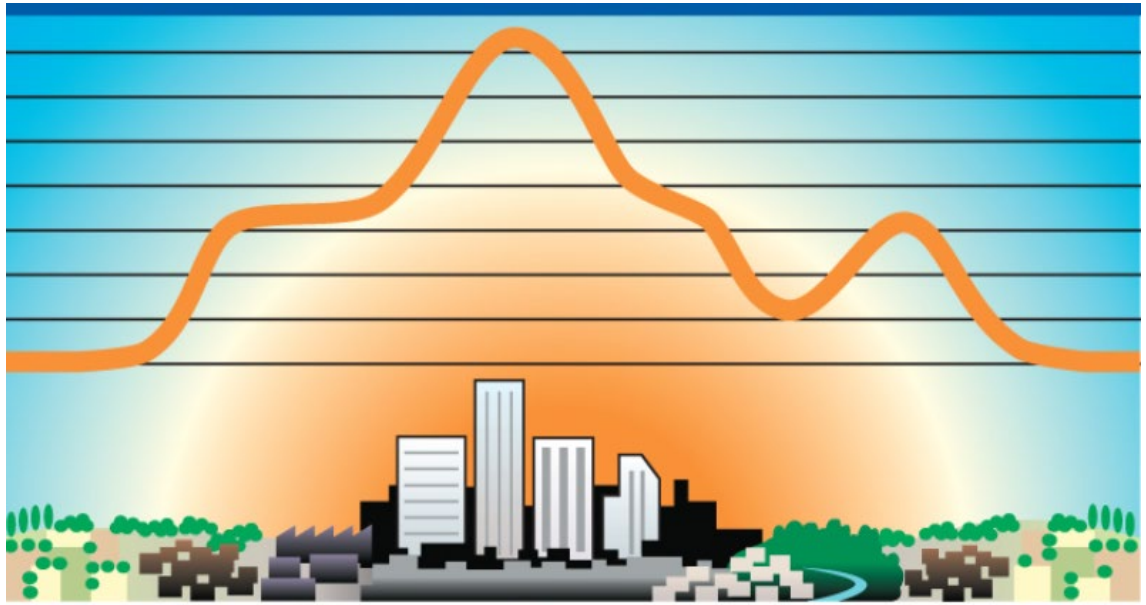
Design and analysis of integrated seismic and energy retrofit technologies for existing buildings exhibiting nonlinear behavior

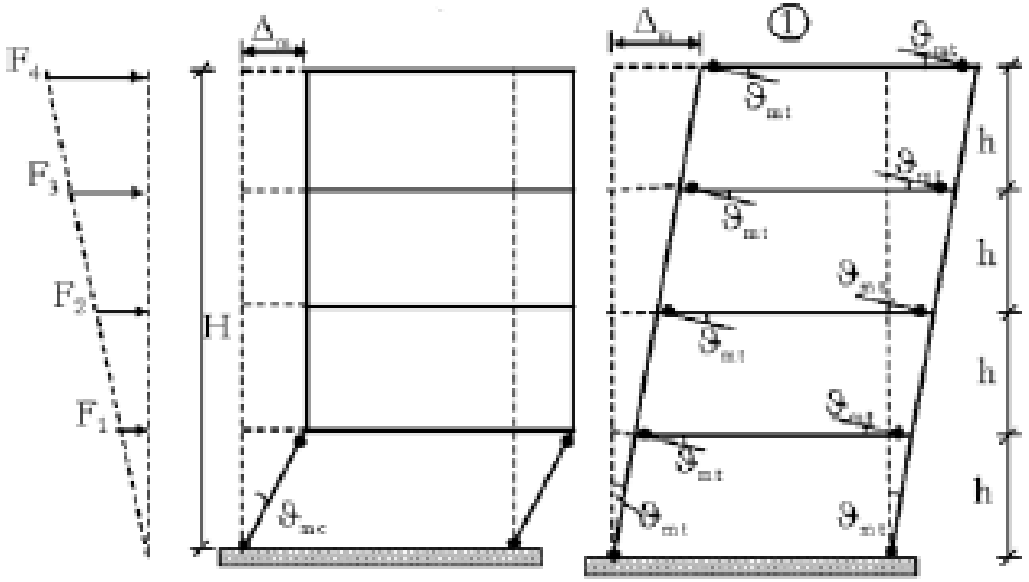
Index

Background

Issues



Heat island due to high intensity buildings



- Plastic hinges

Nonlinear behavior and dangerous damage mechanisms

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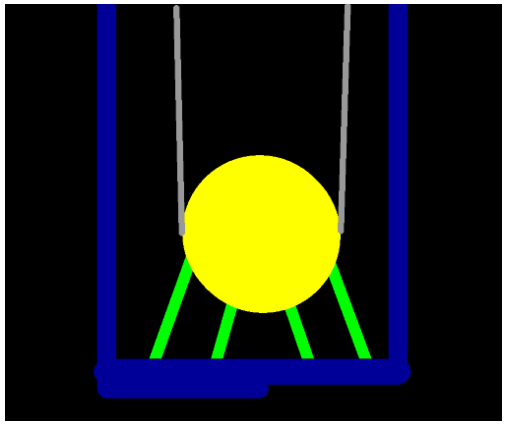
Motivation

- How to mitigate these issues in parallel?
- To relax the structural linear behavior assumption to include a more realistic nonlinear response that accounts for damage.

Goals

- To assess how the structural response is modified under nonlinear behavior assumption and evaluate the effectiveness of the integrated techniques in mitigating inelastic effects
- To assess the suitability of the control design process based on linear elasticity assumptions when accounting for nonlinear structural behavior

Tuned mass damper (TMD)



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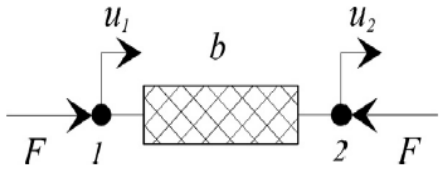
TMD or TMDI?

- Important conventional TMD issue → detuning → solved with non-conventional TMD/large mass TMD/ TMDI
- Large mass TMD/ non-conventional TMD → Issue with columns resistance → solved it using a small mass ratio with TMDI

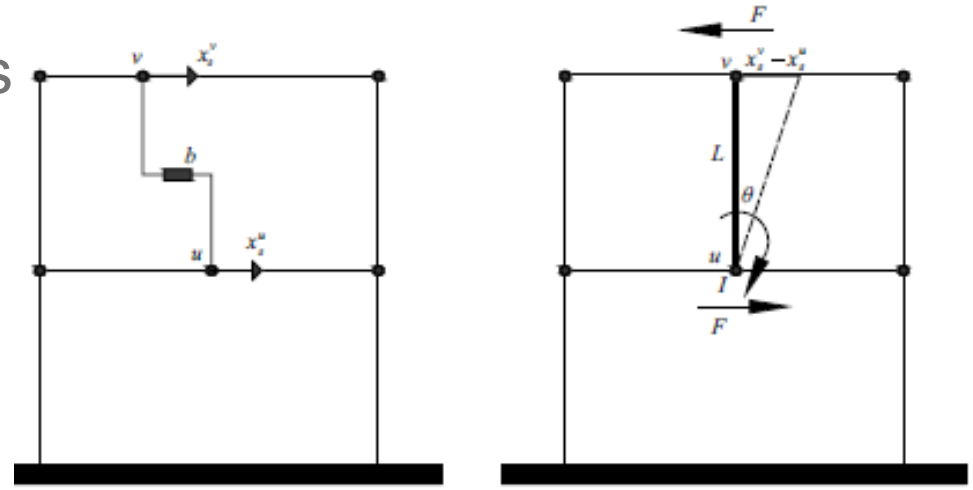
Inerter device

- Devices two terminals relative acceleration produces an inertial force which contrasts the structure motion



$$F = b(\ddot{u}_1 - \ddot{u}_2)$$

- b inertial mass → inertance



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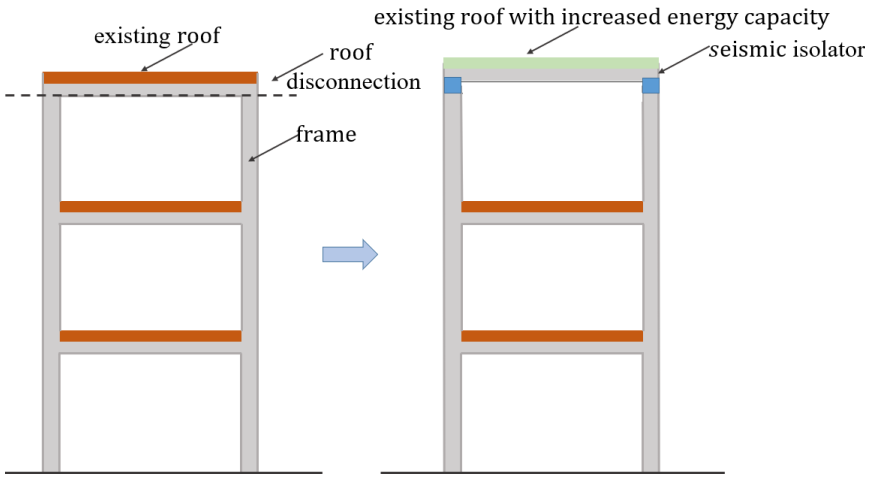
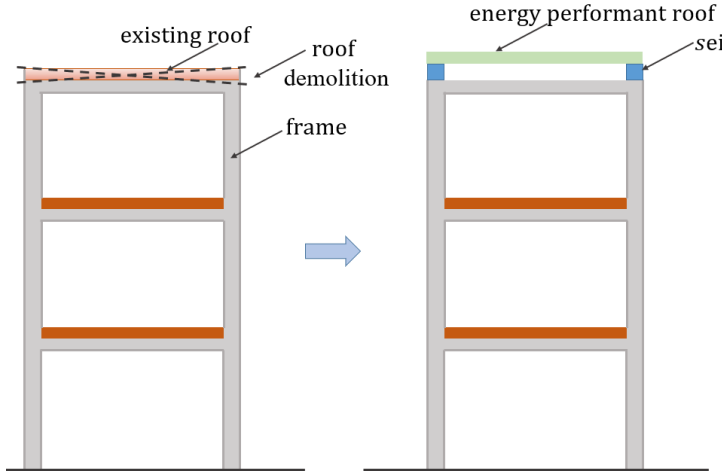
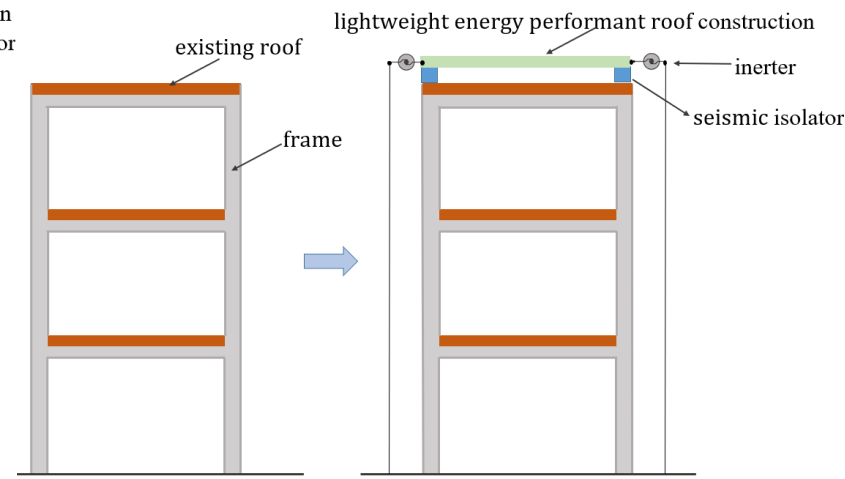
Seismic interventions (#S)







#S1

Roof disconnection and isolation from the substructure with seismic isolators and renovation of the existing roof with increased energy capacity, realizing a non-conventional TMD

#S2

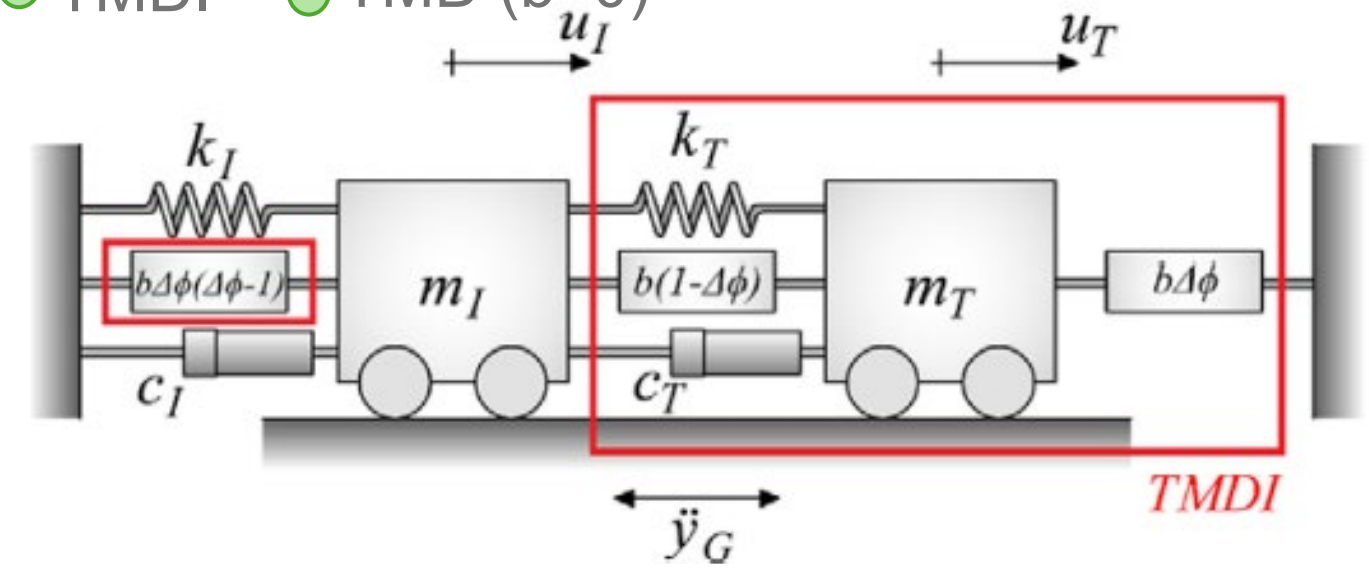
Demolition of the existing roof and reconstruction of a new energy performant roof isolated from the substructure with seismic isolators, realizing a large mass TMD

#S3

Construction of a new lightweight energy performant roof above the existing building isolated from the substructure with seismic isolators and inerter, realizing a small mass TMD + inerter, i.e. TMDI system

Mechanical models → M-DOF + control system → 2-DOF model

- TMDI
- TMD (b=0)



Assumed variables:

- $\mu = \frac{m_T}{m_I}$
- $\Delta\phi = 1 - \phi_k$ j top floor, k ground floor → $\phi_k=0$
- $\beta = \frac{b}{m_I}$ based on previous studies

Design parameters:

- $\nu = \frac{\omega_T}{\omega_I}$
- $\xi_T = \frac{c_T}{2(m_T+b)\omega_T}$

Design → objective function to maximize an energy dissipation index EDI

→ dissipated energy scalar measure respect to the total energy input by a dynamic action

- $K_{optimal}$
- $C_{optimal}$

→ Ad hoc for each control system

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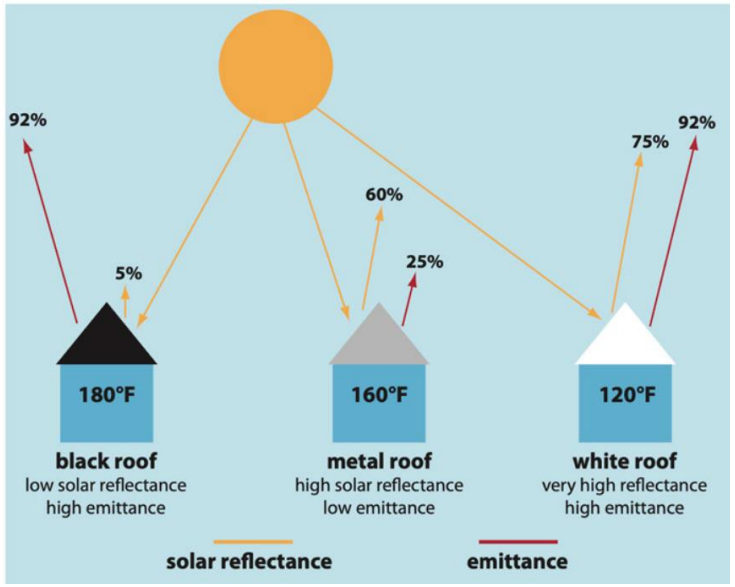
Methodoloy

Modify the radiative thermal properties of the outdoor surface of the roof thanks to the cool material painting



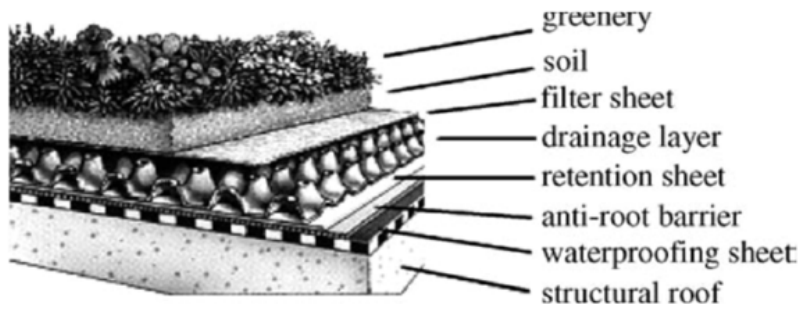
Cool roof:
use of a cool material painting

To install photovoltaic panels on the surface

Based on the available surface the choice of the number of panel moduli and the corresponding resultant peak power is evaluated

Photovoltaic roof:
installation of a photovoltaic system

Installation of an "extensive" green roof with thickness 30 cm



Green roof:
installation/building of a green roof system

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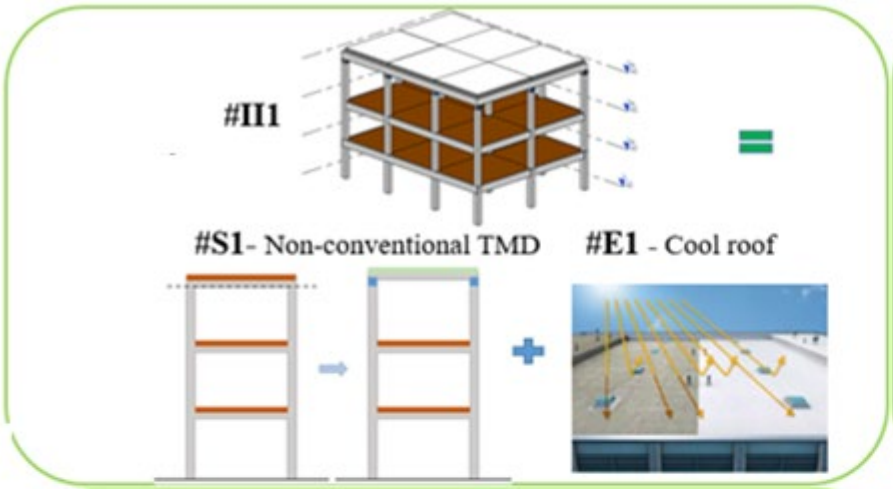
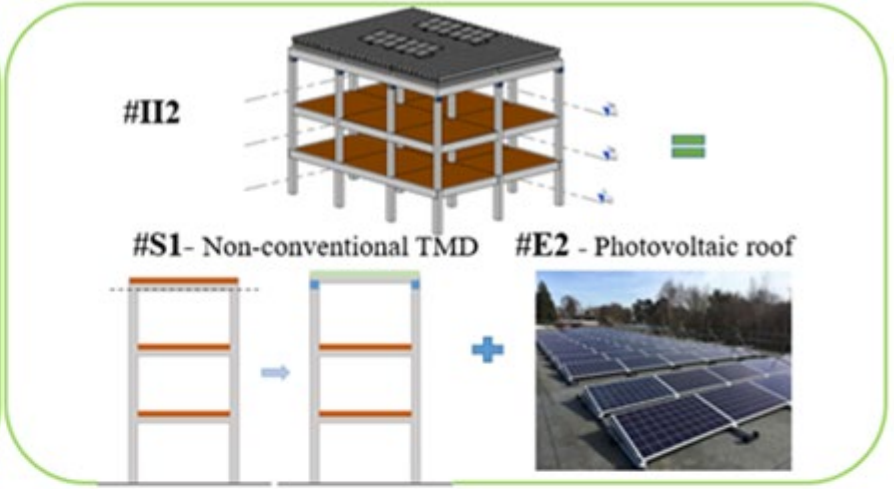
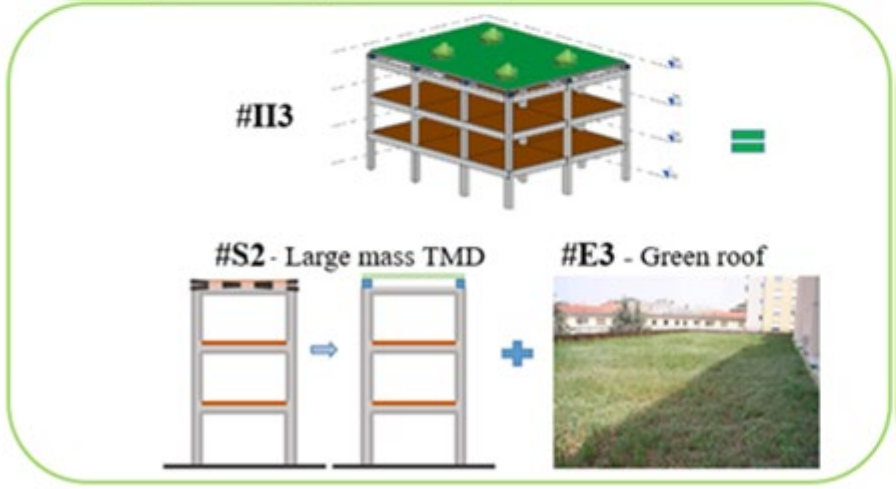
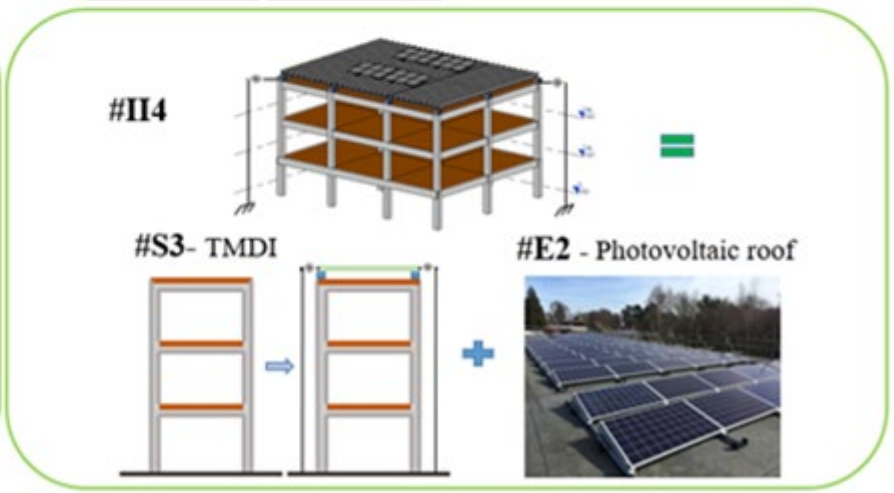
Integrated interventions









Intervention	μ [%]	ν [%]	ξ_T [%]
#II1	0.57	0.61	0.30
#II2	0.59	0.59	0.30
#II3	0.50	0.64	0.28
#II4	0.03	0.83	0.34

Intervention	m_T [kNs^2/m]	k_T [kN/m]	c_T [ton rad/sec]
#II1	92.00	7563.76	496.01
#II2	95.25	7625.60	512.38
#II3	80.00	7278.60	433.89
#II4	7.00	9218.45	650.78

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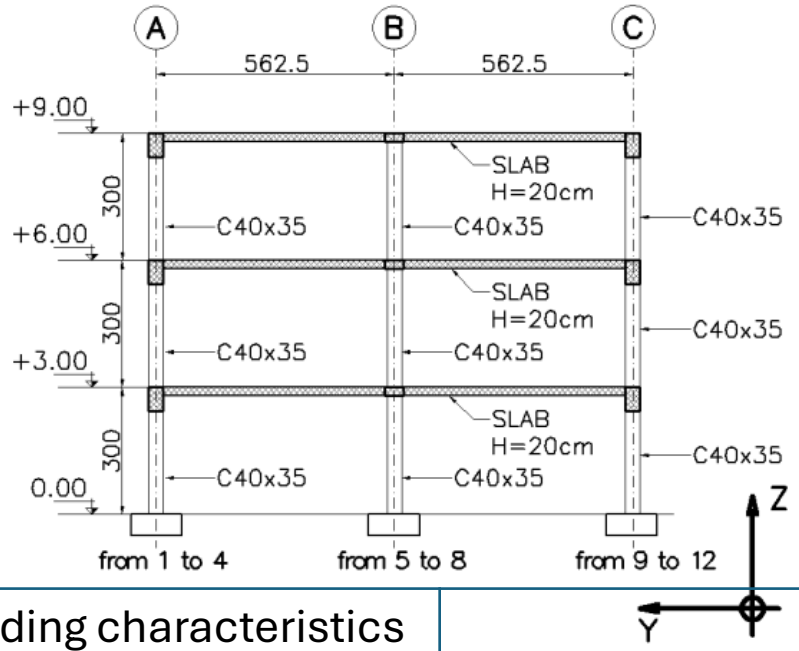
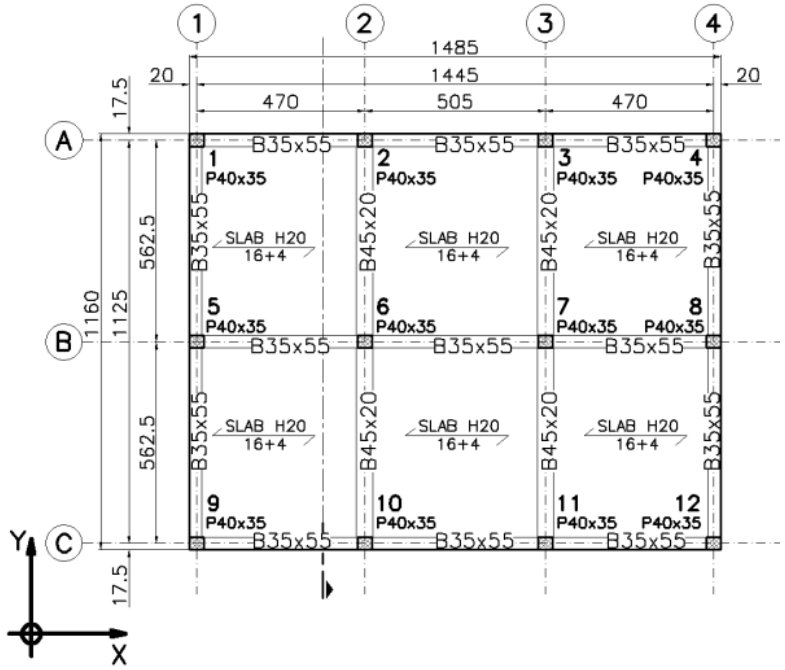
Case study

Section (plane yz)



Plan (plane xy)



Building characteristics	
Site	Catania, Italy
Number floors	3
Construction's period	1960-1970
Structure's material	Reinforced concrete
Soil characteristics	B, T1

Structural elements	Section dimensions
Columns	40x35 cm
Projecting beams	35x55 cm
Slab-depth beams	40x20 cm
Slabs	4 cm + 20 cm

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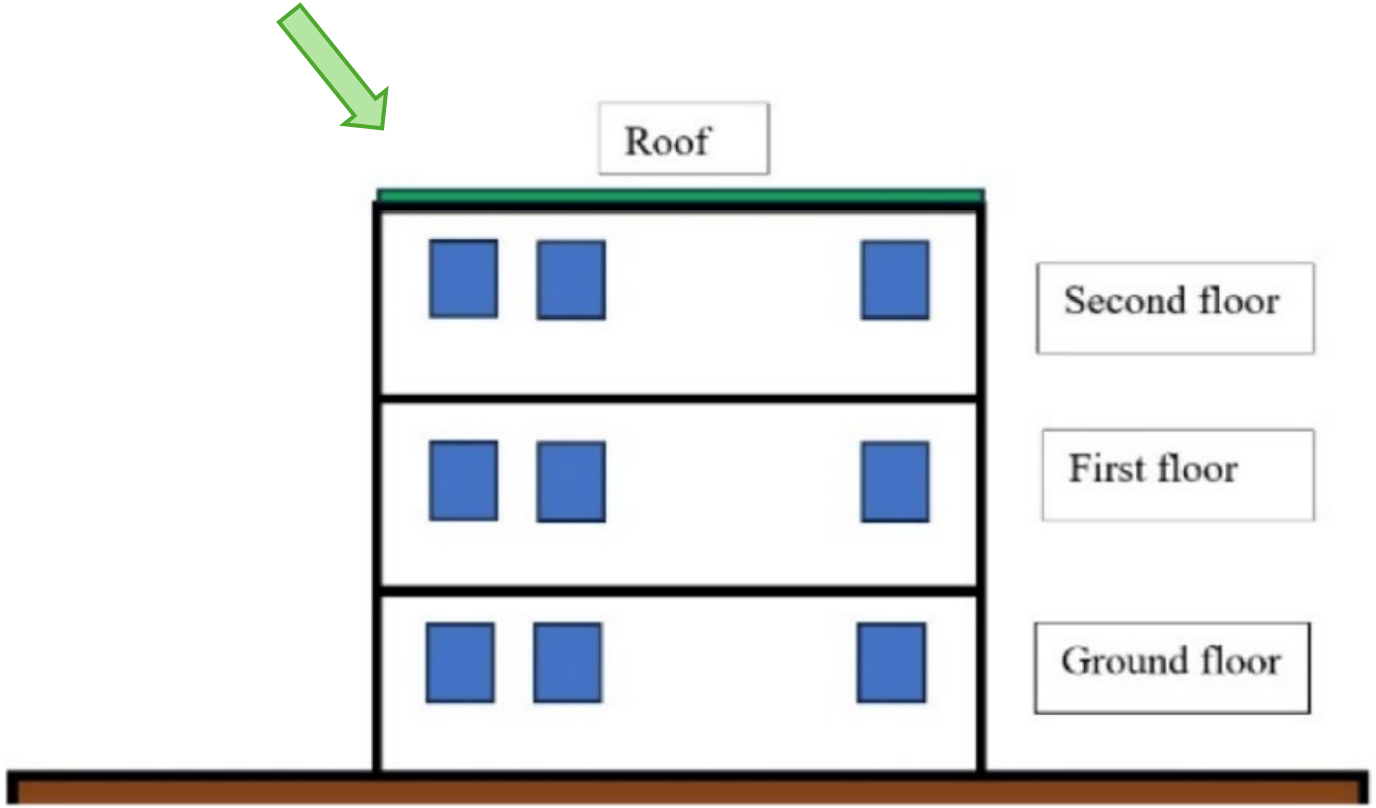
Energy modeling

- **Three thermal zones → ground, first and second floor**
- **Considering:**
  - Opaque surfaces
  - Glazing systems
  - Heating and cooling system
  - Infiltrations
- **Timestep: 1 h**



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Characteristics of the site considered

Data	Site
Name	Catania,Italy
Altitude	7 m
Latitude	37°30' N
Longitude	15°4' E
PGA [g]	0.29
Soil type[1]	B
Classification climate[2]	Csa

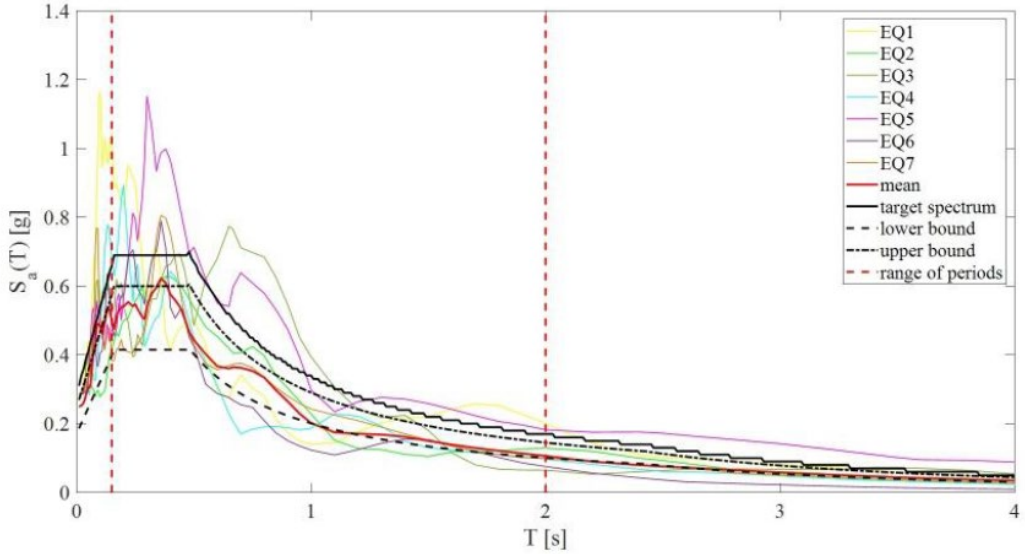
NTC18

Köppen Map:

Csa → Hot-summer Mediterranean climate

Characteristics:

- Mild, wet winters
- Hot, dry summers



- life safety limit state characterized by a 10 % probability of exceedance in 50 years, return period 475-years
- magnitude Mw ranging from 0 to 6,5, epicentral distance R ≤ 100 km
- lower bound = 10 % and upper bound = 30 %
- reference periods = T_1, T_2 and T_3

Mode	T [sec]
1	0.55
2	0.17
3	0.09

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Optimal choice of the integrated intervention

Structural indicator

$$J_S(h) = \frac{\frac{1}{ng}\sum_{n=1}^{ng}\|\boldsymbol{d}^n(h)\|}{\frac{1}{ng}\sum_{n=1}^{ng}\|\boldsymbol{d}^n_{AS-IS}\|}$$

Based on interstory drifts of the primary structure (structural components seismic vulnerability)

Energy indicator

$$J_E(h) = \frac{PEC}{PEC_{AS-IS}}$$

$$PEC = PEC_{gas} + PEC_{el} - PEP = \frac{H_{nd}}{\eta_G} + \frac{C_{nd}}{COP} \cdot PE_{el,f} - REN_{PV} \cdot PE_{el,f}$$

i.e. primary energy consumption PEC

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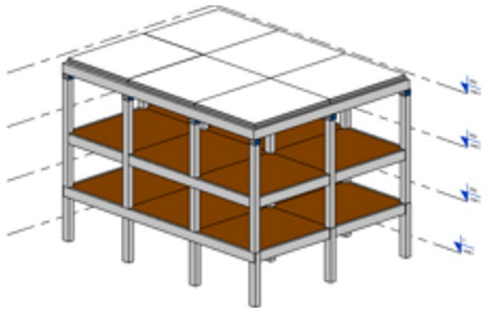
Results

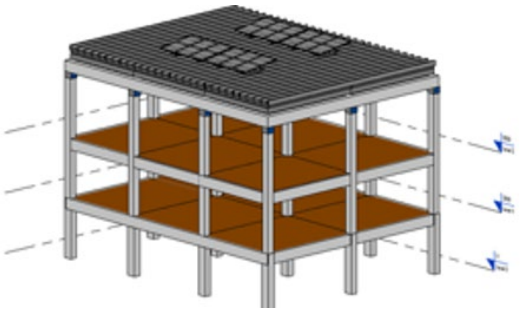
Sum of interventions

Non-conventional TMD + cool roof

#II1



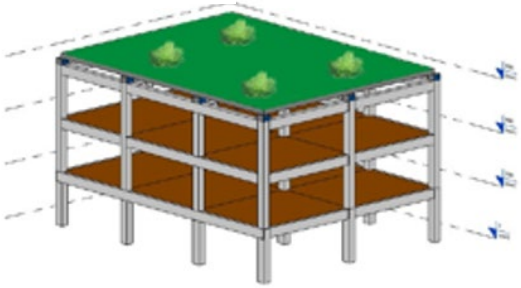
#II2



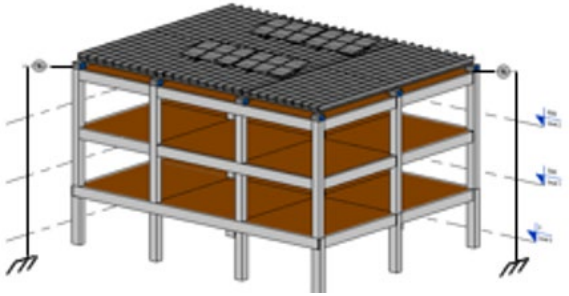
Non-conventional TMD + photovoltaic roof

Large mass TMD + green roof

#II3



#II4



TMDI + photovoltaic roof

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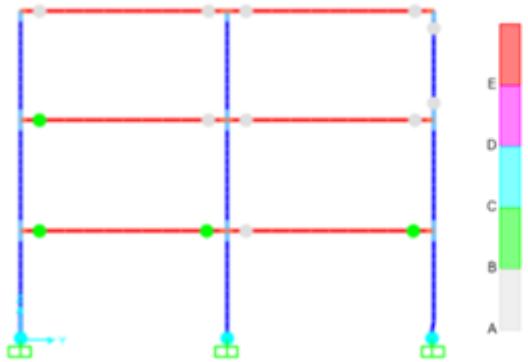
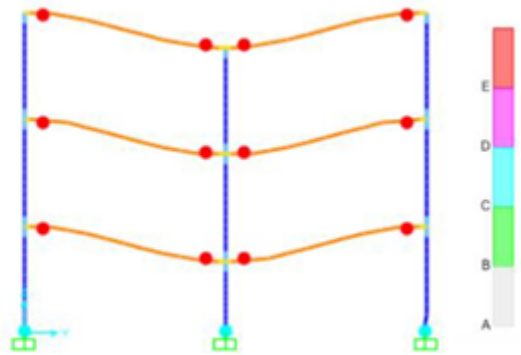
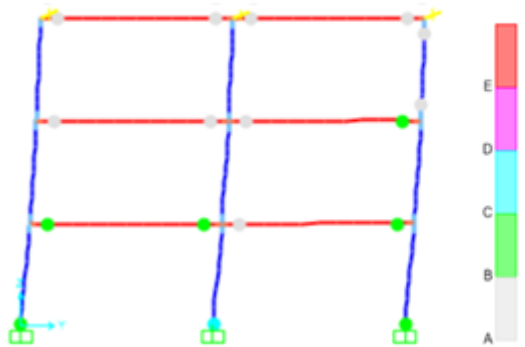
Response under dynamic time history analysis – Earthquake n°3 input

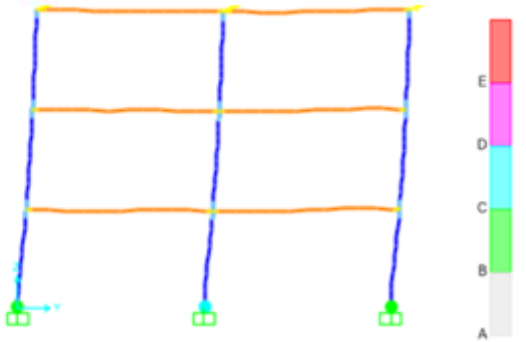
Lateral alignments **AS-IS** Internal alignments



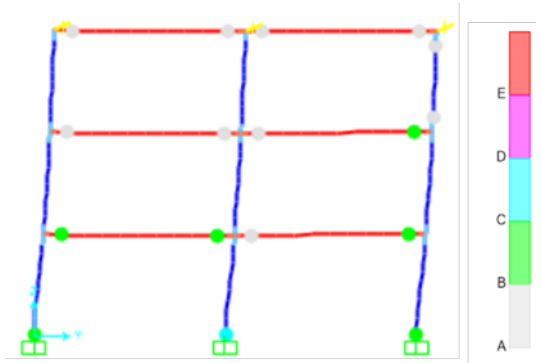


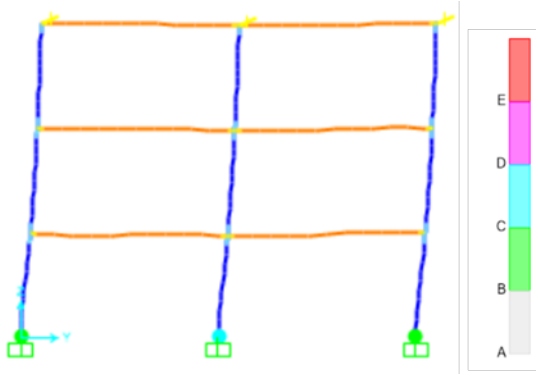
Lateral alignments **#II1- #II2** Internal alignments



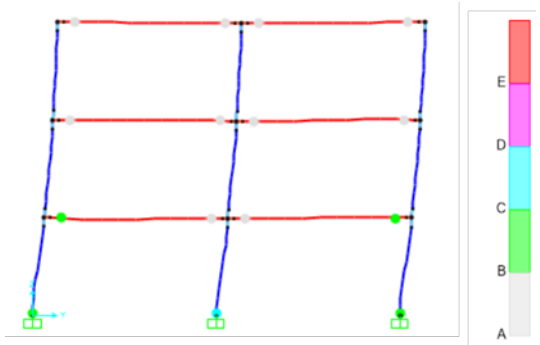


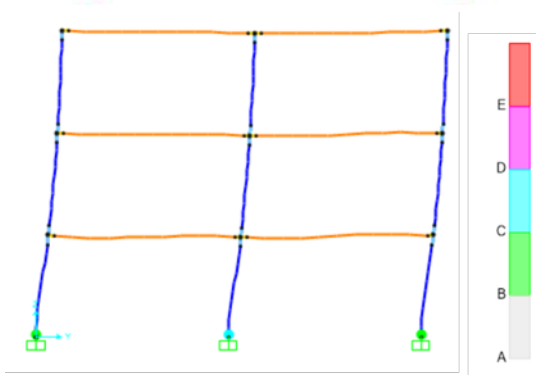
Lateral alignments **#II3** Internal alignments





Lateral alignments **#II4** Internal alignments





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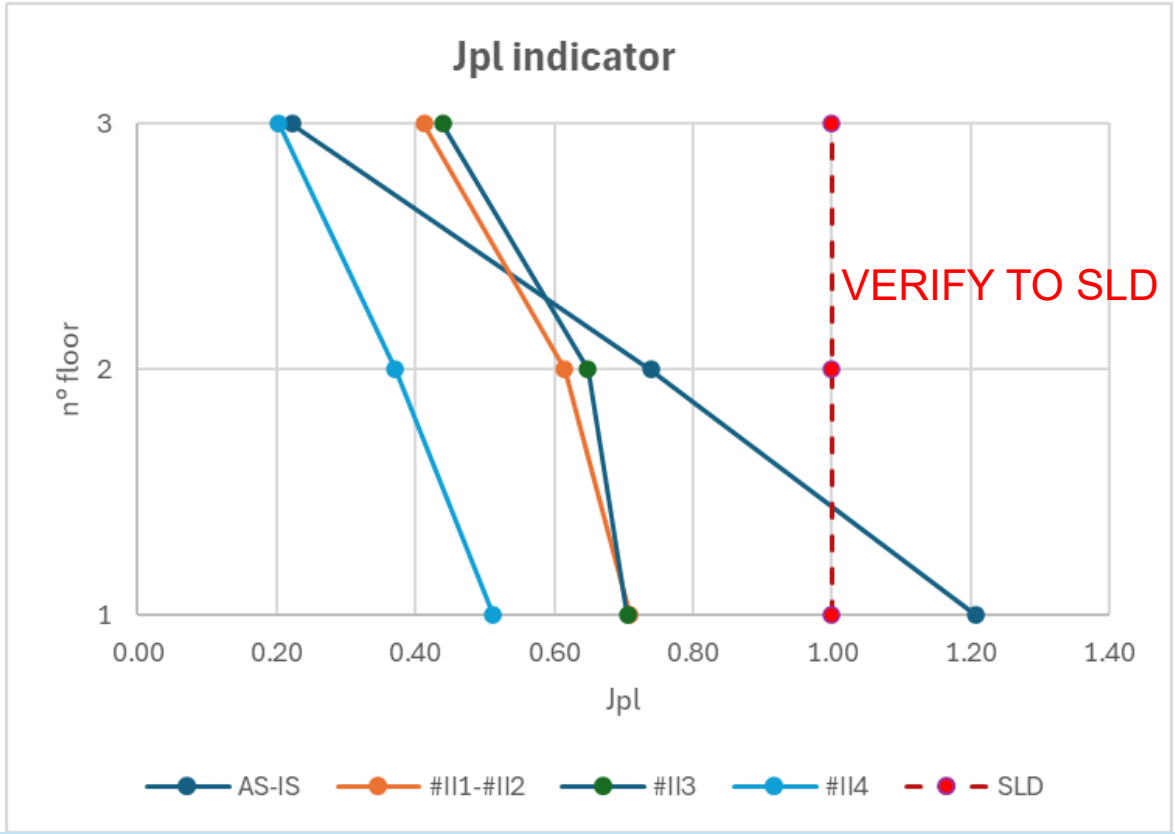
Indicator for nonlinear behavior

$$J_{pl1,2,3} = \left(\frac{\max(drift_1)}{drift_{1,SLD}}; \frac{\max(drift_2)}{drift_{2,SLD}}; \frac{\max(drift_3)}{drift_{3,SLD}}\right)$$

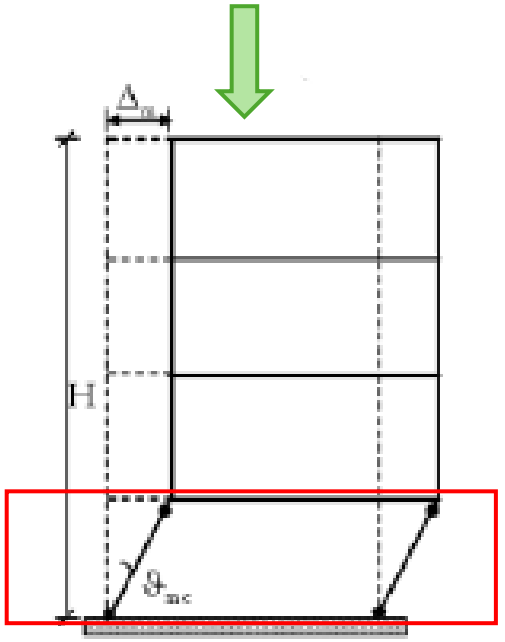


AS-IS → Soft-story mechanism

#II1-#II2

#II3

#II4



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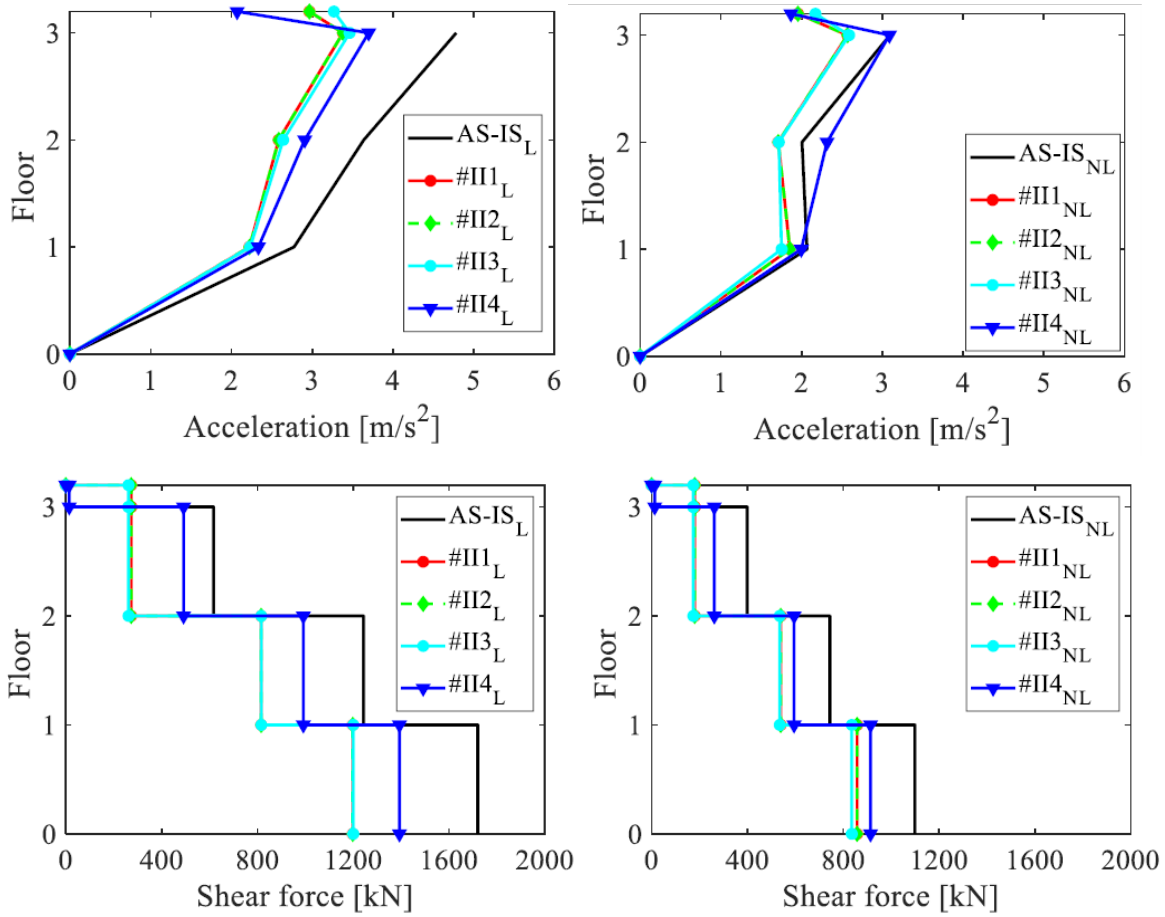
Comparison between linear and nonlinear behavior



L: linear NL: nonlinear

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Optimal integrated intervention

Intervention (h)	J_S	J_E
#II1	0.72	0.94
#II2	0.72	-1.42
#II3	0.74	0.98
#II4	0.46	-1.44

Energy comments

- #II1 (cool roof) and #II3 (green roof) limited impact on the building's overall PE demand
- #II2 and #II4 (photovoltaic roof) not only improve energy efficiency but also transform the building into a net energy producer with renewable energy → positive energy building

Structural comments

- Based on the nonlinear analysis
- All interventions effective in reducing the AS-IS case structural response and suitability even in the nonlinear regime
- #II1, #II2 and #II3 (TMD-based) response almost equivalent with reduction of 30% of index
- #II4 (TMDI-based) overperformed with reduction of 50%

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Conclusions

Studies in progress

- To compare plane analysis in both the directions under sismic input
- To compare the effectiveness of the integrated seismic and energy interventions in sites with different seismic and climatic condition

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Thank you for your kind attention

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