Structural design codes define force levels and detailing of structural (force-resisting), as well as non-structural components, e.g. piping, storage racks, equipment. While the likelihood of severe damage and collapse is starkly reduced for structures designed and detailed to modern code requirements, the same cannot be said for non-structural components. The significant vulnerability of non-structural components to even low levels of shaking has been amply demonstrated by evidence from historical earthquake events. This vulnerability poses a hazard not only to operations, but also to employee safety, especially with increasing incidence of man-made, and not only naturally-occurring, seismic activity.

Introduction

Since the current state of knowledge does not allow prediction of location, time of occurrence or magnitude of earthquake events, design, detailing and construction of facilities and their contents to best practice, which is embodied in state-of-the-art structural design codes, is essential to guarantee employee safety and continued operations (resilience).

Structural design codes define force levels, which structures must withstand to minimize damage to the structure due to frequent, low-level shaking and ensure the safety of its occupants in the event of low probability, large magnitude events. Factors such as building occupancy, local soil conditions, height of building, construction material, etc. are considered in defining these force levels. Issues such as overlap of reinforcement, shape and dimensions of hoop reinforcement, length, diameter and configuration of anchor bolts for structural steel beam-column connections, etc. are known as “detailing” and are prescribed in the codes. The design and detailing of structural elements are mostly well-established in engineering practice.

However, another source of earthquake damage and fatalities is non-structural elements. Damage to such components also leads to “secondary” seismic damage such as fire, or even water damage (due to ruptured pipelines), following earthquake. Seismic damage to non-structural elements can occur at much lower levels
of ground shaking than that of structural elements. As with structural elements, detailing, and not only design, of non-structural elements is important to ensure seismic performance, as defined in the structural design codes. However, since many of these components are “off-the-shelf”, i.e. standardized, they are not specifically designed for the actual seismic conditions under which they will be used.

This Risk Topic will focus on issues related to the detailing of non-structural elements and provide examples of some potential mitigation measures.

**What are Structural and Nonstructural Elements**

The structural portions or components of a building are those that resist gravity, earthquake, wind, and other types of loads. These components include columns; beams (girders, joists); braces; floor or roof sheathing, slabs; load-bearing walls (i.e., walls designed to support the building weight and/or provide lateral resistance); and foundations.

The nonstructural portions of a building include every part of the building and all its contents with the exception of the structural portion. For seismic resilience, common nonstructural components include ceilings; windows; office equipment; inventory stored on shelves; storage racks; heating, ventilation, and air conditioning (HVAC) equipment; electrical equipment; furnishings; lights; etc. Typically, nonstructural items are not analyzed by engineers, despite specific requirements in most structural design codes. Such components are typically specified by architects (windows, partitions, fittings, etc.), mechanical engineers (HVAC systems, plumbing, etc.), electrical engineers, or interior designers; or they may be purchased without the involvement of any design professional by owners or tenants after construction of a building.

**Discussion**

Generally, for the purpose of structural design and detailing, the parts of a building can be categorized into two types of components; structural and non-structural.

While the design and detailing of non-structural elements are also prescribed in structural design codes, in reality compliance with these requirements is generally inadequate. Some of the reasons for this are given below:

- The majority of structural design codes follow the “limit state” design philosophy, which focuses primarily on occupant safety. Performance-based design philosophy, on the other hand, focuses on limitation of damage levels and not only occupant safety. The latter approach is gradually increasing in acceptance over the past 20 years, but not yet implemented globally in all structural design codes.

- Details of non-structural components are usually not available during the structural design phase and are procured only during, or even after, construction of the facility. As a result, details such as mass, anchorage details, etc. are approximated or assumed in the design stage of the facility.

- Non-structural components are usually standard “off-the-shelf”, i.e. not specifically designed for local hazards, and are procured based on operational criteria or price.

- Installation of new equipment, either as replacement of existing equipment or due to change in operations, usually does not consider impact on the seismic response of the structure. Modifications to the building structure are sometimes implemented to accommodate new equipment, e.g. removal or addition of walls,
columns, reinforcing elements (Figure 2). Difference in equipment specifications (increase in mass or difference in mass distribution), or location (installation on roof) can also result in changes to the dynamic response of the structure under seismic loading (Figure 3).

Figure 2: Piping (left) is supported by heavy structural steel elements (arrows) rigidly bolted to the columns comprising the force-resisting system. Such supports should be considered in the design stage as they could potentially affect the behavior of the entire building during an earthquake and cause local damage and potential collapse of the columns. Right photo shows pipe supports attached to the columns by means of steel “collars” and not bolts, limiting damage to force-transmitting column [Photo: Zurich Risk Engineering, 2013].

Figure 3: The influence of roof-mounted equipment (circled) on the dynamic response of the buildings is to be considered during the design stage as such equipment can increase building lateral deformation. The force-resisting elements, i.e. beams, walls, etc. must be designed accordingly [Photo: Zurich Risk Engineering, 2013].

Damage to non-structural components can occur in seismic intensity as low as MMI VII (corresponding to ground accelerations 0.9 to 1.8 m/s²). An approximate correlation between the Modified Mercalli Scale classification system, which is a descriptive scale of earthquake intensity, and earthquake magnitude, i.e. energy release of a seismic event, as well as the Japan Meteorological Agency scale (as an example) is provided in the Appendix.

In the regions with PGA over 1.25 m/s², as a general guideline, seismic consideration is required for non-structural components which are needed for life-safety purposes e.g. fire protection sprinkler systems, or components support or contain hazardous substances. In the regions with PGA over 2.00 m/s², seismic consideration is required for all non-structural components. More detail is provided in the Appendix.
When unrestrained items are shaken by an earthquake, inertial forces may cause them to slide, swing, strike other items, or overturn. One common misconception is that large, heavy equipment are stable and not as vulnerable to earthquake damage as lighter ones. However, because inertial forces during an earthquake are proportional to the weight of an object, a heavily equipment requires much stronger restraints to keep it from sliding or overturning than a light one.

During an earthquake, building structures distort, or bend, from side to side in response to the earthquake. For example, the top of a tall building may displace a few decimeter in each direction during an earthquake. The displacement over the height of each story, known as the story drift, might range from a few mm to several cm, depending on the size of the earthquake and the characteristics of the particular building structure. Most architectural components, such as glass panels, partitions, and utility pipeline are damaged because of this type of building distortion.

Another source of nonstructural damage involves pounding between adjacent structures, often two wings of the same facility which allows the structures to move independently of one another. The separation may be only a few cm in older construction or as much as 30 cm in some newer buildings. Flashing, piping, fire sprinkler lines, HVAC ducts, partitions, and flooring all have to be detailed to accommodate the movement expected at these locations when the two structures move.

Guidance

The most cost effective method of implementing seismic mitigation measures is to consider these during the planning stage of a project. Any measures applied during operation of the facility will not only cost more but also disrupt operation.

Besides structural design codes, a large number of best practice guidelines exist pertaining to the design and detailing of non-structural elements. This section will outline some of the issues to be considered during the planning phase of a project as well as for facilities in operation. As already mentioned, structural issues will not be dealt with in this Risk Topic.

**Steel storage racks & floor storage**

**Potential Damages & Causes**

Collapse of racks or fall of contents from the racks cannot only pose a significant threat to employee safety, but also damage to goods and material stored in the racks.

When rack are installed in several rows, failure of one rack can cause progress collapse (domino effect) of other racks.

Main causes of failure of the racks are:

- Inadequate sizing of frame (beam-column) elements
- Poor detailing of connections at the beam-column joints
- Poor anchorage of the racks to the floor slab
- Unapproved modifications to the rack, e.g. shelving configuration or loading
- Poor maintenance, e.g. damage due to forklift impacts
• Incorrect securement of stored material

• Missing frame elements

• Connection of the racks to the building frame, e.g. columns, walls or roof trusses, not accounted for in the design of racks or building.

Figure 5: Pallets (1) can slide off the support beam (2) Light-gauge metal bracing (3), which could be susceptible to buckling. Also, no redundant elements provided (dotted red line), necessary to prevent buckling in columns (blue elements) [Photo: Zurich Risk Engineering, 2013].

Recommendations

• Racks are to be designed and detailed for seismic forces in accordance with national design codes, guidelines or best practice, e.g. FEMA 460, ANSI MH16.1, BRANZ, AS 4084, AS/NZS 4600, etc. This includes all components of the steel racks, i.e. base plates, beam-column connections, columns, beams, etc.

• Provide support bars between the main down-aisle beams under the pallets, to prevent them falling through.

• Test seismic stability of pallets and contents through, e.g. a “pallet tilt test” (BRANZ), which tests the effectiveness of stretch-wrapping, shrink-wrapping, and banding during a shaking event.

• In case shims are used under the base plates the total thickness of these shims shall not exceed 6 times the largest diameter of the anchorage bolts used at that base plate (MH16.1).

• Shims that are a total thickness of less than or equal to six times the anchor bolt diameter under bases where only two anchor bolts are used are to be welded together to allow transfer of shear forces into the foundations (ANSI MH16.1).
Piping & overhead ducts
Potential Damages & Causes

The effect piping and overhead ducts collapse or leakage of pipe content fire can either be a trigger for an explosion or event (gas leakage), environmental contamination, flooding, or loss of firefighting system due to leakage of firefighting water, for example.

- Main causes of damage to piping and overhead ducts are:
  - Swaying and impact of unbraced pipes with adjacent piping or structure
  - Shearing of piping due to lateral forces imposed by the walls during a seismic event
  - Insufficient clearance provided between pipe and wall
  - Incorrect (rigid) filler material between pipe and wall at pipe penetrations
  - Differential lateral displacements between piping and equipment, resulting in damage to the joints and, potentially, to equipment
  - Differential movements between the different parts of the building(s), leading to damage in the piping between the buildings
Recommendations

- Refer to section “Suspended equipment” for bracing of pipelines.

- Provide adequate clearance around piping at wall penetrations. According to NFPA 13, the clearance, i.e. diameter of hole, for firefighting water pipes shall be 50 mm larger than the pipe diameter of pipes between 25 mm to 90 mm and 100 mm larger for pipe diameters larger than 100 mm.

- The filler material between the pipe and wall should have a fire rating equal or greater than that of the wall and flexible enough to accommodate the pipe movements without damage to pipe. Qualification testing is to be conducted according to recognized standards, e.g. UL2079 (with regards to manufacturing as well as testing) or ASTM E1399 (joint cycling requirements). Fire rating of material shall be according to pertinent standards, e.g. EN 1366.

- Connections between piping and equipment are to be carefully detailed to consider the differential movements between these components. Guidance is provided in FEMA E74, for example.

- Consideration is to be given to influence of location of heavy equipment on building shaking levels, e.g. buildings with roof-mounted equipment will be subject to higher lateral accelerations than equipment at lower levels. Piping needs to be designed and detailed accordingly, especially at crossings with building joints. For example, provide bends or flexible joints/piping at building separation joints.

Figure 9: Clearance around piping at wall penetrations. Note the filler material between the pipe and the wall should be flexible and fire rated [Photo: Zurich Risk Engineering, 2013].

Figure 10: Flexible connection between piping and equipment, which can accommodate differential movements due to shaking of equipment and piping [Photo: Zurich Risk Engineering, 2013].
Machinery and equipment

Potential Damages & Causes

• Installation of roof-mounted equipment (Figure 3) or at upper stories, not accounted for during building design, leading to a concentrated mass on top of the building. Heavy equipment at upper levels change the dynamic response of structures (especially structural steel, which tend to be lighter than reinforced concrete buildings) under earthquake loading, leading to larger lateral displacements. As a result, higher demands will be placed on the structural elements, e.g. columns and walls, leading to damage (even in a small seismic event) and even potential collapse (under heavy seismic loading). The effect is the same as that of a “top-heavy” pendulum; the horizontal displacement of the tip of the pendulum is larger with increasing mass under the same horizontal acceleration.

• Floor-mounted equipment are typically non-anchored or connected to the floor with simple screws (not bolts) at the base plate, more for equipment alignment during installation, rather than for anchorage against seismic overturning or shifting. Examples of such equipment include, but are not limited to, long conveyors, electrical cabinets, chiller units, emergency generators, firefighting pumps, pipe racks, air handling units (AHU), etc.

• Shifting of tanks, silos, etc. and connected piping can lead to damage in the pipe-equipment connections. “Sloshing” of the liquid inside silos during seismic shaking results in high internal loading on the silo walls and consequent local buckling of the silo shell, due to inadequate tank wall material thickness and/or strength.

• Inadequate size or inadequate load bearing capacity of foundation can cause displacement or collapse of installed equipment. Examples of such equipment include, but are not limited to conveyors, silos, tanks and etc.
Figure 13: Circuit breakers and insulators in a high-voltage substation are susceptible to seismic damage [Photo: Zurich Risk Engineering, 2013].

Figure 14: Poor (or even missing) equipment-to-floor slab anchorage [Photo: Zurich Risk Engineering, 2013].

Figure 15: Missing straps at the lower third of all cylinders [Photo: Zurich Risk Engineering, 2013].

Figure 16: Alignment screws, to ensure correct installation of equipment on the foundation, are often mistaken for seismic anchor bolts. The former provide no resistance to lateral forces as they are of a different grade (material strength), diameter, etc. than anchor bolts [Photo: Zurich Risk Engineering, 2013].
Figure 17: Missing anchor bolts connecting diesel storage tank to the foundation pedestal [Photo: Zurich Risk Engineering, 2013].

Figure 18: Missing anchor bolts in the supporting frame of a tall piece of equipment [Photo: Zurich Risk Engineering, 2013].

Figure 19: Missing anchor bolts or, if the transformers are on tracks, no toppling restraints on the wheels [Source: Zurich Risk Engineering, 2013]

Figure 20: Unanchored, unrestrained lockers (arrow) can topple and damage adjacent firefighting equipment in the event of an earthquake [Photo: Zurich Risk Engineering, 2013].

**Recommendations**

- For new projects, equipment details are to be provided to the structural designer as early as possible in the project planning phase. This will allow more accurate computer simulation of the building seismic response and, consequently, proper dimensioning of the structural (load-bearing) elements.

- If roof-mounted equipment (or those at upper storeys) is being replaced, ensure that, prior to acquisition of the equipment, a qualified structural engineer conducts an analysis of the building with the specifications, e.g. mass, dimensions, anchorage points and types, of the replacement equipment. Ensure that the effective structural conditions are considered in the structural analysis and not only the parameters indicated from the as-built drawings and original calculations of the building. Especially for older buildings, the effective condition could deviate significantly from the original designs, due to changes in occupancy, processes, operations, structure, etc. The aim of the structural analysis is to determine if the equipment will adversely impact the seismic performance of the building. If this is the case, consider procurement of other equipment or a seismic retrofit and strengthening program, in accordance with the output of the structural analysis and recommendations of the structural engineer.
• Consider installation of seismic dampers under sensitive equipment.

• Besides proper anchorage of the equipment itself, the operation (functionality) of the equipment after the event must be guaranteed. In some countries, e.g. USA, equipment is certified, based on specific testing criteria, for post-earthquake functionality, e.g. Office of Statewide Health Planning and Development\(^1\).

![Battery rack for uninterrupted power supply system, supported by a correctly detailed frame (arrow), anchored to the floor](Photo: Zurich Risk Engineering, 2013).

• Provide anchorage for all floor-mounted equipment with a safety- or production-critical function in accordance with best practice guidelines, e.g. FEMA E74. Foundations are to be designed and detailed to account for the effects of the seismic anchor bolts.

• Seismic anchorage of equipment is to be expressly defined during equipment procurement. Ensure that equipment anchorage is suitable for the shaking conditions expected for the region, as well as for the location of the equipment within a building. For example, electrical cabinets, storage tanks, etc. at upper levels of a multi-storey building experience higher acceleration levels than equipment at lower stories.

• Not only type of anchorage, but also foundation type and details must be considered, especially for tall equipment. Soil conditions must be investigated to determine type, e.g. separate, pile, slab, etc. of foundation and any soil improvement or modification measures required. As an example of the latter; dewatering of ground water levels, soil compaction or replacement, cement injection, vibro-impact (stone columns), etc.

• Substation electrical components are to be designed, installed, tested, commissioned and maintained according to internationally-recognized best practice. Seismic qualification of high voltage equipment must be conducted according to standard IEEE 693 “Recommended Practice for Seismic Design of Substations” or equivalent.

• Movement of liquids inside silos and tanks needs to be considered in their design. Shell material type and thickness, as well as foundation type and anchorage, are some of the characteristics to be considered in the selection of silo of tank. These should meet the seismic demands of the site. Piping connections to the tanks must also consider seismic displacements expected at the location, as defined in national structural design codes.

\(^1\) [http://www.oshpd.ca.gov/FDD/Pre-Approval/index.html](http://www.oshpd.ca.gov/FDD/Pre-Approval/index.html)
Suspended equipment

Potential Damages & Causes

Collapse of suspended equipment cannot only damage the equipment and contents below them but also pose a significant threat to employee safety.

In addition, damage to piping connected to suspended equipment, can lead to fire and flood following earthquake due to impairment of firefighting system or damage of sprinkler piping.

Main causes of damage to piping and overhead ducts are:

- Swaying of unbraced suspended equipment due to tension failure of the suspension rods and supports
- Poor seismic bracing of lightning, which can impact adjacent piping and equipment
- Poorly designed frames of equipment anchored to walls

![Figure 23: Unbraced heavy equipment suspended by long, small-diameter rods (arrow) over piping, some of which transport hazardous material. [Photo: Zurich Risk Engineering].](image)

Recommendations

- All suspended equipment and piping are to be adequately braced according to best practice guidelines or internationally recognized standards, e.g. FEMA E-74, ASCE/SEI 7-10, FEMA P414, etc. Such documents define not only the specifications of bracing rods/wires to be used but also define connection points in terms of locations and number, etc.

- The forces transferred to the load-bearing elements from the swaying elements through the bracing at the anchorage points must be considered. No detrimental effects on the load-bearing elements must occur due to anchorage of anti-sway bracing.
Unreinforced masonry or concrete walls and partitions

Potential Damages & Causes

- Extensive historical evidence exists of poor seismic performance of masonry and block walls. Damage levels range from cracking to total collapse of units creating falling hazards and blocking corridors and exits with debris, resulting in loss of life as well as damage to adjacent equipment and content.

- Where piping, electrical cabinets, storage shelves, or other nonstructural items are attached to partitions, the failure of the partition wall may result in damage to these components.
• Non-load bearing walls or partitions are sometimes installed without considering their impact on adjacent force-resisting elements, e.g. columns. When the separation between the partition and column is inadequate, so-called “short-column effects” are induced in the column, resulting in concentration of forces at specific locations along the column height, which were not accounted in design. This could lead to extensive column damage, increasing the likelihood of building collapse.

• Both lightweight and heavier walls may be damaged by deformations of the building frame if not properly detailed, e.g. provision of a gap with the building. Heavier walls may be damaged directly by the shaking.

• Lack of reinforcement, both vertical through the block cells and horizontal, poor detailing, e.g. large wall panel dimensions (aspect ratio), inadequate gap between wall panel and frame are the main cause of damage to the walls.
Figure 29: Unreinforced masonry exterior panels. Note the firefighting sprinkler water piping attached to the wall. Damage to the wall will result in impairment of firefighting sprinklers due to loss of sprinkler water, increasing the likelihood of fire following earthquake [Photo: Zurich Risk Engineering, 2013].

Figure 30: Potential short-column effects between the openings (arrows). These result in concentration of forces and damage to the columns and walls if the short walls between the openings have not been designed as beams [Photo: Zurich Risk Engineering, 2013].

Recommendations

- Non-load-bearing partitions, brick and concrete block walls are to be designed to accommodate the lateral force and displacement levels (strength and stiffness) defined in the structural design codes.

- The partition must be detailed so that it does not interact with the structural system or other nonstructural elements when the building displaces laterally under seismic according to best practice guidelines or internationally recognized standards, e.g. FEMA E-74. Walls should be self-supported and isolated from the structural framing.

- If the partition is used to provide lateral restraint for other nonstructural items, the wall and its lateral restraints should be adequate to resist the additional loading.

- Locations of partitions and walls within the buildings to be carefully considered. Walls at higher floors are subject to higher acceleration levels and must be designed and detailed accordingly.

- Intermediate columns to be provided to reduce the panel dimensions (length-to-height aspect ratio).

- Guidance for the rehabilitation of existing buildings is provided in some national structural design codes and best practice guidelines. An example of the latter is FEMA 547. Note that special details may be required to meet fireproofing.
Figure 31: Intermediate columns (1) reduce the length of the unreinforced concrete block panels, reducing likelihood of damage. Note the “short-column effect” (2), where the exterior wall does not extend along the entire height of the column, leading to concentration of lateral forces at the top of the wall. This can result in extensive damage to the column and even collapse [Photo: Zurich Risk Engineering, 2013].

**Suspended Ceilings**

**Potential Damages & Causes**

Ceiling failures is not only a potential threat to life safety but also can lead to damage to equipment installed below them. In addition damage to suspended ceiling system can also damage fire sprinklers, leading to water damage or fire following earthquake.

- Swaying of the ceiling system due to lack of lateral bracings, usually leading to collapse.
- Movement of unrestrained piping, mechanical ducts, or lighting in a tightly braced ceiling can also damage the ceiling.

**Recommendations**

- All suspended ceiling are to be adequately braced according to best practice guidelines or internationally recognized standards, e.g. FEMA E-74, ASCE/SEI 7-10, ASTM E580.

- Seismic bracing for suspended ceilings, based on the mentioned code, typically includes a vertical compression strut and diagonally braces. Special perimeter details typically include 5 cm wide perimeter closure angles, fixed attachments on two adjacent walls and clearance of at least 2 cm from the two opposite walls. Penetrations for sprinkler heads in ceilings are required to have a 5 cm oversized opening to allow for free movement of 2.5 cm in all horizontal directions.

- Ceiling anchorage needs to be coordinated with the anchorage or other suspended equipment, e.g. piping, ventilation, and sprinkler lines

**Piping of hazardous materials**

**Potential Damages & Causes**

Damage to piping of hazardous material can lead to fire following earthquake or environmental contamination due to leakage of LPG or other hazardous material from damaged piping.
Main causes of damage to piping are:

- Piping issues, as outlined in a previous section in this document, e.g. swaying due to inadequate bracing, shear of piping due to insufficient clearance at wall penetrations, rigid piping-to-equipment joints, etc.

- Damage of hazardous material piping at a critical location, which contains a fire trigger, e.g. heating tower, or short-circuited electrical equipment.

![Seismic shut-off valve at the site LNG inlet](Photo: Zurich Risk Engineering, 2013)

**Recommendations**

- Emergency response plan must consider shut-off of critical pipelines, which could trigger a fire following earthquake. Power is not to be activated until all pipelines have been checked for leakage.

- Installation of seismic gas shut-off valves is quite common, especially in industrial facilities. The following issues must be noted, however:
  - Device must be certified, i.e. calibrated to activate at a specific range of ground accelerations.
  - As it is installed at the gas meter, which is close to the structure, it must be protected from falling debris.
  - Must be mounted close to the ground otherwise will not “feel” the ground shaking but that of the pipe system (industrial pipes are commonly on racks).
  - Requires installation and regular maintenance by qualified personnel only
  - Existing standard ASCE 25 is dedicated to residential use and does not deal with issues specific to industrial environments such as: venting of pressurized material already in pipeline, control of secondary processes, e.g. shutoff pumps, fault monitoring of back-up power, oils or corrosive fluids, false positives, pipe diameters, pressures, temperatures commonly found in industrial applications.

**Conclusion**

Even low levels of seismic shaking can result in disruption to operations through damage to non-structural elements, e.g. ducts, piping, storage racks, equipment, partitions, façade elements, etc. Collapse of such elements can also pose a significant hazard to employee safety. Such magnitude/intensity events, as low as Modified Mercalli Intensity VII, corresponding to peak ground accelerations of 1.5 m/s², are typically high-probability events, depending on the region.
One of the major causes of such type of damage is that non-structural elements are typically “off-the-shelf”, i.e. not specifically designed for the seismic conditions expected at site. The elements are procured after the building design phase, with cost usually being the decisive criteria, in addition to operational specifications.

To avoid disruption to operations and ensure employee safety to such low-magnitude, commonly-occurring events, it is highly recommended to consider seismic issues at an early stage of the planning process for new facilities. Also, the requirements of national design codes (or best practice guidelines) with regards to non-structural elements are to be adhered to and one of the aspects to be considered during the procurement process, either for new facilities as well as during facility retrofit or equipment upgrade. Early implementation of such simple measures is one of the most cost-effective seismic protection measures.

References

FEMA 460 (2005), “Seismic Consideration for Steel Storage Racks Located in Areas Accessible to the Public”.


AS 4084 (1993), “Steel Storage Racking Standard”

AS/NZS 4600 (2005) “Cold formed steel structures”


Appendices

Table 1: Correlation between Japan Meteorological Agency (JMA), Modified Mercalli Intensity (MMI) and Peak Ground Accelerations.

It is to be noted that such approximate correlations are regional in nature, as they are highly dependent on local features, e.g. geotechnical properties, faulting systems, and so forth. As such, these correlations are to be considered indicative only.

<table>
<thead>
<tr>
<th>The JMA Seismic Intensity Scale</th>
<th>Modified Mercalli Scale of Earthquake Intensity (MMI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>I: Acceleration of 0.02 (m/s²) or less</td>
</tr>
<tr>
<td></td>
<td>Only seismometers detect the earthquake and it is not felt by humans, except in especially favorable circumstance.</td>
</tr>
<tr>
<td>1</td>
<td>II: 0.02 – 0.05 (m/s²)</td>
</tr>
<tr>
<td></td>
<td>A few people might notice the earthquake if they are at rest and/or on the upper floors of tall buildings. Objects that move easily shake.</td>
</tr>
<tr>
<td></td>
<td>III: 0.05 – 0.14 (m/s²)</td>
</tr>
<tr>
<td></td>
<td>Many people indoors, especially those on upper floors or otherwise favorably place, feel the earthquake. Parked cars may rock slightly, but people outdoors might not realize that an earthquake is occurring.</td>
</tr>
<tr>
<td>2</td>
<td>IV: 0.14 – 0.38 (m/s²)</td>
</tr>
<tr>
<td></td>
<td>Most people indoors feel the earthquake. Dishes, windows, and doors rattle. The earthquake feels like a heavy truck hitting the walls. Parked cars rock considerably.</td>
</tr>
<tr>
<td>3</td>
<td>V: 0.38 – 0.90 (m/s²)</td>
</tr>
<tr>
<td></td>
<td>Almost everyone feels the earthquake. Sleeping people are awakened. Small unstable objects are displaced or upset. Pendulum clocks stop, start, or change rate.</td>
</tr>
<tr>
<td></td>
<td>VI: 0.90 – 1.80 (m/s²)</td>
</tr>
<tr>
<td></td>
<td>Everyone feels the earthquake. Many run outside.</td>
</tr>
<tr>
<td>4</td>
<td>VII: 1.80 – 3.40 (m/s²)</td>
</tr>
<tr>
<td></td>
<td>Almost all people run outside. Damage is slight to moderate in well-built buildings; considerable in poorly built buildings.</td>
</tr>
<tr>
<td>Weak 5</td>
<td>VIII: 3.40 – 6.50 (m/s²)</td>
</tr>
<tr>
<td></td>
<td>Even well-built buildings have fairly severe damage. Chimneys and monuments are twisted or brought down. Panel walls are thrown out of frame structures. Sand and mud spurt up and well water may change.</td>
</tr>
<tr>
<td>Strong 5</td>
<td>IX: 6.50 – 12.40 (m/s²)</td>
</tr>
<tr>
<td></td>
<td>Well-built buildings suffer considerable damage and sometimes completely collapse. The ground cracks.</td>
</tr>
<tr>
<td>Weak 6</td>
<td>X: Over 12.4 (m/s²)</td>
</tr>
<tr>
<td>Strong 6</td>
<td>XI: Most buildings are destroyed. The bridges are heavily cracked and destroyed and most structures are destroyed.</td>
</tr>
<tr>
<td>7</td>
<td>XII: The ground surface is wavy with eruptions from underneath.</td>
</tr>
</tbody>
</table>
**Table 2: General Guideline on Requirement of Seismic Protection of Non-Structural Component**

The below table is an overall summary of ASCE7-10 requirement for seismic design of non-structural components of ordinary building (buildings and other structures, the failure of which do not pose a substantial hazard to the community) and it is provided only as a guideline. Refer to national design code for detailed information.

<table>
<thead>
<tr>
<th>PGA</th>
<th>Non-Structural Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 1.25 m/s²</td>
<td>None</td>
</tr>
<tr>
<td>Between 1.25 m/s² and 2.00 m/s²</td>
<td>Components that are required for life-safety purposes after an earthquake, e.g. fire protection sprinkler systems, OR component conveys, supports, or contains hazardous substances.</td>
</tr>
<tr>
<td>More than 2.00 m/s²</td>
<td>Components that are required for life-safety purposes after an earthquake, e.g. fire protection sprinkler systems, OR component conveys, supports, or contains hazardous substances.</td>
</tr>
<tr>
<td></td>
<td>All Components weigh over 180 kg (400 lb) with center of mass below 1.2 m (4 feet) above the floor.</td>
</tr>
<tr>
<td></td>
<td>All Components weigh over 90 kg (20 lb) with center of mass over 1.2 m (4 feet) above the floor</td>
</tr>
<tr>
<td></td>
<td>The pipelines and ducts weigh more than 7 kg/m (5 lb/ft)</td>
</tr>
<tr>
<td></td>
<td>Other components still need to be positively attached (not engineered) to the structure and flexible connections to be provided between the component and associated ductwork, piping, and conduit.</td>
</tr>
</tbody>
</table>
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