Concepts of Seismic Vulnerability and Risk

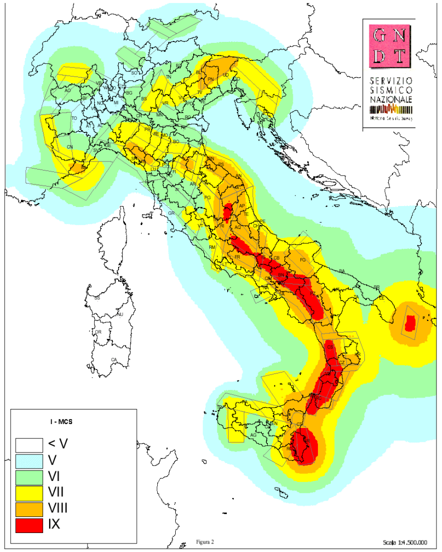
Definitions

EUCENTRE
European Centre for Training and Research in Earthquake Engineering

IUSS

SEVENTH FRAMEWORK PROGRAMME

Hazard



Vulnerability

Exposure

Seismic Risk

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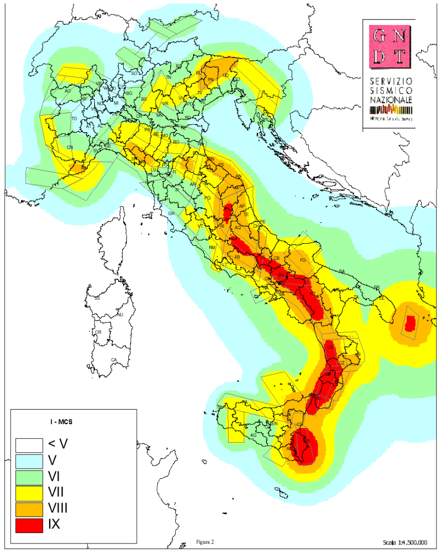
Hazard



Vulnerability

Exposure

Seismic Risk

Target of the lecture

Vulnerability

- It is fundamental to understand the vulnerability concept
- The seismic risk, that quantifies the losses, is the convolution of vulnerability, hazard and exposure. It is impossible to act on hazard, nearly impossible to act on exposure, it is feasible to act on vulnerability. Hence, the feasible way to mitigate the seismic risk is to mitigate the seismic vulnerability
- Vulnerability measures how prone a structure is to be damaged when an earthquake occurs
- To deal with vulnerability, a mathematical definition is needed

Mathematical Definition of Vulnerability

$$P_{ik} = P[D \geq d_i \mid S = s_k]$$

Damage

Shaking

Methods to quantify the vulnerability

- ❑ Empirical methods based on post earthquake observations
- ❑ Mechanic methods
- ❑ Hybrid methods

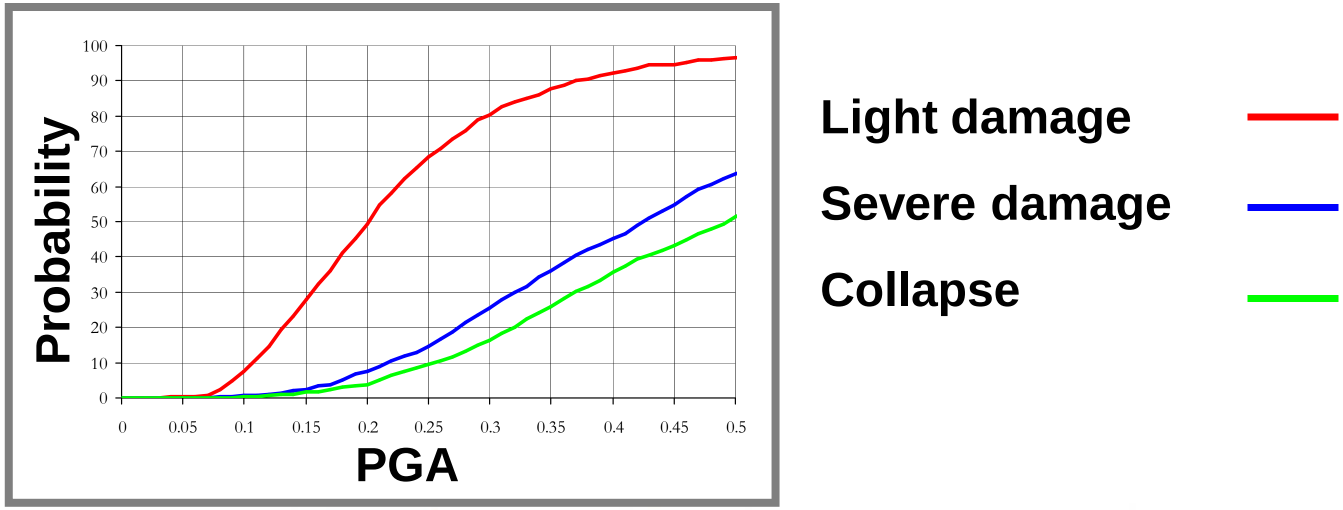
Methods to quantify the vulnerability

- ❑ Damage Probability Matrix (DPM)
- ❑ Fragility curves

DPM

		Intensity Scale						
		VI	VII	VIII	IX	X	XI	XII
Damage level	0							
	1							
	2							
	3							
	4							
	5							

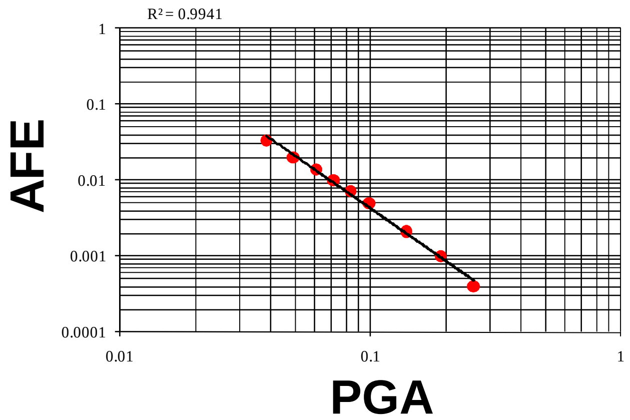
Fragility Curves



Seismic Risk

- Unconditional damage/failure probability

If the probability of having a certain ground shaking severity is also taken into account, the unconditional damage/failure probability is computed. The probability of having a certain ground shaking severity is taken into account through the hazard curve:



AFE: Annual frequency of exceedance

AFE=1/T_r with T_r the return period of the ground shaking

Unconditional damage/failure probability

In order to compute the seismic risk, the hazard curve must be transformed in terms of probability. The assumption usually undertaken is that the events follow the Poisson's distribution, that is the probability distribution of rare events without memory (what happens one year is independent from what happened in the years before). The occurrence probability "q" of a ground shaking with a certain AFE in an observation time window t_d is:

$$q = 1- \exp (t_d \, AFE)$$

Hence, the seismic risk is computed by solving the integral of structural reliability

integral of structural reliability

$$P_f = \int_{-\infty}^{+\infty} f_d(E)\, F_c(E)\, dE = \int_{-\infty}^{+\infty} f_c(E)\, [1 - F_d(E)]\, dE$$

Fragility curve

Exceedace probability of ground shaking severity “q”

Where:

•*f* and *F* are the probability density function and the cumulative probability, respectively
•*E* is the parameter that represents the ground motion severity;
•*d* and *c* are the random variables that represent the demand and the capacity respectively

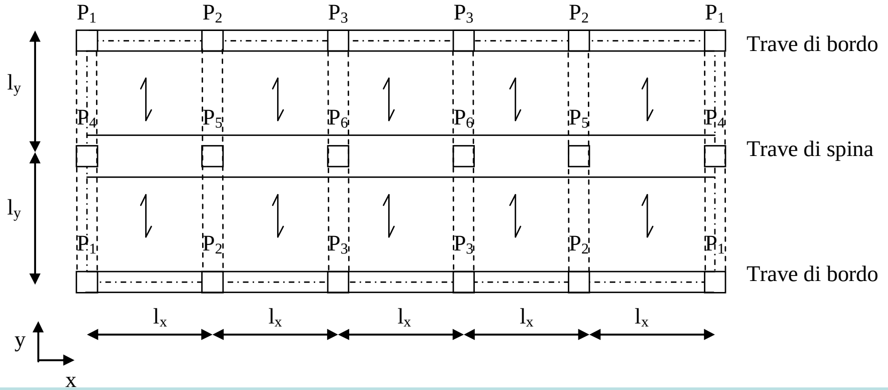
Mechanics Based Vulnerability Assessment:

SP-BELA

(Simplified Pushover - Based Earthquake Loss Assessment)

SP-BELA – Building Capacity

1st step: choice of prototype building



2nd step: definition of random variables that describe the bldg.(i.e.: loads, material properties, geometry, etc.)

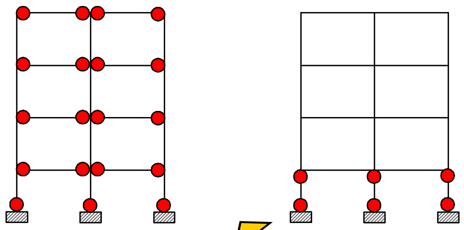
3rd step : montecarlo generation of buildings' population

4th step : simulated building design with reference to the regulation adopted in the year of real building design

5th step : simplified pushover analysis

Check of relative resistance of beams and columns

Collapse mechanism

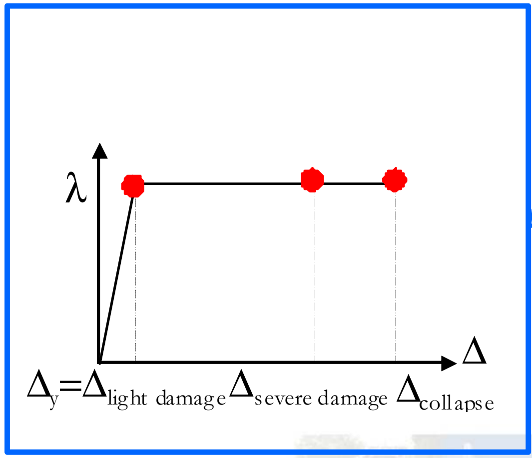


Deformed shape:

- ✓ Assumption of linear deformed shape into the elastic range
- ✓ Deformed shape consisent with the failure mechanism into the inelastic range

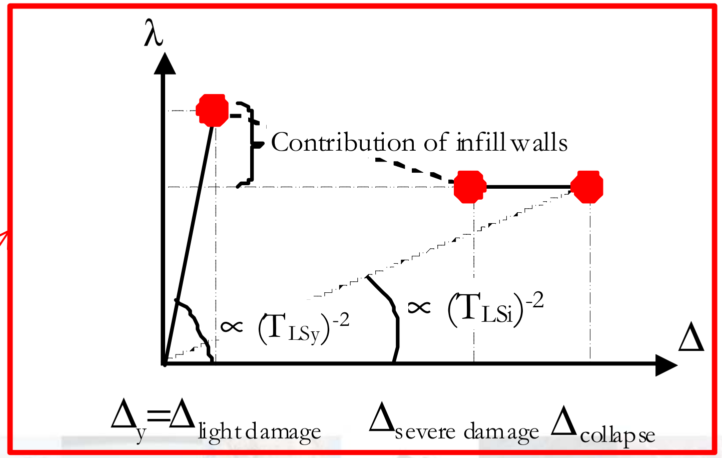
Resistance

Once the deformed shape, the limit conditions and the resistance are known ….



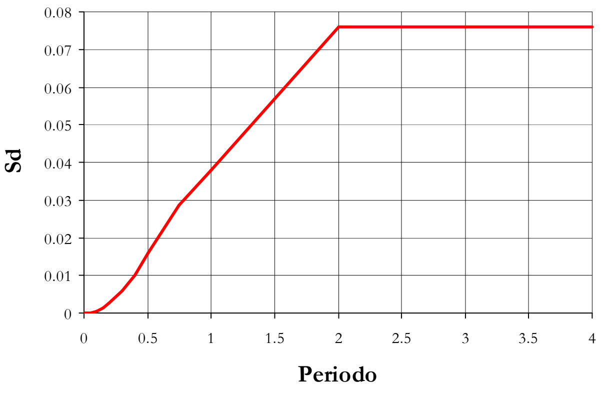
Bare frame

Frame with infill walls



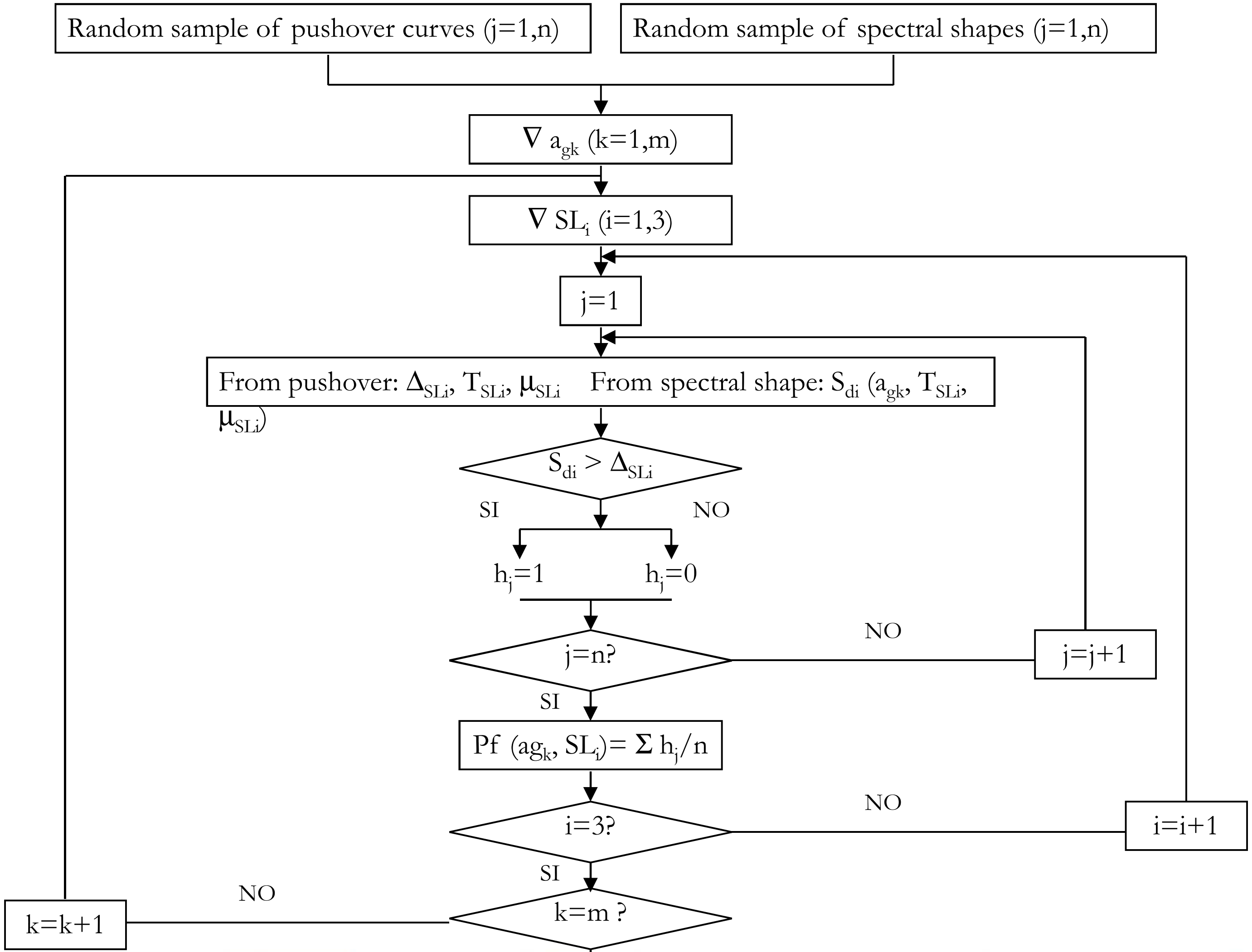
SP-BELA – Seismic Demand

1st step: choice of spectral shape

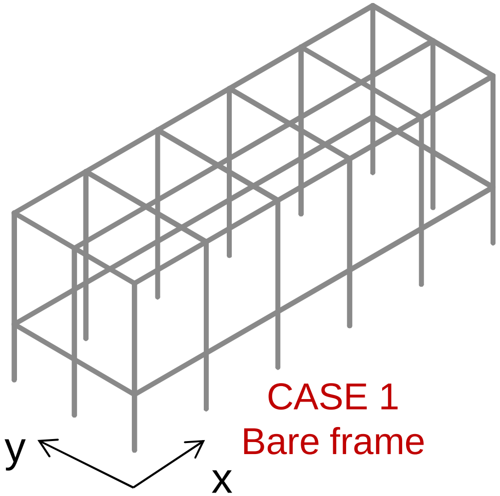


2nd step : definition of random variables that describe the spectral shape (i.e. corner periods, dynamic amplification, …)

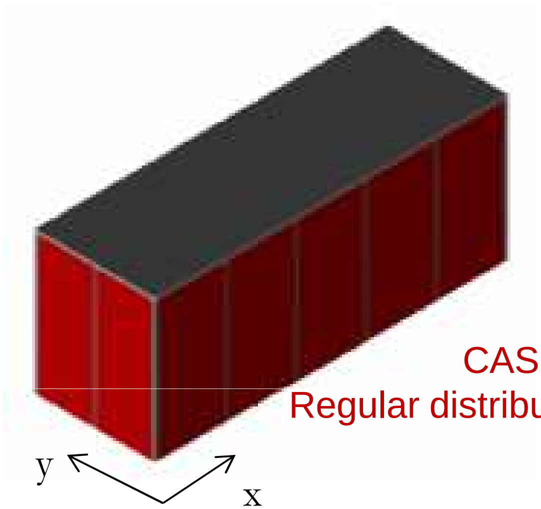
3rd step : montecarlo generation of a population of spectral shapes


Random sample of pushover curves (j=1,n)
Random sample of spectral shapes (j=1,n)
∇ a_{gk} (k=1,m)
∇ SL_i (i=1,3)
j=1
From pushover: Δ_{SLi}, T_{SLi}, μ_{SLi} From spectral shape: S_{di} (a_{gk}, T_{SLi}, μ_{SLi})
$S_{di} > \Delta_{SLi}$
SI
NO
h_j=1
h_j=0
j=n?
NO
j=j+1
SI
Pf (ag_k, SL_i)= Σ h_j/n
i=3?
NO
i=i+1
SI
k=m ?
NO
k=k+1
SI
END

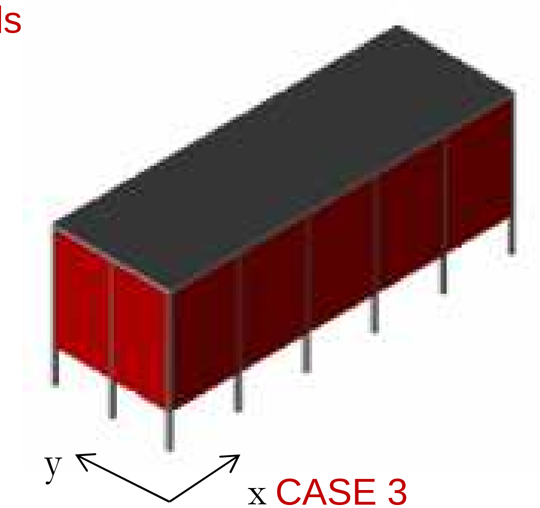
SP-BELA – Validation Exercise



CASE 1
Bare frame

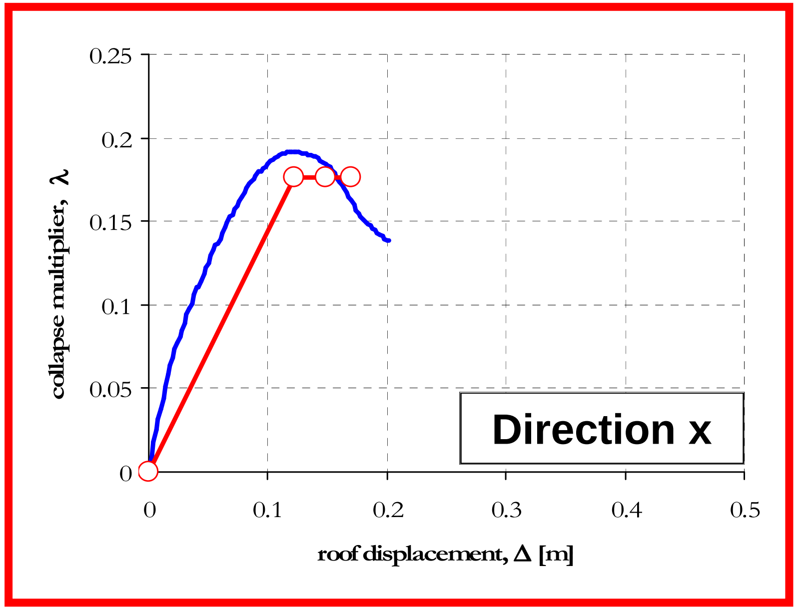


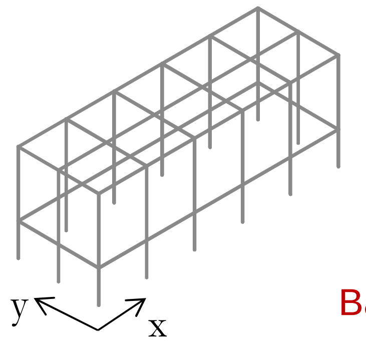
CASE 2
Regular distributed infill walls



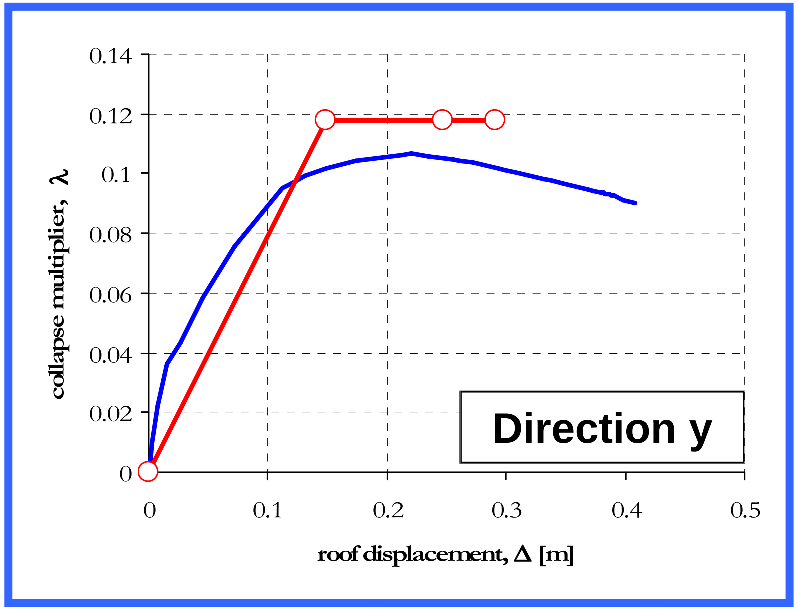
CASE 3
Non regular distributed infill walls

Non seismically designed buildings





CASE 1
Bare frame



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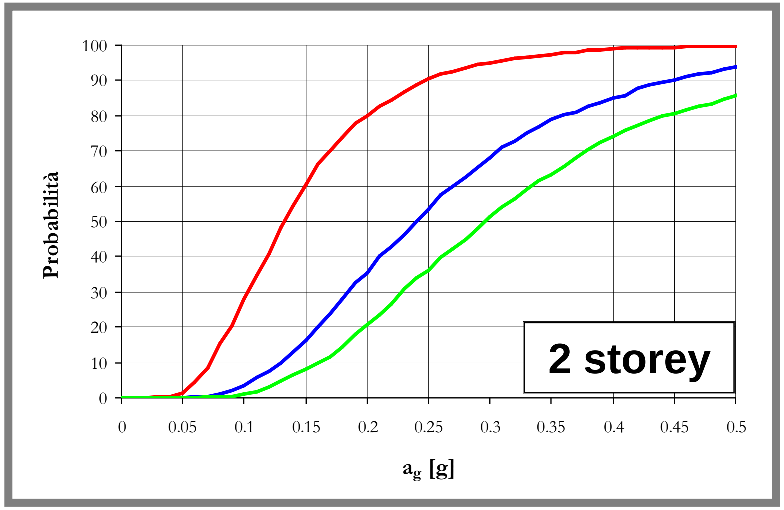
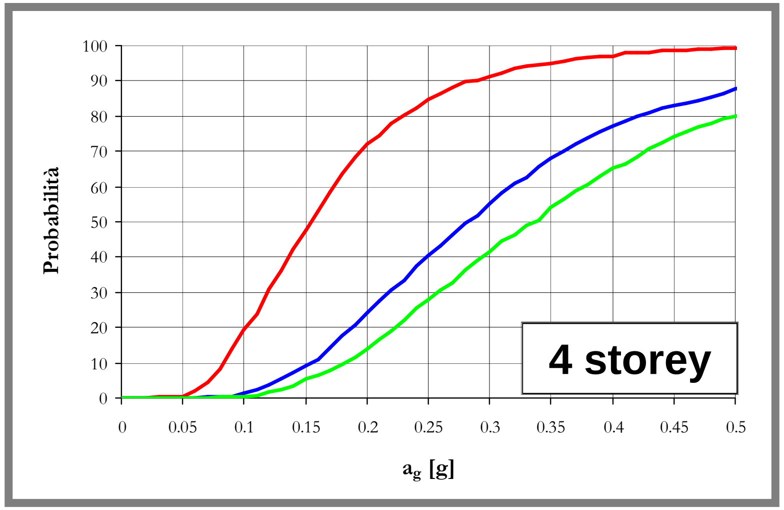
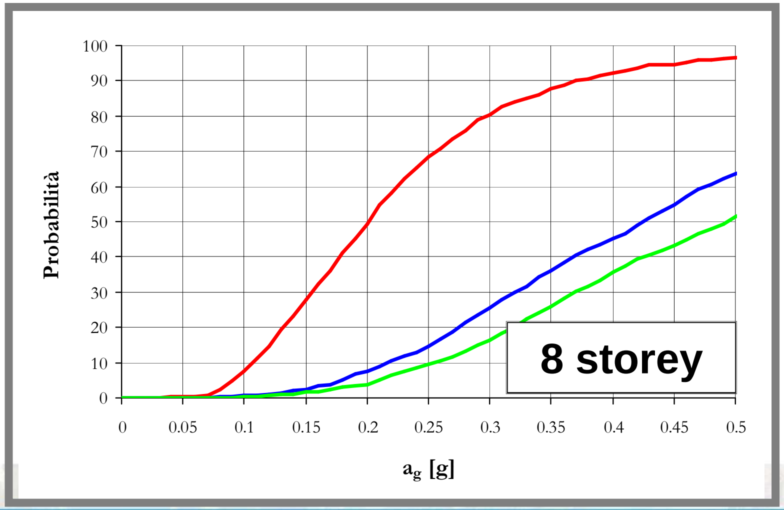


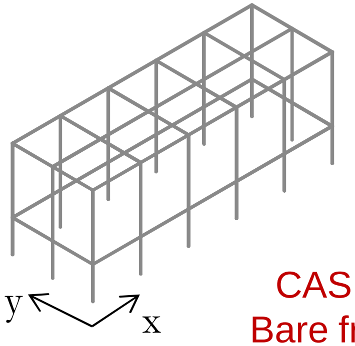




Light damage

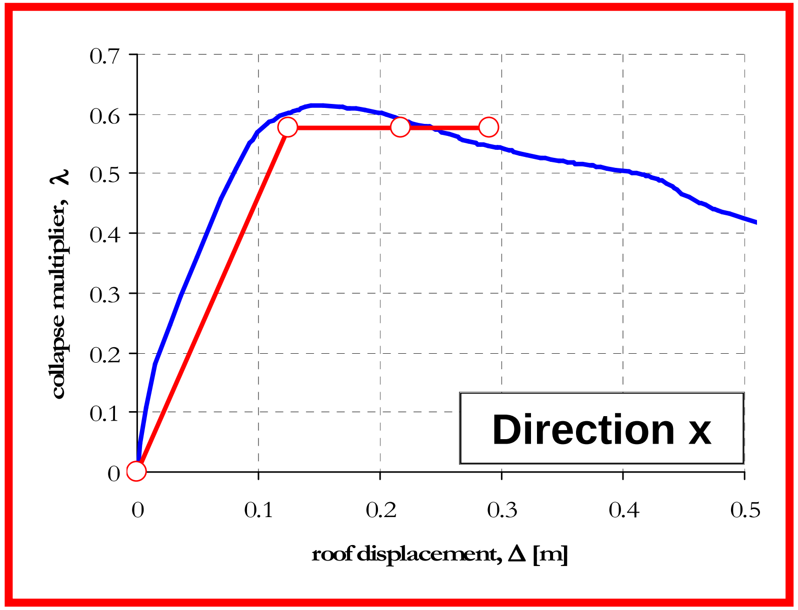
Severe damage

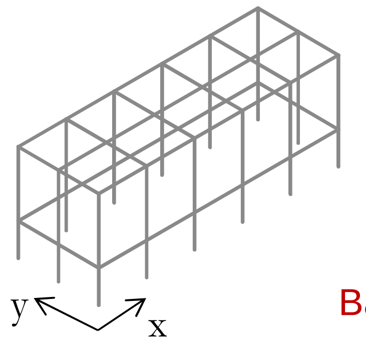
Collapse



CASE 1
Bare frame

Seismically designed buildings





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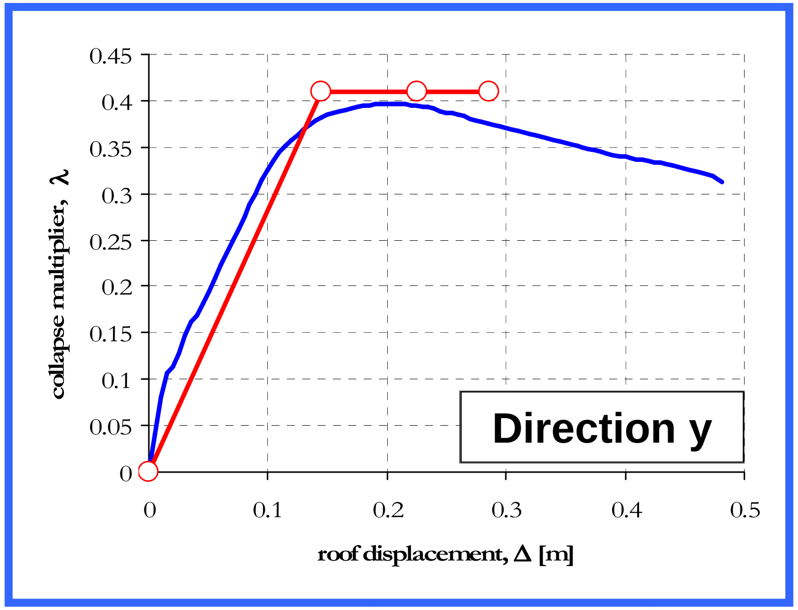

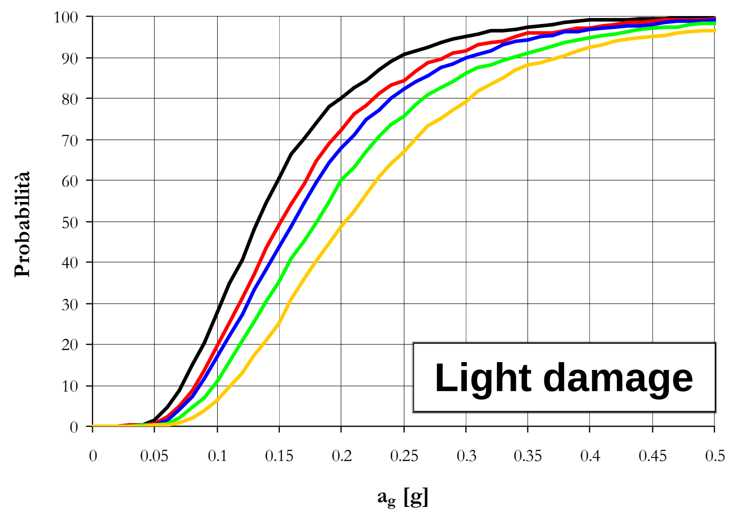

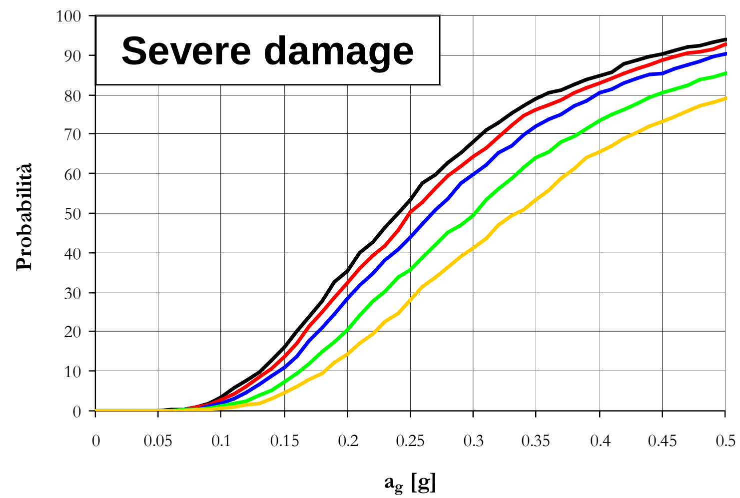

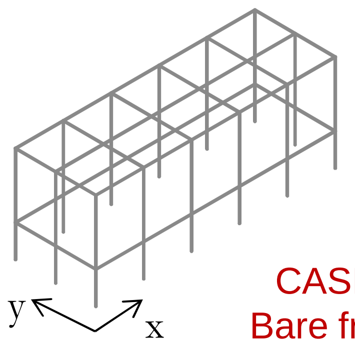

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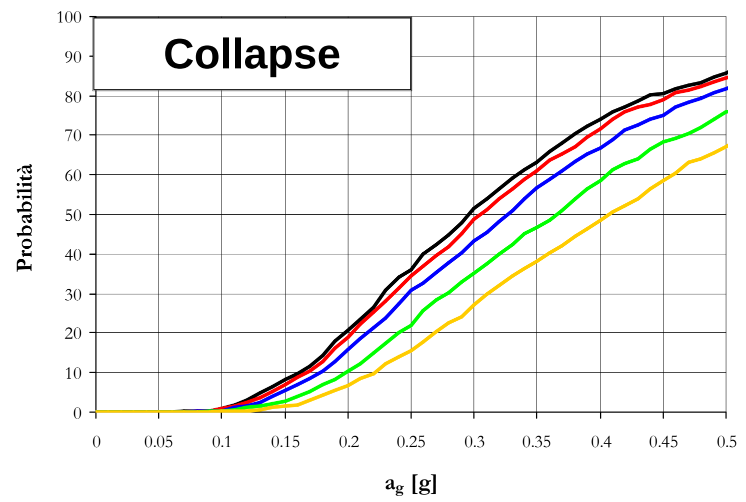


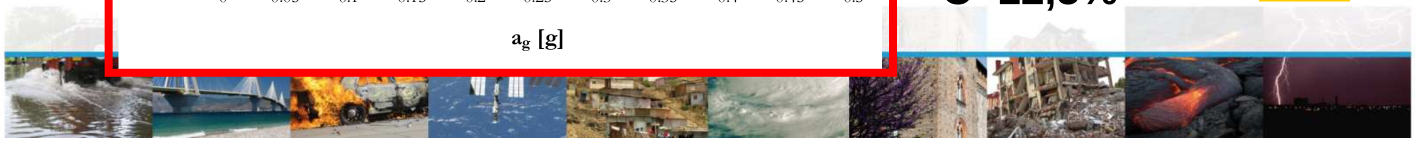
Non Prog.

C=5%

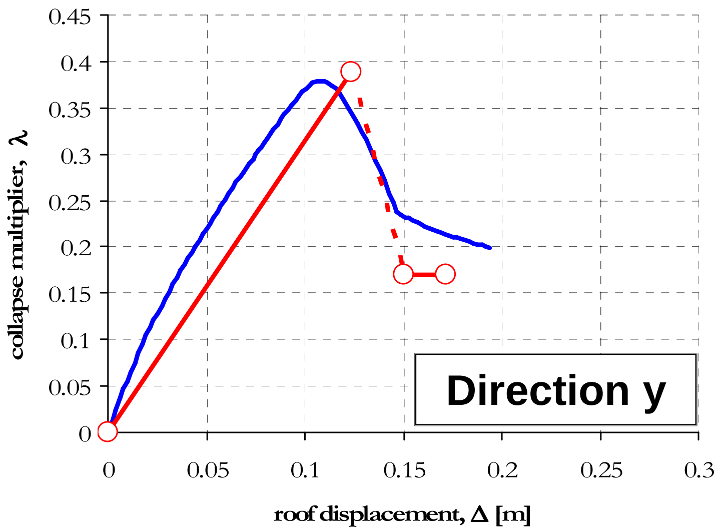
C=7,5%

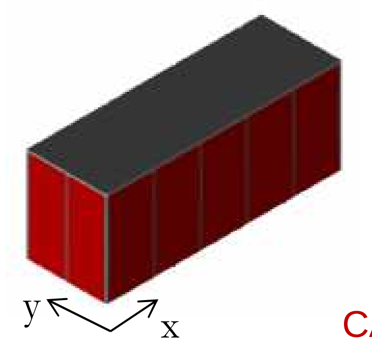
C=10%

C=12,5%

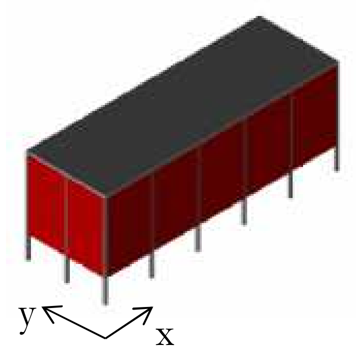


Non seismically designed buildings

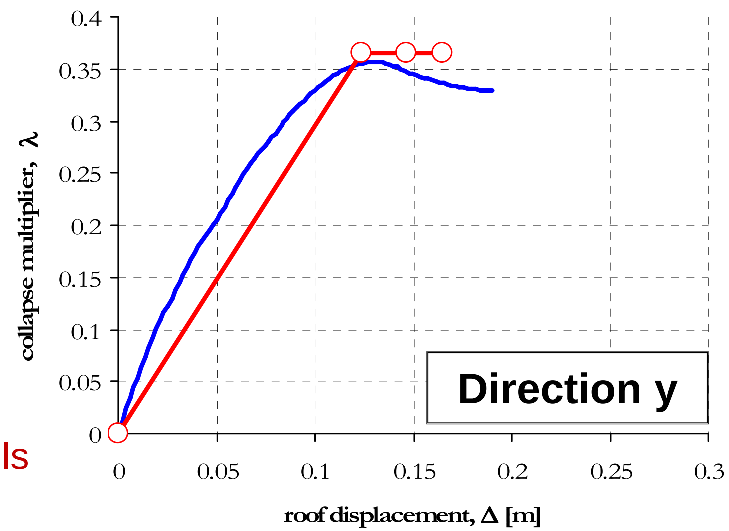


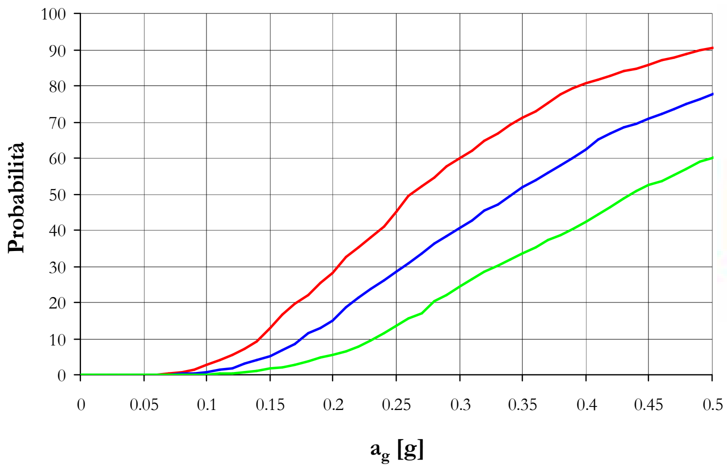


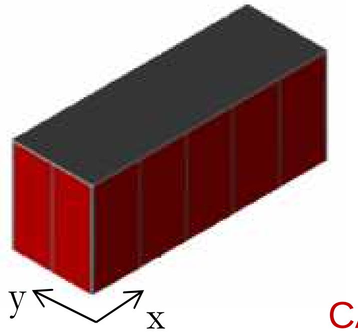
CASE 2
Regular distributed infill walls



CASE 3
Non regular distributed infill walls





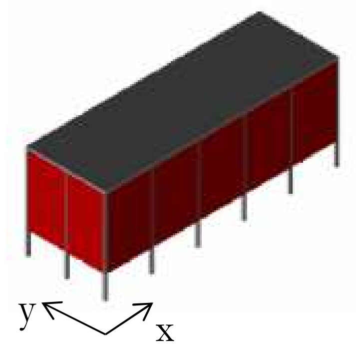


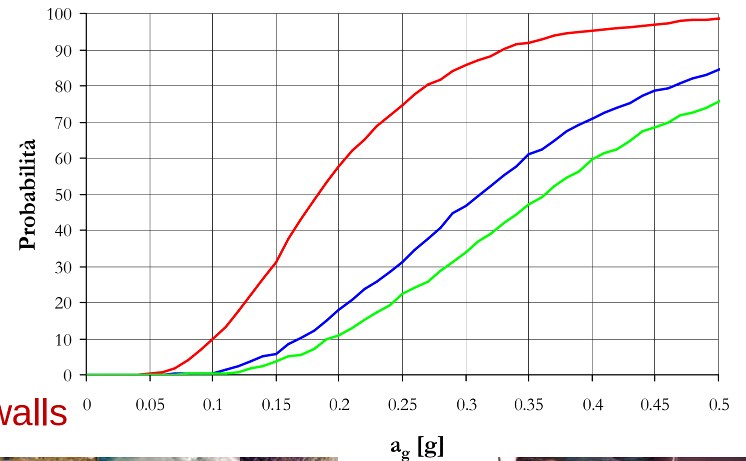
CASE 2
Regular distributed infill walls

Light damage

Severe damage

Collapse





CASE 3
Non regular distributed infill walls

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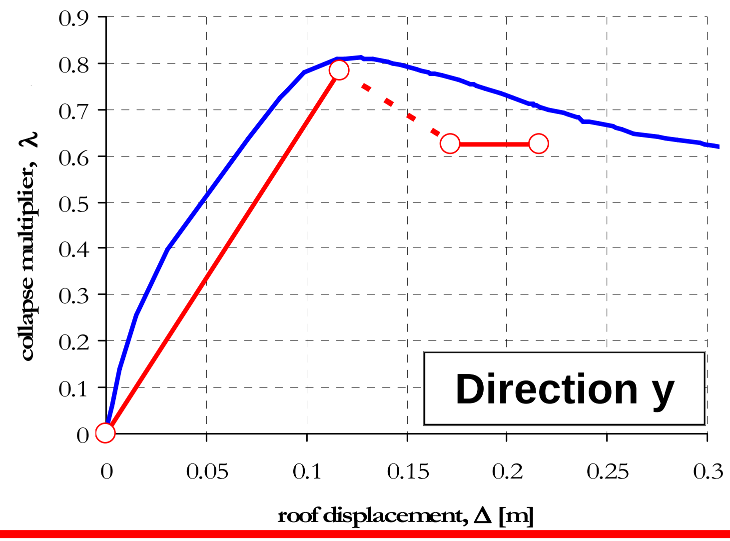
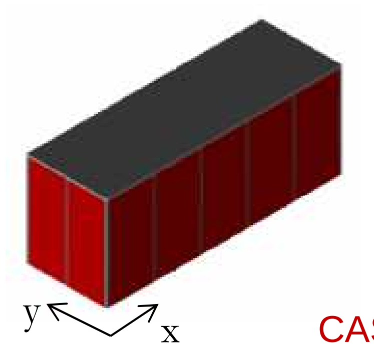
Seismically designed buildings





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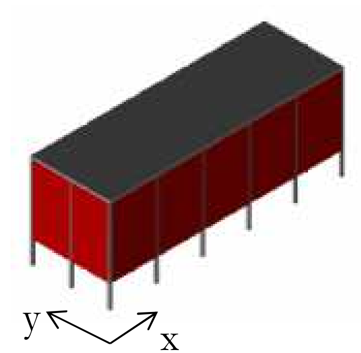
Non regular distributed infill walls



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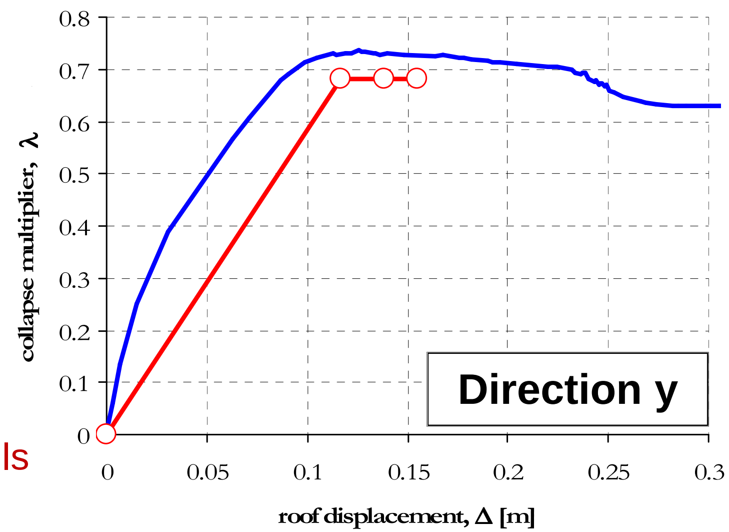
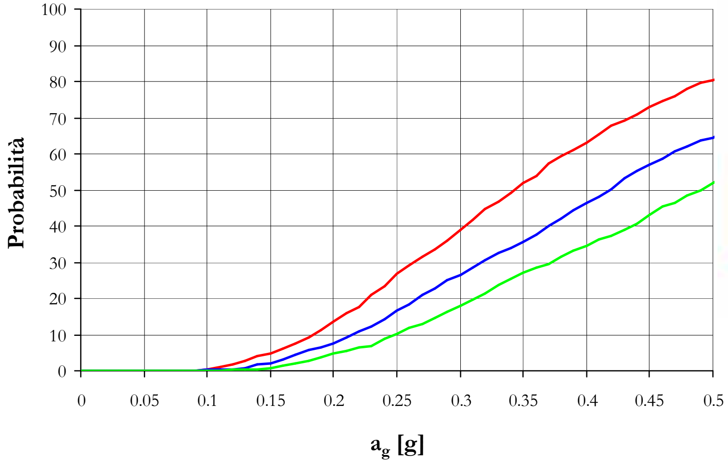
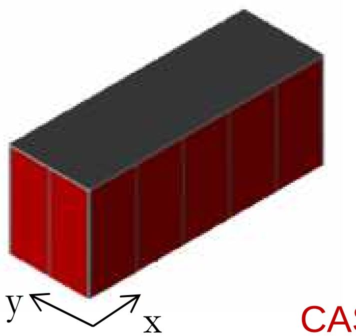






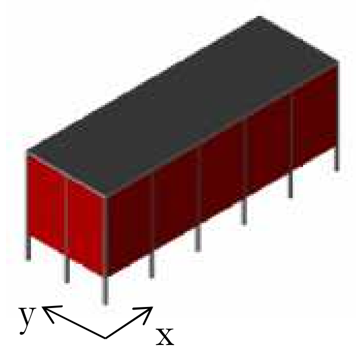
CASE 2

Non regular distributed infill walls

Light damage (red)

Severe damage (blue)

Collapse (green)



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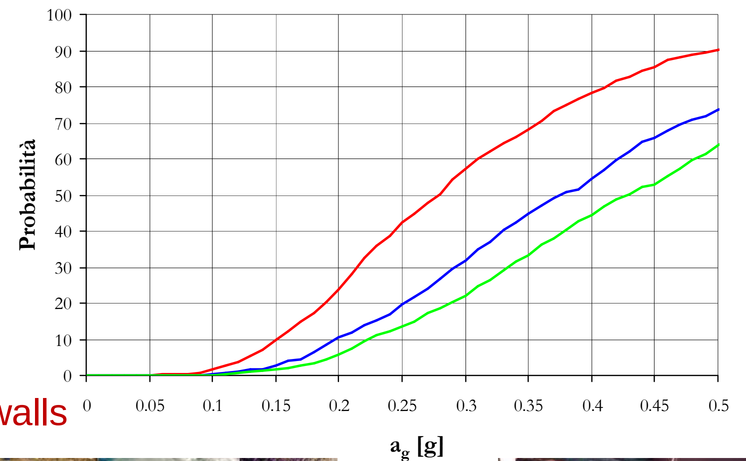
Non regular distributed infill walls



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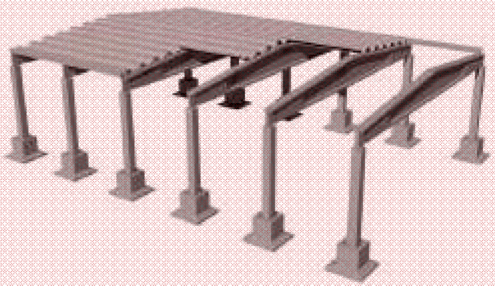
Masonry Buildings

Borzi B., Crowley H., Pinho R. (2008b), “Simplified pushover-based earthquake loss assessment (SP-BELA) for masonry buildings,” International Journal of Architectural Heritage, Vol. 2, No. 4, pp. 353-376.

Precast RC Buildings



Bolognini D., Borzi B., Pinho R. “Simplified Pushover-Based Vulnerability Analysis of Traditional Italian RC Precast Structures”, Proceeding of 14th World Conference on Earthquake Engineering, Bejing 2008

Applications

Seismic Risk Assessment of Hospitals in Lombardia District

Seismic risk assessment of a large industrial estate

DPC Project
Seismic risk assessment of Italian building stock

DPC Project
Priority of intervention on Italian school buildings

DPC Project
Seismic risk assessment of transportation network

Related Publications

Borzi B., Pinho R., Crowley H. [2007], “Simplified Pushover-Based Vulnerability Analysis for Large Scale Assessment of RC Buildings”, Engineering Structures, Vol. 30, No. 3, pp. 804-820

Borzi B., Crowley H., Pinho R. [2008], “Simplified Pushover-Based Earthquake Loss Assessment (SP-BELA) Method for Masonry Buildings”, International Journal of Architectural Heritage, Vol. 2, No. 4, pp. 353-376

Borzi B., Crowley H., Pinho R. [2008], “The Influence of Infill Panels on Vulnerability Curves for RC Buildings”, Proceeding of 14th World Conference on Earthquake Engineering, Bejing 2008

Bolognini D., Borzi B., Pinho R. [2008], “Simplified Pushover-Based Vulnerability Analysis of Traditional Italian RC Precast Structures”, Proceeding of 14th World Conference on Earthquake Engineering, Bejing 2008

Fiorini E., Onida M., Borzi B., Pacor F., Luzi L., Meletti C., D’Amico V., Marzorati S., Ameri G. [2008], “Microzonation study for an industrial site in southern Italy”, Proceeding of 14th World Conference on Earthquake Engineering, Bejing 2008

Borzi B., Dell’Acqua F., Faravelli M., Gamba P., Lisini G., Onida M., Polli D. [2011], “Vulnerability study on a large industrial area using satellite remotely sensed images”, Bulletin of Earthquake Engineering 2011, No. 9, pp. 675-690.

Borzi B., Ceresa P., Faravelli M., Fiorini E., Onida M. [2011], “Definition of a prioritization procedure for structural retrofitting of Italian school buildings”, Proceedings of COMPDYN 2011, Corfù, Paper N. 302.

Fiorini E., Borzi B., Iaccino R. [2012], “Real Time damage scenario: case study for the L'Aquila Earthquake”, 15WCEE, Paper N. 3707

Borzi B., Ceresa P., Faravelli M., Onida M. [2012], “Vulnerability study of steel storage tanks in a large industrial area of Sicily”, 15WCEE, Paper N. 4137

Ceresa P., Fiorini E., Borzi B. [2012], “Effects of the seismic input variability on the seismic risk assessment of the RC bridges”,15WCEE, Paper N. 5414

Ceresa P., Borzi B., Noto F., Onida M. [2012],, “Application of a probabilistic mechanics-based methodology for the seismic risk assessment of the Italian RC bridges”,15WCEE, Paper N. 5102