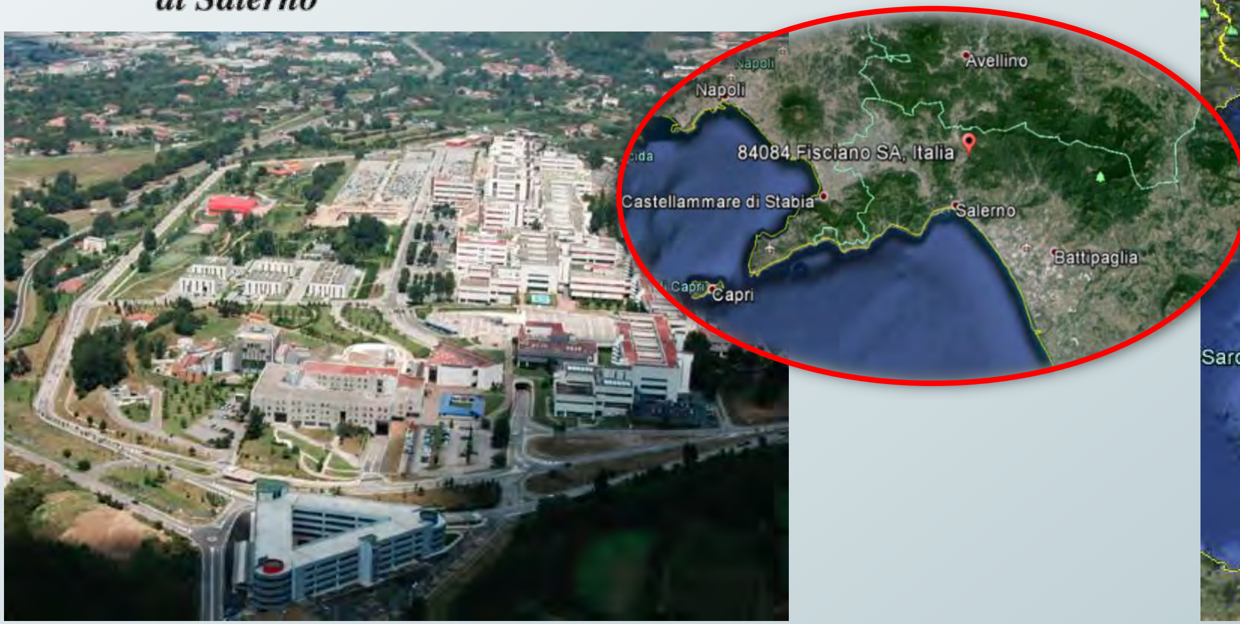
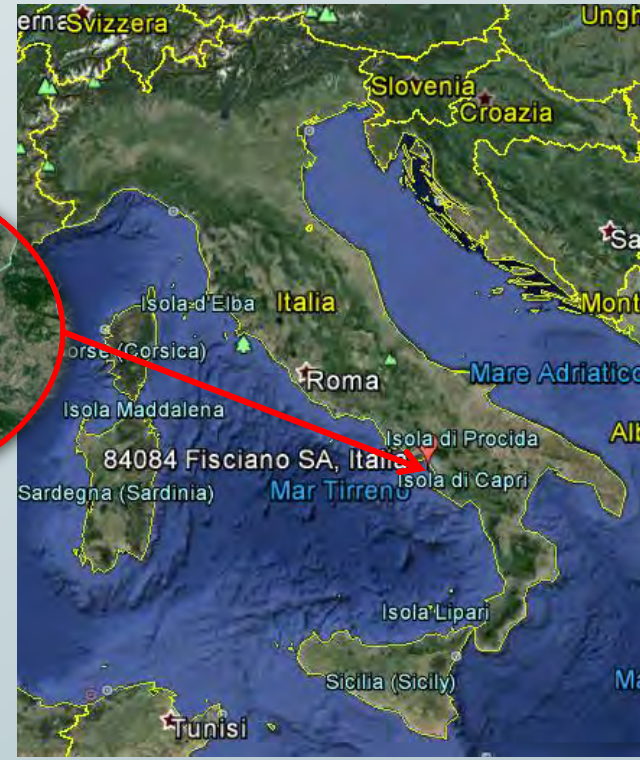
UNIVERSITÀ DEGLI STUDI DI SALERNO

Università degli Studi di Salerno

DIPARTIMENTO DI INGEGNERIA CIVILE
UNIVERSITA' DI SALERNO

Department of Civil Engineering





ON THE SEISMIC RETROFITTING OF EXISTING REINFORCED CONCRETE STRUCTURES

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Universidad de Buenos Aires – Faculdad de Ingenieria

FACULTAD DE INGENIERIA
Universidad de Buenos Aires

Numerical Simulation

↕

Experimental tests

TOPICS

1. **New and existing RC, masonry and steel structures**
2. **Materials**

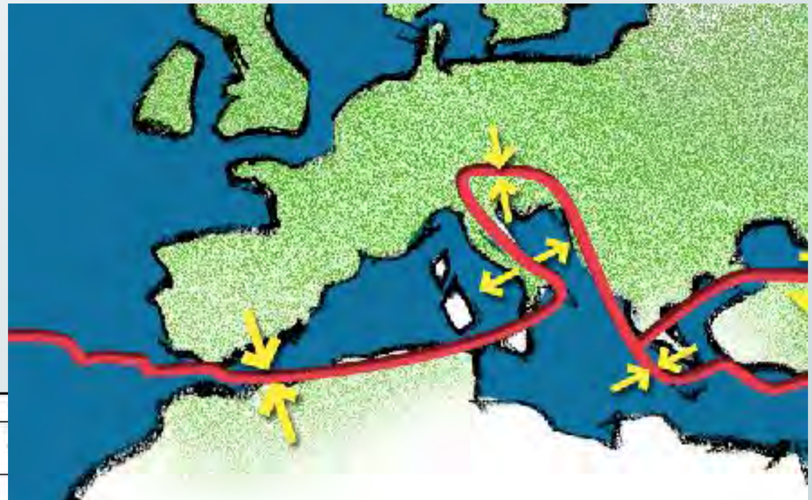
Nonlinear response	Beam-column joints	Seismic retrofitting of existing structures
FRP confinement of columns and joints	Strengthening of masonry walls	EnCoRe project: Eco-friendly solutions for making concrete RECYCLED AGGREGATES, FIBER REINFORCED CONCRETE WITH RECYCLED AND NATURAL FIBERS

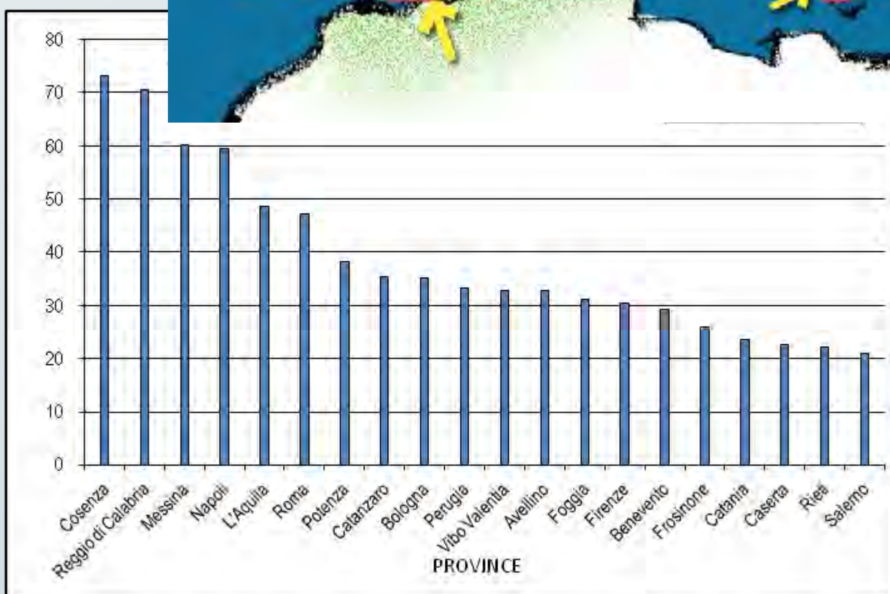
SUMMARY

- **Introduction**
  - Classification
  - Strategies for the seismic retrofitting
    - ✓ *Increasing Stiffness/strength*
    - ✓ *Ductility enhancement*
- **Static Strengthening of floors and beams**
- **Increasing Stiffness**
  - Steel bracings
  - RC shear walls
- **Ductility enhancement**
  - Confinement with steel members
  - RC Jacketing
  - Confinement with FRP
- **Advenced techniques**
  - Seismic Isolation
  - Dissipative towers

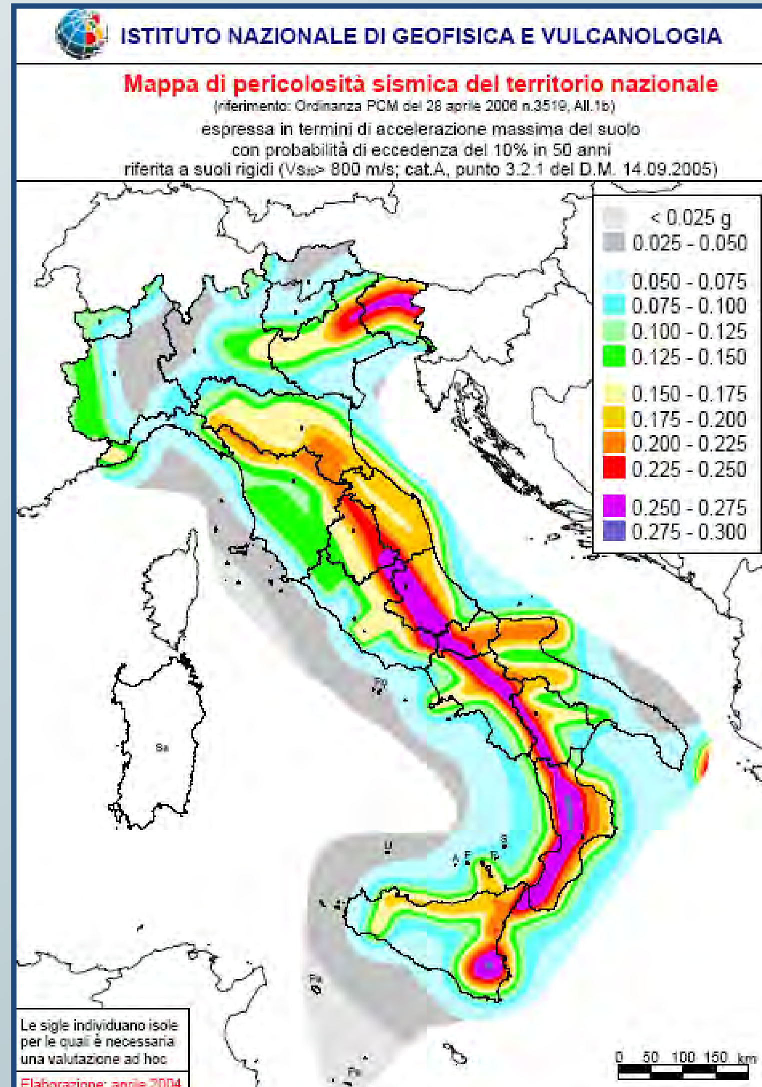
INTRODUCTION

Seismic risk in Italy





Estimated structural collapse for each year



INTRODUCTION

Seismic damage after earthquakes

Seismic damage after earthquakes

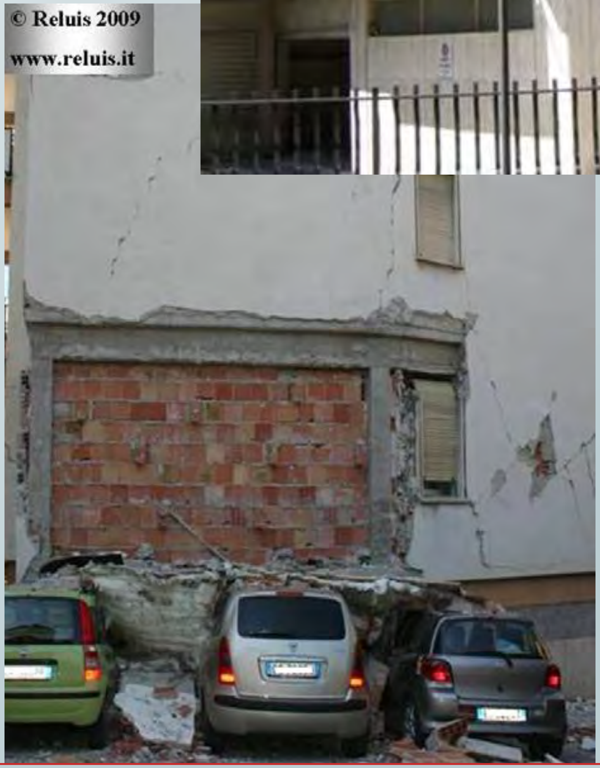
(from Google StreetView)

Seismic damage after earthquakes

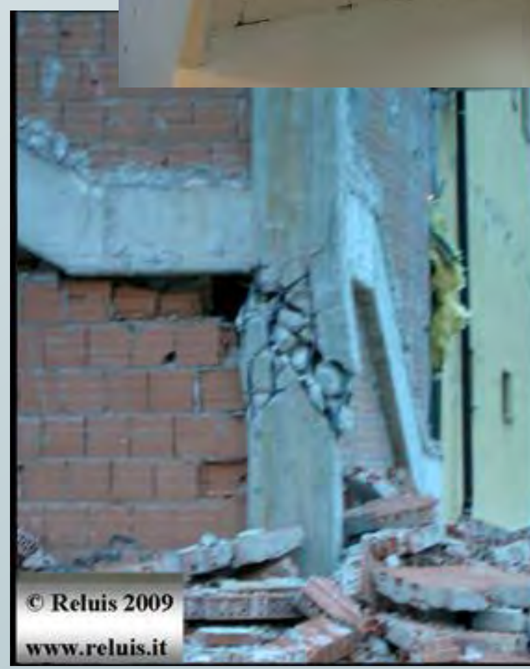
INTRODUCTION

Seismic damage after earthquakes

Seismic damage after earthquakes



Seismic damage after earthquakes



Seismic damage after earthquakes

INTRODUCTION

Seismic damage after earthquakes

Seismic damage after earthquakes

INTRODUCTION

Seismic damage after earthquakes

INTRODUCTION

The seismic assessment of a structure should allow to evaluate if:

- The structure can be used without retrofitting interventions;

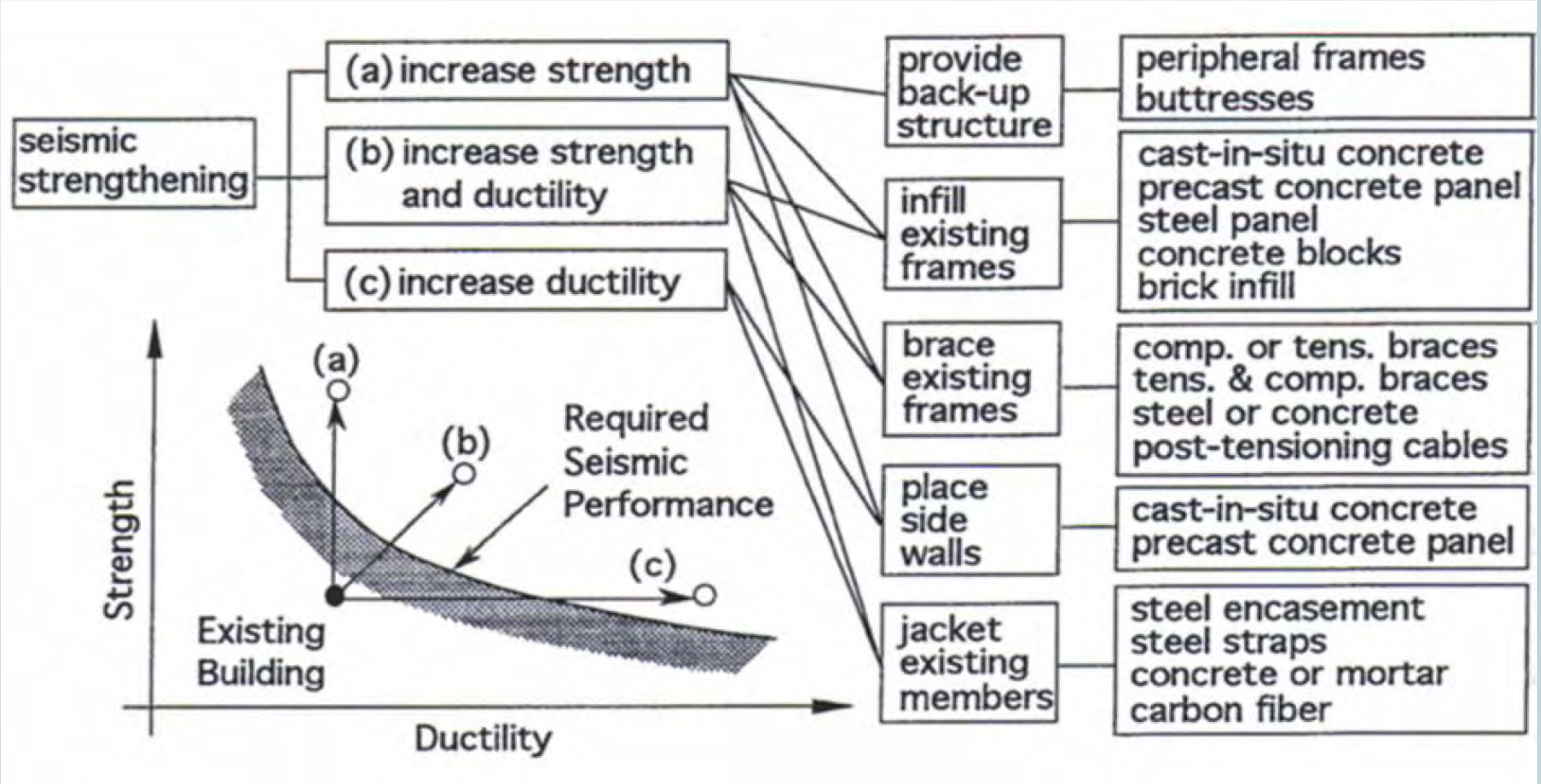
- The use have to be reduced [reducing loads, changing the destination (i.e. library to residence) or introducing limitation in the use (i.e. access permitted to only n-persons at the same time)];

- <u>The structure is needed for retrofitting in order to repair it or increase the structural safety under static and seismic conditions</u>

INTRODUCTION – Classification and strategies for the seismic retrofitting

Two classes can be identified:

- Strategies that allow to increase the stiffness and strength of the existing structure
- Strategies that allow to increase the displacement capacity (**ductility enhancement**) of the structure.



INTRODUCTION – Strategies for seismic retrofitting

Tecnica	Effetti locali	Effetti globali	Costo relativo	"Disturbo"	Livello tecnologico	Commenti
Iniezione di resine	Ripristino resistenza e rigidezza	Nessuno	Da basso a medio	Basso	Medio	Approccio di ripristino
Camicie in c.a.	Incremento rigidezza e resistenza ed eventualmente duttilità	Modifica della risposta sismica. Se applicate ai pilastri, sposta la richiesta plastica verso le travi	Basso, per elemento	Da medio a alto	Basso, a meno che non si faccia uso estensivo di saldature	Può porre rimedio alla risposta di "piano soffice". Se interessa pochi piani, può spostare tale meccanismo ai piani superiori
Camicie o collari in acciaio	Incremento duttilità e resistenza a taglio. Garantendo una forte azione composita, incremento di rigidezza	Incremento capacità deformativa globale	Medio	Basso	Medio	Efficace ove il principale problema sia scarsa armatura trasversale. Veloce installazione.
Fasciatura parziale con FRP	Sensibile incremento di duttilità. Limitati effetti su resistenza o rigidezza	Come per collari in acciaio	Alto	Basso	Da medio a alto	Soluzione adeguata quando il costo non è un criterio predominante
Rinforzo dei nodi con FRP	Eliminazione rottura a taglio dei nodi	Riduce marginalmente il drift globale riducendo la deformabilità dei nodi trave-pilastro	Alto	Basso	Da medio a alto	Come sopra

INTRODUCTION – Strategies for seismic retrofitting

Tecnica	Effetti locali	Effetti globali	Costo relativo	"Disturbo"	Livello tecnologico	Commenti
Fasciatura completa in FRP	Notevole incremento di duttilità e resistenza a taglio; piccolo incremento di rigidezza	Distribuzione delle rigidezze invariata. Sensibili effetti in termini di distribuzione delle resistenze	Alto	Basso	Da medio a alto	Come sopra
Tecniche selettive	Incremento di un parametro scelto o di una combinazione di parametri	Regola la risposta strutturale per adeguarla agli obiettivi prestazionali	Basso, per elemento	Medio	Da medio a alto (maggiore per le analisi ed il know-how che non per i materiali)	E' l'approccio più adeguato se si dispone di elevate capacità di analisi ed esperienza di ingegneri specializzati
Pareti in c.a.	Potrebbe portare ad un incremento di sollecitazioni nelle immediate vicinanze	Riduzione drastica della domanda di deformazione in tutti gli altri elementi. Risolve i problemi di "piano soffice"	Medio	Alto	Basso	E' l'approccio più adeguato se il "disturbo" arrecato non è un problema. E' necessario un drastico intervento in fondazione.
Controventi in acciaio	Protezione nei confronti del collasso di elementi fragili in c.a. posti nelle vicinanze. Può indurre notevoli sollecitazioni nei nodi.	Incremento di duttilità globale a capacità dissipativa. Può risolvere i problemi di "piano soffice".	Da medio a alto.	Da basso a medio	Medio	Occorre porre attenzione nel progetto di aste e connessioni al fine di proteggersi da fenomeni di instabilità locale e rotture post-buckling.

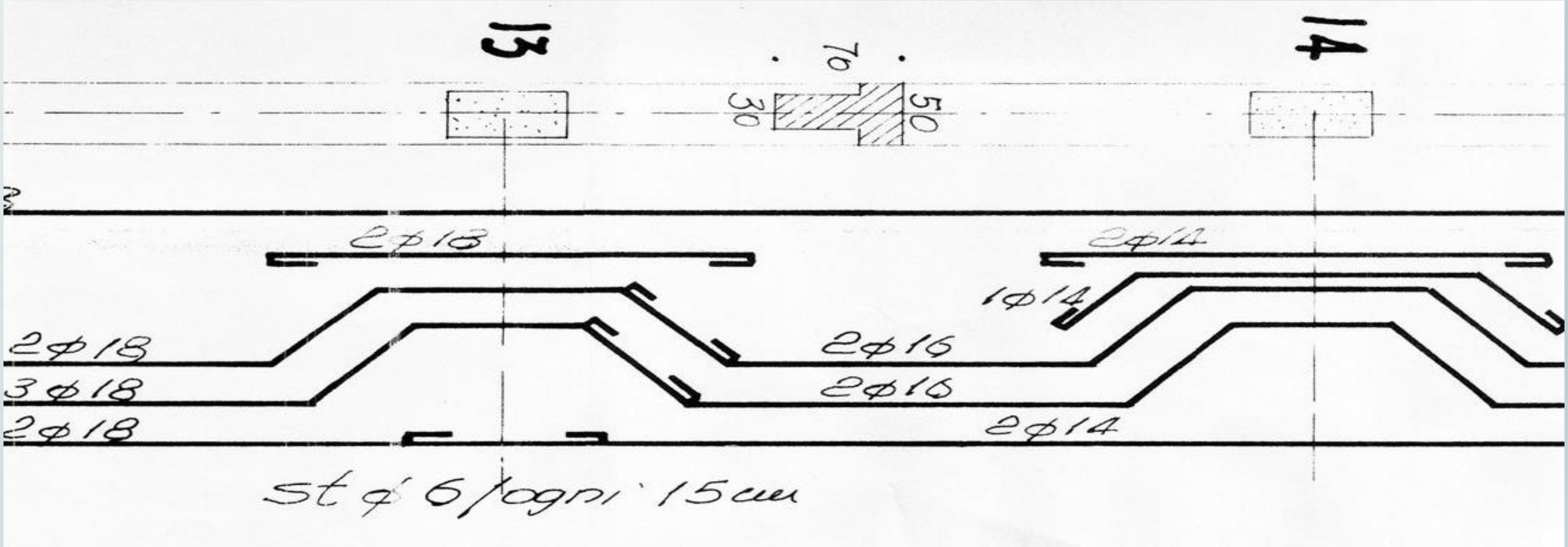
Strengthening of floors and beams

STRENGTHENING OF FLOORS AND BEAMS

Before taking into account the seismic conditions, an assessment under static gravitational loads is needed.

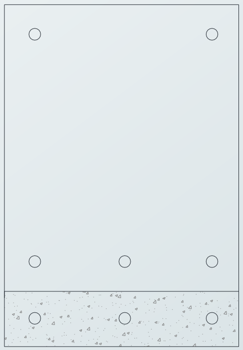
Generally, structures can be modified or the use can be modified resulting in increasing loads. Moreover, degradation can affect the structural materials (concrete, steel, etc.) resulting in a reduction of their mechanical characteristics.

<u>The first assessment is performed in terms of flexural and shear capacity of floors and beams, and axial load in the columns.</u>

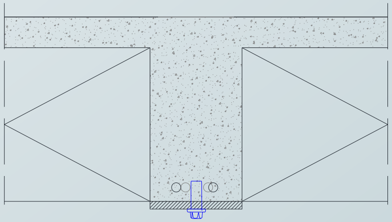


STRENGTHENING OF FLOORS AND BEAMS

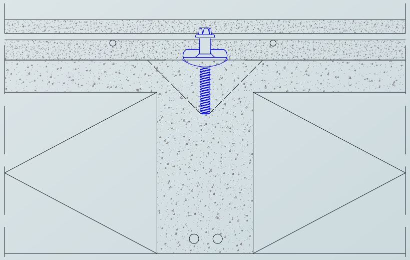
Flexural strengthening



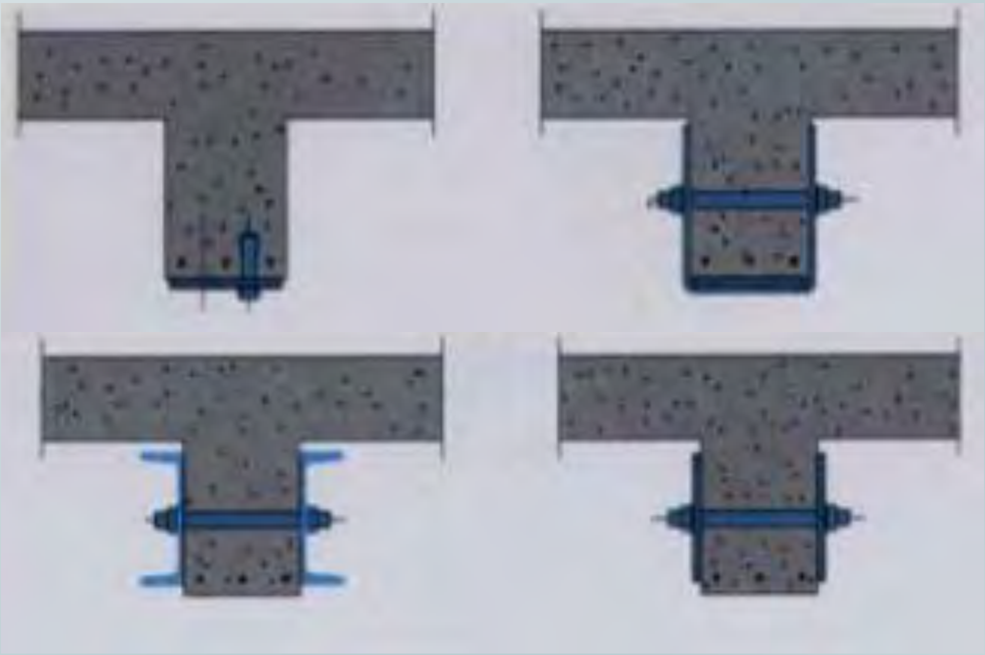
Including steel bars in tension



Steel plates in tension, joined with mechanical anchors

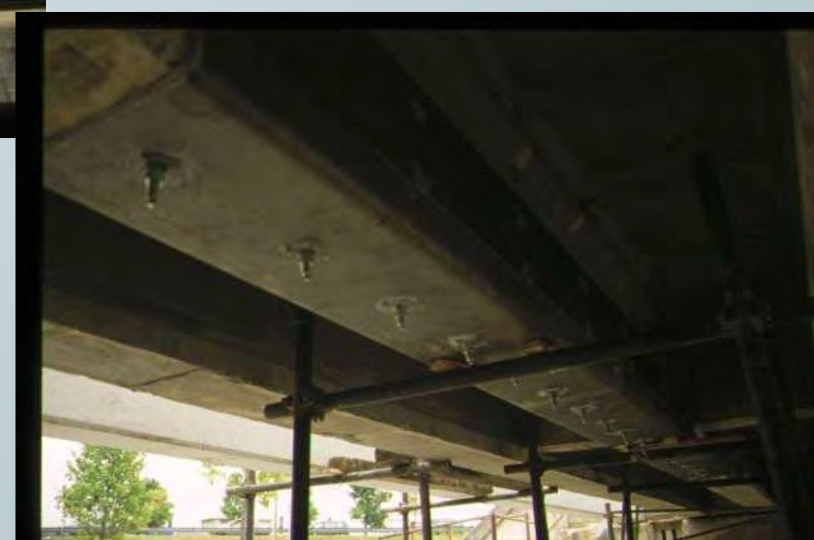


Slab on the top (increasing of stiffness, but also lads)



STRENGTHENING OF FLOORS AND BEAMS

Flexural strengthening



STRENGTHENING OF FLOORS AND BEAMS

Design of the strengthening

- Taking into account the existing deformation (due to the load on the structural member at the time of the strengthening) and the deformation of the strengthened section

hypothesis:

- Plane cross section;
- Optimal adherence between steel and concrete;
- Concrete with zero tension strength;

Modes of crisis:

- **Crisis of the existing steel;**
- **Crisis in compression of the concrete;**
- **Crisis of the strengthening**
  - ✓ Rupture of the steel plate
  - ✓ De-bonding and crisis of the connection

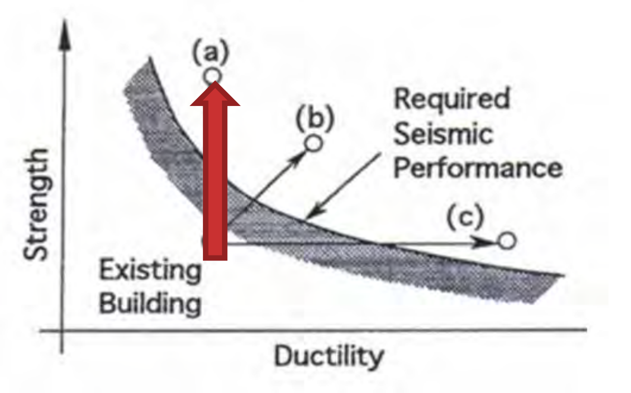
Increasing Stiffness

STIFFNESS

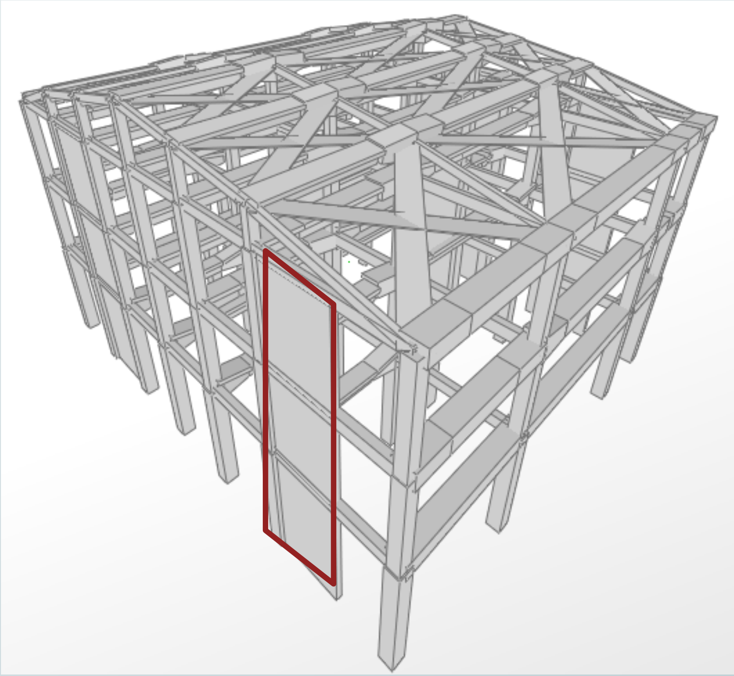
Including new elements and sub-structures

Control the seismic demand

(reducing displacement) of the existing structure



RC shear walls

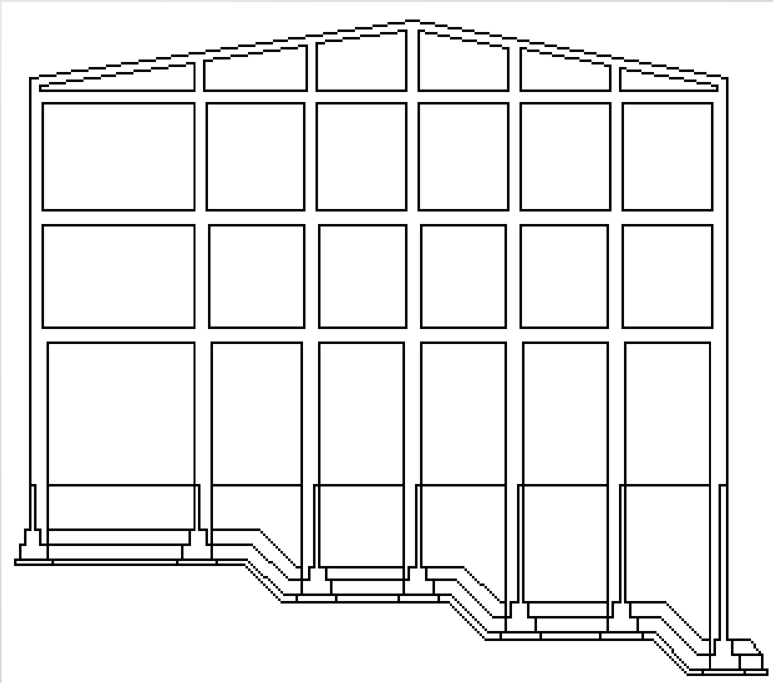


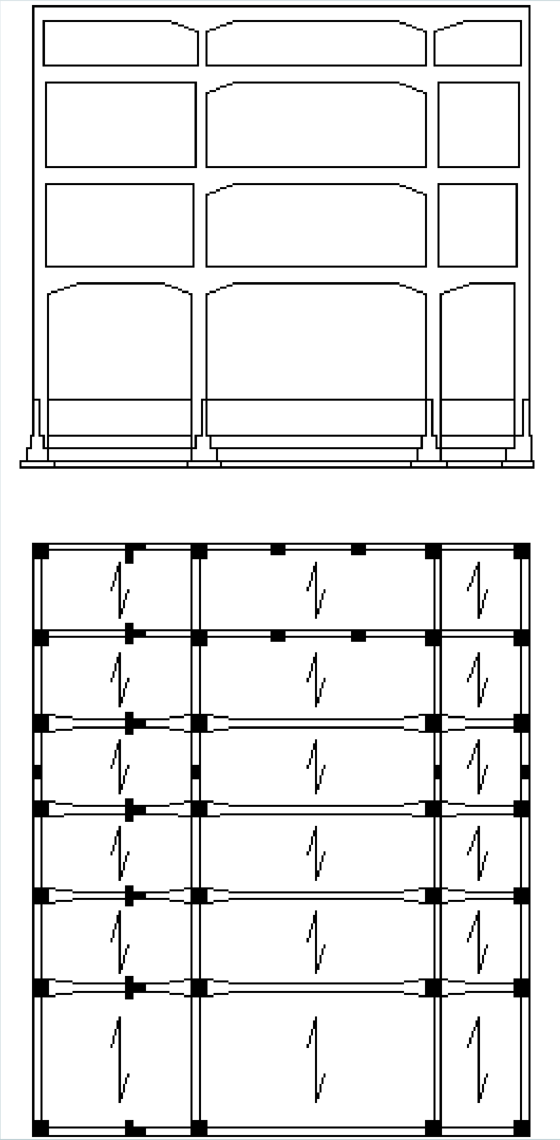
Steel Bracings

RC SHEAR WALLS

Case of study

- School building
- Avellino (South Italy)
- Three-story reinforced concrete structure
- Unidirectional reinforced concrete floors
- Foundation T-beam section





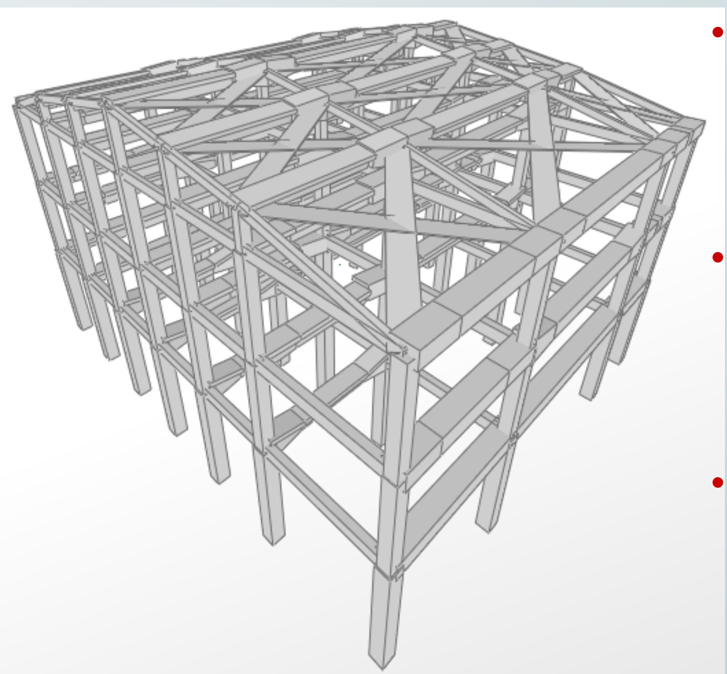
RC SHEAR WALLS

Seismic assessment of the existing structure

$$\theta_{c,DL} = \theta_y = \phi_y \frac{L_V}{3} + 0.0013\left(1 + 1.5\frac{h}{L_V}\right) + 0.13\phi_y \frac{d_b f_y}{\sqrt{f_c}}$$

$$\theta_{c,LS} = \frac{3}{4}\theta_u$$

$$\theta_{c,CO} = \frac{1}{\gamma_{el}} 0.016 \cdot (0.3)^{\upsilon} \left[\frac{\max(0.01;\omega')}{\max(0.01;\omega)} f_c\right]^{0.225} \left(\frac{L_V}{h}\right)^{0.35} 25^{\left(\alpha\rho_{sx}\frac{f_{yw}}{f_c}\right)} 1.25^{100\rho_d}$$

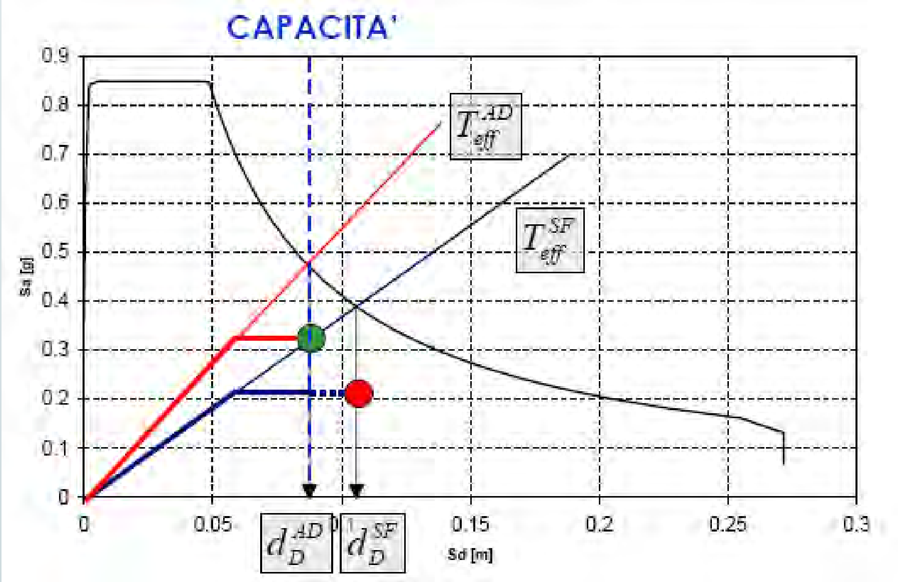


- First storey:
  - Meccanismi duttili: $\min_i\{(\theta_{c,LS,i}-\theta_{d,i})/\theta_{c,LS,i}\}$ = - 0,15
  - Meccanismi fragili: $\min_i\{(V_{Rd,i}-V_{Sd,i})/V_{Rd,i}\}$ = - 0,16
- Second storey:
  - Meccanismi duttili: $\min_i\{(\theta_{c,LS,i}-\theta_{d,i})/\theta_{c,LS,i}\}$ = - 0,30
  - Meccanismi fragili: $\min_i\{(V_{Rd,i}-V_{Sd,i})/V_{Rd,i}\}$ = - 0,14
- Third storey:
  - Meccanismi duttili: $\min_i\{(\theta_{c,LS,i}-\theta_{d,i})/\theta_{c,LS,i}\}$ = 0,08
  - Meccanismi fragili: $\min_i\{(V_{Rd,i}-V_{Sd,i})/V_{Rd,i}\}$ = 0,04

RC SHEAR WALLS

Design

$$\delta_i = \frac{V_i}{k_i} = \theta_{d,i} \cdot H_i \longrightarrow \delta_i = \frac{V_i}{k_i + \Delta k_{p,i}} = \theta_{c,i} \cdot H_i$$



$$\Delta k_p = \frac{V_i}{\theta_{c,i} \cdot H_i} - k_i$$

Required stiffness

$$\Delta k_{p,i} = \frac{V_i}{\delta_{p,i}} = \frac{V_i}{\Delta_{p,i}(a_i, b_i) - \Delta_{p,i-1}(a_{i+1}, b_{i+1})}$$

Stiffness of one shear wall

From $\Delta_{p,i}$ can be evaluated the geometrical dimensions a and b of walls:

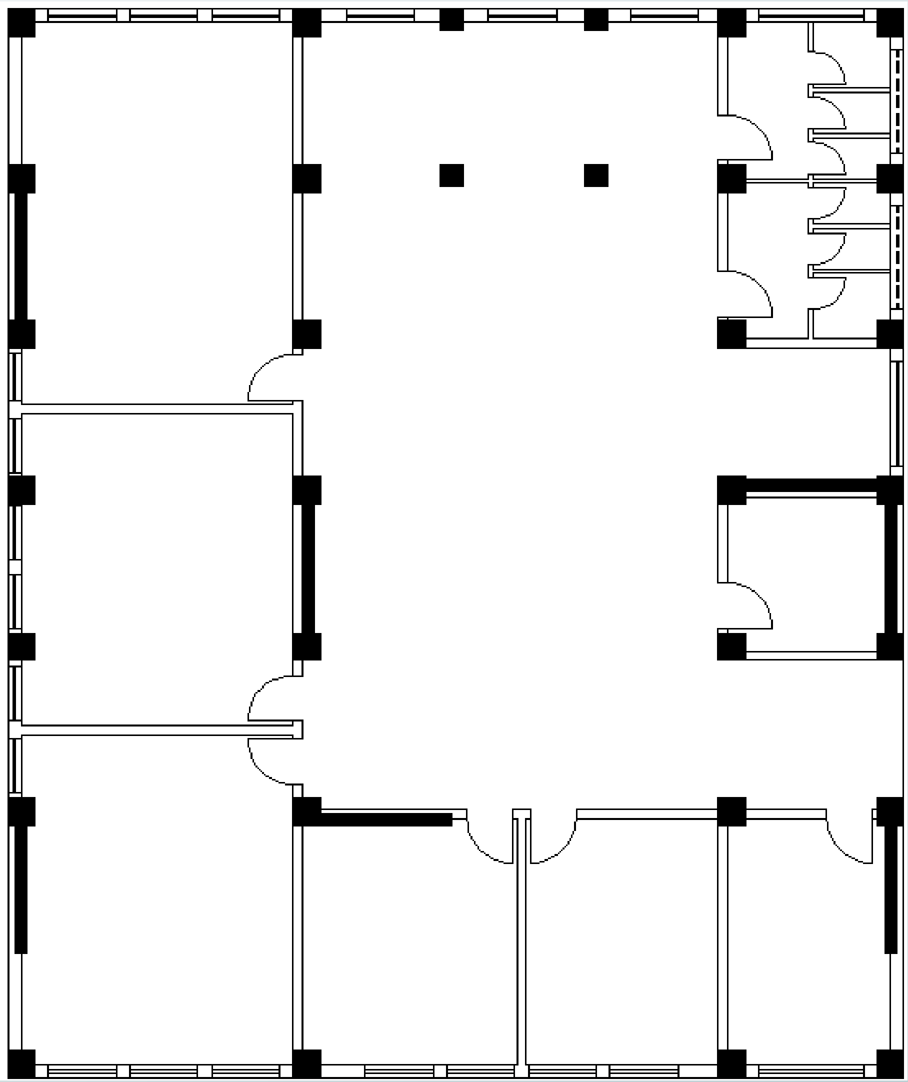
$$\delta_{p,1} = \Delta_{p,1} = \frac{1}{EI_1}\left(V_1 \frac{H_1^3}{3} + V_2 \frac{H_1^2 H_2}{3} + V_3 \frac{H_1^2 H_3}{3}\right) + \chi \frac{V_1 H_1}{GA_1}$$

$$\delta_{p,3} = \Delta_{p,3} - \Delta_{p,2} = \frac{1}{EI_1}\left(V_1 \frac{H_1^2 H_3}{2} + V_2 H_1 H_2 H_3 + V_3 H_1 H_3^2\right) + \frac{1}{EI_2}\left(V_2 \frac{H_2^2 H_3}{2} + V_3 H_2 H_3^2\right) + \frac{1}{EI_3} V_3 \frac{H_3^3}{3} + \chi \frac{V_3 H_3}{GA_3}$$

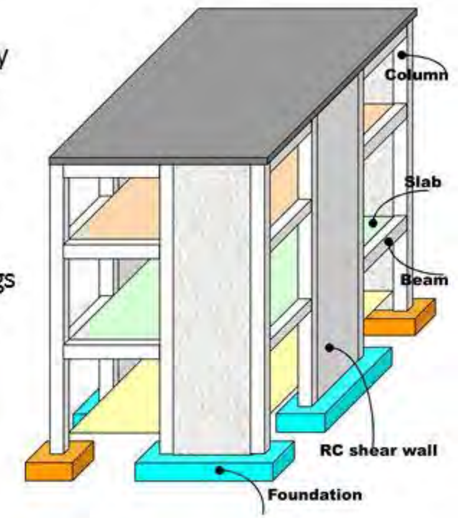
$$\delta_{p,2} = \Delta_{p,2} - \Delta_{p,1} = \frac{1}{EI_1}\left(V_1 \frac{H_1^2 H_2}{2} + V_2 H_1 H_2^2 + V_3 H_1 H_2 H_3\right) + \frac{1}{EI_2}\left(V_2 \frac{H_2^3}{3} + V_3 \frac{H_2^2 H_3}{2}\right) + \chi \frac{V_2 H_2}{GA_2}$$

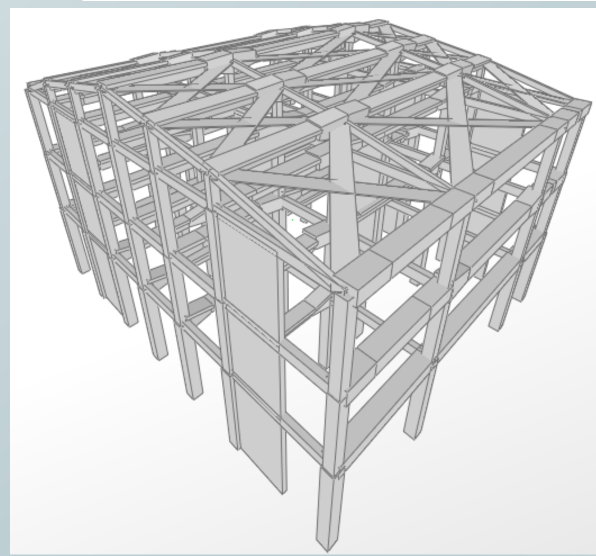
RC SHEAR WALLS

- 7 rc walls are needed, 2 in x-direction and 5 in y-direction.

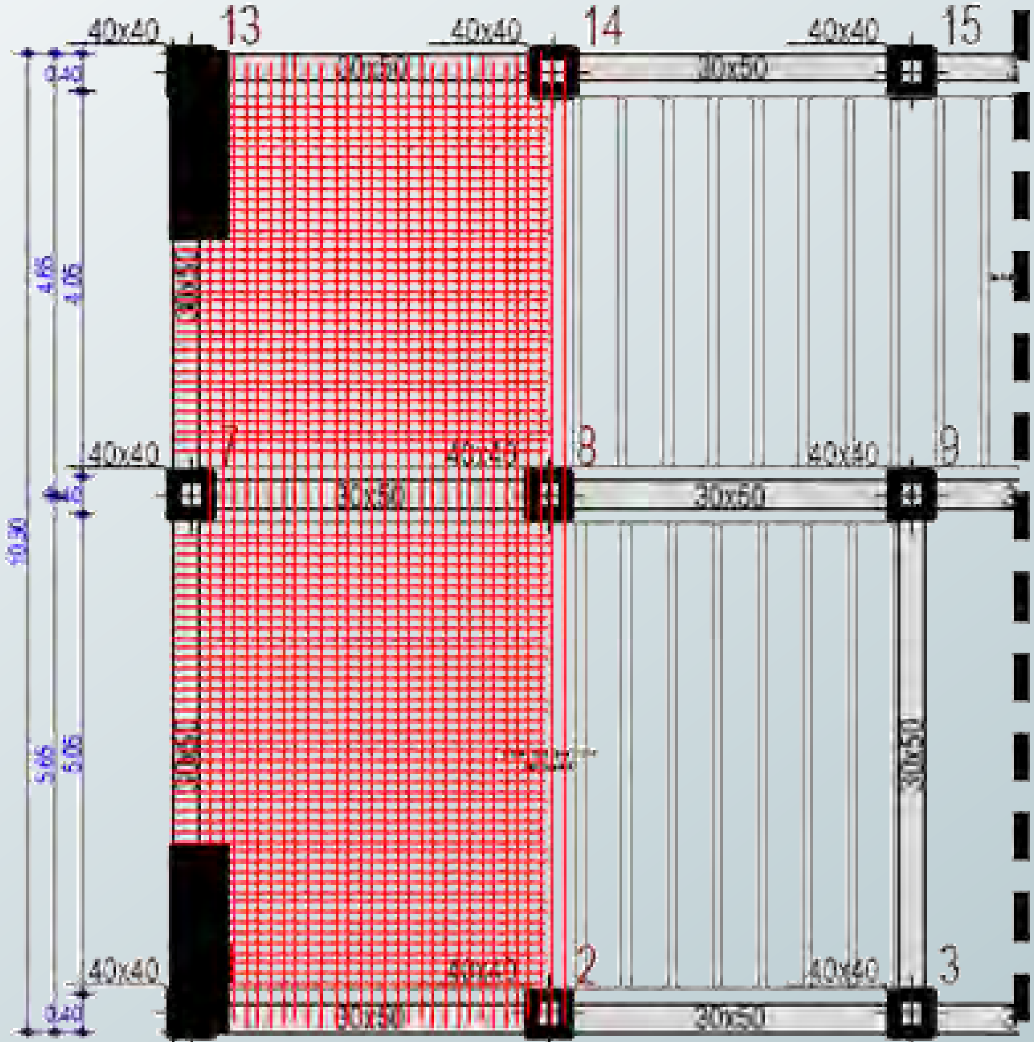


RC shear walls carry earthquake loads down to the foundation. They provide large strength and stiffness to buildings in the direction of their orientation.



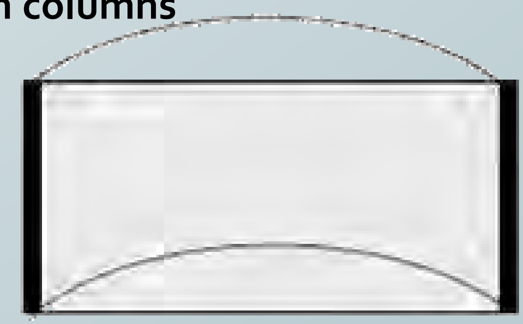


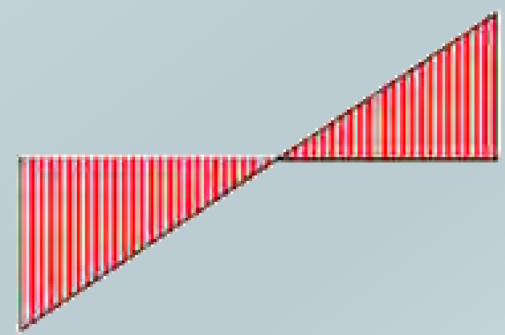
Assessment of floors



RC floors transmits the actions at columns and walls. Before the intervention the actions are almost distributed and diffused on the floor.

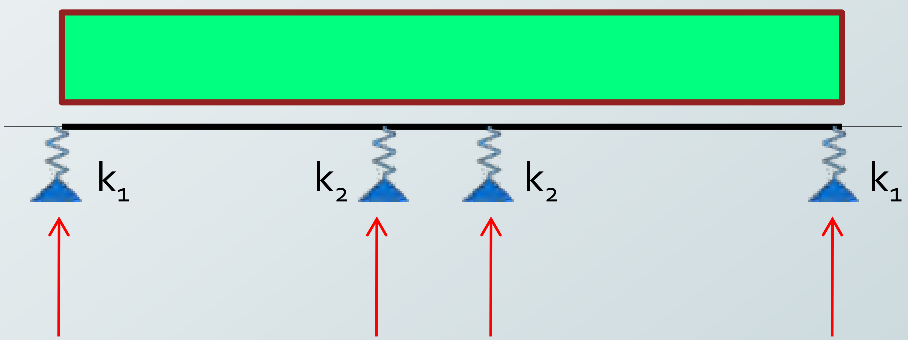
After the intervention the seismic action are concentrated within the walls that have a stiffness higher than columns



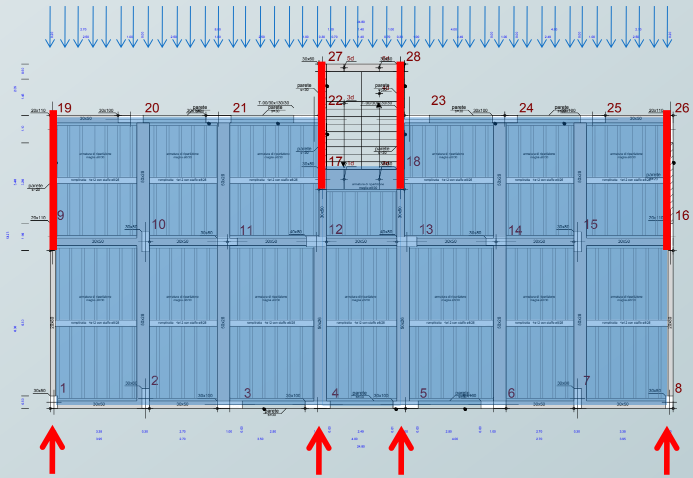


Assessment of floors

$$q = \frac{1,3\left(2 \cdot 755 + 2 \cdot 680\right)}{24,80m} = 150,44\ kN\ /\ m$$



1,3*755 kN   1,3*680 kN   1,3*755 kN



Section with base 5cm (slab thickness)

$$\delta = \frac{H^3}{3EI}\left[1 + 3\chi \frac{EI}{GA \cdot H^2}\right]$$ *deformabilità parete*

$$k = \frac{1}{\frac{H^3}{3EI}\left[1 + 3\chi \frac{EI}{GA \cdot H^2}\right]}$$ *rigidezza parete*

K_1 = 8931,81 N/mm

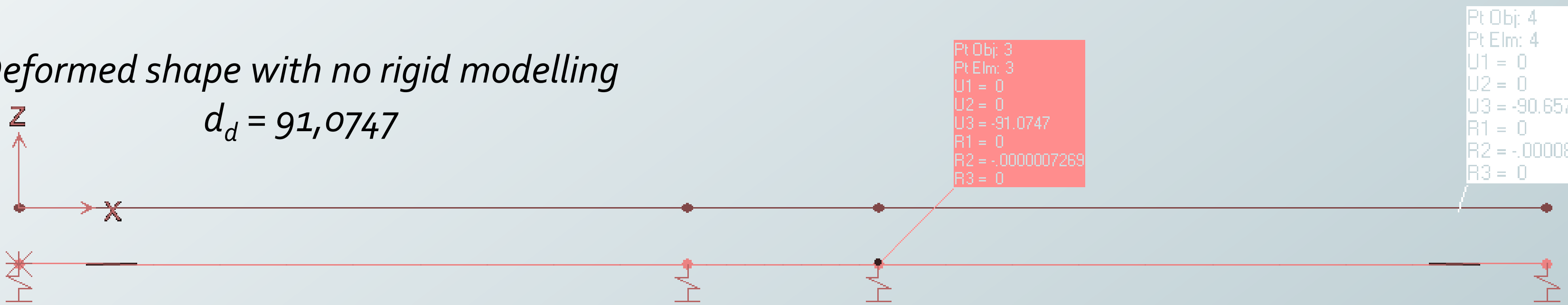
K_2 = 11591,78 N/mm

RC SHEAR WALLS

Assessment of floors

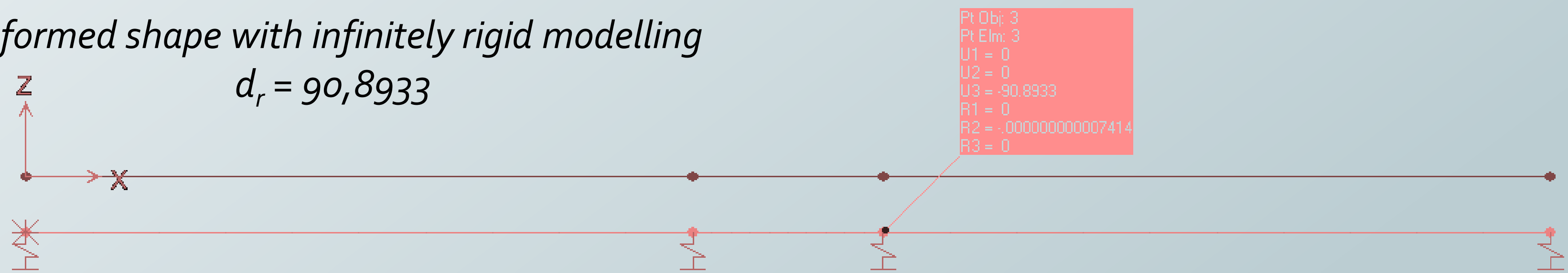
Deformed shape with no rigid modelling

$d_d = 91,0747$



Deformed shape with infinitely rigid modelling

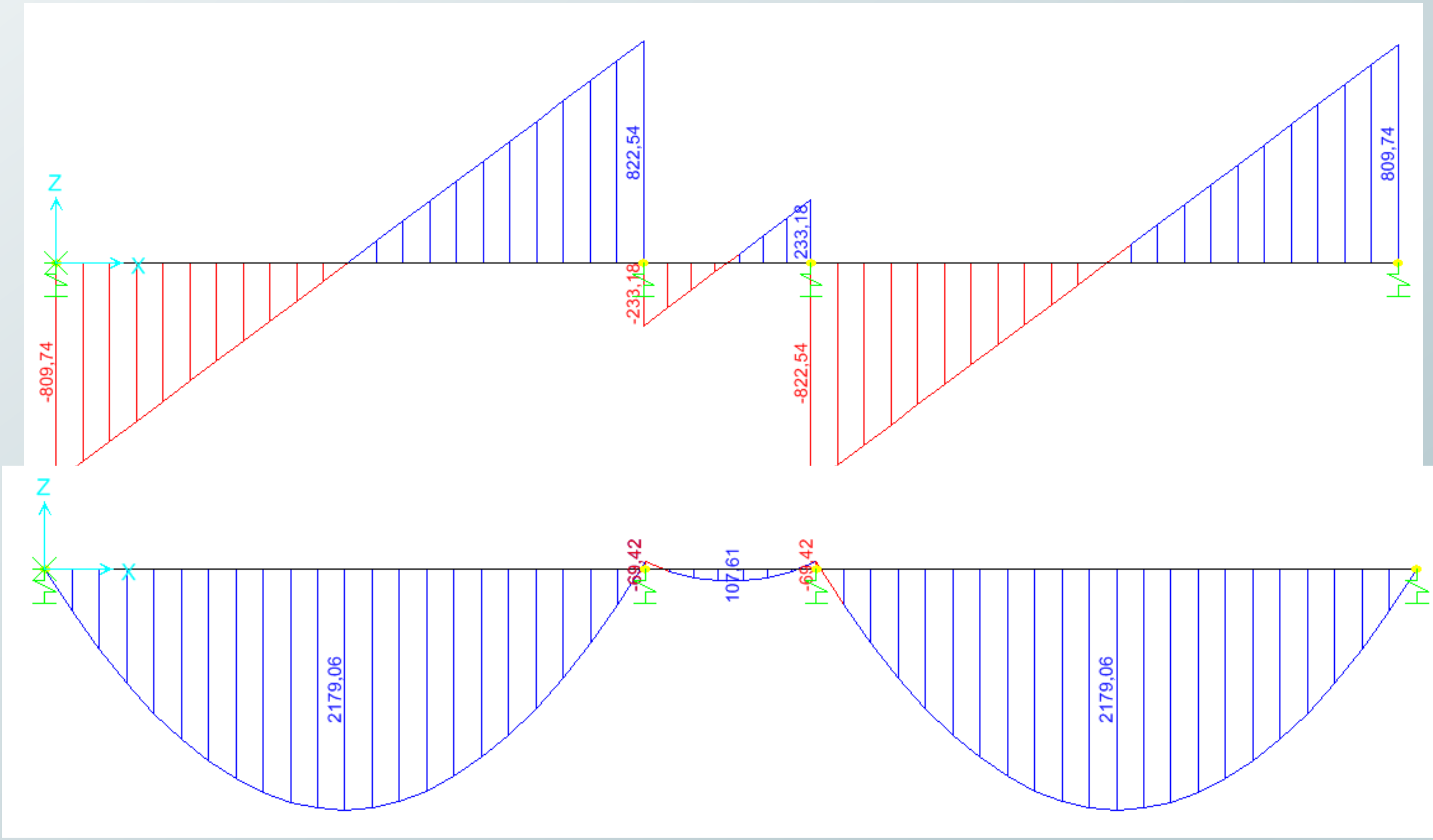
$d_r = 90,8933$



$d_d < 1,10 \cdot d_r$ infinite stiffness

Assessment of floors

Strength assessment [kN-m]



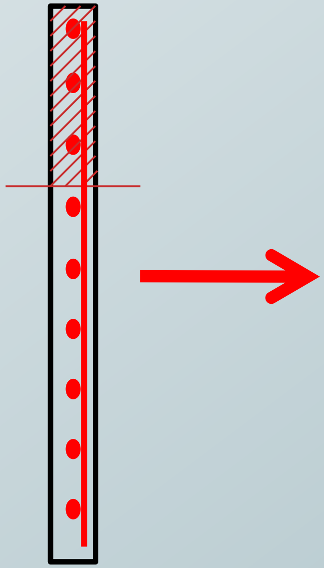
Assessment of floors

Strength assessment [kN-m]

- ***Bending and shear resistance taking into account the steel reinforcement in the slab (section with base 5cm and height 11m)***

$$M_{Sd} = 2179,06\ kNm$$
$$V_{Sd} = 822,54\ kN$$

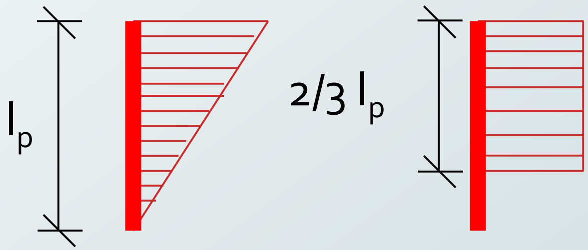
rete $\phi 8$ / 25x25



$$M_{Rd} = 2179,06\ kNm$$
$$V_{Rd}\left(ctg\theta = 1\right) = 823\ kN$$

Assessment of floors

Width = 2/3 of the wall width



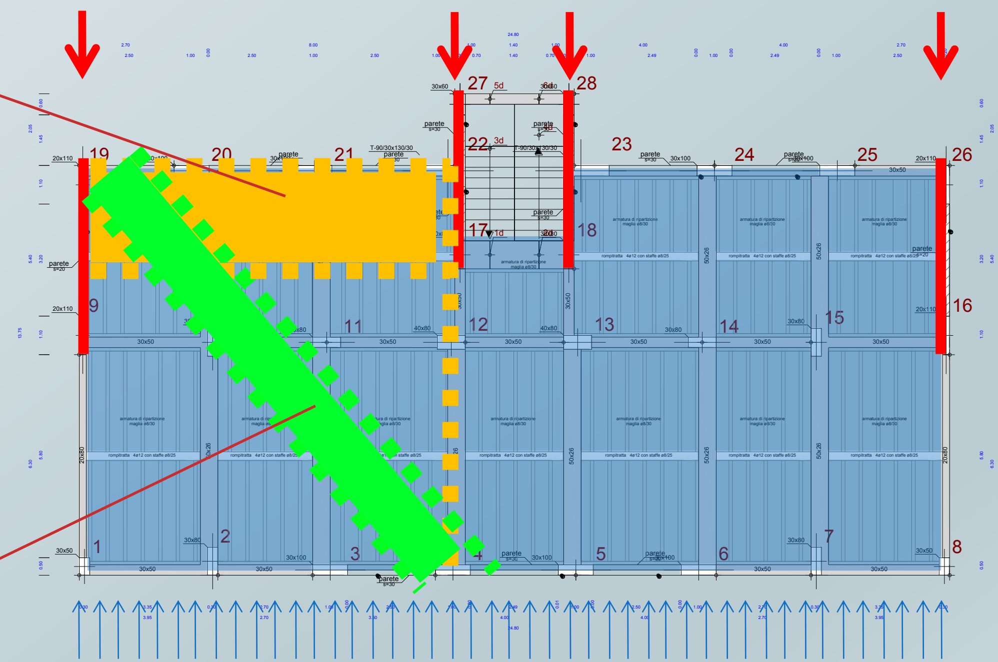
Strength assessment[kN-m]

- Strut-and-tie mechanism

Steel tie

Concrete strut

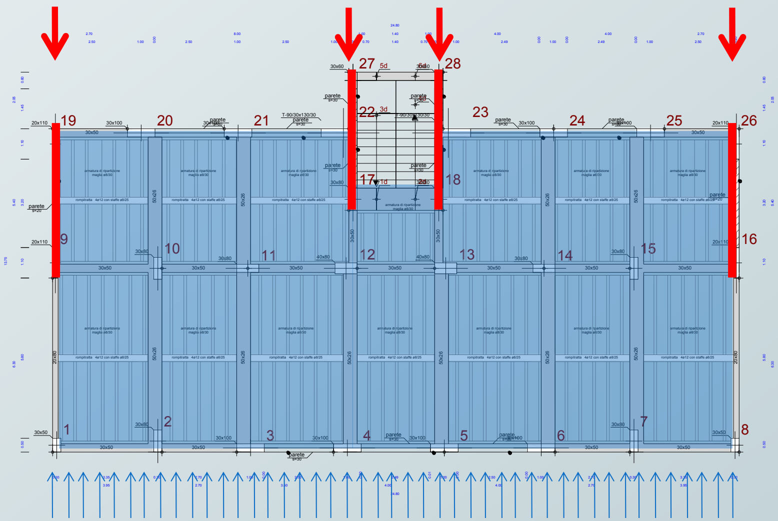
Strut width =L/10;
The maximum stress in the concrete should be verified

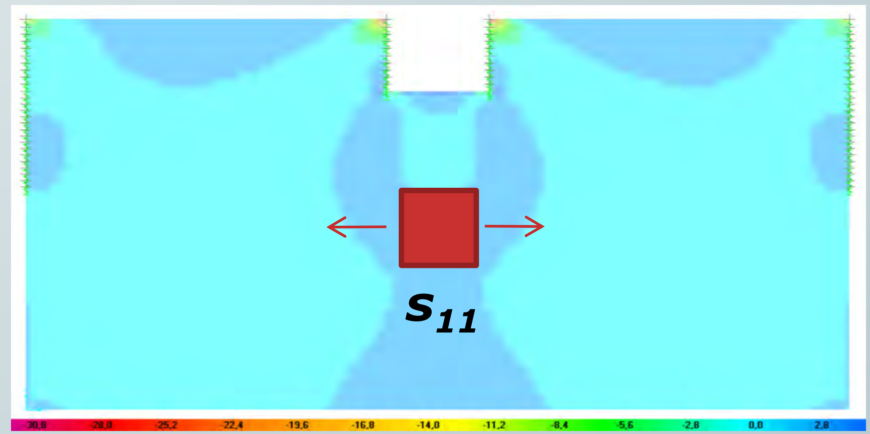


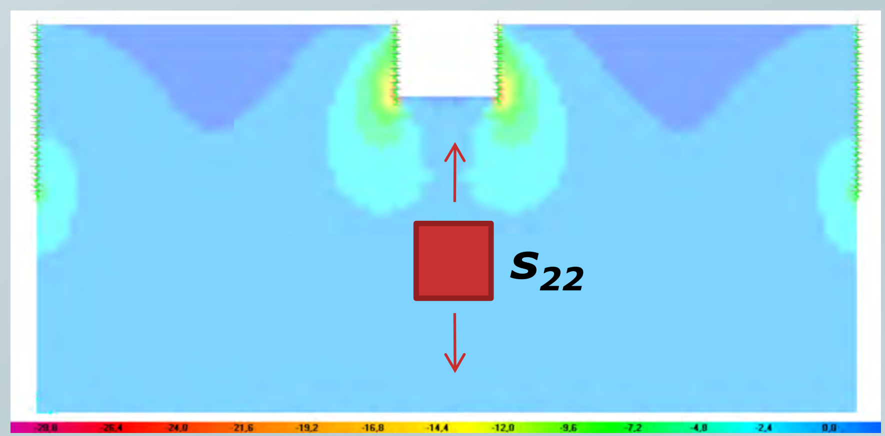
Assessment of floors

Strength assessment [kN-m]

- FEM modellign: shells

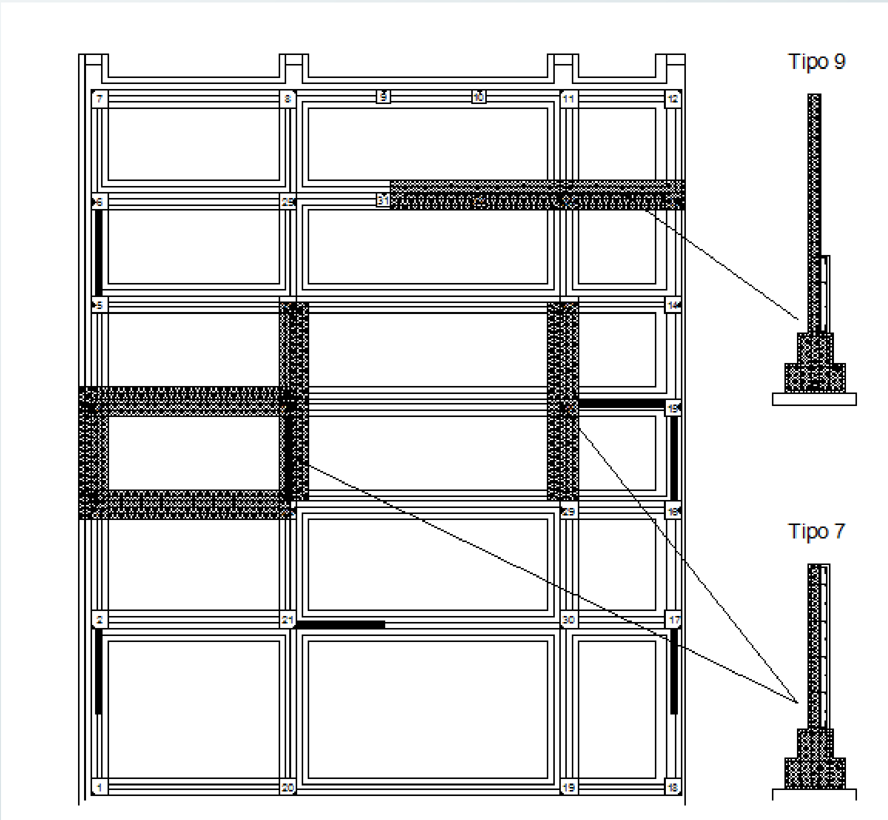


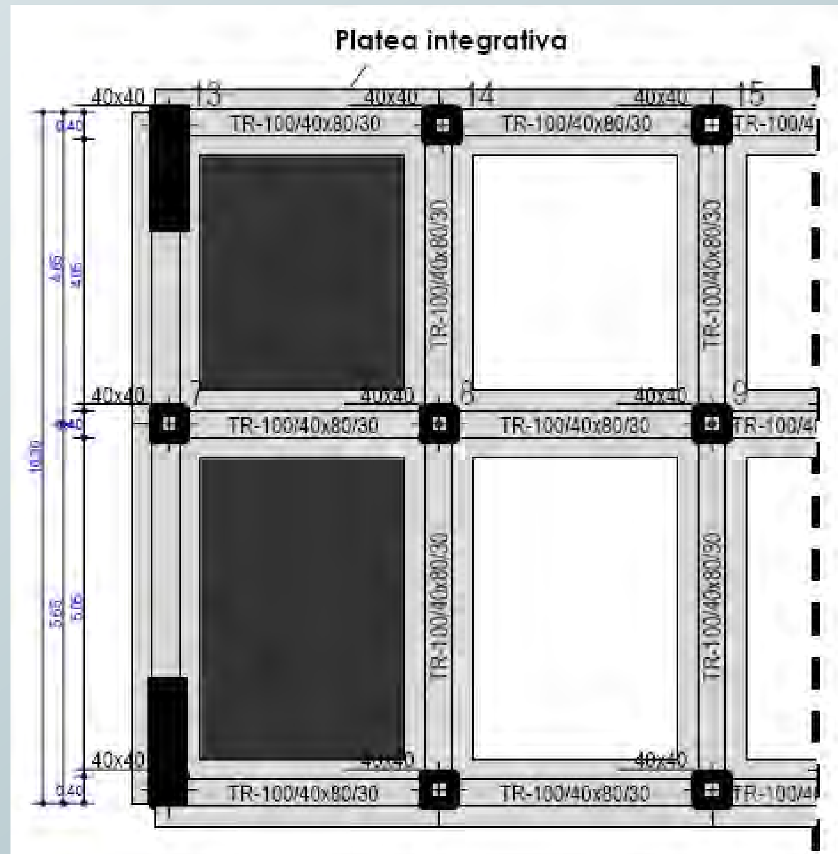




RC SHEAR WALLS

Strengthening of the foundation





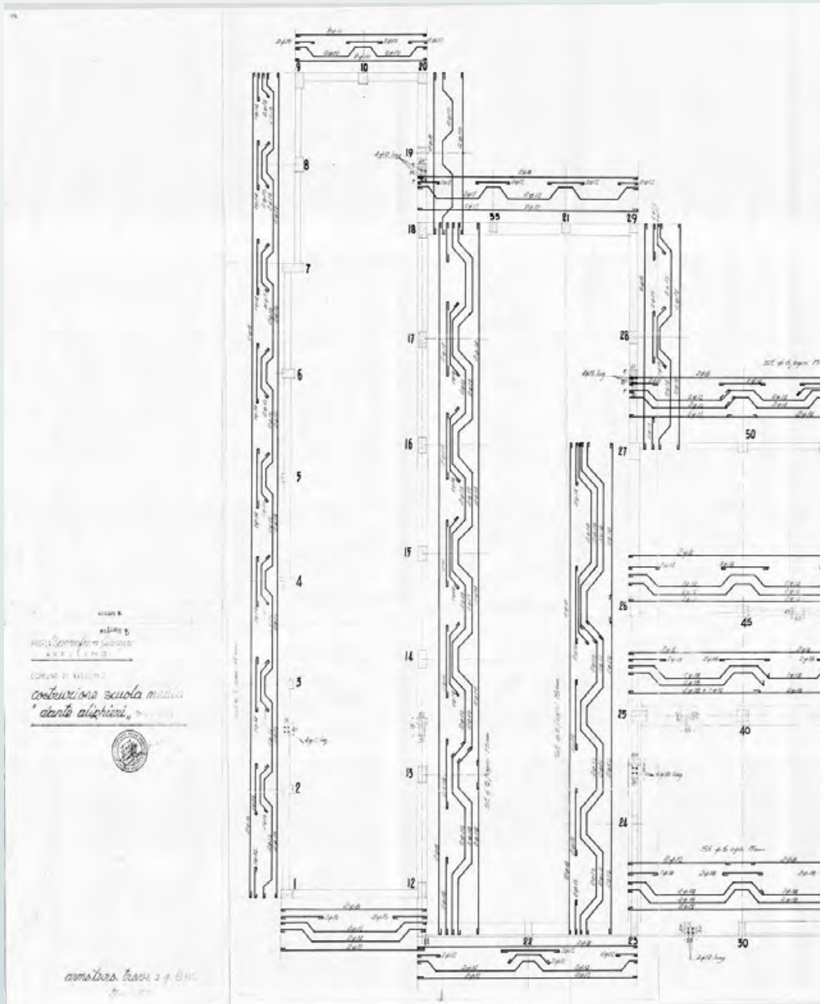
RC SHEAR WALLS

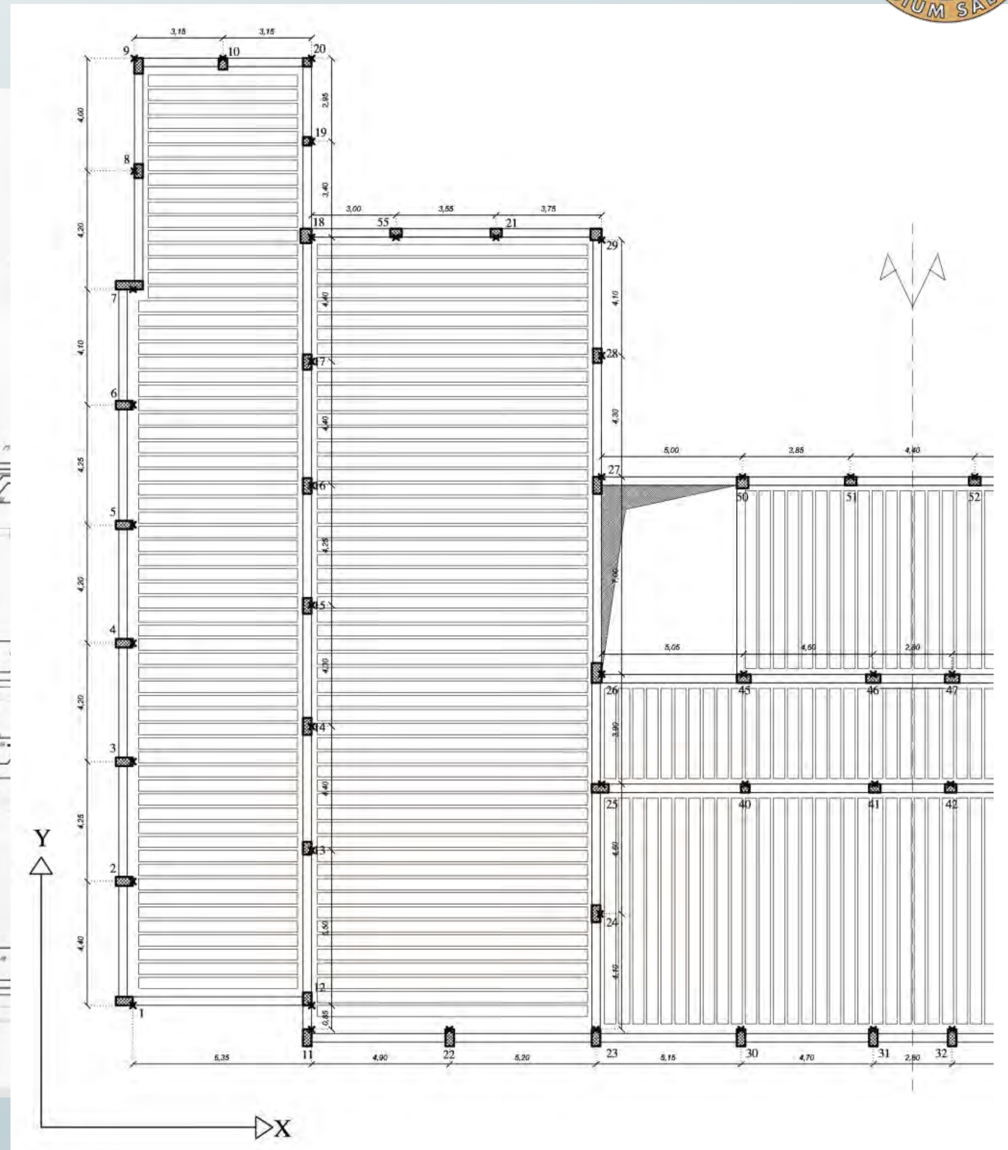
Application

Steel bracings

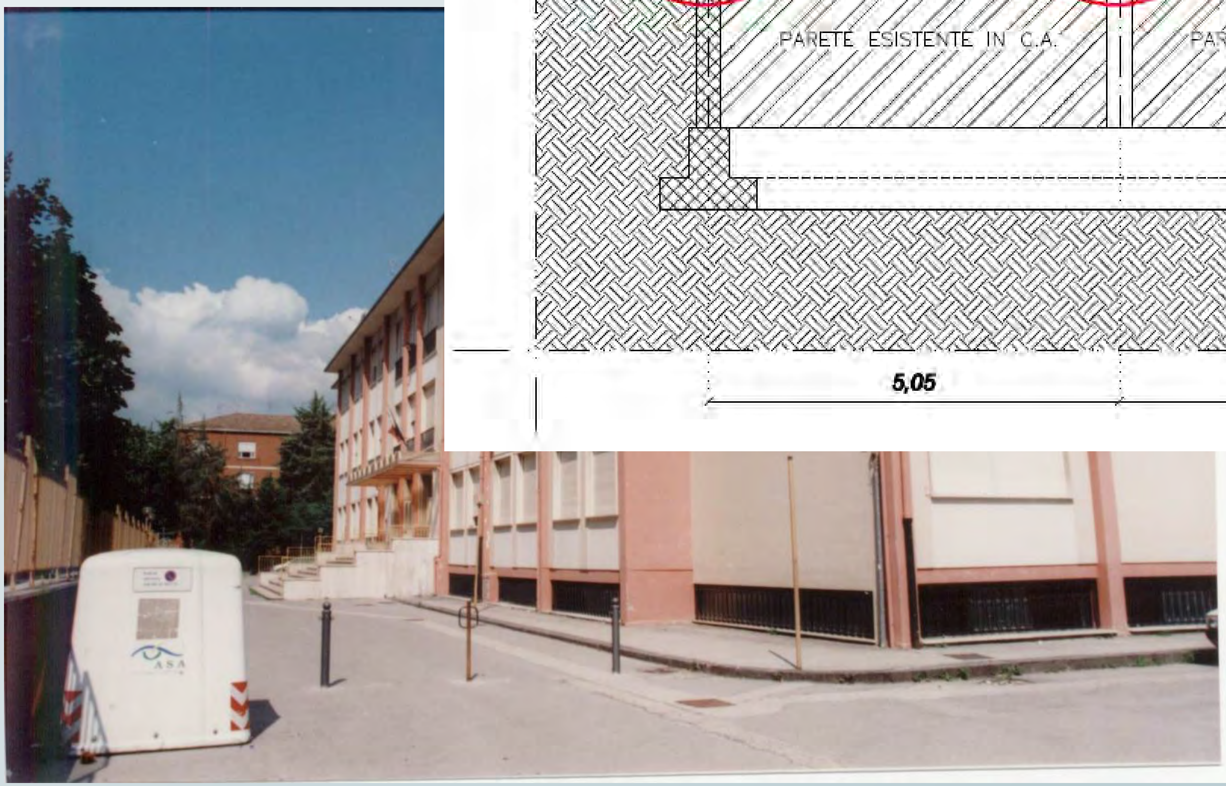
STEEL BRACINGS

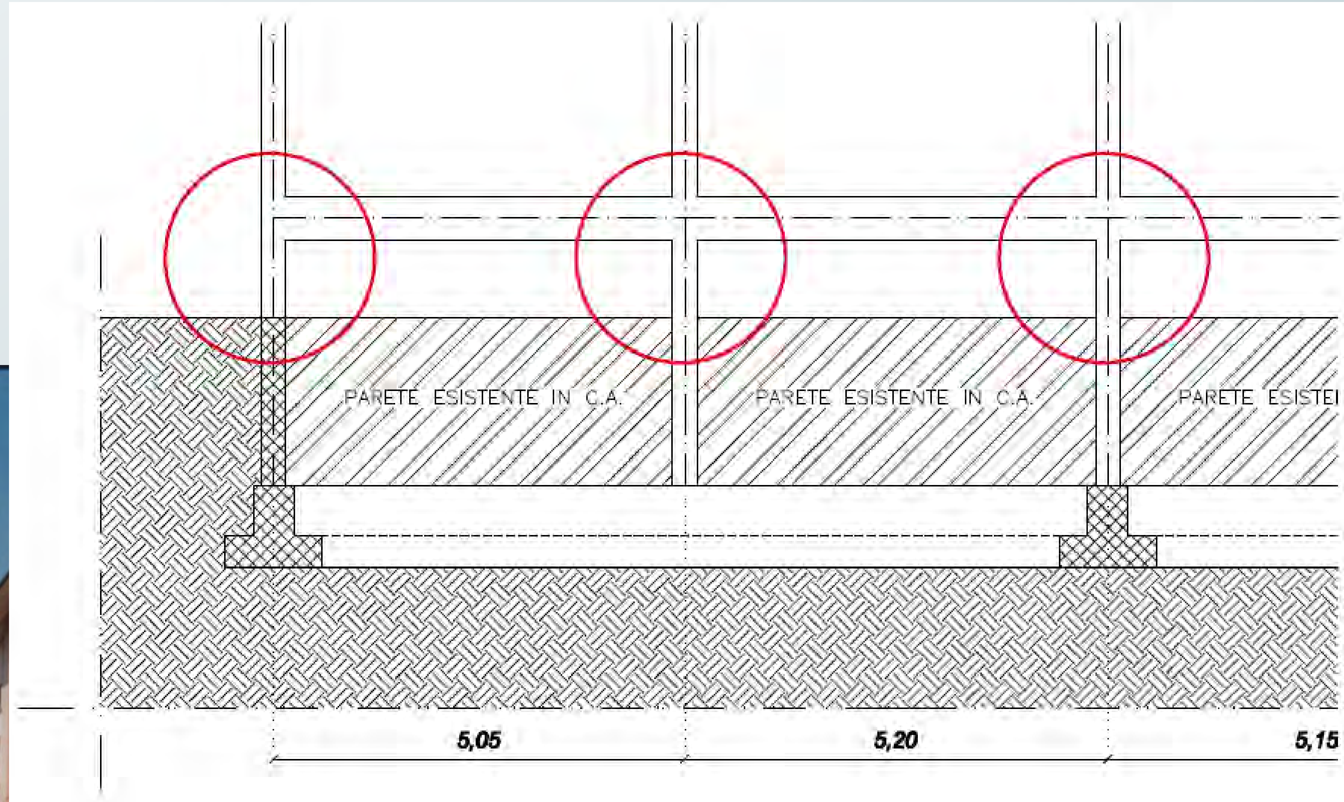
Case-of-study





STEEL BRACINGS

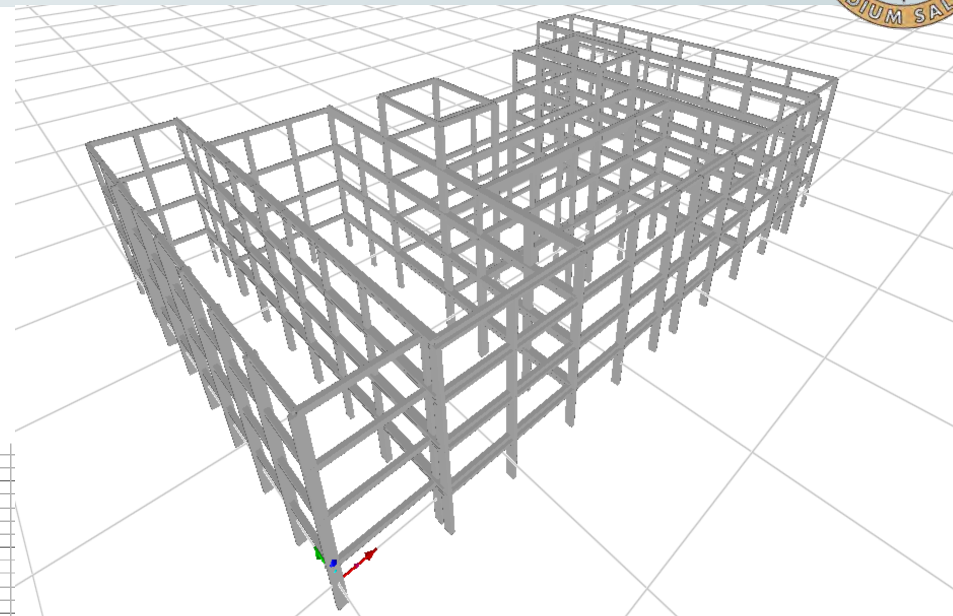


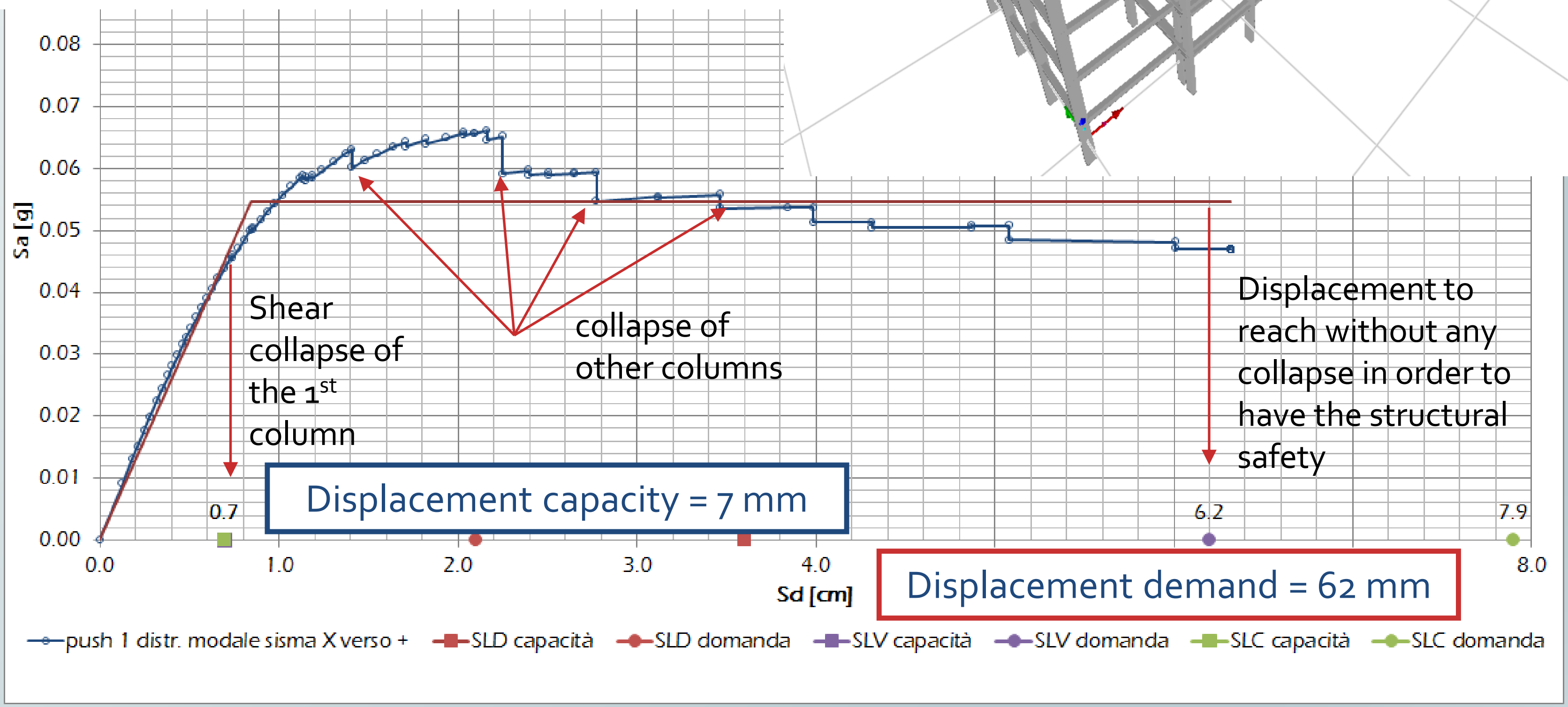


STEEL BRACINGS

Results of the seismic assessment

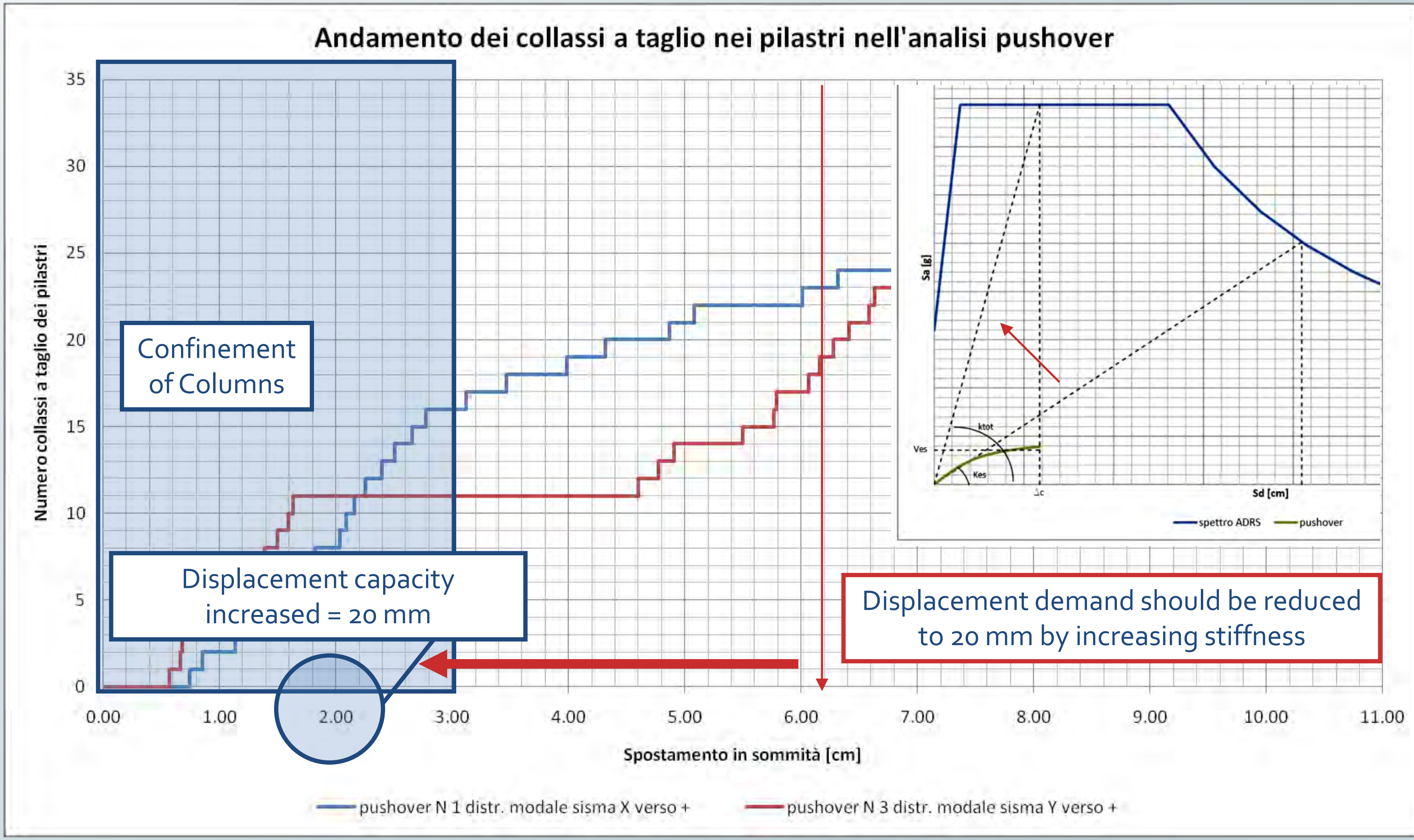
- The structures is verified in respect to seismic actions related to earthquakes with low and medium intensity
- Vulnerability is achieved in respect to high seismic intensity. Flexural and shear collapse is expected for columns





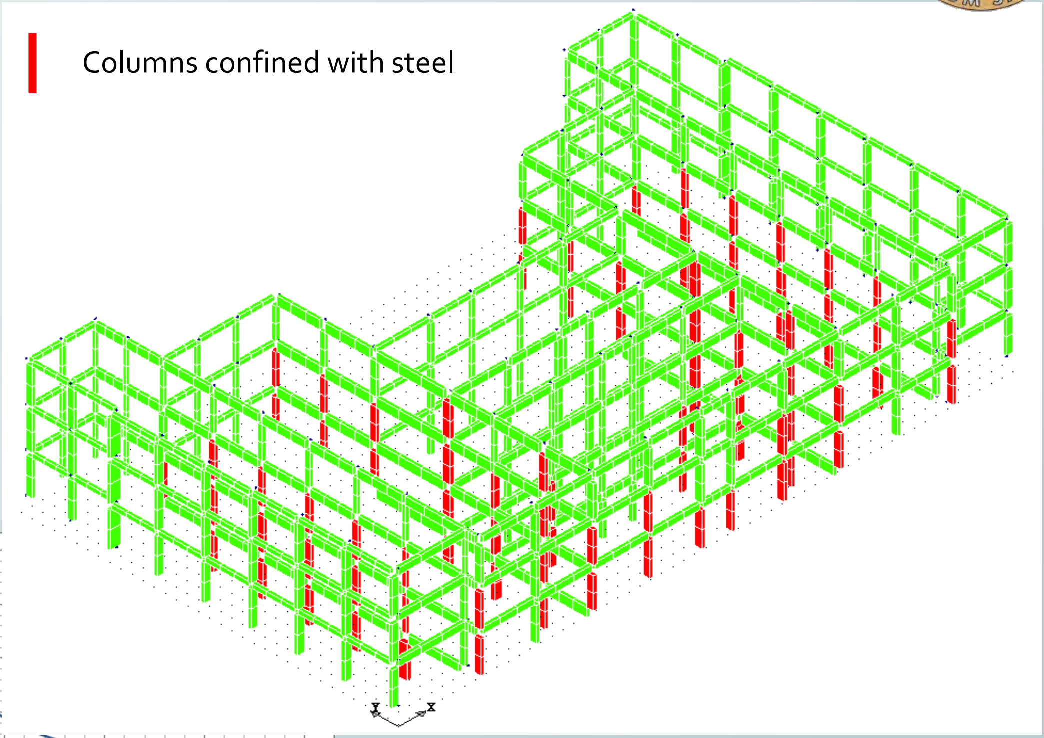
STEEL BRACINGS

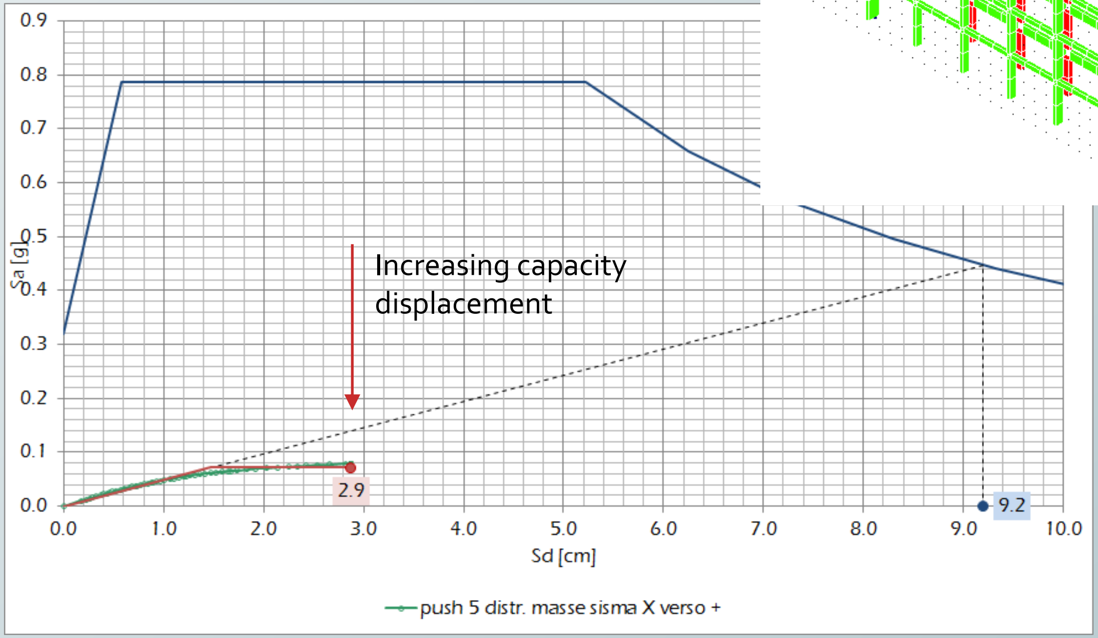
Design of the retrofitting intervention



STEEL BRACINGS

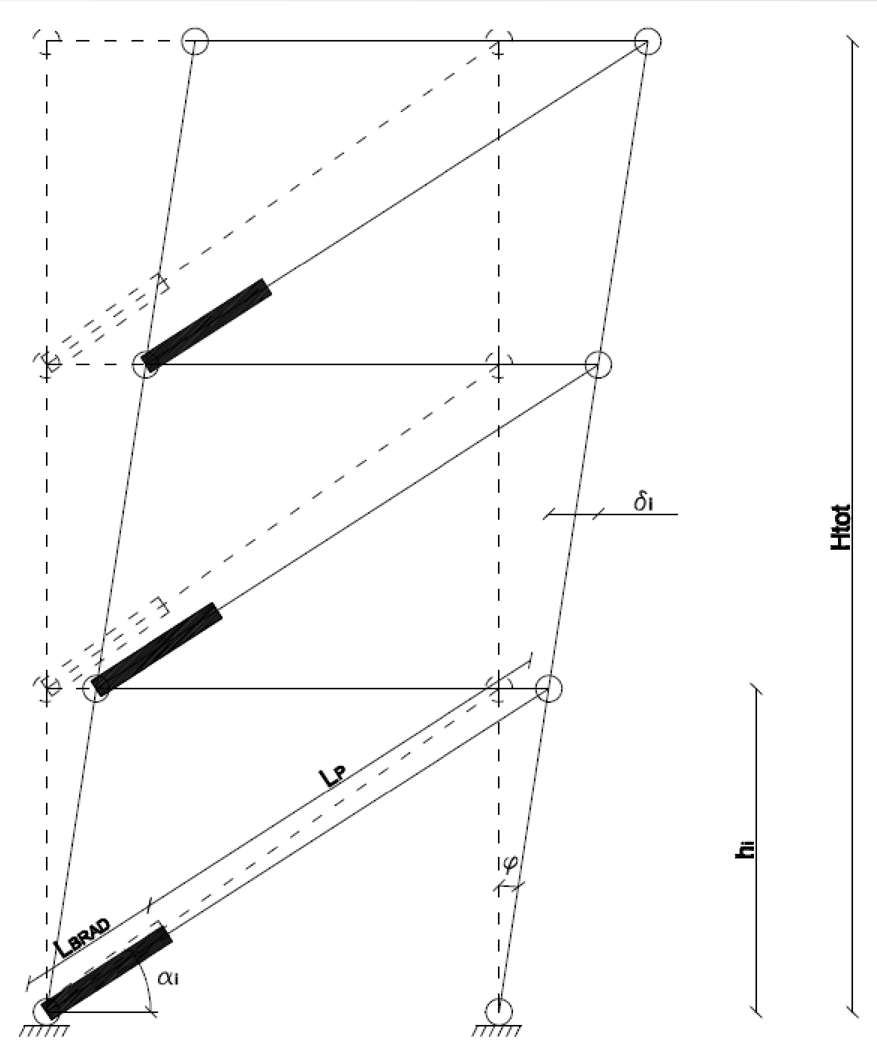
Design of the retrofitting intervention

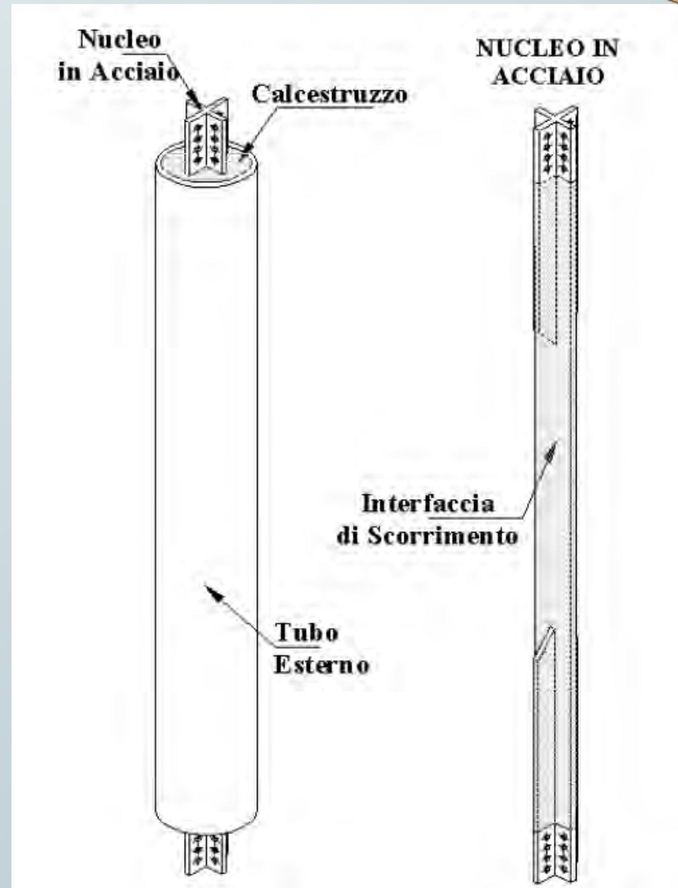




STEEL BRACINGS

Design of the retrofitting intervention



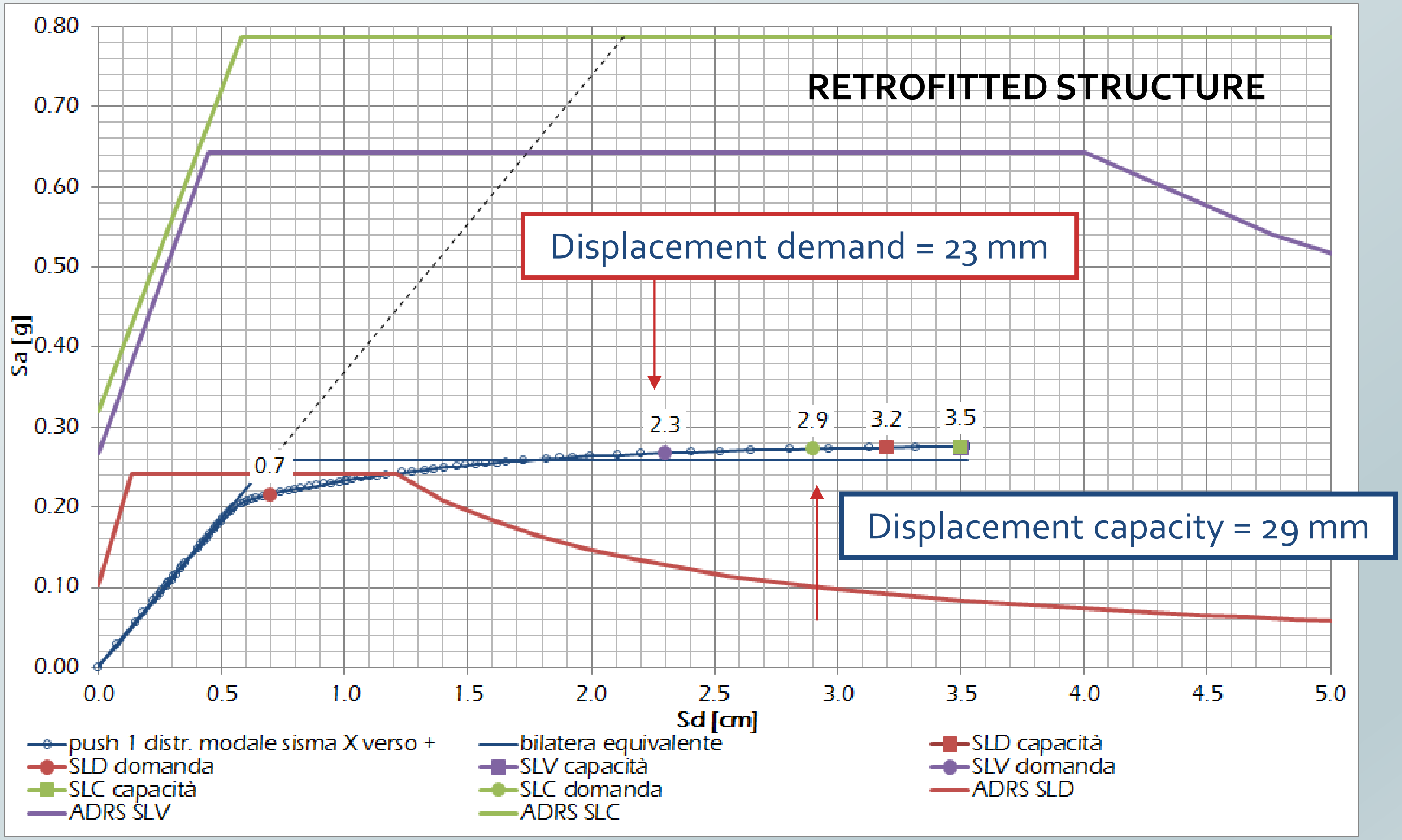


Buckling restrained bracings (BRB)

Working in tension and compression

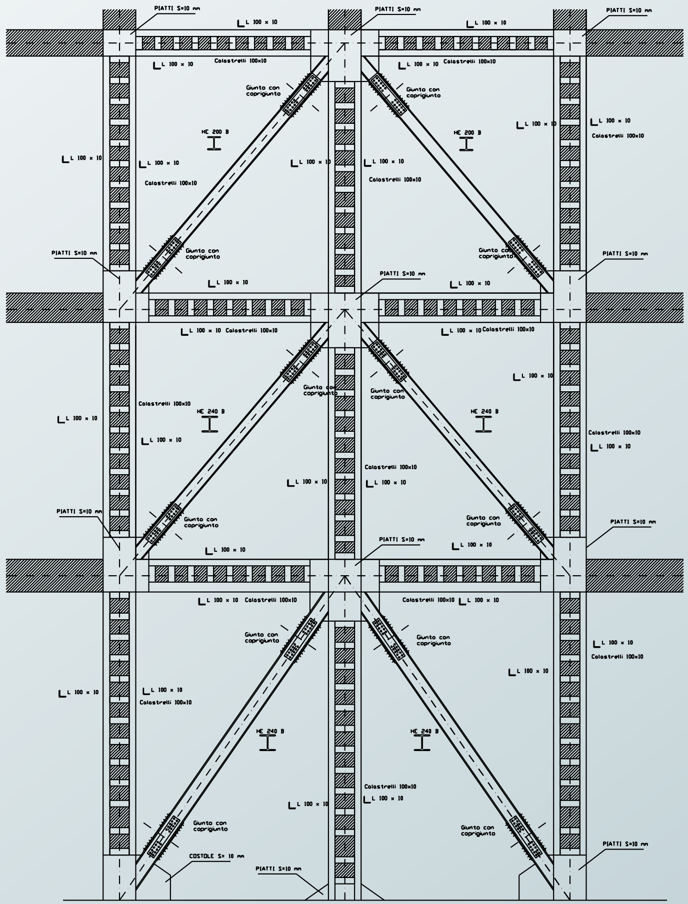
STEEL BRACINGS

Design of the retrofitting intervention

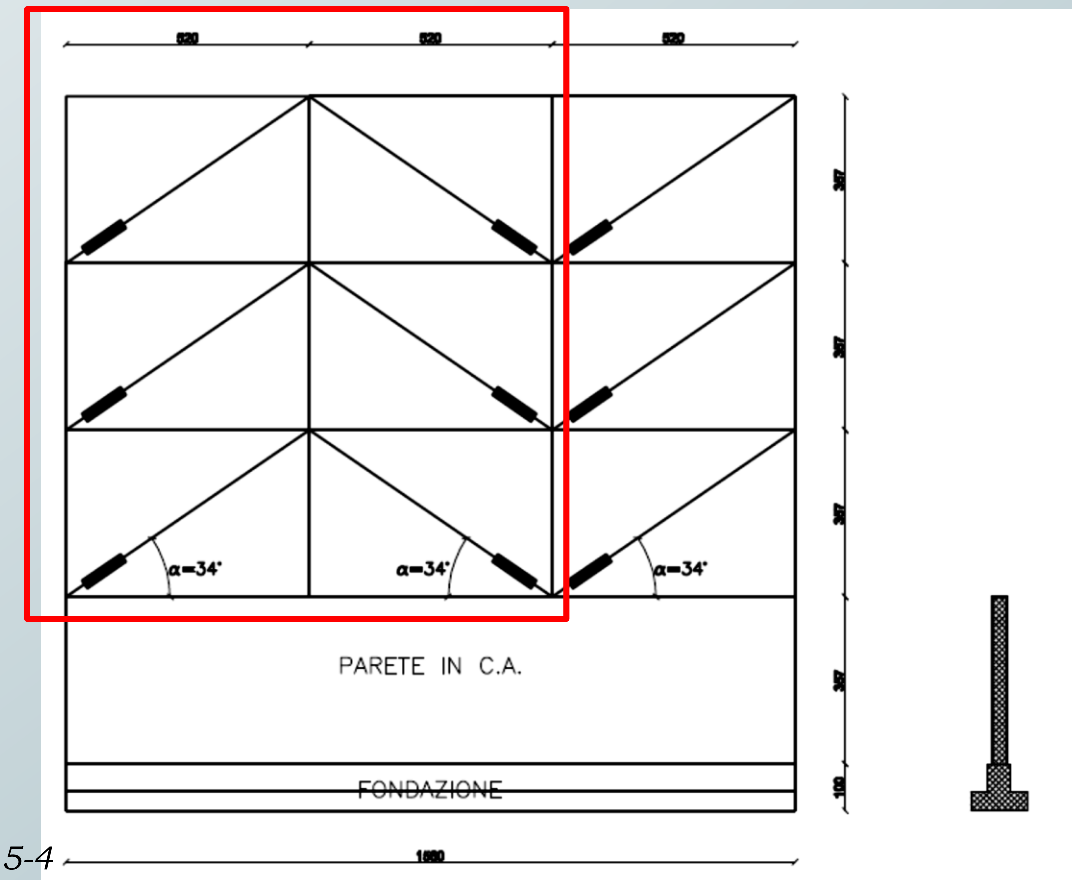


STEEL BRACINGS

Design



CORPO 2 - CONTROVENTO CAMPATE 6-5 e 5-4



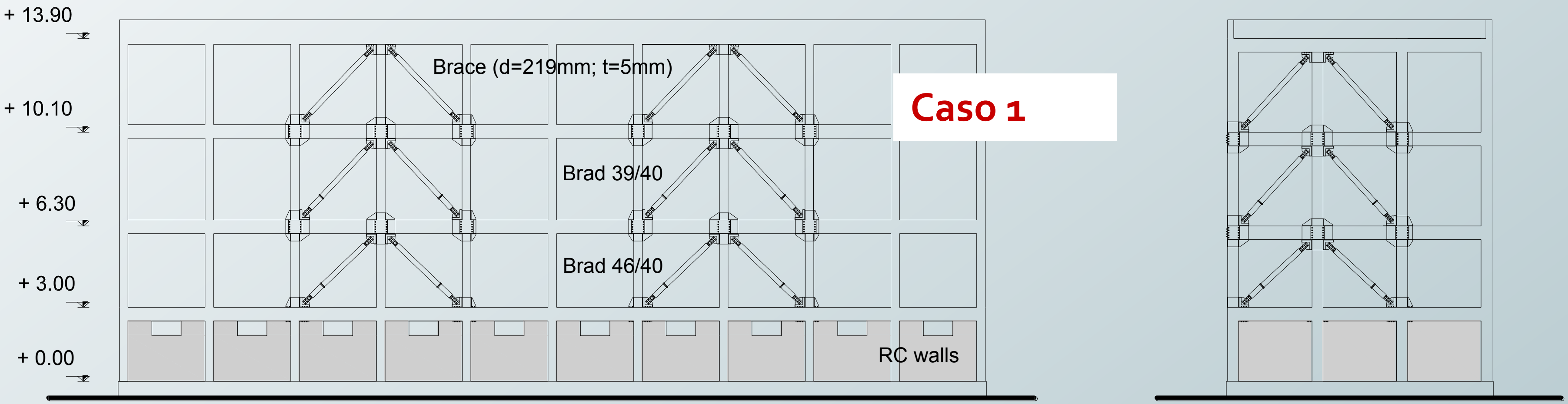
STEEL BRACINGS

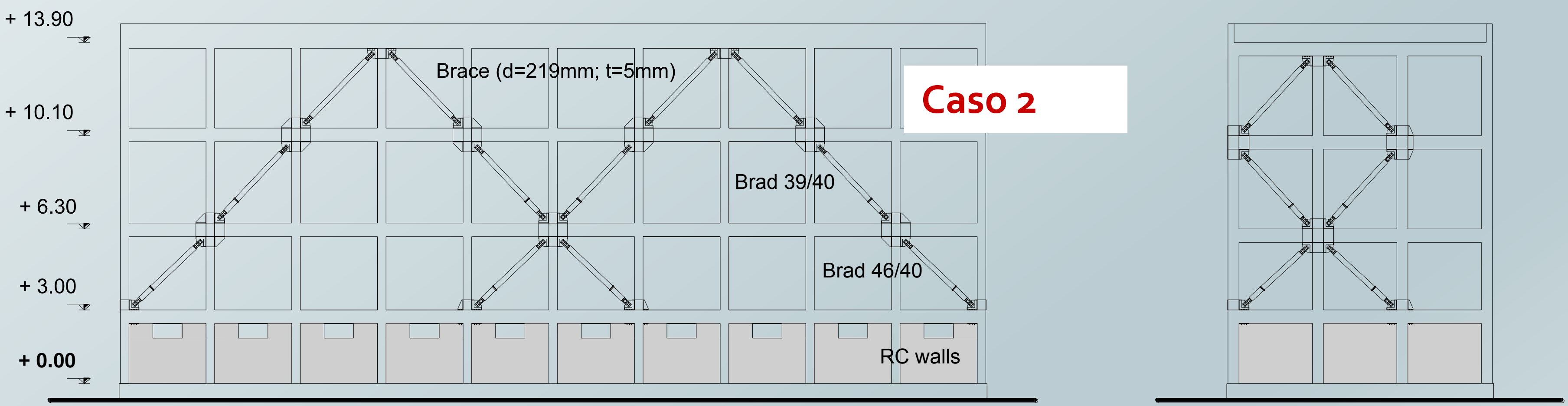
Traditional steel bracings

STEEL BRACINGS

STEEL BRACINGS

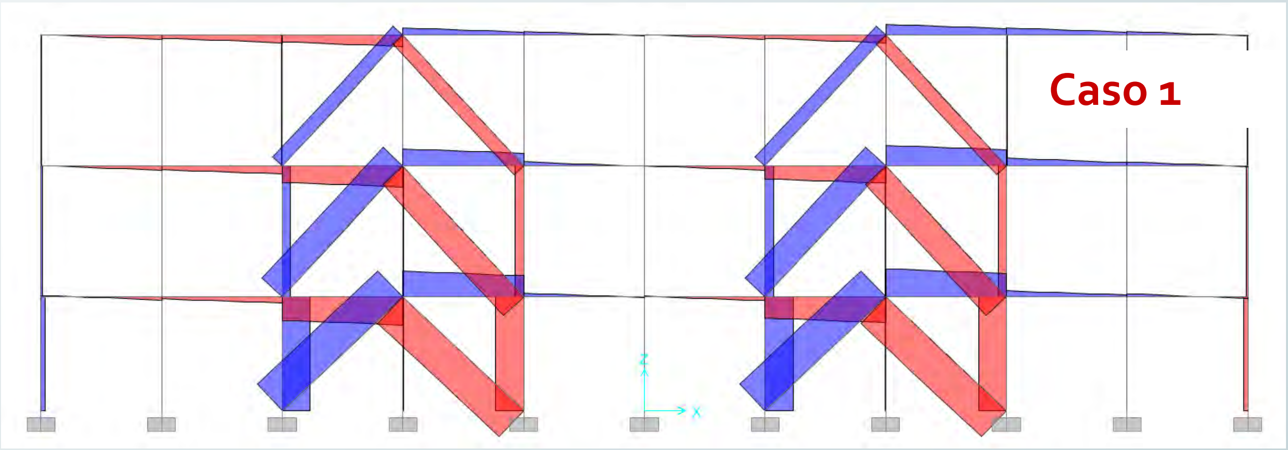
Influence of the structural shape

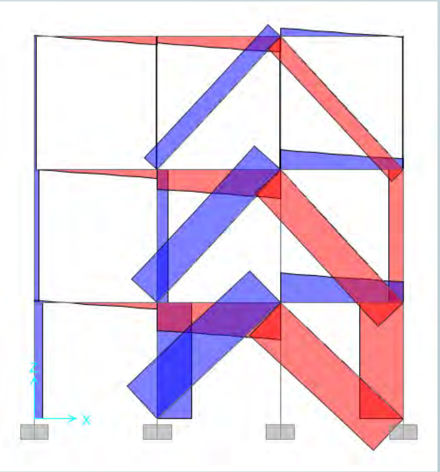


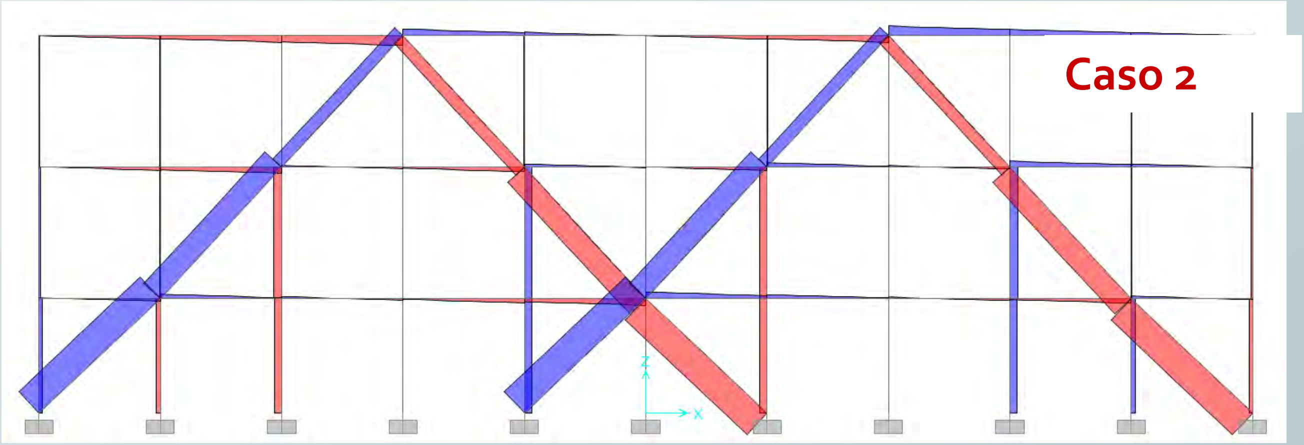


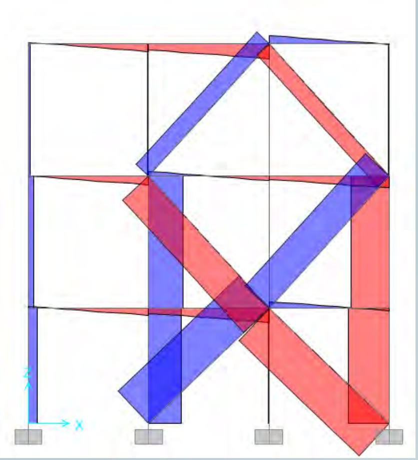
STEEL BRACINGS

Influence of the structural shape



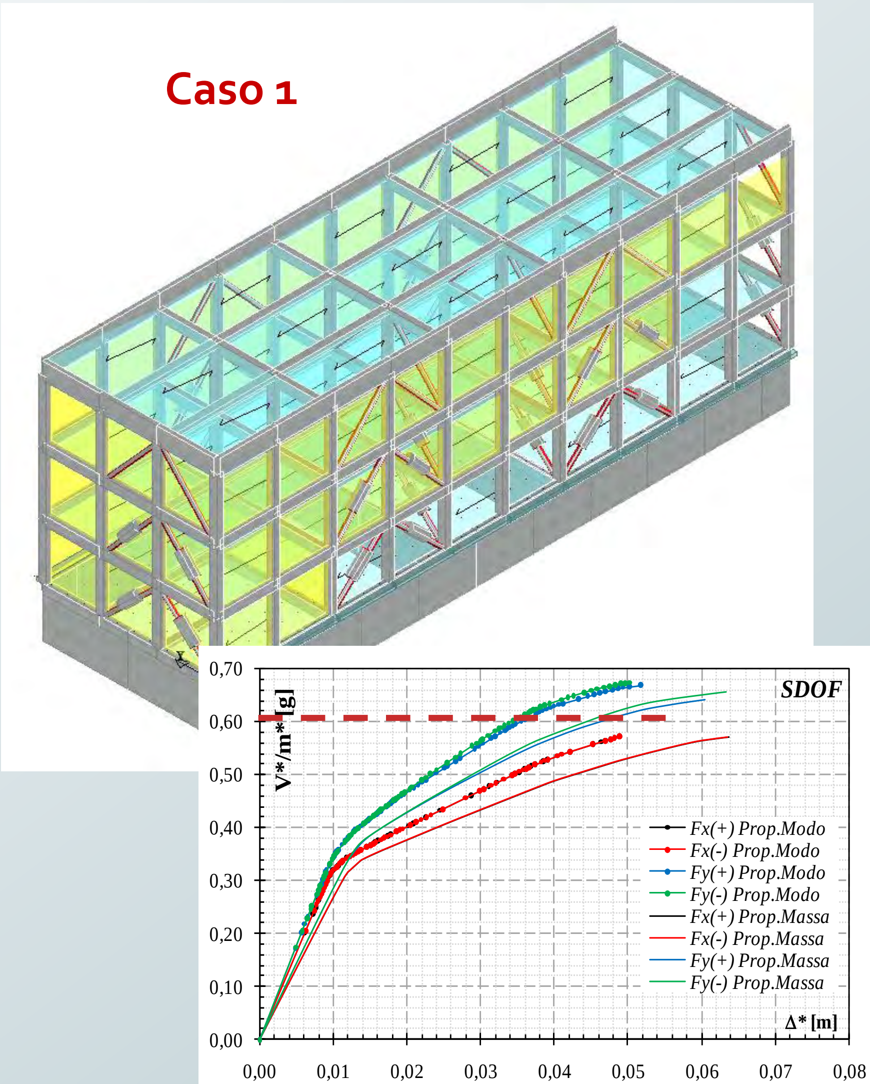


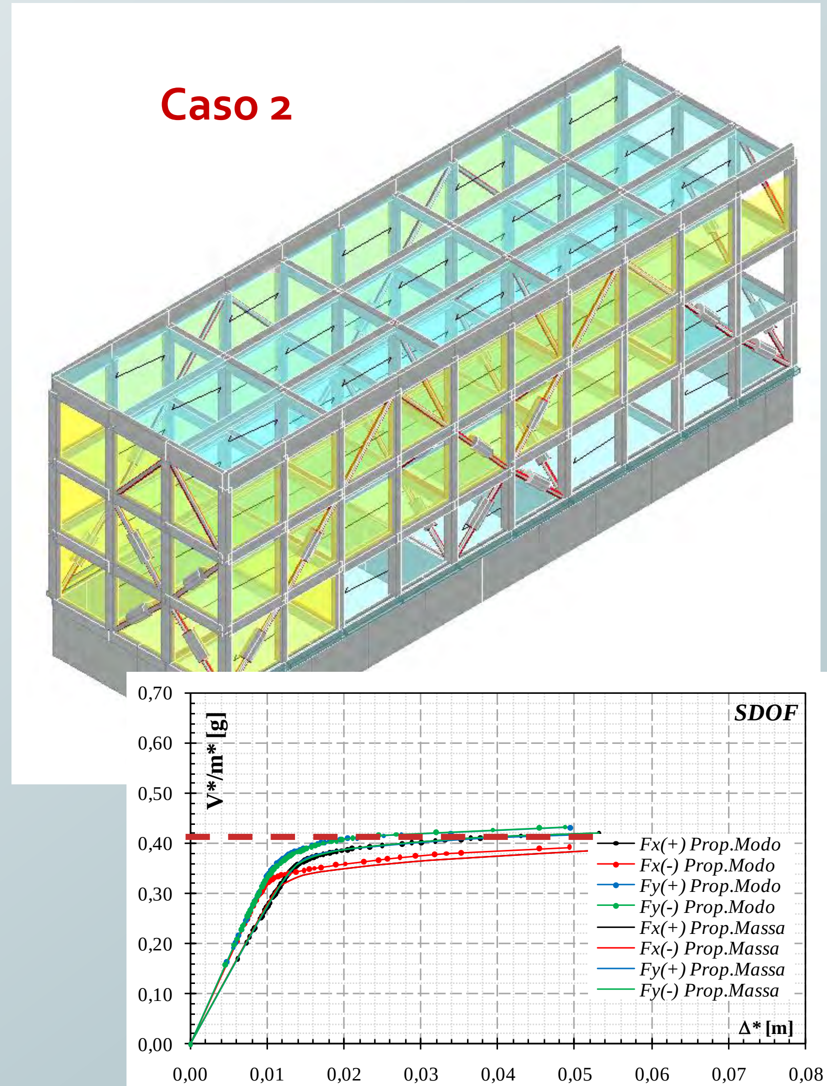




STEEL BRACINGS

Influence of the structural shape – Base shear

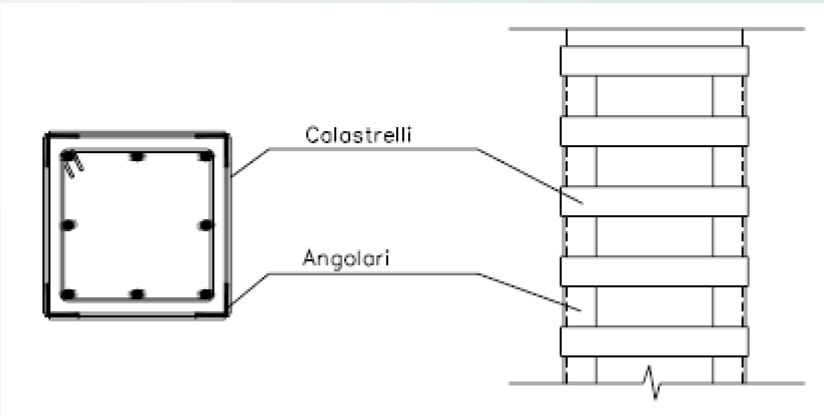


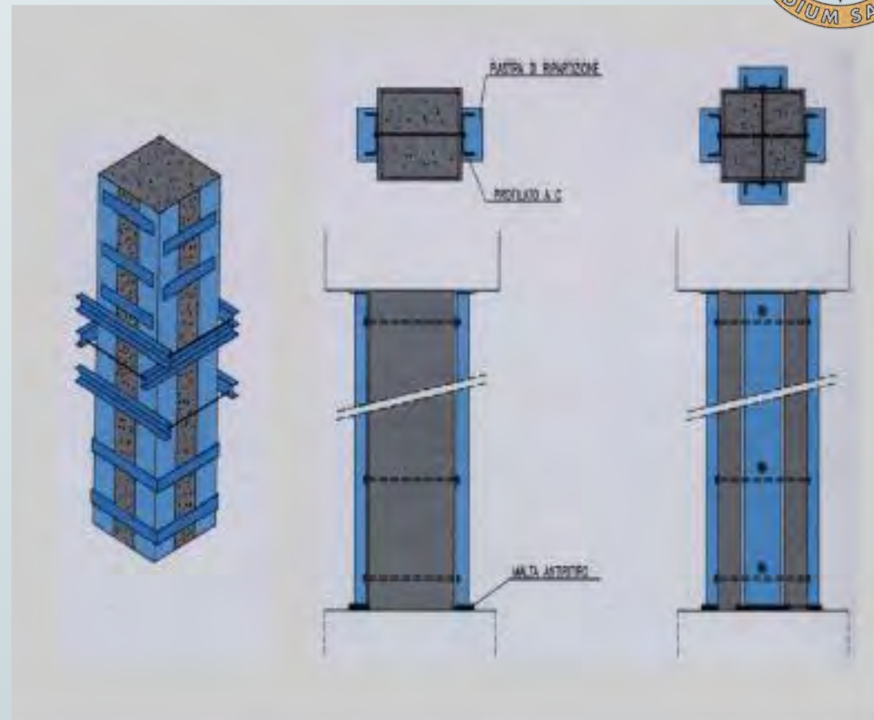


Confinement with steel members

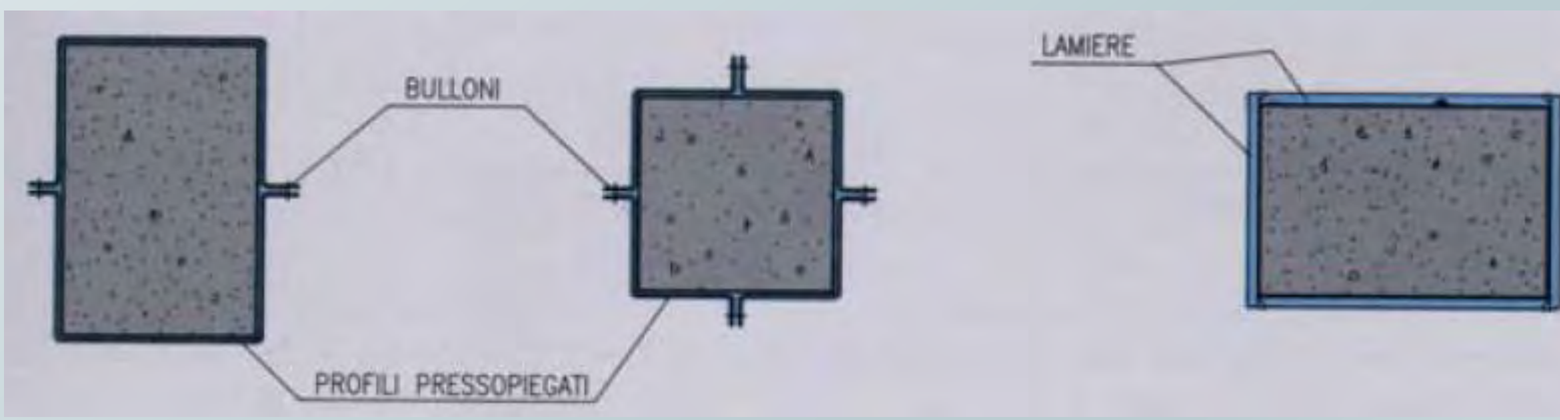
CONFINEMENT WITH STEEL MEMBERS

Steel members





Continuum plates

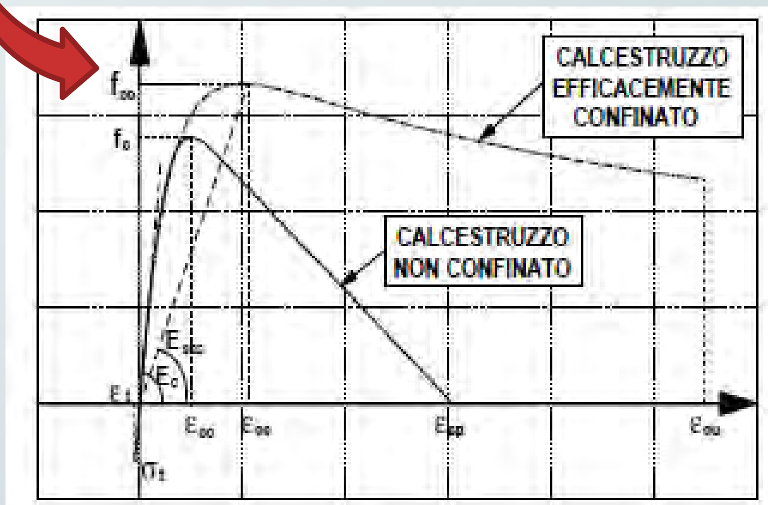


CONFINEMENT WITH STEEL MEMBERS

Effects of the confinement

$$f_{cc} = f_c \left[1 + 3.7 \left(\frac{0.5 \cdot \alpha_n \cdot \alpha_s \cdot \rho_s \cdot f_y}{f_c} \right)^{0.86} \right]$$

$$\varepsilon_{cu} = 0.004 + 0.5 \frac{0.5 \cdot \alpha_n \cdot \alpha_s \cdot \rho_s \cdot f_y}{f_{cc}}$$



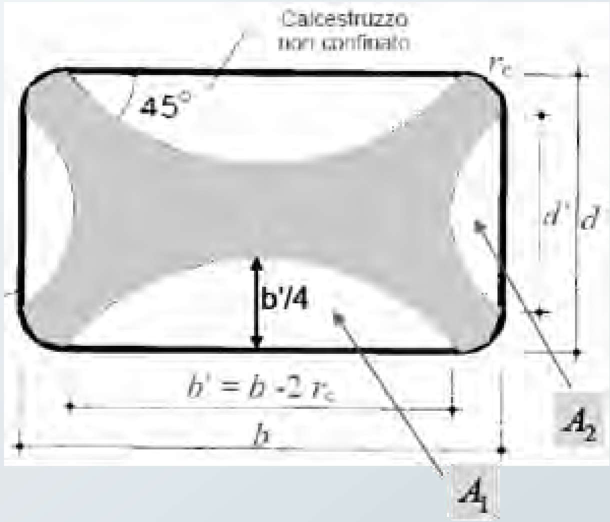
$$\alpha_n = 1 - \frac{(b-2R)^2 + (h-2R)^2}{3bh}$$

Confinement efficiency factors

$$\alpha_s = \left(1 - \frac{s-h_s}{2b}\right)\left(1 - \frac{s-h_s}{2h}\right)$$

CONFINEMENT WITH STEEL MEMBERS

Confinement effects– horizontal confinement



$$\alpha_n = 1 - \frac{(b-2R)^2 + (h-2R)^2}{3bh}$$

R = raggio arrotondamento degli spigoli della sezione,

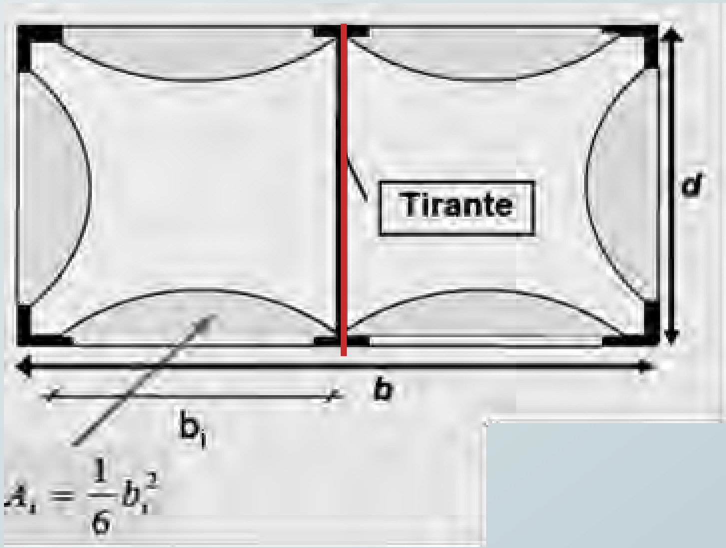
b e h = dimensioni della sezione

$$A_1 = \frac{2}{3} b' \frac{b'}{4} = \frac{1}{6}(b')^2$$

$$A_2 = \frac{2}{3} d' \frac{d'}{4} = \frac{1}{6}(d')^2$$

$$A_e = A - 2A_1 - 2A_2 = bd - \frac{1}{3}(b')^2 - \frac{1}{3}(d')^2 = bd - \frac{(d')^2 + (b')^2}{3}$$

$$\alpha_n = \frac{A_e}{A} = 1 - \frac{(d')^2 + (b')^2}{3bd}$$



The confinement effect are negligible in sections in which b/d>2

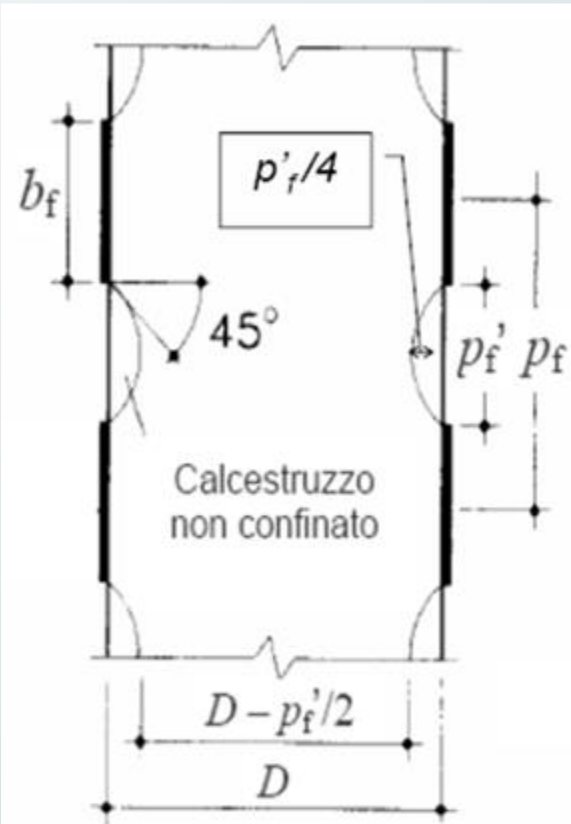
This case can be overcomes introducing a steel bar for the connection (a perforation of the column is needed)

$$A_e = A - \sum A_i = A - \frac{\sum b_i^2}{6}$$

$$\alpha_n = \frac{A_e}{A} = 1 - \frac{\sum b_i^2}{6bd}$$

CONFINEMENT WITH STEEL MEMBERS

Confinement effects– vertical confinement



$$\alpha_s = \left(1 - \frac{s - h_s}{2b}\right)\left(1 - \frac{s - h_s}{2h}\right)$$

h_s = altezza delle bande,

s = passo delle bande,

(se la camicia è continua si pone $h_s = s$)

$$A_e = \left(b - \frac{p'_f}{2}\right)\left(h - \frac{p'_f}{2}\right)$$

$$\alpha_s = \frac{A_e}{A} = \left(b - \frac{p'_f}{2}\right)\left(h - \frac{p'_f}{2}\right)\frac{1}{bh} = \left(1 - \frac{p'_f}{2b}\right)\left(1 - \frac{p'_f}{2h}\right)$$

CONFINEMENT WITH STEEL MEMBERS

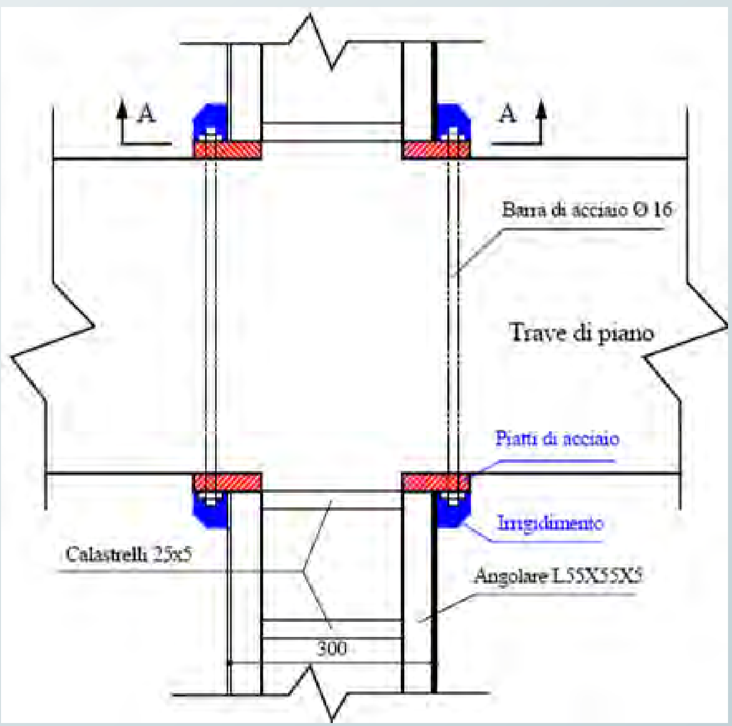
Effects of the vertical steel members

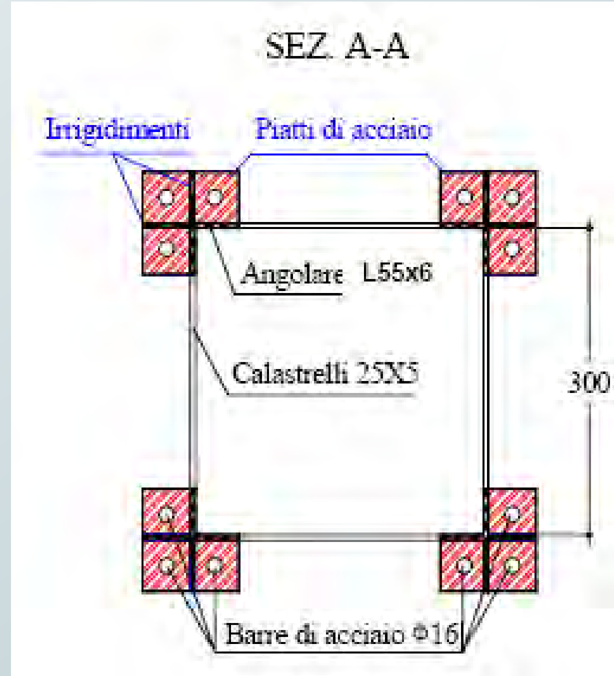
Increasing strength (composite section):

Existing concrete

Existing bars

New steel members





$$f_{y,ang} \cdot A_{ang} = f_{y,barre} \cdot A_{barre} \Rightarrow A_{barre} = \frac{A_{ang} \cdot f_{y,ang}}{f_{y,barre}}$$

Esempio numerico

$f_{y,ang}$ = 275 MPa; $f_{y,barre}$ = 450 Mpa; A_{ang} = 6.31 cm^2

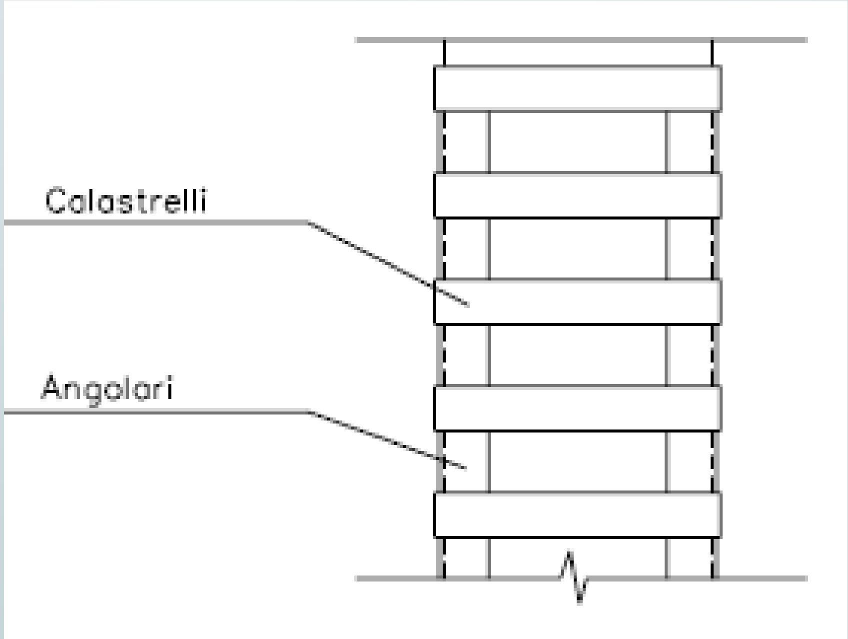
$$A_{barre} = \frac{A_{ang} \cdot f_{y,ang} / \gamma_{M0}}{f_{y,barre} / \gamma_s} = \frac{631 \cdot 275 / 1.05}{450 / 1.15} = 4.22 cm^2 \Rightarrow 3\phi16$$

CONFINEMENT WITH STEEL MEMBERS

Effects of horizontal steel members

Increasing shear strength (they are equivalent to stirrups)

$$V_j = 0.5 \frac{2 \cdot t_j \cdot b}{s} f_{yw} \frac{1}{\cos \alpha_t}$$



In which:

$\mathbf{t_j}$ = thickness of horizontal steel members;

b = width of the horizontal steel members;

s = spacing (b/s=1 if continuum plate);

$\mathbf{f_{yw}}$ **=** yielding strength of steel;

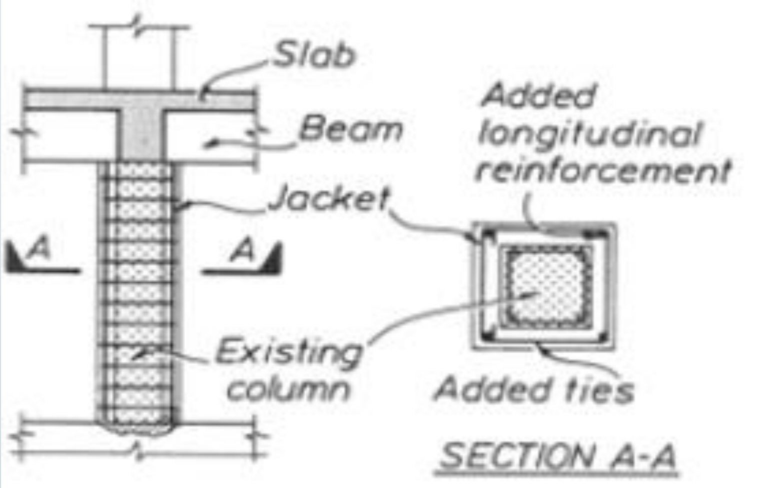
α_t **= inclination of the shear cracks (generally 45°)**.

RC Jacketing

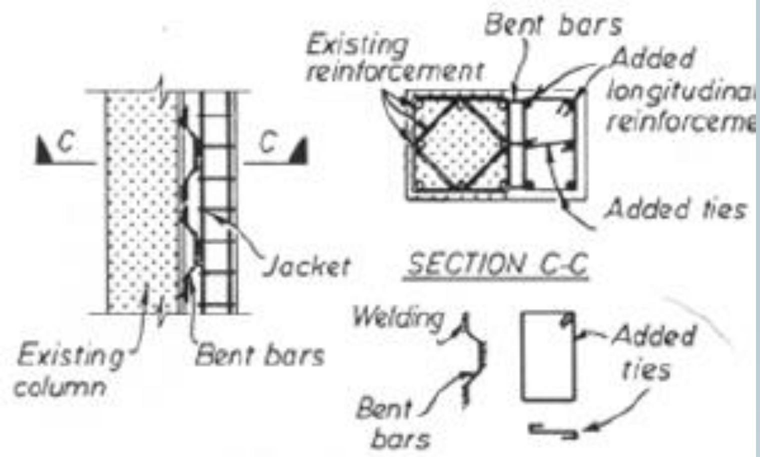
RC JACKETING

RC JACKETING

Types



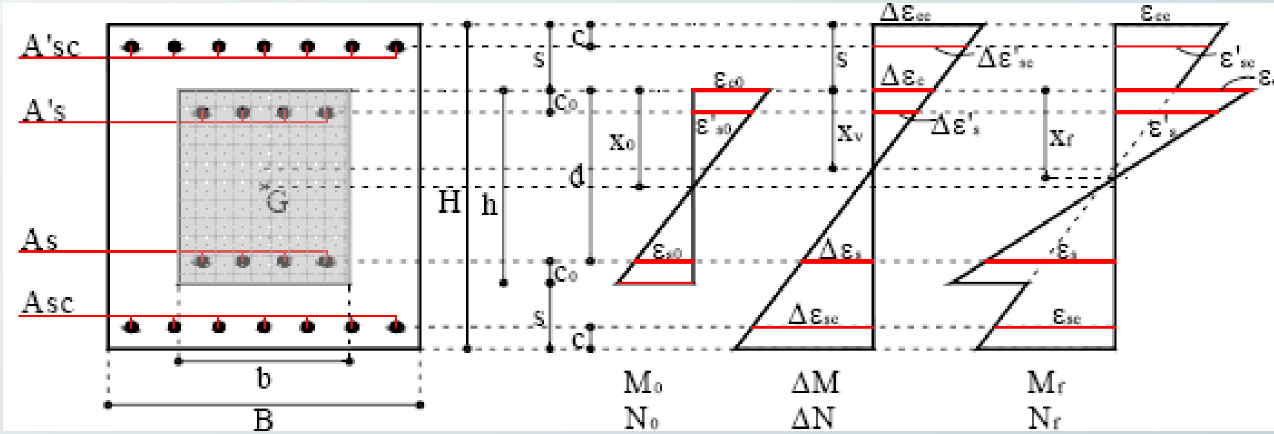
Full jacketing

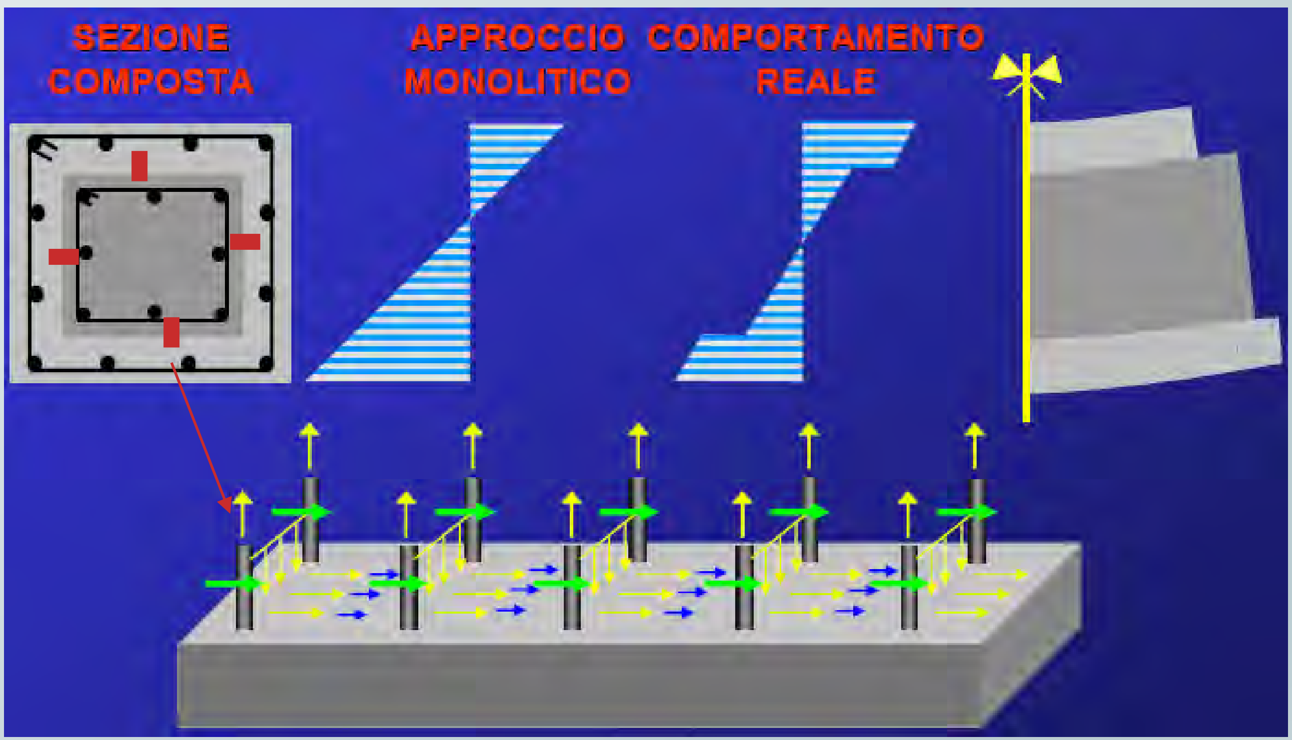


Partial jacketing

RC JACKETING

Design



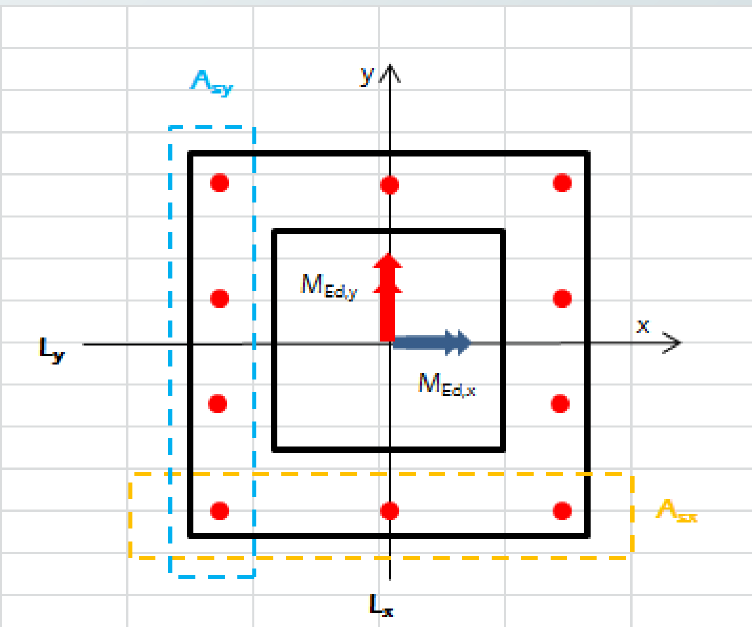


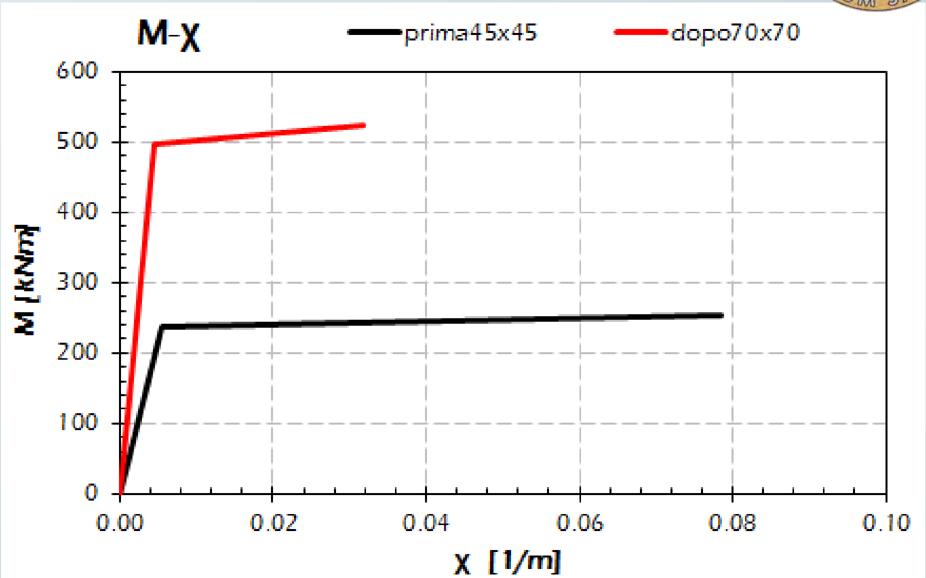
RC JACKETING

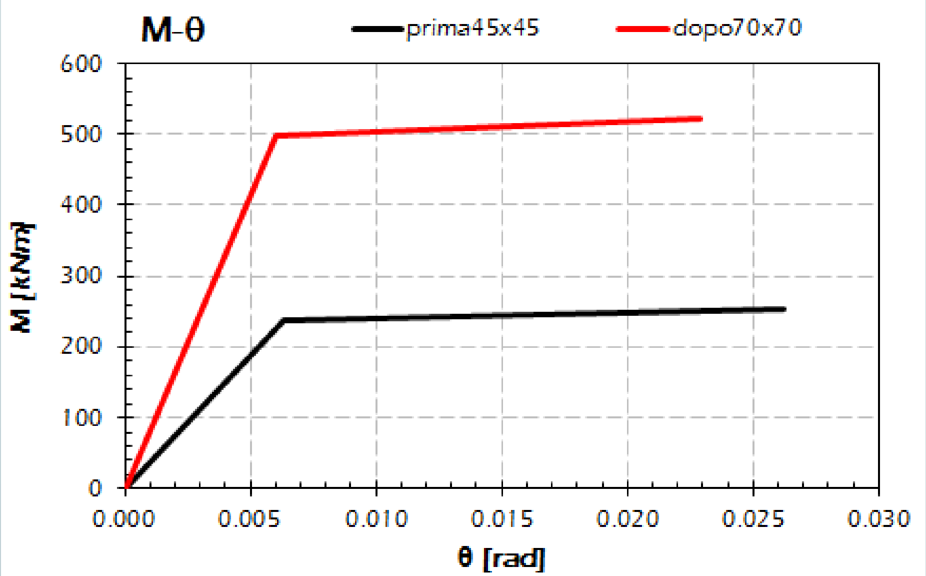
Numerical example

Existing Column 45x45

Confined column 70x70 cm







Confinement with FRP

FRP = Fiber-Reinforced Polymers

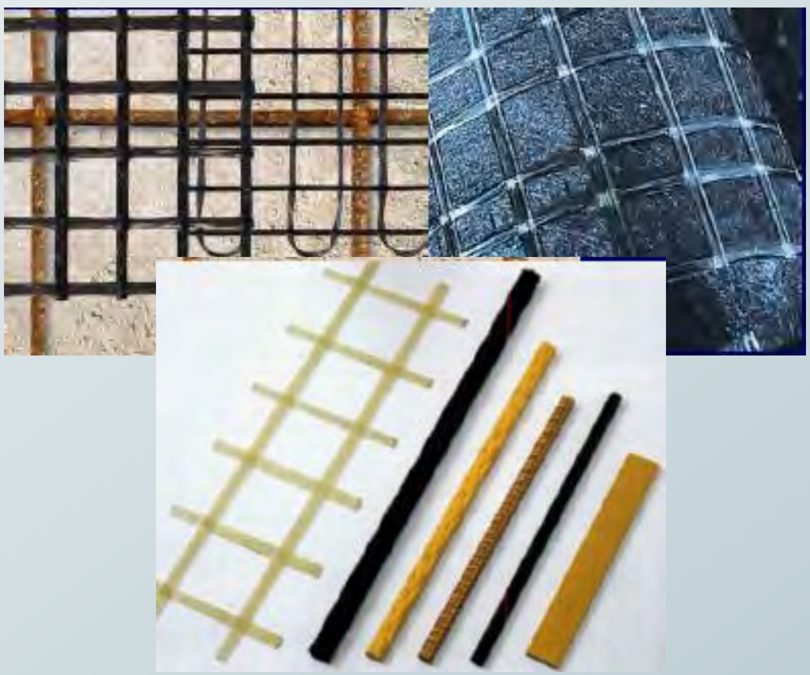
GFRP = Glass Fiber-reinforced polymers

CFRP = Carbon Fiber-reinforced polymers

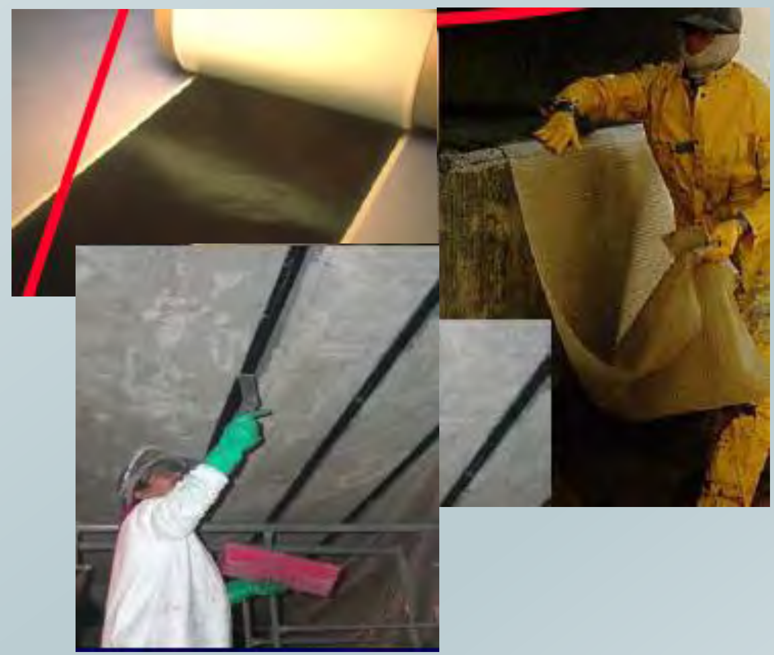
AFRP = Aramid Fiber-reinforced polymers

In a lot of cases FRP can be a valid and economic alternative to traditional materials in many engineering applications

New structures

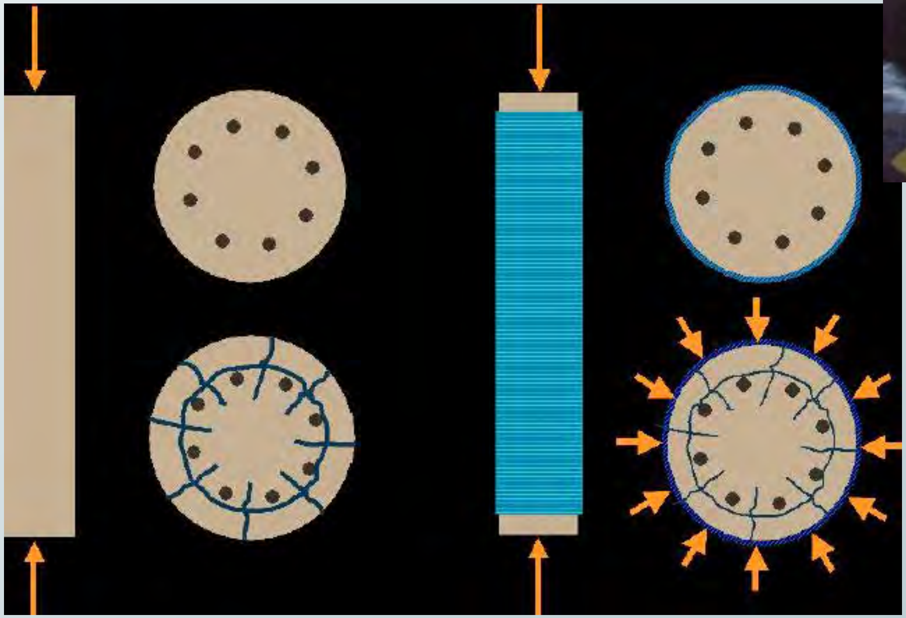


Existing structures



CONFINEMENT WITH FRP

Confinement with FPR can enhances the mechanical properties of concrete

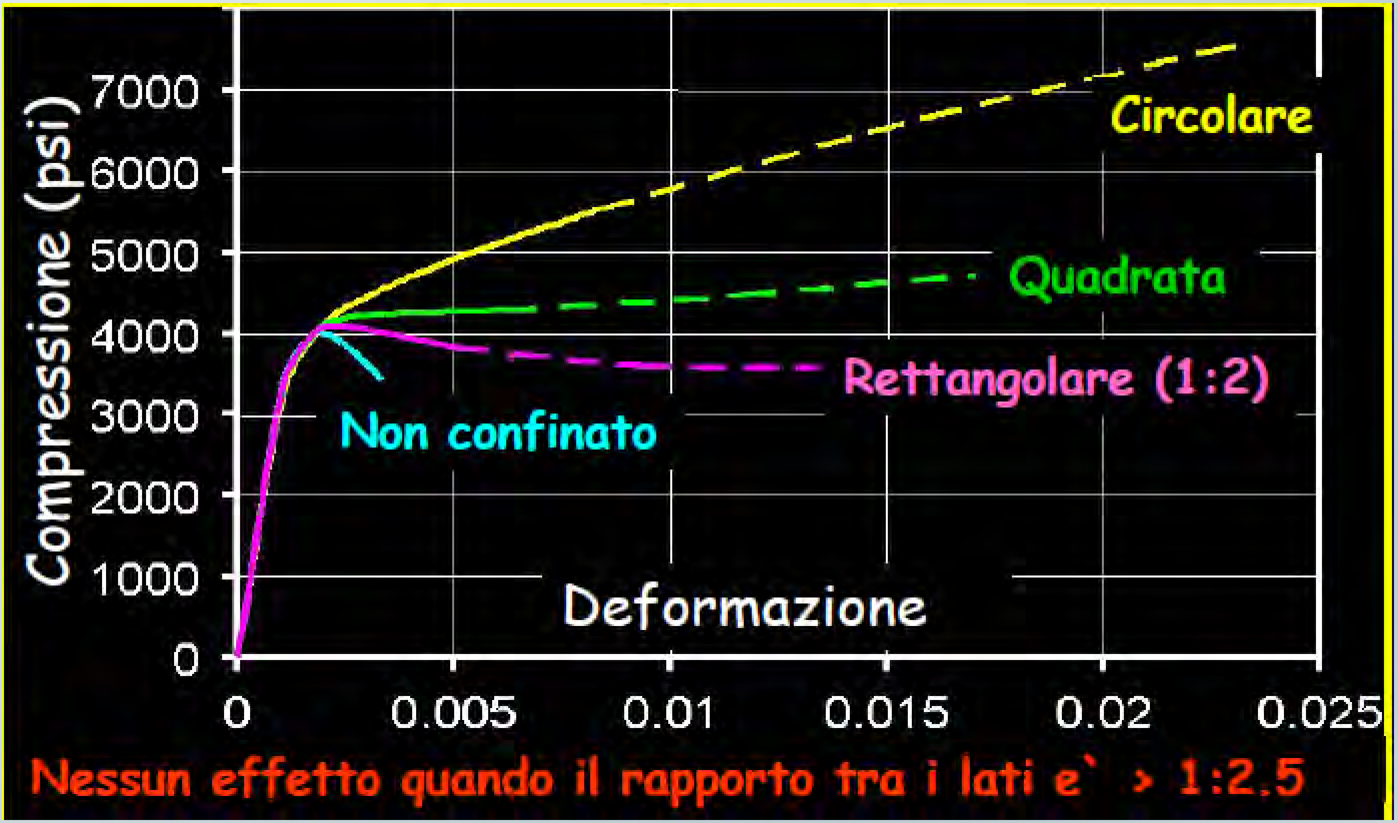


- Increasing the ultimate strength and the ultimate strain (ductility) for elements with axial load and small eccentricity
- Increasing ductility in members with high bending moment

CONFINEMENT WITH FRP

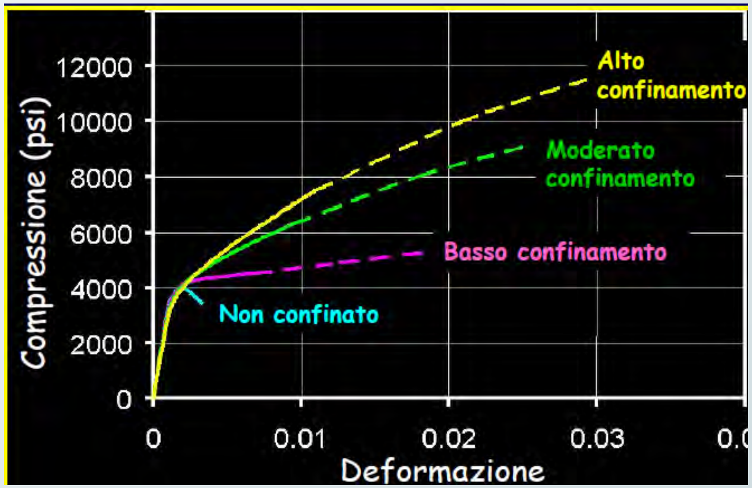
Increasing compressive strength and ultimate strain depends on the pressure of confinement related to:

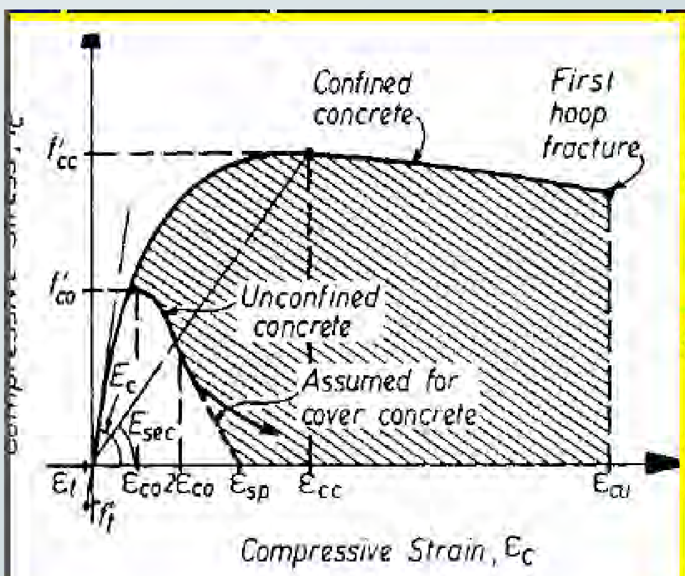
- Stiffness of the FRP material;
- Shape of the cross section

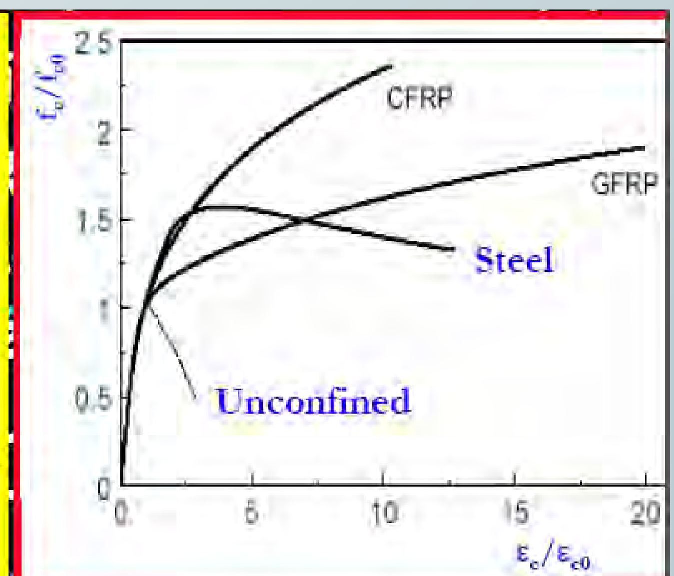


CONFINEMENT WITH FRP

Confinement can be provided as continuum or not continuum





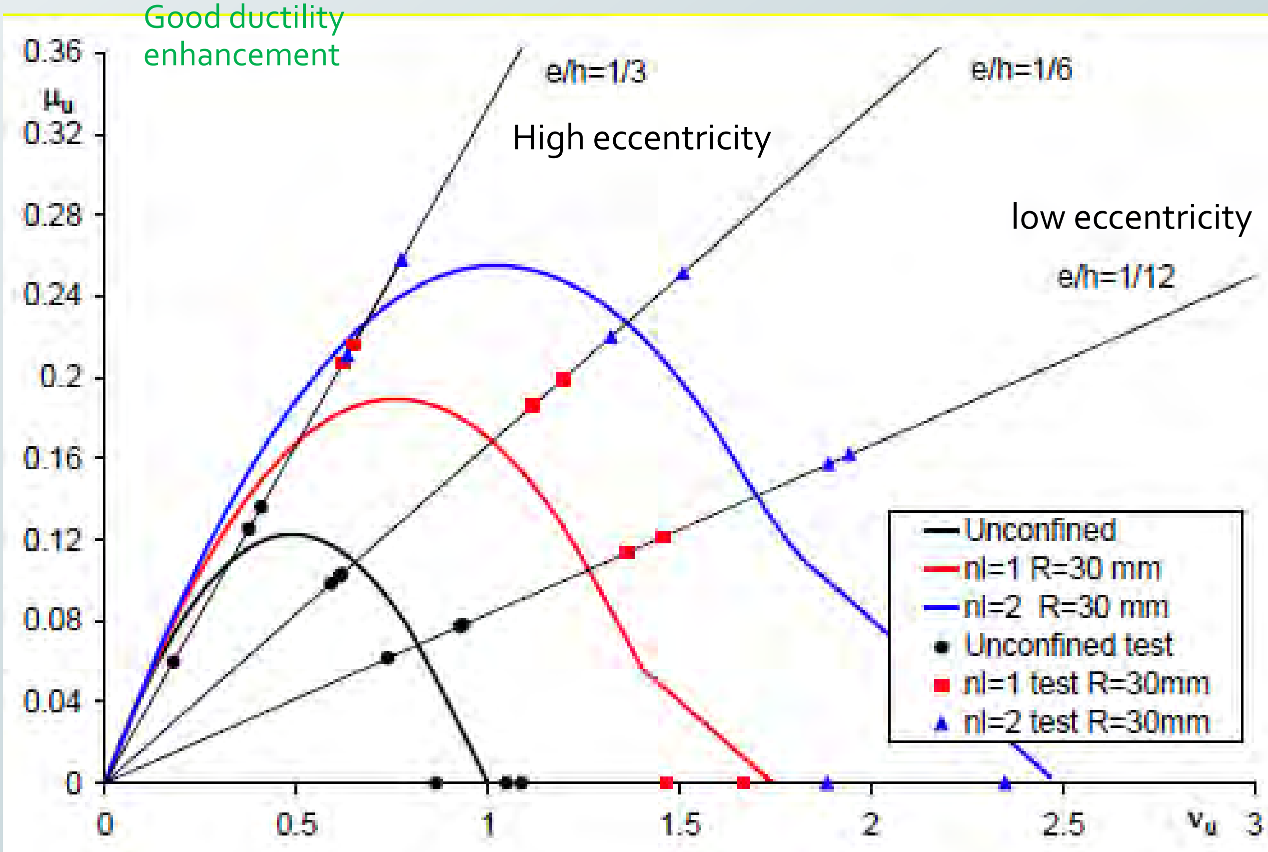


CONFINEMENT WITH FRP

Increasing strength: Dominium M-N

Increasing strength is negligible

Good ductility enhancement



Good Increasing strength

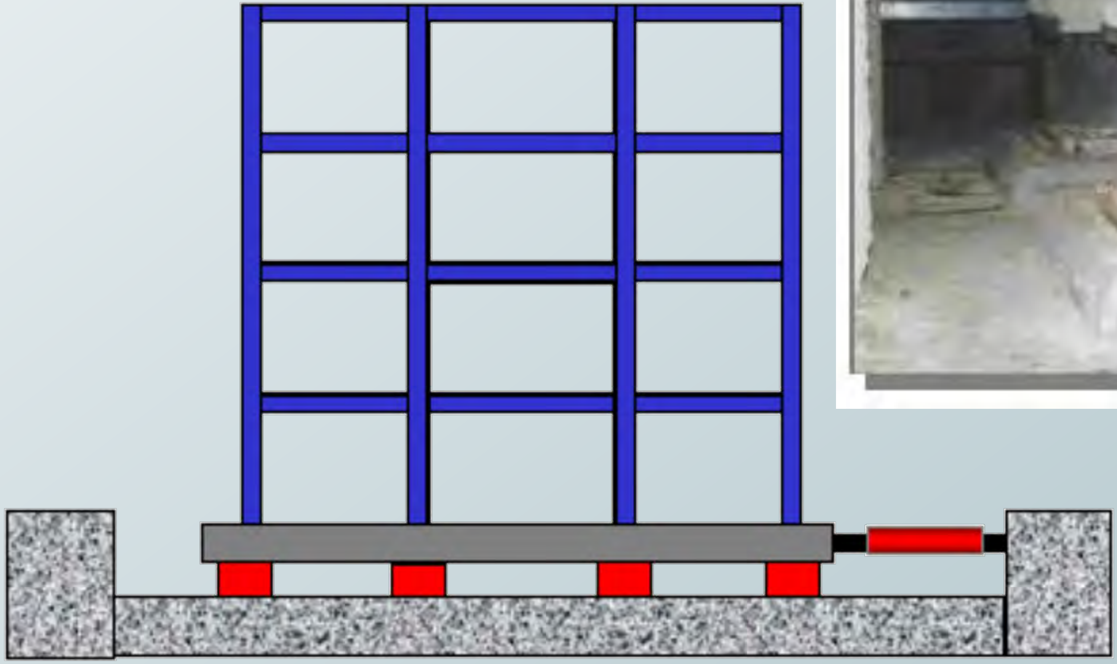
Good ductility enhancement

Axial load

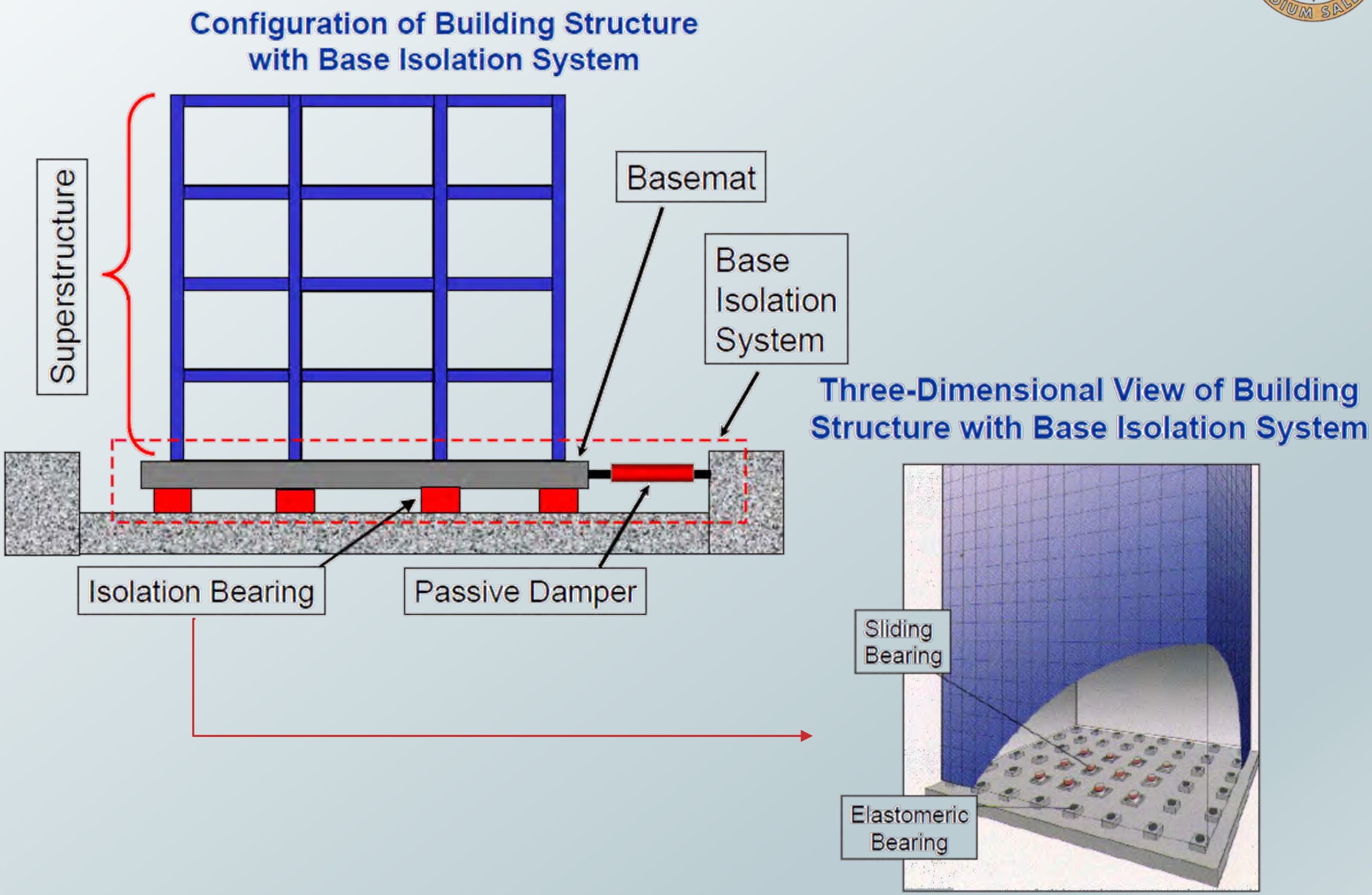
Advanced techniques

SEISMIC ISOLATION

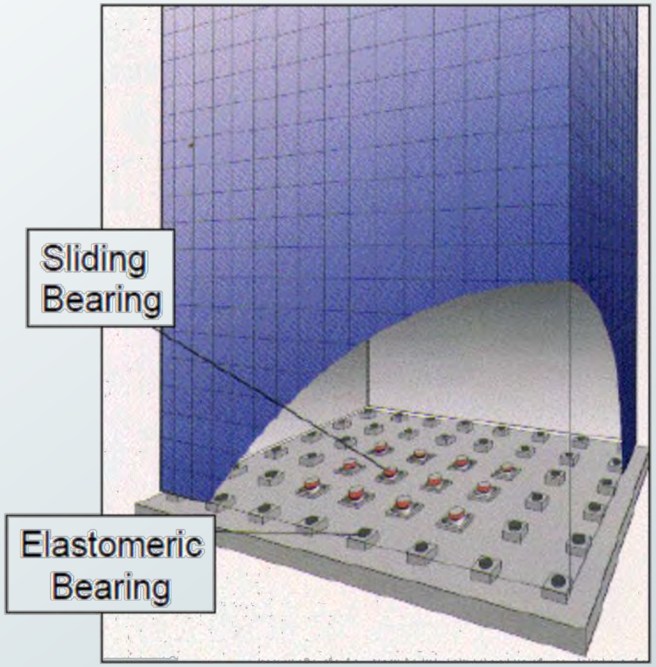
- Why use of seismic isolation systems may be beneficial
- Types of seismic isolation systems available



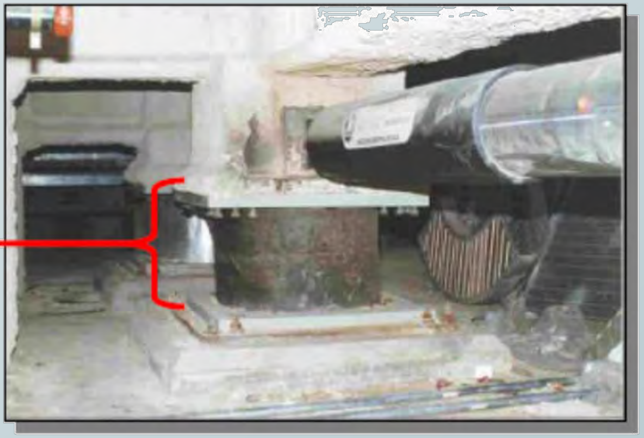
SEISMIC ISOLATION

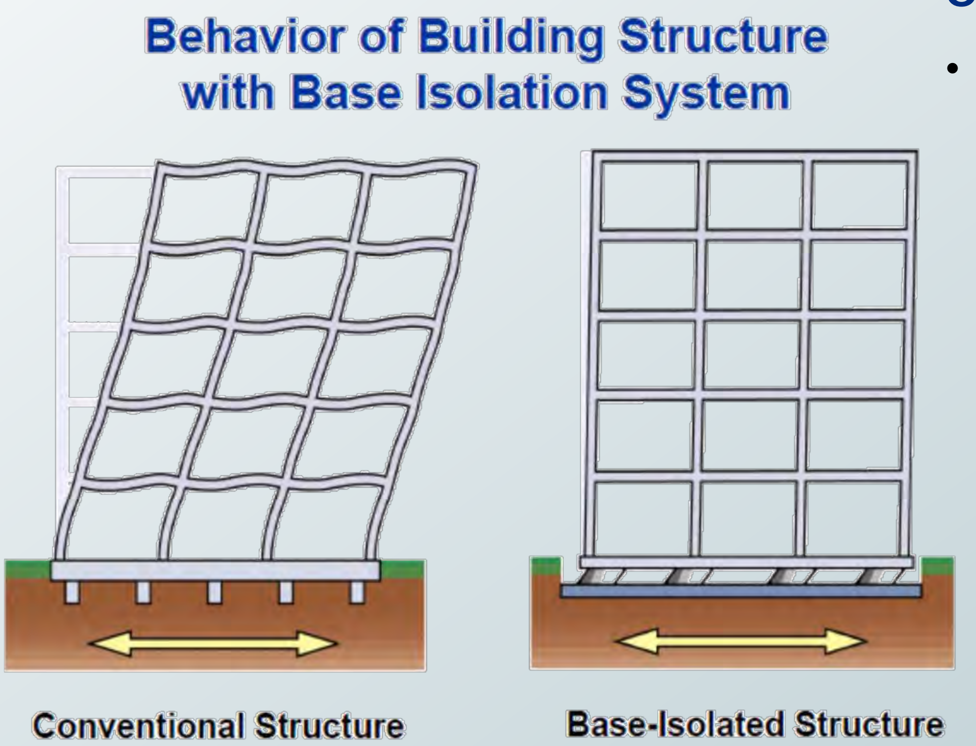


SEISMIC ISOLATION



Installed Seismic Isolation Bearings





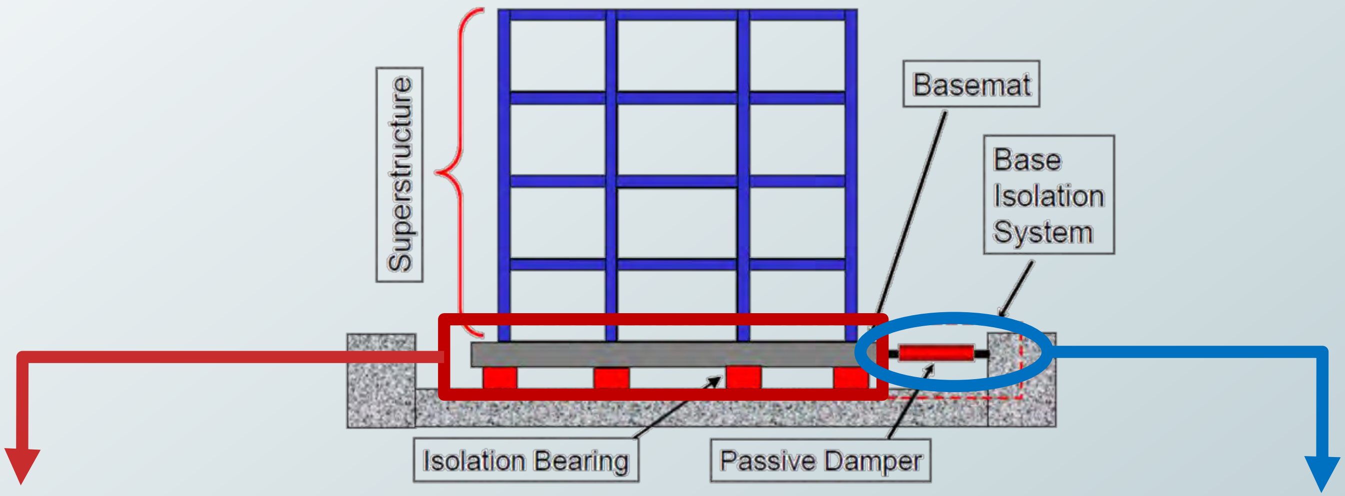
Objectives of Seismic Isolation Systems

- Enhance performance of structures at all hazard levels by:
  - Minimizing interruption of use of facility (*e.g., Immediate Occupancy Performance Level)*
  - Reducing damaging deformations in structural and nonstructural components
  - Reducing acceleration response to minimize contents related damage

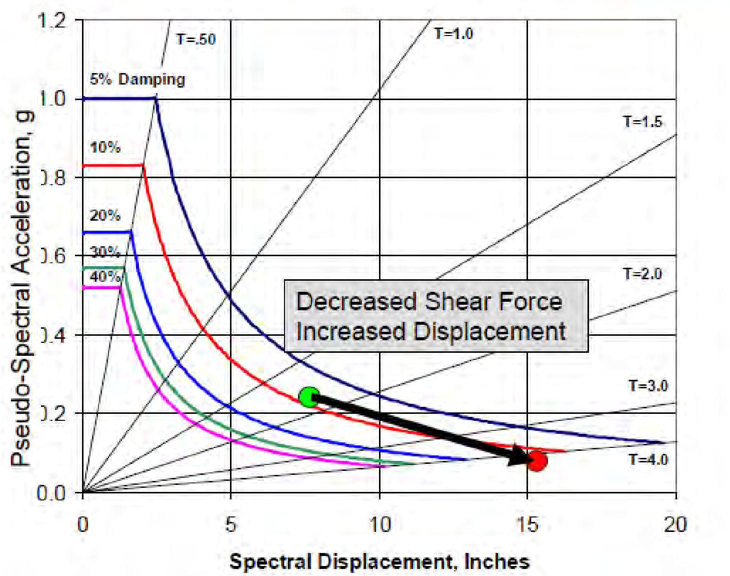
Characteristics of Well-Designed Seismic Isolation Systems

- Flexibility to increase period of vibration and thus reduce force response
- Energy dissipation to control the isolation system displacement
- Rigidity under low load levels such as wind and minor earthquakes

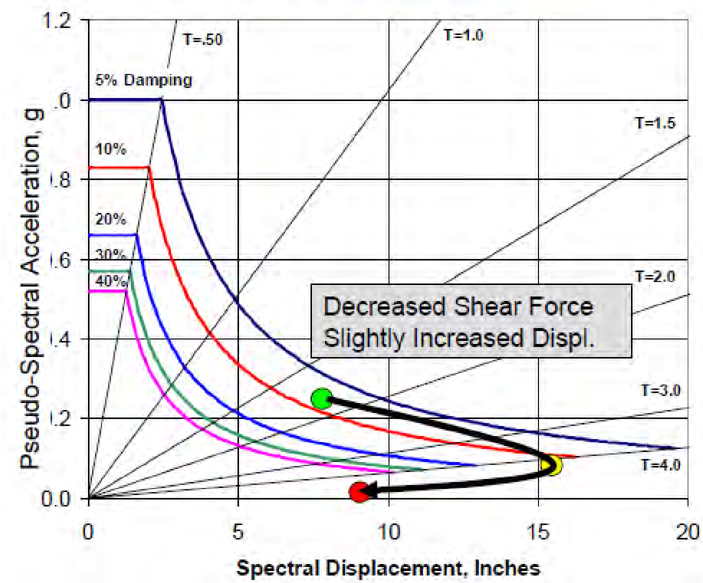
SEISMIC ISOLATION



Effect of Seismic Isolation (ADRS Perspective)



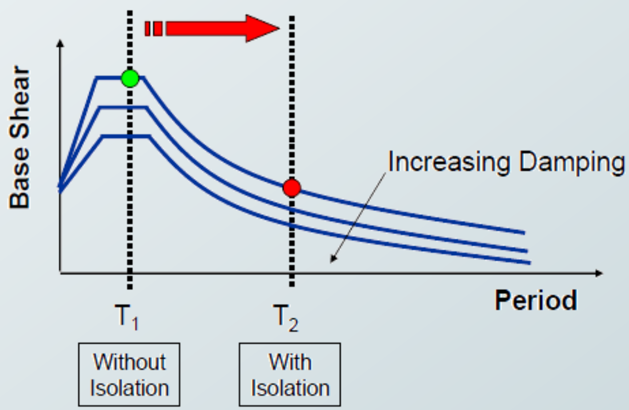
Effect of Seismic Isolation with Supplemental Dampers (ADRS Perspective)



SEISMIC ISOLATION

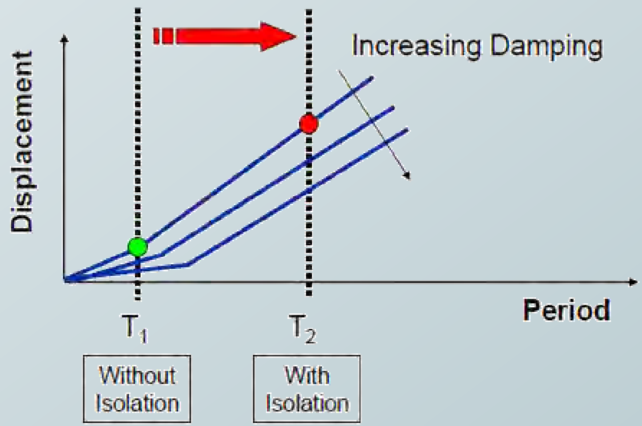
Effect of Seismic Isolation
(Acceleration Response Spectrum Perspective)

Increase Period of Vibration of Structure to Reduce Base Shear



(Displacement Response Spectrum Perspective)

Increase of period increases displacement demand (now concentrated at base)

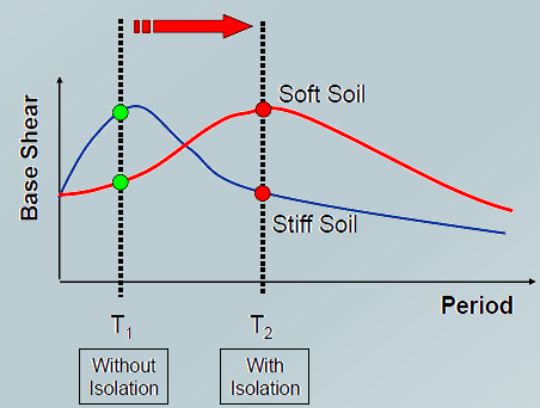


Applicability of Base Isolation Systems

MOST EFFECTIVE
- Structure on Stiff Soil
- Structure with Low Fundamental Period (Low-Rise Building)

LEAST EFFECTIVE
- Structure on Soft Soil
- Structure with High Fundamental Period (High-Rise Building)

Effect of Soil Conditions on Isolated Structure Response



Application of Seismic Isolation to Retrofit Projects

Motivating Factors:

- Historical Building Preservation (minimize modification/destruction of building)
- Maintain Functionality (building remains operational after earthquake)
- Investment Protection (long-term economic loss reduced)
- Content Protection (Value of contents may be greater than structure)

Disavantages

- Expensive intervention
- Interaction with non-structural elements and systems
- Structures on soft soils or with low gravitational loads
- Displacement after earthquakes (re-centering)

SEISMIC ISOLATION

Types of Seismic Isolation Bearings

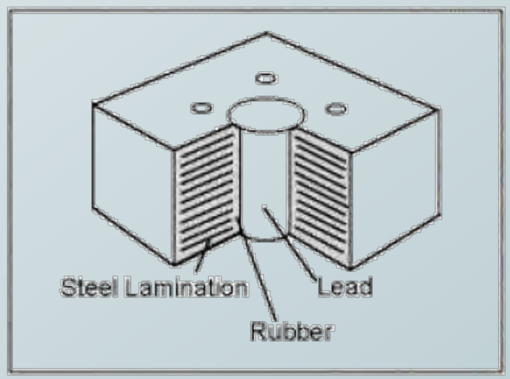
Elastomeric Bearings

- Low-Damping Natural or Synthetic Rubber Bearing
- High-Damping Natural Rubber Bearing
- Lead-Rubber Bearing (Low damping natural rubber with lead core)

Sliding Bearings

- Flat Sliding Bearing
- Spherical Sliding Bearing

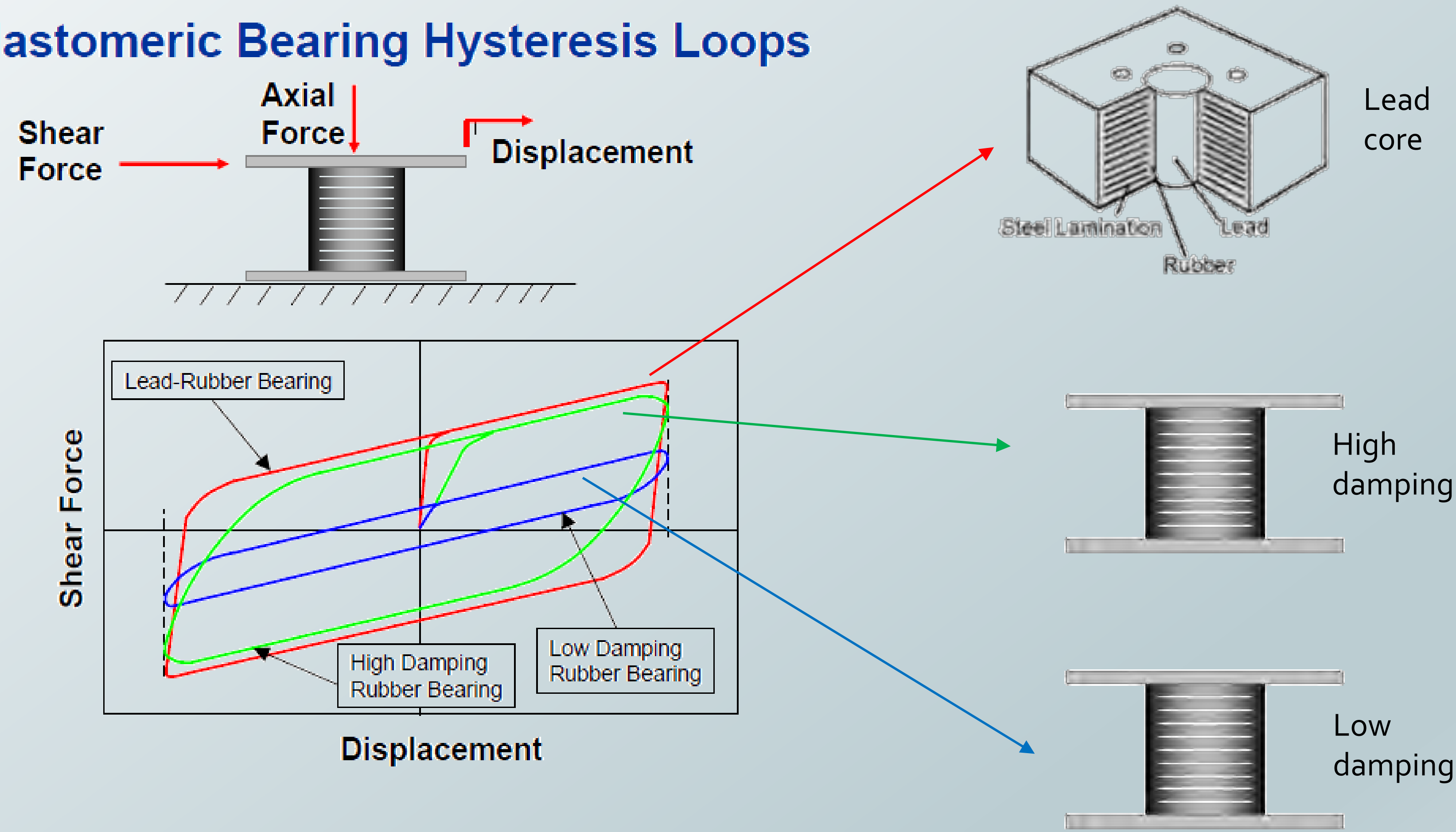
Geometry of Elastomeric Bearings



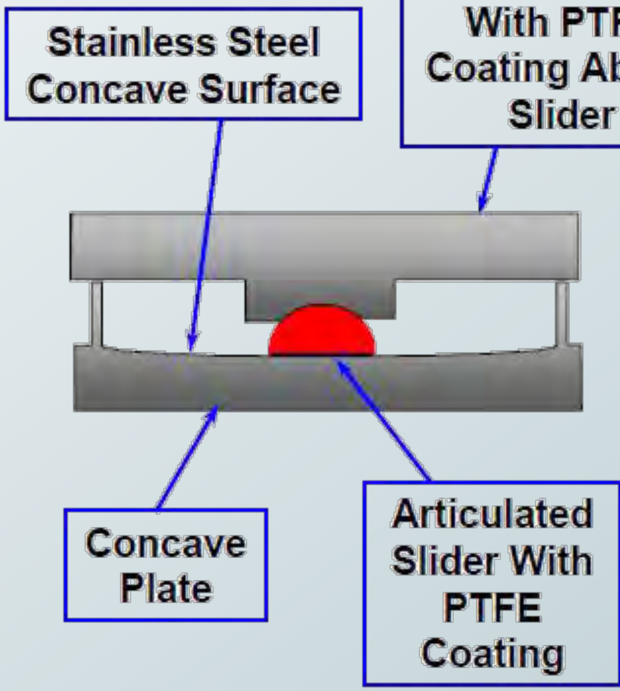
Major Components:

- Rubber Layers: Provide lateral flexibility
- Steel Shims: Provide vertical stiffness to support building weight while limiting lateral bulging of rubber
- Lead plug: Provides source of energy dissipation

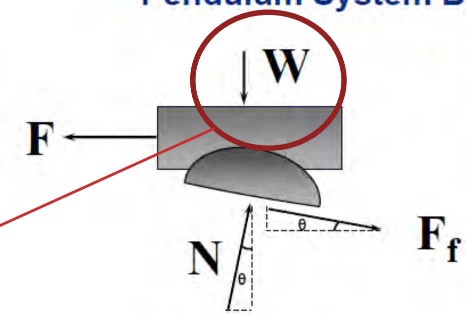
Elastomeric Bearing Hysteresis Loops



Spherical Sliding Bearing:
Friction Pendulum System (FPS)



Mathematical Model of Friction Pendulum System Bearings



Free-Body Diagram of Top Plate and Slider Under Imposed Lateral Force F

$$F = W \tan\theta + \frac{F_f}{\cos\theta}$$

The response of the dispositive depends on the axial load W, which changes during earthquakes

Dissipative tower

New system patented in Italy by
www.torridissipative.com

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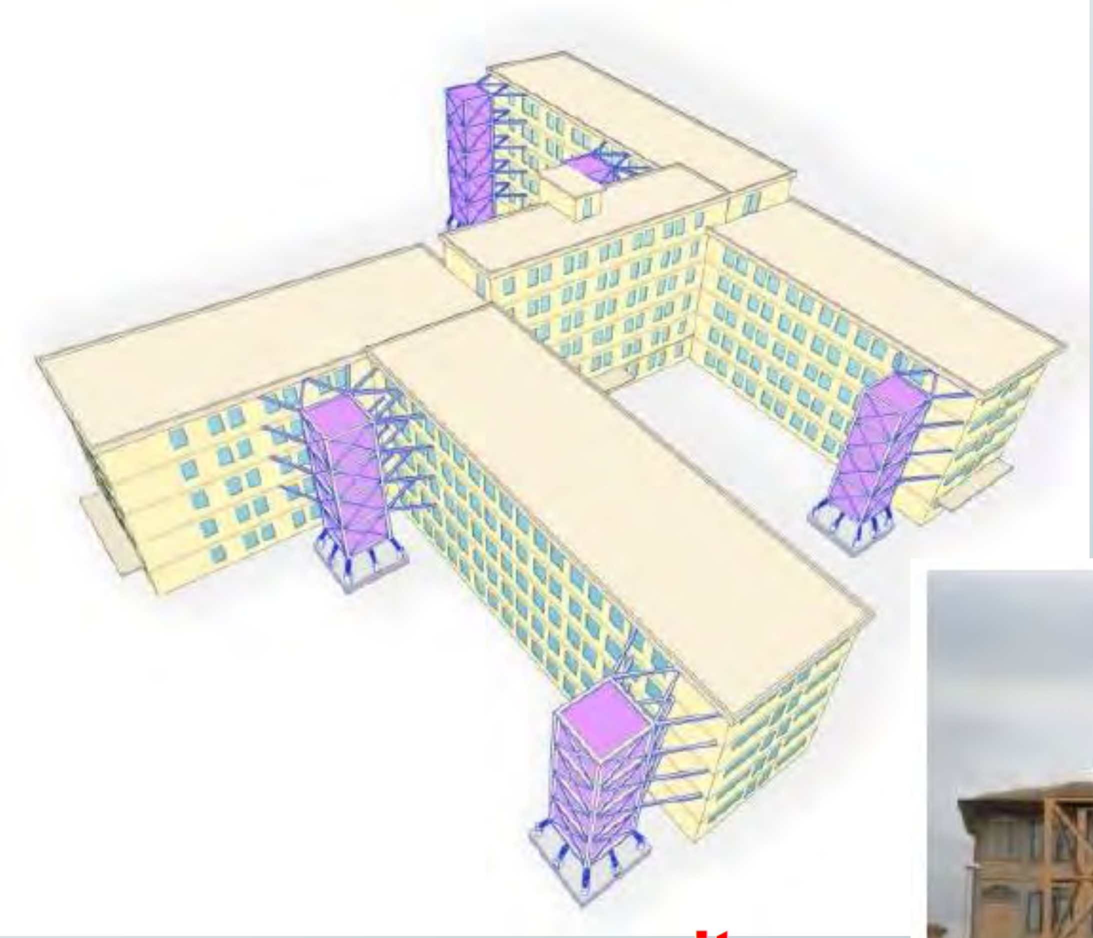
INNOVATIVE TECHNIQUES



Design of external tower for the seismic protection, equipped with damping systems for the energy dissipation.

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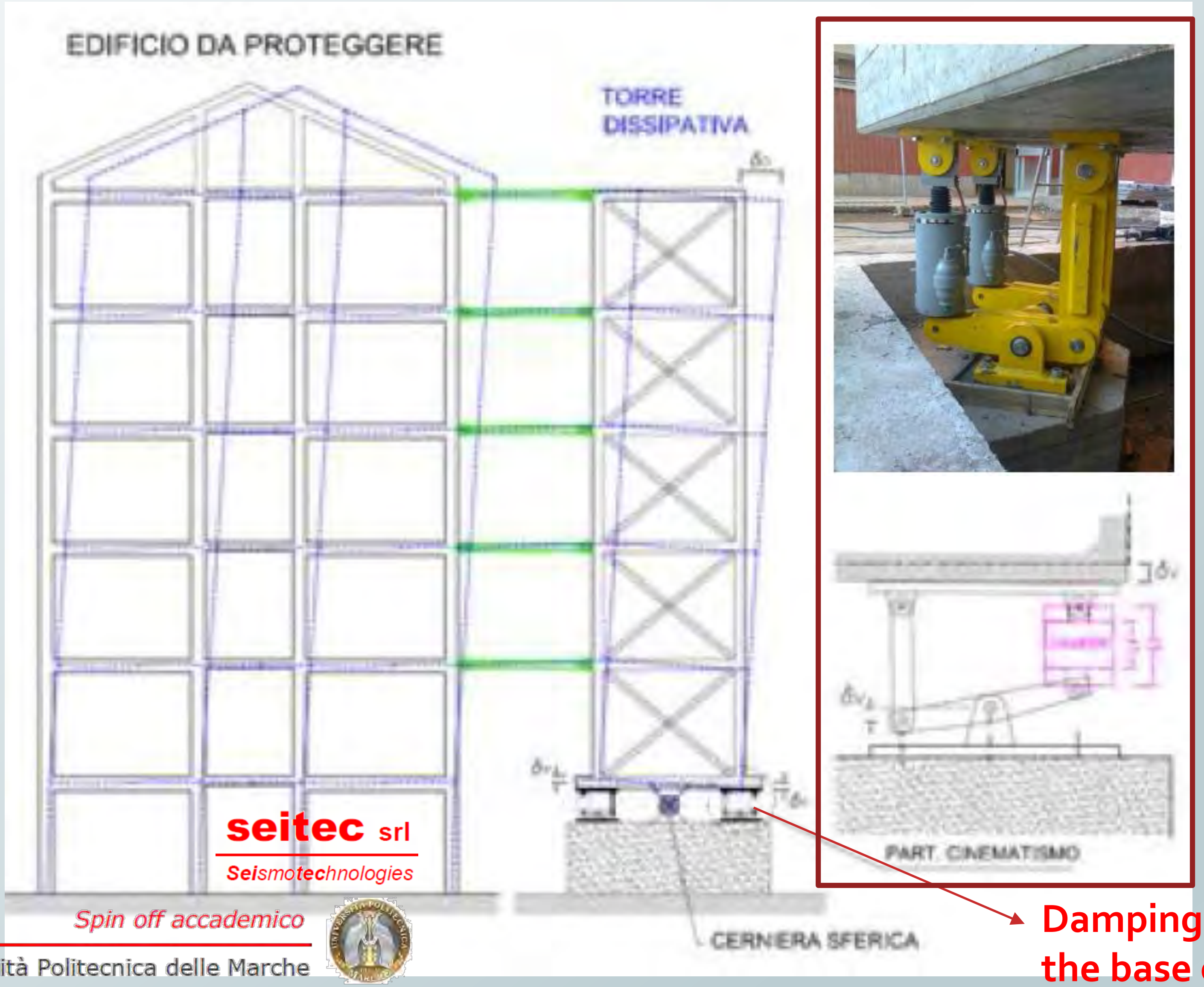
INNOVATIVE TECHNIQUES



Damping system at the base of the tower

INNOVATIVE TECHNIQUES

Advantages

- Economic solution (reduction of the interventions within the existing structure)
- The tower can be used as a new buildings (stairs, elevators, etc.)
- The damping system is easily accessible for maintenance
- Completely reversible intervention.

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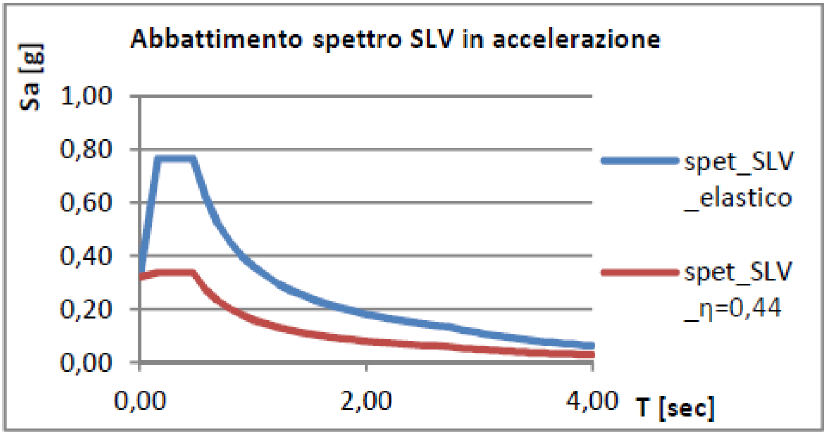
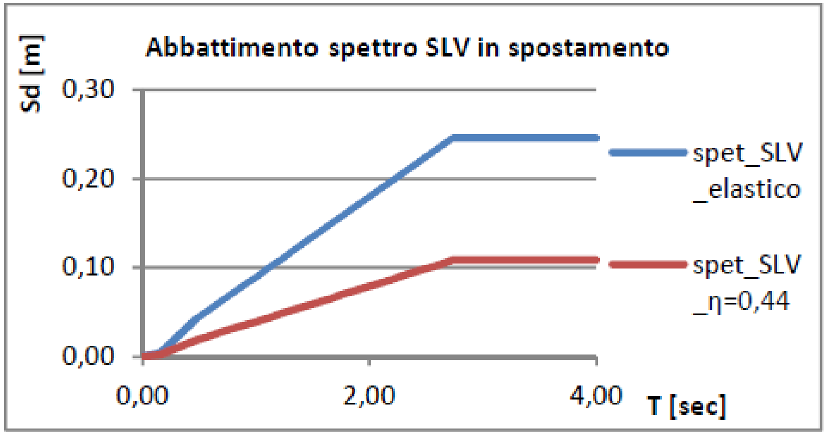
Effects: increasing damping ➔ decreasing accelerations and displacement of the existing structure





Acknowledgments and references

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2. ReLuis: Emargenza terremoto Abruzzo/Report: http://www.reluis.it/index.php?option=com_content&view=article&id=73&lang=it&Itemid=108

3. Michael D. Symans, PhD, Rensselaer Polytechnic Institute – FEMA

Instructional Material Complementing FEMA 451, *Design Examples*

4. Seitec s.r.l. – Spin off Università Politecnica delle Marche (Italy): **"Un sistema innovativo per la protezione sismica di scuole e ospedali: "le torri dissipative" –** www.torridissipative.com

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