INTERNATIONAL WORKSHOP ON ADVANCES IN ASSESSMENT AND MODELING OF EARTHQUAKE LOSS

"What have we learnt? What is the future?"

TURKISH NATURAL CATASTROPHE INSURANCE POOL

Damage Assessment in Italy, and Experiences after Recent Earthquakes on Repairability and Repair Costs

Prof. Marco Di Ludovico

University of Naples Federico II

Dept. of Struictures for Engineering and Architecture (DiST)

Email: diludovi@unina.it

Laboratories University Network of seismic engineering

Wyndam Grand Levent, Istanbul,Turkey

4-5 November, 2019

EARTHQUAKES OF THE LAST 50 YEARS IN ITALY

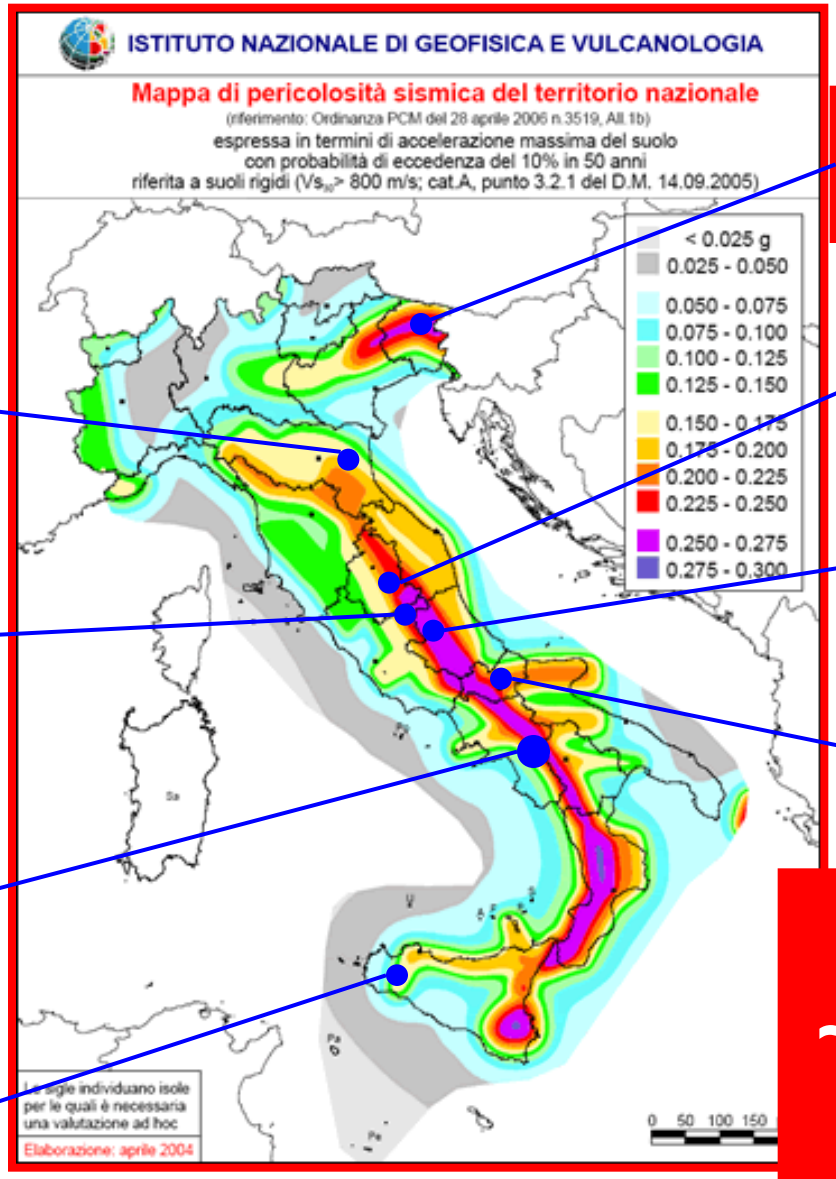
Victims and costs of earthquakes in the last 50 years in Italy

EMILIA 2012
Mw 5.9
27 victims, 13.300 M€

ITALIA CENTRALE
2016-17
Mw 6.5
299 vitctims, 23.500 M€

CAMPANIA-BASILICATA 1980 Mw 6.9
2700 victims, 52.000 M€

BELICE 1968
Mw 6.1
296 victims, 9.200 M€



FRIULI 1976
Mw 6.4
989 victims, 18.500 M€

UMBRIA-MARCHE 1997 Mw 6.1
11 victims, 13.400 M€

ABRUZZO 2009
Mw 6.3
309 victims, 13.700 M€

MOLISE 2002
Mw 5.7
30 victims, 1.400 M€

1968 – 2017
~ 5000 victims
~ 150.000 M€

Courtesy of Prof. Angelo Masi

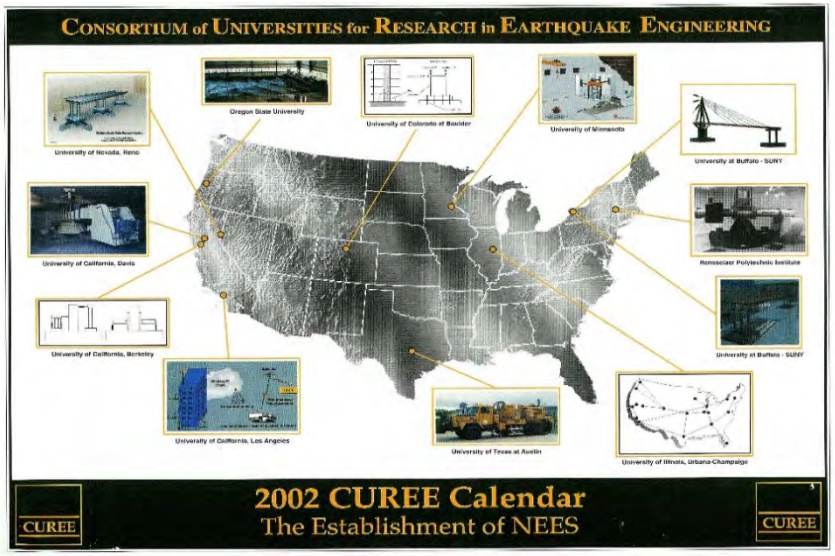
ReLUIS – Competence Centre of Civil Protection Dept.

- ***What is ReLUIS?***

Network of University Laboratories in Earthquake Engineering

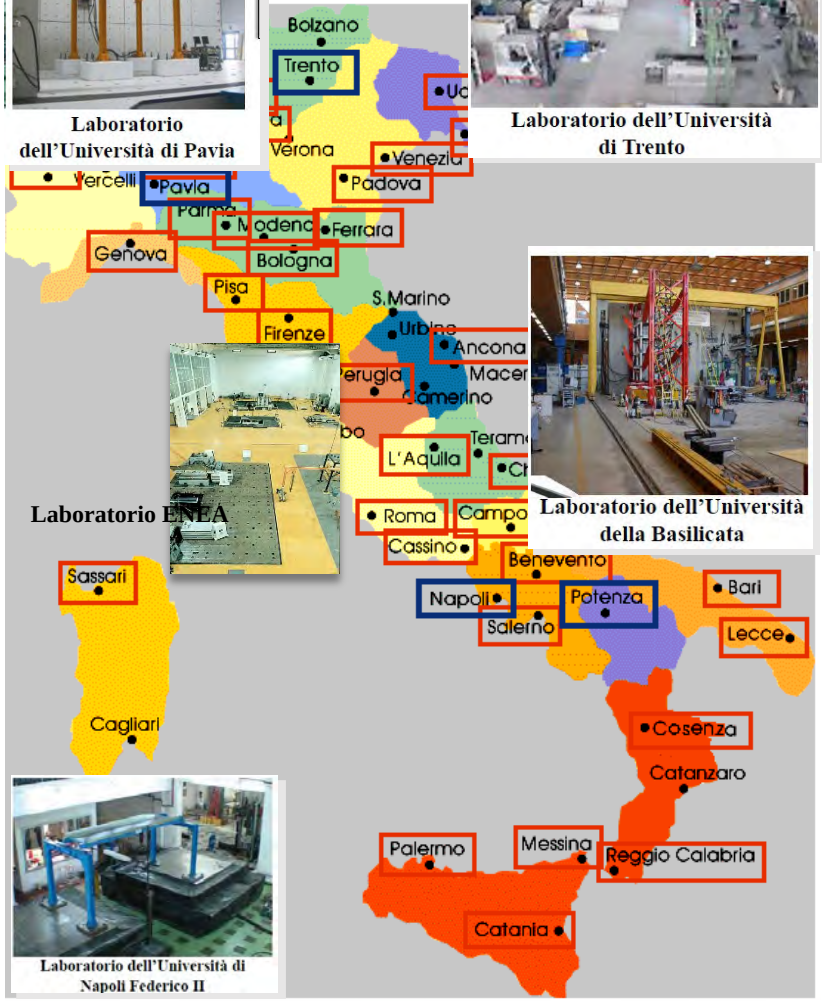
Agreement DPC-ReLUIS signed on 17.4.2003

•The consortium ReLUIS has many similarities with other earthquake engineering networks (i.e. *Network for Earthquake Engineering Simulation* – ***NEES*** *and* Asian Pacfic Network for Center of Engineering Reaserch - ***ANCER***).




Laboratorio dell'Università di Pavia


Laboratorio dell'Università di Trento



Laboratorio ENEA

Laboratorio dell'Università della Basilicata

Laboratorio dell'Università di Napoli Federico II

•ReLUIS, is a interuniversity consortium with the purpose to coordinate the University Laboratories activity of seismic engineering, giving scientific, organizational, technical and financial supports to associated University

The role of ReLUIS in the emergency phases

- **USABILITY ASSESSMENT OF PUBLIC AND RESIDENTIAL BUILDINGS**

- **DAMAGE ANALYSIS, REPORT AND GUIDELINES**

PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile

reluis

CNI
Consiglio Nazionale degli Ingegneri

ASSOBETON

- **INITIATIVE FOR SEISMIC RISK REDUCTION :**
Earthquake: let's talk together – Earthquake I do not risk

PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile

INGV

ANPAS

Regione Emilia-Romagna

reluis

POST EARTHQUAKE SAFETY EVALUATION OF BUILDINGS

- **USABILITY ASSESSMENT FORMS**

Damage and Safety assessment

➢ ATC-20

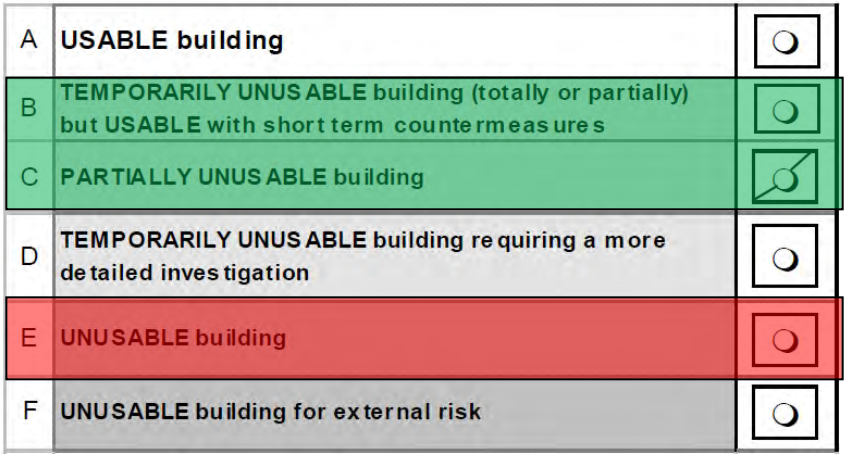
Applied Technology Council

Posting systems:

- Inspected - Appears safe for lawful occupancy
- Limited Entry / Restricted Use - Some restriction on use, controlled by building owner/manager
- Unsafe – Entry controlled by jurisdiction

➢ Aedes Form

Field Manual for post-earthquake damage and safety assessment and short term countermeasures



Six usability rates:

- Usable
- Unusable but usable after short countermeasures
- Partially unusable
- Temporarily unusable
- Unusable
- Unusable due to external risk

POST EARTHQUAKE SAFETY EVALUATION OF BUILDINGS

• USABILITY ASSESSMENT OF PUBLIC AND RESIDENTIAL BUILDINGS

➢ AeDES Form

Six usability rates:

- Usable
- Unusable but usable after short countermeasures
- Partially unusable
- Temporarily unusable
- Unusable
- Unusable due to external risk

A	USABLE building	○
B	TEMPORARILY UNUSABLE building (totally or partially) but USABLE with short term countermeasures	○
C	PARTIALLY UNUSABLE building	◎
D	TEMPORARILY UNUSABLE building requiring a more detailed investigation	○
E	UNUSABLE building	○
F	UNUSABLE building for external risk	○

SECTION 4 **Damage to structural elements and existing short term countermeasures**

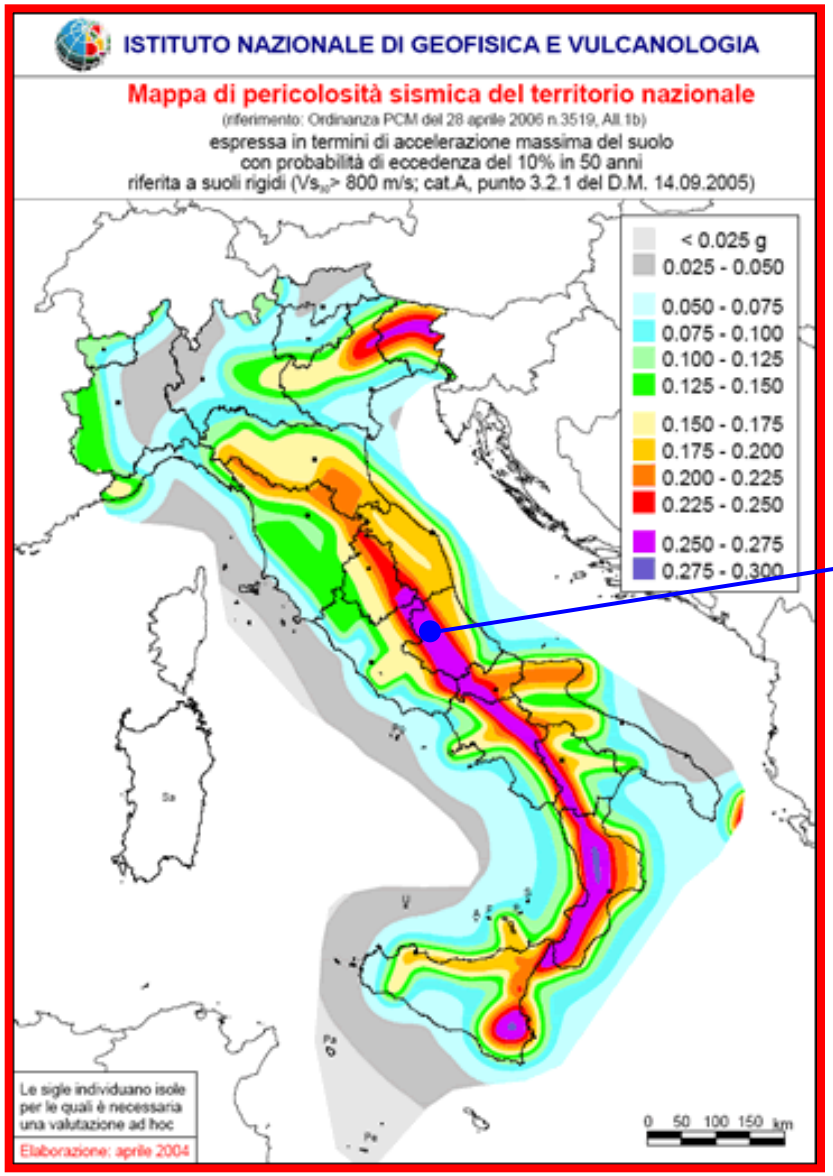
Structural component / Damage level - extension / Pre-existing damage		DAMAGE (1)										EXISTING SHORT TERM COUNTERMEASURES					
		D4-D5 Very Heavy			D2-D3 Medium-Severe			D1 Light			Null	None	Removal	Ties	Repair	Propping	Barriers or passage protection
		> 2/3	1/3 - 2/3	< 1/3	> 2/3	1/3 - 2/3	< 1/3	> 2/3	1/3 - 2/3	< 1/3							
		A	B	C	D	E	F	G	H	I	L	A	B	C	D	E	F
1	Vertical structures	□	□	□	□	□	□	□	□	□	○	○	□	□	□	□	□
2	Floors	□	□	□	□	□	□	□	□	□	○	○	□	□	□	□	□
3	Stairs	□	□	□	□	□	□	□	□	□	○	○	□	□	□	□	□
4	Roof	□	□	□	□	□	□	□	□	□	○	○	□	□	□	□	□
5	Infills and partitions	□	□	□	□	□	□	□	□	□	○	○	□		□	□	□
6	Pre-existing damage	□	□	□	□	□	□	□	□	□	○						

(1) - The damage extension must be filled only if the corresponding damage level is present in the building.

- Vertical structures
- Floors
- Stairs
- Roof
- Infills and Partitions

➢**Section 4 /5 - Damage to structural an non structural elements and existing short term countermeasures**:;

The role of ReLUIS in the emergency phases



2009 L'AQUILA EARTHQUAKE

ABRUZZO 2009
Mw 6.3
309 victims, 13.700 M€

reluis

Laboratories University Network of seismic engineering)

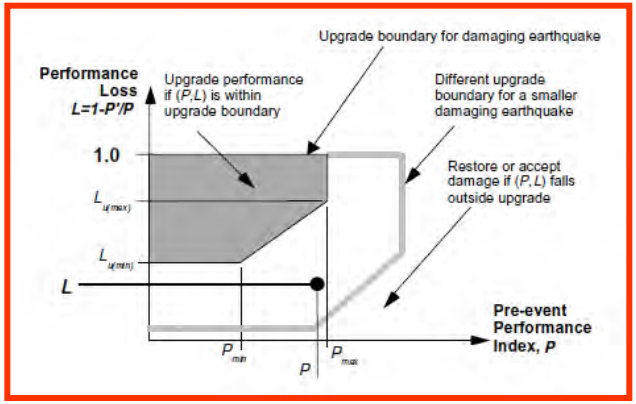
PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile

Italian Department of Civil Protection (DPC)

Post-earthquake decisions

Repair / Retrofit criteria: Policies after L'Aquila earthquake

FEMA 308 (1998)



Damage level

	E_{dem} class: Demolition & recontruction	
Heavy structural damage (Building classified with **E tag**)	**E class**: Repair + Retrofit (400-600 €/m²)	**E-B class**: Repair + Retrofit or repair + local upgrade (250 €/m²)
Insignificant structural damage (Building classified with **B/C tag**)	**B-C class**: Repair or repair + local upgrade (150 €/m²)	

60 % $\%NBS$;

$$\%NBS = \frac{PGA_{capacity}}{PGA_{demand}}$$

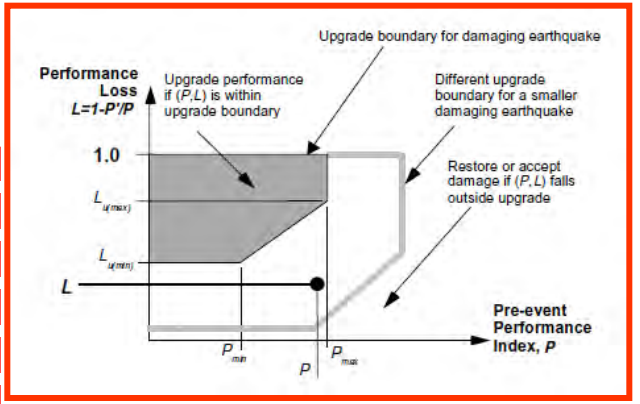
Repair works: costs fully covered by public contribution

Retrofit works(E tag) :
mandatory safety threshold 60 % NBS (<80 % NBS with public funds)

Post-earthquake decisions

Repair / Retrofit criteria: Policies after L'Aquila earthquake

FEMA 308 (1998)



Damage level

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60 % $\%NBS$;

"HEAVY-DAMAGE" RECONSTRUCTION

"LIGHT-DAMAGE" RECONSTRUCTION

$$\%NBS = \frac{PGA_{capacity}}{PGA_{demand}}$$

Repair works: costs fully covered by public contribution

Retrofit works: mandatory safety threshold 60 % NBS (<80 % NBS with public funds)

Post-earthquake decisions

Policies after L'Aquila earthquake

Policies for **BUILDING DEMOLITION**

demonstrating the ECONOMIC CONVENIENCE

to demolish and rebuild instead of repair and retrofit **up to 60% NBS**

(art. 5 comma 1 OPCM 3881)

WITHOUT demonstrating the ECONOMIC CONVENIENCE

(*forfait* grant 500 or 750 €/m^2)

(art. 5 comma 2 e 3 OPCM 3881)

WITHOUT demonstrating the ECONOMIC CONVENIENCE

(**SEVERE DAMAGES**)

(art. 5 comma 5 OPCM 3881)

For Masonry buildings

❖ partial failure of bearing walls for at least 25% of the building volume

For R.C. buildings

❖ excessive residual deformations

(≥1.5% on more than 50% columns of a storey)

❖ weak concrete (fc <8 Mpa)

The reconstruction process details

Bull Earthquake Eng (2017) 15:667–692
DOI 10.1007/s10518-016-9877-8

ORIGINAL RESEARCH PAPER

Reconstruction process of damaged residential buildings outside historical centres after the L'Aquila earthquake: part I—"light damage" reconstruction

Marco Di Ludovico[1] · Andrea Prota[1] · Claudio Moroni[2] · Gaetano Manfredi[1] · Mauro Dolce[2]

Bull Earthquake Eng (2017) 15:693–729
DOI 10.1007/s10518-016-9979-3

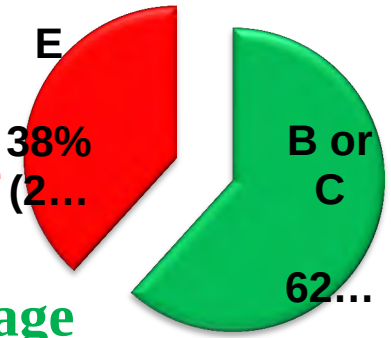
ORIGINAL RESEARCH PAPER

Reconstruction process of damaged residential buildings outside historical centres after the L'Aquila earthquake: part II—"heavy damage" reconstruction

Marco Di Ludovico[1] · Andrea Prota[1] · Claudio Moroni[2] · Gaetano Manfredi[1] · Mauro Dolce[2]

WHITE BOOK ON THE RECONSTRUCTION PROCESS OF DAMAGED RESIDENTIAL BUILDINGS OUTSIDE HISTORICAL CENTRES AFTER L'AQUILA EARTHQUAKE

5,775 buildings



Heavy damage

Light damage

Freely downloadble on website *www.reluis.it*

Reconstruction phases

How much is the reconstruction cost?

repair and seismic strengthening (or demolition and reconstruction) of private buildings (4.885) outside historical centres of L'Aquila

2,6 billion euros

PHASE I: THE "LIGHT DAMAGE " RECONSTRUCTION

✓ **2.904 buildings:**

Total grant **0,5 billion euros**

Mean grant per building **184.000€** **(128.000 for repair interv., 70%)**

PHASE II: THE "HEAVY DAMAGE " RECONSTRUCTION

✓ **1.951 buildings:**

Total grant **2,1 billion euros**

Mean grant per building **1 million €** **(580.000 for repair interv., 58%)**

Reconstruction costs

How much is the reconstruction cost?

repair and seismic strengthening (or demolition and reconstruction) of private buildings (4.885) outside historical centres of L'Aquila

2,6 billion euros

Repair

1,3 billion euros

Seismic Strengthening

0,7 billion euros

Demolition / Reconstruction

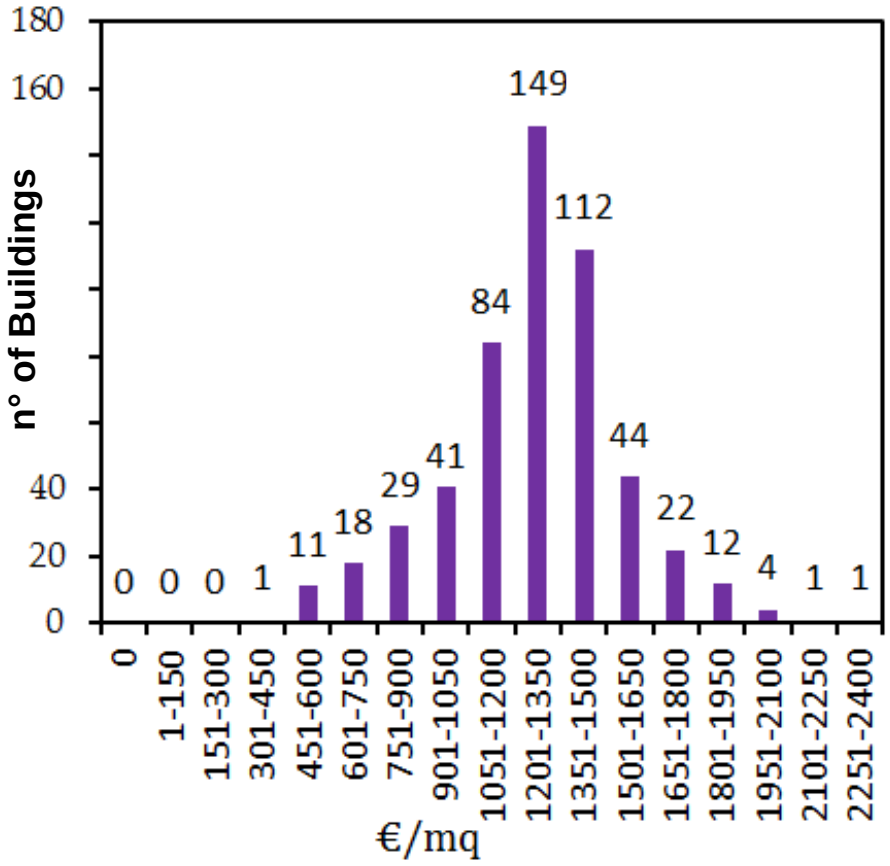
0,6 billion euros

541 buildings out of 2.211 (24%) with severe damage

Heavy damage reconstruction – Demolition

- ***Demolition and reconstruction:***

541 buildings (out of 2211) – 24% of the E building stock



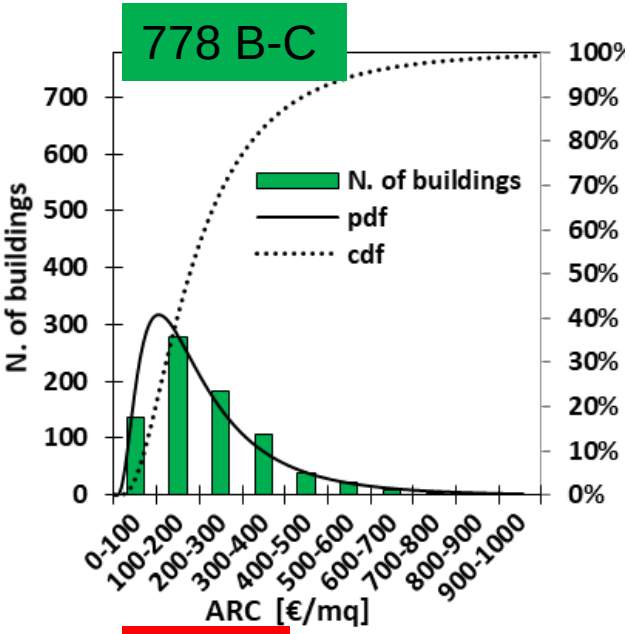
- **421 buildings:** repair and retrofit economically not viable
- **22 Buldings** forfait grant of 750 €/m^2
- **17 Buldings** forfait grant of 500 €/m^2
- **44 masonry buildings** partially collapsed (more than 25% in volume);
- **1 R.C. building**: more than 50% of storey's columns with a drift greater than 1.5% ;
- **34 R.C. buildings:** average compressive cylindrical strength fcm< 8 MPa

-Demolition and reconstruction mean cost: 1192,00 €/m^2

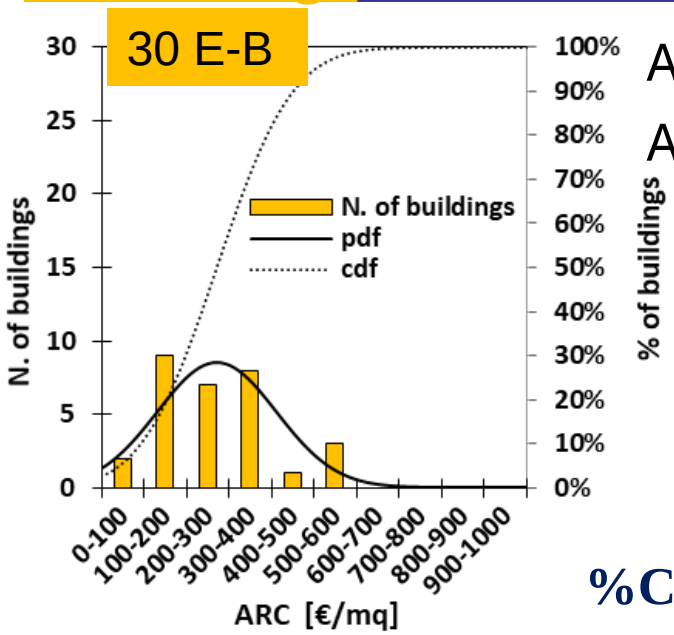
ACTUAL REPAIR COST OF MASONRY BUILDINGS

REPAIR COST • *Masonry* ***Residential buildings***

778 B-C



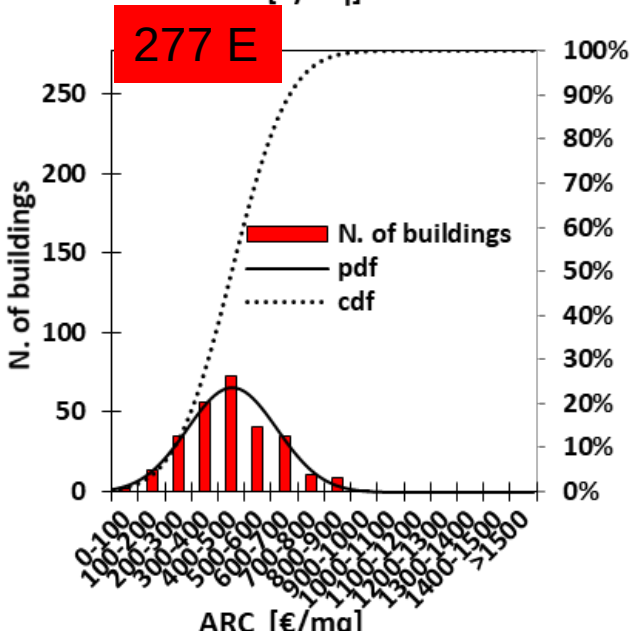
30 E-B



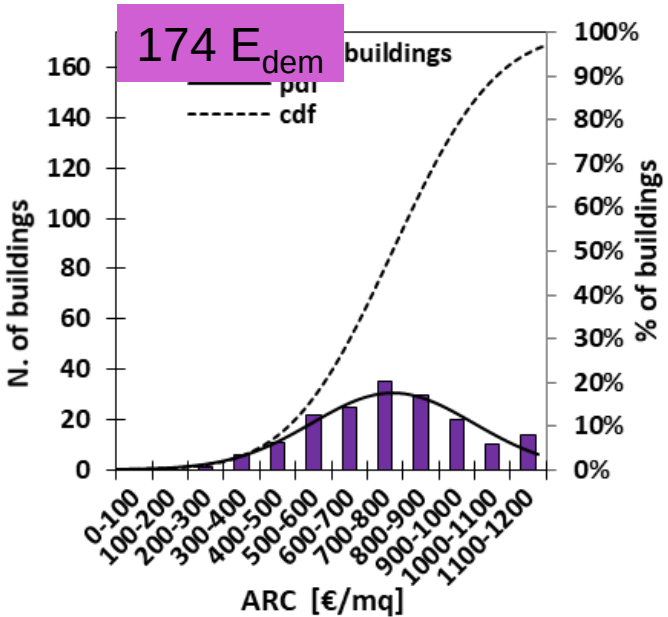
Actual repair cost, ARC,

Costs include practitioners technical fees but does not include V.A.T.

277 E



174 E_{dem}



%Cr Reconstruction cost 1350 €/m²

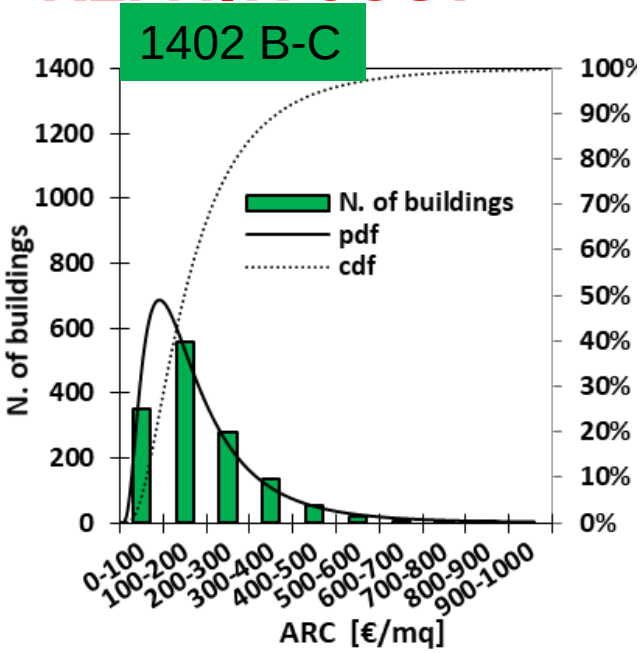
	16th p.le	50th p.le	84th p.le	CoV [%]
B-C	7%	14%	25%	62%
E-B	9%	19%	29%	51%
E	21%	33%	47%	37%
E_{dem}	71%	84%	102%	19%

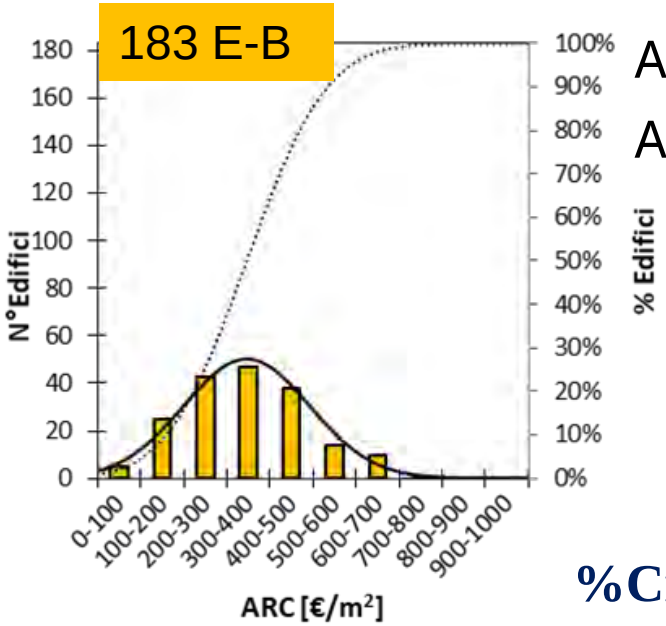
ACTUAL REPAIR COST OF MASONRY BUILDINGS

REPAIR COST

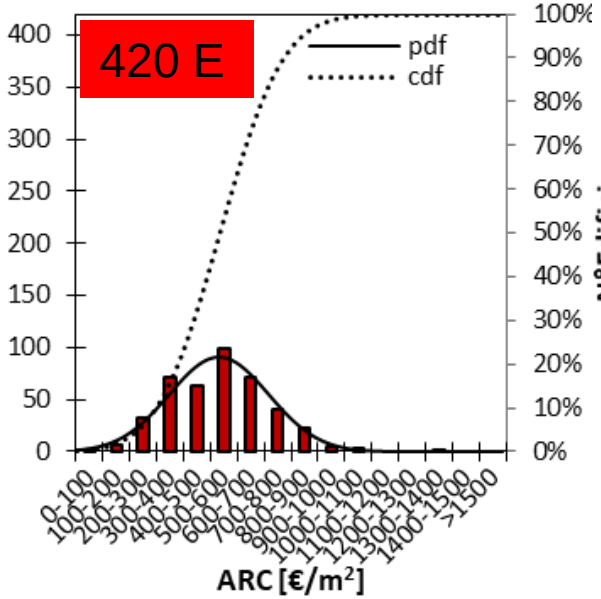
- ***R.C. Residential buildings***

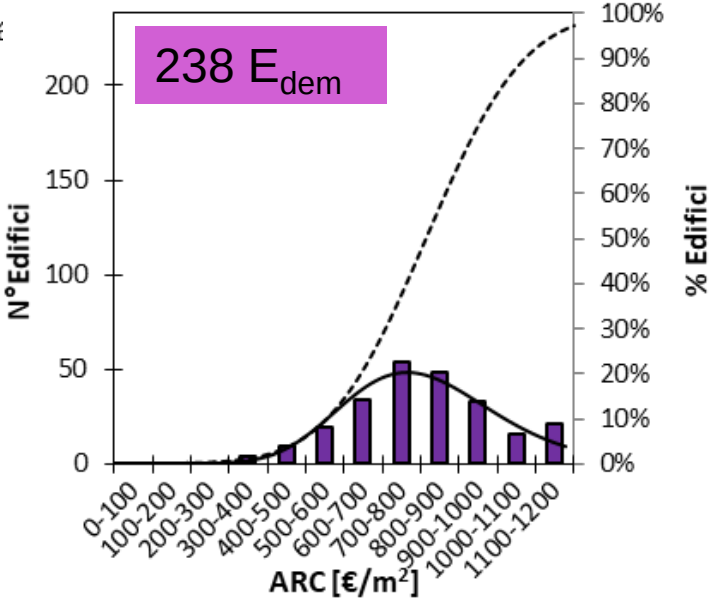
Actual repair cost, ARC,





Costs include practitioners technical fees but does not include V.A.T.





%Cr Reconstruction cost 1350 €/m²

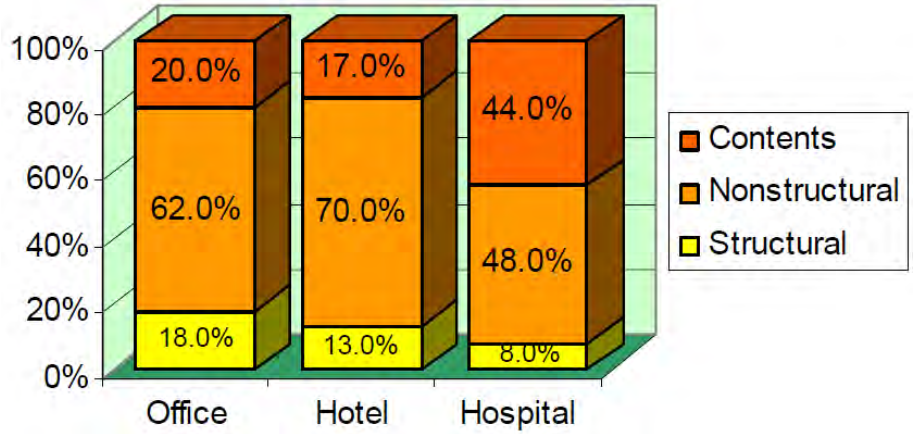
	16th p.le	50th p.le	84th p.le	CoV [%]
B-C	6%	12%	22%	64%
E-B	14%	26%	36%	42%
E	25%	39%	53%	35%
E_{dem}	78%	88%	103%	17%

ACTUAL REPAIR COSTS AT COMPONENT LEVEL

- ***Loss assessment in modern seismic engineering***

In this context, the analysis of actual repair costs at component level could very helpful

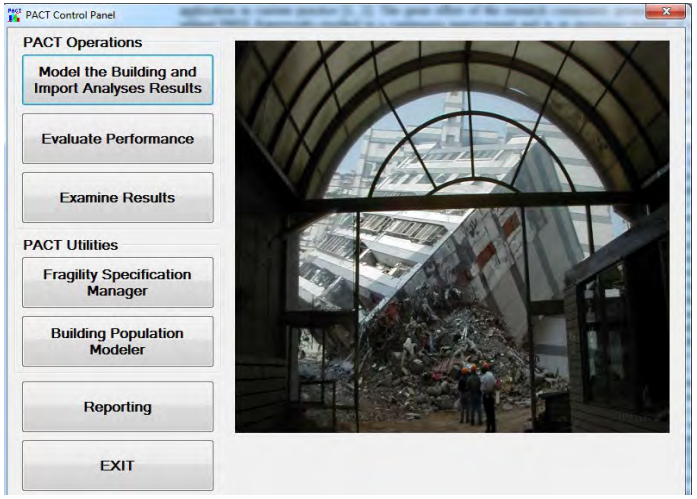
This was done first in the aftermath of 1994 Northridge earthquake (Kircher, 2003)



Disaggregation the total repair costs to evaluate the impact of structural/non-structural components and drift/acceleration sensitive components

REFINED LOSS-ASSESSMENT FRAMEWORKS SUCH AS THE FEMA P-58

to have insights on the components we need to protect to reduce the expected losses



ACTUAL REPAIR COSTS AT COMPONENT LEVEL

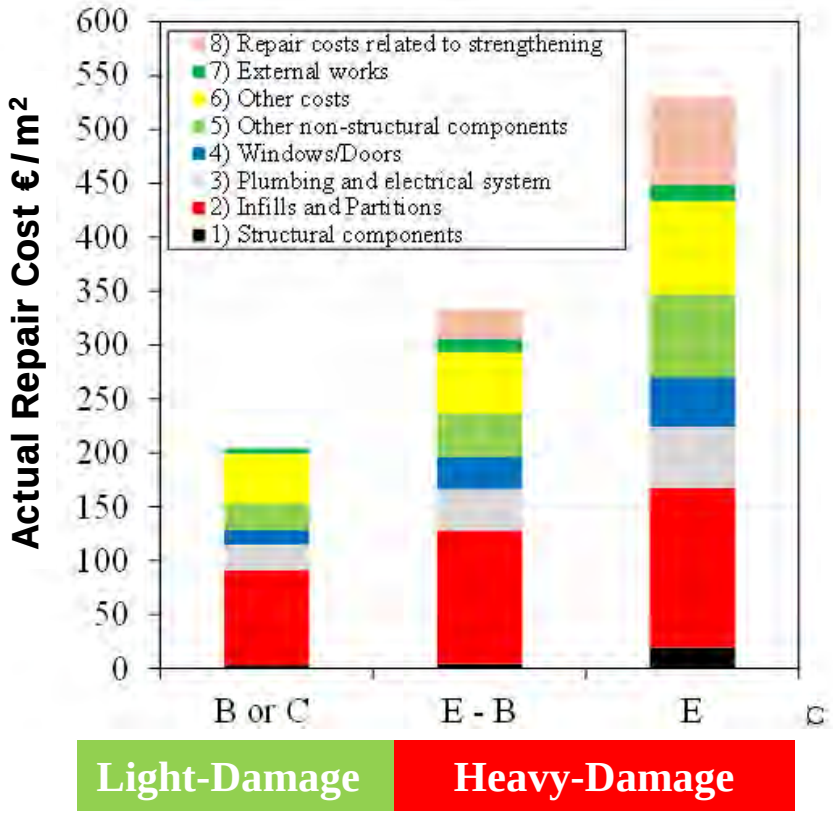
Component classification according to

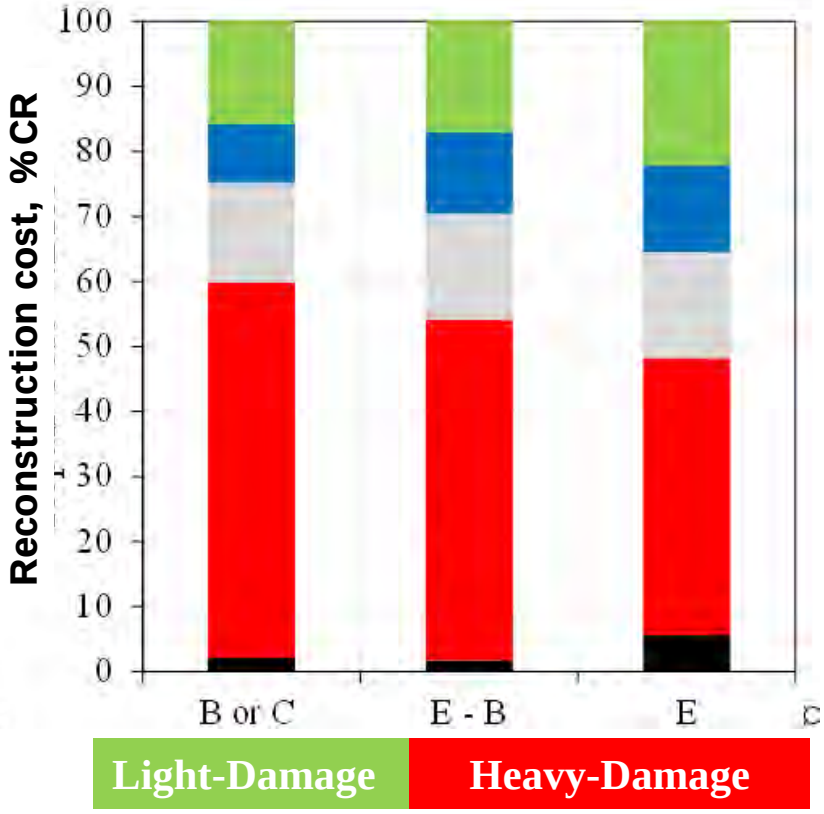
FEMA P-58 (2012):

1) **Structural components**
2) **Infills and partitions**
3) **Windows/doors**
4) **Plumbing and electrical system**
5) **Other non-struct. Components**
6) **Other costs**
7) **External works**
8) **Repair for strengthenting**

Analysis carried out on a subset of 120 R.C. buildings representative of the whole dataset (similar cost frequancy trends)

ACTUAL REPAIR COSTS AT COMPONENT LEVEL





Structural components (2%-6%)*

Infills and partitions (42%-58%)

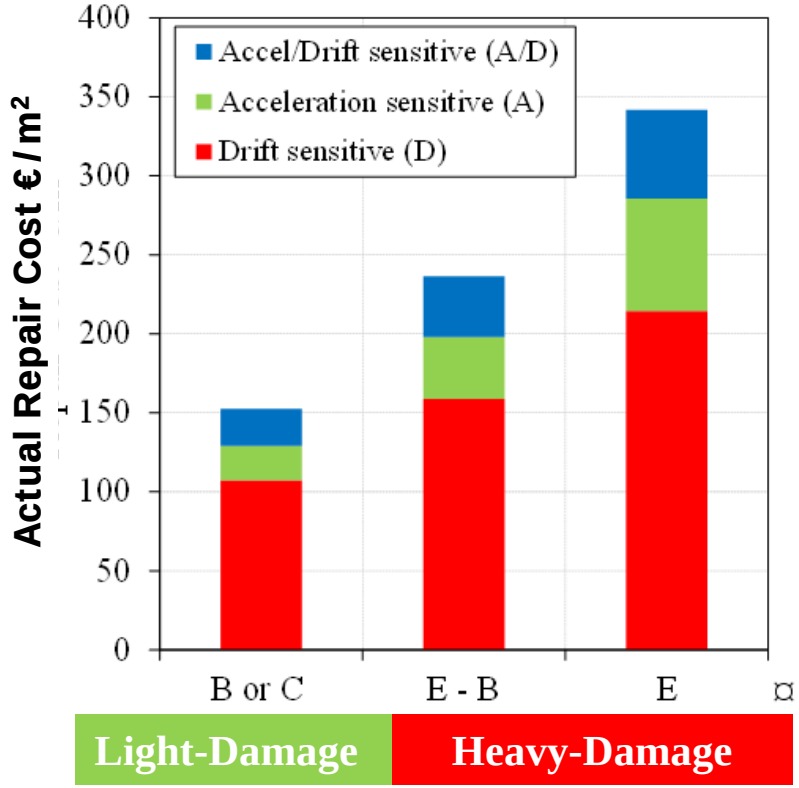
Plumbing and electrical system (10%-12%)

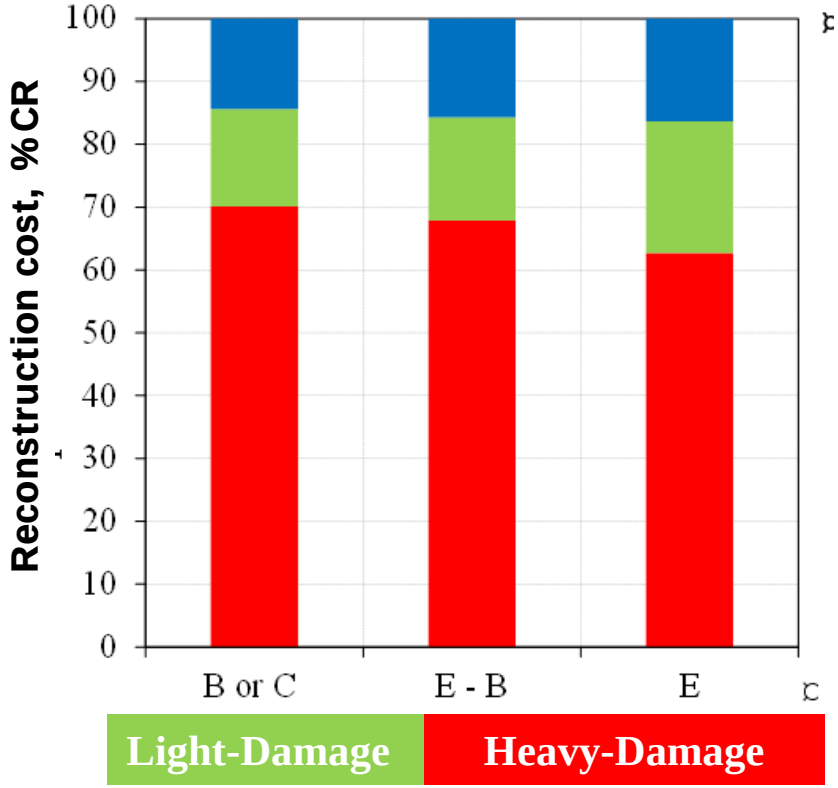
Windows/doors (7%-9%)

Other non-structural components (12%-15%)

*Demolished buildings not included; up to **10%** excluding buildings without structural damage

ACTUAL REPAIR COSTS AT COMPONENT LEVEL





Drift Sensitive Components (63%-70%):

- Structures, Infills and partitions, doors/windows, stairs (FEMA P-58, 2012)00000

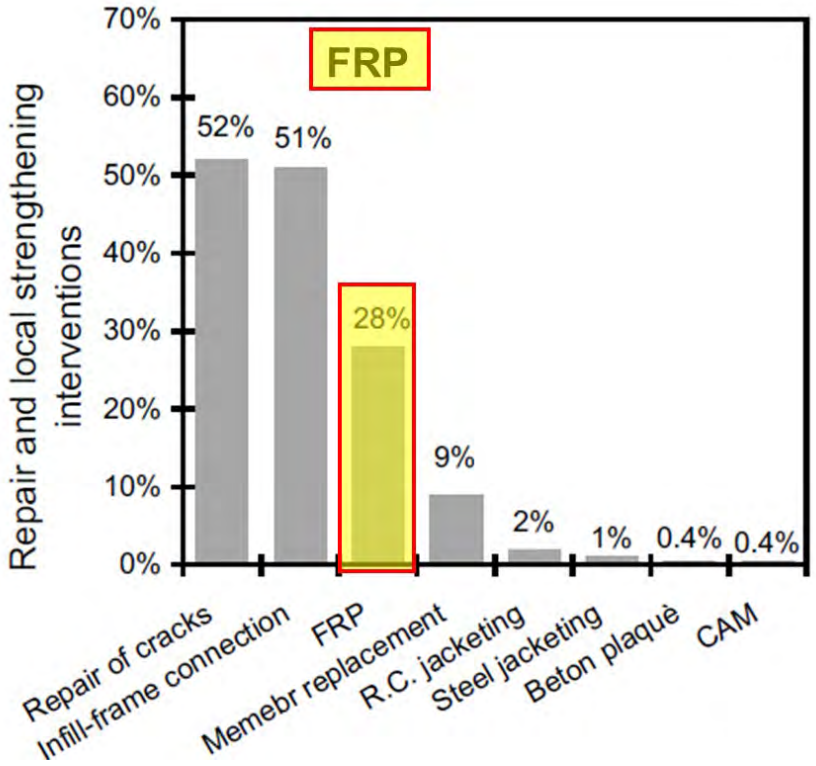
Acceleration Sensitive Components (15%-21%):

- Floor finishes, roof, chimneys, tiles, sanitary and other equipment

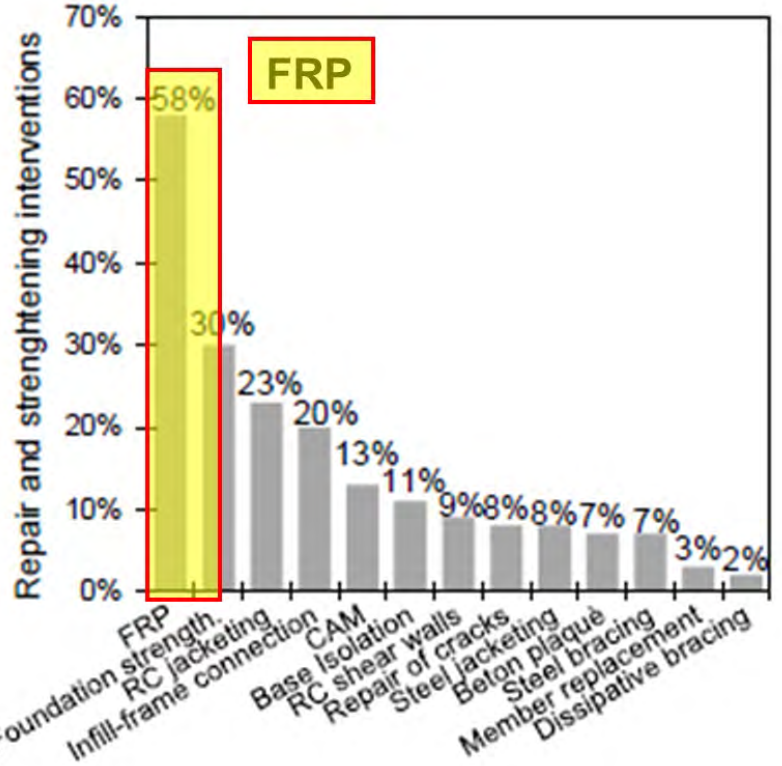
Del Vecchio, C., Di Ludovico, M., Pampanin, S., Prota, A., 2018. Repair costs of existing rc buildings damaged by the l'aquila earthquake and comparison with FEMA P-58 predictions. Earthquake Spectra, Vol. 34, No. 1, pp. 237-263

STRENGHTENING INTERVANTION AND UNIT COSTS

Light-Damage



Heavy-Damage Buildings



28 % of buildings strength. with FRP

Repair and local strengthening

Mean Strengthening cost:
34 €/m² – 139 €/m²-

58 % of buildings strength. with FRP

Repair and global strengthening

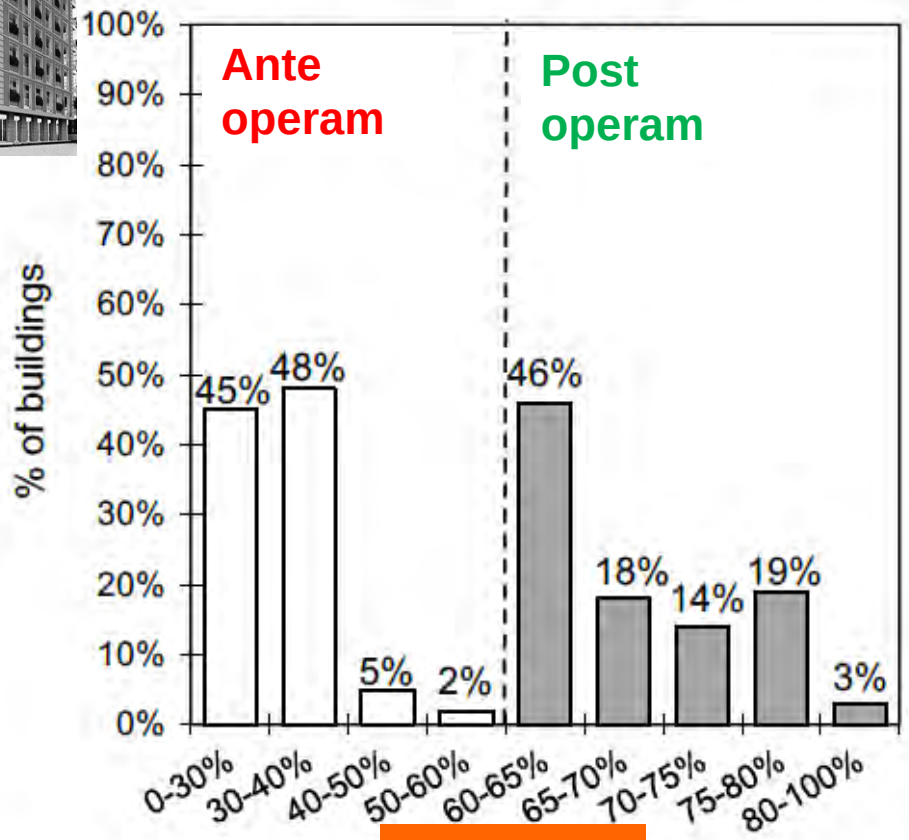
Mean Strengthening cost:
309 €/m²

STRENGHTENING INTERVANTION AND UNIT COSTS

- ***% NBS New building Standard (ante and post operam)***

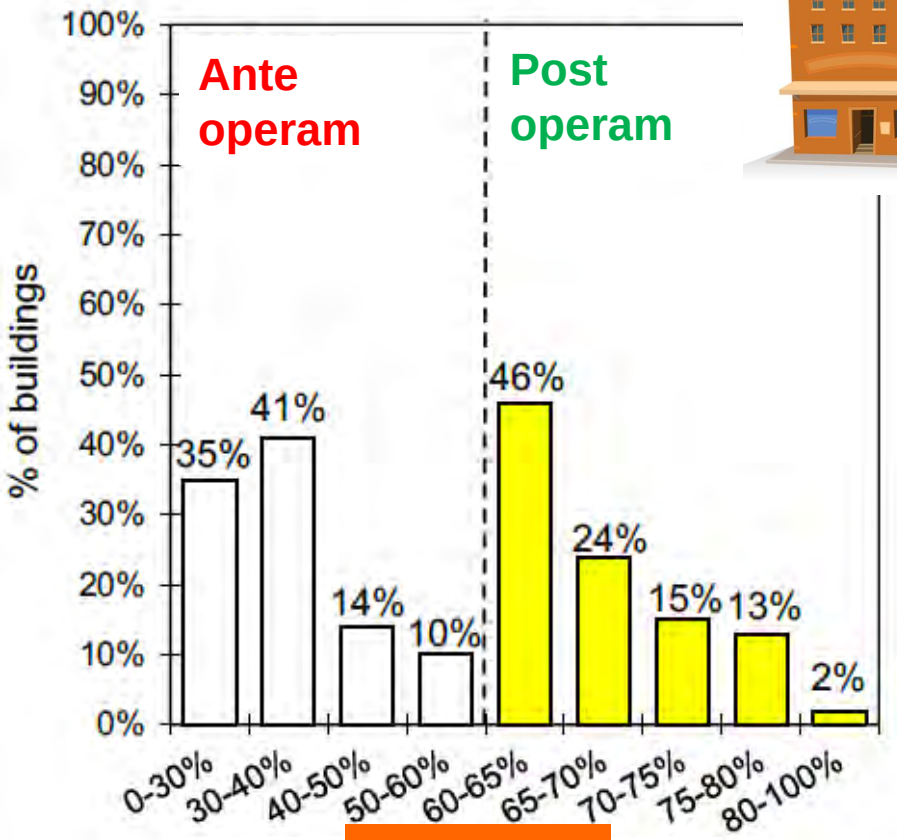
Safety level on E tag buildings

RC Buildings



% NBS

Masonry Buildings



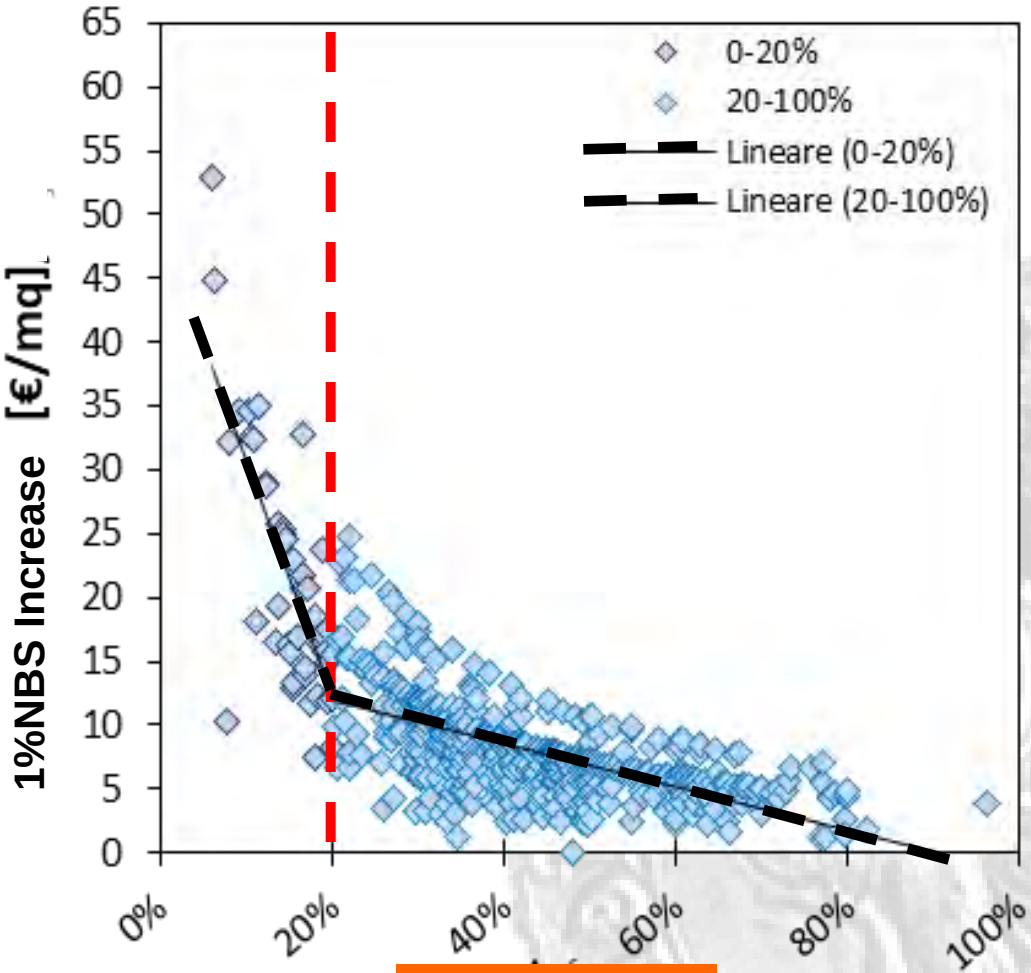
% NBS

1% NBS increase ≈ 10€/m²

STRENGHTENING INTERVANTION AND UNIT COSTS

- **Residential Buildings**

.....Safety level increase, Δ%NBS



Δ%NBS ≤ 20% ➔ on average 22€/mq to attain 1% NBS increase

Δ%NBS >20% ➔ on average 8€/mq to attain 1% NBS increase

Population Assistance and Returning home trend

sustainability

MDPI

Article

Analysis of the Population Assistance and Returning Home in the Reconstruction Process of the 2009 L'Aquila Earthquake

Antonio Mannella [1,*], Marco Di Ludovico [2], Antonio Sabino [1], Andrea Prota [2], Mauro Dolce [3] and Gaetano Manfredi [2]

Sustainability **2017**, *9*, 1395; doi:10.3390/su9081395 www.mdpi.com/journal/sustainability

POPULATION ASSISTANCE AND RETURNING HOME TREND

POPULATION ASSISTANCE – ACCOMMODATION TYPES

❑ **Hotels**

❑ **r.c.a.:**
rent-controlled apartments

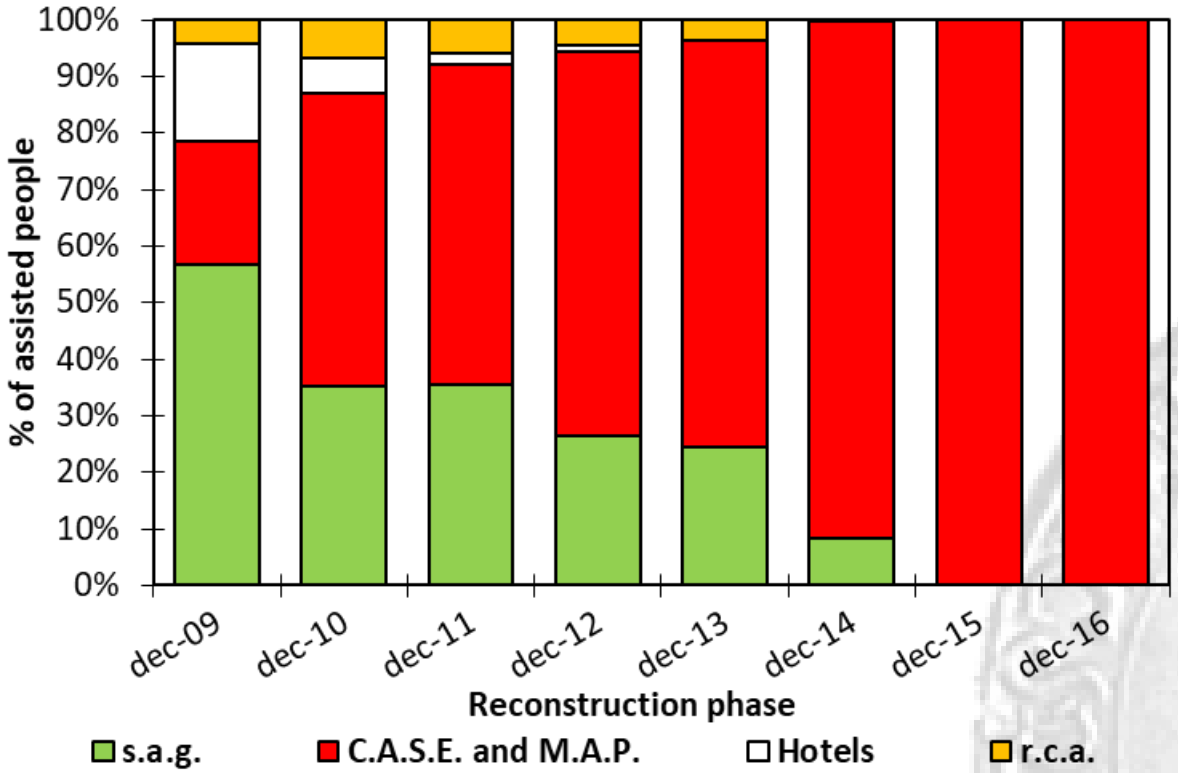
❑ **s.a.g.** self-accommodation grant

❑ **C.A.S.E. and M.A.P.**
C.A.S.E. Anti-seismic, Sustainable and Ecologically Compatible Housing Complexes
M.A.P. Temporary Inhabitable Modules

PHASE I: THE "LIGHT DAMAGE " RECONSTRUCTION

PHASE II: THE "HEAVY DAMAGE " RECONSTRUCTION

POPULATION ASSISTANCE – ACCOMMODATION TREND



People Assistance

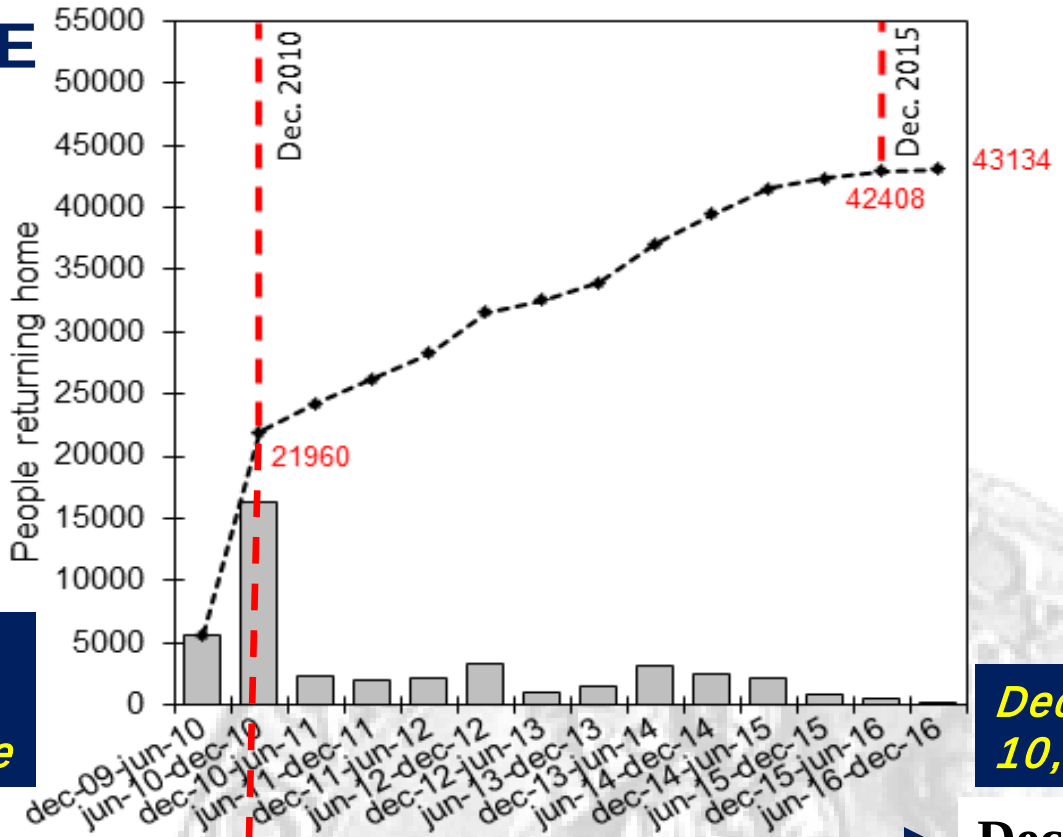
- **Hotels**
- **s.a.g.**
  self-accommodation grant
- **r.c.a.**
  rent-controlled apartments
- **C.A.S.E. and M.A.P.**
  C.A.S.E. Anti-seismic, Sustainable and Ecologically Compatible Housing Complexes
  M.A.P. Temporary Inhabitable Modules

POPULATION ASSISTANCE AND RETURNING HOME TREND

POPULATION ASSISTANCE

RETURNING HOME TREND

April 2009
67,000 displaced people



Dec. 2009
53,968
displaced people

Dec.2016
10,834

Apr. 2009 ⟶ Dec. 2009 ⟶ Dec. 2016

≈1,5 years

1,5 + 6 years

PHASE I: THE "LIGHT DAMAGE " RECONSTRUCTION

21,960 people returned home in about 1,5 year after the earth..

About 14,000 people/year

PHASE II: THE "HEAVY DAMAGE " RECONSTRUCTION

(+21,174) 43,134 people returned home in about 7,5 years after earth.

About 3,500 persons/year

POPULATION ASSISTANCE AND RETURNING HOME TREND

How much is the assistance cost?

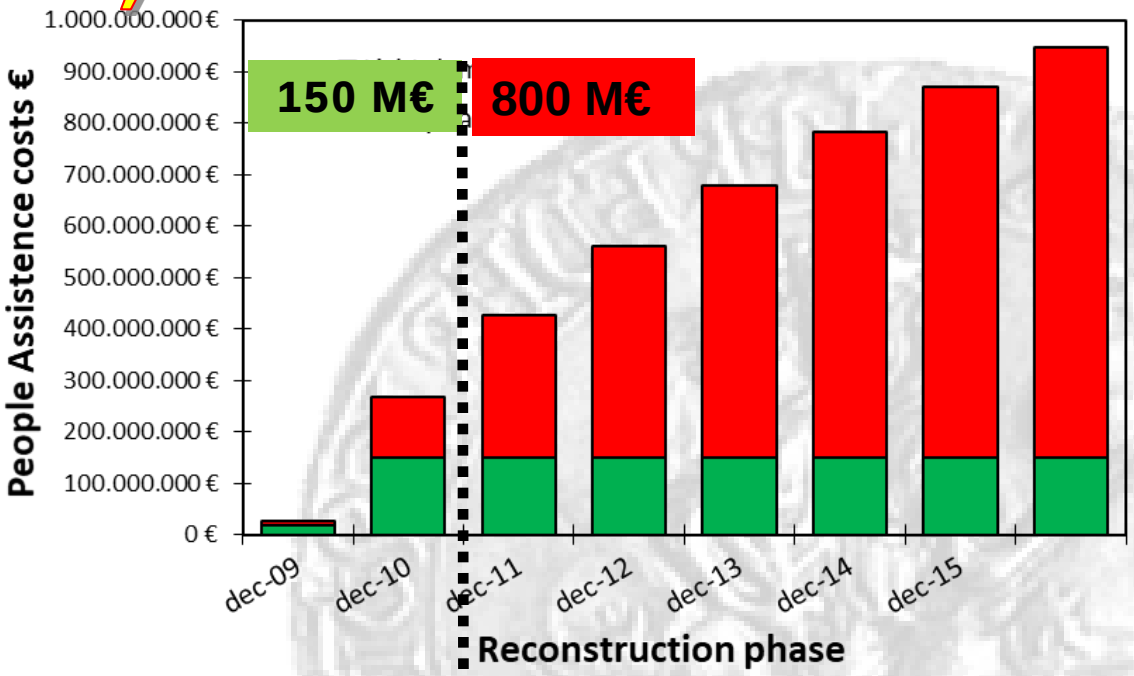
Indirect Costs – Population Assistance

private buildings outside historical centres of L'Aquila

...preliminary analysis.....

0,95 billion euros*

**this value does not take into account the costs for initial assistance (i.e. tends) and the costs related to buildings with usability rating A)*



PHASE I LIGHT DAMAGE
~ 150 M€
~ 100 M€/year
~ 380€/month/person

PHASE II HEAVY DAMAGE
~ 800 M€
~ 106 M€/year
~ 420€/month/person

POPULATION ASSISTANCE AND RETURNING HOME TREND0

Direct repair cost — *Indirect Costs – Population Assistance*

1,3 billion euros — **0,95 billion euros***

PHASE I: THE "LIGHT DAMAGE " RECONSTRUCTION

Direct repair cost — *Indirect Costs – Population Assistance*

128.000€/building for repair intervention — **~ 380€/month/person for 1,5 years**

6.840 €/person ➔ 62.928,00 €/build.*

On average, Tot: direct +indirect ~ 191.000 €/building

PHASE II: THE "HEAVY DAMAGE " RECONSTRUCTION

Direct repair cost — *Indirect Costs – Population Assistance*

580.000€/building for repair interventions — **~ 420€/month/person for 7,5 years**

37.800€/person ➔ 347.760 €/build.*

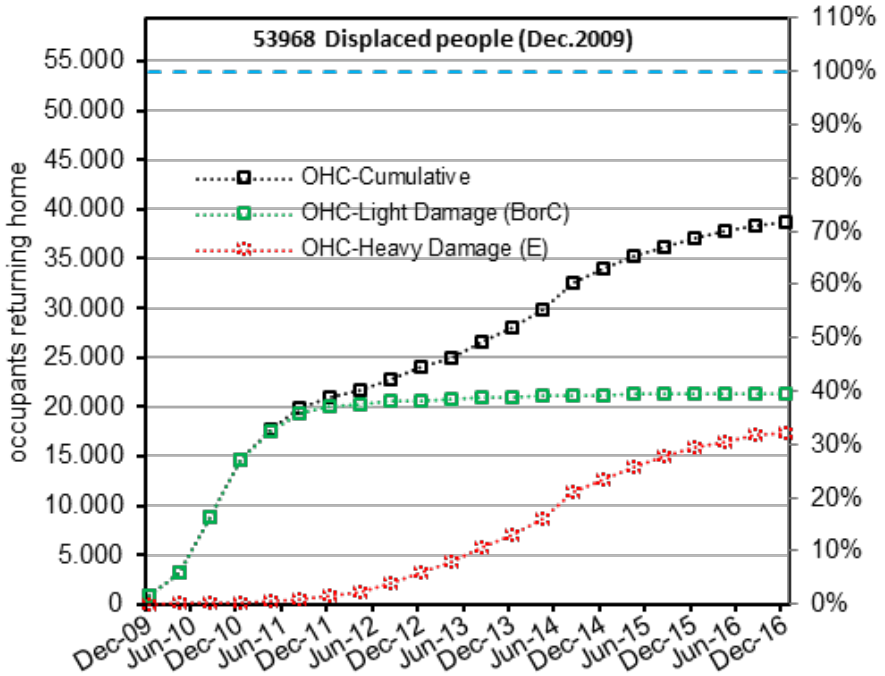
On average, Tot: direct +indirect ~ 928.000 €/building

*** Average number of occupants per building in L'Aquila = 9,2 people/building**

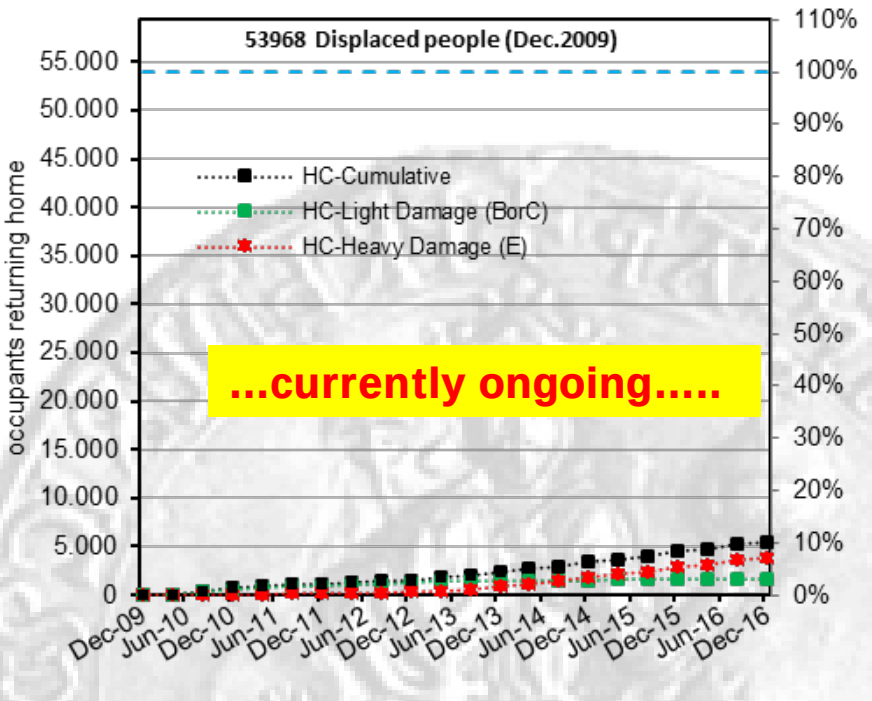
Population Assistance and Returning home trend

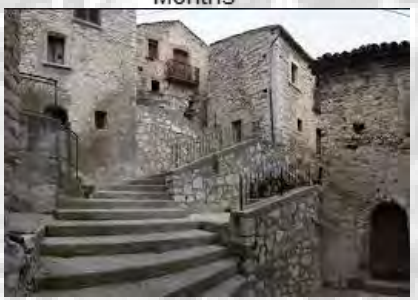
POPULATION ASSISTANCE – RETURNING HOME TREND

Occupants of buildings
outside historical centres, OHC



Occupants of buildings
inside historical centres, HC





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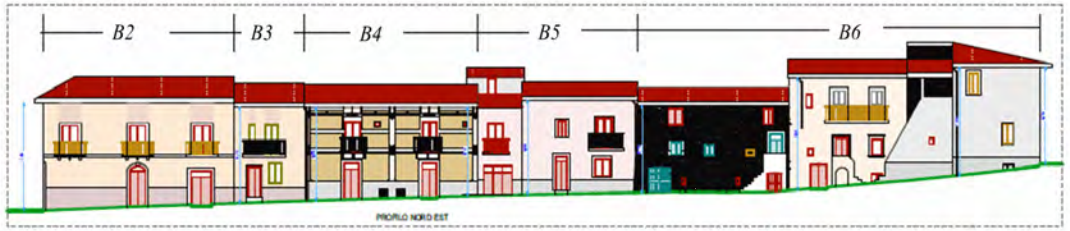
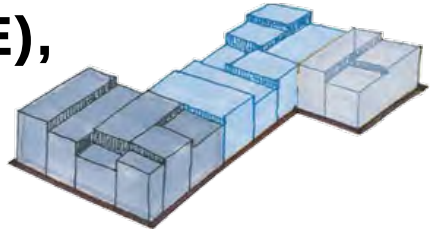
RECOSTRUCTION INSIDE HISTORICAL CENTRES

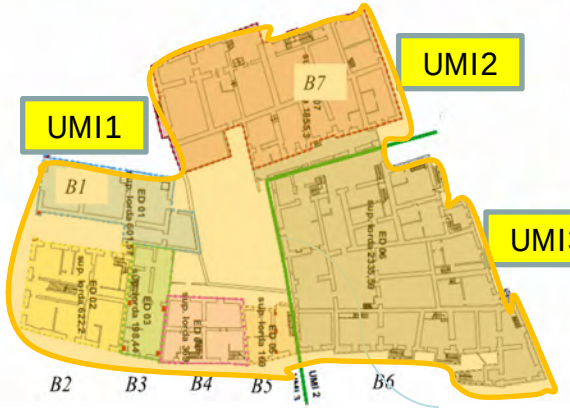
How much is the reconstruction cost historical centres?

There is a unit cost increse



❑ **Aggregate (AE),**



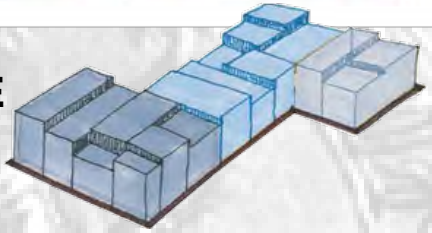


Cost Increase of about +30-40%

❖ **BUILDINGS**

	16th p.le	50th p.le	84th p.le
B-C	7%	14%	25%
E-B	9%	19%	29%
E	21%	33%	47%
E_{dem}	71%	84%	102%

❖ **AGGREGATE**

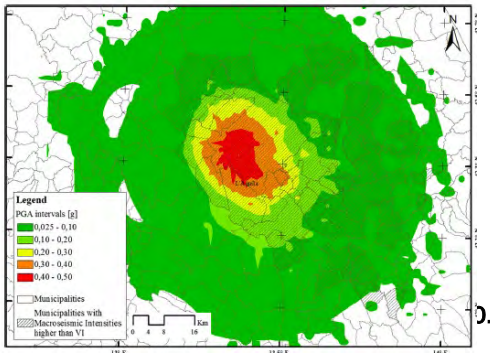


….cost increase due to site difficulties and artistic assets preservetion

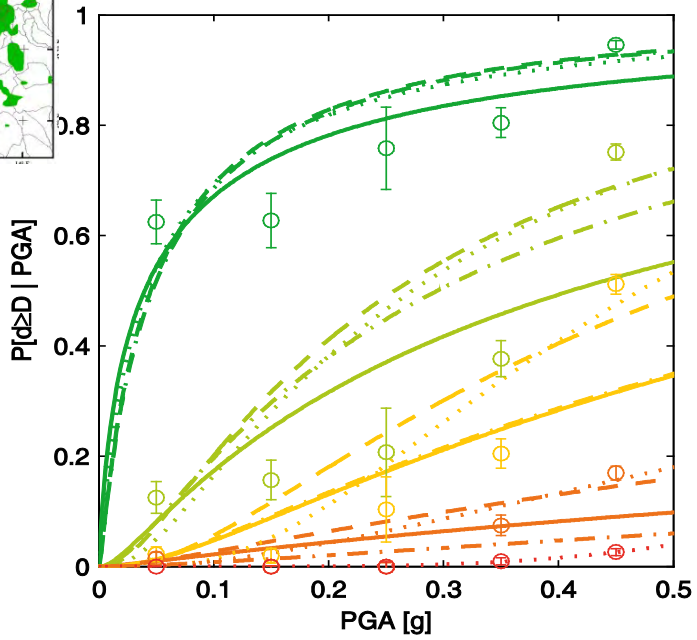
…preliminary analysis…..ongoing activity

SEISMIC RISK EVALUATION FROM EMPIRICAL DATA

…How we can use these data to predict future losses?



Shake map



P[d>usability rate/PGA]

Economic loss assessment

Usability Rating
B-C
E

or

Usability classes
B-C
E-B
E
Edem

…Indirect costs easily computed: time returning home reliably associated to usablity rating

…UNCOMMON: fragility curves to correlate PGA to usability classes

SEISMIC RISK EVALUATION FROM EMPIRICAL DATA

... while

JRC Scientific and Technical Reports

Field Manual for post-earthquake damage and safety assessment and short term countermeasures (AeDES)

Carlo BAGGIO, Alberto BERNARDINI, Riccardo COLOZZA
Livio CORAZZA, Marianna DELLA BELLA, Giacomo DI PASQUALE, Mauro DOLCE
Agostino GORETTI, Antonio MARTINELLI
Giampiero ORSINI, Filomena PAPA, Giulio ZUCCARO

Translation from Italian: Maria ROTA and Agostino GORETTI

Editors: Artur V. PINTO, Fabio TAUCER

EUR 22968 EN - 2007

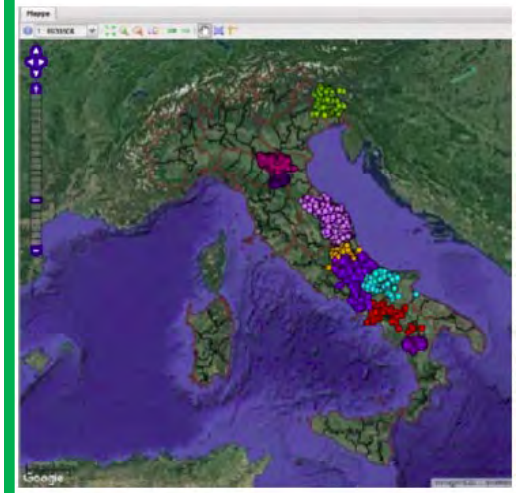
JRC EUROPEAN COMMISSION ipsc

Empirical damage AeDES Form

Structural component / Pre-existing damage	Level - extension	DAMAGE D4-D5 Very heavy > 2/3	D4-D5 Very heavy 1/3 - 2/3	D4-D5 Very heavy < 1/3	D2-D3 Medium-severe > 2/3	D2-D3 Medium-severe 1/3 - 2/3	D2-D3 Medium-severe < 1/3	D1 Slight > 2/3	D1 Slight 1/3 - 2/3	D1 Slight < 1/3	Null
		A	B	C	D	E	F	G	H	I	L
1	Vertical structures	☐	☐	☐	☐	☐	☐	☐	☐	☐	○
2	Floors	☐	☐	☐	☐	☐	☐	☐	☐	☐	○
3	Stairs	☐	☐	☐	☐	☐	☐	☐	☐	☐	○
4	Roof	☐	☐	☐	☐	☐	☐	☐	☐	☐	○
5	Infills-partitions	☐	☐	☐	☐	☐	☐	☐	☐	☐	○
6	Pre-existing damage	☐	☐	☐	☐	☐	☐	☐	☐	☐	○

Da.D.O.

(Dolce et al. 2017)

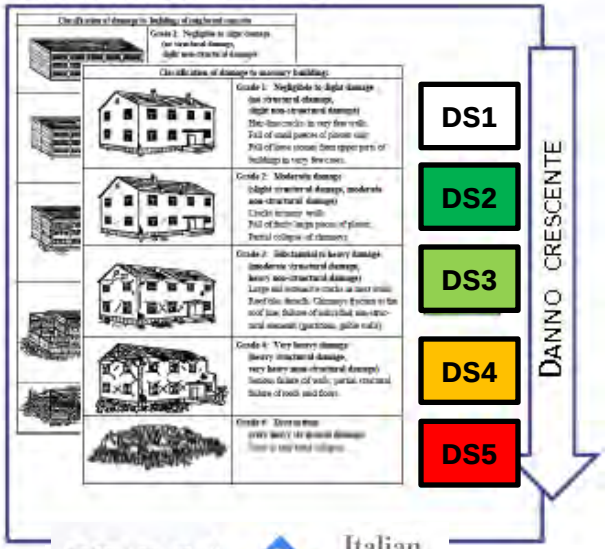


Damage database ≈ 320.00 buildings

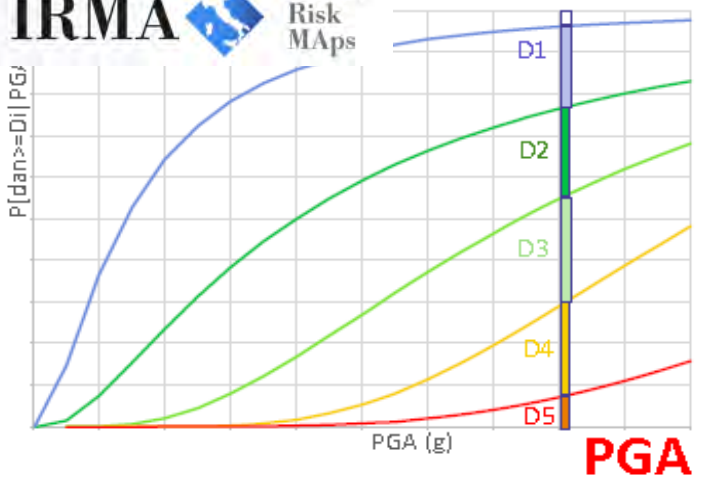
- Friuli 1976
- Irpinia 1980
- Abruzzo 1984
- Umbria-Marche 1997
- Pollino 1998
- Molise e Puglia 2002
- Emilia 2003
- L'Aquila 2009
- Emilia 2012

Project ReLUIS-DPC 2018

SCALA DI DANNO EMS-98



IRMA Italian Risk MAps

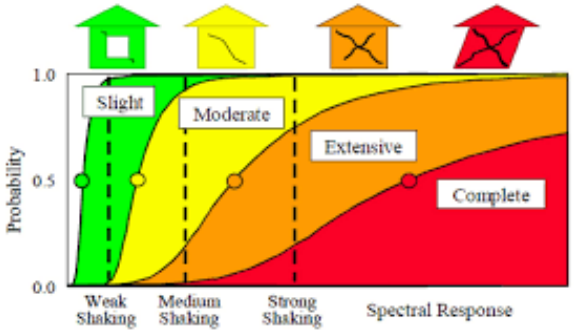


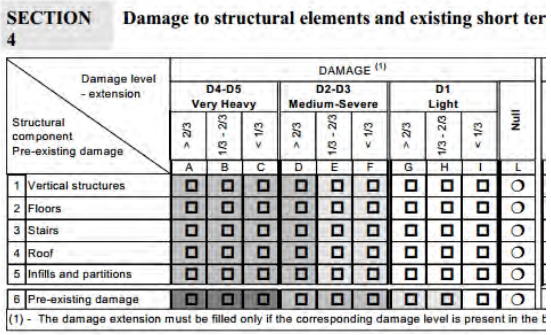
PGA

$$P[dan \geq Di \mid PGA] = \Phi\left(\frac{\ln(PGA) - \mu}{\sigma}\right)$$

SEISMIC RISK EVALUATION FROM EMPIRICAL DATA

...From data collected...





SECTION 4 — Damage to structural elements and existing short ter

Structural component / Pre-existing damage \ Damage level - extension	DAMAGE (1) D4-D5 Very Heavy > 2/3	D4-D5 1/3 - 2/3	D4-D5 < 1/3	D2-D3 Medium-Severe > 2/3	D2-D3 1/3 - 2/3	D2-D3 < 1/3	D1 Light > 2/3	D1 1/3 - 2/3	D1 < 1/3	Null
	A	B	C	D	E	F	G	H	I	L
1 Vertical structures	□	□	□	□	□	□	□	□	□	○
2 Floors	□	□	□	□	□	□	□	□	□	○
3 Stairs	□	□	□	□	□	□	□	□	□	○
4 Roof	□	□	□	□	□	□	□	□	□	○
5 Infills and partitions	□	□	□	□	□	□	□	□	□	○
6 Pre-existing damage	□	□	□	□	□	□	□	□	□	○

(1) - The damage extension must be filled only if the corresponding damage level is present in the b

by using suitable component to global damage conversion matrices (Da.D.O and Del gaudio et al.2019)

AEDES FORM ⇒ **GLOBAL BUILDING DAMAGE**

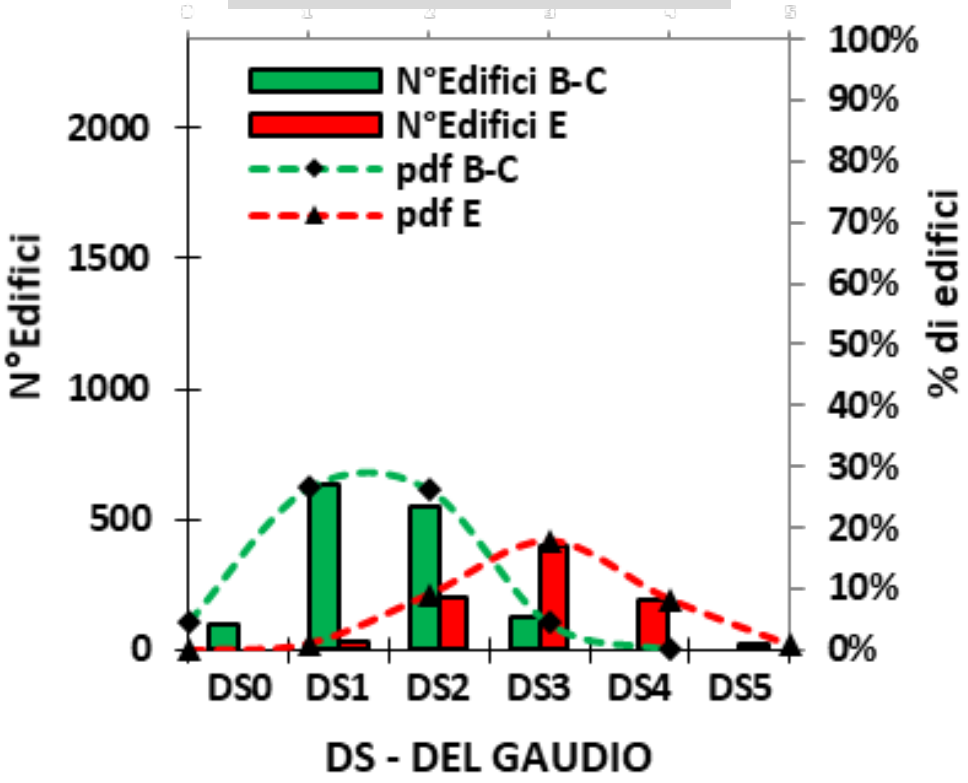
Empirical dabage (AEDES)		GLOBAL BUILDING DAMAGE			
Severity	Extension	Da.D.0 (VS) 2019		DEL GAUDIO 2016	
		VS		VS	IP
NULL	-	DS0		DS0	DS0
D1 LIGHT	< 1/3	DS1		DS1	DS1
	1/3-2/3	DS1		DS1	DS1
	>2/3	DS1		DS1	DS1
D2-D3 MEDIUM-HEAVY	< 1/3	DS2		DS2	DS2
	1/3-2/3	DS3		DS3	DS2
	>2/3	DS3		DS3	DS2
D4-D5 VERY HEAVY-COLLAPSE	< 1/3	DS3 ($+k_{D2-D3}$ <1/3)	DS4 ($+k_{D2-D3}$ >1/3)	DS4	DS3
	1/3-2/3	DS4 ($+k_{D2-D3}$ <1/3)	DS5 ($+k_{D4-D5}$ >1/3)	DS4	DS3
	>2/3	DS5		DS5	DS3

They allow the **estimation of the probability of exceeding several DS** according to the intensity of the seismic ground shaking

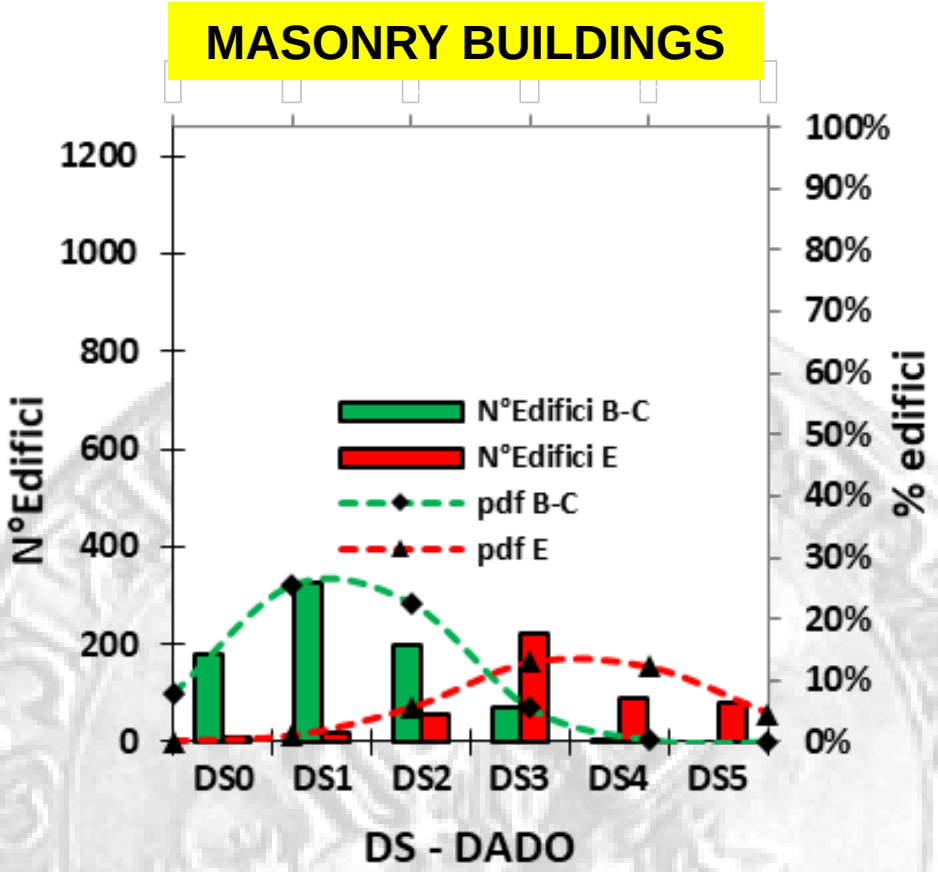
FROM DAMAGE AT COMPONENT LEVEL TO BUILDING DAMAGE

- **USABILITY RATE vs. DAMAGE STATE OF RESIDENTIAL BUILDINGS**

RC BUILDINGS



MASONRY BUILDINGS

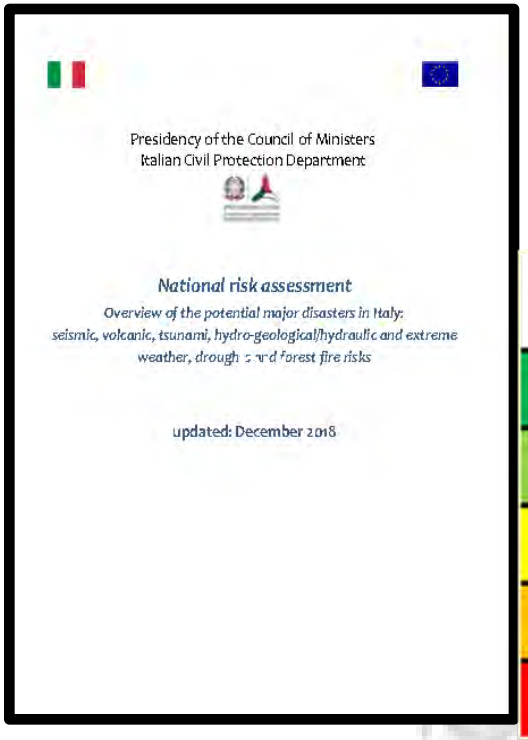


Definition of minimum and maximum %Cr associated to several damage states

SEISMIC RISK EVALUATION FROM EMPIRICAL DATA

...From data collected...

...to National risk assessment, DPC 2018



Definition of minimum and maximum %Cr associated to several damage states

DS	CrMin[%]*	CrMax[%]*
DS1	2	5
DS2	10	20
DS3	30	45
DS4	60	80
DS5	100	100

%Cr - Reconstruction Cost:1350€/mq

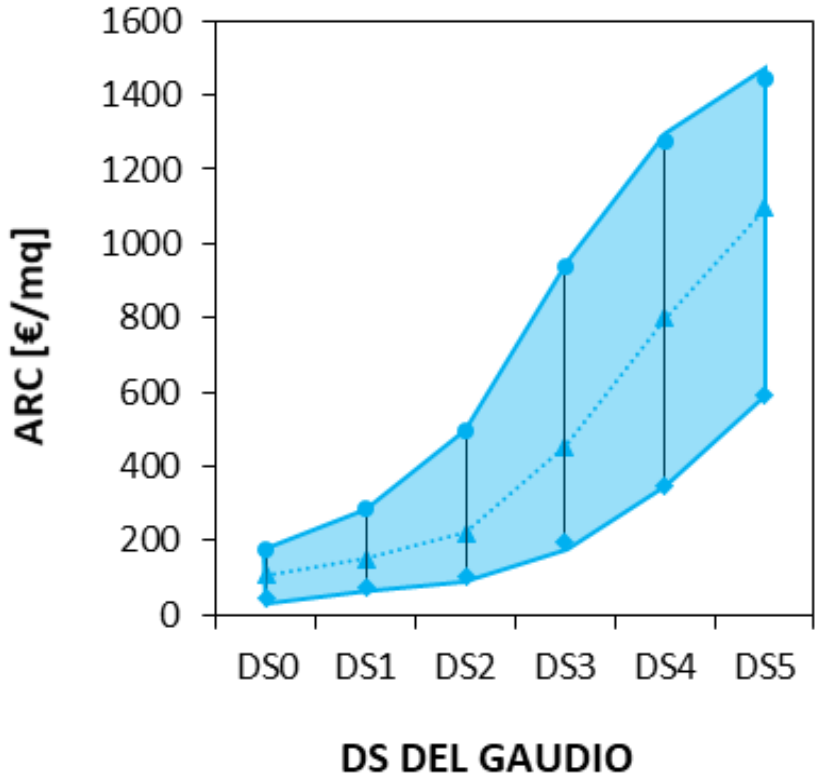
Di Ludovico M., Prota A., Moroni C., Manfredi G., Dolce M., (2017), "Reconstruction process of damaged residential buildings outside historical centres after the L'Aquila earthquake - part II: "heavy damage" reconstruction", Bull. of Earth. Engineering, Volume 15, Issue 2, 2017, Pages 693-729,

Di Ludovico M., Prota A., Moroni C., Manfredi G., Dolce M., (2017), " Reconstruction process of damaged residential buildings outside historical centres after the L'Aquila earthquake: part I—"light damage" reconstruction", Bull. of Earth. Engineering, Volume 15, Issue 2, 2017, Pages 667-692,

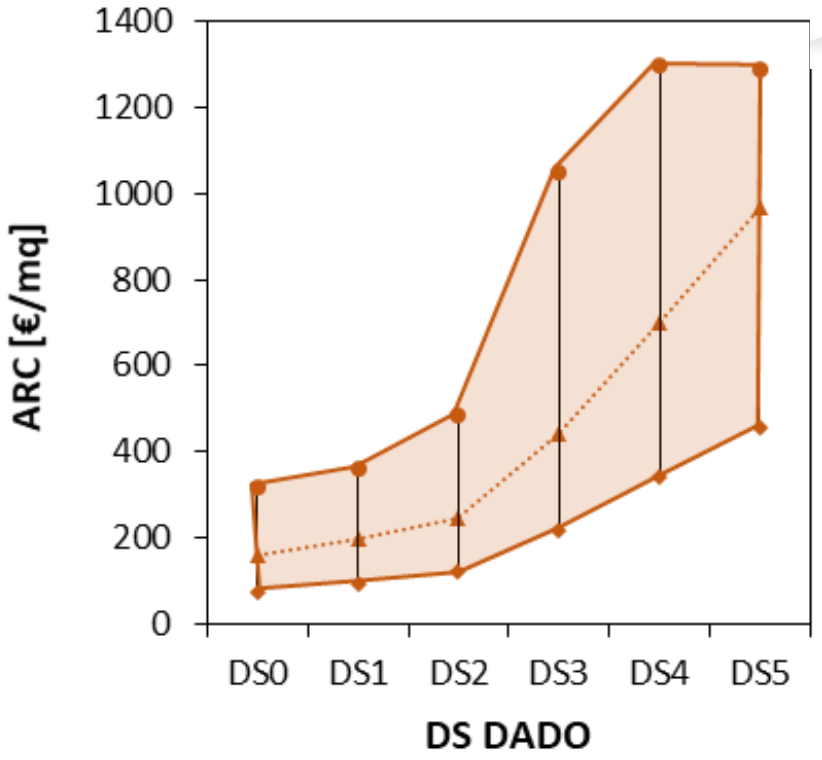
SEISMIC RISK EVALUATION FROM EMPIRICAL DATA

- **ACTUAL REPAIR COSTS AND DAMAGE STATES**

RC BUILDINGS



MASONRY BUILDINGS

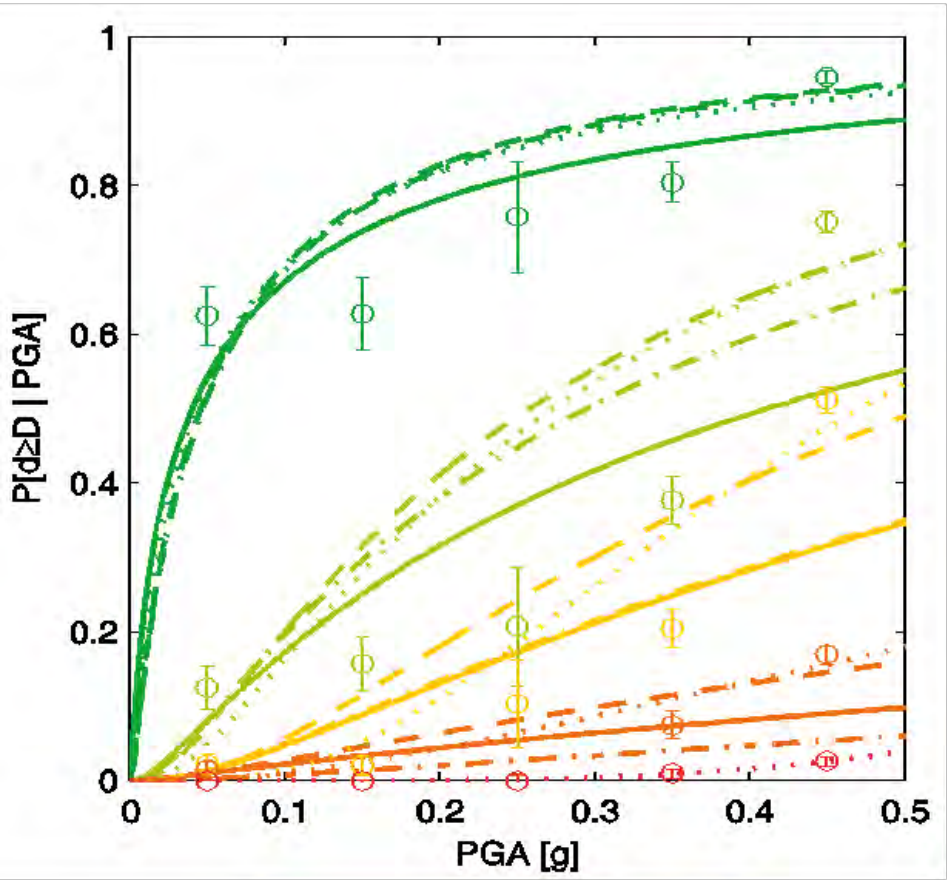


However there is an high variability because global damage and costs are not structly related. Indeed the global damage may be not affected by damage on non structural members

SEISMIC RISK EVALUATION FROM EMPIRICAL DATA

WORK IN PROGRESS…

Fragility curves for define the Pr% of exceeding several %Cr



Cr…
Cr1
Cr2
Cr3
Cr4
Cr5
Cr6
Cr7
Cr8
Cr9
Cr10
Cr11

i.e.

10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
…

P[Cr>Cri/PGA]

SEISMIC RISK MITIGATION

- **INITIATIVE FOR SEISMIC RISK REDUCTION :**

Communication campaigns:

I DO NOT TAKE RISK

http://iononrischio.protezionecivile.it/en/homepage/

LET'S GET A SHOCK

https://www.giornataprevenzionesismica.it/

Governament incentives for seismic strengthening of residential buildings:

ITALIAN GUIDELINES: SEISMIC RISK CLASSIFICATION OF CONSTRUCTIONS

tax deductions (70%-85%) in case of seismic strengthening interventions on existing buildings (*Sismabonus*)

Enhance the seismic risk class

ITALIAN GUIDELINES: SEISMIC RISK CLASSIFICATION

Approved by:
High Council of Public Works
20th February 2017,
Ministry Decree n.58 28/02/2017

- Seismic classes from **A+** **to** **G**

- To facilitate the communication to the large public of the **seismic risk of constructions** and the effectiveness of the retrofit interventions

- It defines the technical principles for exploiting **tax deductions (70%-85%)** in case of seismic strengthening interventions on existing buildings (*Sismabonus*)

Enhance the seismic risk class

Bulletin of Earthquake Engineering
https://doi.org/10.1007/s10518-018-0431-8

ORIGINAL RESEARCH

CrossMark

The Italian guidelines for seismic risk classification of constructions: technical principles and validation

Edoardo Cosenza[1] · Ciro Del Vecchio[1] · Marco Di Ludovico[1] · Mauro Dolce[2] · Claudio Moroni[2] · Andrea Prota[1] · Emanuele Renzi[3]

ITALIAN GUIDELINES: SEISMIC RISK CLASSIFICATION

The **seismic risk class SRC** of a building is the minimum between two classes accounting for:

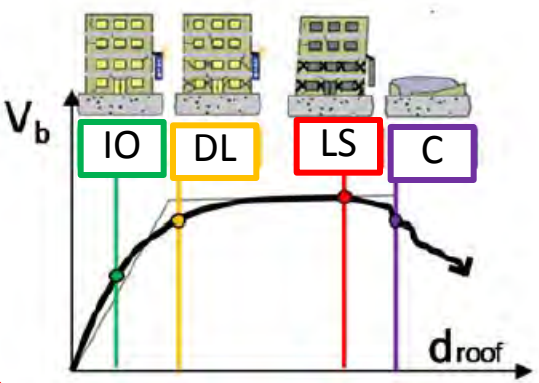
SISMABONUS → evaluation of **SRC**

%NBS class

EAL class

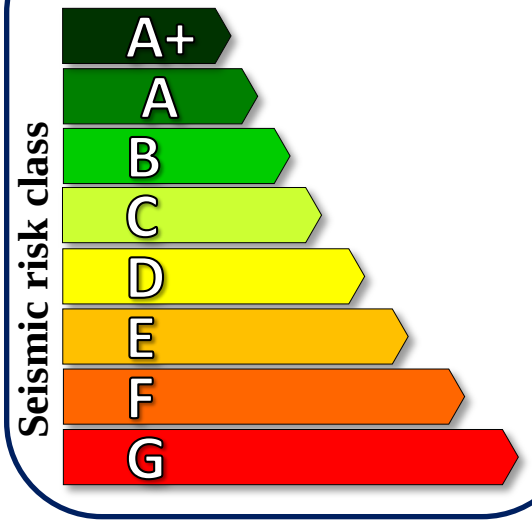
Worst class

Safety index at LS



Expected Annual losses

Seismic Risk Class

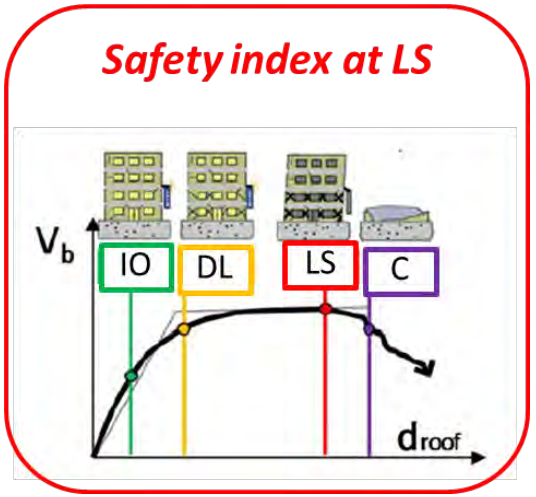


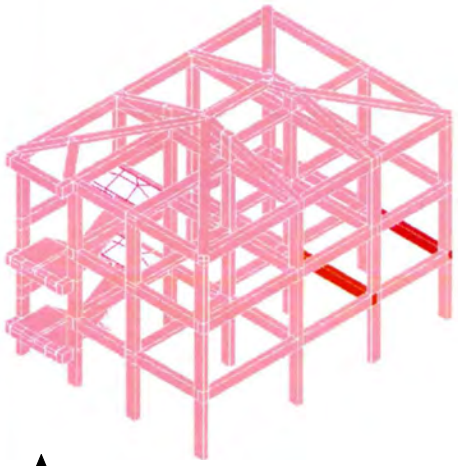
Bonus to upgrade with retrofit

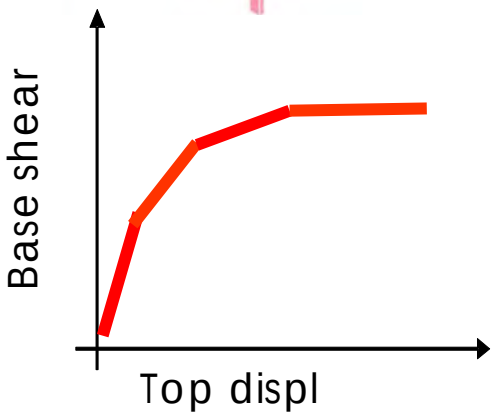
ITALIAN GUIDELINES: SEISMIC RISK CLASSIFICATION

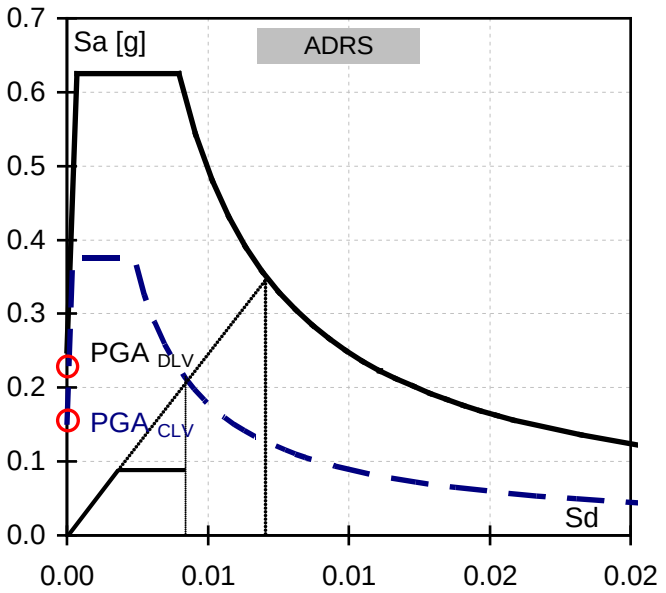
SISMABONUS → evaluation of **SRC**

%NBS class









Life-safety index (SI-LS)	Class $_{SI-LS}$
$100\% \geq$ SI-LS	A^{+}_{SI-LS}
$80\% \leq$ SI-LS $< 100\%$	A_{SI-LS}
$60\% \leq$ SI-LS $< 80\%$	B_{SI-LS}
$45\% \leq$ SI-LS $< 60\%$	C_{SI-LS}
$30\% \leq$ SI-LS $< 45\%$	D_{SI-LS}
$15\% \leq$ SI-LS $< 30\%$	E_{SI-LS}
SI-LS $\leq 15\%$	F_{SI-LS}

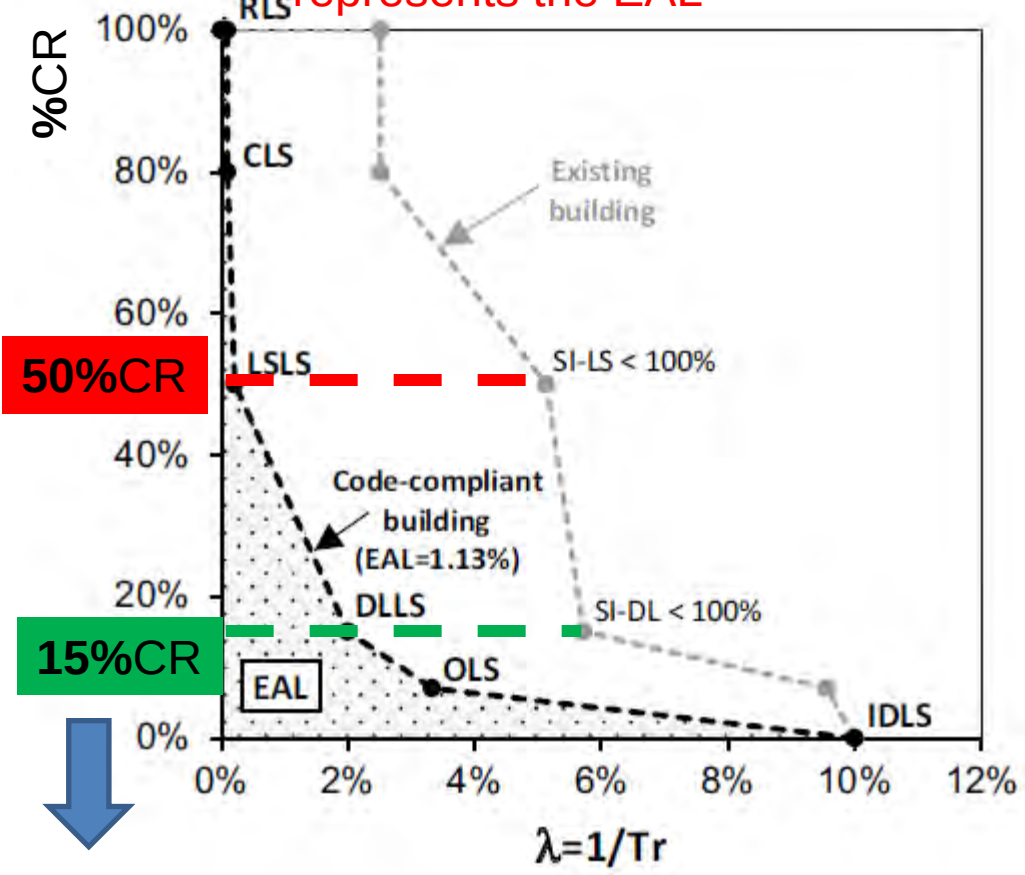
$$\%NBS = PGA_c/PGA_d\ [\%]$$

ITALIAN GUIDELINES: SEISMIC RISK CLASSIFICATION

SISMABONUS → evaluation of **SRC**

EAL class

The area under the curve λ vs. %CR represents the EAL



Expected annual losses (EAL)	$CLASS_{EAL}$
$EAL \leq 0.50\%$	A^{+}_{EAL}
$0.50\% < EAL \leq 1.0\%$	A_{EAL}
$1.0\% < EAL \leq 1.5\%$	B_{EAL}
$1.5\% < EAL \leq 2.5\%$	C_{EAL}
$2.5\% < EAL \leq 3.5\%$	D_{EAL}
$3.5\% < EAL \leq 4.5\%$	E_{EAL}
$4.5\% < EAL \leq 7.5\%$	F_{EAL}
$7.5\% \leq EAL$	G_{EAL}

Repair costs calibrated based on data from L'Aquila Earthquake

SEISMIC RISK MITIGATION

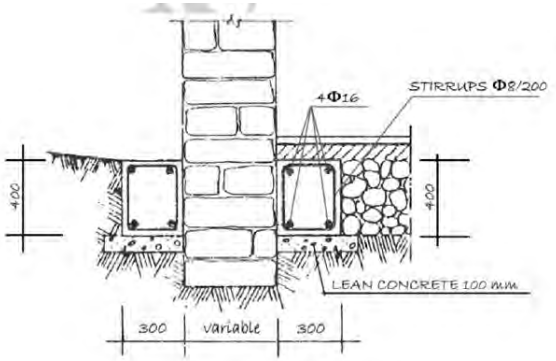
…Are strengthening intervention effective to mitigate the seismic risk?

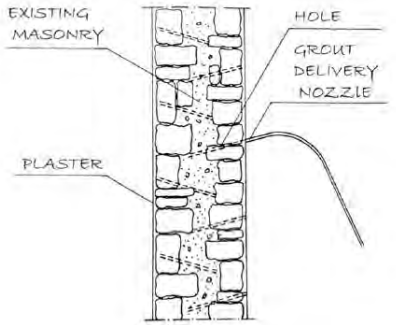
- **The case of Norcia**

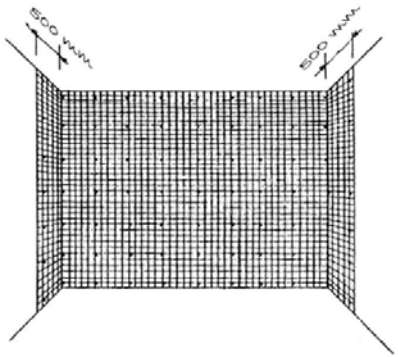
1979 EARTQUAKE

- **After the earthquake strengthening interventions were funded by government**

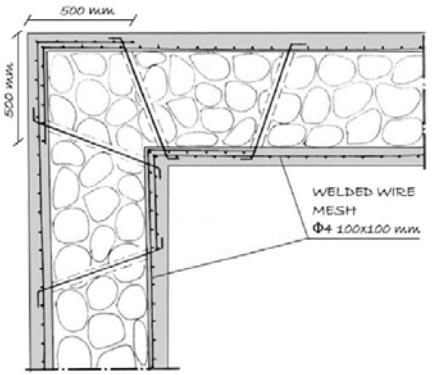
H1: Injections or unreinforced plasters
H2: Reinforced plaster
H3: Other strenthening intrventions



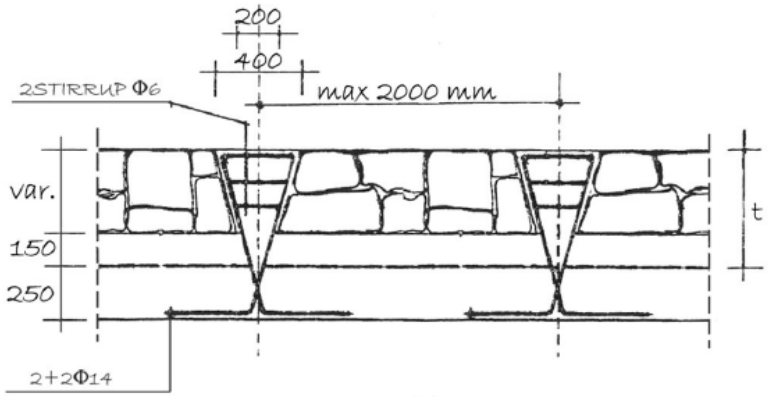




(a)



(b)



STRENGHTENING INTERVENTIONS

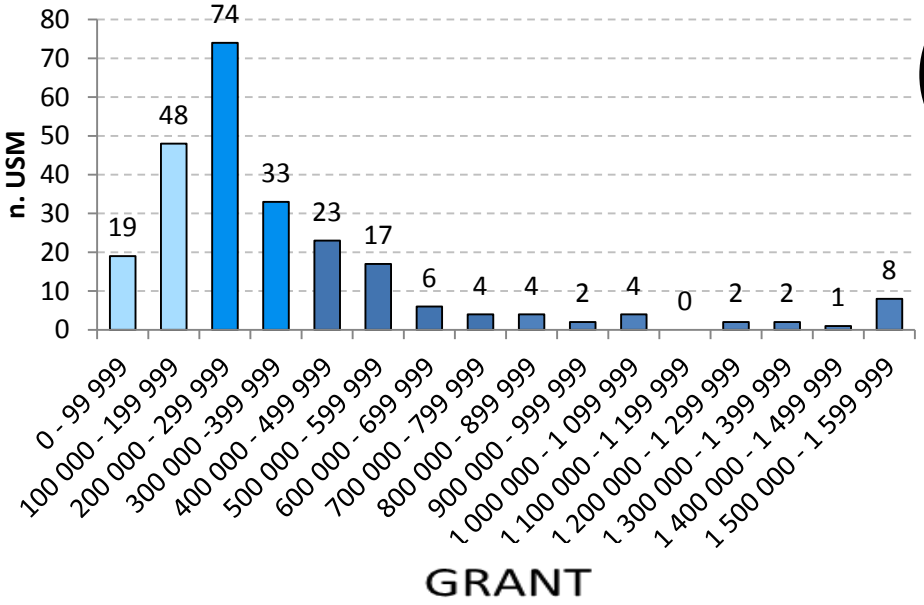
Reconstruction cost of Norcia historical center after 1979 earthquake

189 GRANTS

POST 1979 EARTHQUAKE

The grant (in lire) are related both to structural and non structural and finishing interventions

Cost/m²



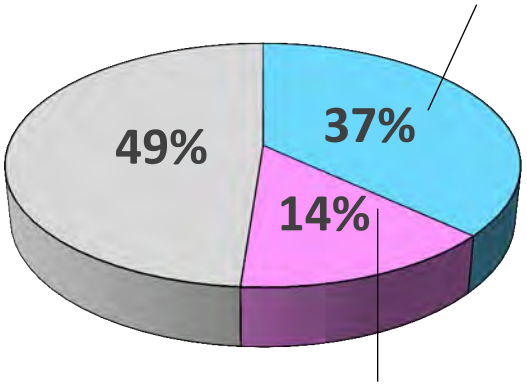
189 grant
about 36 billion lire £
Average grant 200 million £

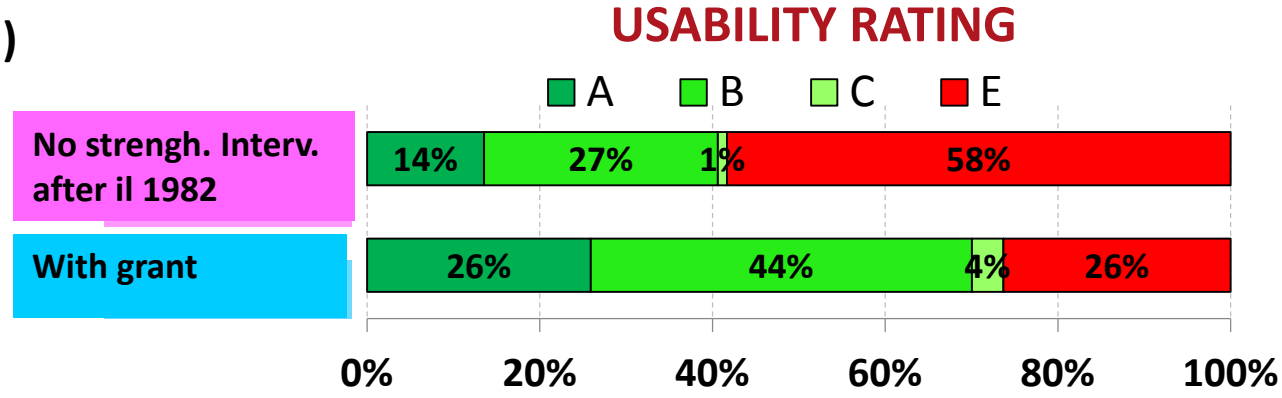
Average cost
389 635 €/m²

discounted to 2018,
it amounts to 398 €/m².

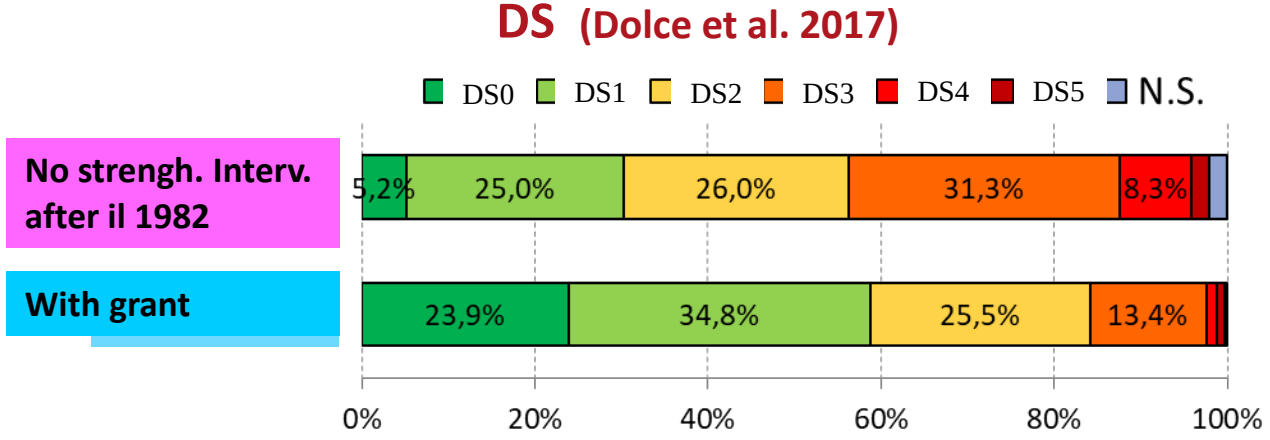
STRENGHTENING INTERVENTIONS

Norcia: 670 STRUCTURAL UNIT (USM)





…..The strengh. Intervention allowed to significanlty decrease the number of E rating buildings (-32%) and increasing A rating buildings (+12%)



STRENGHTENING INTERVENTIONS

2016 Center Italy eartquake
AMATRICE 2016, August 24

Mw6.0 – 6,2

Can we avoid it?...

2016 Center Italy eartquake
NORCIA 2016, August 24

Mw6.5

Yes, we can

STRUCTURAL
BUILDING ENGINEERING + STRUCTURAL DESIGN

COMPORTAMENTO STRUTTURALE DEGLI EDIFICI ORDINARI DEL CENTRO STORICO DI NORCIA NELLA SEQUENZA SISMICA DEL 2016

Antonio Borri, Romina Sisti
Università degli Studi di Perugia, Dipartimento di Ingegneria
antonio.borri@unipg.it
rominasisti@hotmail.it

Andrea Prota, Marco Di Ludovico
Università degli Studi di Napoli - Federico II, Dipartimento di Strutture per l'Ingegneria e l'Architettura
aprota@unina.it
diludovi@unina.it

Sandro Costantini, Marco Barluzzi, Alessandro De Maria, Elisabetta Aisa, Alessio Bragetti, Francesco Savi, Gianluca Fagotti, Luciano Baldi
Regione Umbria – Servizio rischio sismico
ademaria@regione.umbria.it

Thanks for your attention

REte dei **L**aboratori **U**niversitari di **I**ngegneria **S**ismica

PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile

Marco Di Ludovico
University of Naples Federico II
Department of Structures for Engineering and Architecture
Email: ***diludovi@unina.it***