TG 6.6
Seismic Retrofitting and Repair of Precast Concrete Buildings

Progress update

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Key Content/Topic (Part I – Assessment)

1. **Lessons learnt, *damage observations* and *seismic performance* of precast buildings;**

2. **Typical critical or less *critical vulnerabilities* of this class of buildings;**

3. ***Simplified assessment methodologies* (e.g. from quick screening to hand calculation to more detailed computer based analysis)**

Key Content/Topic (Part II – Retrofit)

4. **Overview of *Retrofit strategies* (e.g. drift control or local ductility, combination of global vs. local intervention)**

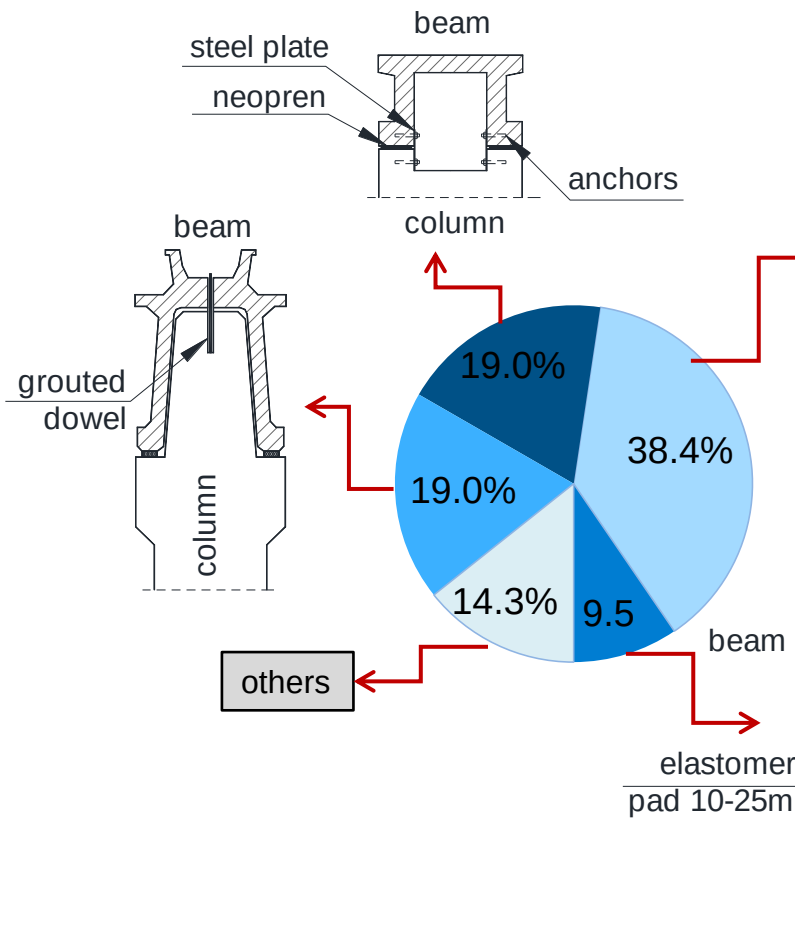
4. **Scenario/flowcharts of *retrofit techniques* (presented only conceptually but with practical aspects) to fulfill/achieve the targeted performance**

6. **High-level discussion on pros and cons of each retrofit solution including *cost, invasiveness, downtime* and other indirect but important**

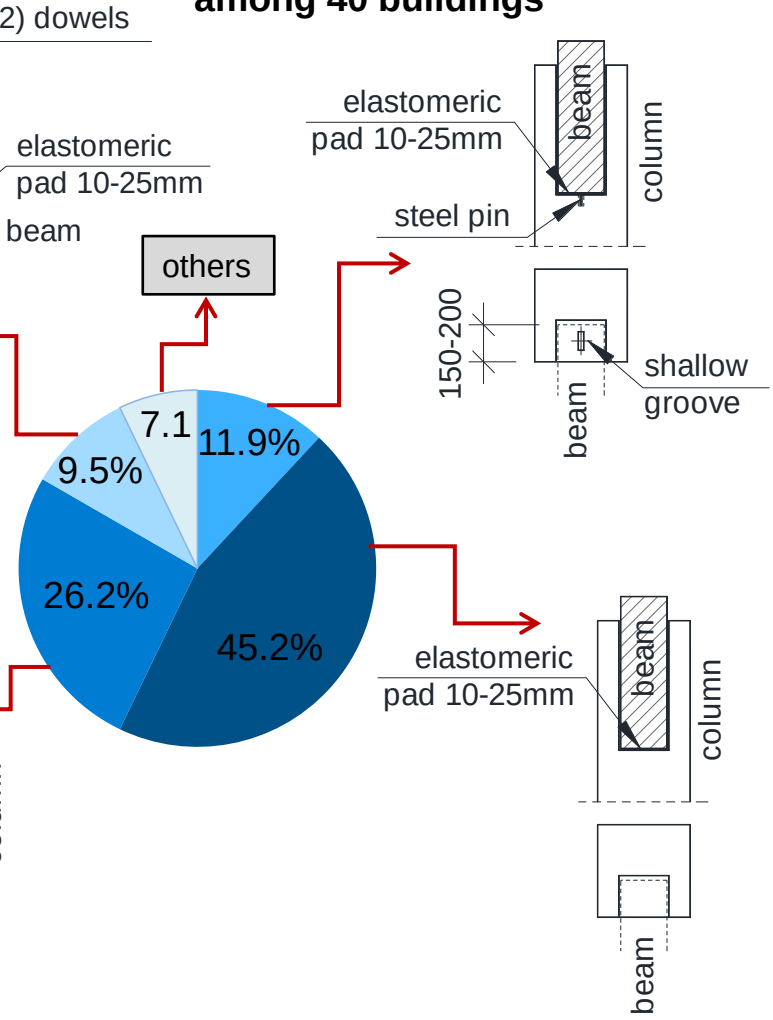
0. Typical connections of existing precast RC industrial structures (qualitative inventory)

Beam-column connections

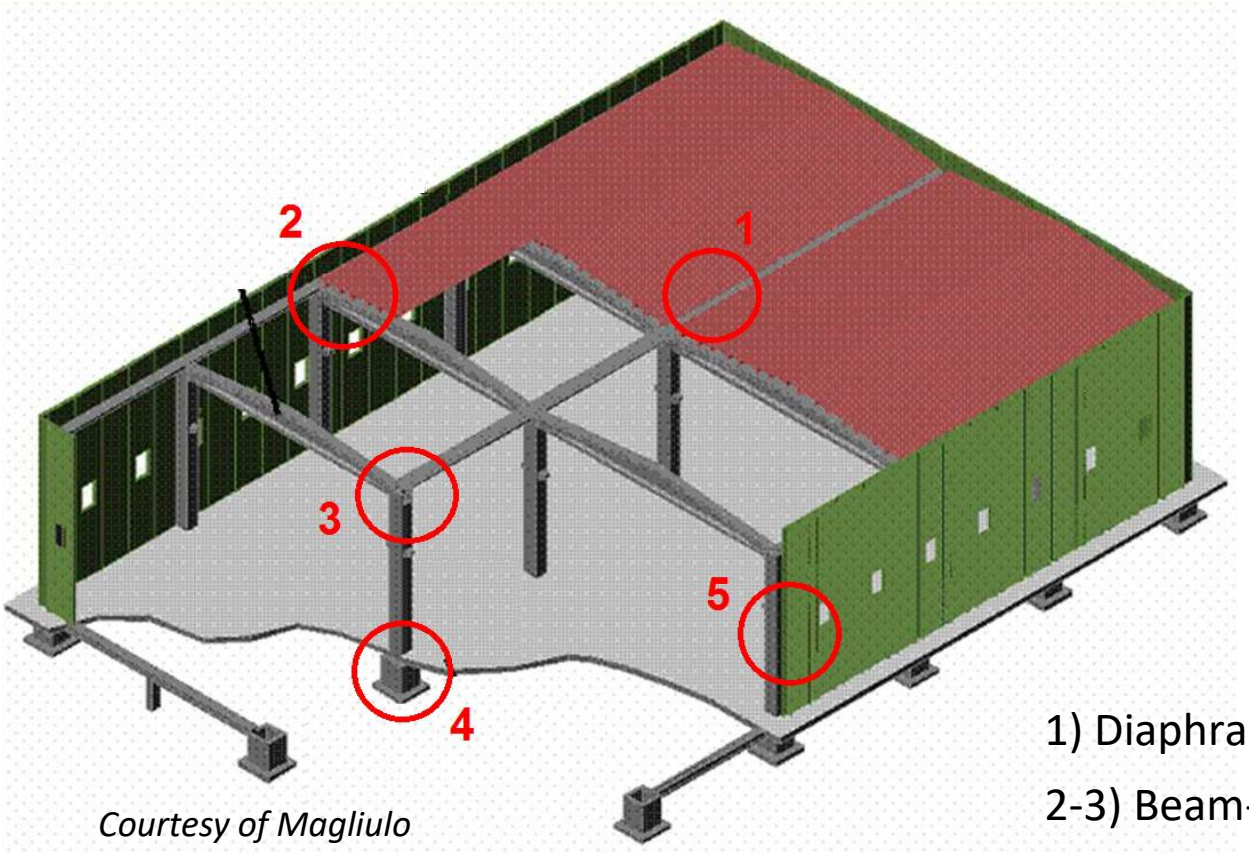
Italy after a report by RELUIS, 2008 among 20 buildings



Emilia-Romagna region, Italy among 40 buildings



1. Critical Structural Vulnerabilities



Courtesy of Magliulo

1) Diaphram action and Connections

2-3) Beam-column connections

4) Column-to-foundation connections

5) Facade/non-structural elements

2. Observed Seismic Performance

(a)

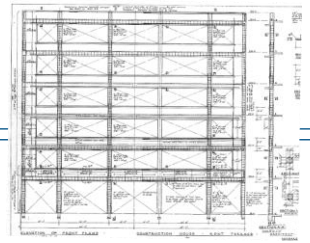
(b)

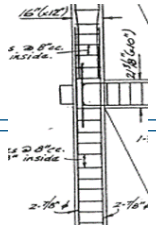
Courtesy of Magliulo

3. Simplified Assessment Methodolog

Step 1- CAPACITY (Vulnerability)

Building data:
- Geometry
- Material properties
- Structural details

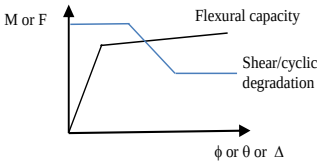




1a- Component Level (beam, column, joint)

Evaluate strength and deformation capacity:
-Flexure, Shear, Flexure-shear interaction
- Cyclic degradation; Lap splices failure; Bi-directional effects

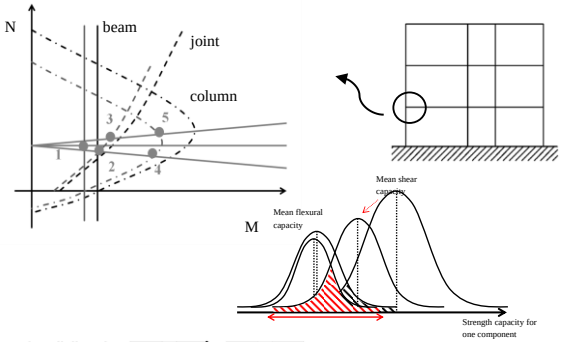
Outcomes (capacity curves):
Moment-curvature/rotation and/or Force-Displacement



1b - Subassembly Level

Evaluate the Hierarchy of Strength and sequence of events at a subassembly level

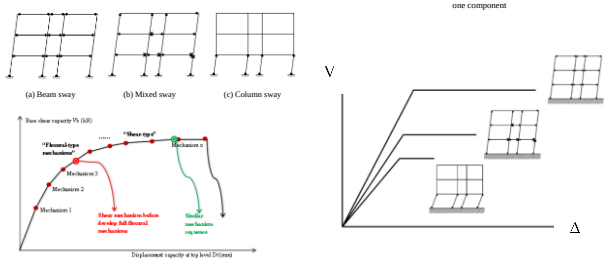
Account for variation on material properties and/or other geometric/mechanical characteristics



1c - Structural System Level

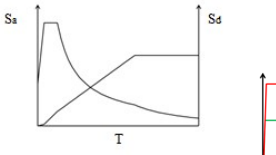
Identify the global mechanism

Evaluate the Global (Force-Displacement) Capacity Curve



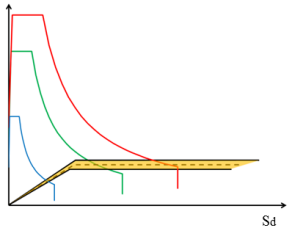
Step 2 – DEMAND (Hazard)

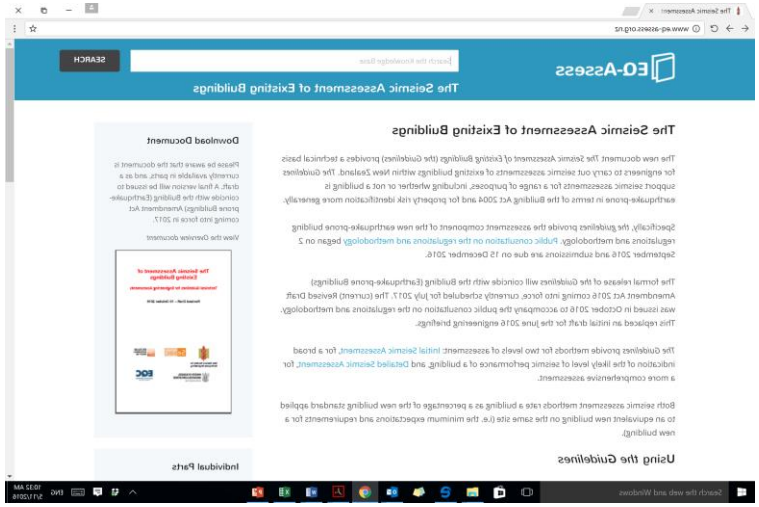
Create ADRS Spectra for different Intensity Level (Return Period)



Step 3 - CAPACITY vs. DEMAND (Performance)

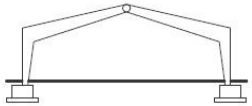
Determine Performance Point at different intensity levels (Earthquake Return Period) and/or intensity corresponding to given limit states (e.g.. %NBS for ULS)

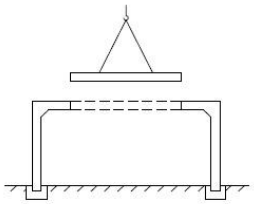




Courtesy of Pampanin (Draft of NZSEE2015/16)

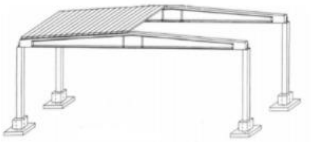
3. Simplified Assessment Methodolog

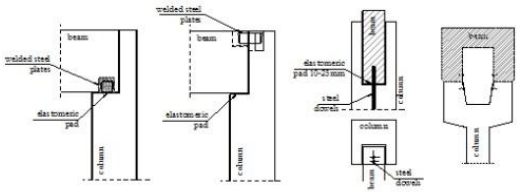




Step 1
VULNERABILITY

Building data:
- Geometry
- Material property
- Strucutural details
- Connections
- Diaphragm





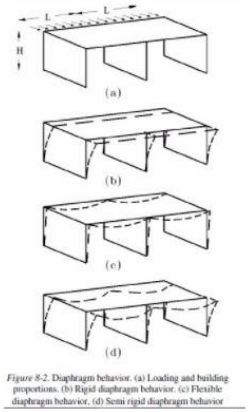
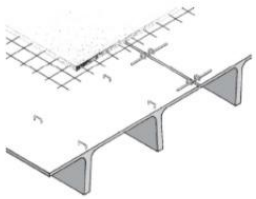
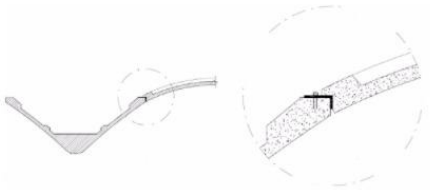


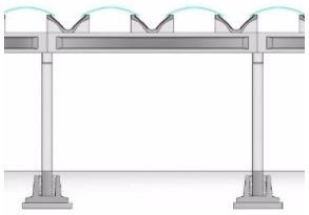
Figure 8-2. Diaphragm behavior. (a) Loading and building proportions. (b) Rigid diaphragm behavior. (c) Flexible diaphragm behavior. (d) Semi rigid diaphragm behavior



Step 2
ANALYSIS OF DIAPHRAGM

-Rigid
-Deformable
-No Rigid

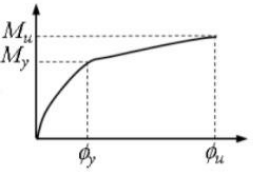


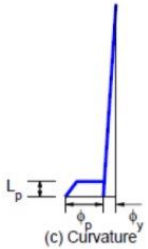


Step 3
COLUMN CAPACITY

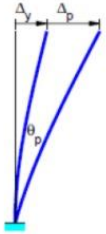
COLUMN SECTION ANALYSIS
Evaluate strenght and deformation capacity:
-Moment-curvature
-Flexure, Shear, Flexure-Shear interaction
-Plastic hinge lenght

COLUMN ELEMENT ANALYSIS
Evaluate strenght and deformation capacity:
-Force-displacement

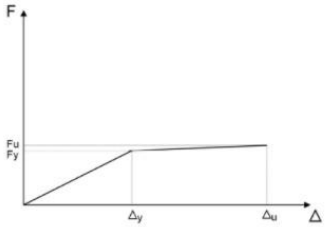




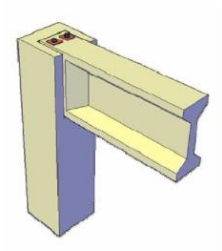
(c) Curvature



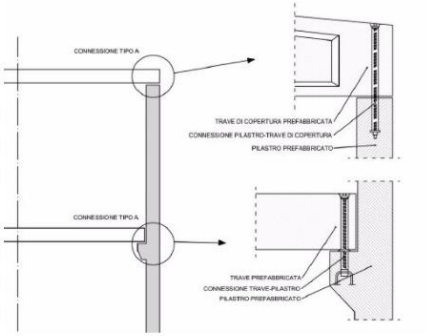
(d) Deflections



3. Simplified Assessment Methodolog



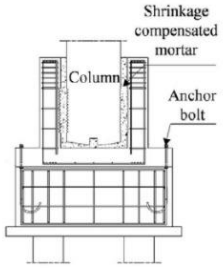
Step 4
BEAM-COLUMN CAPACITY



Assume M-ϑ capacity of the beam-to-colum-connection

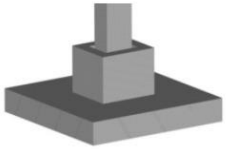
CONNECTION MODEL (Beam-Column)
-Low rotational strength
-High rotational strength
-No rotational strength

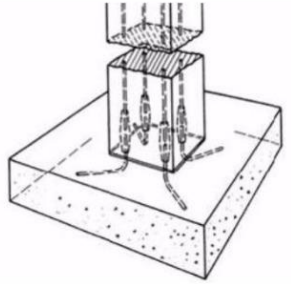
Assume F-Δ capacity of the beam-to-colum connection



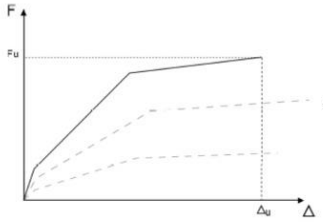
Step 5
FOUNDATION CAPACITY

DETAILS OF CONNECTION
-Pocket foundation and plastic hinge
-Flexural and shear capacity
-Ductility and dissipation
-Floor to column connection



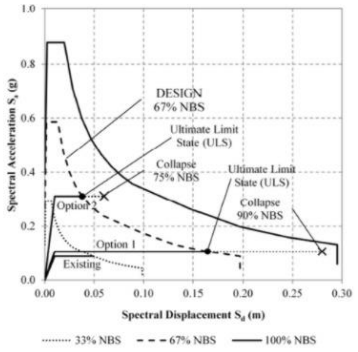


Step 6
STRUCTURE CAPACITY



Sum all the column simplified pushover to obtain the global one

Compare the global pushover with the ADRS format **(PERFORMANCE)**

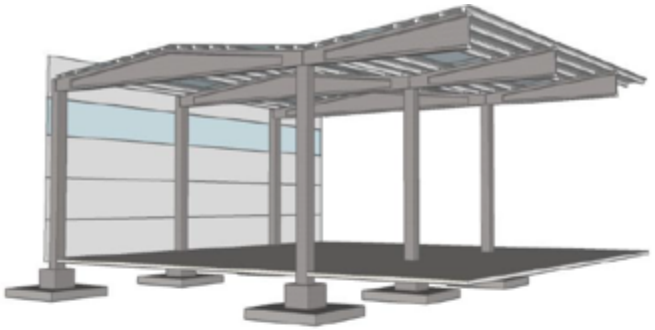


3. Simplified Assessment Methodologi

STEP1

GENERAL

- Geometry
- Material property
- Structural details



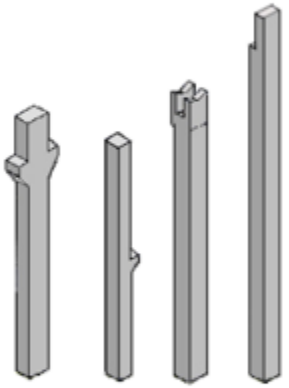
STEP2

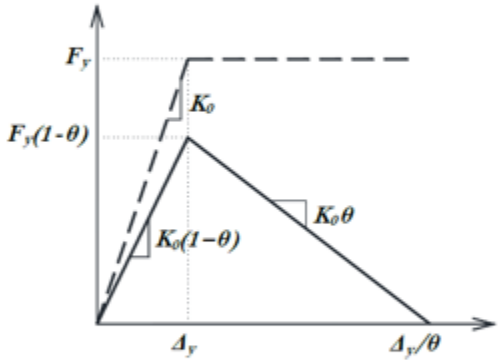
COLUMN

- Flexural-Shear Capacity
- Deformation Capacity
- Plastic lenght
- P-delta effects

(M_y, φ_y) ; (M_u, φ_u)

(F_y, Δ_y) ; (F_u, Δ_u)



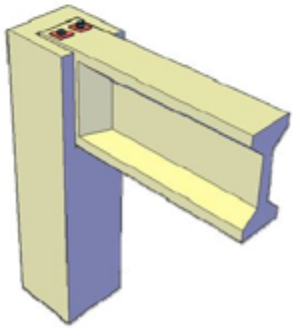


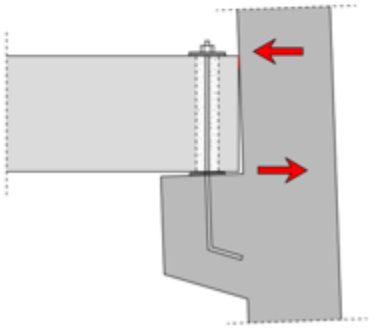
STEP 3

BEAM-COLUMN CONNECTIONS

- Flexural-Shear Capacity
- Rotaional Capacity
- Internal Hierarchy

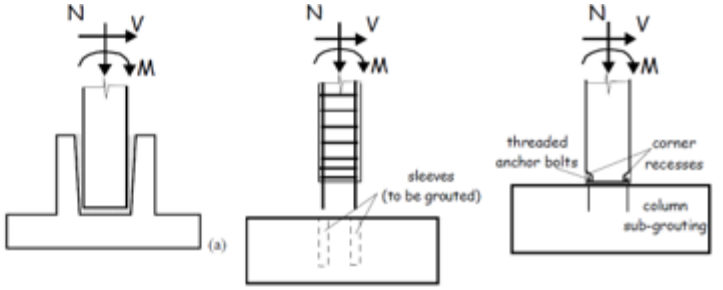
(M, ϑ) ; (F, Δ)



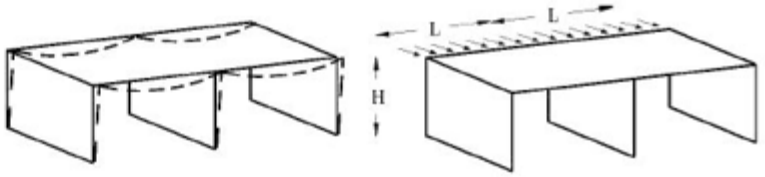


3. Simplified Assessment Methodologi

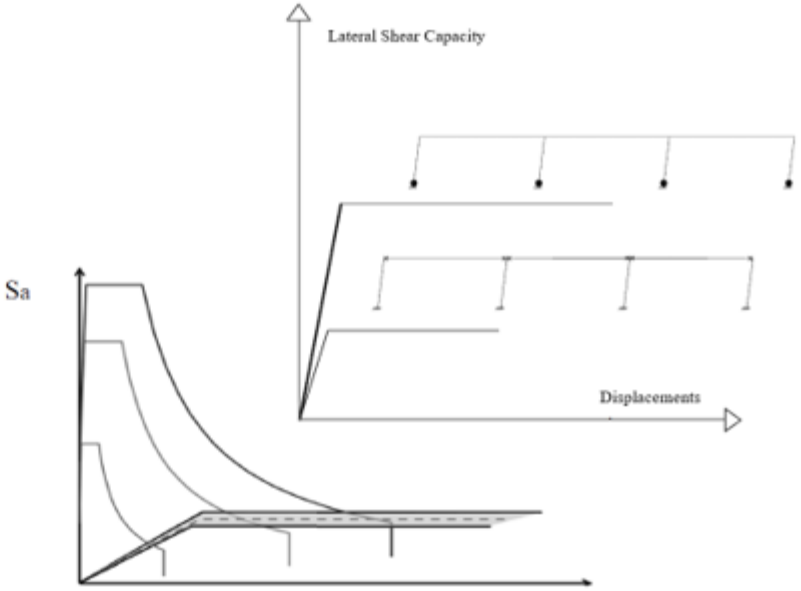
STEP 4
FOUNDATION
- Flexural-Shear Capacity
- Flexibitity
- Rotaional Capacity



STEP 5
DIAPHRAGM
- Horizontal transfer actions
- Plane deformability
- Cladding panels Interaction

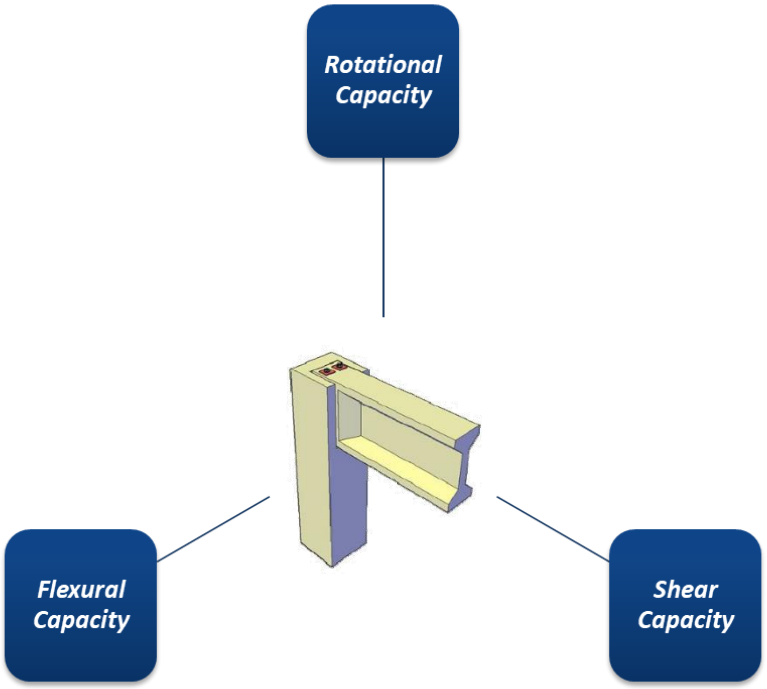


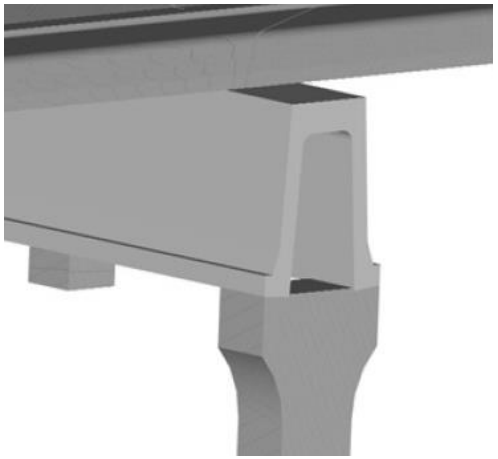
STEP 6
GLOBAL FRAME CAPACITY
- Sequence of Mechanism
- Analitical Push-over Calculation
- Global Capacity



STEP 7
PERFORMANCE
- Capacity Spectrum
- Performance Level

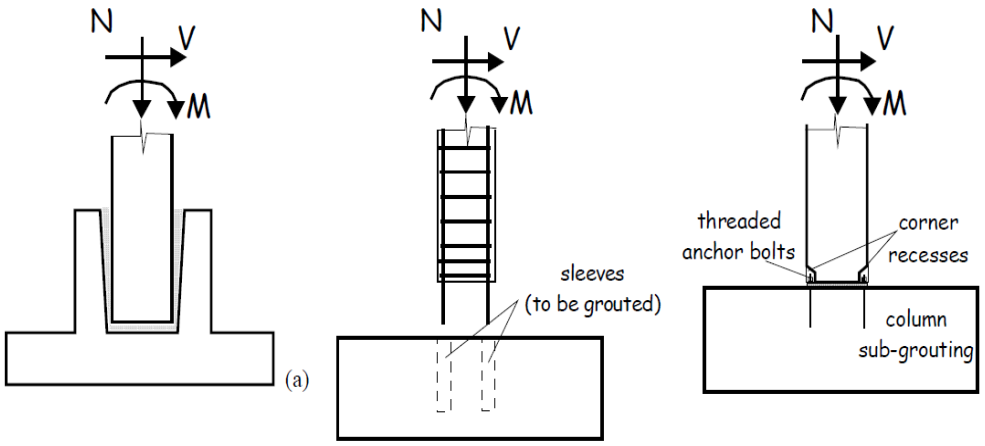
3. Simplified Assessment Methodologi

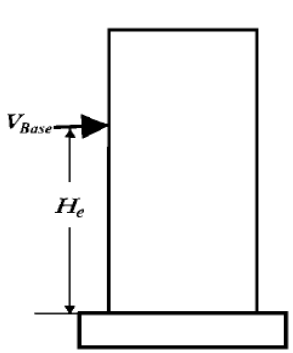




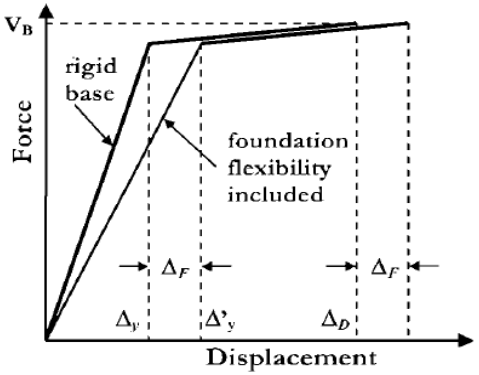
- TRILINEAR FORCE-DISPLACEMENTE
- PROBABLE MOMENT-ROTATION
- BRITTLE MECHANISM

- SIMPLY SUPPORTED BEAM
- FRICTIONAL COEFFICIENT

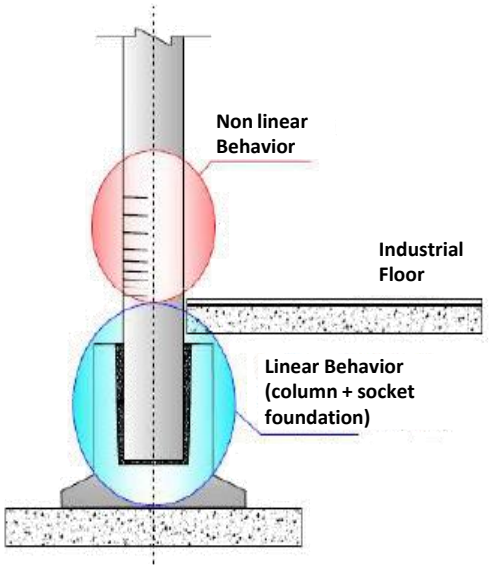


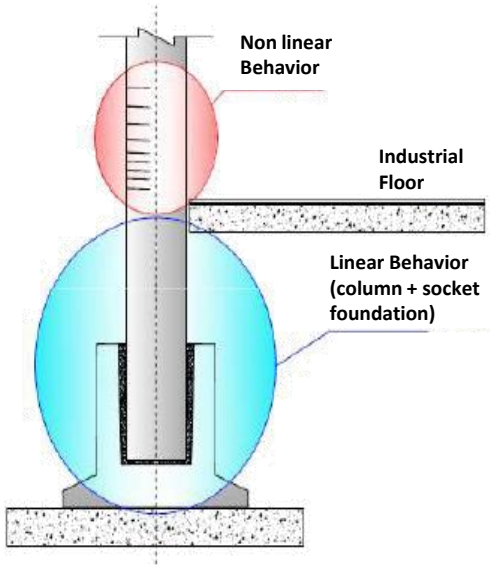


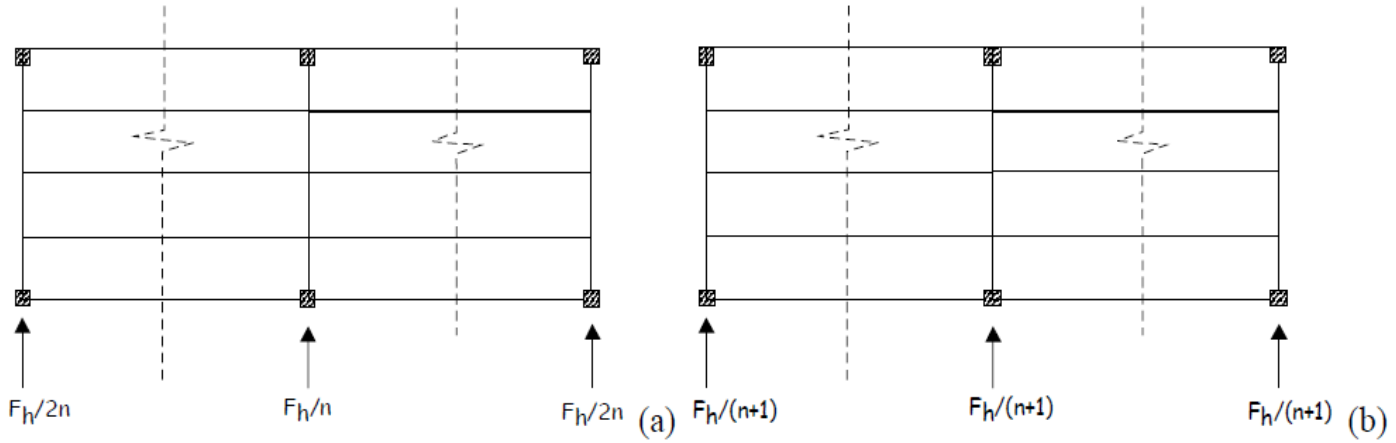
(a) Structure



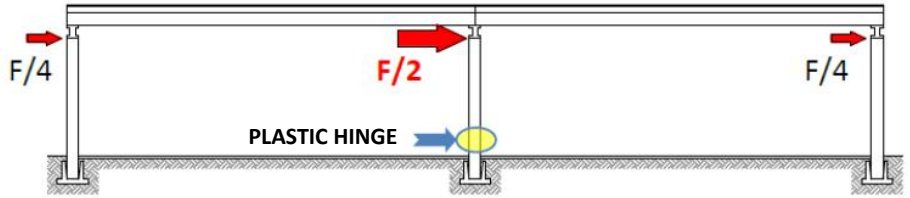
(b) Force-Displacement



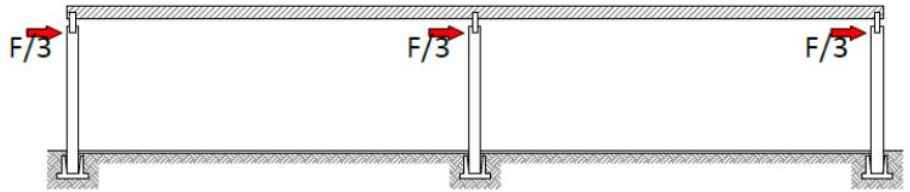




FLEXIBLE DIAPHRAGM



RIGID DIAPHRAGM



4. Seismic Retrofit Strategies

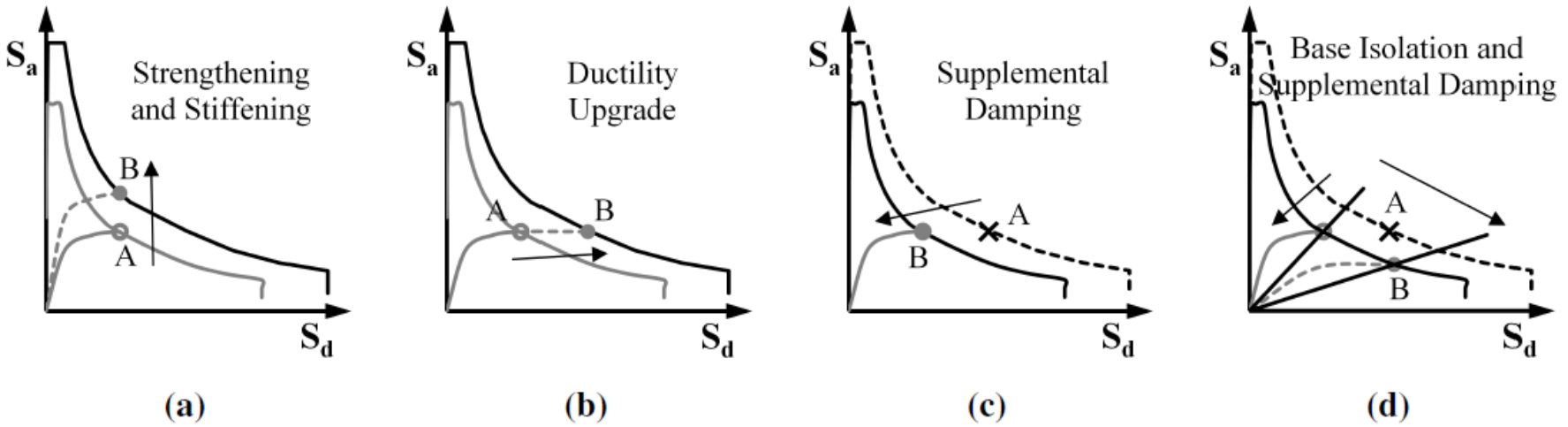
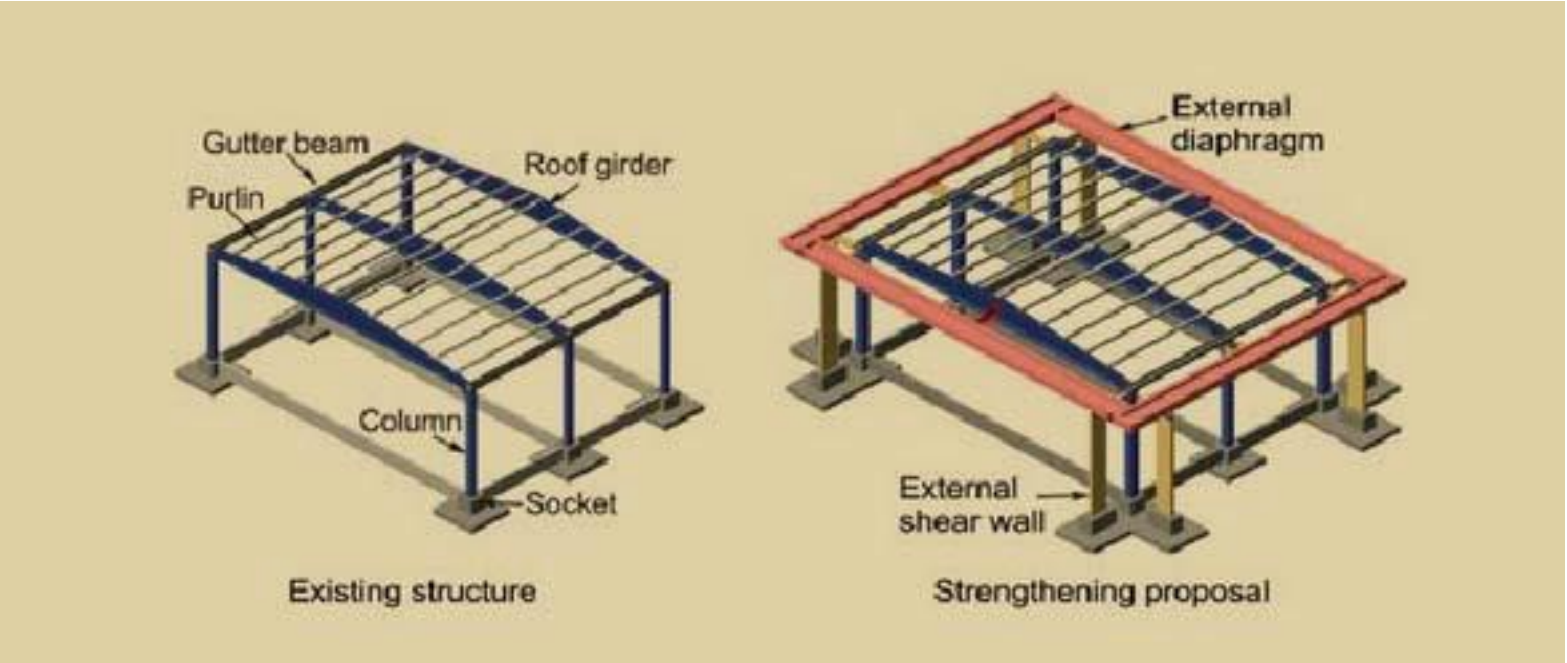


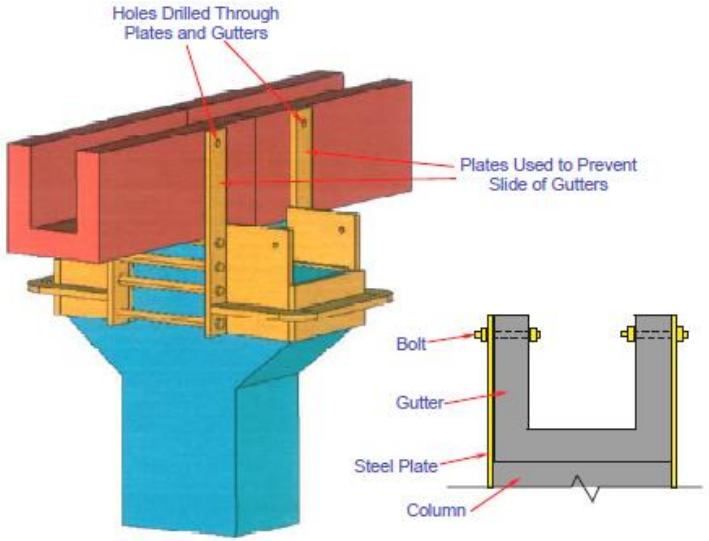
Figure 3.3. ADRS representation of different retrofit philosophies and strategies a) strengthening and stiffening, b) ductility capacity increase, c) supplemental damping, d) base isolation (Weng (2010) and Kam and Pampanin (2009))

5. Seismic Retrofit Techniques



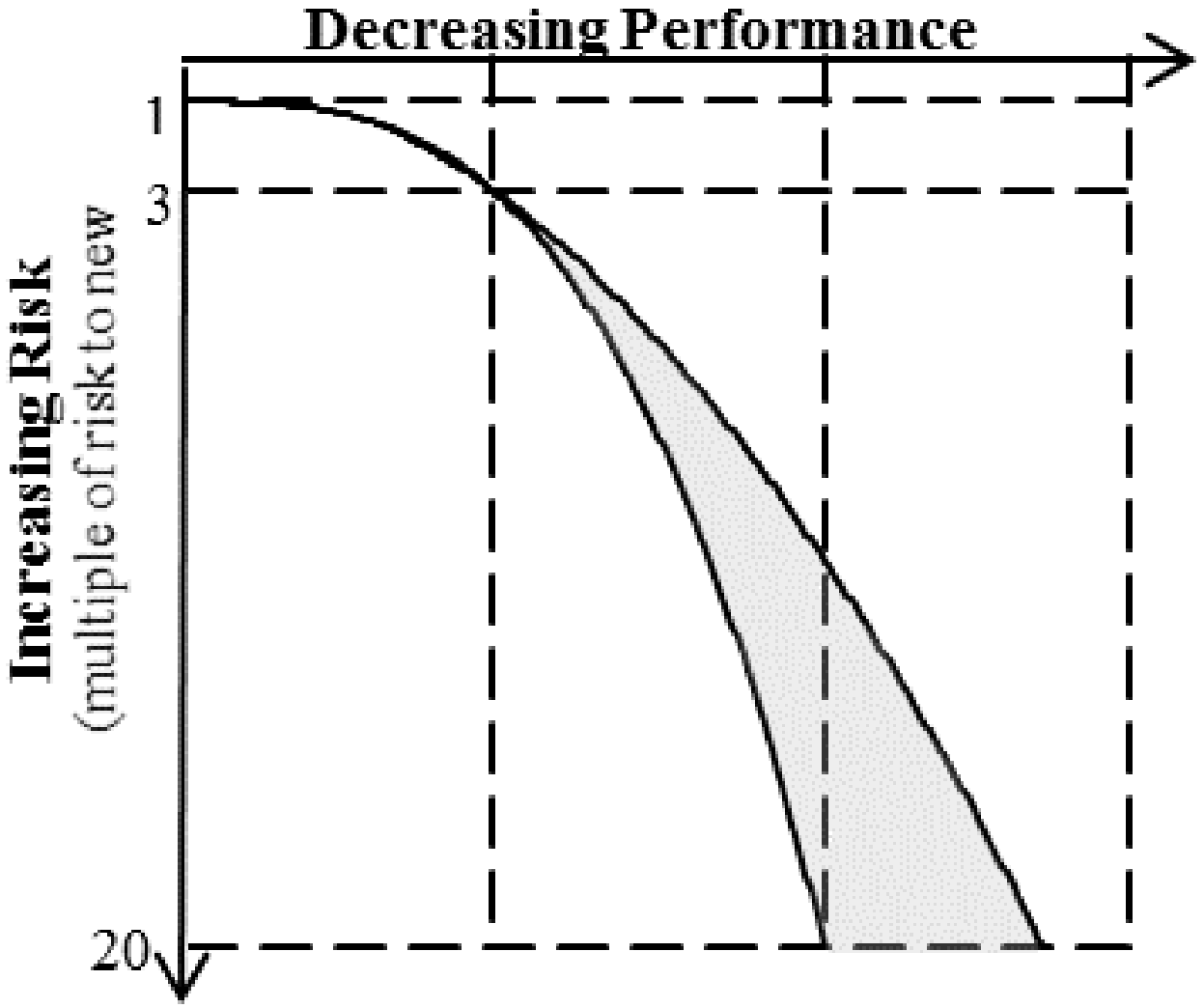
Courtesy of Kaplan

Global vs. Local intervention



Courtesy of Wang

5. Seismic Risk vs. Performance



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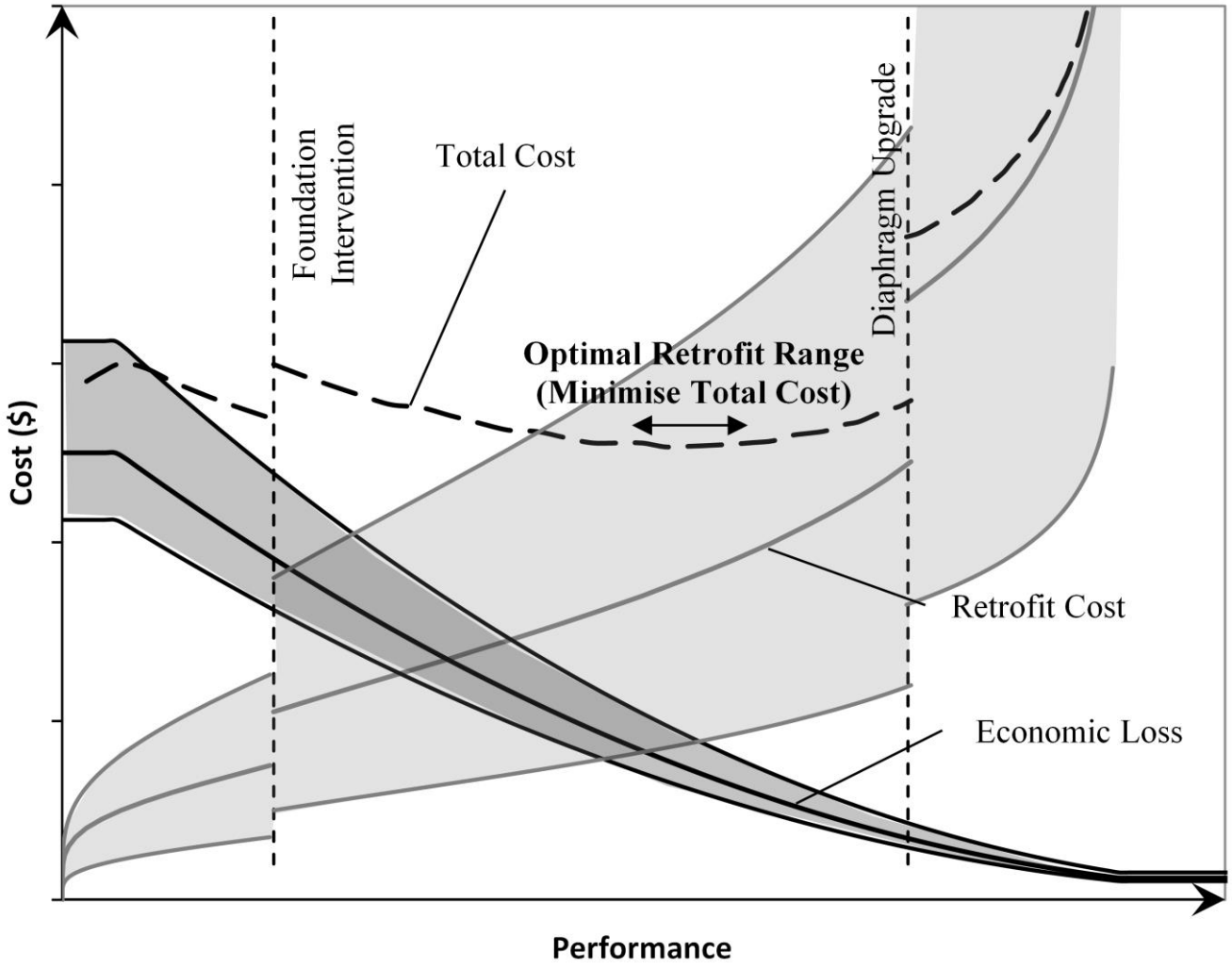
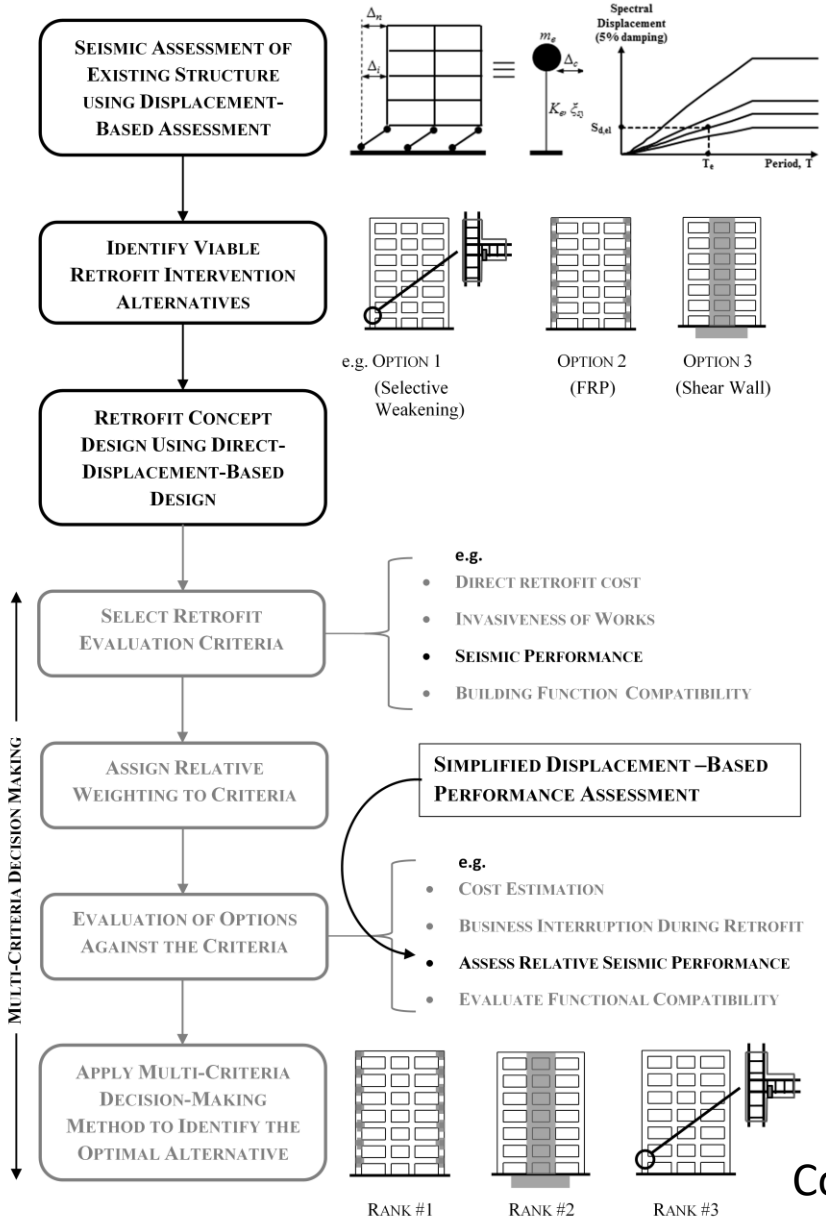
6. Cost vs. Performance (1/2)



Courtesy of Betham-Pampanin

6. Multi-criteria decision making - Alternative retrofit options (2/2)



Courtesy of Betham-Pampanin

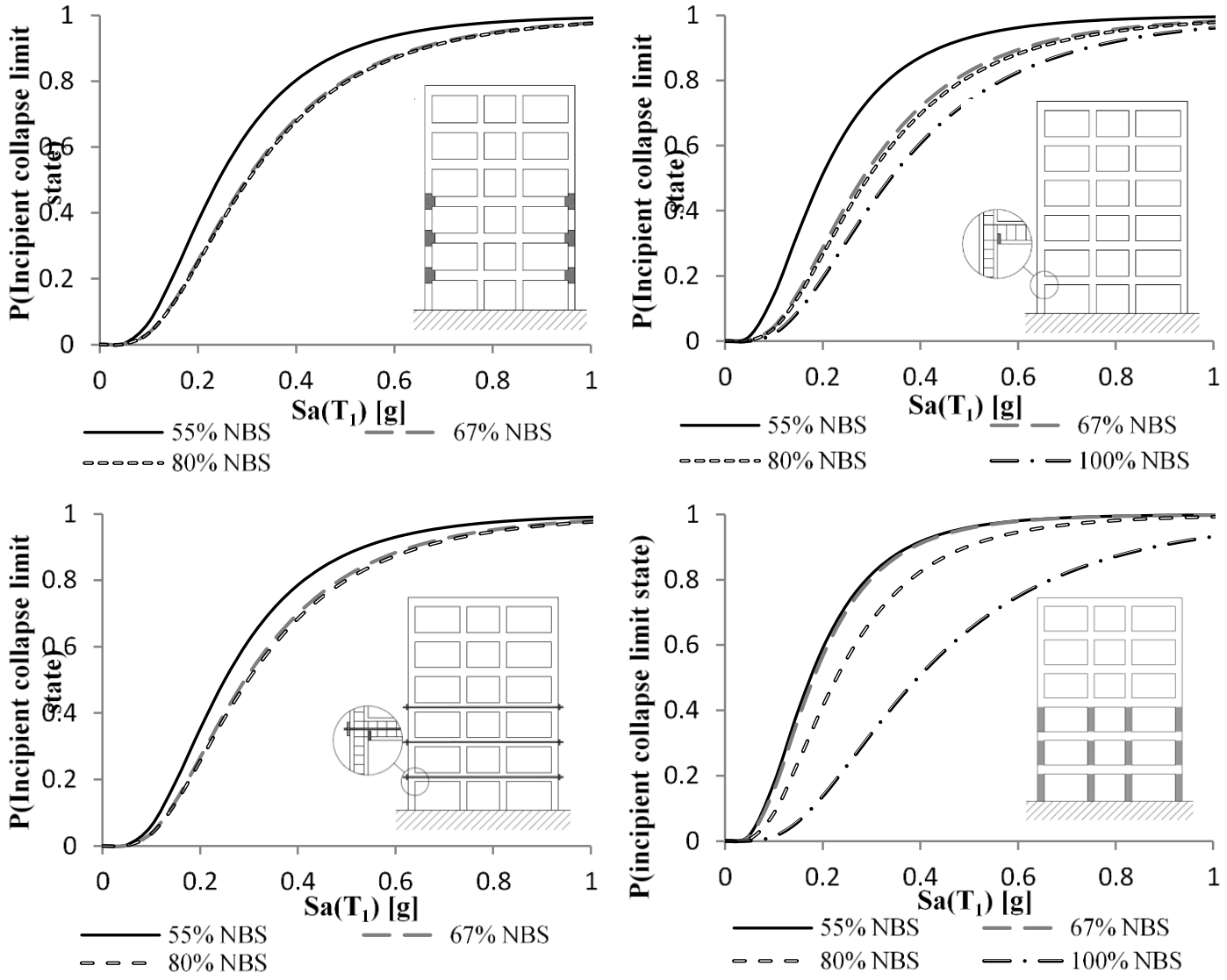
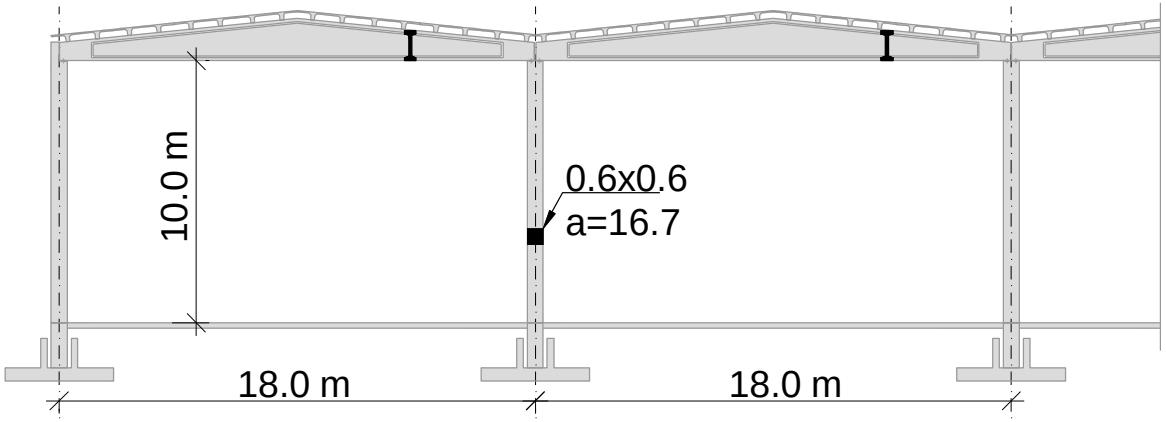


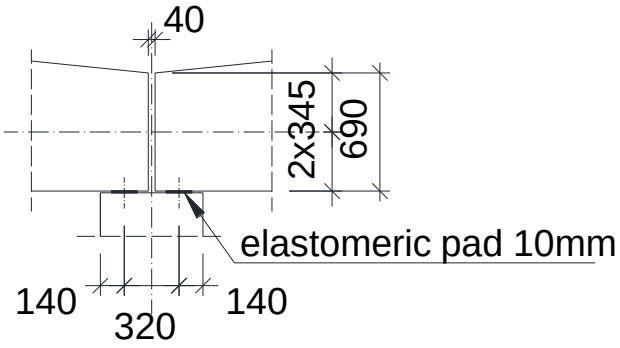
Figure 1: Collapse fragilities for the retrofit options. From the top-left graph, in clockwise order: FRP, Selective Weakening, Concrete Jacketing and Full Selective Weakening.

Courtesy of Ligabue-Savoia-Pampanin

APPENDIX : Case-study(ies) Design Example(s) (Vulnerabilities, Seismic Assessment, Expected Performance, Alternative Retrofit Options, Considerations on cost-effectiveness)

Frame Type A





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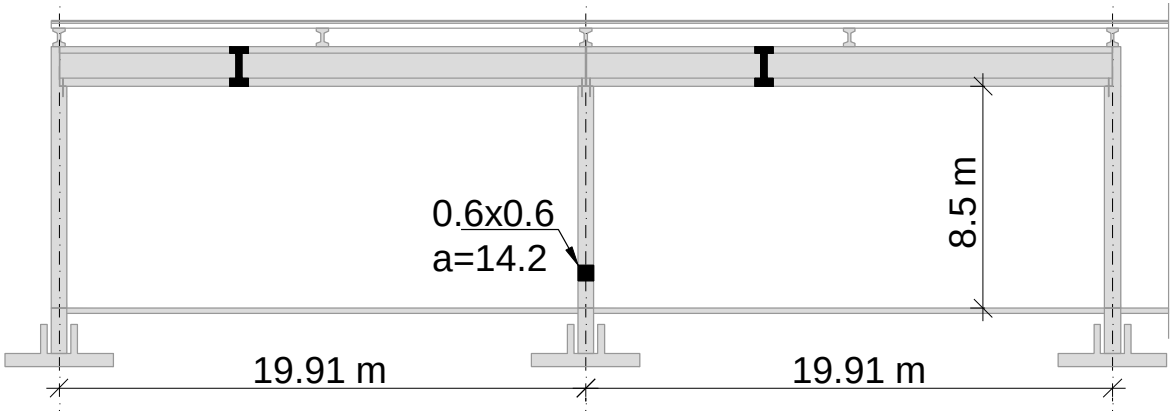

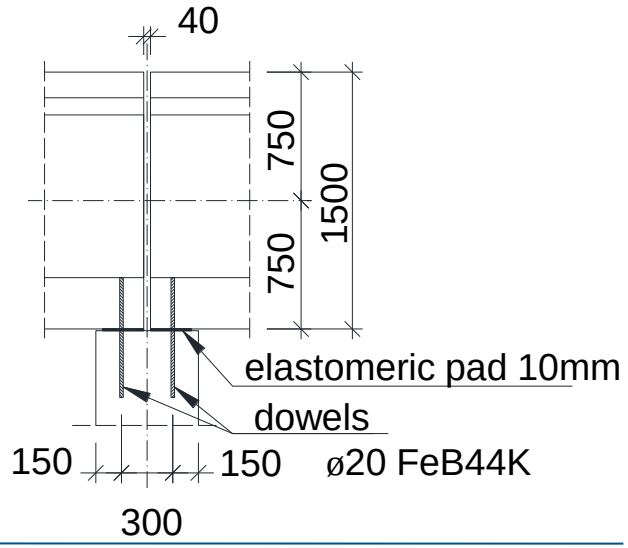

Courtesy of Denayova-Pampanin-Nascimbene