Concepts of Seismic Vulnerability and Risk
Definitions
Hazard | Vulnerability | Exposure
---|---|---
Seismic Risk
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

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

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

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<th>Damage level</th>
<th>VI</th>
<th>VII</th>
<th>VIII</th>
<th>IX</th>
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### Fragility Curves

- **Light damage**
- **Severe damage**
- **Collapse**

![Fragility Curves Graph](image)
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:

\[ R^2 = 0.9941 \]

\[ 0.0001 \quad 0.001 \quad 0.01 \quad 0.1 \quad 1 \]

AFE

AFE: Annual frequency of exceedance

AFE = 1/TR with TR 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:

$$q = 1 - \exp (t_d \text{ AFE})$$

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

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

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)
1st step: choice of prototype building

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

3rd step: Monte Carlo 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 consistent 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

λ

Δ

Δ_y = Δ_{light damage} Δ_{severe damage} Δ_{collapse}

Δ

Δ_y = Δ_{light damage} Δ_{severe damage} Δ_{collapse}
SP-BELA – Seismic Demand

1\textsuperscript{st} step: choice of spectral shape

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

3\textsuperscript{rd} 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)  

\[ \nabla a_{gk} (k=1,m) \]

\[ \nabla S_{L_i} (i=1,3) \]

\[ j=1 \]

From pushover: \( \Delta_{S_{L_i}}, T_{S_{L_i}}, \mu_{S_{L_i}} \)

From spectral shape: \( S_{di} (a_{gk}, T_{S_{L_i}}, \mu_{S_{L_i}}) \)

\[ S_{di} > \Delta_{S_{L_i}} \]

SI

\[ h_i=1 \]

NO

\[ h_i=0 \]

\[ j=n? \]

SI

\[ j=j+1 \]

NO

\[ k=k+1 \]

NO

\[ k=m? \]

SI

\[ Pf (a_{gk}, S_{L_i}) = \sum h_i / n \]

\[ i=3? \]

SI

\[ i=i+1 \]

NO

\[ i=3? \]

NO

\[ k=k+1 \]

SI

END
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

Direction x

Direction y

roof displacement, $\Delta$ [m]

collapse multiplier, $\lambda$

roof displacement, $\Delta$ [m]

collapse multiplier, $\lambda$
CASE 1
Bare frame

Light damage
Severe damage
Collapse
Seismically designed buildings

CASE 1
Bare frame

Direction x

Direction y
Probabilità

Light damage

Severe damage

Collapse

Non Prog.
C=5%
C=7,5%
C=10%
C=12,5%

CASE 1
Bare frame
Non seismically designed buildings

CASE 2
Regular distributed infill walls

collapse multiplier, $\lambda$

roof displacement, $\Delta$ [m]

CASE 3
Non regular distributed infill walls

Direction y
CASE 2
Regular distributed infill walls

CASE 3
Non regular distributed infill walls
Seismically designed buildings

CASE 2
Non regular distributed infill walls

CASE 3
Non regular distributed infill walls
CASE 2
Non regular distributed infill walls

CASE 3
Non regular distributed infill walls

Light damage
Severe damage
Collapse
Masonry Buildings


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, Beijing 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


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, Beijing 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, Beijing 2008


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