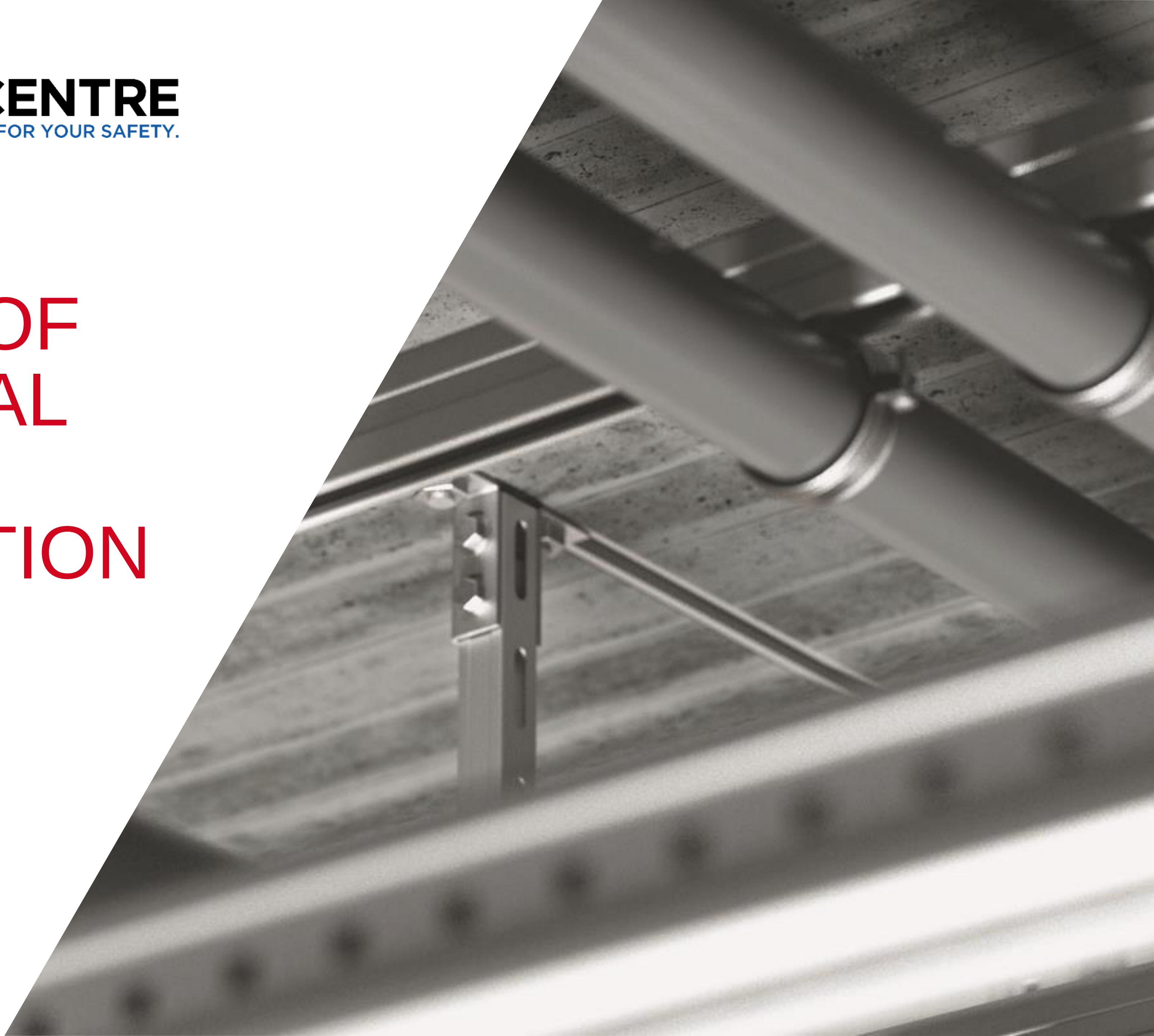
SEISMIC PERFORMANCE OF NON-STRUCTURAL ELEMENTS FOR DAMAGE MITIGATION

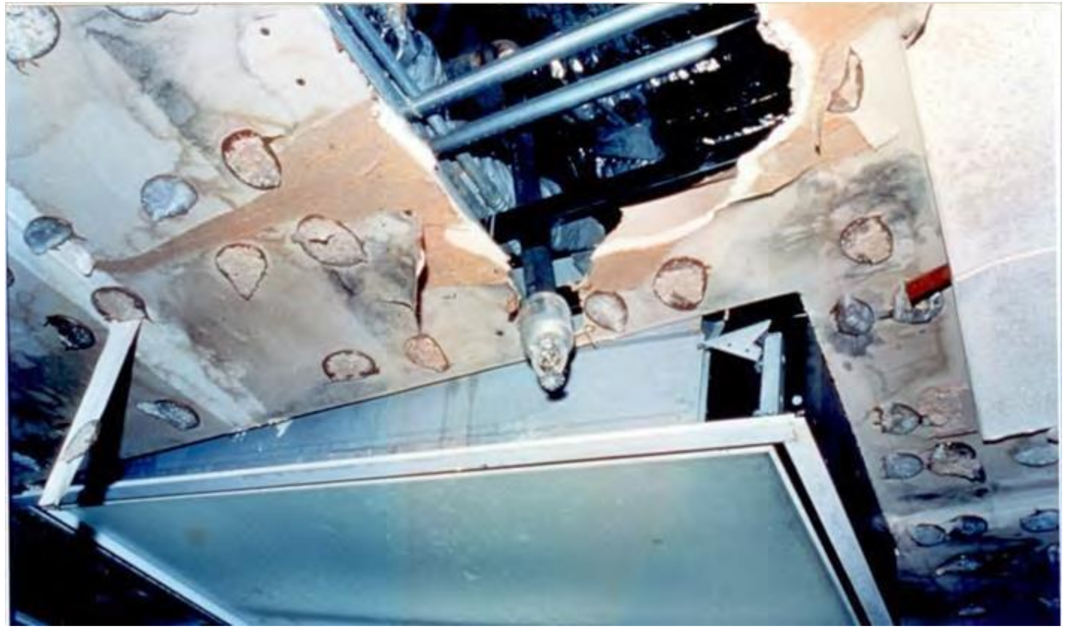


Davide Belotti
Researcher – Eucentre Foundation

NON-STRUCTURAL ELEMENTS

Non-Structural elements represent:

- Suspended elements subject to the risk of falling which may represent a threat to the safety and security of the occupants of the buildings in which they are installed (Life Safety - LS);
- Elements whose collapse could lead to significant economic losses (Property Loss - PL);
- Elements necessary to comply with the SSE (safe shutdown) limit state in critical buildings (Functional Loss - FL);



NON-STRUCTURAL ELEMENTS

The subject "Non-Structural Elements" is intended to include those elements within a building that do not form part of the primary load bearing system.

Architectural components

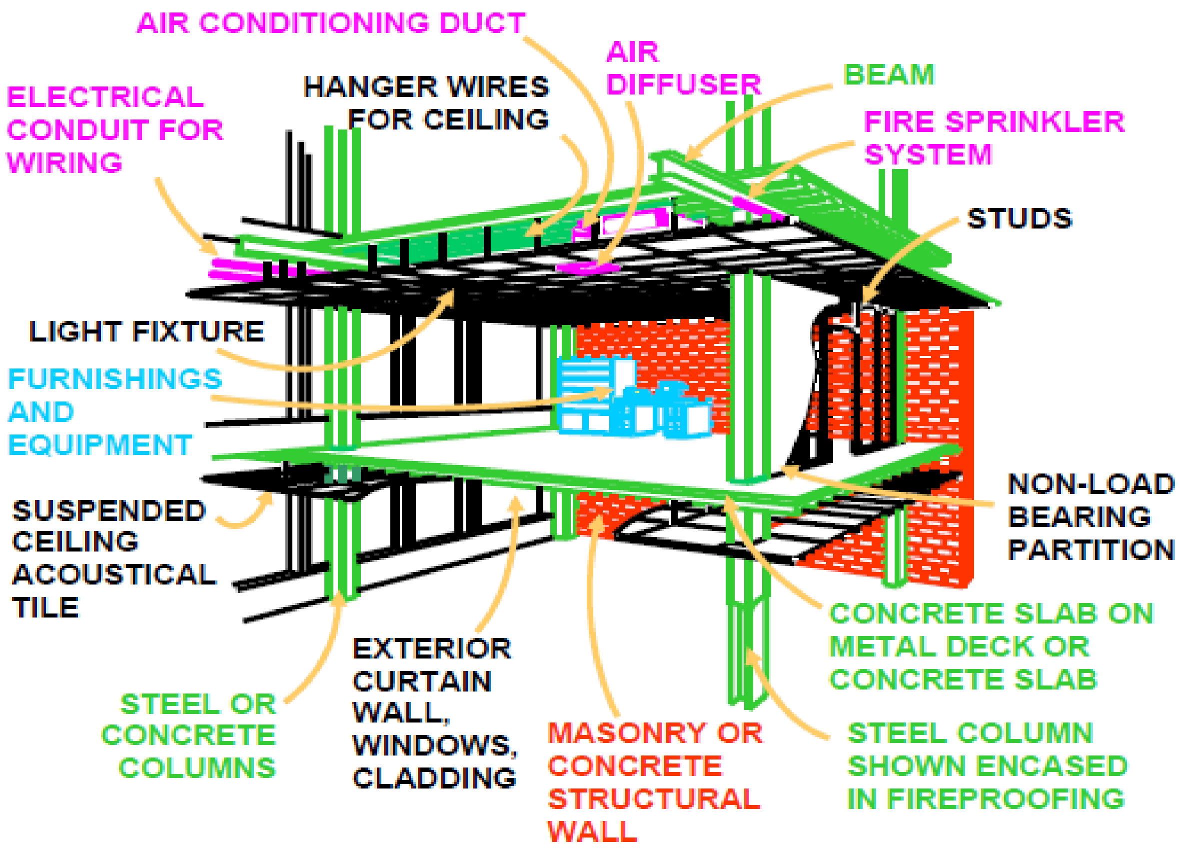
Architectural components are built-in nonstructural components that form part of the building.

Mechanical and electrical components

They include HVAC equipment, engines, turbines, pumps, compressors, pressure vessels, generators, batteries, motors, transformers, panel boards, switch gears, instrumentation cabinets, communication equipment, computers, cooling towers, piping systems, ductwork and electrical conduits.

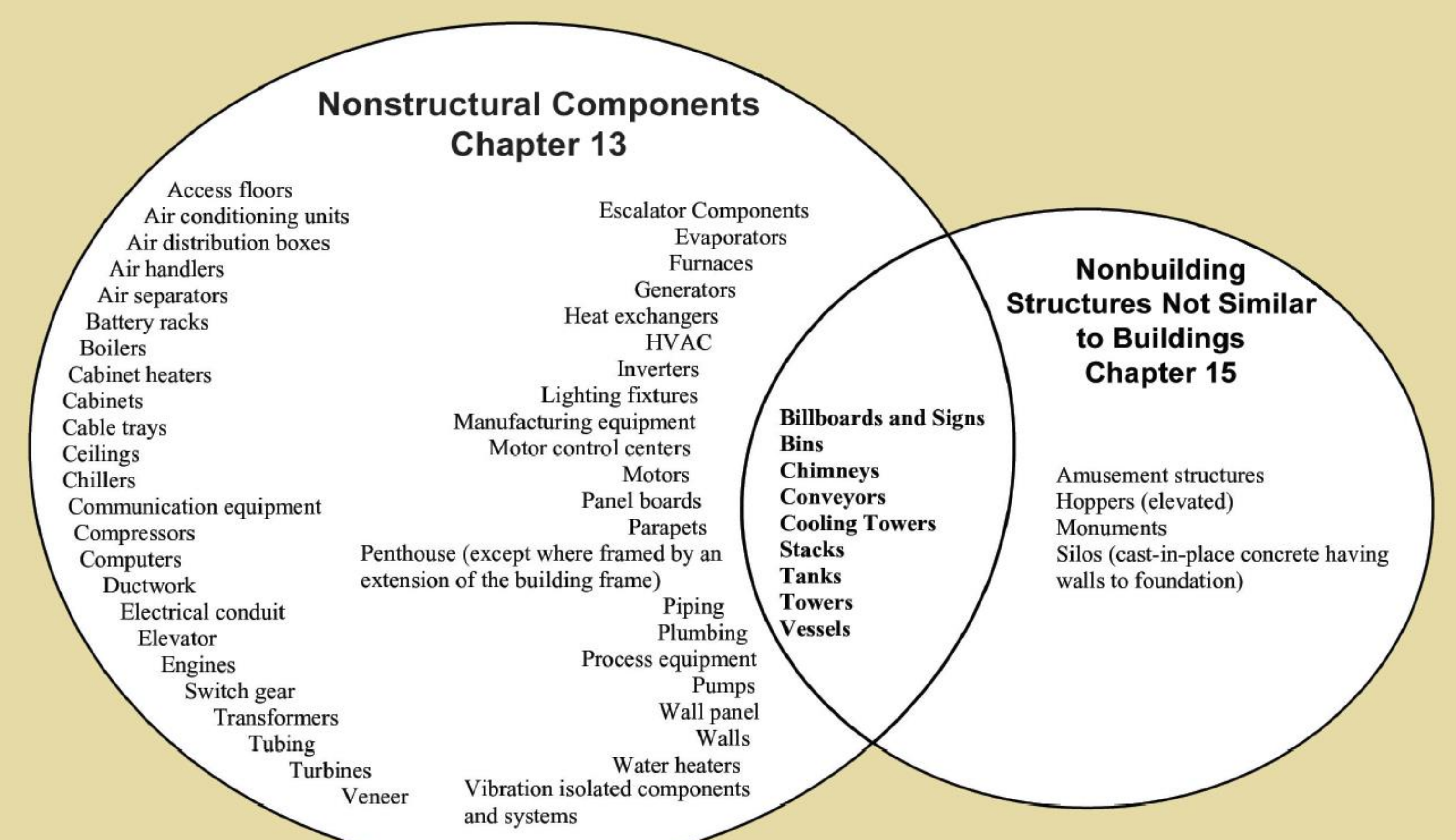
Building contents

Building contents are nonstructural components belonging to tenants or occupants of the building. They include filing cabinets, bookshelves and all pieces of furniture found inside buildings.



NON-STRUCTURAL ELEMENTS

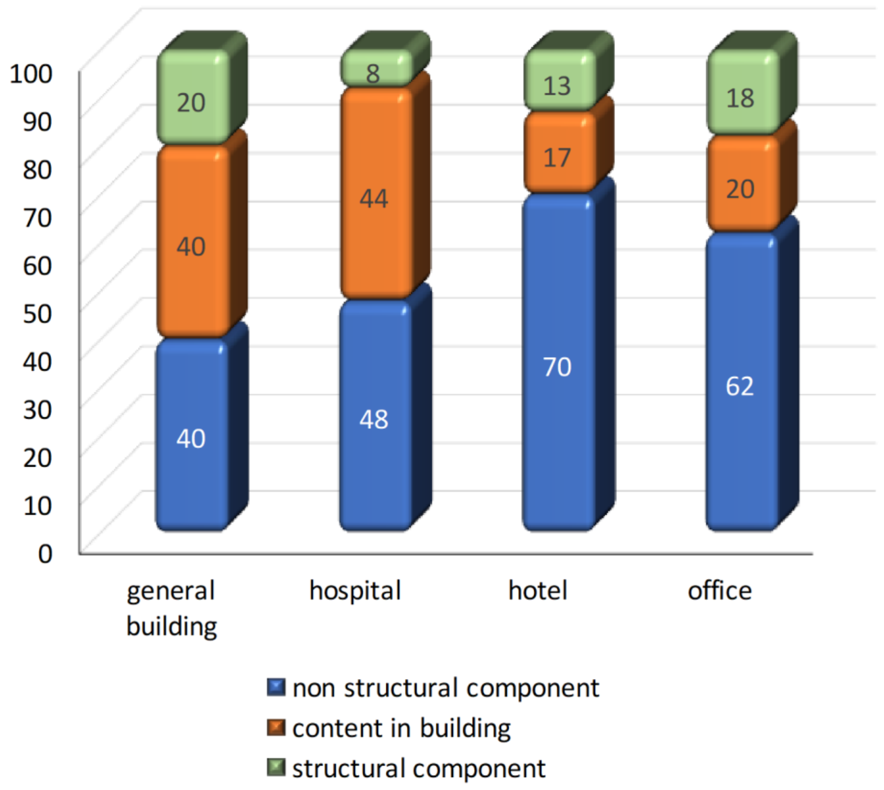
Nonbuilding structures are self-supporting structures other than buildings that carry gravity loads and resist the effects of earthquakes.



Robert Bachman and Susan Dowty based on ASCE 7

NON-STRUCTURAL ELEMENTS

Non structural components of a building represent a high value of the whole and often cause great life losses.

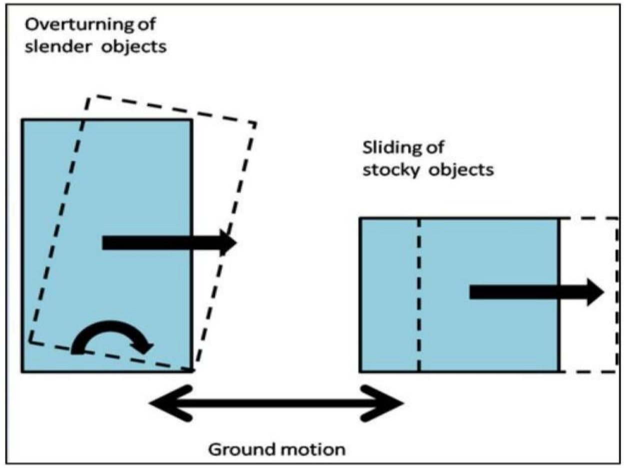


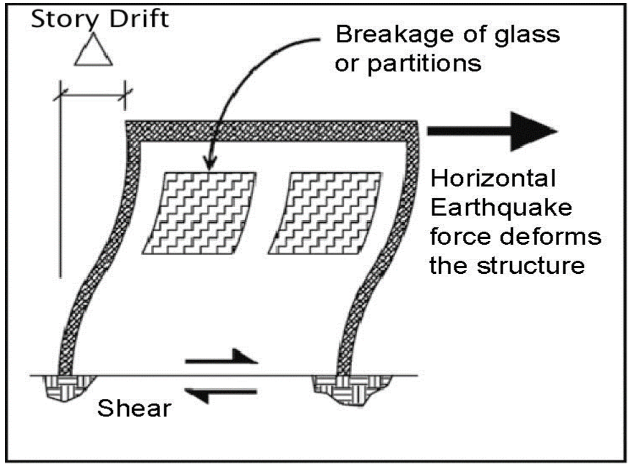
They are all of the architectural, mechanical, electrical, and plumbing systems, as well as furniture, fixtures, equipment, and contents:

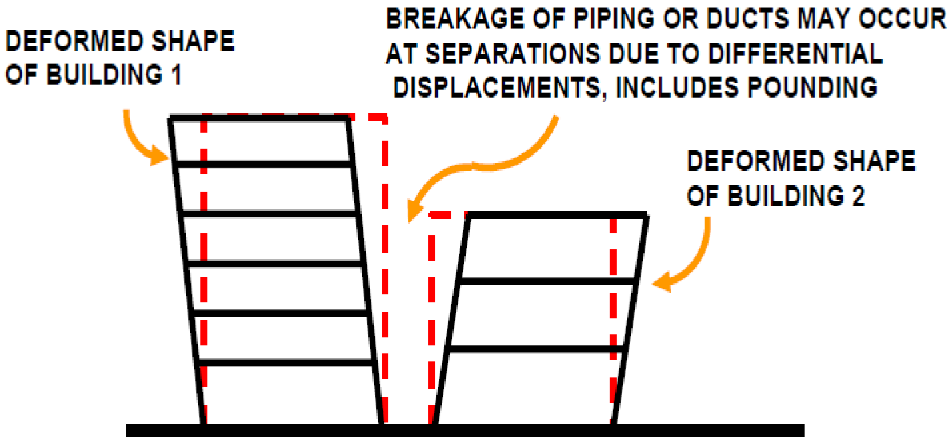
- windows
- partitions
- piping
- ceilings
- air conditioning ducts and equipment
- elevators
- computer and hospital equipment
- cabinets
- …

DAMAGE MITIGATION OF NON STRUCTURAL ELEMENTS

Based on the installation point of the non-structural element and the typology (sensitive to accelerations or displacements) it is possible to provide systems for mitigating seismic damage (FEMA E-74).







Inertial Forces ***Building Deformations*** ***Building Separations***

FEMA

HILTI EUCENTRE FOR YOUR SAFETY.

DAMAGE MITIGATION OF NON STRUCTURAL ELEMENTS

Non-Engineered (NE) Details

These are simple, generic seismic protection details that do not require engineering design to determine the requirements.

- Restraints for tenant-supplied movable equipment and furniture
- Restraints for cabinet doors and drawers
- Restraints for shelved items

Prescriptive (PR) Details

These mitigation solutions rely on standard restraint details that have been previously developed and can be implemented without the need for an engineer as:

- Water heaters, up to 100 gallons capacity
- Suspended acoustic ceilings, up to 4 pounds per square foot in weight

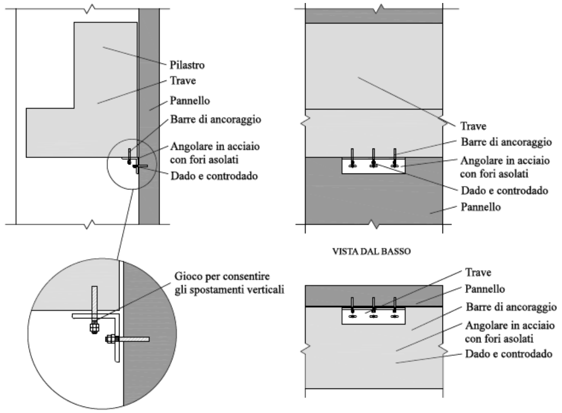
Engineering Required (ER) Details

- Bracing, anchorage, or restraint details for these components require design by an engineer or design professional experienced in the seismic design of nonstructural elements.

DAMAGE MITIGATION OF NON STRUCTURAL ELEMENTS

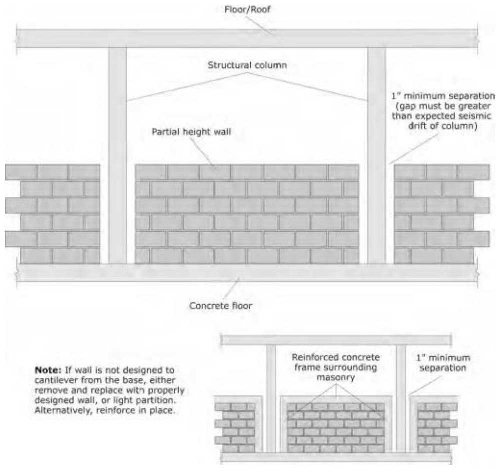
Closure external panels

2012 Northern Italy earthquakes (Emilia Romagna)



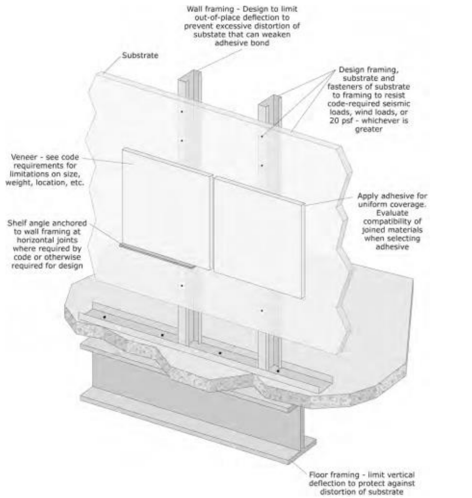
Precast panels (ER)

Partial height heavy partition (ER)



Adhered veneer (ER)

2016 Central Italy earthquake

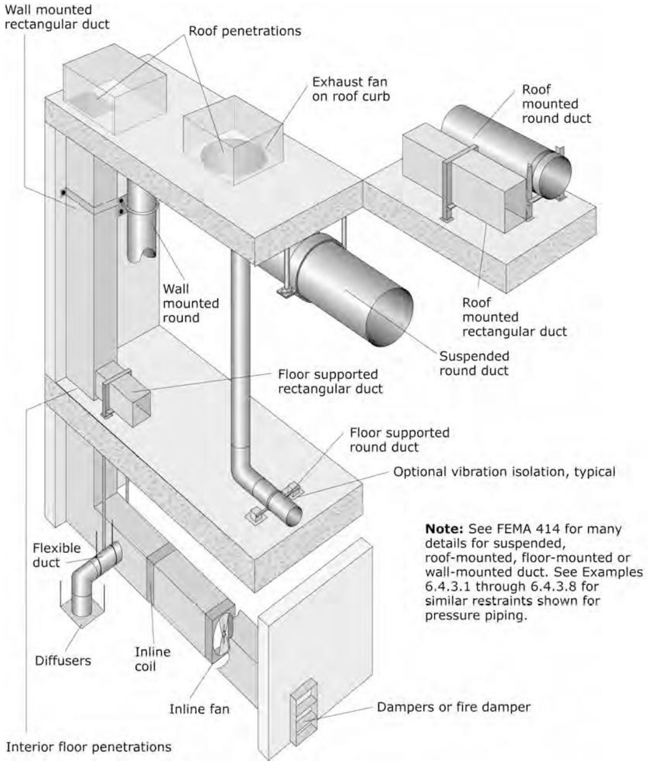


Bellotti, D., Cavalieri, F., & Nascimbene, R. (2023). Influence of Closure External Panels Modelling on the Seismic Response of Non-Residential Precast Buildings. *Journal of Earthquake Engineering*, *28*(1), 288–304. https://doi.org/10.1080/13632469.2023.2197517

DAMAGE MITIGATION OF NON STRUCTURAL ELEMENTS

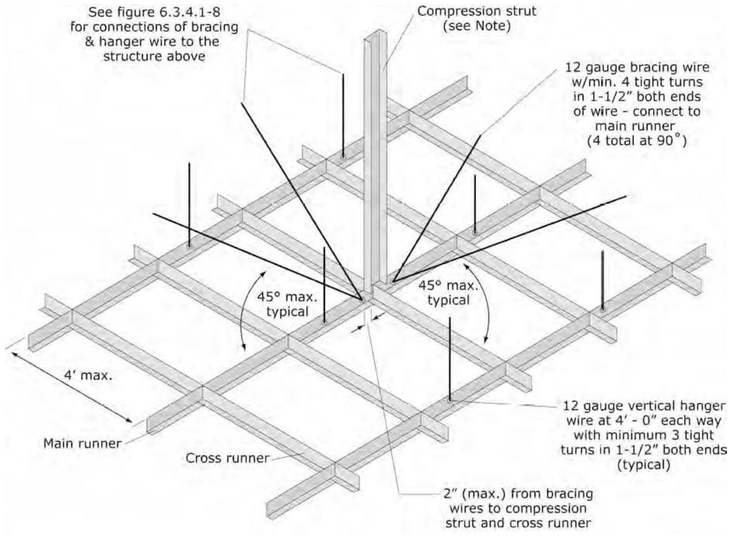
Ceilings: Suspended Lay-in Tile Ceiling Systems

2009 L'Aquila earthquake



Overview of ductwork restraints (ER)

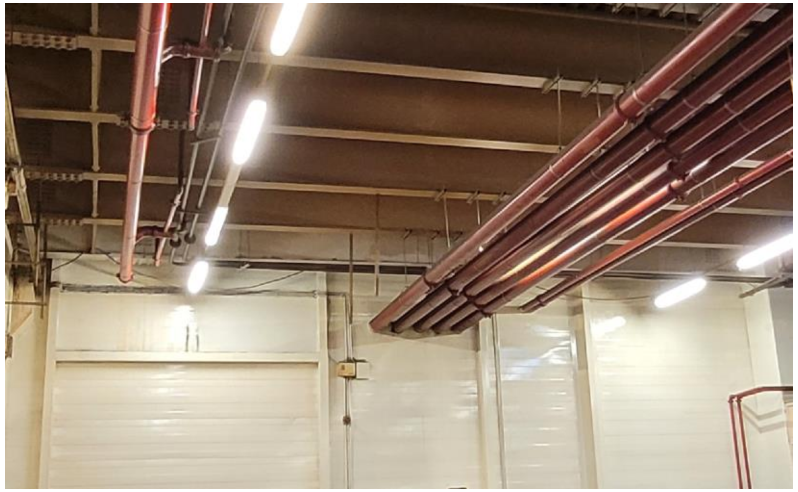
2016 Central Italy earthquake

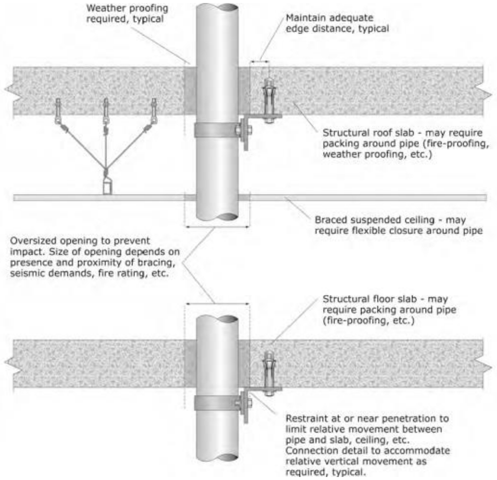


Suspension system for acoustic lay-in panel ceilings – lateral bracing assembly (PR).

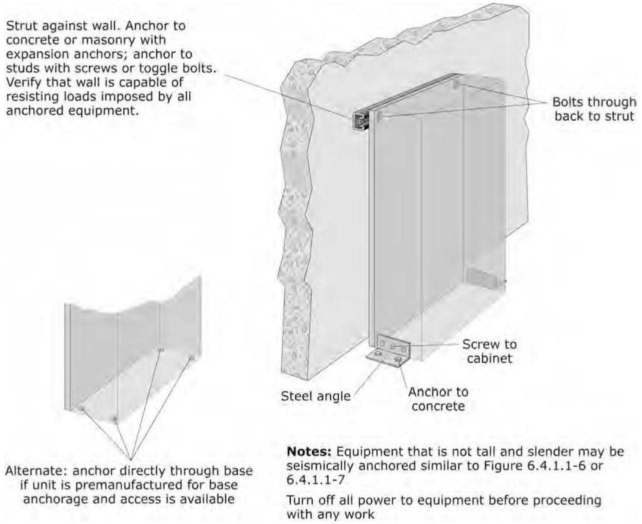
Note: Compression strut shall not replace hanger wire. Compression strut consists of a steel section attached to main runner with 2 - #12 sheet metal screws and to structure with 2 - #12 screws to wood or 1/4" min. expansion anchor to structure. Size of strut is dependent on distance between ceiling and structure (l/r ≤ 200). A 1" diameter conduit can be used for up to 6', a 1-5/8" X 1-1/4" metal stud can be used for up to 10'

DAMAGE MITIGATION OF NON STRUCTURAL ELEMENTS

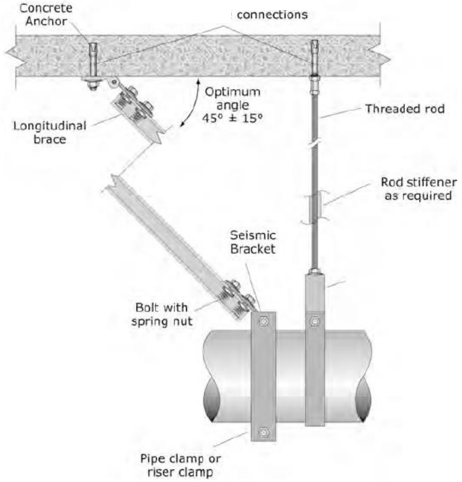




Adequate distance (ER)



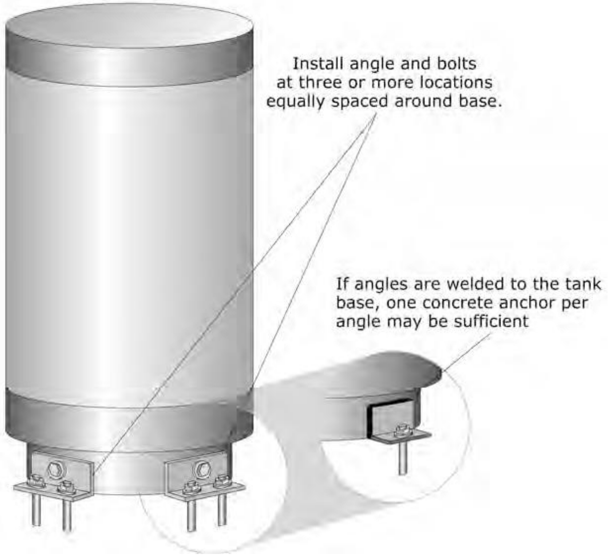
Bolts, anchors (ER)

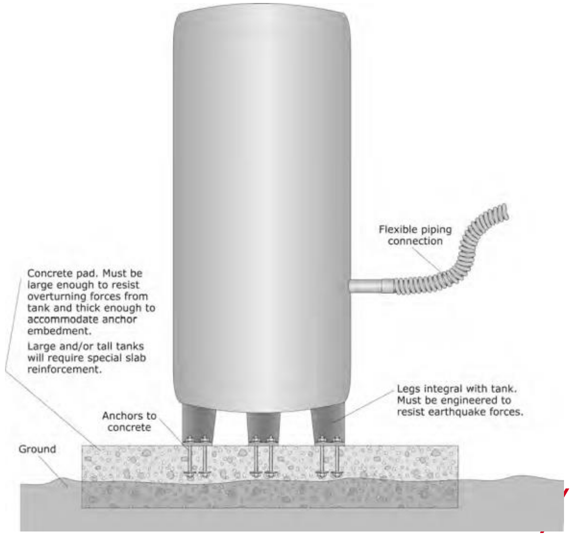


single pipe longitudinal/transverse (ER)

DAMAGE MITIGATION OF NON STRUCTURAL ELEMENTS

2023 Türkiye–Syria earthquakes
(Italian Joint Reconnaissance EUCENTRE-ReLUis Mission)





Install bolts, Flexible piping (ER)

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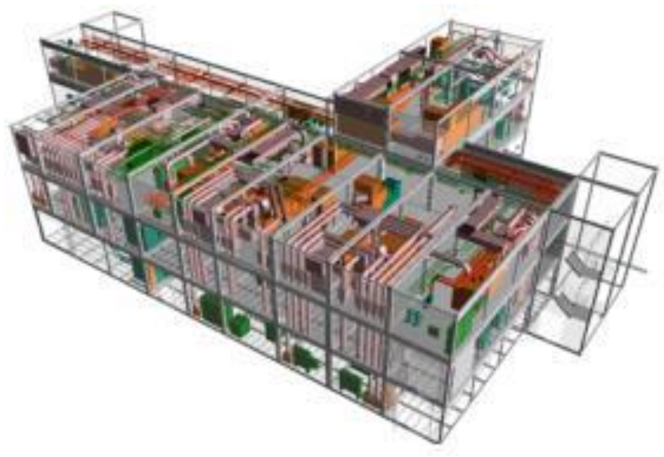
SEISMIC DESIGN OF NON-STRUCTURAL ELEMENTS

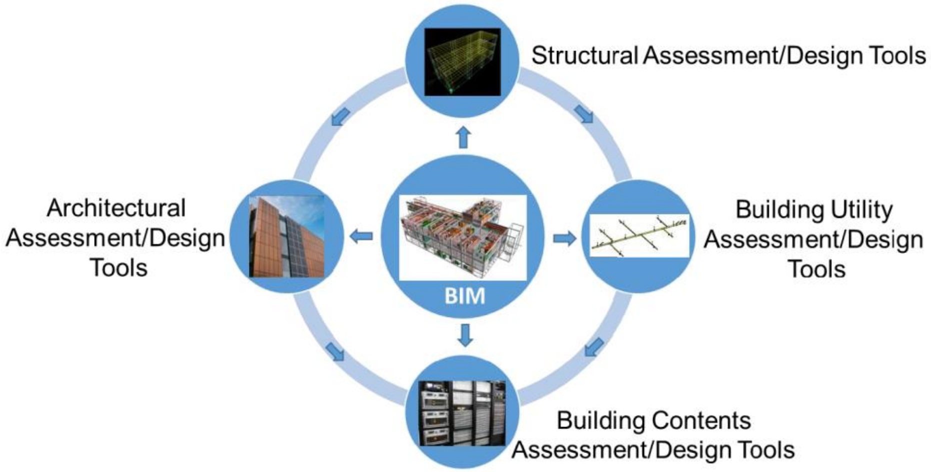
The design of non-structural elements requires collaboration between different professional figures.

Various initiatives are currently being undertaken towards possible solutions.

Building Information Modeling (BIM) allows to:

- promote the exchange of information and skills between the figures involved;
- perform seismic design and assessment of the seismic vulnerability of non-structural elements





SEISMIC DESIGN OF NON-STRUCTURAL ELEMENTS

Eurocode 8, §4.3.5: Non-structural elements (appendages) of buildings (e.g. parapets, gables, antennae, mechanical appendages and equipment, curtain walls, partitions, railings) that might, in case of failure, cause risks to persons or affect the main structure of the building or services of critical facilities, shall, together with their supports, be verified to resist the design seismic action.

For non-structural elements of great importance or of a particularly dangerous nature, the seismic analysis shall be based on a realistic model of the relevant structures and on the use of appropriate response spectra derived from the response of the supporting structural elements of the main seismic resisting system.

For calculating the response spectra is necessary to evaluate the design seismic action that is expressed in terms of:

a) the reference seismic action associated with a reference probability of exceedance, P_{NCR}, in 50 years or a reference return period, T_{NCR}

b) the importance factor γ_I to take into account reliability differentiation.

→ For the following non-structural elements the importance factor γ_a shall not be less than 1,5:
− anchorage elements of machinery and equipment required for life safety systems;
− tanks and vessels containing toxic or explosive substances considered to be hazardous to the safety of the general public.

SEISMIC DESIGN OF NON-STRUCTURAL ELEMENTS

The seismic force is calculated as (Eurocode 8, §4.3.5.2):

$$F_a = \frac{(S_a W_a \gamma_a)}{q_a}$$

- Mass;
- spectral acceleration at the vibration period;
- importance factor
- behavior factor of the element

$$S_a = \alpha \cdot S \cdot [3(1 + z/H) / (1 + (1 - T_a/T_1)2)-0,5]$$

Table 4.4: Values of q_a for non-structural elements

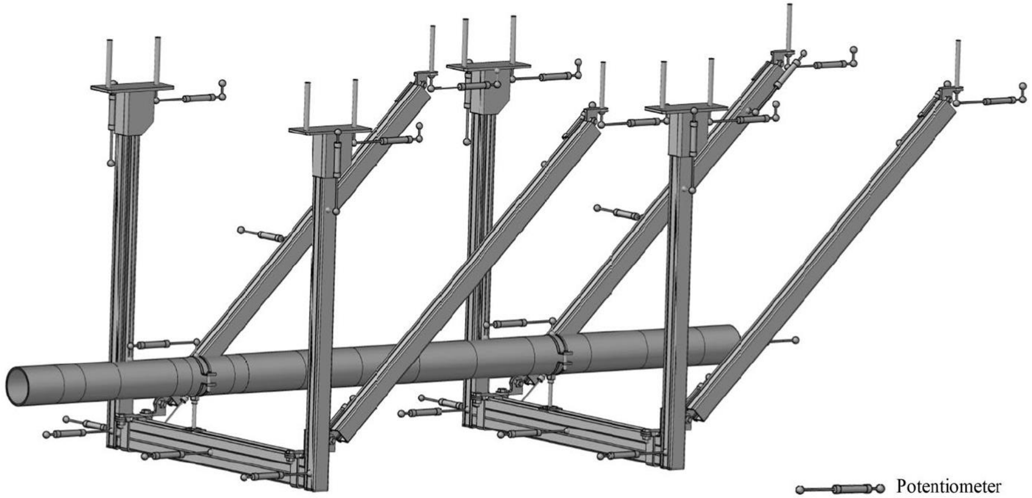
Type of non-structural element	q_a
Cantilevering parapets or ornamentations Signs and billboards Chimneys, masts and tanks on legs acting as unbraced cantilevers along more than one half of their total height	1,0
Exterior and interior walls Partitions and facades Chimneys, masts and tanks on legs acting as unbraced cantilevers along less than one half of their total height, or braced or guyed to the structure at or above their centre of mass Anchorage elements for permanent cabinets and book stacks supported by the floor Anchorage elements for false (suspended) ceilings and light fixtures	2,0

α is the ratio of the design ground acceleration on type A ground, *a*g, to the acceleration of gravity g;
S is the soil factor;
T_a is the fundamental vibration period of the non-structural element;
T_1 is the fundamental vibration period of the building in the relevant direction;
z is the height of the non-structural element above the level of application of the seismic action;
H is the building height measured from the foundation or from the top of a rigid basement.

SEISMIC DESIGN OF NON-STRUCTURAL ELEMENTS

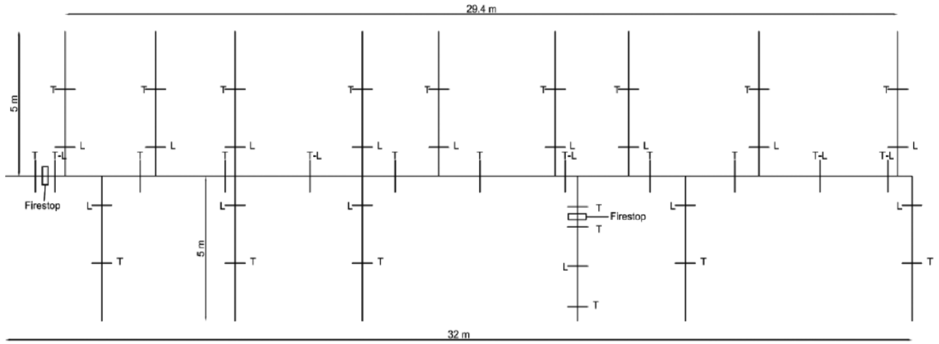
Evaluation of the behavior factor:

- ➢ Experimental characterization of components and assemblies;
- ➢ Nonlinear modeling of archetypes;
- ➢ Calibration of equivalent simplified models;
- ➢ Modeling and analysis of complex systems;
- ➢ Large-scale experimental validation.



D.Perrone, A.Filiatrault, S.Peloso, E.Brunesi, C.Beiter, R.Piccinin(2020) "Experimental seismic performance evaluation of suspended piping restraint installations". Bulletin of Earthquake Engineering, DOI10.1007/s10518-019-00755-5

Channel frame installation

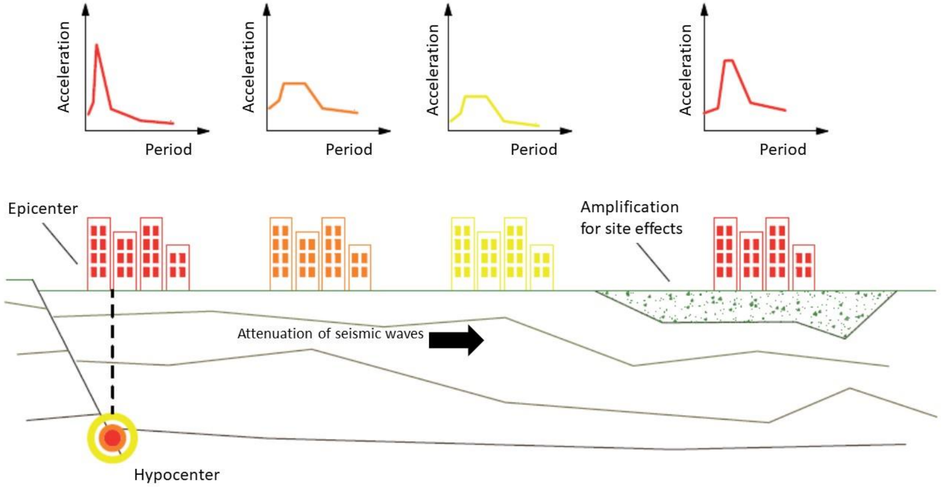


Perrone, D., Rodriguez, D., Filiatrault, A., Brunesi, E., Beiter, C., & Piccinin, R. (2022). A Framework for the Quantification of Non-Structural Seismic Performance Factors. *Journal of Earthquake Engineering*, *26*(16), 8468–8494. https://doi.org/10.1080/13632469.2021.1991516

SEISMIC QUALIFICATION OF NON-STRUCTURAL ELEMENTS

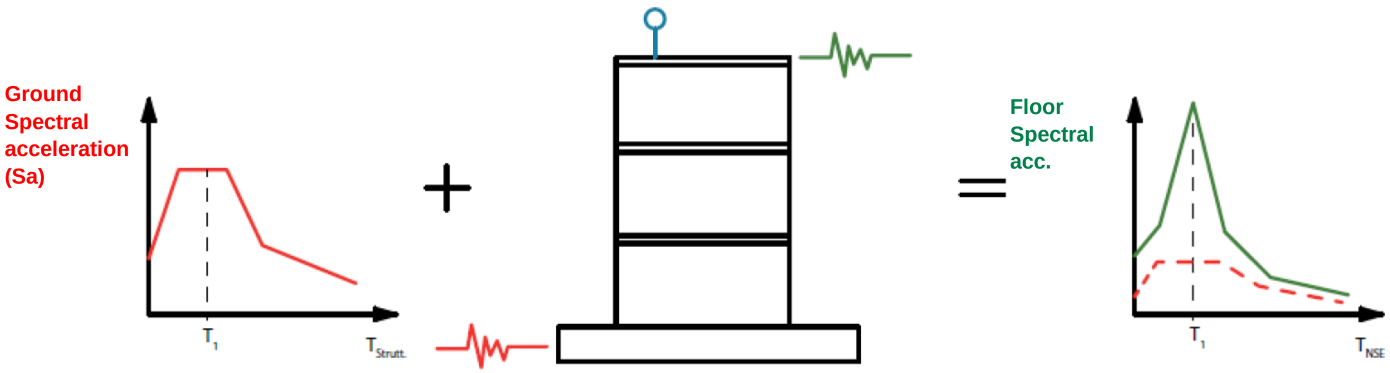
The seismic qualification aims to verify that a non-structural element, or the components of a system, or a system as a whole can satisfy certain requirements with respect to a seismic event.

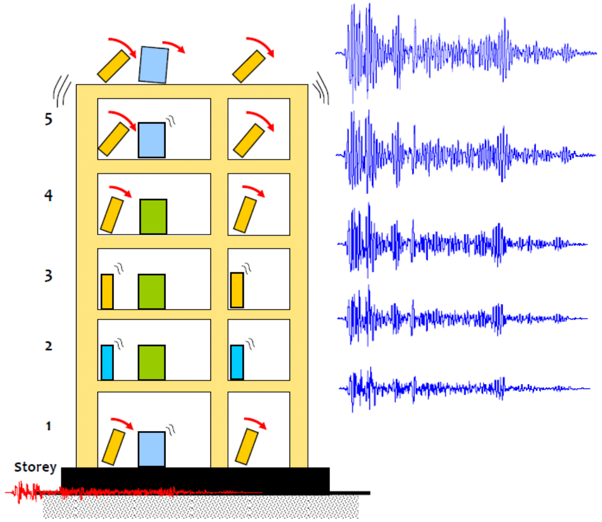
Ground Spectrum vs. Floor spectrum (or at the point of installation)



Sources of modification of seismic waves:

- Ground: hypocenter to building site
- Building: from foundation to installation plan
- Structural or non-structural component: from the installation surface to the anchoring point





SEISMIC QUALIFICATION OF NON-STRUCTURAL ELEMENTS

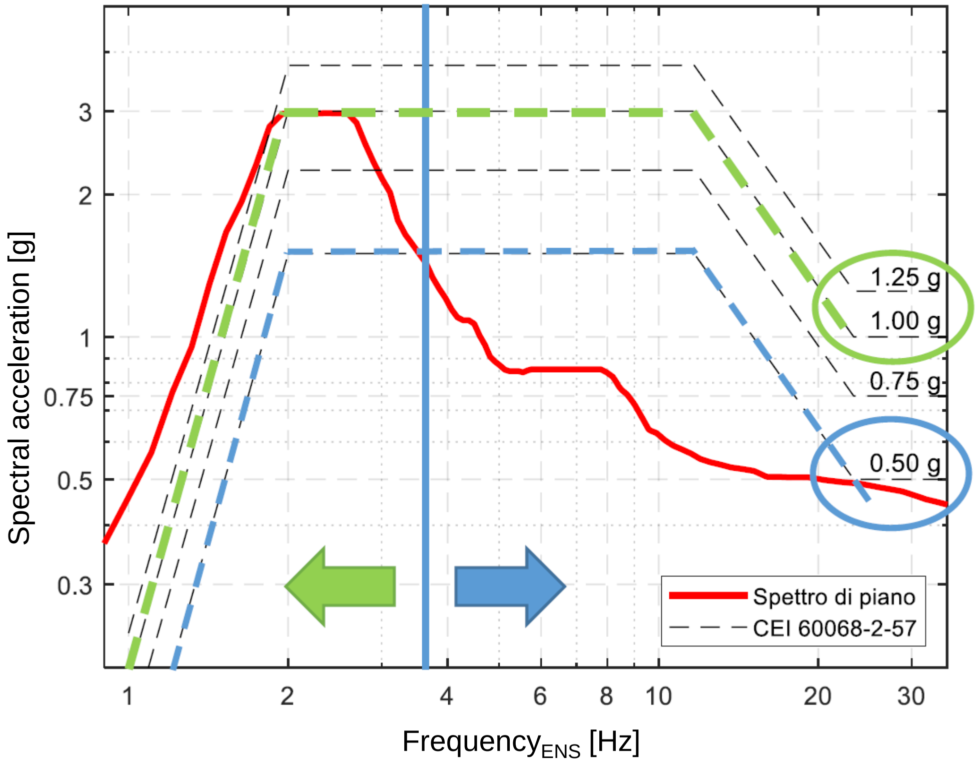
The seismic qualification aims to verify that a non-structural element, or the components of a system, or a system as a whole can satisfy certain requirements with respect to a pre-established seismic input.

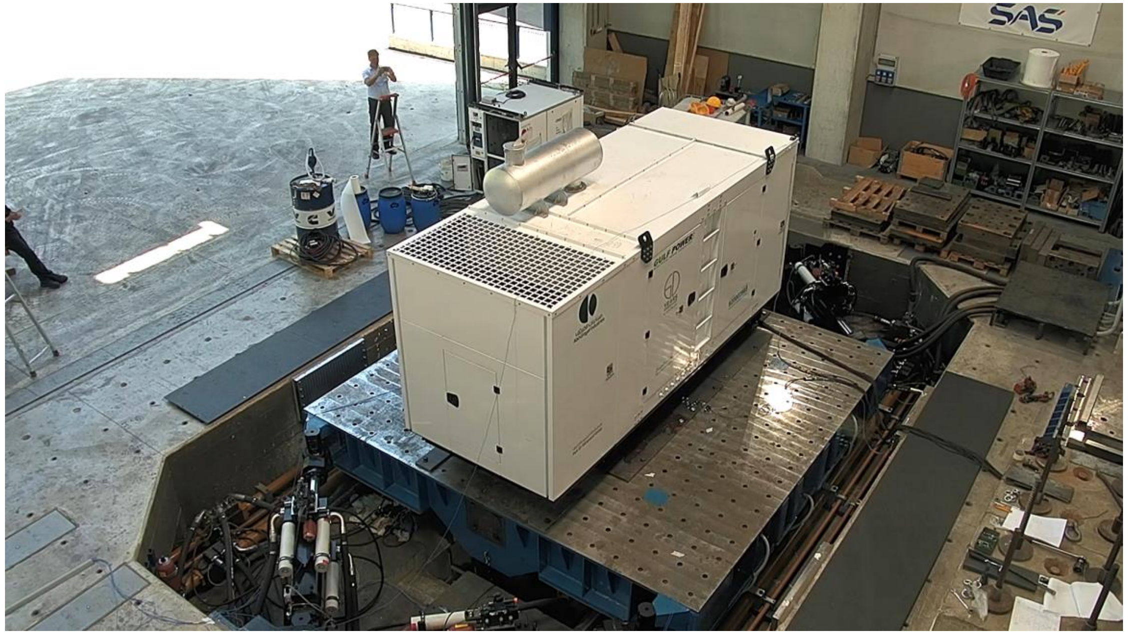
The parameters that influence qualification and which must be known in detail are therefore:

- **Specimen**:
  - dynamic characteristics: mass distribution and stiffness
  - static characteristics: resistance/instability/ductility
- **Boundary Conditions**: anchoring and assembly system, perfectly consistent between tests and reality
- **Input**: Peak Ground Acceleration (PGA) or Zero Period Acceleration (ZPA), spectral shape, frequency range
- **Performance criteria**: design specifications, not required by all standards

SEISMIC QUALIFICATION OF NON-STRUCTURAL ELEMENTS

The design can be resolved by choosing a non-structural element that is qualified with respect to an acceleration spectrum that envelops the floor spectrum, at least around the element's own vibration frequency (evaluated during the seismic qualification).





LEGISLATIVE FRAMEWORK

Below are some reference standards, from the most general to the most specific, relating to non-structural components of an electrical/electronic nature or parts of the building envelope.

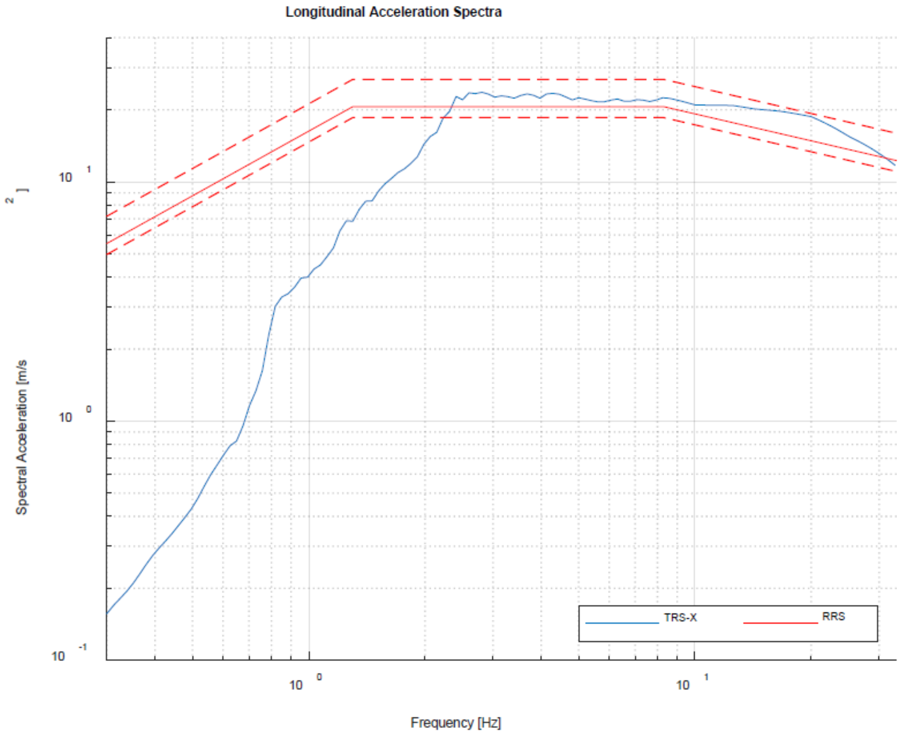
ISO 13033 -2013 Bases for design of structures – Loads, forces and other actions – Seismic actions on nonstructural components for building applications

ICC ES AC-156 Acceptance Criteria for Seismic Certification by Shake-Table Testing of Nonstructural Components and Systems (related to ASCE-7);

IEEE 693-2005 Recommended Practice for Seismic Design of Substations;

IEC EN 60068-2-57 2013 – Environmental testing: Time-history and sine-beat method;

IEC EN 60068-3-3 Seismic test methods for equipment;



LEGISLATIVE FRAMEWORK

Below are some reference standards, from the most general to the most specific, relating to non-structural components of an electrical/electronic nature or parts of the building envelope.

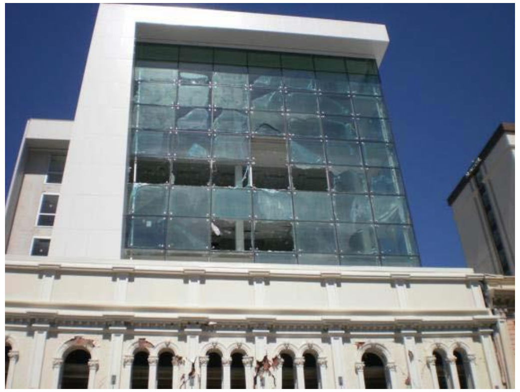
Telcordia -GR-63-CORE; Physical Protection

ANSI/AHRI Standard1271: Requirements for Seismic Qualification of HVACR Equipment;

AAMA 501-4 2018 Recommended Static Test Method for Evaluating Window Wall, Curtain Wall and Storefront Systems Subjected to Seismic and Wind-Induced Inter-Storey Drift

AAMA 501-6 2018 Recommended Dynamic Test Method for Determining the Seismic Drift Causing Glass Fallout from Window, Curtain Wall and Storefront Systems

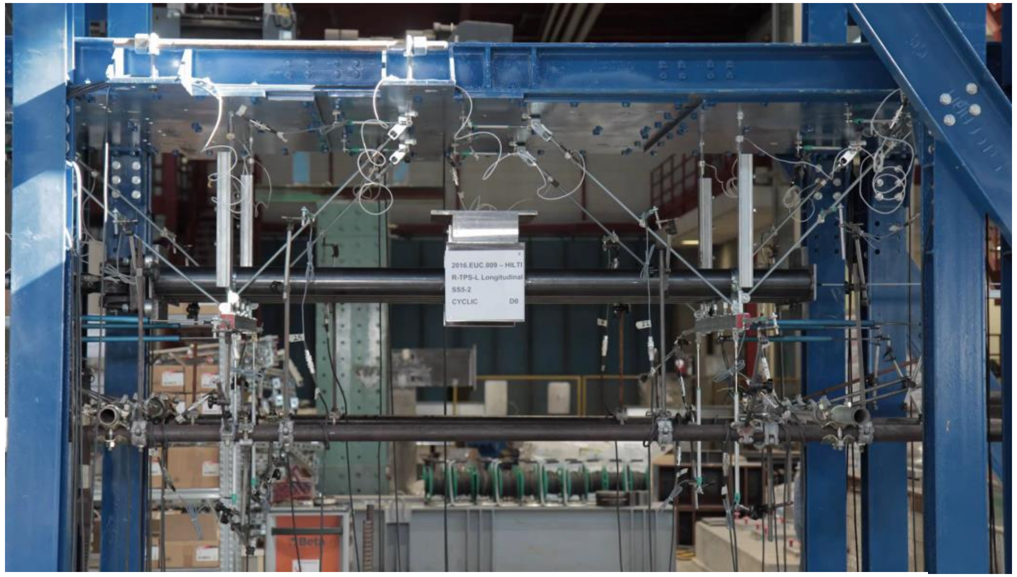
FEMA 461 Interim Testing Protocols for Determining the Seismic Performance Characteristics of Structural and Nonstructural Components

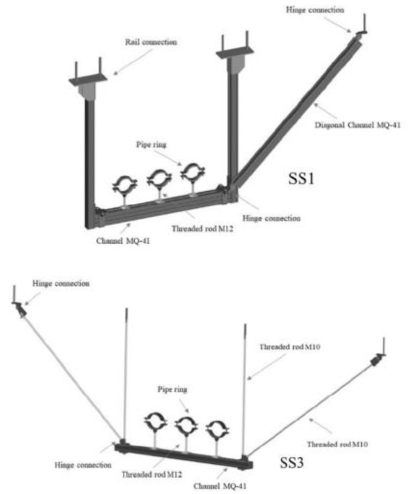


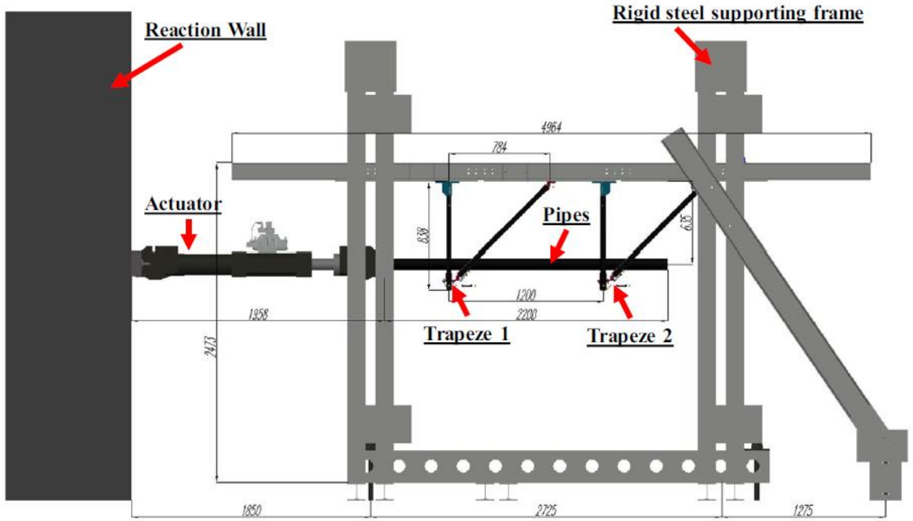
TESTING NON STRUCTURAL COMPONENTS

The experimental set-up to conduct the monotonic and reverse cyclic tests on the selected suspended piping restraint installations consisted of a 3 m high steel frame connected to the strong floor of the laboratory through a system of steel beams and post-tensioned Bars. Two systems were tested:

- *Trapeze with channel with bracing system*
- *Trapeze with rod bracing system*







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TESTING NON STRUCTURAL COMPONENTS

SERA SPIF Project (**S**eismic **P**erformance of multi-component systems in special risk **I**ndustrial **F**acilities)

The objective of the project was the holistic investigation of the seismic behaviour of industrial plants equipped with complex process technology by means of shaking table tests.

The structure is a three-storey steel moment frame with vertical and horizontal vessels, arranged on the three levels with some of them connected to each other by pipes.

SERA
Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe

TESTING NON STRUCTURAL COMPONENTS

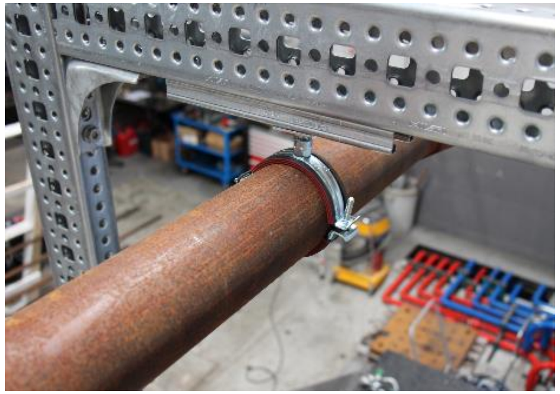
CADS Project (Creating a Safe Home Environment)

Individual tests were carried out on the "smart" and technologically advanced components developed in the project and at the same time a shaking table test was carried out which involves the study in a small building within which the components themselves were installed. The tested building consists of a mobile precast house.

CADS

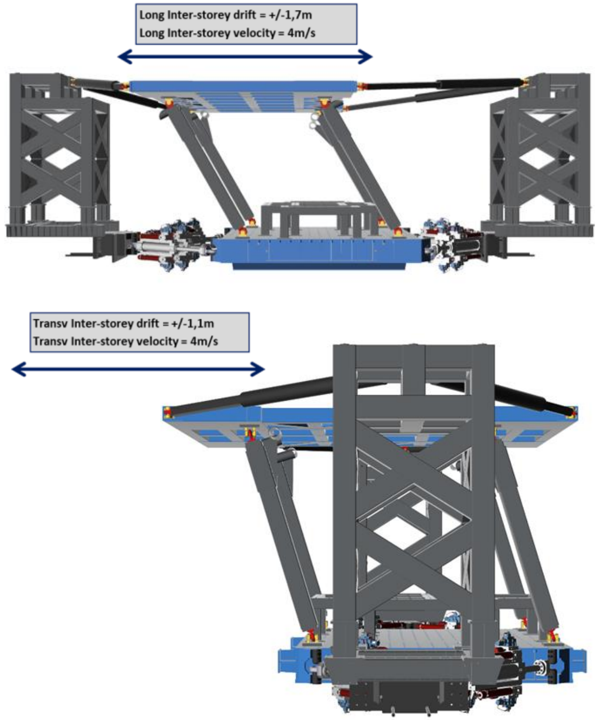
Creazione di un Ambiente Domestico Sicuro

www.progetto-cads.it



TESTING NON STRUCTURAL COMPONENTS

Innovative 9DoF testing system developed at EUCENTRE Laboratories consisting of two overlapping shaking tables controlled to simulate the dynamic behavior of a building sub assemblage when the main structure is subjected to a seismic input.



TESTING NON STRUCTURAL COMPONENTS

THANKS

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