Faial island's vernacular architecture.

P4 Maximum distance between walls

Class, C_{vi}	Wall thickness
A	0.70
B	0.60
C	0.50
D	0.40

Assumptions:

- Maximum distance between walls equal to 10 m;
- Inter-story height constant and equal to 2.50 m.

P5 Number of floors

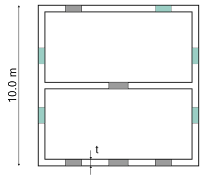
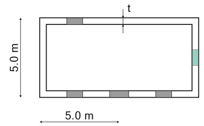
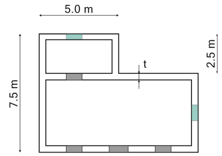
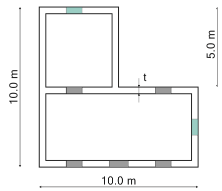
Class, C_{vi}	Number of floors
A	1
B	2
C	3
D	4

Assumptions:

- We assumed that the great majority of Faial island's building stock has a maximum of 4 storeys.

from I_v to numerical modelling

P8 Irregularity in plan

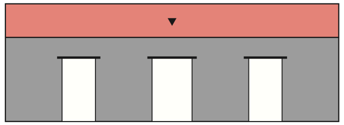
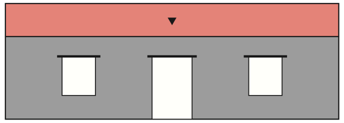
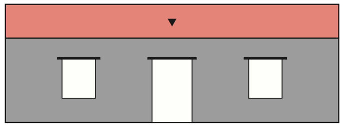
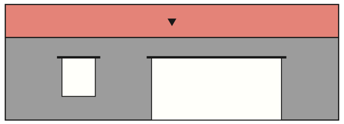
Class, C_{vi}	Designation	Plan
A	Square shape	
B	Rectangular shape	
C	L-shape	
D	Square L-shape	

Assumptions:

- We assumed these configurations as representative of the majority of both urban and rural typologies of Faial island’s vernacular architecture.

from I_v to numerical modelling

P10 Openings alignment

Class, C_{vi}	Designation	Façade wall
A	Regular and aligned	
B	Misaligned horizontally	
C	Misaligned both horizontally and vertically	
D	Misaligned both horizontally and vertically + large opening at the ground floor level	

P11 Horizontal diaphragms

Class, C_{vi}	Type	Equivalent thickness t [m]	Equivalent stiffness G_{eq} [MPa]
A	Rigid and well connected	0.050	11920
B	Flexible and well connected	0.050	5.3
C	Rigid and poorly connected	0.025	11920
D	Flexible and poorly connected	0.025	6.8

Assumptions:

- The Elastic modulus of horizontal diaphragms were calculated by 3D-Macro® according to the geometrical properties of the floor typology.
- The equivalent stiffness, G_{eq}, was adopted according to the NZSEE (2015) guidelines.

sample generation

Model	P2	P4	P5	P6	P8	P10	P11
M001	A	B	B	A	A	C	B
M002	A	A	B	A	D	D	A
M003	A	A	B	A	C	A	D
M004	A	D	B	A	B	A	B
M005	B	B	D	A	C	D	A
M006	B	A	C	A	D	A	A
M007	B	C	D	A	B	D	D
M008	B	A	D	A	B	B	D
M009	C	C	D	A	B	C	A
M010	C	D	C	A	B	D	D
M011	C	D	A	A	A	A	A
M012	C	A	D	A	A	B	B
M013	D	C	A	A	C	B	C
M014	D	C	A	A	C	C	A
M015	D	C	B	A	D	C	D
M016	D	C	A	A	C	A	C
M017	D	A	B	A	B	D	A
M018	B	A	D	A	B	D	A
M019	A	A	C	A	C	C	A
M020	B	A	D	A	D	C	D
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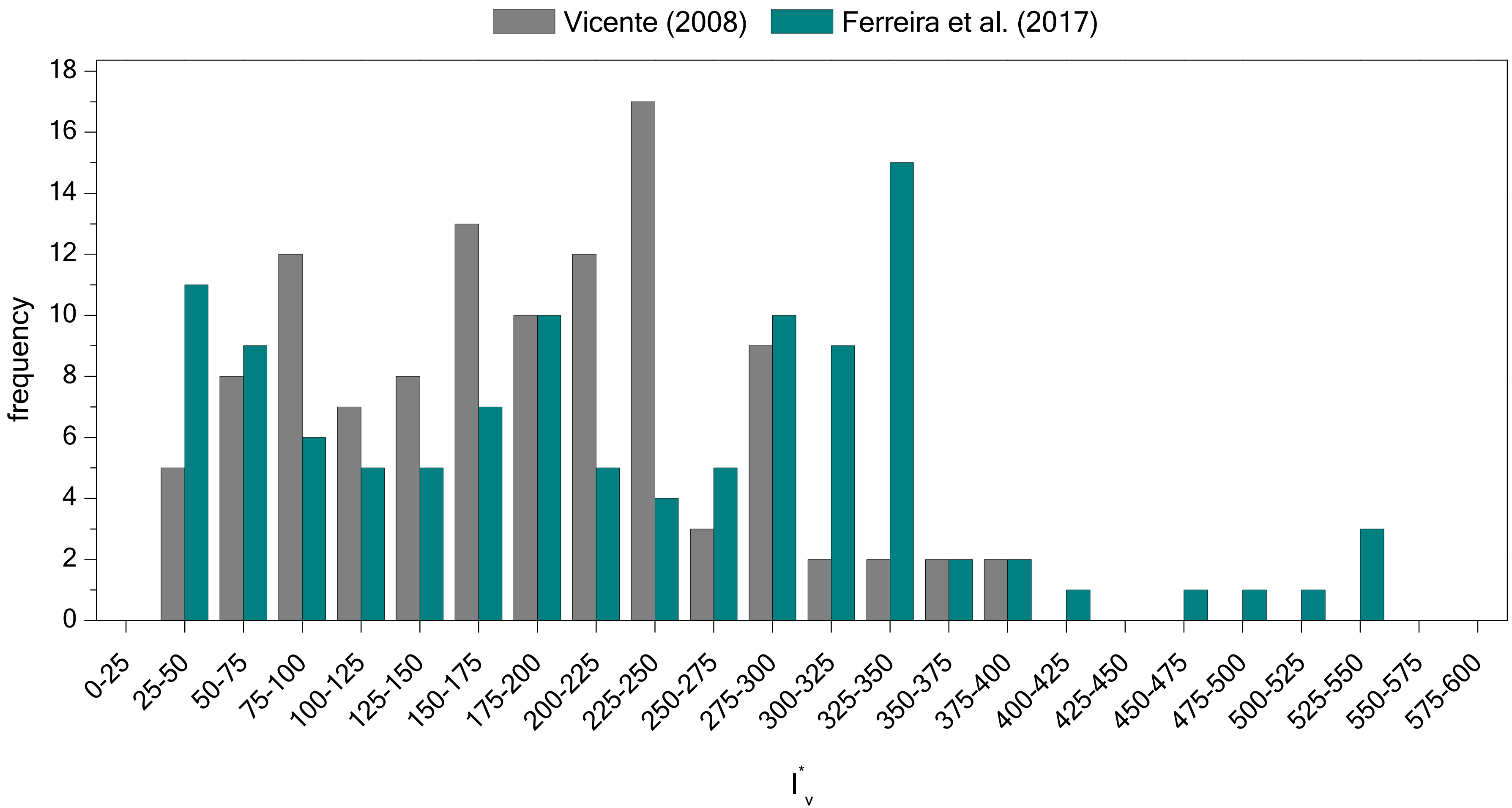
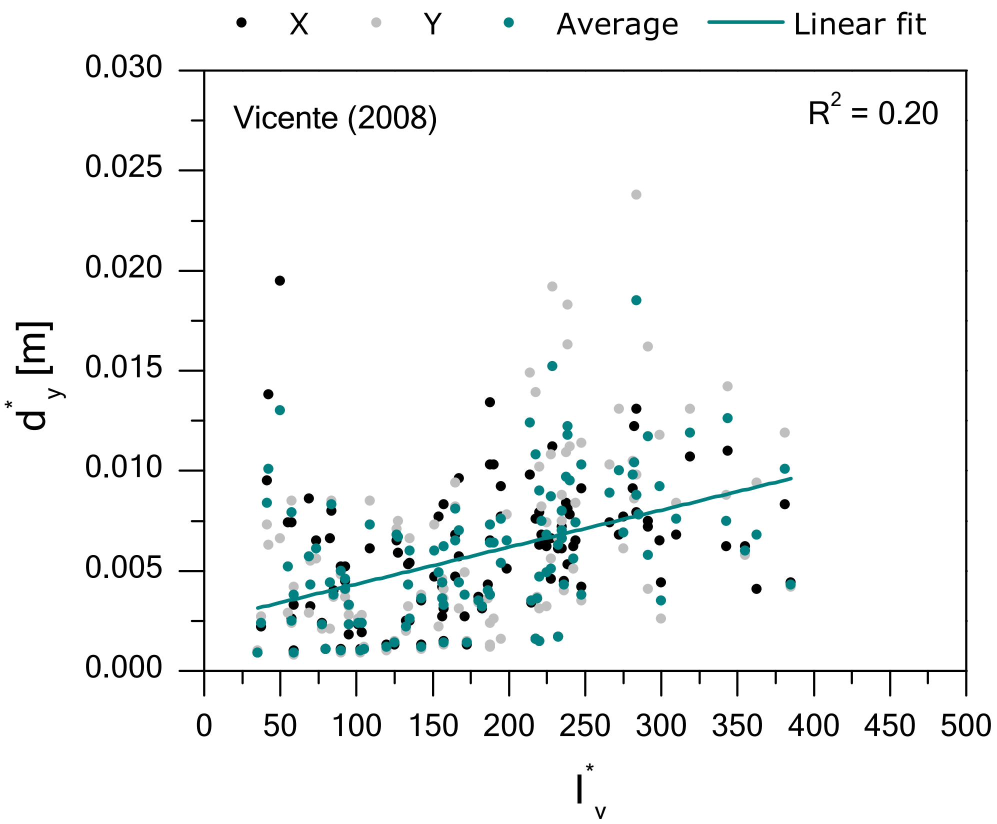
.	.	.	.	.	.	.	.

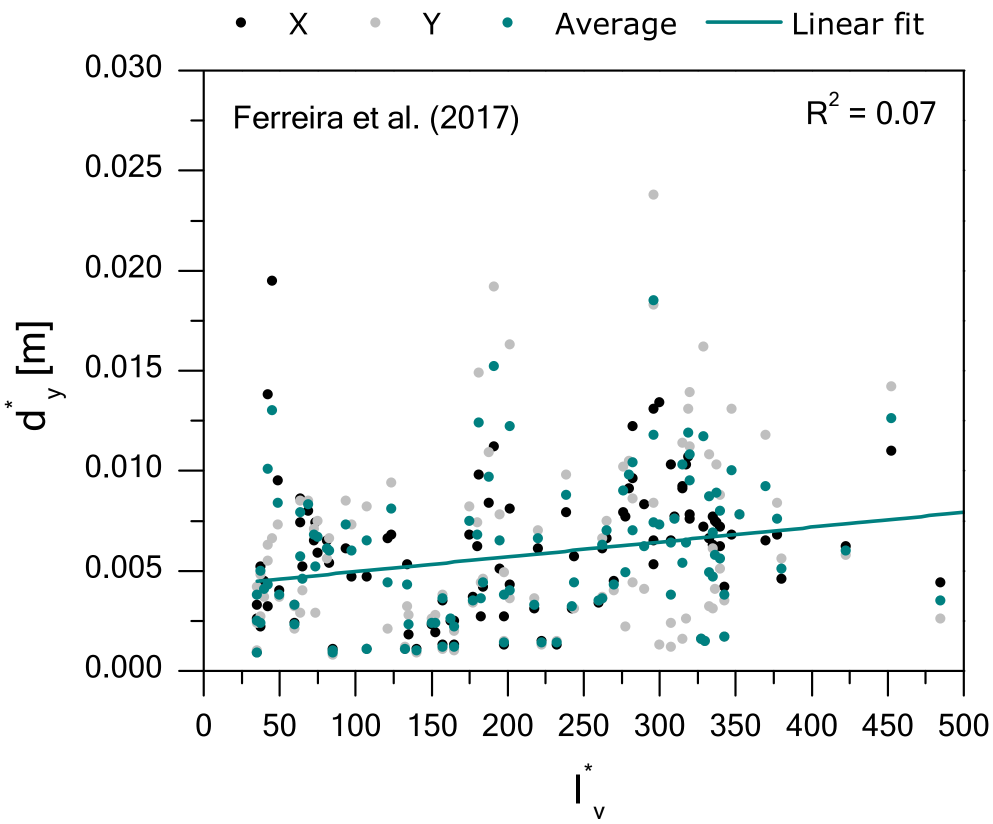
estimation of I^*_v



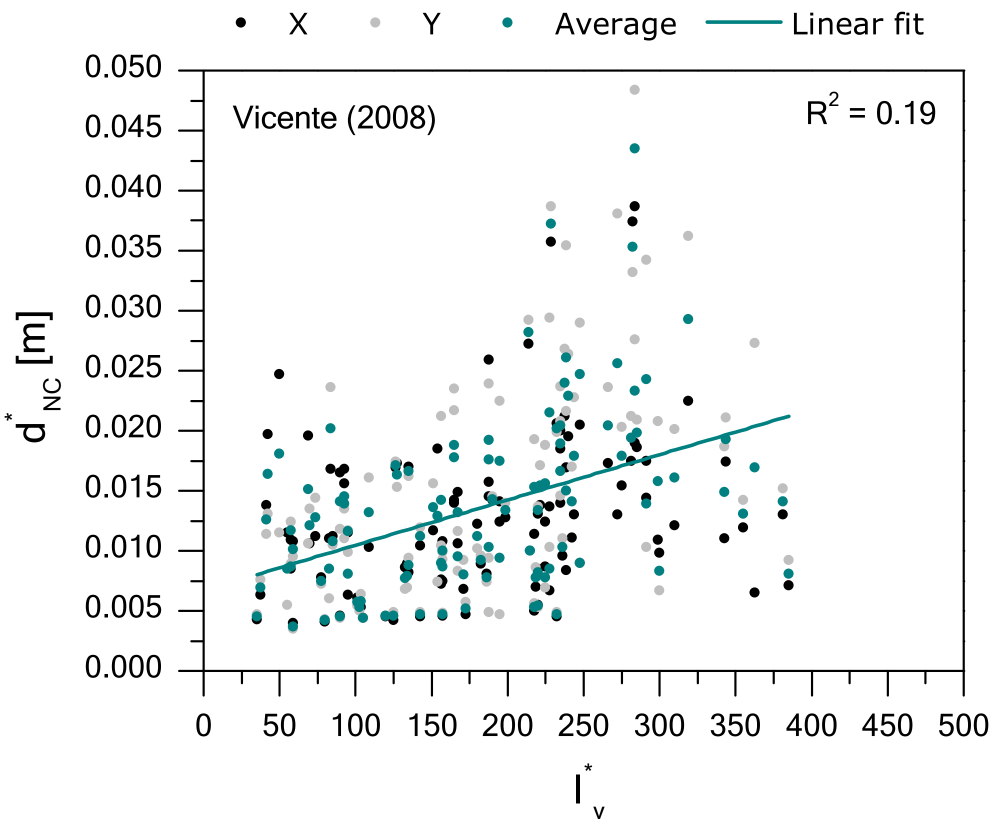
- The three-dimensional model proposed by Pantò et al. (2017) incorporated in 3D-Macro®, was used to perform a set of nonlinear static (pushover) analyses;
- A total of 12 analyses were considered to each model: considering the positive and negative directions of the main planar directions X and Y, both positive and negative accidental eccentricity;
- Only the uniform load pattern distribution was considered;
- Global displacement capacity was defined according to the EN 1998-3 (2005);
- The global seismic performance of the sample was evaluated according to the N2 Method (Fajfar & Gašperšič, 1996), following the recommendations of EN 1998-1 (2004).

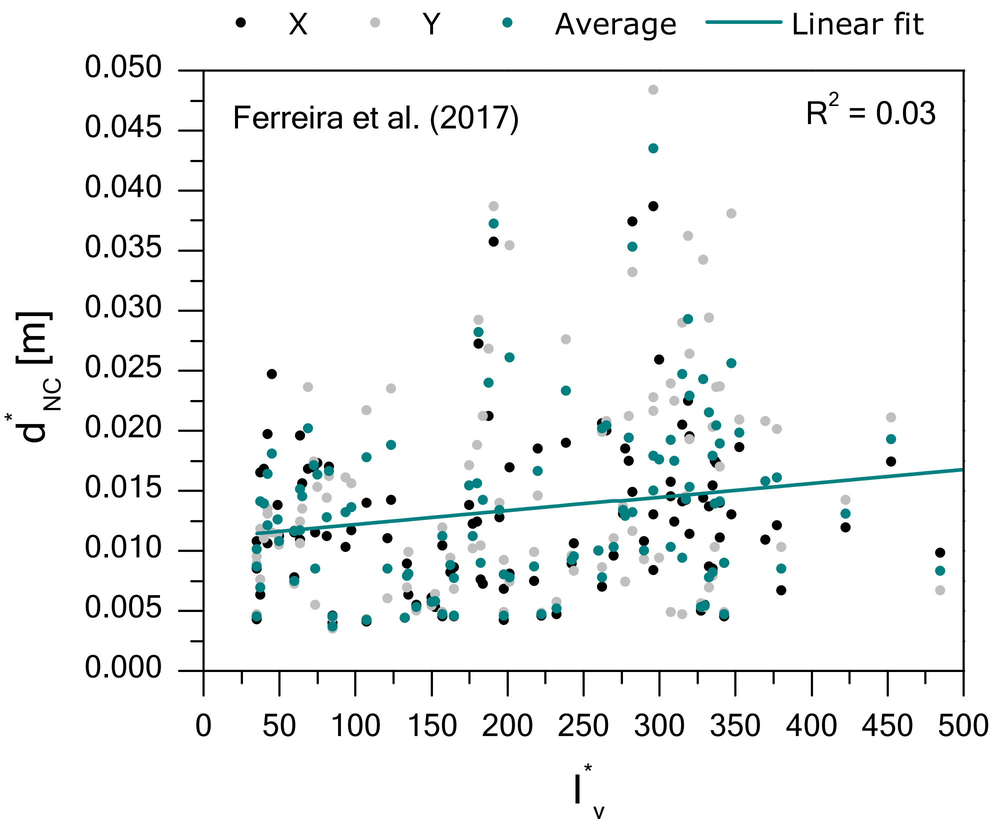
preliminary results





preliminary results





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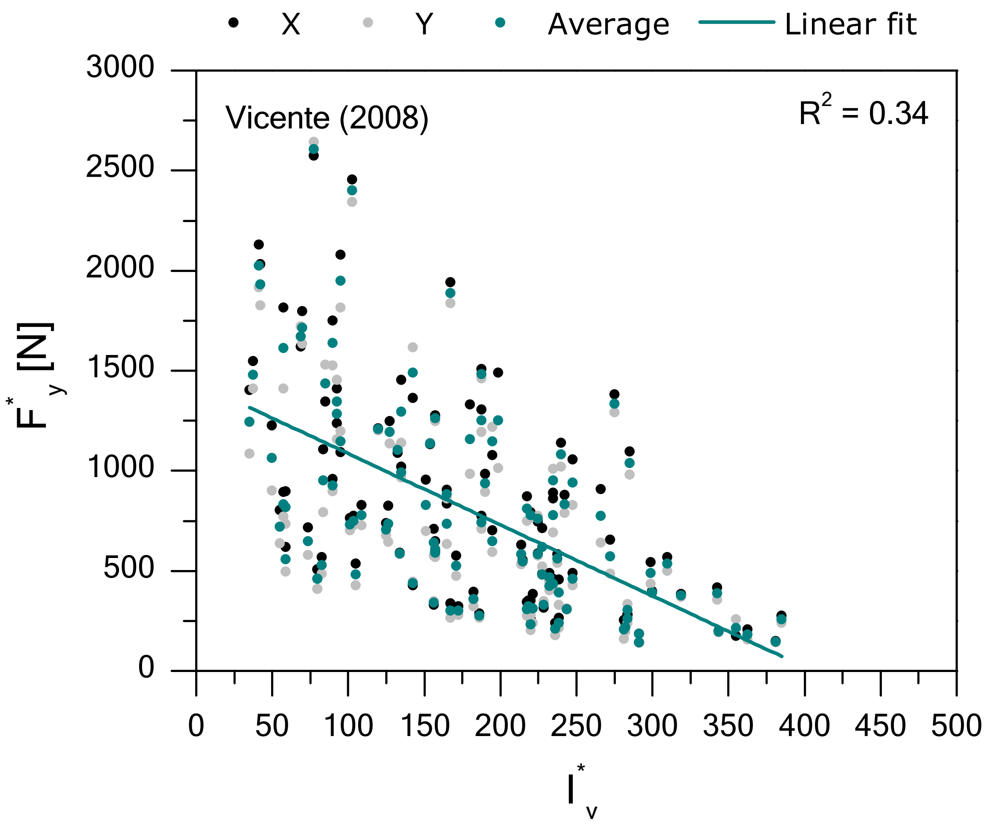

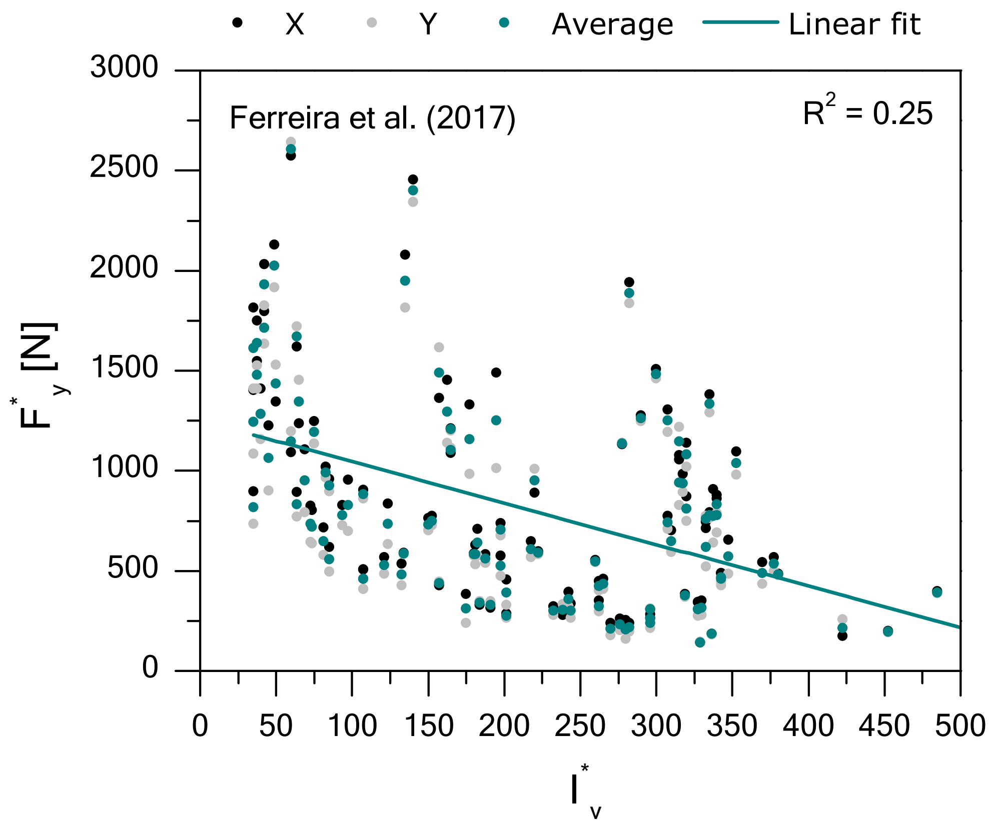

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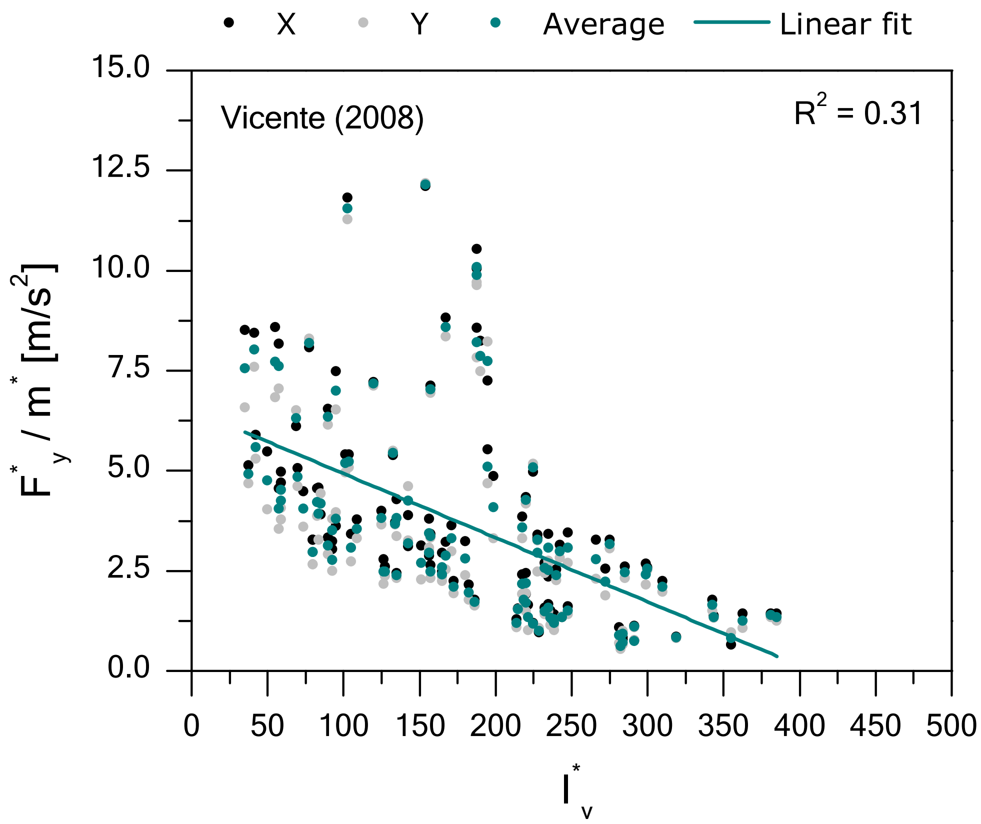
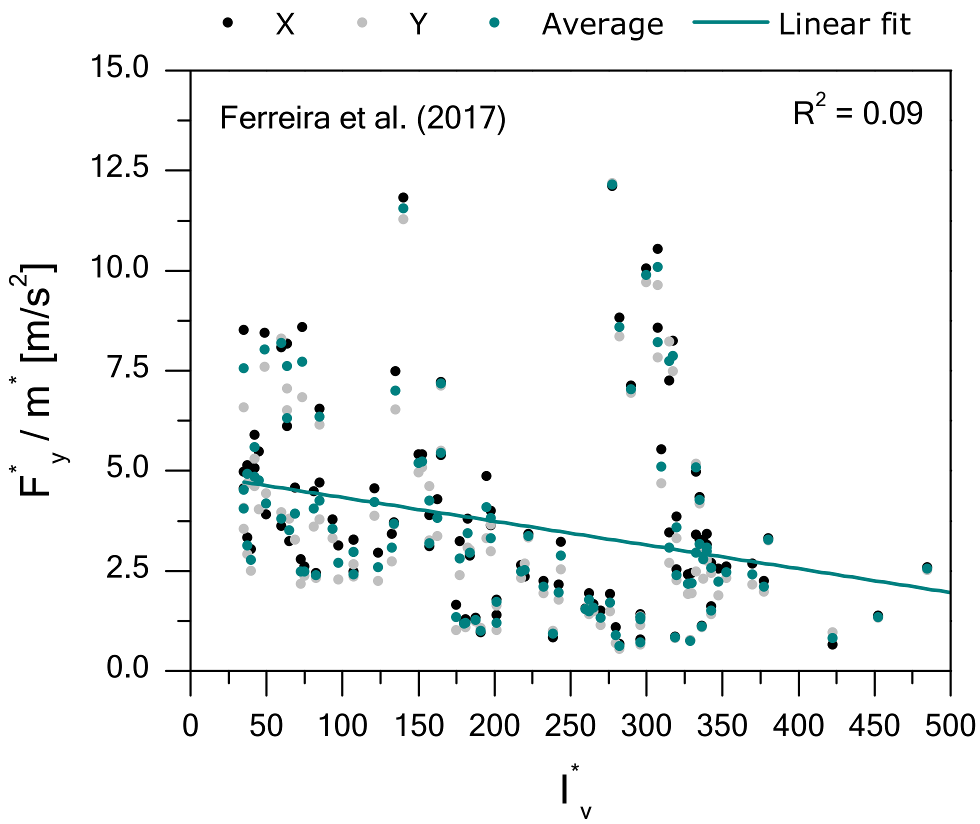
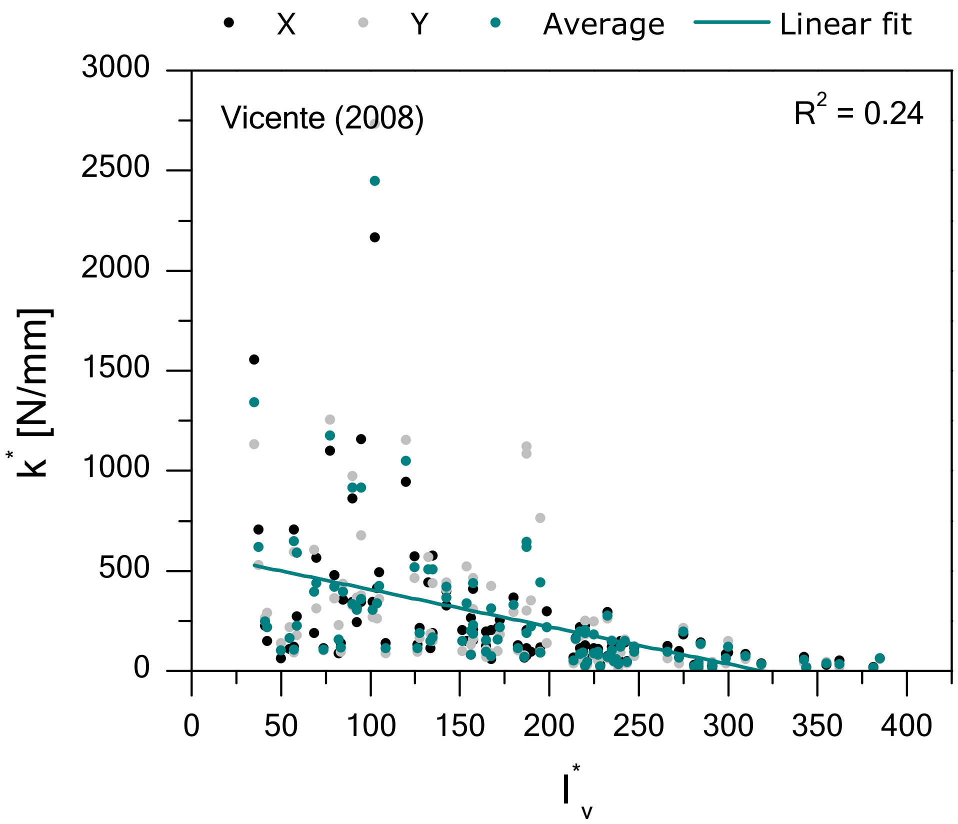
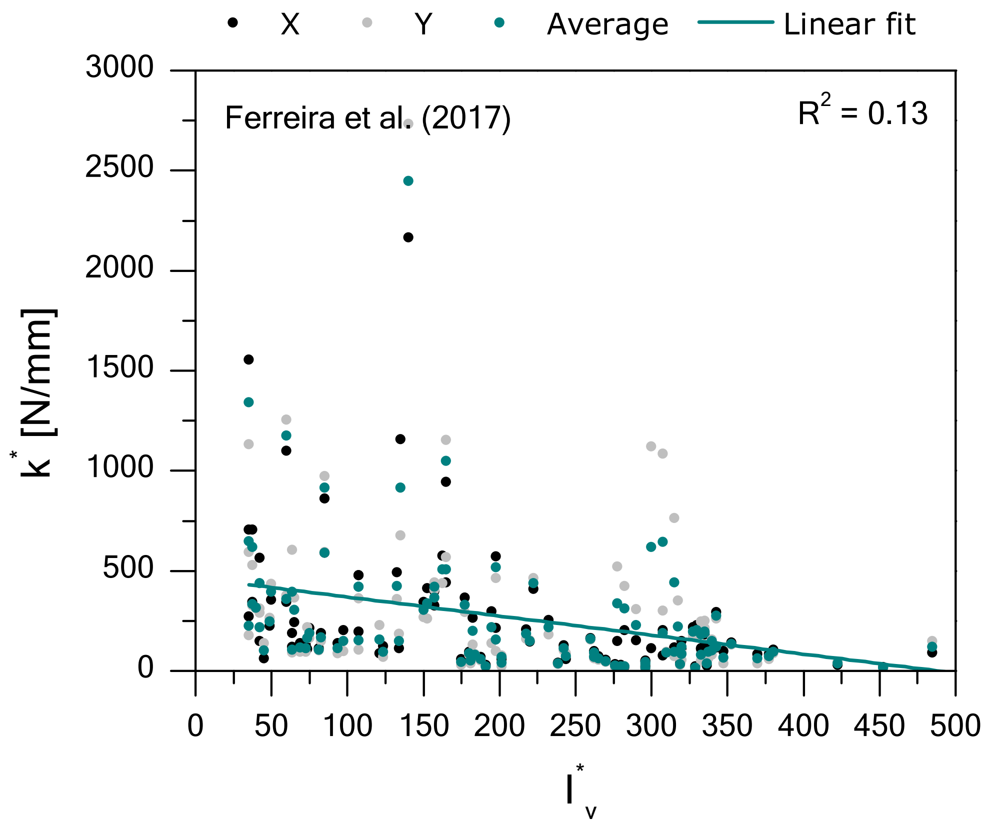


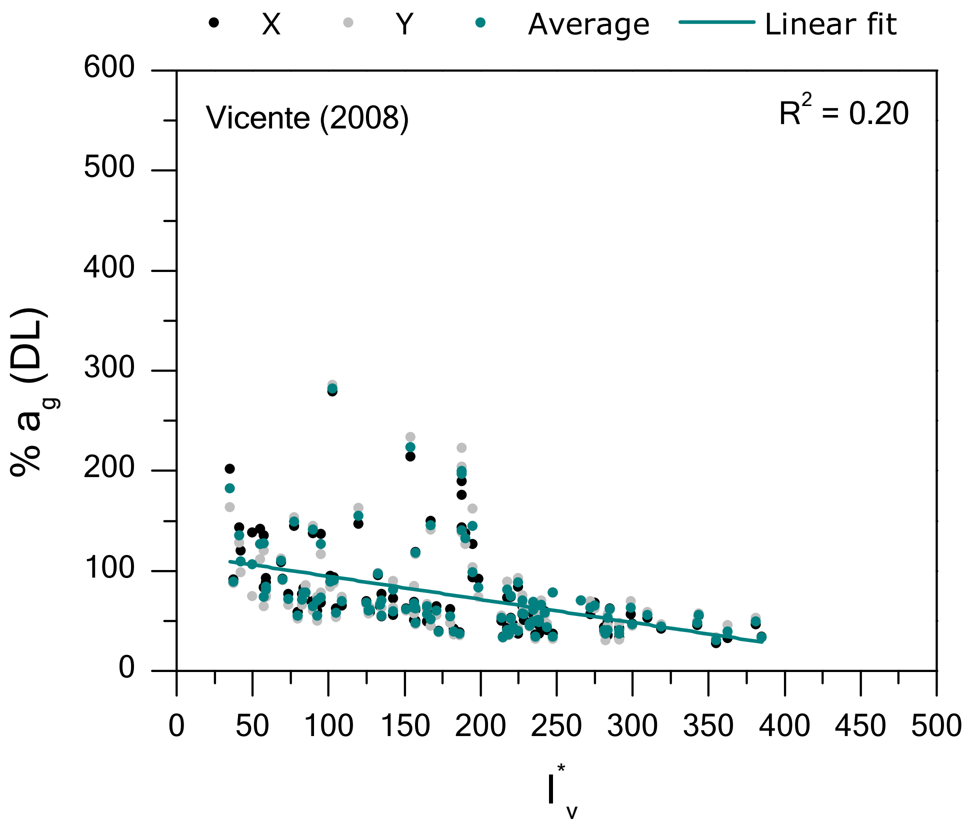


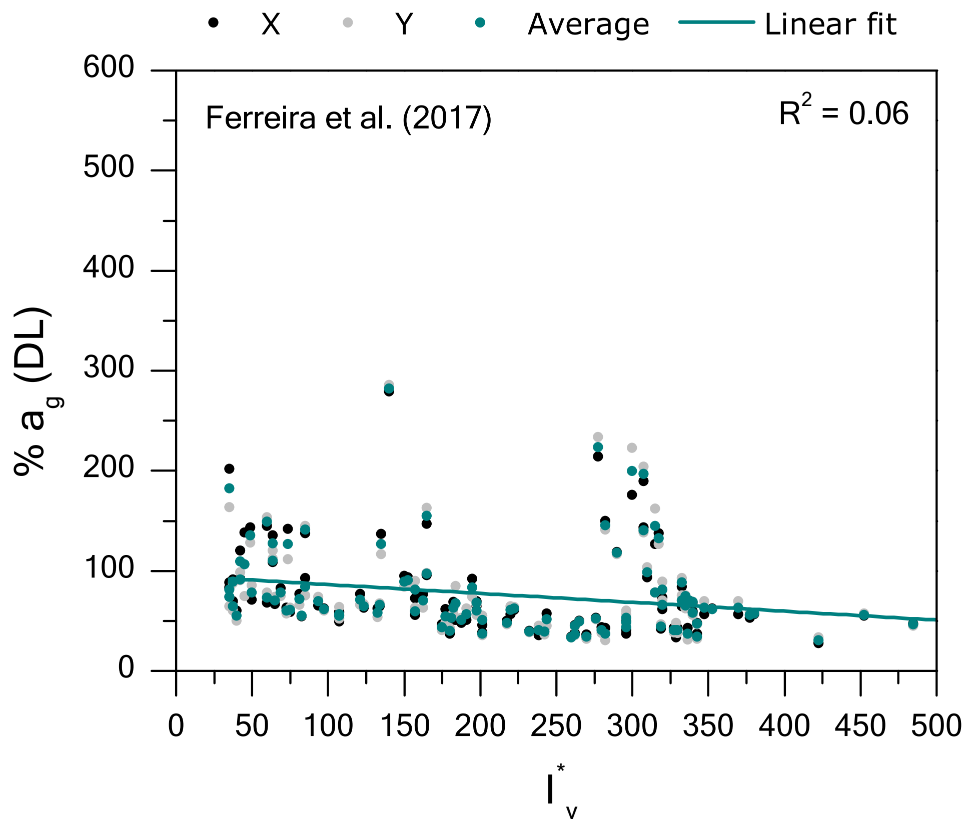
preliminary results



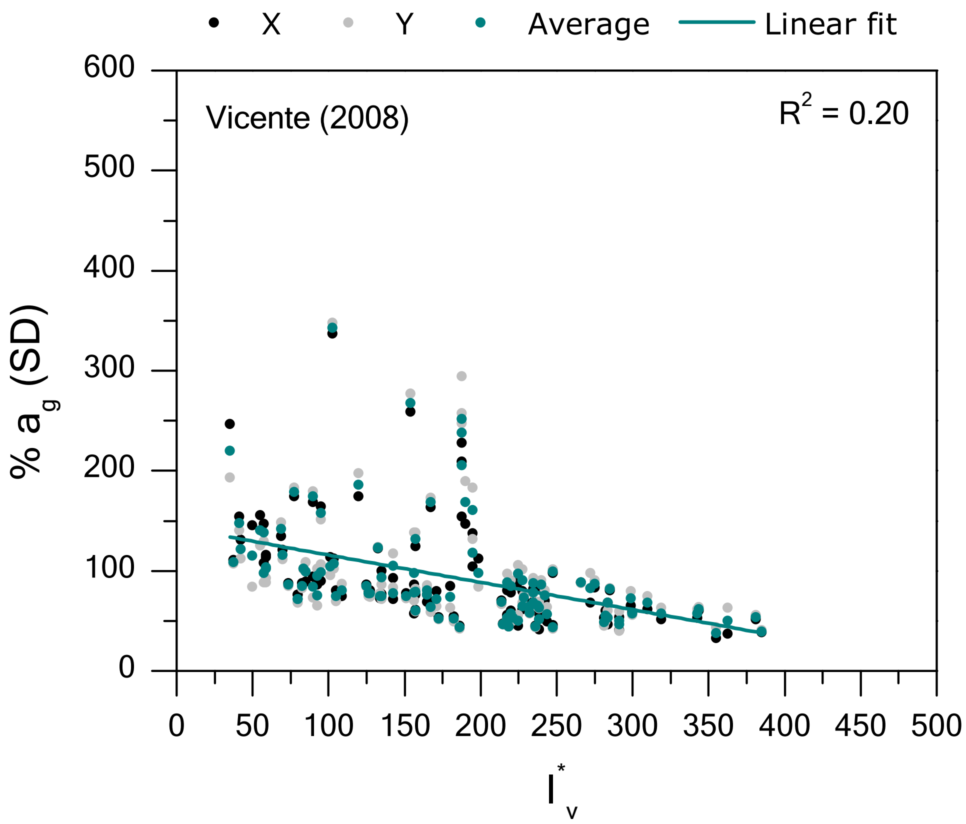


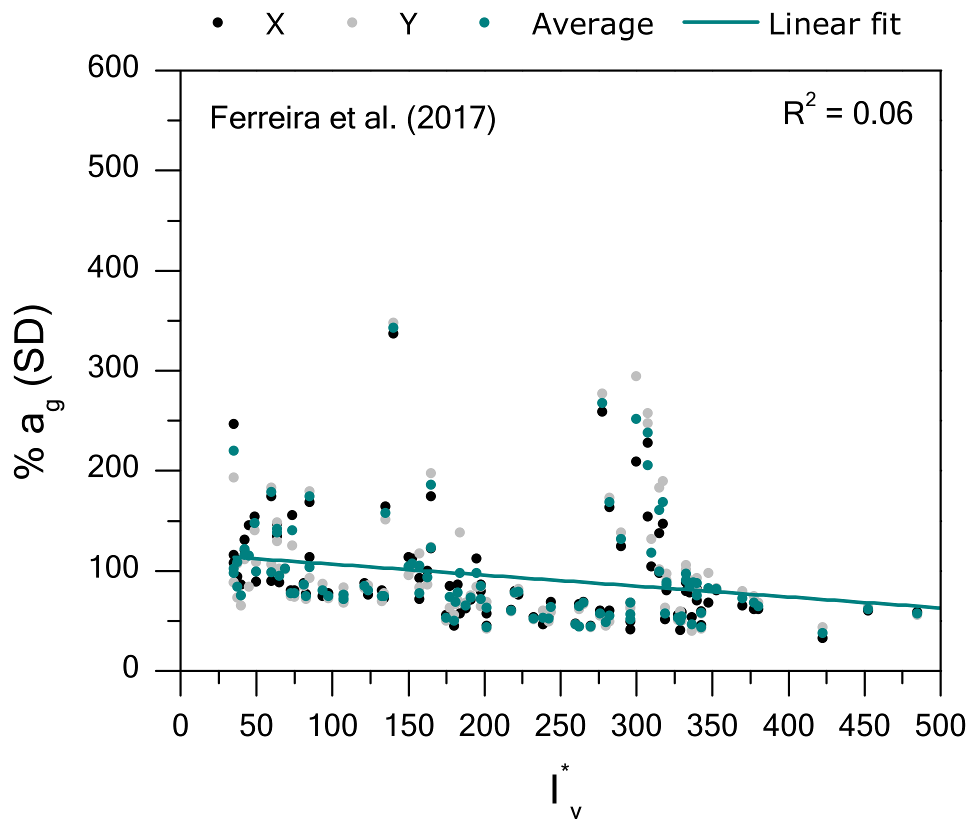
preliminary results



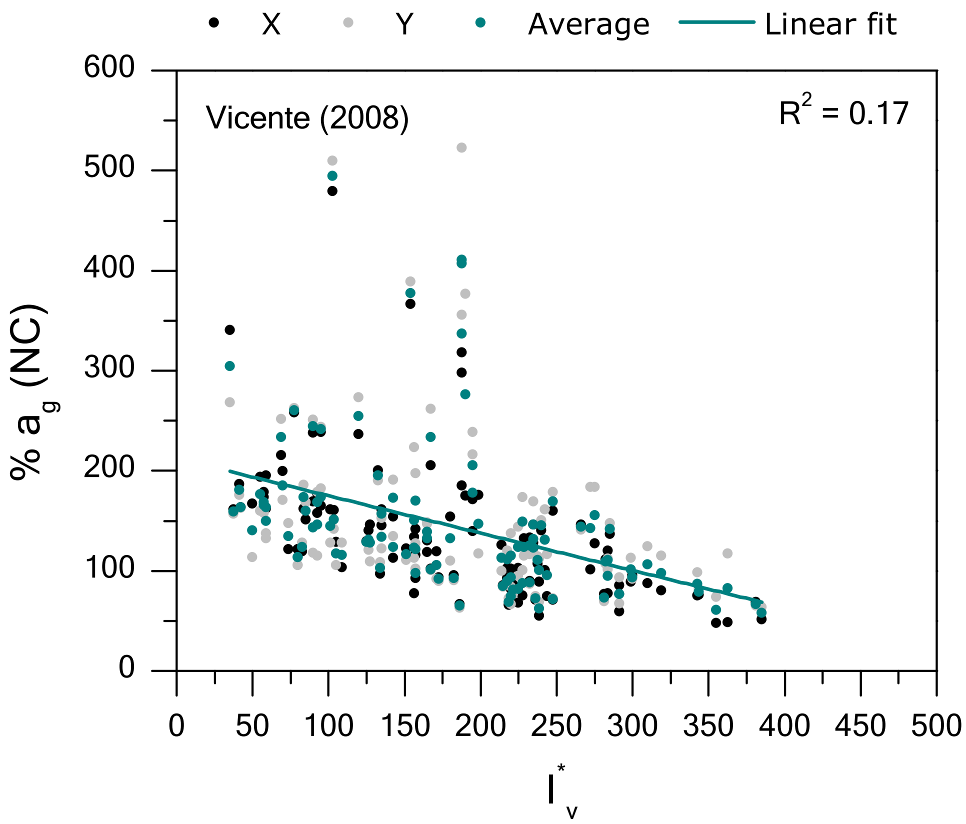


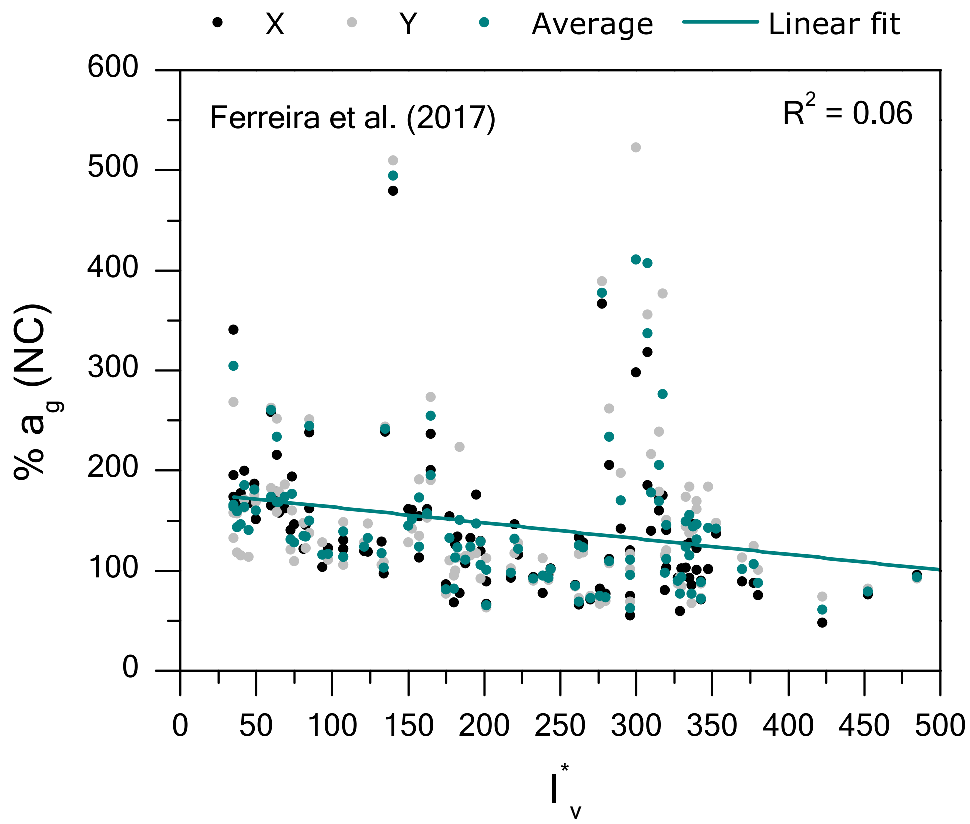
preliminary results





preliminary results





preliminary results

No. models	112	29	31	22	30
Variable	Total	1-story	2-story	3-story	4-story
d*y	0.20	0.07	0.02	0.36	0.29
d*NC	0.19	0.07	0.00	0.23	0.20
F*y	0.34	0.02	0.48	0.63	0.34
F*y/m*	0.31	0.01	0.54	0.76	0.18
k*	0.24	0.16	0.24	0.52	0.46
%ag DL	0.20	0.03	0.50	0.50	0.02
%ag SD	0.20	0.02	0.50	0.67	0.05
%ag NC	0.16	0.01	0.46	0.67	0.09
average	0.23	0.05	0.34	0.54	0.20

discussion

- The results show a reasonable correlation between the I_v and the global characteristics of the sample;
- In general, a better fitting was obtained for the weights proposed originally by Vicente (2008);
- This study confirms the ability of the vulnerability index method to rank the buildings within the same typology;
- However, the global seismic performance has proved to be extremely sensitive to local order issues, demonstrating for this reason, a weaker correlation with the vulnerability index (which translates the effect of buildings global characteristics only);
- This happens because we are trying to drift the definition of the seismic action from its original use, i.e., from macroseismic intensity to response spectrum (a highly nonlinear problem).

Further developments

- Study the possibility of using different curve fitting functions;
- Introduce the variability of the soil type by testing different distribution functions;
- Identify which properties have more impact over the global seismic performance;
- Investigate the possibility of developing of a new hybrid method that could provide a rough estimate of the global capacity curve of a large number of structure (within the same building typology) and the respective $\%a_g$ values, using the vulnerability index, I_v, as input.

Thank you for your attention

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