Risk Control Guide

Earthquake – Property Protection

Introduction and Scope

Earthquakes are not predictable events. We don't know when they will happen and how severe they will be. Nevertheless, continents continue to move, and seismic activity is inevitable. Loss experience shows that property damage caused by earthquakes can include damage or collapse of structures, shake damage to equipment and often even more damaging is fire or water damage as a result of damage to utilities or hazardous processes.

Earthquake shaking does not usually result in total loss (for example, collapse of a building).The majority of facilities can be quickly returned to production, if ...

- Non-structural damage, including fire protection system damage, is minimized
- Fires are prevented or controlled if leaks of flammable liquids or gases are prevented
- Critical equipment and utilities are not damaged

To this end, it is important to apply the knowledge and experience gained from the past events to those that are still to come.

This guide is intended to provide an overview of practical and procedural measures which can be put in place to mitigate the damage that may be caused by an earthquake, allowing more prompt resumption of business.

This document is divided into the following parts:

1. Chapter One – Seismic consideration for fixed fire protection and piping systems including equipment bracing.
2. Chapter Two – Emergency Response Planning and Business Continuity Planning.
3. Chapter Three – Key considerations for safe building design.
4. Chapter Four – Steps to be taken for mothballed plants in EQ exposed areas.

How Earthquakes act on Buildings.

Earthquake ground shaking submits buildings to quick displacements in every direction, generating inertia forces. Although an earthquake generates inertia forces in all directions, some of them are more critical than others. Since a building is primarily designed to withstand vertical loads under normal conditions (like the building self-weight and the weight of its contents), the additional contribution of the seismic forces to the vertical loads represents a relatively limited increment which does not significantly overstress a building structure. Horizontal seismic forces however are much more critical, as horizontal actions for which a building is typically designed to withstand are of much lower intensity (like wind actions).

These horizontal movements can cause structural damage, but even if the building is sound there can be significant amounts of movement of equipment or swaying of pipes etc which can also lead to substantial damage.

Chapter One – Seismic consideration for fixed fire protection and piping systems including equipment bracing.

A facility that suffers fewer damages during an earthquake is a facility that will recover swiftly, gaining a competitive edge over those that suffer more damages.

The approach suggested by this chapter is to identify critical processes that are needed for the continuity of operations. Amongst these processes, critical equipment should be identified and assessed against the potential to suffer damages during an earthquake. A decision should then be made to which level of protection is needed.

It is important to understand the applicability and limitations of various protection schemes. Some schemes aim at reducing the consequences of failure. These tend to be inexpensive options. Some schemes aim at protecting the functional integrity so that equipment is ready for immediate or continued operation. These schemes may be more complex and expensive.

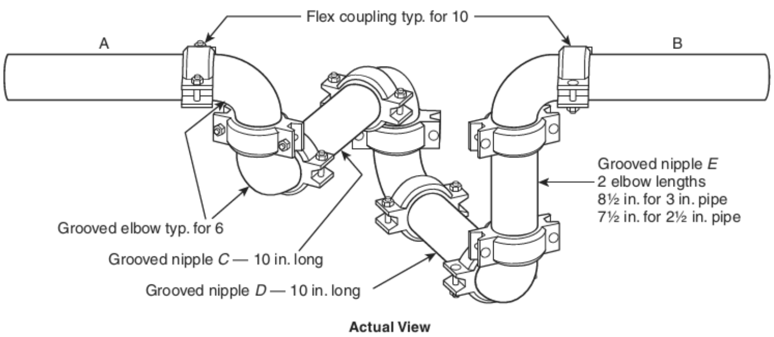
Fire Protection Piping

This category comprises piping associated with fire protection sprinkler systems. Other components including pumps, tanks and control panels are addressed in specific sections of this guide.

Fire protection piping is treated separately from other piping systems as failure leads to extensive impairment of fire protection systems and significantly increases the risk that a fire following an earthquake is not controlled. There is also the potential for significant water damage. Most vulnerable locations are joints, bends, connection to rigidly mounted equipment and risers passing through floors

Mitigation measures include bracing, flexible connections, penetration protections and expansion joints.

- Bracing allows piping to be solidly connected to the building structure (either wall or roof/ceiling) in order to limit its relative dislodgment. In order to achieve this task, bracing is always a combination of transverse and longitudinal supports. Spacing between supports is a key feature and depends on the pipe size, pipe type and seismicity.
- Flexible connections are generally required to accommodate relative displacement in a pipeline, e.g. pipes attached to vibration-isolated equipment and between pipe runs braced to different building structures.
- NFPA13:2019 Chapter 18 outlines installation requirements for seismic protection. Alternative standards are available but insurer should be consulted as to acceptability.



Example of flexible coupling

Boilers, furnaces, chillers, compressors, pump and water heaters

Whether mounted directly to the floor or onto a skid, the most common cause of damage is associated with equipment sliding, when the equipment is secured to the skid, but the skid is not anchored to the floor or the anchorage is not designed to withstand the expected seismic forces.

If equipment is mounted onto vibration isolators, these can fail, causing the failure of the equipment.

While sliding, the equipment breaks connections to pipes, ducts and electrical wiring. A fuel leak could result, leading to a fire.

This equipment should be attached or anchored to the floor and the attachment should be able to withstand the anticipated seismic forces. For equipment requiring vibration isolation, open springs should be used in conjunction with snubbers or bumpers, or restrained springs should be used.

Flexible connections should be provided for fuel lines and piping.

Additional examples can be found in the guidance document FEMA 412 Installing Seismic Restraints for Mechanical Equipment

Storage Tanks

This category covers tanks and vessels supported on legs or flat bottom tanks resting on a concrete pad.

Unanchored tanks will slide, eventually breaking the connection with supply lines. Seismic forces may damage their supporting legs and the tank walls of poorly anchored tanks. Seismic forces cause the sloshing of any liquid content and this leads to an increase in horizontal and uplift forces that cause the failure of the tank wall or base.

If tanks hold flammable liquids, tank failure would likely lead to a pool fire scenario. Failure of nitrogen tanks would impair the safe shut-down / purging of critical processes.

Mitigation measures include adequate vertical and horizontal supports, calculated based on the weight of the tank plus its content. When tank has legs, these should be braced or solidly secured to the tank and to the support. Flexible connections should be provided for piping.

Suspended equipment

This category includes equipment of sheet metal construction, suspended to the ceiling such as gas-heaters, fans, HVAC equipment.

Seismic forces result in equipment swinging and poorly supported items will fall. Connection to fuel lines can break and the resulting fuel leak can start a fire.

In order to limit the potential damages, equipment should be braced to structural elements such as wall or ceiling. Bracing can be by means of steel angle or cable connections, designed for the anticipated seismic forces and displacement. Flexible connections should be provided for fuel lines and piping.

Additional examples can be found in the guidance document FEMA 414 Installing Seismic Restraints for Duct and Pipe

Piping

This category comprises pipes that carries fluids (except fire protection piping).

Seismic forces cause pipes to move. Poorly supported pipes may dislodge, impact adjacent items, crash against penetrations through walls and ultimately break. Fluids leaking from damaged joints or broken pipes are a primary cause of property damage and business interruption. If the fluid is a flammable liquid or gas, a fire/explosion can result.

To limit the potential for a fire following an earthquake, piping carrying hazardous liquids and gases should be provided with seismic shut-off valves / switches or excess flow valves / switches. These devices are designed to detect a range of seismic accelerations and automatically close the valve(s), shutting off the flow of fluids. The valves should be installed outside buildings, to isolate the supply in the case of an earthquake. Smaller diameter pipes can be protected with motion sensor caged ball shut-off valve. These operate when the metal ball falls from a retaining ring due to a seismic accelerations, causing the flow of gas to be blocked by the ball. An alternative is a safety shut-off valve that is linked to a seismic sensor. These can be used for a variety of pipe sizes, gases and liquids, and can be arranged to close multiple valves from one sensor, or can require activation of two sensors to close the valve (double-knock).

Industrial Storage Racks

This category includes typical pallet storage racks found in warehouse and storage areas.

Industrial storage racks can slide horizontally in an earthquake and if any component fails, these can collapse. Stored components can be dislodged by the seismic forces and can fall.

Mitigation measures include the provision of storage racks designed for seismic resistance. Alternatively, existing racks can be improved by suitably designed, horizontal and vertical bracing, base plate anchorage and additional connectors.

Control panel, MCC, switchgears

This category comprises fixed electrical installations generally housed inside metal cabinets whose footprint is relatively small compared to the height and overturning is very likely.

If the cabinet slides or topples, internal components will be damaged and electrical connection will break. This results in a loss of functionality and could start an electrical fire. The resulting business interruption can be severe.

Mitigation measures include anchorage the cabinet to the floor and/or bracing it to walls. Flexible connections are generally recommended between the equipment and any raceway, bus duct or conduits that are braced to other building structures like walls or ceiling.

If equipment is set on a raised floor, anchoring should secure the equipment to the building structure below the raised floor.

Additional examples can be found in the guidance document FEMA 413 Installing Seismic Restraints for Electrical Equipment, freely available from internet.

Chapter Two – Emergency Response Planning and Business Continuity Planning.

The suggested approach to planning and preparation should be consistent with an organisation Crisis Management Plan. This should address the evolution of a crisis over an initial Emergency Response to prevent loss of life, minimise injuries and property damage. This is generally followed by the implementation of Business Continuity Plans, to resume critical operations at an emergency or alternative site. The Crisis Management plan continues to ensure full recovery of operations. RSA Risk Control documents for Emergency Organisation (RCG001) and Business Continuity (RCG020) are available for reference.

Plant Emergency Organisation

After a seismic shake, typically the local Public Fire Department is not in the position to ensure a prompt intervention focused to the site, due to the simultaneous occurrence of multiple emergencies over a vast area, which will drive their intervention toward the most critical emergencies only. For this reason, the role of the Plant Emergency Organisation becomes very important in preventing and controlling on-site fires.

In case of earthquake, following the shake and giving the priority to the evacuation and rescue of personnel, the site emergency organisation should be focused on shutting off all utilities and other hazardous systems present on-site (gas distribution, electrical supply excluding fire pumps feeds, centralised flammable/hazardous fluid or gas distribution, etc.). Also, assess condition of the various areas (as far as it is safe to do so) for any sign of or damages and/or fire ignition, verify the condition of fire protection systems by excluding any damaged part that might be present, ensuring proper operating condition to the remaining ones, and fight any fire that might be developing, if safe to do so. Some site emergency personnel may need to leave the site to deal with emergencies at home, which should be taken into account in overall planning.

Contingency Plans

When safe access to buildings is determined, recovery actions are started by proceeding with the assessment of the damages to building structure and production equipment and planning for repairs to be completed. To manage this phase, an effective contingency plan should be already available. This should refer to both internal resources and original manufacturers, external suppliers of proven availability and efficiency, also identifying alternative sources, considering about the possible unavailability of some of the site personnel and of external suppliers as consequence of the seismic event.

Business Continuity Plan

Several standards have been developed and resources are freely available on the internet to initiate and manage Business Continuity efforts.

NFPA1600 and ISO22301 are the internationally recognized standards, with online resources provided for example by RISCAuthority's Business Continuity suite Robust (https://robust.riscauthority.co.uk/) or the IBHS tool kit Open for Business-EZ (https://disastersafety.org/business-protection/ofb-ez/).

Regardless the level of maturity of your business continuity plans, every organisation exposed to earthquakes should carefully define the physical and geographic reach of the plans, as earthquakes tend to impact large regions, closing portions of major roads and railways, disrupting phone/broadband lines, damaging utilities, destroying power stations and power lines. Employees might be restricted from coming back to work.

Chapter Three – Key considerations for safe building design

The response of a building to seismic actions is influenced by various factors such as;

- the material used for construction
- type and characteristics of loads bearing structural elements and of associated connecting systems
- geometrical characteristics of the building, type of foundation, presence of building joints, etc.

A structural engineer can evaluate the building seismic behaviour by completing a detailed seismic calculation analysis that includes all these factors. This is a highly specialist procedure, requiring a lengthy data collection and calculations. However, a qualitative evaluation of the vulnerability of a building to a seismic shaking can be estimated by gathering basic information like the type of material used for construction and type of structural model adopted.

For instance, steel construction generally shows lower vulnerability to earthquakes, mainly due to the lower mass of the structural elements, if compared to masonry or concrete construction, which significantly reduces the magnitude of the generated seismic forces. In addition to this, the structural elements may be deformed by the seismic actions without losing their bearing capacity (ductile behaviour).

If compared to steel buildings, reinforced concrete (RC) constructions are penalised by a significantly higher mass (which increases the magnitude of the seismic inertia forces). However, a proper design of the building (implying an engineered design and distribution of steel reinforcement) means RC buildings may be able to absorb deformations without losing their bearing capacity, thanks to the ductile characteristics of the steel rebar, thus experiencing possible damages to non-structural elements, but preventing a collapse.

Precast concrete (PC) constructions are characterized by a relatively high mass, and by a non-ductile behaviour. The various precast parts composing the building structure (columns, beams, decks, etc.) are essentially rigid elements connected by joints (often being simple supports or bolted connections) allowing large deformations of the structure with little or no ductility resource. Unless special measures are taken (like properly cast-in-place connections, or other specific seismically designed joint reinforcements), PC buildings are normally very sensitive to earthquakes, and potentially exposed to severe damage. A detailed structural analysis is needed to verify the adequacy of a PC building's resistance to seismic events.

Masonry buildings rely on load bearing brick walls (typically clay or concrete bricks) to resist seismic actions. Such construction typically has a low seismic resistance, due to the relative mass of the building and to the limited ductile behaviour of the brick walls. The seismic performance of such buildings is increased if walls are provided with steel reinforcement. In case of earthquake, masonry buildings are potentially exposed to significant losses. A detailed structural analysis is needed to verify the adequacy of a masonry building's resistance to seismic actions.

Other Factors: Beside the type of material used for construction, other characteristics of the buildings may influence their response to an earthquake.

These are related to;

- irregular shape of the construction
- improper type of foundations
- vertical discontinuities in multi-story buildings
- type and distribution of vertical bracings and shear walls
- type of connections between vertical and horizontal structural elements
- presence and distribution of expansion joints.

Specific calculations are typically needed to determine their actual impact on the seismic behaviour of the building.

Buildings Structural Retrofitting: For constructions located in seismic areas, in absence of specific documentation certifying the seismic design of the building in accordance to the local building codes, a structural seismic evaluation of the buildings is recommended. Priority should be given to buildings considered more critical for the site operations, and to those which type of construction is potentially more vulnerable to earthquakes, or show deficiencies or irregularities.

Upgrade solutions may be different from case to case. These are often invasive upgrades with a commensurate cost, especially in cases where a widespread upgrade to the structural elements is required.

Typical actions include:

- the installation of additional vertical/horizontal bracings (typical for steel, RC and PC constructions)
- the erection of new shear walls (RC and PC constructions)
- the upgrading of the connections between structural elements (PC, wood and masonry constructions)
- the reinforcement of columns (RC/PC constructions), the reinforcement of walls (masonry construction), etc.

Retrofitting actions described above do not eliminate the possibility of damage; instead their purpose is to prevent severe damage to the building, or its collapse, in the event of a major seismic event.

Non-structural Seismic Construction Upgrades

An earthquake often causes numerous and extensive damage to non-structural building elements.

Damage includes non-bearing walls, internal partitions, suspended ceilings, window frames, eaves, roofing, building finishing, etc. Differently from the main building structure, non-structural elements are often not specifically engineered to resist seismic forces, and often suffer damages in case of moderate or even low intensity seismic shakes. This can impact production activity even when no damages are recorded to the main building structure.

Assessing the increased probability of moderate to strong seismic events compared to major earthquakes, helps to understand why upgrades to non-structural elements can be of significant benefit even if the upgrades won't allow the elements to withstand a major earthquake.

Conversely from assessment of the main structure of a building, a seismic upgrade of non-structural elements typically does not require sophisticated calculations. The retrofitting actions are often simple and easy to be completed, with a reasonable economical investment. These include the installation of additional anchoring elements, the fastening of loose parts, installation of bracings, and so forth.

The purpose of the retrofitting of non-structural elements is to reduce to a minimum any damage that could be experienced as consequence of a moderate or strong seismic shake, to allow the prompt restoration of the site activities soon after the emergency, provided existing or alternative building are still available.

Chapter Four – Steps to be taken for mothballed plants in earthquake exposed areas

In case of earthquake, plants which are temporarily shut down or idle have a higher chance of suffering post-shake losses, as they typically cannot rely on a prompt emergency intervention, due to the lack of an on-site emergency organisation, and a likely delayed intervention from the Public Fire Department.

Thus it is imperative for such plants to set up a good loss prevention program. Provide utility equipment, production machinery, tanks, racks, sprinklers and fire water supplies with proper anchoring to ground. Conditions of fire protections should be checked on regular basis to ensure about their efficiency. All fire and anti-intrusion alarms should be maintained in operating condition, with alarms relayed to a constantly attended location.

To reduce the chances of fire ignition, flammable materials should be removed from the site, and plant utilities not required to be in operation (gas supply, electrical supply, hazardous systems, etc.) should be safely shut off and isolated, including draining down of tanks and piping systems.

An emergency plan should also be established for plants that are shut down or idle. In case of a seismic event hitting the site, complete a survey of the site as soon as possible (regardless to the lack of any alarms received from the plant), to verify if and what damages have occurred, and trigger emergency actions as needed, and start recovery plans.