Seismic Restraint of Engineering Services

Introduction

Despite Australia's seemingly low seismic risk, being in the middle of one of the earth's larger tectonic plates, we have been subjected to 17 earthquakes registering 6 or more on the Richter Scale in the last 80 years. There have been six major earthquakes recorded in South Australia;

- 1897 Beachport M6.5
- 1902 Warooka M6.0
- 1954 Adelaide (Darlington) M5.5
- 1986 Marryat Creek M6.0
- 2012 & 2013 Ernabella M5.7

Seismologists advise that based on local geology earthquakes of up to Richter magnitude M7.5 can occur in South Australia however earthquakes of such a magnitude are very rare.

Experience from around the world shows that failure of engineering services as a result of an earthquake can have a significant effect on life safety and economic loss. The seismic loads that engineering services must be designed to resist are calculated using Section 8 of AS 1170.4 - 2007 Structural design actions Part 4: Earthquake actions in Australia. The standard requires that engineering services be designed to resist earthquake forces except where the services are located in domestic structures less than 8.5m tall and "Importance Level One" structures. The Standard is applicable to equipment mounted on structures as well as on the ground, such as high voltage circuit breakers, transformers and tanks.

The aim of this Guidenote is to make designers aware of the:

- Requirement to restrain engineering services against seismic forces in accordance with Section 8 of AS 1170.4 - 2007;
- Requirement that the seismic bracing of engineering services be documented in detail in the tender drawings and specification on DPTI projects and that the Lead Professional Service Contractor is required to co-ordinate this work across all disciplines;
- Technical information available to assist in designing and detailing the seismic restraint of engineering services.

The following items are excluded from the scope of this Guidenote:

- The restraint of engineering services in an importance level 4 building as a special study is required to be carried out to ensure they remain serviceable for immediate use following the design event for importance level 2 structures (1 in 500 year earthquake).
- Suspended ceilings.
- Building contents including portable appliances.

Definitions

- Anchor – A fastener installed into concrete used to transfer seismic forces.
- Brace – An element of the restraint system used to transfer seismic force from a component to the supporting structure.
- Domestic structure – Single dwelling or one or more detached dwellings complying with Class 1a or 1b as defined in the National Construction Code.
- Ductile material – flexible and tough material, eg: steel, copper, aluminium.

- Importance Level – The classification of the building on the basis of its consequences of failure.
- Non-ductile or brittle material – easily broken or fragile materials, materials unable to deform plastically after yielding. eg: cast iron, plastic.
- Non-structural elements – those parts of a building that do not lie in the primary load-bearing path of the building and are not part of the seismic resisting system.
- Supporting structure – The primary earthquake resisting structure of the building.

Design Responsibility

When designing a building the role of engineering services in protecting life and property and providing safe egress from the building, as well as the seismic resistance of engineering services, needs to be considered. One of the common problems in achieving compliance with AS1170.4 - 2007 in regard to engineering services is identifying who is responsible for ensuring compliance. There is no clear answer for the responsibility of many non-structural seismic design issues. In order to help designers determine who might best be allocated responsibility for engineering services the following table is provided as a guide only. Lead Professional Service Contractors may wish to use this guide in establishing contractual relationships within their team. Regardless the Lead Contractor has overall responsibility and must ensure that the requirements of Section 8 of AS1170.4 - 2007 and this Guidenote are met.

Table 1: Design responsibilities for restraint of engineering services to comply with AS1170.4-2007 *(Extract from FEMA 454 table 9-3)* Note: 1 = Primary Responsibility 2 = Support Responsibility

Engineering Service	Architect	Structural Engineer	Electrical Engineer	Mechanical Engineer	Other Design Professional
HVAC systems	2	2		1	
Plumbing systems	2			1	
Plumbing equipment	2	2		1	
Communication and data systems	2		1		May consider a specialty consultant
Electrical equipment	2	2	1		
Vertical transportation systems	2	1	2	2	
Emergency power supply	2	2	1	2	
Fire protection systems	2		2	1	May consider a specialty consultant
Kitchen systems	1	2			May consider a specialty consultant
Lighting systems	2		1		
Medical systems	1	2	2	2	May consider a specialty consultant
Tanks and vessels	2	2		1	
Other:					
Suspended ceilings	1	2			

Methodology

The suggested steps to design and document the requirements for seismic bracing of engineering services to AS1170.4 - 2007 are as follows.

Building importance level and earthquake annual probability of exceedance

Establish the importance level of the building using the definitions given in Table B1.2a of the National Construction Code (NCC). A discussion should take place with the project team and the importance level be confirmed with the Lead Agency as being appropriate for their intended use of the building.

Table 2: Combination of tables B1.2a and B1.2b from the National Construction Code.

Importance Level	Building Type	Examples of building types	**Earthquake** Annual probability of exceedance
1	Buildings or structures presenting a low degree of hazard to life and other property in the case of failure.	Farm buildings. Isolated minor storage facilities. Minor temporary facilities.	1:250 years
2	Buildings or structures not included in Importance Levels 1, 3 and 4.	Low rise residential construction. Buildings and facilities below the limits set for Importance Level 3.	1:500 years
3	Buildings or structures that are designed to contain a large number of people.	Buildings and facilities where more than 300 people can congregate in one area. A primary school, secondary school or day care facility with a capacity greater than 250. Colleges or adult education facilities with a capacity greater than 500. Health care facilities with a capacity of 50 or more residents but not having surgery or emergency treatment facilities. Jails and detention facilities. Any occupancy with an occupant load greater than 5000. Power generating facilities, water treatment and wastewater treatment facilities, any other public facilities not included in Importance level 4.	1: 1000 years
4	Buildings or structures that are essential to post disaster recovery or associated with hazardous facilities.	Buildings and facilities designated as essential facilities or having special post disaster functions. Medical emergency or surgery facilities. Emergency service facilities: fire, rescue, police station and emergency vehicle garages. Utilities required as backup for buildings and facilities of Importance Level 4. Designated emergency shelters, centres and ancillary facilities. Buildings and facilities containing hazardous materials capable of causing hazardous conditions that extend beyond property boundaries.	1:1500 years

Forces on engineering services

Having determined the Importance Level of the building now determine whether seismic bracing of engineering services is required and the method to be used to calculate those forces.

Table 3: Summary of Earthquake Force Calculations based upon Building Description and AS1170.4 - 2007

Building Description	Does AS1170.4 Section 8 Apply?	Earthquake Force calculation
Domestic dwellings with h ≤ 8.5m	No	Fc = 0
Domestic dwellings with h > 8.5m (Class 1a or 1b)	Yes	Treat as for Importance Level 2 buildings
Importance Level 1 buildings	No	Fc = 0
Importance Level 2 and 3 buildings with height ≤ 15m	Yes	Fc = 0.1 x Wc for non-brittle parts and components as per section 5.4.6 of AS1170.4 - 2007.
Importance Level 2 and 3 buildings with height > 15m	Yes	Refer Section 8.2 or 8.3 of AS1170.4 – 2007 for more detailed calculations.

Where AS1170.4 Section 8 does not apply no further consideration is required. Should Section 8 apply then proceed to review the engineering services design.

Review the engineering services design

Review the mechanical and electrical services design to determine which services do and do not require seismic restraint.

In accordance with AS1170.4 - 2007 the following services **always** need to be provided with seismic restraints in Importance Level 2 and 3 buildings:

- Smoke control systems.
- Emergency electrical systems (including battery racks).
- Fire and smoke detection systems.
- Fire suppression systems (including sprinklers).
- Life safety system components.
- Boilers, furnaces, incinerators, water heaters, and other equipment using combustible energy sources or high energy sources, chimneys, flues, smokestacks, vents and pressure vessels.
- Communication systems (such as cable systems, motor control devices, switchgear, transformers and unit substations.
- Reciprocating or rotating equipment
- Utility and services interfaces
- Anchorage of lift machinery and controllers
- Lift and hoist components including structural frames providing support for guide rail brackets, guide rails and brackets, car abd counterweight members
- Escalators

- Machinery (manufacturing and process)
- Lighting fixtures
- Electrical panel boards and dimmers
- Conveyor systems (non personal)

Ducts and piping distribution systems also need to be provided with restraints/bracing to resist seismic loads **except where they are below the thresholds set in AS1170.4**. The thresholds below which duct and piping distribution **do not** need to be seismically restrained are:

- Gas piping less than 25mm inside diameter.
- Piping in boiler and mechanical rooms less than 32mm inside diameter
- All other piping less than 64mm inside diameter.
- All electrical conduit less than 64mm inside diameter.
- All rectangular air-handling ducts less than 0.4m^2 in cross sectional area.
- All round air handling ducts less than 700mm in diameter.
- All ducts and piping suspended by individual hangers 300mm or less in length from the top of the pipe to the bottom of the support for the hanger.

Note that if a straight run of duct starts at 0.2m^2 at one end and grows to greater than 0.4m^2 at the other end then the whole run should be braced, not just the section over 0.4m^2. The same applies where the hanging distance varies from less than 300mm to more than 300mm in a straight run.

Review engineering service clearances

Separation between services and between services and walls or services and ceilings is an important consideration in ensuring damage in an earthquake is minimised, whether services are braced or not. Such service clearances need to be allowed for in the design and shown on the tender drawings. The following minimum clearances are recommended as a guide.

Table 4: Minimum clearances (Part extract from NZS 4219:2009 Table15)

Condition being considered	**Minimum clearance**	
	Horizontal	**Vertical**
Unrestrained component to unrestrained component (where allowed by AS1170.4 - 2007)	250mm	50mm
Unrestrained component to restrained component	150mm	50mm
Restrained component to restrained component	50mm	50mm
Penetration through structure such as walls or floor	50mm	50mm
Unrestrained services passing through the ceiling	25mm	25mm
Sprinkler heads with flexible droppers	nil	nil
Note: Ceiling hangers and braces are considered to be restrained components for the purpose of this table, hence 150mm horizontal clearance is required between ceiling hangers and unrestrained services.		

Determine the location of bracing

Having identified those components that do need to be seismically restrained determine the location of bracing to those components. The recommended maximum spacing of seismic bracing for piping, conduit and ductwork is as follows:

- 9m for transverse bracing of ductile materials
- 18m for longitudinal bracing of ductile materials

- 6m for transverse bracing of non-ductile materials (uncommon)
- 12m for longitudinal bracing of non-ductile materials (uncommon).

The spacing of bracing may need to be reduced, for example:
- Brace both sides of piping, conduit or ductwork at flexible connections
- Brace to avoid collisions between piping, conduit or ductwork and adjacent other non-structural components
- Brace within 600mm of changes in direction, whether it be horizontal or vertical changes (note that offsets of less than 600mm along a run are not considered a change of direction)
- Brace where components penetrate floors or ceilings
- Brace in both directions at the top of all risers where risers exceed 900mm.

The spacing and type of bracing along a run of piping, conduit or ductwork should not vary greatly in order to ensure uniform deflection and loading. Each unit of equipment connected to a run of piping, conduit or ductwork shall be individually and independently braced. Where the equipment is rigidly connected to the piping, conduit or ductwork it shall be designed for the tributary seismic forces. Suspended rectangular equipment shall be provided with a minimum of one sway brace per corner. Flexibility should be provided where pipes pass through seismic or expansion joints. Thermal expansion and contraction forces, where present, must be considered in the layout of braces.

Once the location of bracing is determined mark them on the relevant drawings, checking as best as possible for clashes with other services. In some cases it will be appropriate to tie together a number of services and provide one brace to resist the sum of their seismic loads.

Calculate design loads for those services needing to be seismically restrained

Having identified those components that need to be seismically restrained, the location of required restraints and method for calculating the seismic force calculate the design forces in the bracing.

Where clause 5.4.6 of AS1170.4 – 2007 applies the designer can choose to calculate the seismic forces as 10% of the component weight that they are considering. Alternatively the designer can choose, or for IL 2 and 3 buildings greater than 15m tall is required to undertake more detailed calculations using Section 8.2 or 8.3 of AS1170.4 – 2007. The more detailed calculations require assessment of the following factors:
- Acceleration coefficient
- Site sub-soil class
- Height at which the service is fixed within the structure
- Importance factor
- Component amplification factor
- Component ductility factor

The following is an example of a calculation of a horizontal earthquake force (Fc) using section 8.3 of AS1170.4-2007, known as the “Simple Method”.

$F_C = [k_p Z C_h(0)]\ a_x\ [I_c a_c / R_c]\ W_c$ but $> 0.05\ W_c$ (ie: the force is a minimum of 5% of the component’s seismic weight)

Seismic Criteria for Example

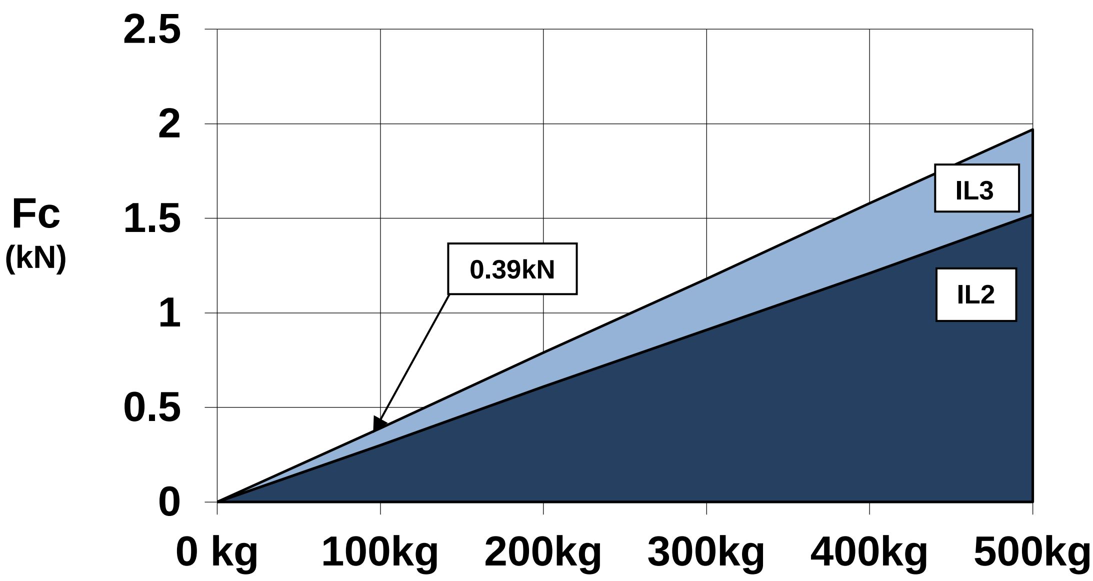
- Importance Level 3 building
- 1 in 1000 year annual probability of exceedence
- Site sub-soil class “C_e”.

- 100kg unit (W_c)
- Unit attached to building at 10m above structural base of structure (h_x)
- Unit is not attached with a flexible spring type mounting system.
- Unit is non-ductile with brittle materials.
- Total height of structure above structural base = 15m (h_n)

  - k_p = 1.3 (for 1:1000 year, would be 1.0 for 1:500 year)
  - Z = 0.1 (for a building in Adelaide, Mt Gambier, Port Pirie, Port Lincoln)
  - $C_h(0)$ = 1.3 (for C_e soil, A_e = 0.8, B_e=1.0, D_e = 1.1, E_e=1.1)
  - $a_x = (1 + k_c h_x)$
  - h_n = total height of structure above the structural base, in metres.
  - h_x = height at which the component is attached above the structural base of the structure, in metres.
  - $k_c = 2/h_n = 2/15 = 0.133$ (or where total height <12m = 0.17)
  - $a_x = (1 + 0.133x10) = 2.33$
  - I_c = component importance factor = 1.5 for components critical to life safety, which includes parts and components required to function immediately following an earthquake, those critical to containment of hazardous materials, storage racks in public areas and all parts and components in importance level 4 structures. I_c = 1.0 for all other components. I_c = 1.0
  - a_c = component amplification factor = 2.5 for flexible spring type mounting system for mechanical equipment, else 1.0 for all other mounting systems. a_c = 1.0
  - R_c = component ductility factor = 1.0 for rigid components with non-ductile or brittle materials or connections. For all other parts and components = 2.5.
  - R_c = 1.0
  - W_c = seismic weight of component = 100 kg = 1.0 kN
  - $\mathbf{F_C} = [1.3x0.1x1.3] \text{ x } 2.33 \text{ x } [1.0x1.0/1.0] \text{ x } 1.0 =$ **0.39 kN**
  - Check this is above the minimum value required by the code.
  - $F_{C(min)} = 0.05\ W_c = 0.05 \text{ x } 1.0 = 0.05$ kN

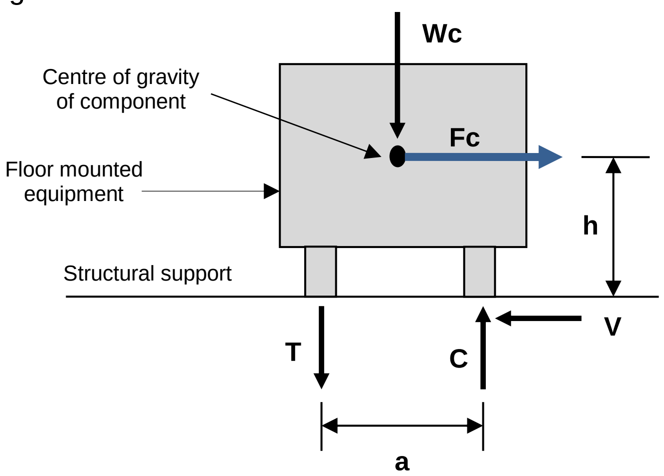
Hence adopt F_C = 0.39 kN. Forces calculated for importance level 2 and 3 buildings using AS1170.4 - 2007 correspond to the strength limit state for life safety purposes.

Graph of horizontal seismic force (F_c) in kilonewtons (kN) for non-critical engineering service components mounted 10m above ground level in a 15m tall building for importance level 2 & 3 buildings .



Calculate forces in bracing and anchors to resist design loads

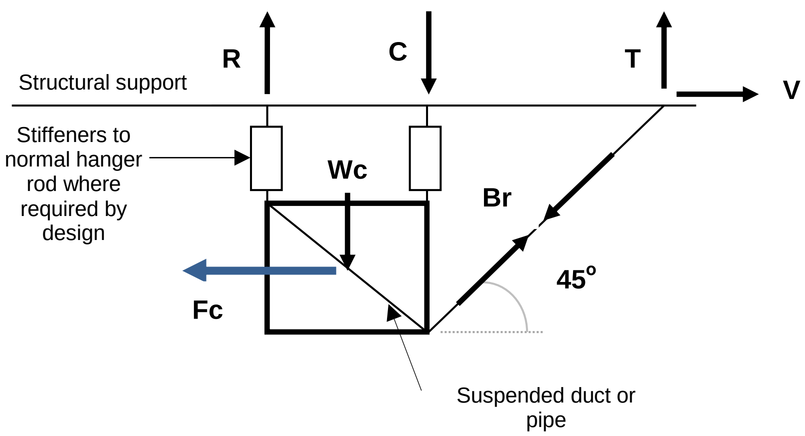
Having calculated the seismic load calculate the forces that the bracing and anchors must resist so that they can be included in the design documentation. Do not consider friction to reduce seismic design loads.



$V^* = F_c$

$T^* = (F_c \times h / a) - (W_c / 2)$

$C^* = (F_c \times h / a) + (W_c / 2)$



$Br^* = 1.414 \times F_c$ (45^o angle only)
V^* and $T^* = F_c$
$C^* = F_c - (W_c / 2)$
$R^* = W_c / 2$

Design the seismic bracing elements

Design the seismic bracing elements including the bracing members, supporting members and their fixings. Consider the following when undertaking the design:

- Where wire bracing is used it must be installed on both sides as it will not act in compression.
- Select a rod hanger that has a tensile strength greater than required.
- When diagonal braces are used to stabilise trapeze hangers they can cause compression forces in the hanger, check if a stiffener or change to a steel angle is required.
- Select anchors that are rated by the manufacturer for seismic loads.
- Design shall not consider frictional resistance produced by the effects of gravity as it cannot be relied upon.
- Wind forces may exceed seismic forces on exposed elements such as roof mounted equipment.
- Check the structural adequacy of the supporting structure to carry the seismic loads from engineering services.

In order to ensure that seismic bracing elements are fit for purpose they shall be certified for use as part of a seismic bracing system. Anchors, bracing members and vibration isolation mounts are of most concern in this respect. Until relevant Australian codes are published an international certification from a recognised body such as the following would be sufficient:

- Sheet Metal and Air-conditioning Contractors National Association – U.S.A
- American Society of Heating, Refrigerating and Air Conditioning Engineers
- American Society of Civil Engineers
- International Building Code
- Federal Emergency Management Agency (FEMA) – U.S.A
- California Office of Statewide Health Planning and Development – U.S.A.

Document the locations and details of restraint of engineering services for earthquake forces.

Co-ordinate the documentation of the restraint of engineering services for earthquake forces such that they can be understood by the installer and appropriate allowance made in the project tender. Documentation shall include as a minimum:

- Identification of all engineering services and components to be braced
- Details and/or schedules specifying the fixing requirements for all components
- Identification of the locations of seismic bracing taking into consideration any structural limitations
- Details of seismic bracing including fixings and anchors
- Minimum spacings between services, between services/walls and services/ceilings.

Vibration isolated and resilient mountings

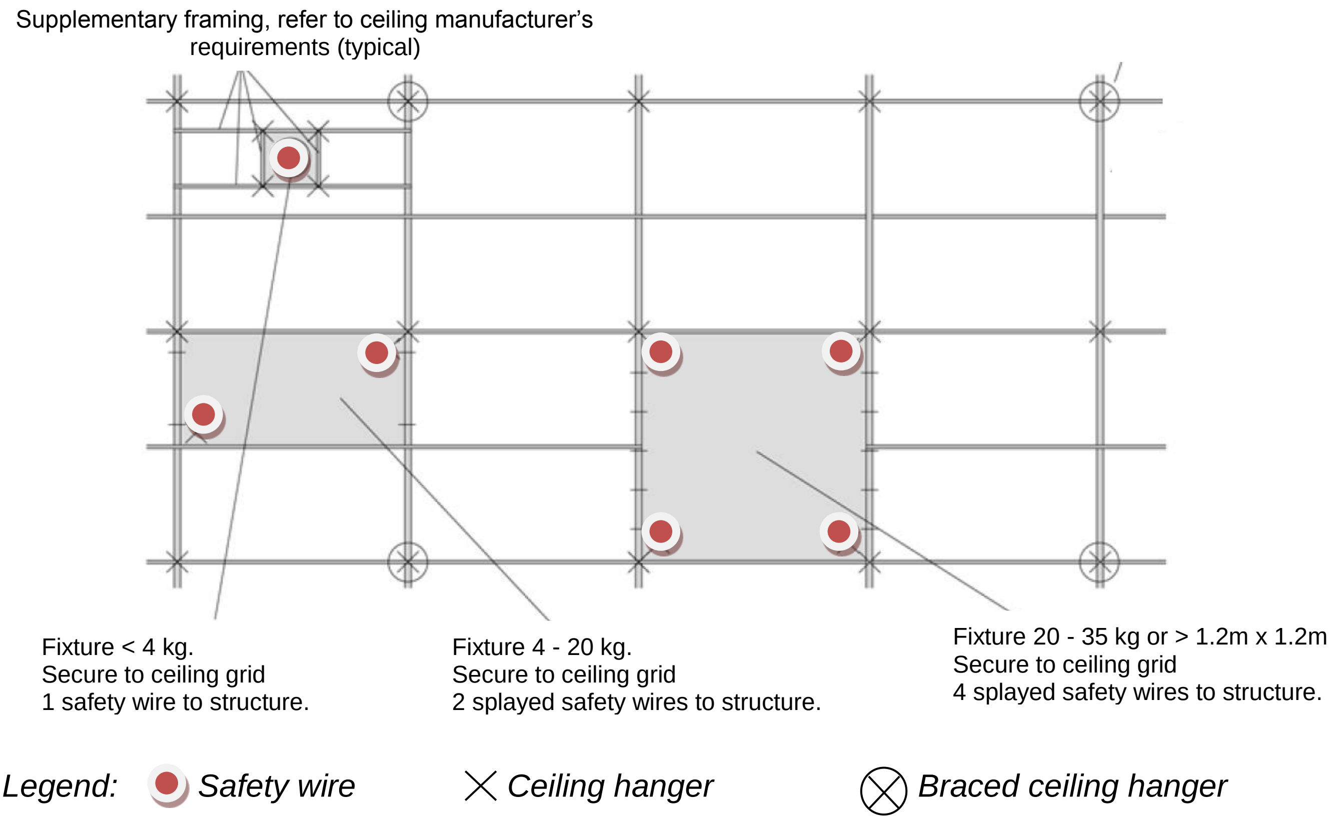
Components mounted on vibration isolators shall have a bumper or snubber in each orthogonal direction, and vertical restraints shall be provided, where required, to resist overturning.
Snubbers and their fixings shall be designed to resist the dynamic impact force imparted by the component on the snubber in an earthquake. Associated connections and piping shall have flexible connections to reduce the potential for damage.

Safety wires for light fixtures and cushion head boxes in T- bar suspended ceiling grids

Overhead light fixtures in T-bar ceiling grids have often been damaged in past earthquakes with fixtures becoming dislodged and falling. The attachment of safety wires to light fixtures and cushion head boxes ensures that while they may fall from the ceiling grid and dangle from the safety wire after an earthquake they will not threaten occupants. The splaying of the safety wires from the fixtures or box provides some lateral restraint.

Fixing of safety wires to light fixtures and cushion head boxes shall be in accordance with the diagram below except as follows:

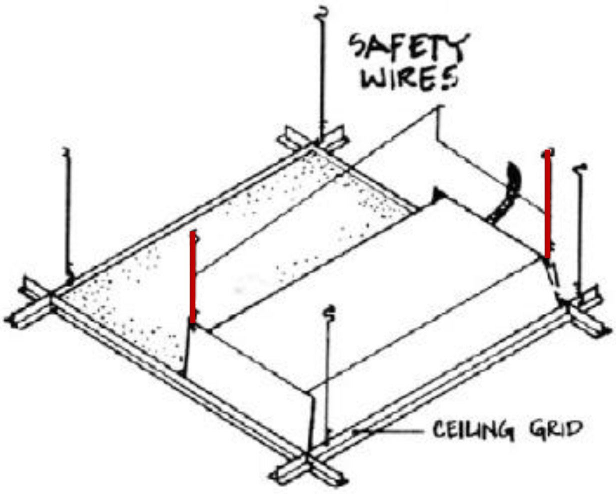
- Where light fixtures and cushion boxes are supported and braced independently of the ceiling then safety wires are not required;
- Where the ceiling grid has been specifically designed to provide vertical and lateral restraint (from seismic forces) to the light fixtures and cushion head boxes and fixings are provided to transmit the seismic force from the lights and boxes to the ceiling grid then safety wires are not required.



Notes:

1. Safety wire to be 2mm galvanised soft annealed mild steel wire. Use a minimum of four twists within 40mm each end to develop full wire strength.
2. Alternatively use load rated wire and clamps.
3. Loads on the ceiling grid must not exceed those allowed by the ceiling manufacturer.

Figure: Plan of recessed lights in T-bar ceiling showing safety wire requirements.
Source: FEMA E-74, January 2011, Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide.



Source: FEMA 454, December 2006, Designing for Earthquakes.

Seismic bracing examples

For examples of seismic bracing of engineering services refer to the DPTI drawings "*Examples of Seismic Bracing for Services – Detail Sheets 1 (DG51) and Seismic Bracing for Services – Detail Sheets 2 (DG52)"*. Note that the drawings do not cover all possible bracing options and that the details need to be adapted and expanded upon to suit specific projects by the design team. Refer also to the reference documents below for further information.

References

- AS 1170.4 - 2007, Structural design actions Part 4: Earthquake actions in Australia
- Australian Earthquake Engineering Society, AS1170.4 - 2007 Commentary
- NZS 4219 – 2009, Seismic performance of engineering systems in buildings
- FEMA E-74, January 2011, Reducing the Risks of Nonstructural Earthquake Damage
- FEMA 454, December 2006, Designing for Earthquakes, A Manual for Architects.
- Gripple, 2010, Seismic Installation Manual.
- Tyco Flow Control, 2002, Unistrut Seismic Bracing Systems.
- SMACNA Seismic Restraint Manual, Guidelines for Mechanical Systems, 1998, SMACNA,

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Appendix – Photographs of Damaged Service Components

Examples of earthquake damage to mechanical and electrical components.

Photo: Overturned equipment in the 1985 Mexico earthquake.
Source: FEMA E-74, January 2011, Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide.

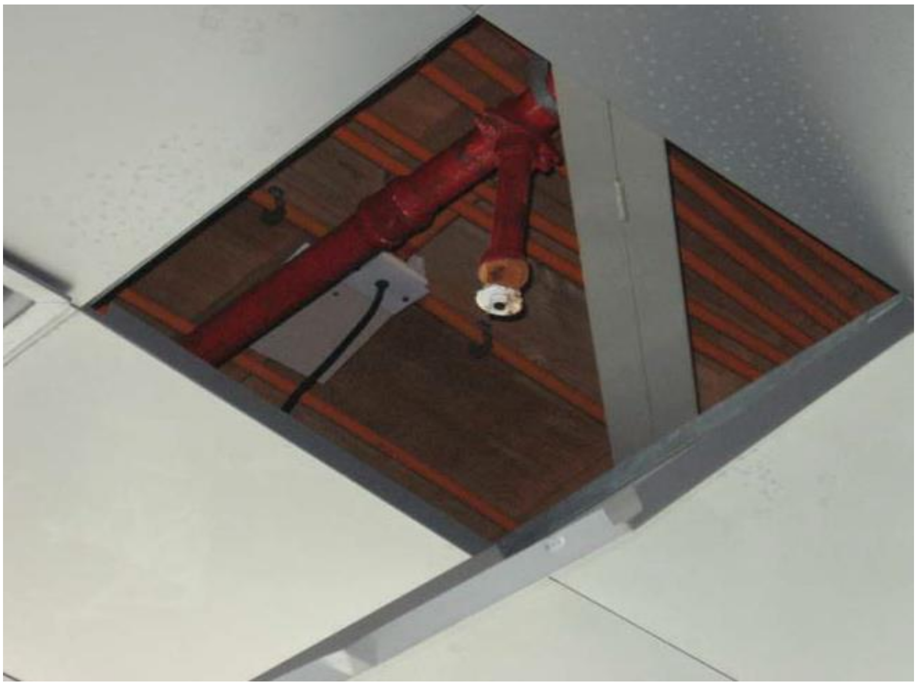

Photo: Ceiling and sprinkler head damage, 2010 Chile earthquake.
Source: FEMA E-74, January 2011, Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide.

Photo: Light fixture dangling from conduit following the 1994 Northridge earthquake, U.S.A.
Source: FEMA E-74, January 2011, Reducing the Risks of Non-structural Earthquake Damage – A Practical Guide.

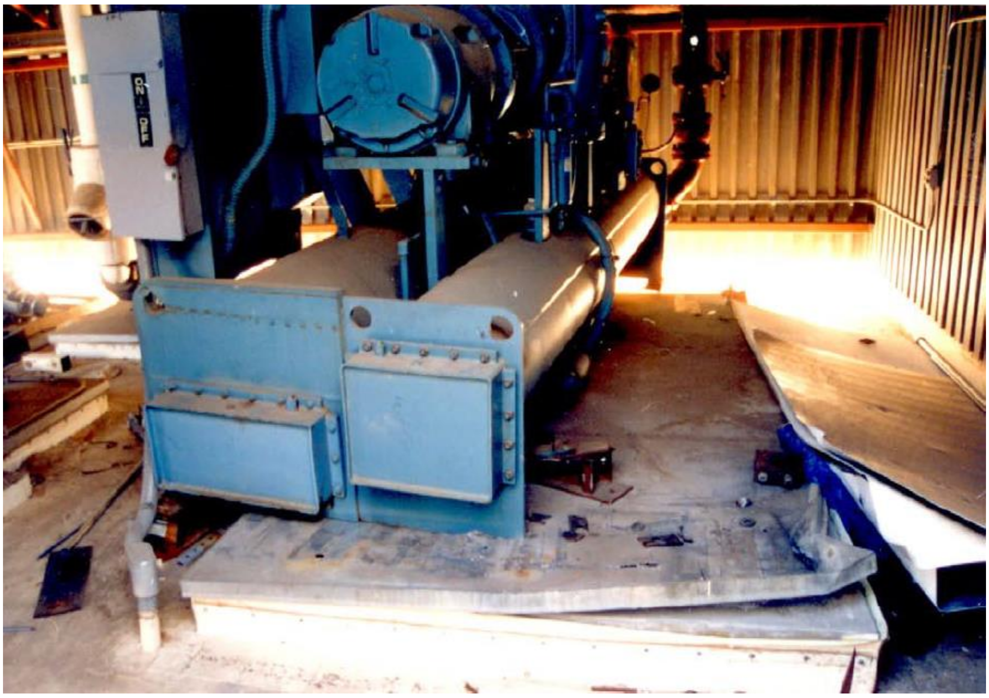

Photo: Failed chiller mounts in the 1994 Northridge earthquake, U.S.A.
Source: FEMA E-74, January 2011, Reducing the Risks of Non-structural Earthquake Damage – A Practical Guide.

Photo: A vertical tank overturned in the 1994 Northridge earthquake, U.S.A.
Source: FEMA E-74, January 2011, Reducing the Risks of Non-structural Earthquake Damage – A Practical Guide.

Photo: Toppled air-conditioning units following the 2010 Chile earthquake.
Source: FEMA E-74, January 2011, Reducing the Risks of Non-structural Earthquake Damage – A Practical Guide.