Introduction to Earthquake Engineering

Notes Compiled by: Engr. Abdul Rahim Khan

- **Non-structural Elements**
- Non-structural systems include all the elements within a building that are not part of the primary gravity or lateral force-resisting structure, but are still required for the building to function.
- Examples
- Cladding
- Partitions
- Ceiling Systems
- Lights
- Mechanical Equipment's
- Pipes

- **Categories of Non-structural Elements**

- Broadly, non-structural components can be divided into two categories:
  - Engineered systems, such as ducting, electrical distribution, piping, engineering plant and fire suppression systems.
  - Architectural elements, such as suspended ceilings, internal partitions and façades.

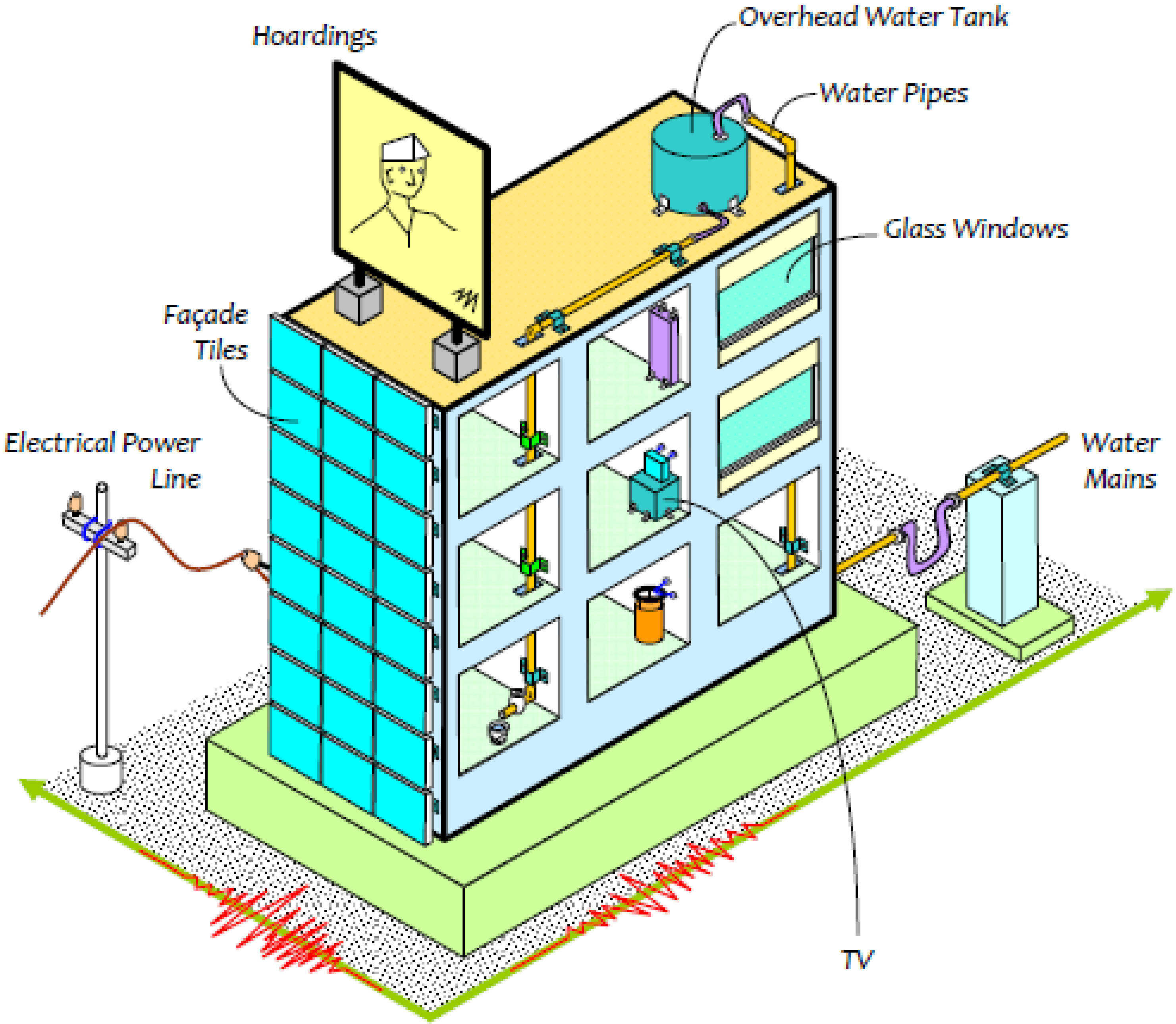
- Non-structural systems with proper designing generally present a low risk to life in a large earthquake.
- However, poorly restrained non-structural systems or components may collapse with a possible risk to life, both inside and outside the building. They can also render the building unusable, leaving the building owner and occupants facing major disruptions.
- When carrying out the seismic design, designers should consider non-structural systems and components to a degree adequate with the risk they pose to the building and its occupants during a seismic event. Non-structural elements should not be viewed as an isolated system to be added once other design aspects of the buildings, particularly the structure, is complete.

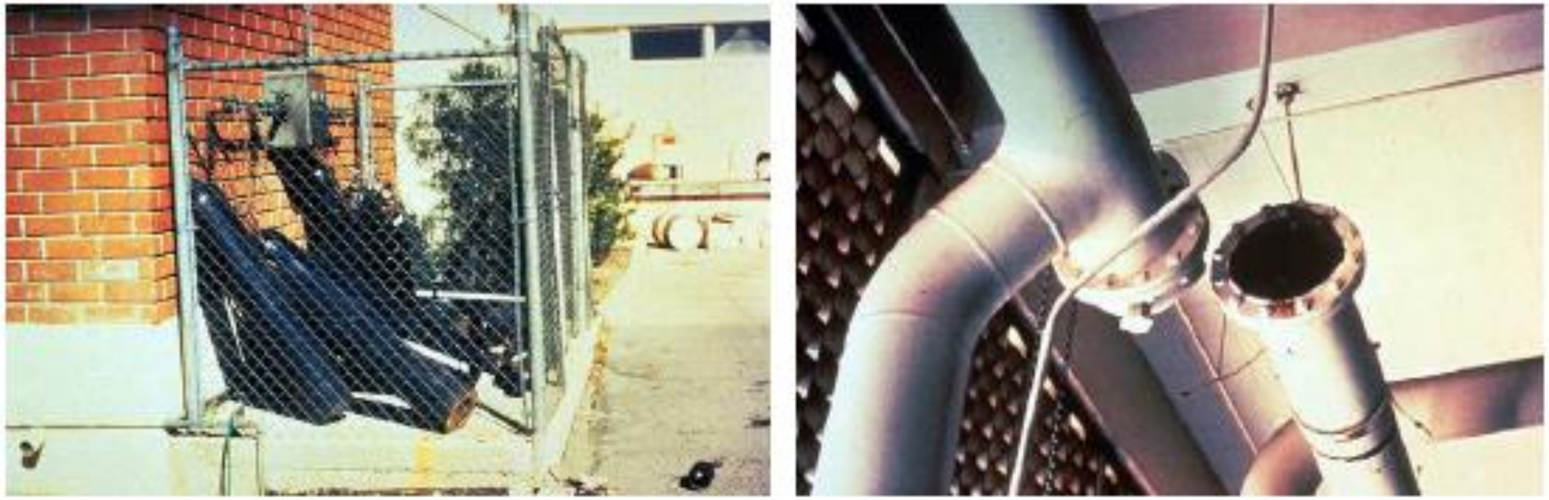
- **Effect of Earthquake on Non Structural Elements**
- Earthquake movement should be expected to influence the following non-structural components of building. Designers should ensure the risks these components represent are properly mitigated in the design.
- **Exterior claddings:**
  - Curtain wall systems (attached to the building at floor levels)
  - Prefabricated panels (sometimes fitted between structural frame members or hung off structural elements)
  - Brick and block veneers (supported at each floor level and fitted between vertical structural elements and the floor above)
  - Masonry veneers

- **Effect of Earthquake on Non Structural Elements**
- **Glazing:**
- Framed glazing fixed between floors or columns or fitted as a horizontal band between spandrel panels
- Structural frameless glazing systems
- **Externally mounted elements:**
  - Decks, balconies and verandas
  - Clip-on or adhered cladding elements and finishes (stone and tile veneer)
  - Sunshades and planters

- **Effect of Earthquake on Non Structural Elements**
- **Glazing:**
- **Floor-mounted equipment**
- **Utility connections (water, power, sewerage, telecommunications)**
- **Shelving and racking**.
- **Suspended ceilings**
- **Stairs and ramps (providing access between floors or carpark decks)**
- **Riser pipes, ventilation ducts, electrical trunking, drainage stacks (running vertically between floors and supported by floors)**
- **Lifts and escalators**
- **Parapets**

- In addition, if the mass of an individual non-structural component exceeds 20% of the combined mass of the component and the building structure, the component may affect the seismic response of the structure. In this case, the structure should be modelled, including the mass of the component.


Hoardings
Overhead Water Tank
Water Pipes
Glass Windows
Façade
Tiles
Electrical Power
Line
Water
Mains
TV



(a)

- **The Protection Strategies**
- Heavy and stiff NSEs are susceptible to sliding, rocking and toppling during earthquake shaking, if UN-ANCHORED, e.g., heavy motor; such NSEs are called Force-Sensitive NSEs (Figure 1a). And, light and flexible NSEs are susceptible to stretching, shortening and shearing, if ANCHORED, and are called Displacement-Sensitive NSEs (Figure 1b).
- Some NSEs are both massive and flexible; such NSEs are susceptible to both force and displacement effects.
- Force-sensitive NSEs are relatively more rugged (by virtue of their manufacture) than displacement-sensitive NSEs. Thus, defiance is the strategy for protecting the former type NSEs and compliance for the latter type.

- **The Protection Strategies**
- This means that in force-sensitive NSEs, the inertia force induced is to be resisted by NSEs ANCHORED to adjoining SEs (Figure 1a); the anchors are designed to have the requisite resisting force capacity. And, in displacement-sensitive NSEs, the expected relative displacement between the two support points of NSE is to be allowed to occur freely without any restraint against the expected deformation, i.e., UNANCHORED to the adjoining SEs; this is achieved by providing required physical space between NSEs and adjoining SEs, or using connectors that permit the expected deformation without allowing NSEs to separate from the SEs (Figure 1b).

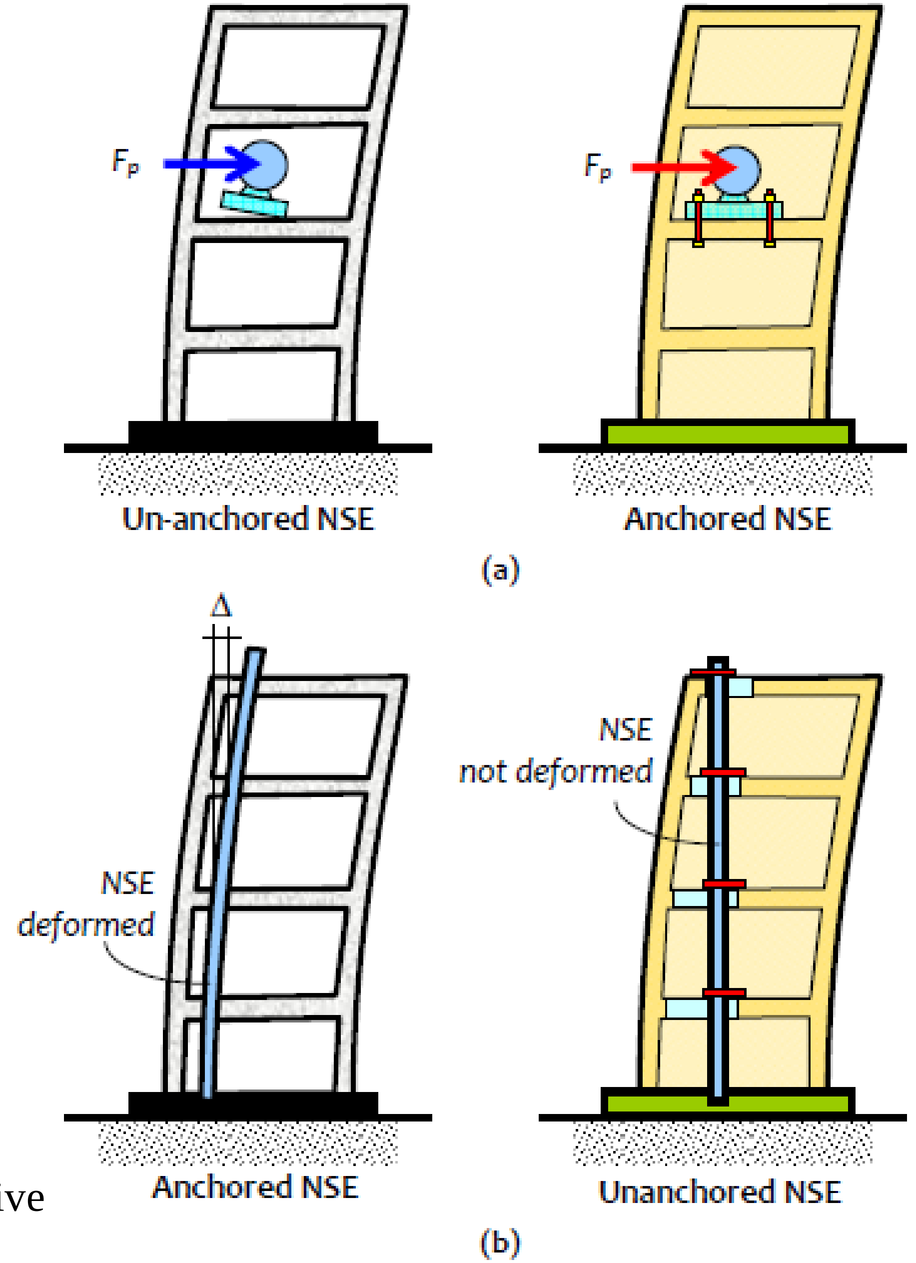


Figure 1: *Strategies for securing NSEs*: (a) Force-sensitive NSEs to be anchored, and not left unanchored, and (b) Displacement-sensitive NSEs to be unanchored, and not anchored

- **Force-sensitive NSEs**
- A force-sensitive NSE (that can rock, slide and topple) can be at any elevation on a building (Figure 2a). They can be secured by connecting them to any SE of the building, namely the vertical elements (like walls and columns), the horizontal elements (like slabs and beams), or both. In turn, these SEs of the building carry the inertia forces of these NSEs along the load path of the structural system of the building down to the foundation. For designing the connectors between the NSEs and the SEs of the building, separate calculations are required when NSEs are anchored to
- (1) Only horizontal SEs of building (Figure 2b),
- (2) Only vertical SEs of building (Figure 2c), and
- (3) Both horizontal and vertical SEs of building (Figure 2d).

- **(a) NSEs anchored only to Horizontal SEs**
- NSEs can topple under lateral earthquake shaking, if they are massive (but not necessarily tall) and do not have adequate width or grip at the base (Figure 3a), e.g., parapets on roof tops, television set placed on table, plastic water storage tanks on roof tops, and machines & generators.
- Sometimes, these NSEs may not topple, but their sliding may cause other losses. Such NSEs can be made safe against toppling and/or sliding by just anchoring them at the base by taking support from the horizontal SEs. Sometimes, NSEs are hung from the horizontal SEs (e.g., a chandelier hanging from the roof slab); they are vulnerable under strong shaking of SE, especially with dominating vertical component.

- **(b) NSEs anchored only to Vertical SEs**
- NSEs that are massive (but moderately tall) can topple under lateral earthquake shaking (Figure 3b), e.g., refrigerators and cupboards. Such NSEs can be secured against toppling by anchoring them just at the top by taking support from vertical SEs. In special cases, even light and short NSEs can be anchored to vertical SEs, e.g., LPG cylinders. These NSEs cannot be tampered with to create a proper grip to anchor them at their bases to horizontal SEs, but have a feature (like the top ring in a LPG cylinder) to enable anchoring them to vertical SEs. Some NSEs may have to be mounted directly on walls from functional considerations, e.g., shelves and flat televisions mounted on walls. Caution is essential to ensure that walls on which such NSEs are mounted, can safely carry the NSEs and resist earthquake shaking in their out-of-plane directions. This is particularly a concern, when NSEs are mounted on unreinforced masonry infill walls. NSEs that are on shelves held against the wall also can be treated as wall mounted.

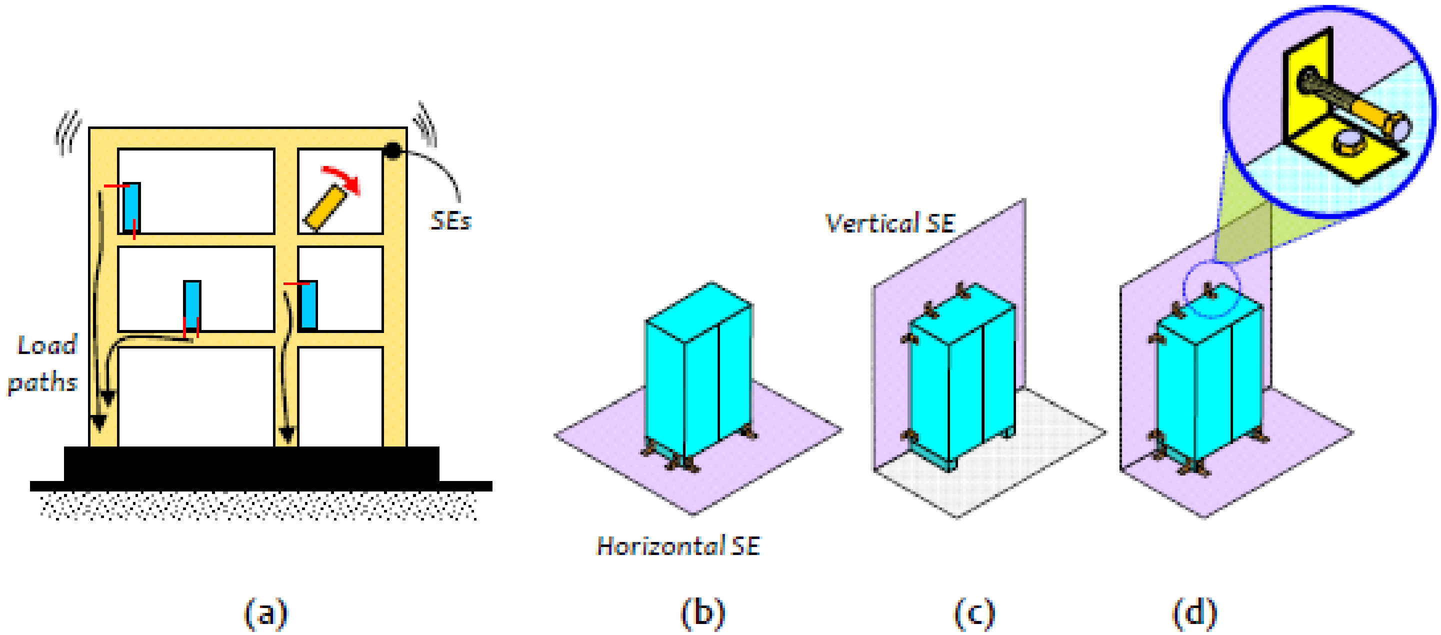


Figure 2: *Securing force-sensitive NSEs*: (a) Safety of NSEs is ensured by connecting NSEs to adjoining SEs of the building, (b) Connecting NSEs to *horizontal* SEs only, (c) Connecting NSEs to *vertical* SEs only, and (d) Connecting NSEs to both *horizontal and vertical* SEs

- **(c) NSEs anchored to both Horizontal and Vertical SEs**
- NSEs that are massive (and tall) can topple under lateral earthquake shaking (Figure 3c), e.g., industrial storage racks stocking raw material or finished products. Such NSEs have a significant part of their mass at higher elevations, narrow width and large height. These factors make such NSEs candidates to topple, because they cannot be made safe against toppling by just anchoring them to horizontal SEs at their bases; supports are required at the upper elevations from vertical SEs also. Some false ceilings are held by both horizontal and vertical SEs.

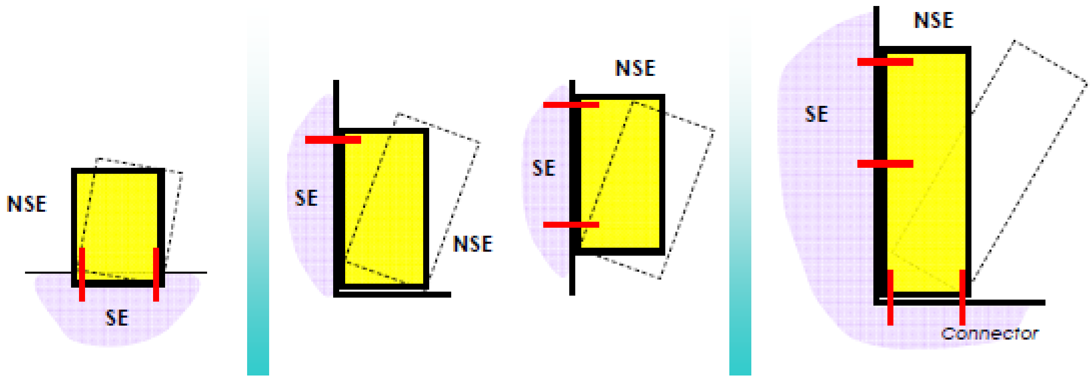


Figure 3: *Anchors to secure force-sensitive NSEs*: Anchor bolts are required to connect NSEs to SEs of the building, (a) Connecting NSEs to *horizontal* SEs only, (b) Connecting NSEs to *vertical* Ses only, and (c) Connecting NSEs to both *horizontal* and *vertical* SEs

- **Important Point**

- When buildings oscillate during earthquake shaking, NSEs mounted on them also oscillate.

- The oscillation causes acceleration, velocity and displacement in NSEs. The intensity and duration of oscillation of NSEs, and the acceleration, velocity and displacement induced in them depend on dynamic characteristics of NSEs, in addition to characteristics of the earthquake and the building.

- In addition, if the mass of an individual non-structural component exceeds 20% of the combined mass of the component and the building structure, the component may affect the seismic response of the structure. In this case, the structure should be modelled, including the mass of the component.

THANK YOU!