The 49nd Risk, Hazard & Uncertainty Workshop Hydra 2023

Damage level uncertainty and the impact on fragility curves for URM buildings

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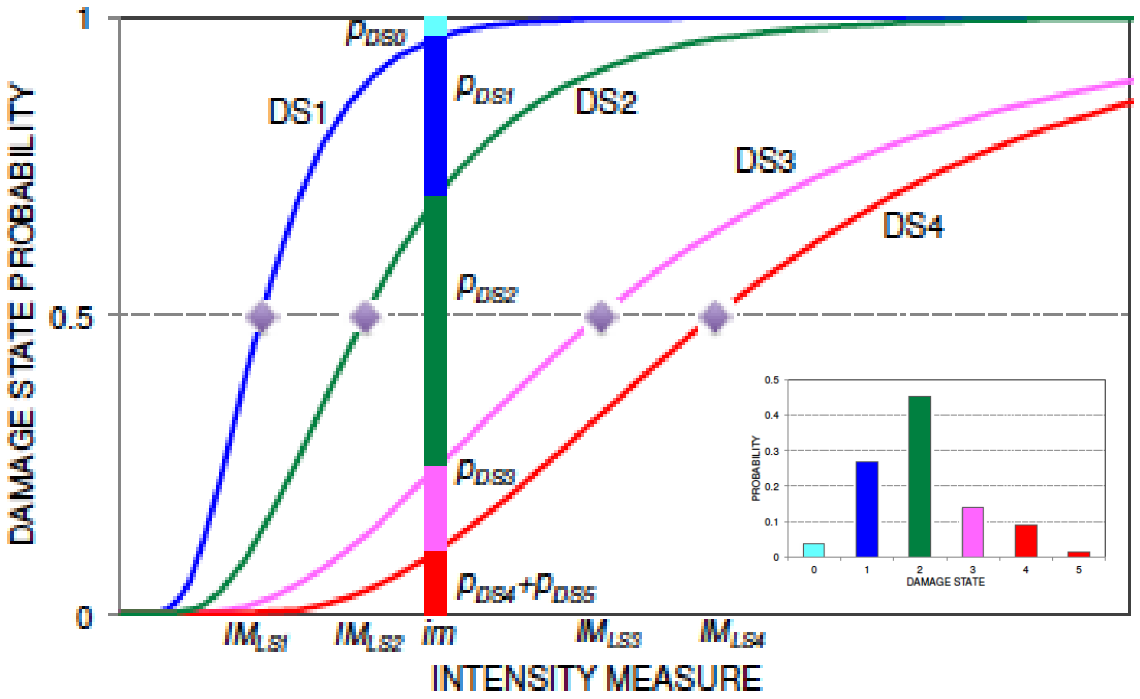
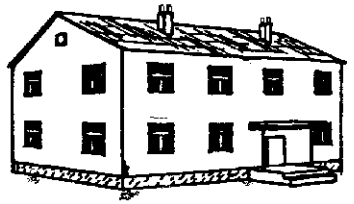
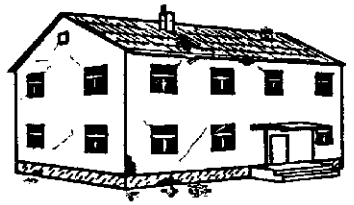
FRAGILITY CURVES AND DAMAGE STATES



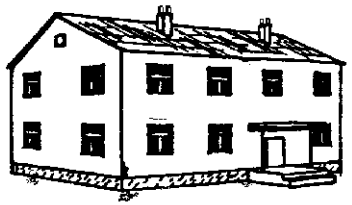
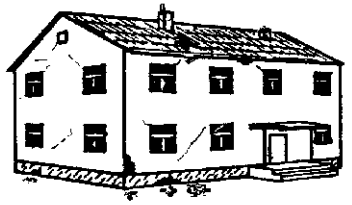
$$P[IM_{DM} < im] = \Phi\left[\frac{log\left(\frac{im}{IM_{DM}}\right)}{\beta_{DM}}\right]$$

$$\beta_{DM} = \sqrt{\beta^2_{hazard} + \beta^2_{rec} + \beta^2_{damage\ level} + \beta^2_{capacity}}$$

Classification of damage to masonry buildings	
	**Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage)** Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases.
	**Grade 2: Moderate damage (slight structural damage, moderate non-structural damage)** Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys.
	**Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)** Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls).
	**Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage)** Serious failure of walls; partial structural failure of roofs and floors.
	**Grade 5: Destruction (very heavy structural damage)** Total or near total collapse.

EMS98 scale (Gruntal 1998)

DAMAGE STATES ACCORDING TO EMS98

Classification of damage to masonry buildings	
	**Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage)** Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases.
	**Grade 2: Moderate damage (slight structural damage, moderate non-structural damage)** Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys.
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EMS98 scale (Gruntal 1998)

Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)

Large and extensive cracks in most walls.

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DAMAGE STATES ACCORDING TO EMS98

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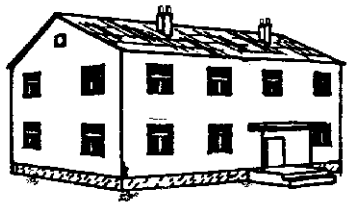
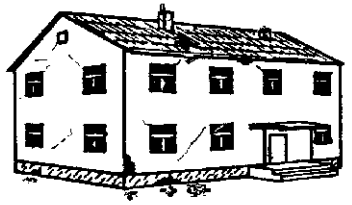
	**Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage)** Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases.
	**Grade 2: Moderate damage (slight structural damage, moderate non-structural damage)** Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys.
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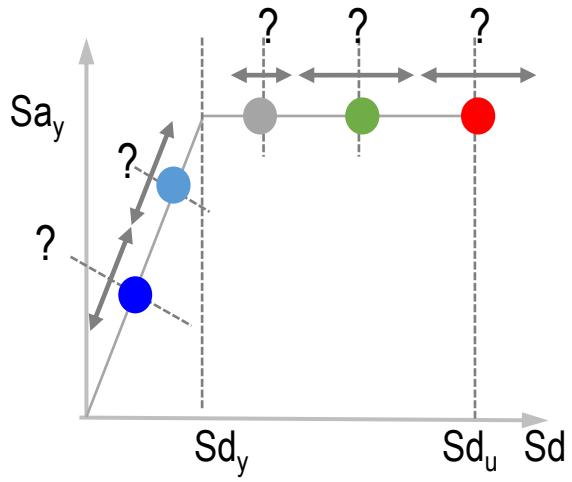
EMS98 scale (Gruntal 1998)

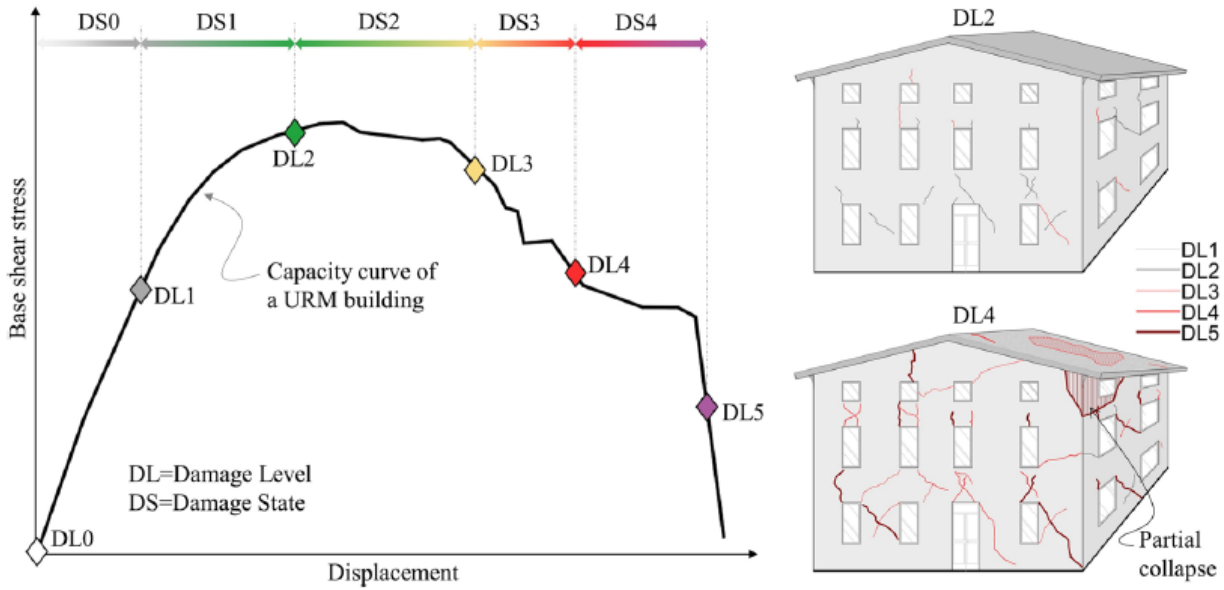
Accumuli

San Francesco Square, East side

After August 24

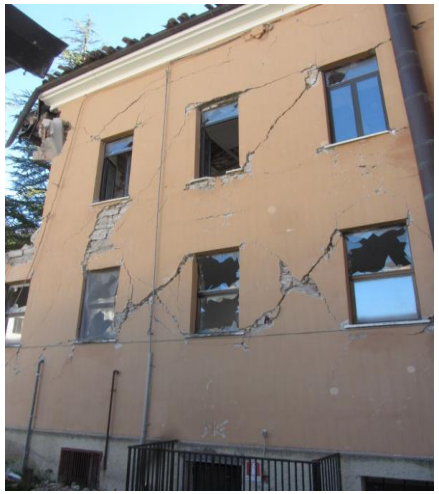
HOW DSs MAY BE DEFINED VARYING THE APPROACHES ADOPTED FOR DERIVING FRAGILITY FUNCTIONS?





- **EMPIRICAL APPROACH**: IT REQUIRES CONVERSION RULES AND DAMAGE METRICS
- **MECHANICAL- NUMERICAL**: USUALLY BY MONITORING SELECTED ONE OR MORE EDPs THROUGH THE NUMERICAL MODEL
- **MECHANICAL-ANALYTICAL**: VARYING THE APPROACH, BASED ON EDPs OR CONVENTIONAL THRESHOLDS DIRECTLY DEFINED ON THE PUSHOVER CURVES

EMPIRICAL APPROACH



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AeDES FORM - Italy

SCHEDA DI 1° LIVELLO DI RILEVAMENTO DANNO, PRONTO INTERVENTO E AGIBILITÀ PER EDIFICI ORDINARI NELL'EMERGENZA POST-SISMICA

(AeDES 07/2013)

PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile

CONFERENZA DELLE REGIONI E DELLE PROVINCE AUTONOME

ATC-45 FORM - USA

ATC-45 Rapid Evaluation Safety Assessment Form

Inspection

Inspector ID: _____ Inspection date: _____

Affiliation: _____ Inspection time: _____ ☐ AM ☐ PM

Areas inspected: ☐ Exterior only ☐ Exterior and interior

EMPIRICAL APPROACH

ATC-45 FORM - USA

Evaluation

Investigate the building for the conditions below and check the appropriate column.

Observed Conditions:	Minor/None	Moderate	Severe
Collapse, partial collapse, or building off foundation	☐	☐	☐
Building significantly out of plumb or in danger	☐	☐	☐
Damage to primary structural members, racking of walls	☐	☐	☐
Falling hazard due to nonstructural damage	☐	☐	☐
Geotechnical hazard, scour, erosion, slope failure, etc.	☐	☐	☐
Electrical lines / fixtures submerged / leaning trees	☐	☐	☐
Other (specify) _____	☐	☐	☐

Estimated Building Damage (excluding contents)

- ☐ None
- ☐ >0 to <1%
- ☐ 1 to <10%
- ☐ 10 to <30%
- ☐ 30 to <70%
- ☐ 70 to <100%
- ☐ 100%

☐ See back of form for further comments.

Posting

Choose a posting based on the evaluation and team judgment. Severe conditions endangering the overall building are grounds for an Unsafe posting. Localized Severe and overall Moderate conditions may allow a Restricted Use posting.

☐ **INSPECTED** (Green placard) ☐ **RESTRICTED USE** (Yellow placard) ☐ **UNSAFE** (Red placard)

Record any use and entry restrictions exactly as written on placard: _____

_____

_____

Number of residential units vacated: _____

AeDES FORM - Italy

Component		DAMAGE: D4-D5 Very heavy or collapse > 2/3 (A)	D4-D5 1/3 - 2/3 (B)	D4-D5 < 1/3 (C)	D2-D3 Medium or heavy > 2/3 (D)	D2-D3 1/3 - 2/3 (E)	D2-D3 < 1/3 (F)	D1 Slight > 2/3 (G)	D1 1/3 - 2/3 (H)	D1 < 1/3 (I)	D0 Null (L)
1	Vertical structures	☐	☐	☐	☐	☐	☐	☐	☐	☐	○
2	Horizontal structures	☐	☐	☐	☐	☐	☐	☐	☐	☐	○
3	Stairs	☐	☐	☐	☐	☐	☐	☐	☐	☐	○
4	Roof	☐	☐	☐	☐	☐	☐	☐	☐	☐	○
5	URM Infill walls	☐	☐	☐	☐	☐	☐	☐	☐	☐	○
6	Pre-existing damage	☐	☐	☐	☐	☐	☐	☐	☐	☐	○

Level / Extension

BOTH CONTAIN PRECIOUS INFORMATION ON THE DAMAGE BUT THE FINAL GOAL IS TO PROVIDE A **SYNTHETIC JUDGEMENT ON THE USABILITY and NOT ON THE DAMAGE LIKE EMS98**….

SECTION 8 Usability assessment

Risk evaluation

RISK	STRUCTUAL (Sect. 3 e 4)	NONSTRUCTURAL (Sect. 5)	EXTERNAL (sect. 6)	GEOTECHNICAL (sect. 7)
LOW	○	○	○	○
LOW WITH COUNTERMEASURES	○	○	○	○
HIGH	○	○	○	○

Usability Classification

A	USABLE building	○
B	UNUSABLE building (totally or partially), but USABLE after short term countermeasures	○
C	PARTIALLY UNUSABLE building (1)	⊘
D	TEMPORARILY UNUSABLE building requiring a more detailed investigation	○
E	UNUSABLE building	○
F	UNUSABLE building due to external risk (1)	○

(1) Restrictions on building use must be clearly reported in the notes when building is classified as B or C; causes of external risk when building is classified as F.

EMPIRICAL APPROACH

AeDES FORM - Italy

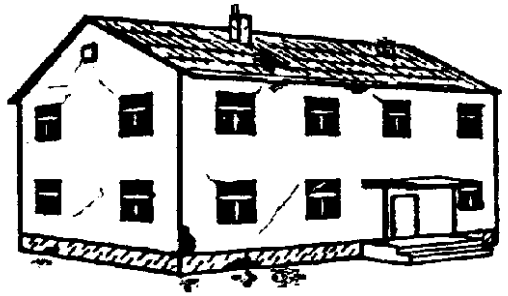
Component		DAMAGE: D4-D5 Very heavy or collapse > 2/3	D4-D5 1/3 - 2/3	D4-D5 < 1/3	D2-D3 Medium or heavy > 2/3	D2-D3 1/3 - 2/3	D2-D3 < 1/3	D1 Slight > 2/3	D1 1/3 - 2/3	D1 < 1/3	D0 Null
Level / Extension		A	B	C	D	E	F	G	H	I	L
1	Vertical structures	☐	☐	☐	☐	☐	☐	☐	☐	☐	○
2	Horizontal structures	☐	☐	☐	☐	☐	☐	☐	☐	☐	○
3	Stairs	☐	☐	☐	☐	☐	☐	☐	☐	☐	○
4	Roof	☐	☐	☐	☐	☐	☐	☐	☐	☐	○
5	URM Infill walls	☐	☐	☐	☐	☐	☐	☐	☐	☐	○
6	Pre-existing damage	☐	☐	☐	☐	☐	☐	☐	☐	☐	○

DAMAGE TO EACH ELEMENT

- Multiple choice possibility
- Combination rule function of the extension of damage: $\sum e_i \leq 1$
- With *i* each structural or non-structural element

ESTIMATE OF THE GLOBAL DAMAGE STATE

EMS-98



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CONVERSION RULE

EMPIRICAL APPROACH

SOME PROPOSALS AVAILABLE FOR URM buildings

Integral damage metric (UniGE) Lagomarsino et al. 2021

$$D_{AeDES} = \sum_{i=1}^{5} w_i \sum_{j=1}^{3} (2j-1)v_{i,j}$$

Weigth assigned to components

Survey	Vertical	Horizontal	Stairs	Roof	Infills
Complete survey	0.6	0.2	0	0.2	0
Survey from outside	0.8	0	0	0.2	0

It accounts for the spread and severity of damge

vi,j : 1 (A); 2/3 (B), 1/3 (C), 0 (when no option is indicated). Where: A—spread on more than 2/3; B— between 1/3 and 2/3; C—< 1/3).

Peak damage metric (DADO) Dolce et al. 2019

D4-D5 Gravissimo	D3-D2 Medio-Grave	D1 Leggero	Danno nullo	Livello danno
			✓	0
			✓	0
		<1/3		1
		1/3-2/3		1
		>2/3		1
	<1/3			2
	<1/3	<1/3		2
	<1/3	1/3-2/3		2
	<1/3	>2/3		2
	1/3-2/3	<1/3		3
	1/3-2/3			3
	>2/3			3
<1/3				3
<1/3		<1/3		3
<1/3		1/3-2/3		3
<1/3	<1/3			3
<1/3	<1/3	<1/3		3
<1/3	1/3-2/3			4
<1/3	>2/3			4
1/3-2/3				4
1/3-2/3		1/3-2/3		4
1/3-2/3	<1/3			4
1/3-2/3	1/3-2/3			5
>2/3				5
>2/3		<1/3		5
>2/3	<1/3			5

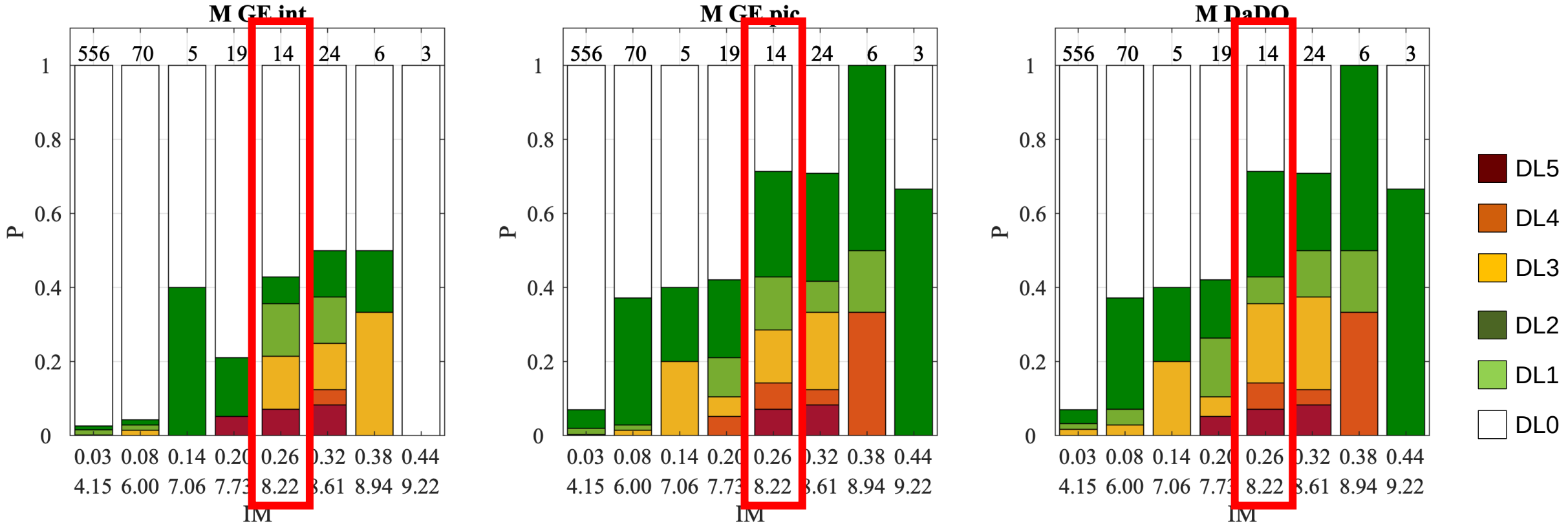
Peak damage metric (UniGE) Di Ludovico et al. 2022

EMS-98	URM buildings	
	Peak damage	Secondary damage
DS0	D0	
DS1	D1- <1/3 D1 - 1/3-2/3 D1- >2/3 D2-D3 - <1/3	D1 =0
DS2	D2-D3 - <1/3 D2-D3 - 1/3-2/3	D1 >0
DS3	D2-D3 - >2/3 D4-D5 - <1/3	D2-D3 <1/3
DS4	D4-D5 - <1/3 D4-D5 - 1/3-2/3	D2-D3 ≥1/3
DS5	D4-D5 - >2/3	

Lagomarsino, Cattari, Ottonelli (2021) Bulletin of Earthquake Engineering, 10.1007/s10518-021-01063-7
Di Ludovico M. et al (2022) Bulletin of Earthquake Engineering, https://doi.org/10.1007/s10518-022-01535-4
Dolce et al. (2019) Bollettino Di Geofisica Teorica Ed Applicata, 60(2), 141-164. doi:10.4430/bgta0254

IMPACT OF CONVERSION RULES IN DPMs

URM schools , L'Aquila 2009 earthquake



Integral damage metric (UniGE)
Lagomarsino et al. 2021

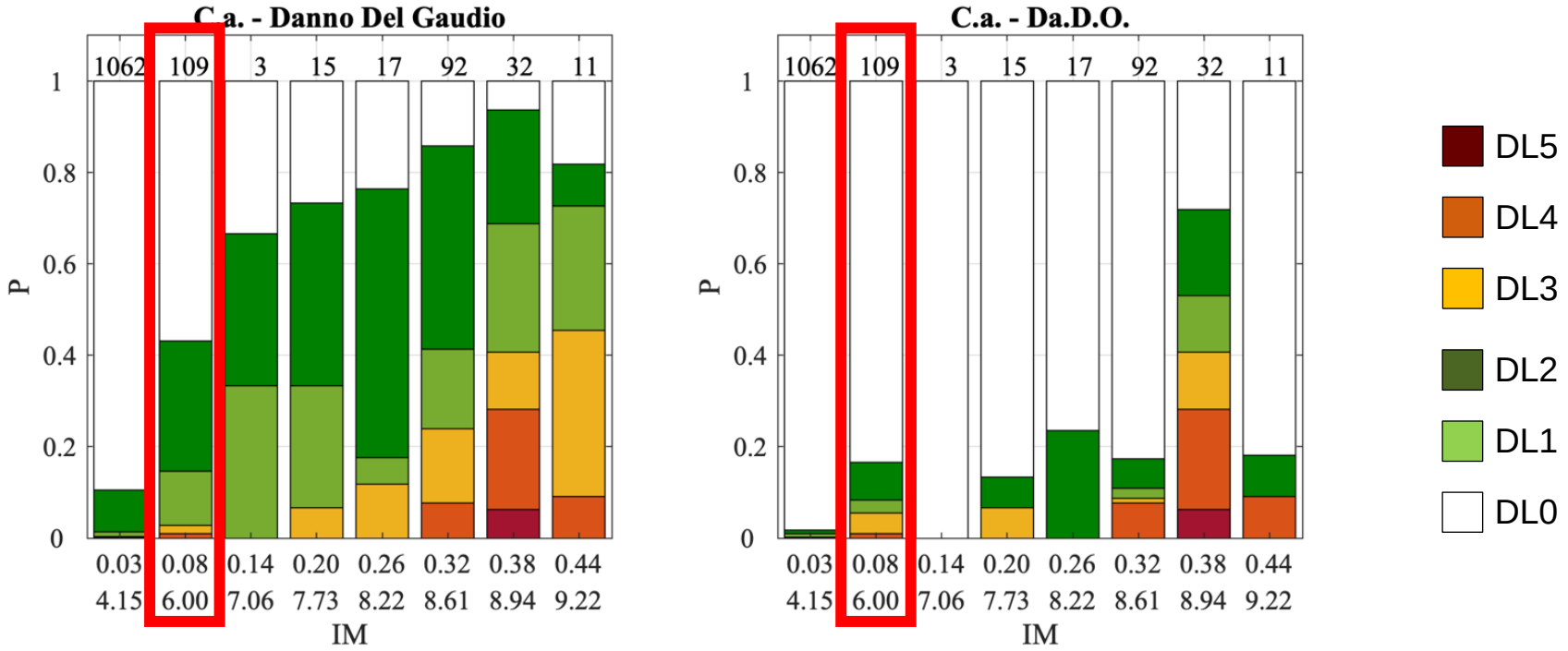
Peak damage metric (UNIGE)
Di Ludovico et al. 2022

Peak damage metric (DADO)
Dolce et al. 2019

EMPIRICAL APPROACH

Example for RC buildings …

RC schools , L'Aquila 2009 earthquake



DAMAGE METRIC THAT CONSIDER BOTH NON-STRUCTURAL COMPONENTS AND STRUCTURAL COMPONENTS

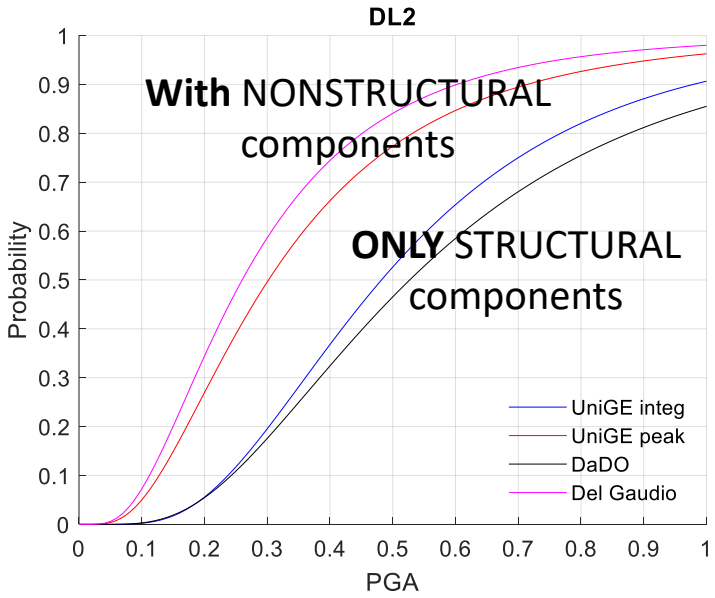
DAMAGE METRIC THAT CONSIDER **ONLY** STRUCTURAL COMPONENTS

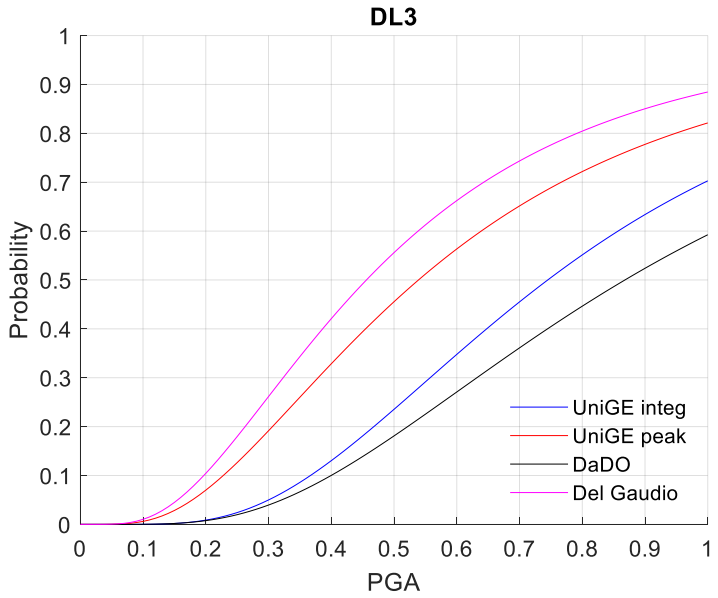
Del Gaudio et al. (2016) Bull Earthquake Eng 14: 2643-2678, DOI 10.1007/s10518-016-9919-2
Di Ludovico M. et al (2022) Bulletin of Earthquake Engineering, https://doi.org/10.1007/s10518-022-01535-4

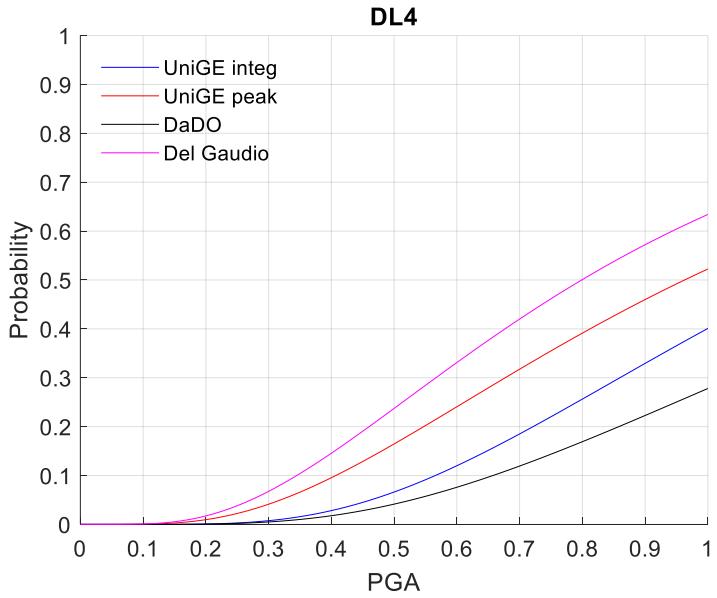
EMPIRICAL APPROACH

Impact on fragility curves …

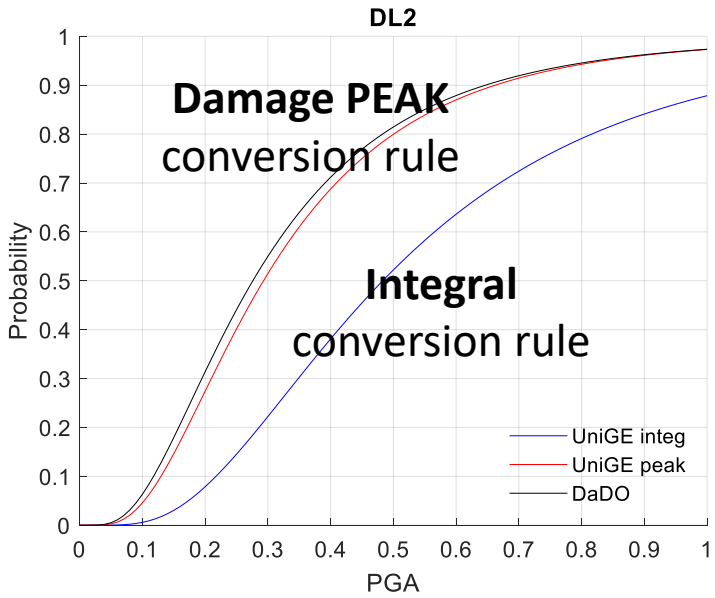
RC school buildings

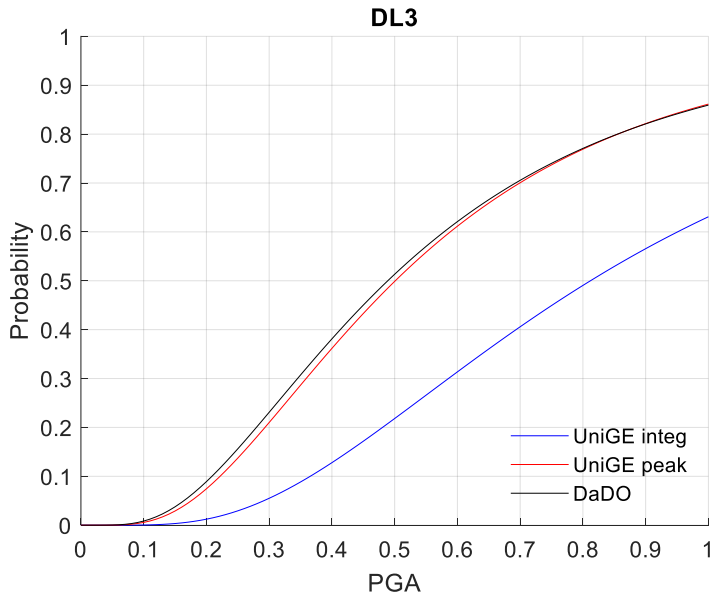


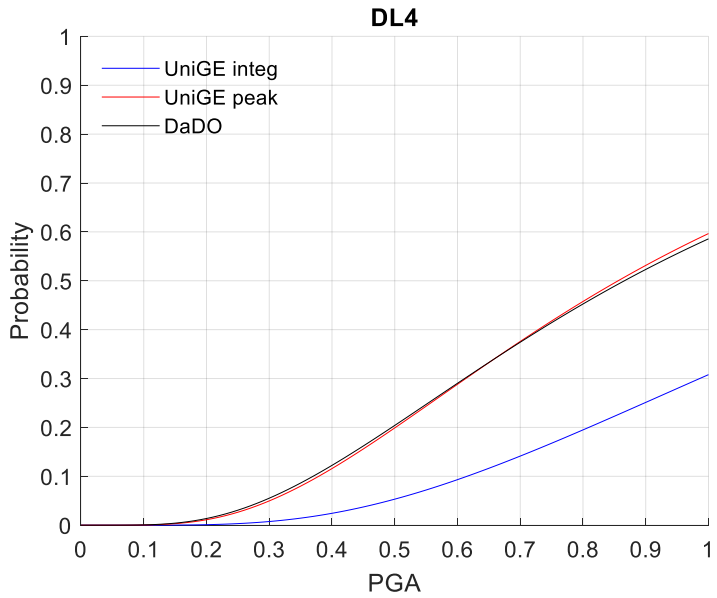




URM school buildings

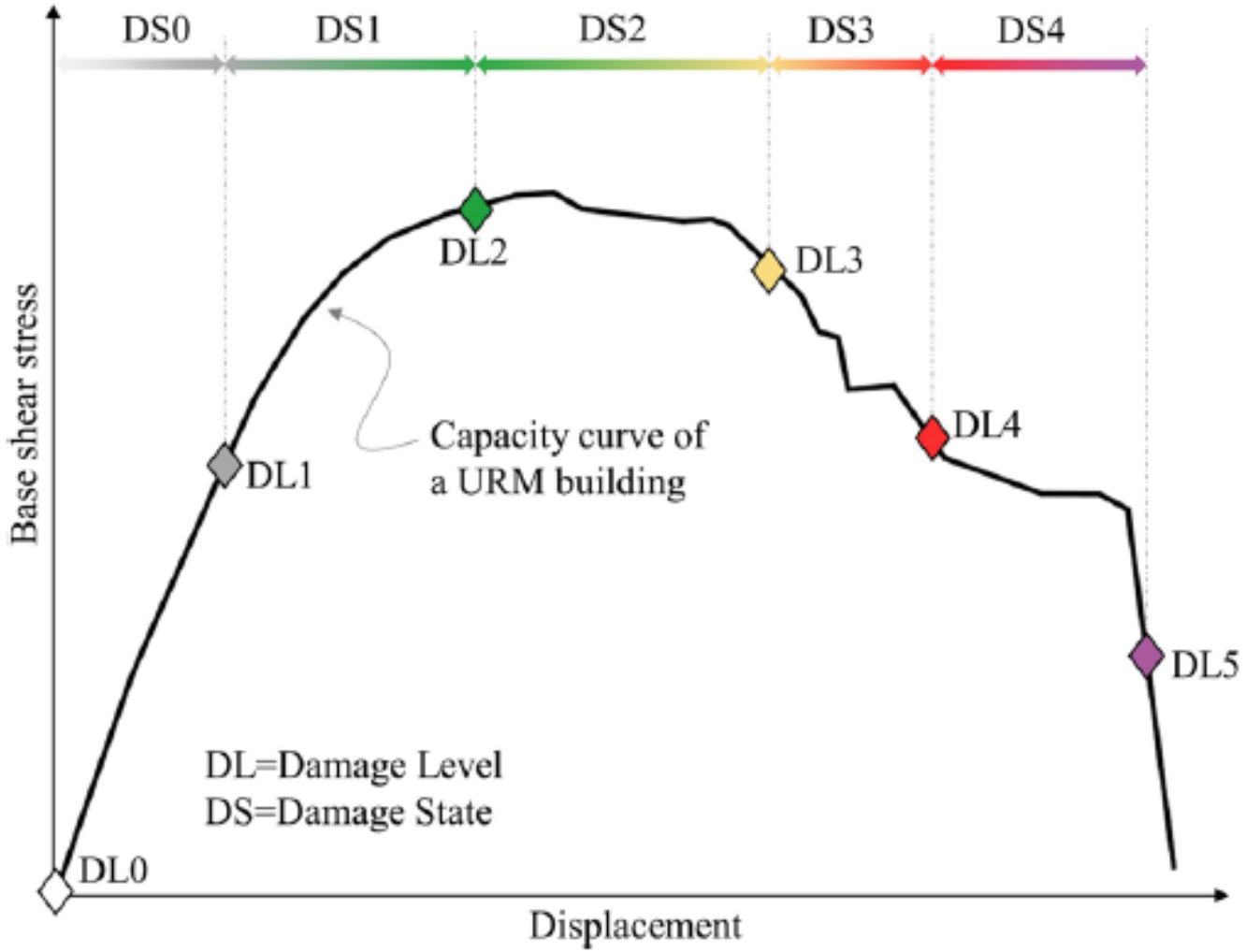






MECHANICAL APPROACH

THE QUITE COMMON APPROACH … *(by referring only to the GLOBAL IN-PLANE response)*



Is to define displacement/roof drift/maximum inter-storey drift (***i.e. the selected EPD***) thresholds on the pushover curves associated to the attainment of given «**conventional conditions**».

Usually «these conditions» refer to the **attainment of given values of the base-shear rate** while in some case they are also defined on the basis of **multi-criteria approaches** which consider the spread of damage.

SOME EXAMPLES FROM LITERATURE… *The RINTC PROJECT*

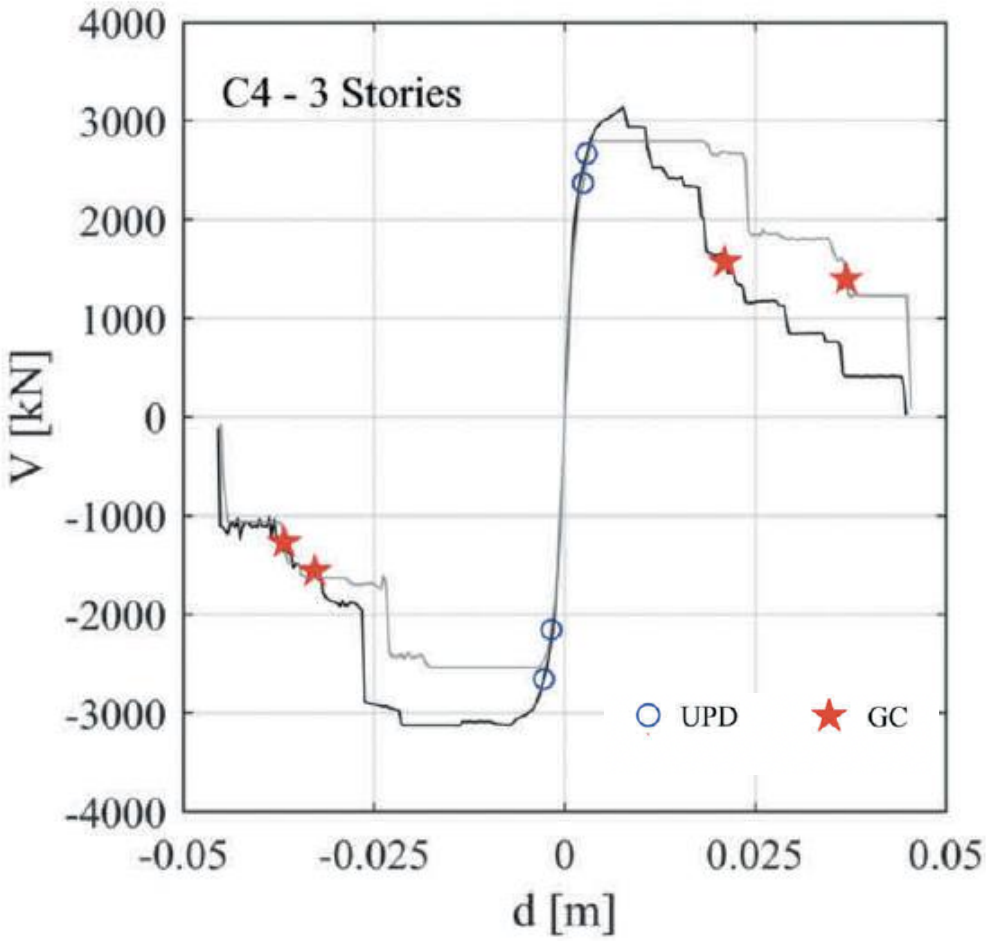
the **GC- GLOBAL COLLAPSE** was identified as the one corresponding to a 50% post-peak deterioration of the total base shear of the building and the maximum inter-story drift among all walls in the direction of analysis at all stories recorded

$$Y_{GC} = max\left(\frac{\theta_{max,X}}{\theta_{GC,X}}; \frac{\theta_{max,Y}}{\theta_{GC,Y}}\right)$$

with θmax;X and θmax;Y maxima inter-story drifts in the two directions recorded during the time-history analysis.

the **UPD- Usability- Prevention Damage** was identified by a multi-criteria approach

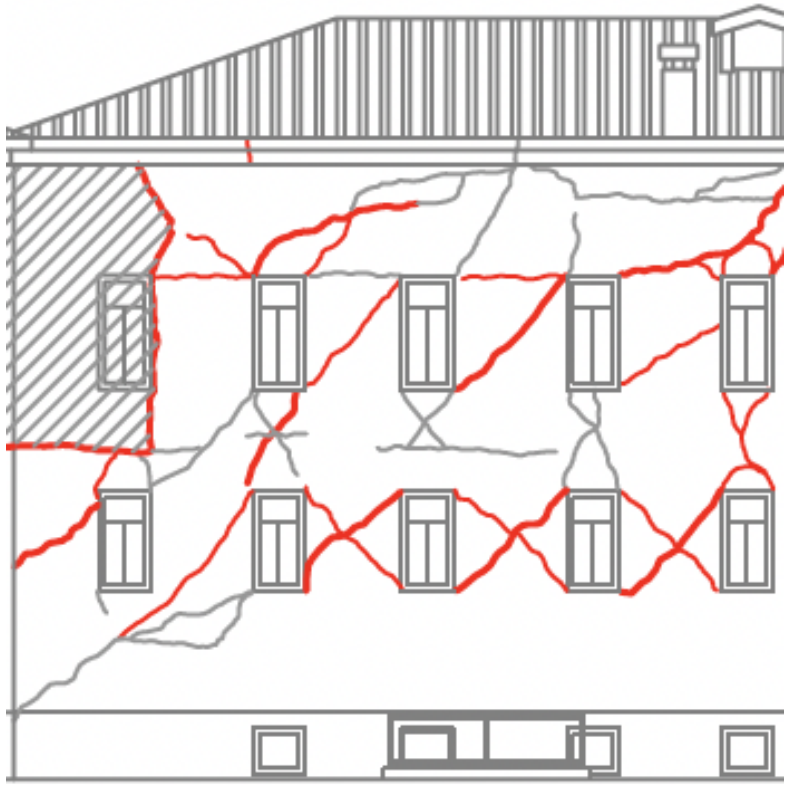
(A) 50% of masonry piers (in terms of resistant area) reached the condition of light/moderate damage;
(B) one masonry pier reached a severe damage condition (drift threshold corresponding to DL3, as indicated in Table 1, for the *NLBEAM*-model or attainment of the toe-crushing or shear failure condition for the macroelement model);
(C) the base shear has reached the 95% of the peak resistance.

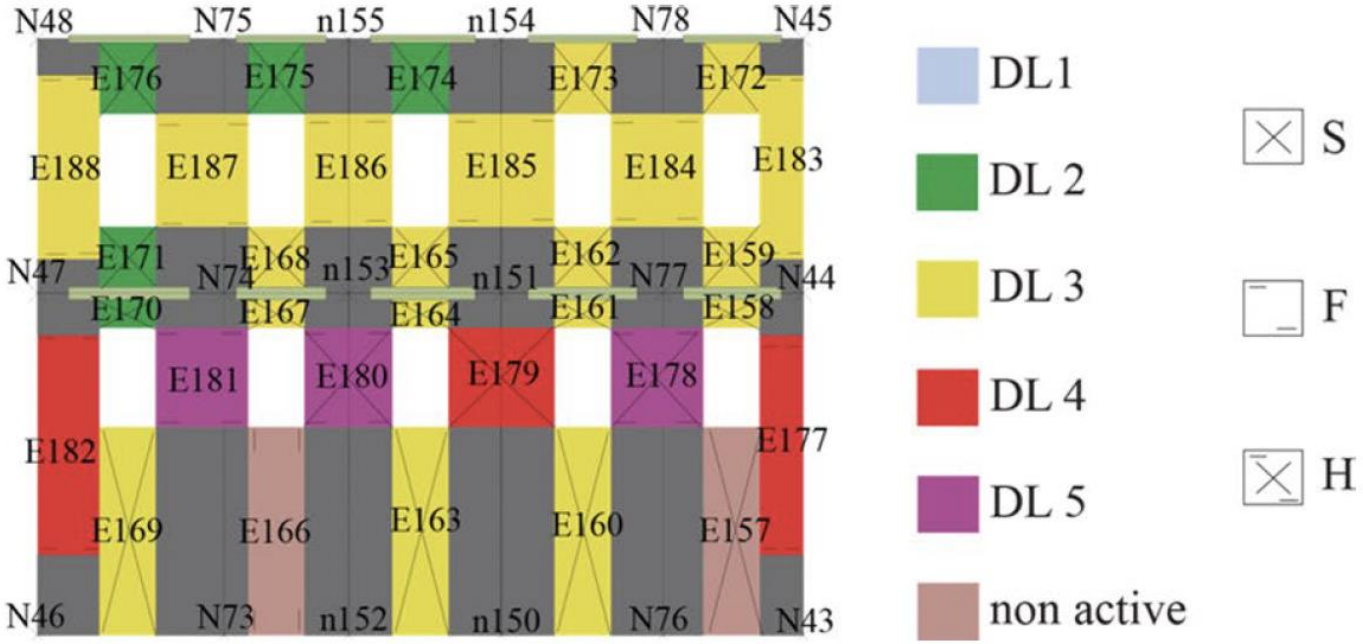


Cattari et al. (2018) https://doi.org/10.1080/13632469.2018.1541030 (Criteria adopted in RINTC project)

MECHANICAL-NUMERICAL APPROACH

Proposal for attributing a synthetic DL coherent to EMS98 in a consistent way from either numerical analyses and observed data and that - in case of NLDA – is auto-consistent (i.e. without relying on results of NLSA)



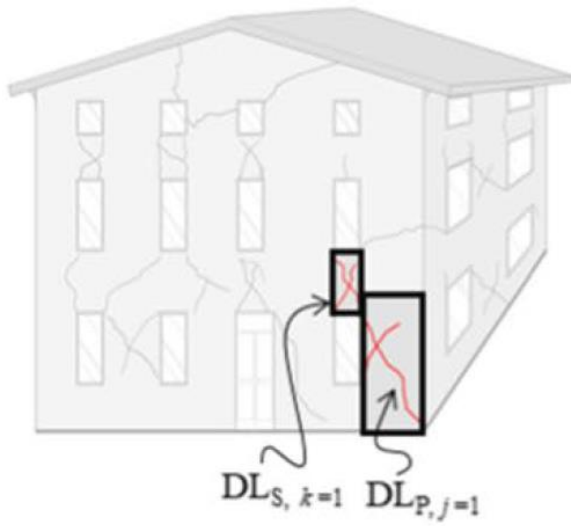


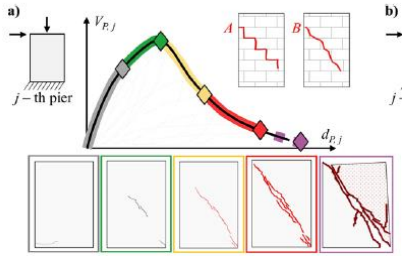
Cattari and Angiolilli (2022) https://doi.org/10.1007/s10518-022-01504-x

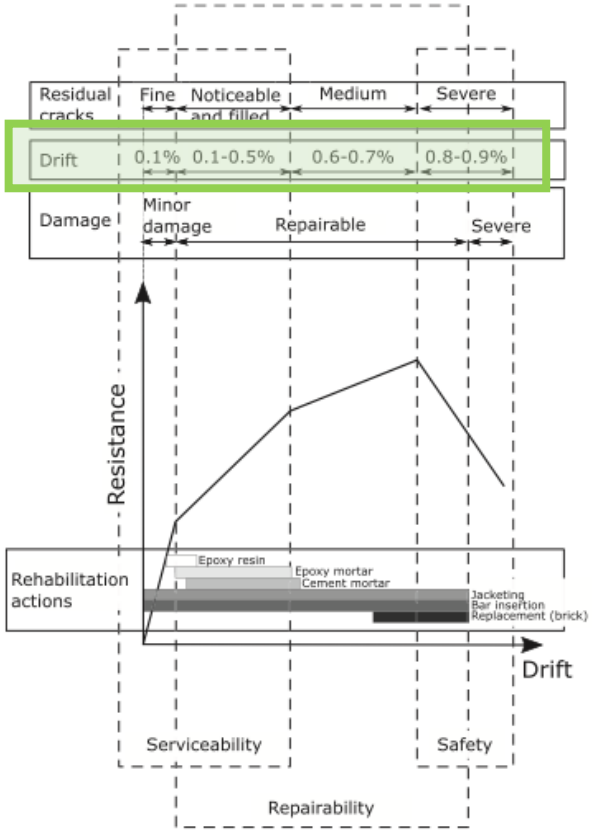
MECHANICAL-NUMERICAL APPROACH

Proposal for attributing a synthetic DL coherent to EMS98 in a consistent way from either numerical analyses and observed data and that - in case of NLDA – is auto-consistent (i.e. without relying on results of NLSA)

Damage Level at panel scale







Bosiljkov et al. (2014)

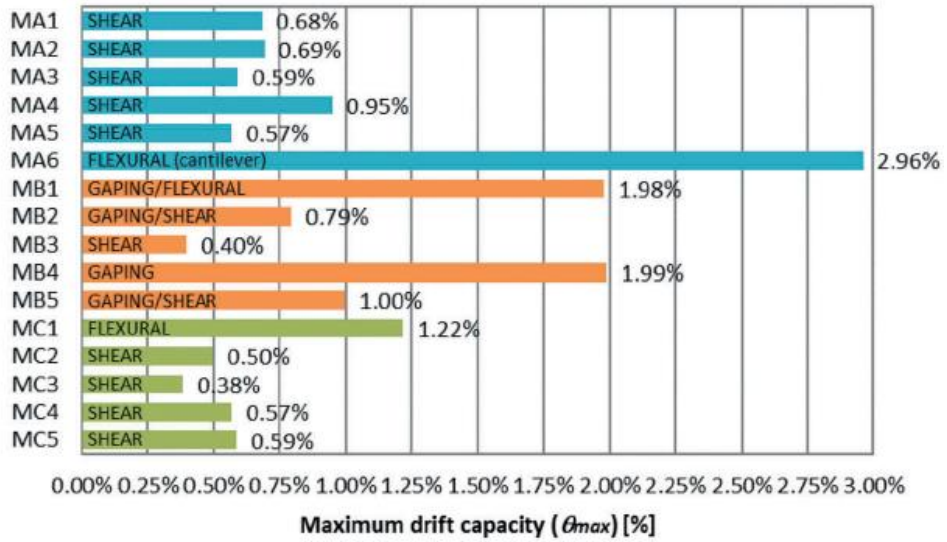


Figure 15. Maximum drift, θ_{max}.

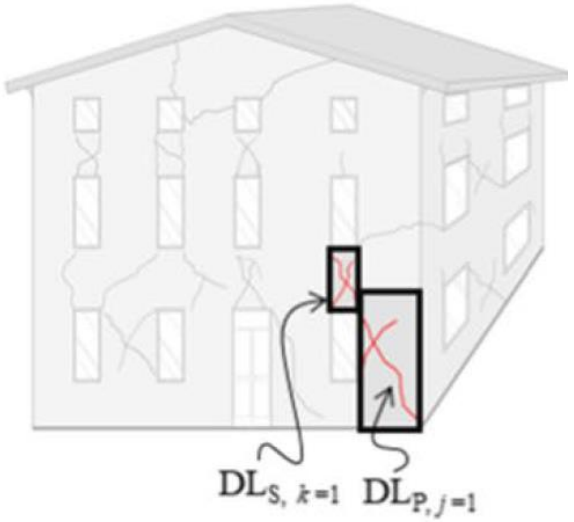
Vanin, F. et al (2017) doi:10.1007/s10518-017-0188-5
Morandi, P. et al (2021).doi:10.1080/13632469.2019.1586801

Cattari and Angiolilli (2022) https://doi.org/10.1007/s10518-022-01504-x

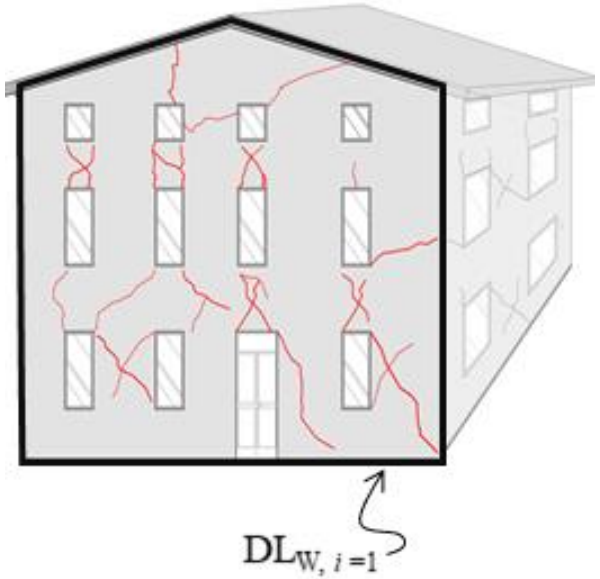
MECHANICAL-NUMERICAL APPROACH

Proposal for attributing a synthetic DL coherent to EMS98 in a consistent way from either numerical analyses and observed data and that - in case of NLDA – is auto-consistent (i.e. without relying on results of NLSA)

Damage Level at panel scale

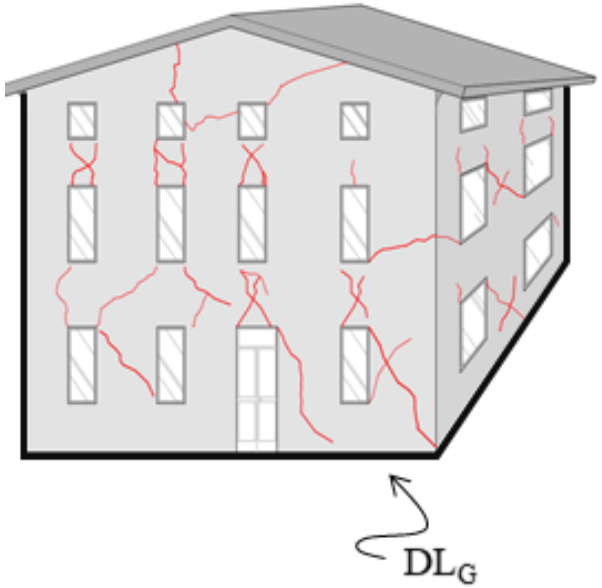


Damage Level at Macroelement (Wall) scale



- Correlation between $D_{P,j}$ and $DL_{S,\ k}$ of each *i*-th wall to obtain $DL_{W,\ i}$

Damage State at GLOBAL SCALE

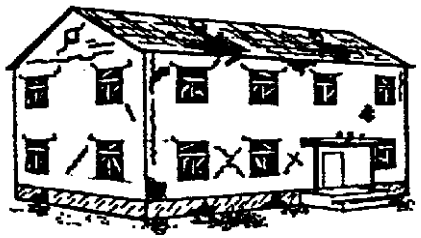


- Attribution of the weight $W_{W,\ i}$ for each *i*-th wall
- Sum of the $W_{W,\ i}$ for which a certain $DL_{W,\ i} = n$ occurred to obtain the extension of that DL
- Definition of the global DL (DL_G) through the extension data and the conversion criteria (Table 2)

Cattari and Angiolilli (2022) https://doi.org/10.1007/s10518-022-01504-x

MECHANICAL-NUMERICAL APPROACH

Proposal for attributing a synthetic DL coherent to EMS98 in a consistent way from either numerical analyses and observed data and that - in case of NLDA – is auto-consistent (i.e. without relying on results of NLSA)



Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)
Large and extensive cracks in most wal
Roof tiles detach. Chimneys fracture at
roof line; failure of individual non-struc
tural elements (partitions, gable walls).

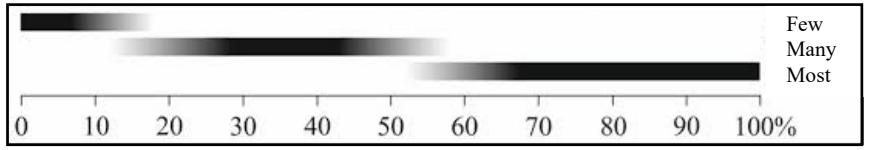


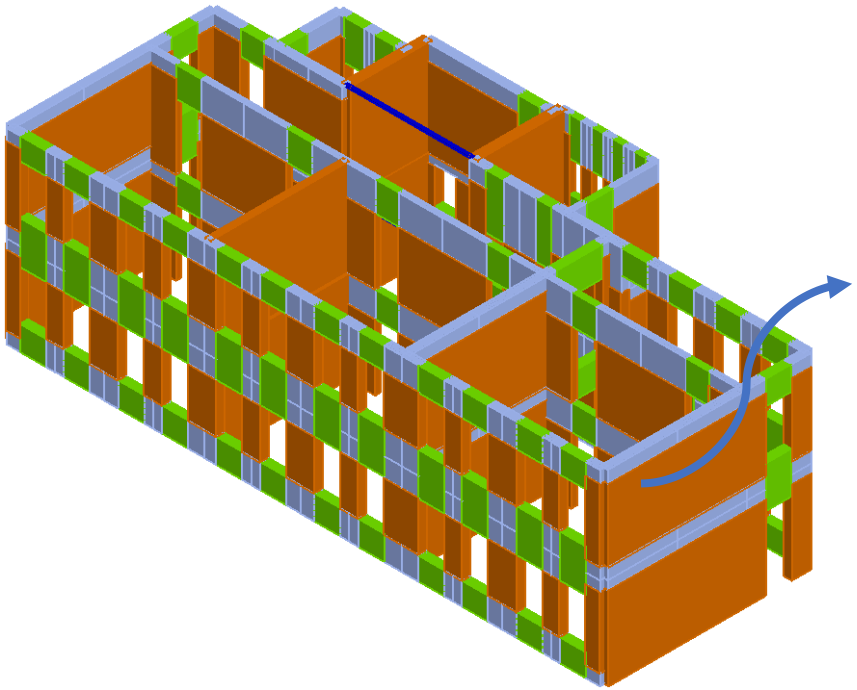
Table 2 Definition of the damage at the global scale from the EMS98 criteria (l = or; BN = but not) only associated with the structural vertical elements

DL_G	EMS98—description and quantification		Proposed conversion criteria to assign DL_G	
1	Negligible to slight damage (no structural damage, slight non-structural damage)	Hair-line cracks in a very few walls	$\sum_{DL_W \geq 1} \geq 0.2$ l	$0.1 \leq \sum_{DL_W=2} < 0.30$ BN $\sum_{DL_W \geq 3} \geq$ (
2	Moderate damage (slight structural damage, moderate non-structural damage)	Cracks in many walls	$\sum_{DL_W \geq 2} \geq 0.30$ l	$0 \leq \sum_{DL_W=3} < 0.50$ BN $\sum_{DL_W \geq 4} >$ (
3	Substantial to heavy damage (moderate structural damage, heavy non-structural damage)	Large and extensive cracks in most walls	$\sum_{DL_W \geq 3} \geq 0.50$	$0 \leq \sum_{DL_W=4} < 0.30$ BN $\sum_{DL_W=5} >$ (
4	Very heavy damage (heavy structural damage, very heavy non-structural damage)	Serious failure of walls	$\sum_{DL_W \geq 4} \geq 0.30$ l	$0.2 \leq \sum_{DL_W=5} < 0.50$
5	Destruction (very heavy structural damage)	Total or near total collapse	$\sum_{DL_W=5} \geq 0.50$	

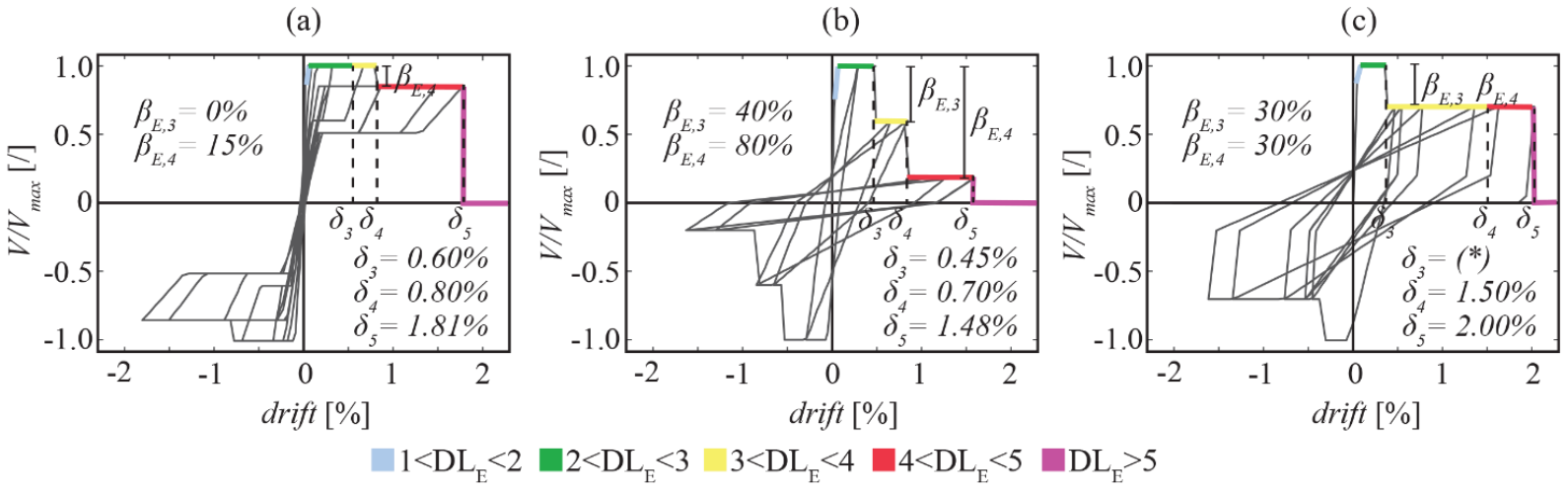
Rules to complete the descriptions of EMS98

Cattari and Angiolilli (2022) https://doi.org/10.1007/s10518-022-01504-x

ANALYTICAL-NUMERICAL APPROACH THROUGH NLDA



Equilvalent frame models representative of archetype of school buildings



Set of accelerograms selected for MARS ReLUIS project for performing NLDA according to CLOUD approach

Bulletin of Earthquake Engineering (2022) 20:4961–4987
https://doi.org/10.1007/s10518-022-01393-0

REVIEW ARTICLE

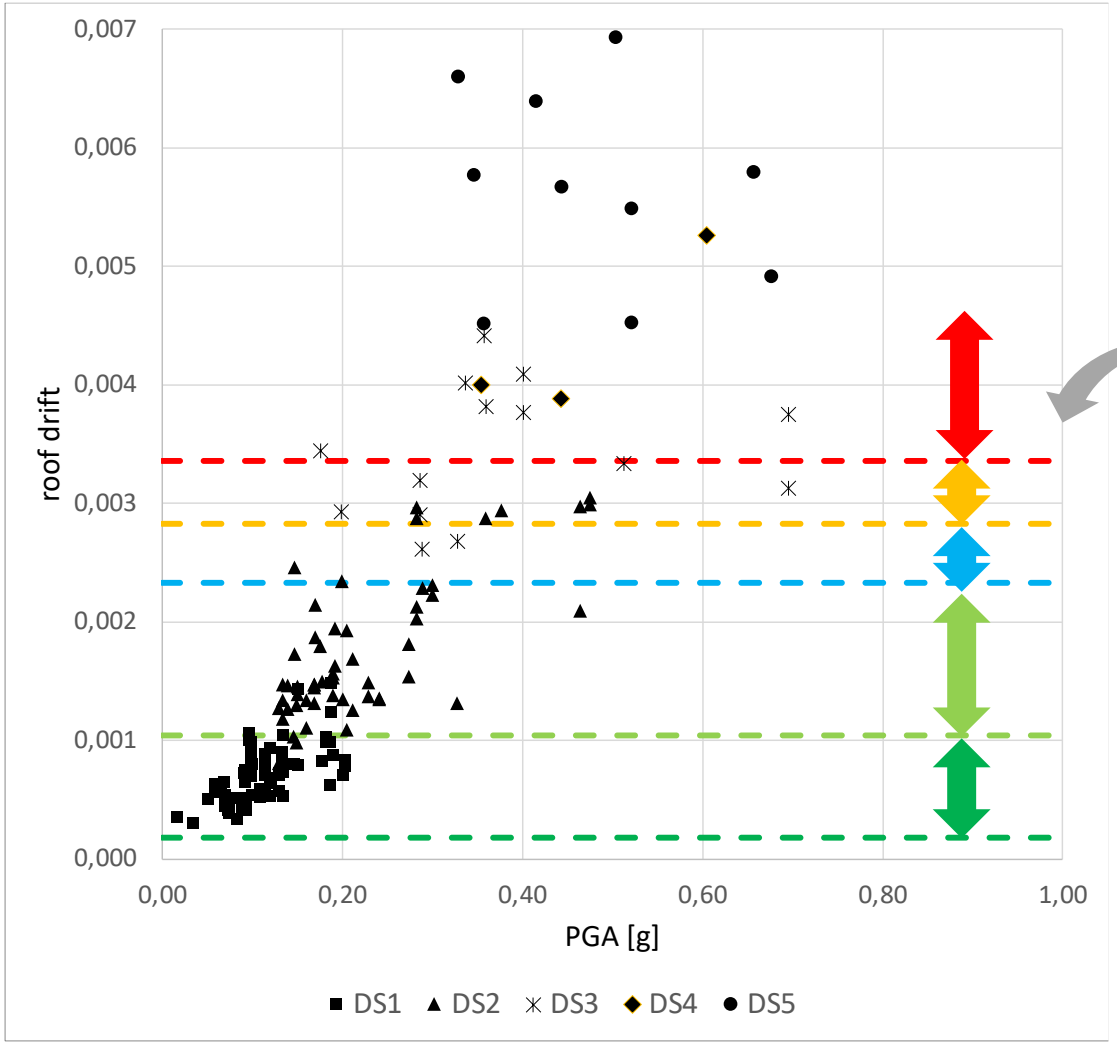
Check for updates

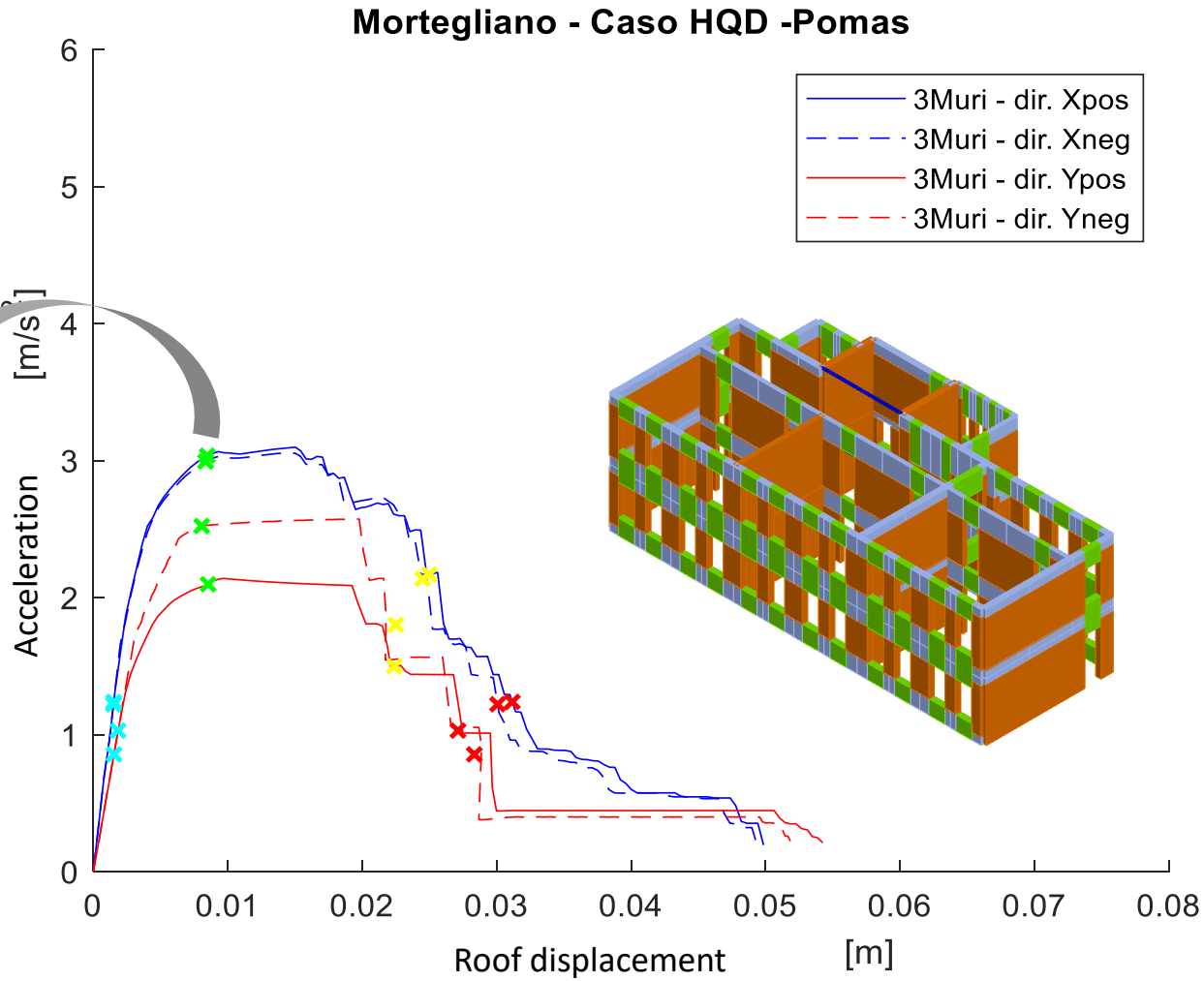
Selection and spectral matching of recorded ground motions for seismic fragility analyses

Vincenzo Manfredi[1] · Angelo Masi[1] · Ali Güney Özcebe[2] · Roberto Paolucci[3] · Chiara Smerzini[3]

ANALYTICAL-NUMERICAL APPROACH THROUGH NLDA

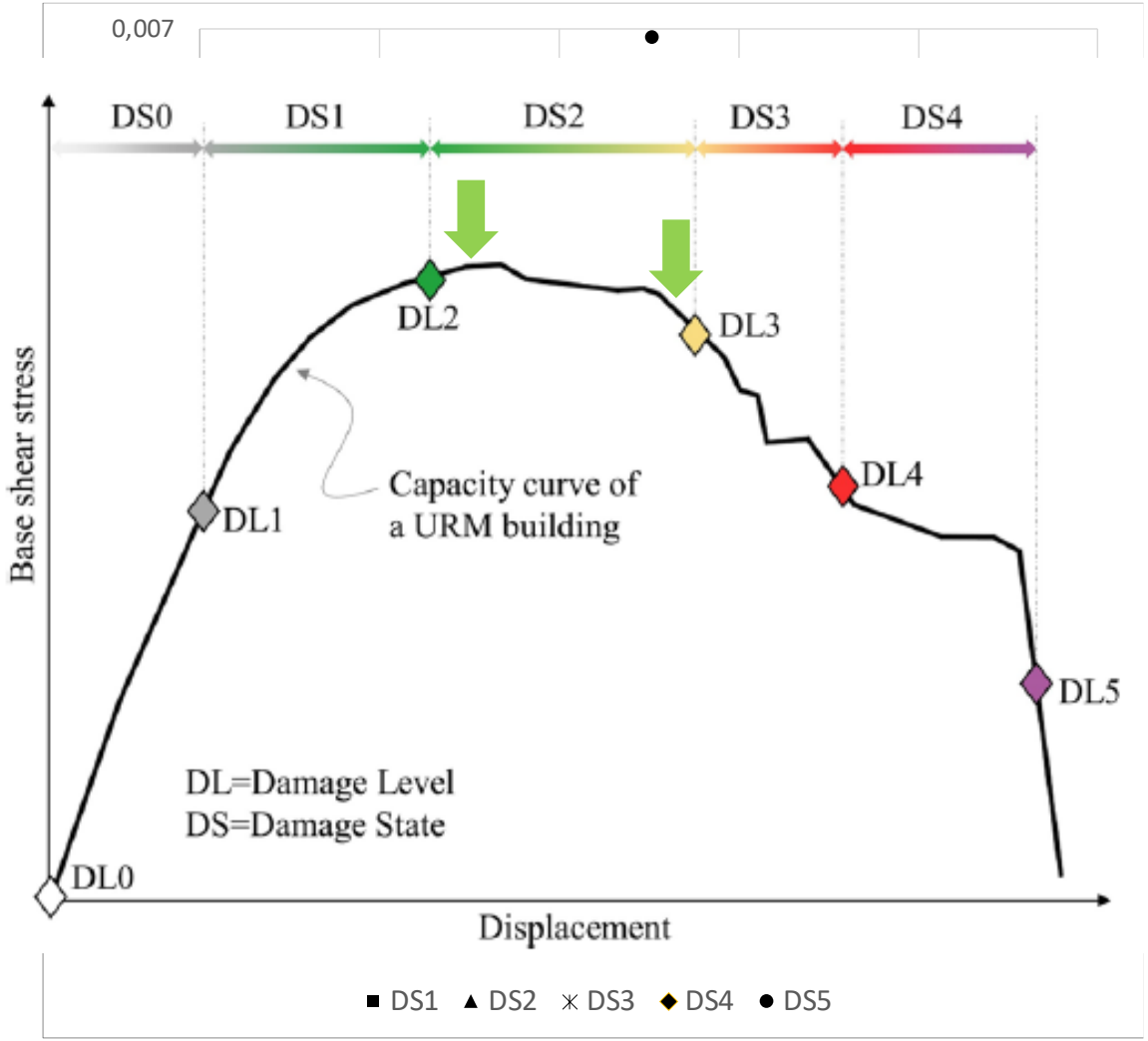
CLOUD METHOD - TRADITIONAL APPROACH TO POST PROCESS THE DATA

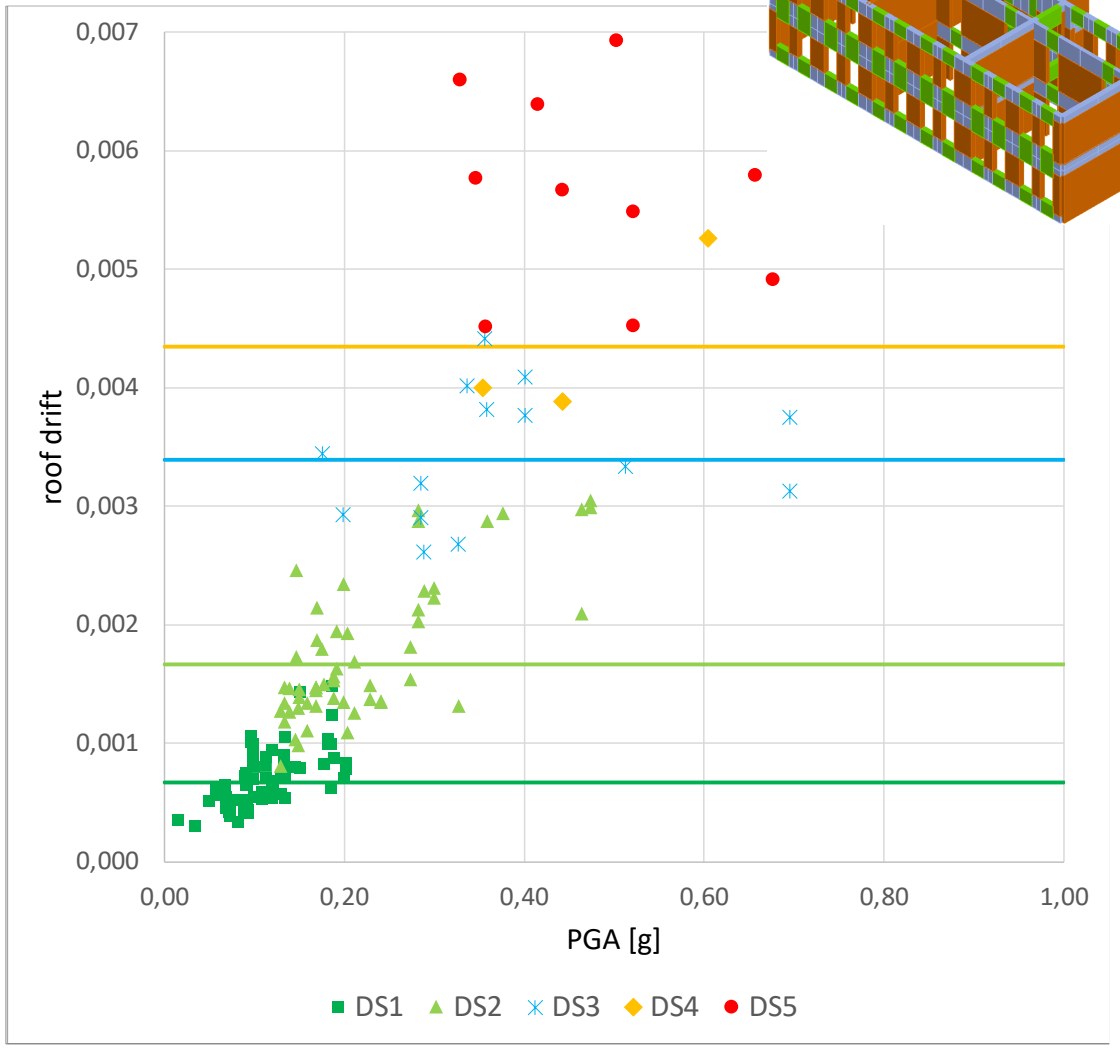




ANALYTICAL-NUMERICAL APPROACH THROUGH NLDA

CLOUD METHOD – COMPARISON WITH THE PROPOSED APPROACH

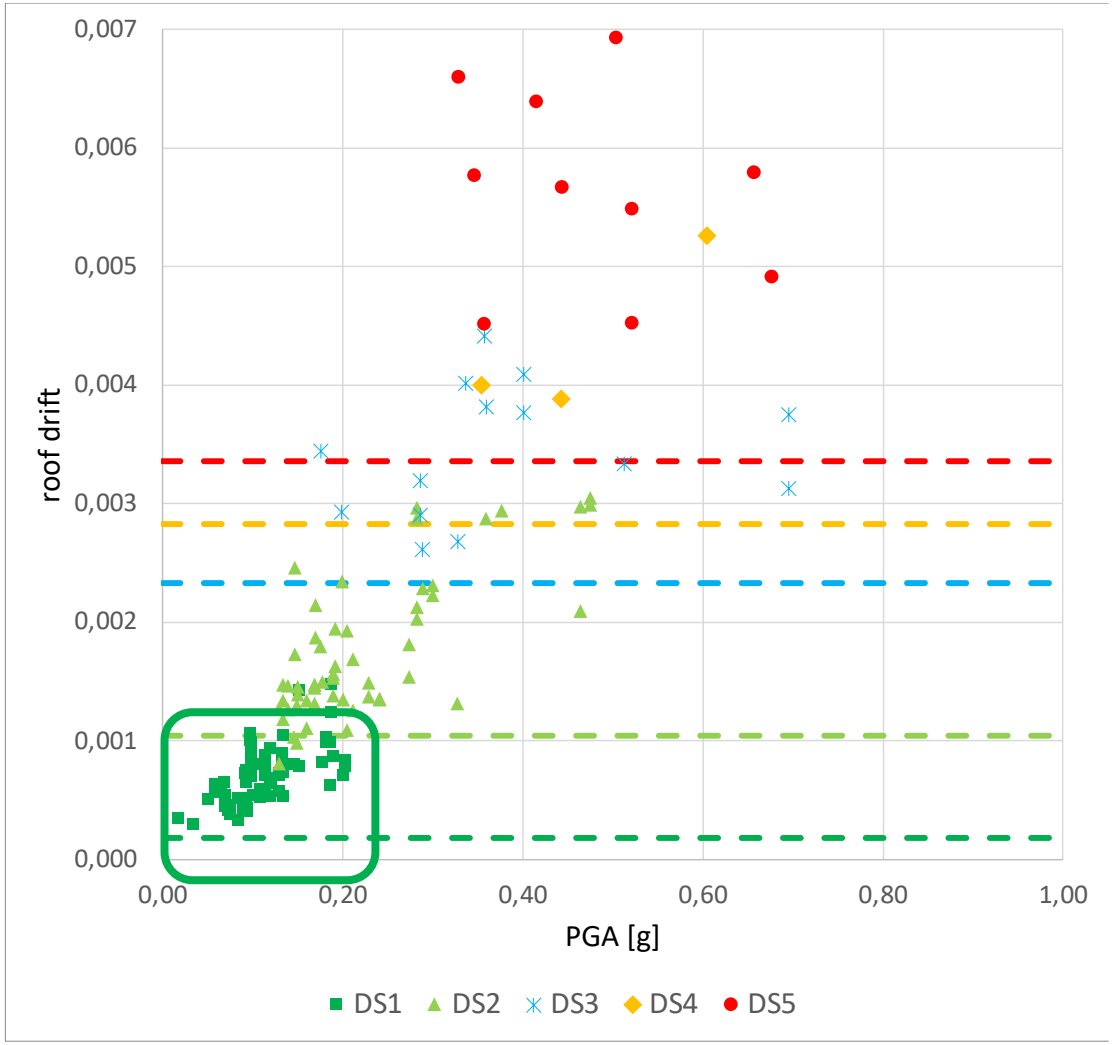




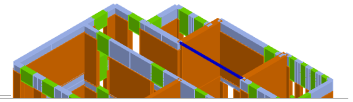
POSSIBILITY OF ASSOCIATING DIRECTLY THE DL FROM NLDA WITHOUT DEFINING A PRIORI EPD THRESHOLDS THROUGH NLSA

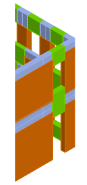
ANALYTICAL-NUMERICAL APPROACH: REFINED IDA TO CLOUD APPROACH

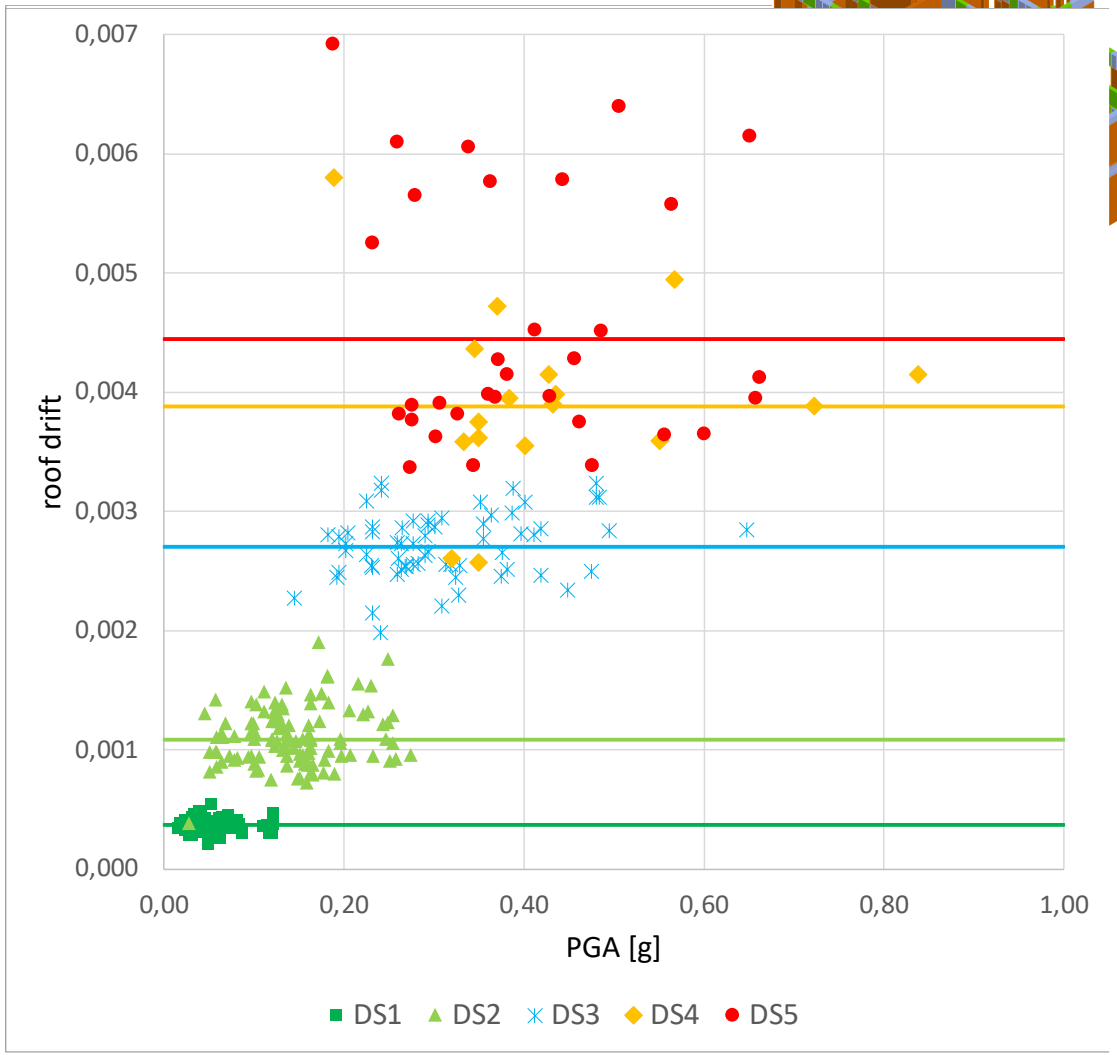
FIRST RUN OF NLDA- CLOUD



IDA+CLOUD

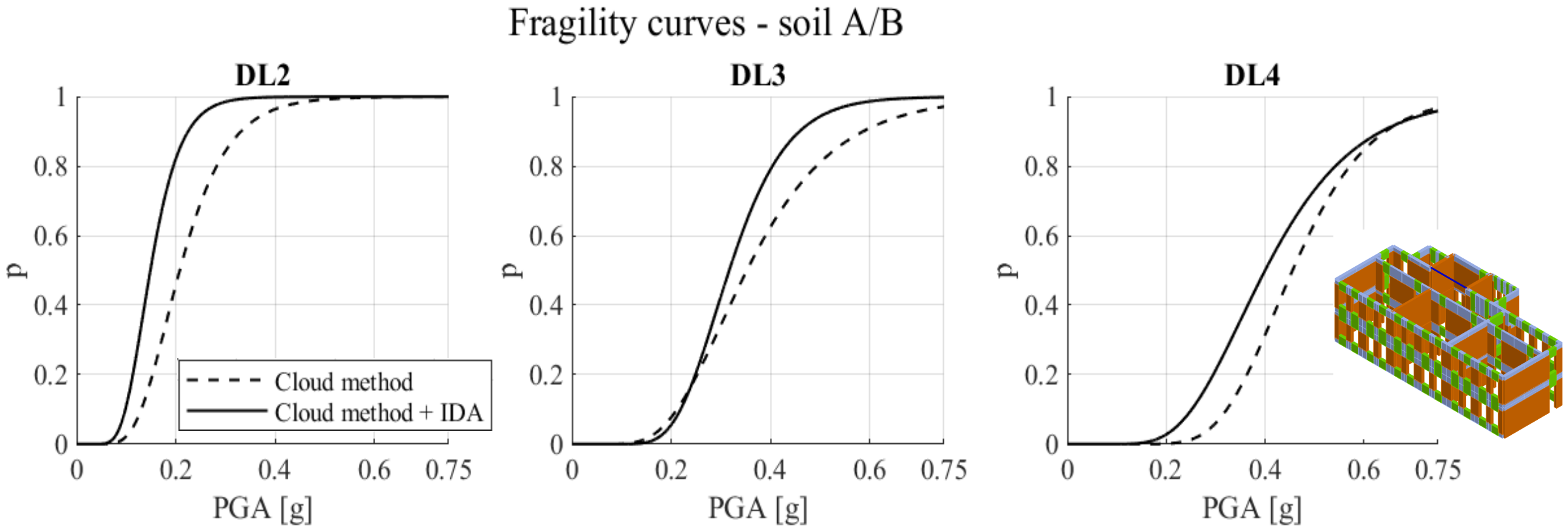






ANALYTICAL-NUMERICAL APPROACH: REFINED IDA TO CLOUD APPROACH

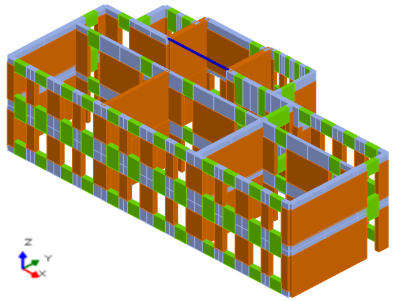
- **Use of the refined ISA to CLOUD approach (Miano et al. 2018 10.1002/eqe.3009)**

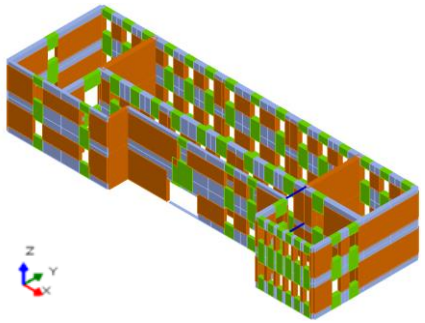


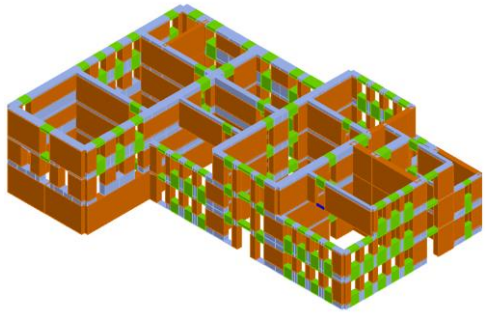
DLs attributed according to the proposed criterion- Comparison between:
- Cloud method (at iteration 0)
- Cloud method + IDA

Results achieved on the ongoing PhD thesis of Sofia Giusto

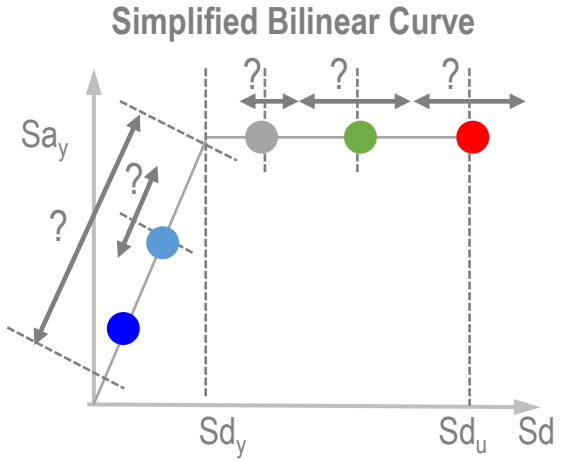
ANALYTICAL-NUMERICAL APPROACH: REFINED IDA TO CLOUD APPROACH



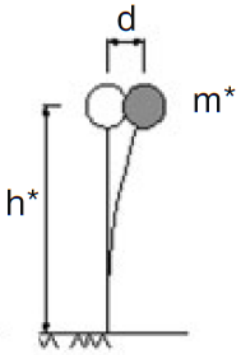




	Mortegliano HQD		Pradamano HQD		Ovaro HQD	
	MAX ROOF-DRIFT					
	median [%]	σ	median [%]	σ	median [%]	σ
DL1	0,04%	0,148	0,03%	0,164	0,01%	0,135
DL2	0,11%	0,223	0,06%	0,185	0,04%	0,183
DL3	0,27%	0,102	0,25%	0,189	0,22%	0,277
DL4	0,39%	0,199	0,35%	0,274	0,32%	0,286
DL5	0,42%	0,323	0,50%	0,388	0,35%	0,457



	MAX INTERSTOREY-DRIFT					
DL1	0,04%	0,150	0,03%	0,197	0,02%	0,146
DL2	0,13%	0,290	0,07%	0,226	0,05%	0,198
DL3	0,36%	0,130	0,38%	0,244	0,33%	0,346
DL4	0,57%	0,286	0,57%	0,316	0,53%	0,466
DL5	0,65%	0,448	0,89%	0,465	0,73%	0,583



THANK YOU FOR YOUR KIND ATTENTION!

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The youngest at heart….

SARA ALFANO

ANDREA BRUNELLI

SOFIA GIUSTO

SERGIO LAGOMARSINO