NZS 4219:2009

New Zealand Standard

Seismic performance of engineering systems in buildings

Superseding NZS 4219:1983

NZS 4219:2009

Single User PDF Terms & Conditions

You have material which is subject to strict conditions of use. Copyright in this material is owned by the New Zealand Standards Executive. Please read these terms and conditions carefully, as in addition to the usual range of civil remedies available to Standards New Zealand on behalf of the New Zealand Standards Executive for infringement of copyright, under New Zealand law every person who infringes copyright may be liable to a fine of up to $10,000 for every infringing copy or imprisonment of up to 5 years, or a fine of up to $150,000 or imprisonment not exceeding 5 years.

You have access to a single-user licence to read this non-revisable Adobe Acrobat PDF file and print out and retain ONE printed copy only.

We retain title and ownership of the copyright in this PDF file and the corresponding permitted printed copy at all times.

Under this license use of both the PDF file and the single permitted printed copy of this PDF file you may make are restricted to you. Under no circumstances are you permitted to save, sell, transfer, or copy this PDF file, the one permitted printed copy of this PDF file, or any part of either of them.

You undertake that you will not modify, adapt, translate, reverse engineer, decompile, disassemble or create derivative works based on any of the downloaded PDF file, nor will you merge it with any other software or document, even for internal use within your organization.

Under no circumstances may this PDF file be placed on a network of any sort without our express permission.

You are solely responsible for the selection of this PDF file and any advice or recommendation given by us about any aspect of this PDF file is intended for guidance only and is followed or acted upon entirely at your own risk.

We are not aware of any inherent risk of viruses in this PDF file at the time that it is accessed. We have exercised due diligence to ensure, so far as practicable, that this file does not contain such viruses.

No warranty of any form is given by us or by any party associated with us with regard to this PDF file, and you accept and acknowledge that we will not be liable in any way to you or any to other person in respect of any loss or damage however caused which may be suffered or incurred or which may arise directly or indirectly through any use of this PDF file.

Regardless of where you were when you received this PDF file you accept and acknowledge that to the fullest extent possible you submit to New Zealand law with regard to this licence and to your use of this PDF file.

COMMITTEE REPRESENTATION

This Standard was prepared under the supervision of the P 4219 Committee, which the Standards Council established under the Standards Act 1988.

The committee consisted of representatives of the following nominating organisations:

Association of Consulting Engineers New Zealand (ACENZ)
BRANZ Ltd
Business New Zealand
Department of Building and Housing
GNS Science
INGENIUM
Institute of Refrigeration, Heating and Air Conditioning Engineers of New Zealand (IRHACE)
Institution of Professional Engineers New Zealand (IPENZ)
Local Government New Zealand (LGNZ)
Master Plumbers, Gasfitters and Drainlayers New Zealand Inc.
New Zealand Society for Earthquake Engineering (NZSEE)
University of Canterbury

ACKNOWLEDGEMENT

Standards New Zealand gratefully acknowledges the contribution of time and expertise from all those involved in developing this Standard.

Published by Standards New Zealand, the trading arm of the Standards Council, Private Bag 2439, Wellington 6140. Telephone: (04) 498 5990, Fax: (04) 498 5994, Website: www.standards.co.nz.

AMENDMENTS

No.	*Date of issue*	*Description*	*Entered by, and date*

NZS 4219:2009

New Zealand Standard

Seismic performance of engineering systems in buildings

ISBN (Print) 1-86975-114-0
ISBN (PDF) 978-1-77551-995-9

NOTES

CONTENTS

Appendix

Table

Figure

REFERENCED DOCUMENTS

Reference is made in this document to the following:

NEW ZEALAND STANDARDS

NZS 1170: - - - -	Structural design actions
Part 5:2004	Earthquake actions – New Zealand
NZS 3101.1 and 2:2006	Concrete structures Standard
NZS 3404.1 and 2:1997	Steel structures Standard
NZS 3501:1976	Specification for copper tubes for water, gas, and sanitation
NZS 3603:1993	Timber structures Standard
NZS 4230:2004	Design of reinforced concrete masonry structures
NZS 4541:2007	Automatic fire sprinkler systems

JOINT AUSTRALIAN/NEW ZEALAND STANDARDS

AS/NZS 1170: - - - -	Structural design actions
Part 0:2002	General principles
Part 1:2002	Permanent, imposed and other actions
Part 2:2002	Wind actions
Part 3:2003	Snow and ice actions
AS/NZS 1664: - - - -	Aluminum structures
Part 1:1997	Limit state design
AS/NZS 2785:2000	Suspended ceilings – Design and installation
AS/NZS 3679.1:1996	Structural steel – Hot-rolled bars and sections
AS/NZS 4600:2005	Cold-formed steel structures
AS/NZS 4673:2001	Cold-formed stainless steel structures

AMERICAN STANDARD

ACI 355.2/355.2R-01	Evaluating the performance of post-installed mechanical anchors in concrete and commentary

AUSTRALIAN STANDARDS

AS 1163:1991	Structural steel hollow sections
AS 1111.1:2000	ISO metric hexagon bolts and screws – Product grade C – Bolts
AS 1112.3:2000	ISO metric hexagon nuts – Product grade C

BRITISH STANDARDS

BS 1387:1985	Specification for screwed and socketed steel tubes and tubulars and for plain end steel tubes suitable for welding or for screwing to BS 21 pipe threads
BS EN ISO 7500-1:2004	Metallic materials. Verification of static uniaxial testing machines. Tension/compression testing machines. Verification and calibration of the force-measuring system

OTHER PUBLICATIONS

Tauby, J R, Lloyd, R, Nice, T, and Tunnissen, J.	*A practical guide to seismic restraint,* Sheet Metal and Air Conditioning Contractors' National Association (SMACNA), 1999.
ASCE 7-05.	*Minimum design loads for buildings and other structures*, American Society of Civil Engineers (ASCE), 2005.

NEW ZEALAND LEGISLATION

Chartered Professional Engineers of New Zealand Act 2002
Local Government Act 2002
New Zealand Building Code (NZBC) and Compliance Documents

LATEST REVISIONS

The users of this Standard should ensure that their copies of the above-mentioned Standards are the latest revisions. Amendments to referenced New Zealand and Joint Australian/New Zealand Standards can be found on www.standards.co.nz.

REVIEW OF STANDARDS

Suggestions for improvement of this Standard will be welcomed. They should be sent to the Chief Executive, Standards New Zealand, Private Bag 2439, Wellington 6140.

FOREWORD

Non-structural components and contents may be a hazard to a building's occupants and cause damage during an earthquake. They may also be required to support critical services after an earthquake.

NZS 4104:1994 *Seismic restraint of building contents* provides requirements for restraining building contents to resist seismic actions. This Standard (NZS 4219:2009) provides requirements for restraining engineering systems in buildings to resist seismic actions.

NZS 4219:2009 specifically excludes lifts and escalators, and fire sprinkler system pipework because they are already provided for by NZS 4332:1997 *Non-domestic passenger and goods lifts* and NZS 4541:2007 *Automatic fire sprinkler systems* respectively.

A revision of NZS 4219:1983 commenced in 2000. However, the revision was put on hold while a review of the loading values within NZS 4203:1992, which underpin this Standard, was undertaken. NZS 4203:1992 has since been superseded by the AS/NZS 1170 series of Standards.

NZS 4219:1983 has now been updated to be consistent with the loading values and requirements from the AS/NZS 1170 series of Standards, given in limit state design. This revision also reflects changes in technology and practice for installing engineering systems.

Guidance and requirements for non-specific design are set out in sections 3 and 5, and for specific design in sections 4 and 5.

Examples of the application of this Standard for restraining common engineering systems are given in Appendix D.

OUTCOME STATEMENT

NZS 4219 will continue to prevent loss of life and provide protection of property for all New Zealanders by ensuring engineering systems in buildings are securely restrained in an earthquake. Where the engineering system supports critical lifesaving functions, it continues to function during and after an earthquake.

NOTES

NEW ZEALAND STANDARD

SEISMIC PERFORMANCE OF ENGINEERING SYSTEMS IN BUILDINGS

1 SCOPE AND INTERPRETATION

1.1 SCOPE

This Standard sets out the criteria for the seismic performance of engineering systems related to a building's function. It covers the design, construction, and installation of seismic restraints for these engineering systems. Verification of the supporting structure for gravity and seismic actions is outside the scope of this Standard.

For engineering systems which enter or exit the building through foundations into the surrounding ground, only those items within one metre outside the footprint of the building are included.

The provisions of the Standard may be used for services in new or existing buildings, and for the purpose of retrofitting engineering systems into existing buildings.

> ***C1.1***
> *Verification of the supporting structure will require consideration of both the local and the global transfer of loading into the structure, for example, heavy plant placed on hollowcore floor slabs and thin toppings.*

1.1.1 The following items are included in the scope of this Standard, except as specifically excluded in 1.1.2:

(a) All engineering systems necessary to ensure compliance of the building with the New Zealand Building Code;

(b) All engineering systems essential for the normal functioning of the building; and

(c) Building Compliance Schedule items, such as emergency lighting.

1.1.2 The following items are excluded from the scope of this Standard:

(a) Engineering systems in buildings of importance level 5, as defined in AS/NZS 1170.0;

(b) Individual components with a mass exceeding 20% of the combined mass of the component and the building structure, and with a period of greater than 0.2 seconds;

(c) Items supported on the ground independently of the building, and external to the building;

(d) Lifts (including guide rails) and escalators;

(e) Contents of buildings including portable appliances, and items which are not attached to the building structure;

(f) Fire sprinkler system pipework; and

(g) Suspended ceilings.

> ***C1.1.2***
> *Fire sprinkler systems require specialist specific design. Fire sprinkler system pipework should comply with NZS 4541, while items such as water storage tanks, fire pumps, diesel fuel tanks, and the like can be designed in accordance with this Standard. Suspended ceilings should be designed in accordance with AS/NZS 2785.*

1.2 INTERPRETATION

1.2.1 Clauses

For the purpose of this Standard, the word 'shall' refers to requirements that are essential for compliance with the Standard, while the word 'should' refers to practices that are advised or recommended.

Clauses prefixed '*C*' and printed in italics are intended as comments on the corresponding clauses. They are not to be taken as the only or complete interpretation. The Standard can be complied with if the comment is ignored.

1.2.2 Appendices

The terms 'normative' and 'informative' have been used in this Standard to define the application of the appendix to which they apply. A 'normative' appendix is an integral part of a Standard while an 'informative' appendix is for information and guidance only.

1.3 COMPLIANCE WITH NEW ZEALAND BUILDING CODE

1.3.1 The intent of this Standard is to provide a means of compliance with the following requirements of the New Zealand Building Code (NZBC):

Clause B1 *Structure*	B1.3.1 and B1.3.2 for loads from B1.3.3 (f), (m), and (p), that is, for loads arising from earthquakes and earthquake actions.
Clause G10 *Piped services*	G10.3.1(a) and (c), to prevent leakage, damage or adverse interaction between services arising from earthquakes and earthquake actions.
Clause G12 *Water supplies*	An acceptable alternative to the restraint systems specified for water tanks and hot water cylinders specified in Acceptable Solution G12/AS1.
Clause G14 *Industrial liquid waste*	G14.3.1(a) and with paragraph 3.2.1 of Verification Method G14/VM1, that is, for free-standing tanks, loads, and deformations from earthquakes and earthquake actions.

1.3.2 Sections 1, 2, 3, and 5, and Appendices A, B, and C of this Standard are intended to be used as an Acceptable Solution to achieve compliance with NZBC B1, G10, G12, and G14.

Sections 1, 2, 4, and 5, and Appendices A, B, and C of this Standard are intended to be used as a Verification Method to achieve compliance with NZBC B1, G10, G12, and G14.

C1.3.2
The citation of AS/NZS 1170 as part of the NZBC Verification Method B1/VM1 in Compliance Document B1 Structure is made on the basis that the person responsible for the interpretation and application of its provisions has relevant experience and skills in structural engineering. A structural engineer who is chartered under the Chartered Professional Engineers of New Zealand Act 2002 would satisfy this requirement.

Where this Standard has provisions that are unbounded, that is in non-specific or unquantified terms (such as where provisions are required to be appropriate, adequate, suitable, and the like), then these will not be considered as part of the Verification Method or Acceptable Solution, and require the approval of the territorial authority.

1.3.3 When this Standard is used as part of the means for compliance with the NZBC as part of a Verification Method an engineer experienced in structural engineering such as a chartered professional engineer with relevant experience and skills in structural engineering shall be responsible for interpreting the requirements of this Standard.

On this basis, engineering judgement and rational analysis may be applied provided that the outcome is bounded by defined engineering criteria.

1.4 DEFINITIONS

For the purpose of this Standard the following definitions shall apply:

Anchor A fastener installed into concrete and concrete masonry used to transfer seismic forces from the component or its restraints to the supporting building structure. An anchor may be cast into wet concrete, or post-fixed after the concrete has hardened (see figure 1)

Brace An element of the restraint system used to transfer seismic force from the component to the supporting structure (see figure 1)

Brittle component A component which lacks ductility

Building services See Engineering systems

Capacity Design strength of a structural element. Equivalent to the 'nominal capacity' multiplied by the 'strength (or capacity) reduction factor', as defined in New Zealand material design Standards

Component An individual part of a building services or engineering systems installation. It is an item that can be considered separately/independently for the purposes of assessing seismic resistance. In the case of items with one significant linear dimension, each straight length may be considered as a single component for the purpose of designing seismic restraints or fixings (see figure 1)

Connection An electrical or mechanical interface between a component and the remainder of the engineering systems (see figure 1)

Ductility The ability of equipment or a component to undergo repeated and reversing inelastic deflections beyond the point of first yield while maintaining a substantial proportion of its initial maximum load-carrying capacity

Ducting Sheet metal or other enclosure for air, gas, smoke, or vapour distribution or extraction from building

Earthquake load demand — The inertial load on a component caused by earthquake actions on the building

Engineering systems — Non-structural systems permanently installed in a building, and providing environmental control, water, gas, steam, electrical or communications services, and active fire suppression or fighting systems

Fastener — A prefabricated item used to transfer loads between the elements of a restraint system (see figure 1). Fasteners include wood screws, coach screws, bolts, concrete anchors, and inserts

Fixing — A structural attachment between a component and the supporting building structure, or between elements of a seismic restraint system, designed and installed to transfer earthquake induced forces (see figure 1)

Hazardous substances — A substance which, if released, could cause injury to the building's occupants, either directly or as a consequence of some secondary effect, such as fire or explosion

Importance level — A classification of the building on the basis of its consequences of failure. It is determined in accordance with its occupancy and use, and as further defined in AS/NZS 1170.0

Linear component — A component with one significant linear dimension and includes pipes, ducts, and cable trays

Longitudinal restraint — A structural assemblage of elements designed and installed to transfer earthquake-induced forces in the direction of the longitudinal axis of a linear component

Luminaire — Lighting fixture

Operating weight — The weight of a component in normal operating conditions. It includes the weight of any contents (such as fuel) likely to be present under normal operating conditions. In the case of a tank or pipeline, the operating weight includes the contents up to overflow level

Orthogonal directions — Two directions perpendicular to each other. Usually, but not necessarily, oriented in the same direction as the building

Proprietary equipment — Equipment intended for general use in any building and forming part of a supplier's normal product range

Relative displacement — The estimated maximum relative movement between items of equipment or between equipment and the building elements under conditions of earthquake loading

Resilient mount A base designed to support equipment but isolate the transmission of vibration to or from the structure

Seismic restraint A structural assemblage of elements designed and installed to transfer earthquake-induced forces from a component to the supporting structure (see figure 1)

Snubber A device used with a resilient mounting to limit movement of a component under seismic actions

Support A structural assemblage of elements, designed and installed to transfer gravity loads from a component to the supporting structure (see figure 1)

Supporting structure The primary earthquake resisting structure of the building in which the engineering systems are installed (see figure 1)

Territorial authority A city or district council as defined by section 5 of the Local Government Act

Transverse restraint A structural assemblage of elements designed and installed to transfer earthquake induced forces in the direction perpendicular to the longitudinal axis of a linear component

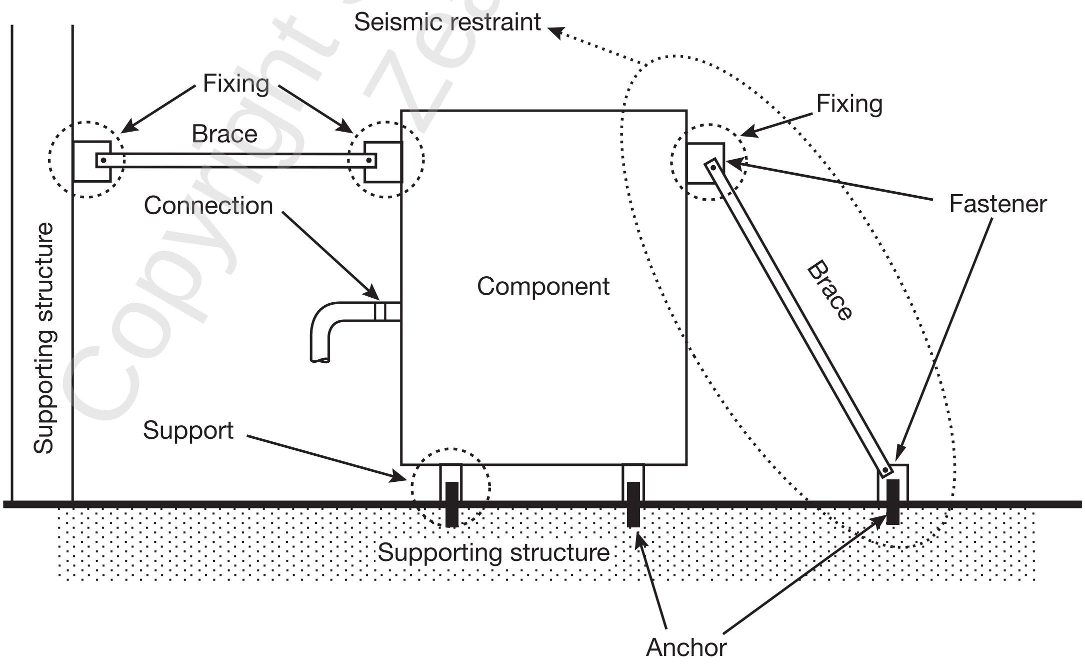


Figure 1 – Illustration of terms

1.5 NOTATION

For the purpose of this Standard the following notation shall apply:

Notation	Description
θ	Angle of the brace
b	Dimension from support to centre of gravity
B	Spacing of supports in the direction being considered
B_{snubber}	Snubber width
C	Lateral force coefficient
C_{H}	Height coefficient
C_{p}	Performance factor
D	Relative seismic displacement
F	Earthquake load demand
F_{ph}	Seismic horizontal force
F_{pv}	Seismic vertical force
h	Height from support to centre of gravity
H	Height from lower fixing to upper support
H_{z}	Height between fixing points
i	Impact factor
M_{d}	Design actions resulting from relative displacements
M_{i}	Design actions resulting from earthquake load demand
M^*	Total seismic action on component
n	Number of supports or fixings acting in tension in the direction being considered
n_{bolt}	Number of anchor bolts
N	Number of supports/Anchors
P	Brace force
P_{c}	Maximum compression
P_{x}	Orthogonal lateral restraints in line with centre of gravity direction x
P_{y}	Orthogonal lateral restraints in line with centre of gravity direction y
R_{c}	Component risk factor
R_{h}	Horizontal force on the anchor, assembly or support
R_{vc}	Vertical force on the anchor, assembly or support – compression
R_{vt}	Vertical force on the anchor, assembly or support – tension
T_{bolt}	Tension per anchor bolt
V_{bolt}	Shear per anchor bolt
W	Operating weight of the component
Z	Zone factor

2 GENERAL REQUIREMENTS

2.1 OBJECTIVES

The objectives of this Standard are to safeguard people from injury and to minimise damage by preventing failure of engineering systems when subject to earthquake actions.

2.2 CRITERIA

All components of engineering systems shall be configured with a clearly defined load path to transfer the actions (horizontal and vertical) generated in an earthquake, together with the gravity loads, and process induced actions (for example, thermal expansion) to the supporting structure.

Engineering systems shall be designed, constructed and installed so that the following criteria are met:

(a) Components representing a hazard (classification P1, P2, P3) will not collapse, rupture or lose support after an Ultimate Limit State (ULS) earthquake;

(b) Components required for emergency evacuation (classification P4) will not collapse, rupture or lose support after an ULS earthquake;

(c) Components required for operational continuity (classification P5) within buildings of importance level 4 are restrained in a manner so that the system is able to continue to perform its functions after a Serviceability Limit State 2 (SLS2) earthquake; and

(d) All components are restrained in a manner so that the system retains its structural and operational integrity without requiring repairs after a Serviceability Limit State 1 (SLS1) earthquake.

The classification of components of engineering systems is set out in 3.3.2.

Building importance levels are reproduced in Appendix A, and summarised in table 1.

ULS, SLS1, and SLS2 earthquakes are as defined in NZS 1170.5.

2.3 GENERAL REQUIREMENTS FOR ENGINEERING SYSTEMS SUBJECT TO EARTHQUAKE ACTIONS

2.3.1 Seismic considerations

The arrangement and layout of engineering systems within the building shall allow for earthquake actions.

The location, design, construction, and installation of engineering systems within the building shall be such as to reduce life and injury hazards and shall protect property and systems from damage or loss of function to the level as required by criteria set out in 2.2.

C2.3.1

When designing a building, consider the role of engineering systems in protecting life and property and providing a safe egress from the building, as well as the seismic resistance of the services and their components. The basic concepts of a building layout should be examined against the likely effect of earthquakes on the particular building.

The following points are of special significance:

(a) The effect of heavy equipment on the structure and other building components should be considered. Heavy equipment breaking loose is a potential source of injury and building damage. The location of heavy plant at a high level within the building not only adds to the earthquake loading, but it may require some main reticulation pipes and electric power to run the full height of the building, requires pumps for water, and it makes the changing of plant or temporary replacement difficult;

(b) The seismic resistance of public utility services, including connections and accessories should be assessed. The need to both reduce the probability of damage and to provide for connection of temporary alternative services should be assessed. Vehicle access, mains pipe connections, the position of shut-off valves, meters, risers, and main reticulation are all important. These services require clear identification;

(c) Where gas or other hazardous substances may leak, it may be an advantage to install seismically operated shut-off valves;

(d) Close liaison is needed between the services, the structural and the architectural designers;

(e) The consequences as a result of an earthquake of leakage from pipes and vessels should be considered; and

(f) There could be a risk of flooding to electric power supply substations, main switchboards and the emergency standby power plant located below ground floor level.

2.3.2 Interactions

Each component's seismic interaction with all other relevant connected building parts, and with the supporting structure, shall be accounted for in the design.

C2.3.2

There are two types of seismic interactions:

(a) A system interaction is a spurious or erroneous signal resulting in unanticipated operating conditions, such as the spurious start-up of a pump motor or the unintended closure of a valve;

(b) Spatial interactions are interactions caused by the failure of a structure or component in close proximity.

Spatial interactions can, in turn, be further divided into falling interactions, swing interactions, and spray interactions. A falling interaction is an impact on a critical component due to the fall of overhead or adjacent equipment or structure. A swing interaction is an impact due to the swing or rocking of adjacent components or suspended systems. A spray interaction is due to the leakage of overhead or adjacent piping or vessels.

The process of considering seismic interactions begins with an interaction review. For new structures, this involves examination of the design drawings, to identify the interaction targets, and credible and significant sources of interaction. In many cases, the design documents may show components and systems in schematic terms only. The actual location of, for example, piping and ductwork systems is determined in the field. In this case, and where work is being performed on an existing structure, it is necessary to begin the interaction review with a walk around taking photos.

2.3.3 Non-seismic requirements

When undertaking seismic design of engineering systems, consideration shall be given to important non-seismic requirements outside the scope of the NZBC that may be affected by seismic bracing.

C2.3.3

For example, thermal expansion is often a critical design consideration in piping systems, and bracing is to be arranged in a manner that accommodates thermal movements. The design for seismic loads should not compromise the functionality, durability, or safety of the overall system and this may require substantial collaboration and cooperation between the various disciplines in the design team. In some cases, such as for essential facilities or hazardous environments, performance levels higher than those required by the NZBC (for example, operability of a piping system, rather than just leak tightness) should be considered.

For some components, such as roof-mounted equipment, the wind design forces may be higher than the seismic design forces. Wind forces should be assessed in accordance with AS/NZS 1170.2.

2.3.4 Fixings and attachments

Components shall be fixed or attached to the supporting structure so that seismic forces are transferred to the structure. Such fixings shall be designed without consideration of frictional resistance produced by the effects of gravity.

A continuous load path of sufficient strength and stiffness between the component and the supporting structure shall be verified. Local elements of the supporting structure shall be designed for the seismically induced component forces in addition to normal design loads.

C2.3.4

Friction produced solely by the effects of gravity cannot be relied on to resist seismic forces, as equipment and fixtures often tend to 'walk' due to rocking when subjected to earthquake actions. Often this is accentuated by vertical ground motions. Because such frictional resistance cannot be relied upon, positive restraint must be provided for each component.

Where components are fixed to non-structural elements of the building, such elements should be checked to verify that their load-carrying capacity is adequate.

Depending on the specifics of the design condition, ductile design of anchors in concrete or masonry may be needed to satisfy one or all of the following objectives:

(a) To ensure adequate load redistribution between anchors in a group;

(b) To allow for anchor overload without precipitous failure; and/or

(c) To dissipate seismic energy.

Unless specific attention is paid to the conditions necessary to ensure the desired hysteretic response (adequate gauge length, anchor spacing, edge distance, steel properties, and so forth), it is not recommended that anchors be relied upon for energy dissipation. Although the anchor can provide the transfer of load from a relatively deformable material (such as steel) to a low deformability material (such as concrete or masonry), achieving deformable, energy-absorbing behaviour in the anchor itself is often difficult.

On the other hand, the concept of providing a fuse, or deformable link, in the load path to the anchor is encouraged. This approach allows the designer to provide the necessary level of ductility and overstrength in the fixing, while at the same time protecting the anchor from overload. It also eliminates the need to balance steel strength and deformability in the anchor with variable edge distances and anchor spacings.

2.4 PROPRIETARY COMPONENTS

Performance of proprietary components, whether manufactured in New Zealand or overseas, shall meet the criteria of 2.2.

Fixing of the component to provide seismic restraint shall comply with all provisions of this Standard.

C2.4

Components of equipment of standard manufacture designed and constructed in New Zealand, but not intended for a specific building, system, or position within a building should be subject to all the provisions of this Standard.

For the seismic design of the component itself, the most onerous assumptions regarding importance level of the intended building, category of use of the component, and position of the component within the building should be made to ensure the widest possible applicability. Seismic design of the component's fixings and bracing may then be made specifically for the application using the provisions of this Standard.

Components of equipment of standard manufacture should be verified as complying with all the relevant provisions of this Standard. Verification should be in accordance with section 4 of this Standard, by either calculation or testing.

Where an overseas Standard provides the basis for the seismic resistant design of the component, that Standard may be used for verification provided the design earthquake actions are not less than those determined from section 4.

Methods of fixing to the structure and bracing should comply with all provisions of this Standard.

3 NON-SPECIFIC DESIGN OF RESTRAINT SYSTEMS

3.1 GENERAL

This section sets out the methodology to be used for design of component restraint systems to resist the following actions:

(a) Earthquake actions exerting horizontal forces on all components within or attached to a building; and

(b) Earthquake actions causing relative displacements of floors within a building which will induce forces on all components attached to multiple floor levels.

3.2 DESIGN PROCEDURE

The design procedure consists of three steps, which shall be followed for each component of each of the relevant criteria:

(a) Determination of earthquake demand;

(b) Determination of the forces on the restraint system; and

(c) Design of all the elements of the restraint system.

NOTE – The design objective has been achieved when the capacities of the restraint systems provided for all components equal or exceed the earthquake demand.

3.2.1 Determination of earthquake demand

Determine the earthquake demand on all components of engineering systems within the building. The procedure for determination of demand shall be as follows:

(a) Classify the building and components using 3.3;

(b) Determine the earthquake load demand (that is static forces) from 3.4; and

(c) Determine the relative displacement from 3.5.

NOTE – Relative displacement from item (c) may be applicable to all systems.

3.2.2 Determination of restraint forces

Determine the required restraint forces on all components. The procedure for determination of restraint forces shall be as follows:

(a) Determine restraint forces for linear components from 3.6;

(b) Determine restraint forces for floor-mounted components from 3.7; and

(c) Determine restraint forces for suspended components from 3.8.

3.2.3 Design of restraint systems

Design a restraint system for all components. Restraint systems shall be designed and installed to have sufficient capacity to resist the forces determined from the following clauses:

(a) Fixings to the structure from 3.10; and

(b) Braces from 3.11.

3.3 CLASSIFICATION

3.3.1 Building

The importance level of the building containing the engineering system shall be established from table 1, and Appendix A.

Table 1 – Classification of importance level

Criteria	Importance level
Normal buildings, and buildings not in other importance levels	1, 2
Buildings that may contain people in crowds, or contents of high value to the community, or pose risks to people in crowds	3
Buildings with special post-disaster functions	4

C3.3.1
This table has been adapted from AS/NZS 1170.0. A more detailed description, including examples, may be obtained by reference to that Standard or Appendix A. Clause 1.1.2 (a) of this Standard excludes buildings of importance level 5 from the scope of this Standard.

3.3.2 Components

Components of the engineering system shall be classified into the categories shown in table 2.

Table 2 – Determination of category

Criteria	Category	Limit state
Component representing a hazard to life outside the building	P1	ULS
Component representing a hazard to a crowd of greater than 100 people within the building	P2	ULS
Component representing a hazard to individual life within the building	P3	ULS
Component necessary for the continuing function of the evacuation and life safety systems within the building	P4	ULS
Component of a system required for operational continuity of the building	P5	SLS2
Component for which the consequential damage caused by its failure is disproportionately great	P6	SLS1
All other components	P7	SLS1
NOTE – Category P5 only applies to importance level 4 buildings as this is a requirement of NZS 1170.5. The design loads derived for components contained in lower importance level buildings may be increased unnecessarily if category P5 is applied instead of P6 or P7 to other components in importance level 1, 2, and 3 buildings.		

C3.3.2
This table is adapted from NZS 1170.5. Some specific components are given in Appendix B.

3.4 EARTHQUAKE LOAD DEMAND

The earthquake load demand, F, on a component for each criterion (see 2.2) shall be assessed on the basis of the lateral force coefficient, C, and the weight of the component as given in equation 3.1. The lateral force coefficient comprises building location within earthquake zones (zone factor), performance factor, and component risk factor.

F = $C\,W$ ....(Equation 3.1)

where

W = operating weight of the component (see 3.4.4)

C = lateral force coefficient (see equation 3.2).

The lateral force coefficient shall be taken as

C = $2.7\,C_H\,Z\,C_p\,R_c$, but not greater than 3.6 ....(Equation 3.2)

where

C_H = 3.0 for components above ground floor or 1.0 at or below ground floor

Z = zone factor (see 3.4.1)

C_p = performance factor (see 3.4.2)

R_c = component risk factor (see 3.4.3).

C3.4
The floor height coefficient, C_H, allows for the dynamic amplification of ground motion by the supporting building structure.

This design method is based on section 8 of NZS 1170.5 but with conservative assumptions about soil types, floor height coefficients and part spectral shape coefficients. As such it is suitable for designing the seismic restraint of a component for any location in New Zealand. More economic designs may result from using the section 4 procedures for a specific site.

3.4.1 Earthquake zone

The zone factor, Z, shall be determined from table 3, or interpolated from figure 2.

C3.4.1
Table 3 and figure 2 have been adapted from NZS 1170.5.

Table 3 – Zone factors for New Zealand locations (north to south)

#	Location	Z
1	Kaitaia	0.13
2	Paihia/Russell	0.13
3	Kaikohe	0.13
4	Whangarei	0.13
5	Dargaville	0.13
6	Warkworth	0.13
7	Auckland	0.13
8	Manakau City	0.13
9	Waiuku	0.13
10	Pukekohe	0.13
11	Thames	0.16
12	Paeroa	0.18
13	Waihi	0.18
14	Huntly	0.15
15	Ngaruawahia	0.15
16	Morrinsville	0.18
17	Te Aroha	0.18
18	Tauranga	0.20
19	Mount Maunganui	0.20
20	Hamilton	0.16
21	Cambridge	0.18
22	Te Awamutu	0.17
23	Matamata	0.19
24	Te Puke	0.22
25	Putaruru	0.21
26	Tokoroa	0.21
27	Otorohanga	0.17
28	Te Kuiti	0.18
29	Mangakino	0.21
30	Rotorua	0.24
31	Kawerau	0.29
32	Whakatane	0.30
33	Opotiki	0.30
34	Ruatoria	0.33
35	Murupara	0.30

#	Location	Z
36	Taupo	0.28
37	Taumarunui	0.21
38	Turangi	0.27
39	Gisborne	0.36
40	Wairoa	0.37
41	Waitara	0.18
42	New Plymouth	0.18
43	Inglewood	0.18
44	Stratford	0.18
45	Opunake	0.18
46	Hawera	0.18
47	Patea	0.19
48	Raetihi	0.26
49	Ohakune	0.27
50	Waiouru	0.29
51	Napier	0.38
52	Hastings	0.39
53	Wanganui	0.25
54	Waipawa	0.41
55	Waipukurau	0.41
56	Taihape	0.33
57	Marton	0.30
58	Bulls	0.31
59	Feilding	0.37
60	Palmerston North	0.38
61	Dannevirke	0.42
62	Woodville	0.41
63	Pahiatua	0.42
64	Foxton/Foxton Beach	0.36
65	Levin	0.40
66	Otaki	0.40
67	Waikanae	0.40
68	Paraparaumu	0.40
69	Masterton	0.42

Table 3 – Zone factors for New Zealand locations (north to south) (continued)

#	Location	Z
70	Porirua	0.40
71	Wellington CBD (north of Basin Reserve)	0.40
72	Wellington	0.40
73	Hutt Valley – south of Taita Gorge	0.40
74	Upper Hutt	0.42
75	Eastbourne – Point Howard	0.40
76	Wainuiomata	0.40
77	Takaka	0.23
78	Motueka	0.26
79	Nelson	0.27
80	Picton	0.30
81	Blenheim	0.33
82	St Arnaud	0.36
83	Westport	0.30
84	Reefton	0.37
85	Murchison	0.34
86	Springs Junction	0.45
87	Hanmer Springs	0.55
88	Seddon	0.40
89	Ward	0.40
90	Cheviot	0.40
91	Greymouth	0.37
92	Kaikoura	0.42
93	Harihari	0.46
94	Hokitika	0.45
95	Fox Glacier	0.44
96	Franz Josef	0.44
97	Otira	0.60
98	Arthurs Pass	0.60
99	Rangiora	0.33
100	Darfield	0.30
101	Akaroa	0.16

#	Location	Z
102	Christchurch	0.22
103	Geraldine	0.19
104	Ashburton	0.20
105	Fairlie	0.24
106	Temuka	0.17
107	Timaru	0.15
108	Mt Cook	0.38
109	Twizel	0.27
110	Waimate	0.14
111	Cromwell	0.24
112	Wanaka	0.30
113	Arrowtown	0.30
114	Alexandra	0.21
115	Queenstown	0.32
116	Milford Sound	0.54
117	Palmerston	0.13
118	Oamaru	0.13
119	Dunedin	0.13
120	Mosgiel	0.13
121	Riverton	0.20
122	Te Anau	0.36
123	Gore	0.18
124	Winton	0.20
125	Balclutha	0.13
126	Mataura	0.17
127	Bluff	0.15
128	Invercargill	0.17
129	Oban	0.14

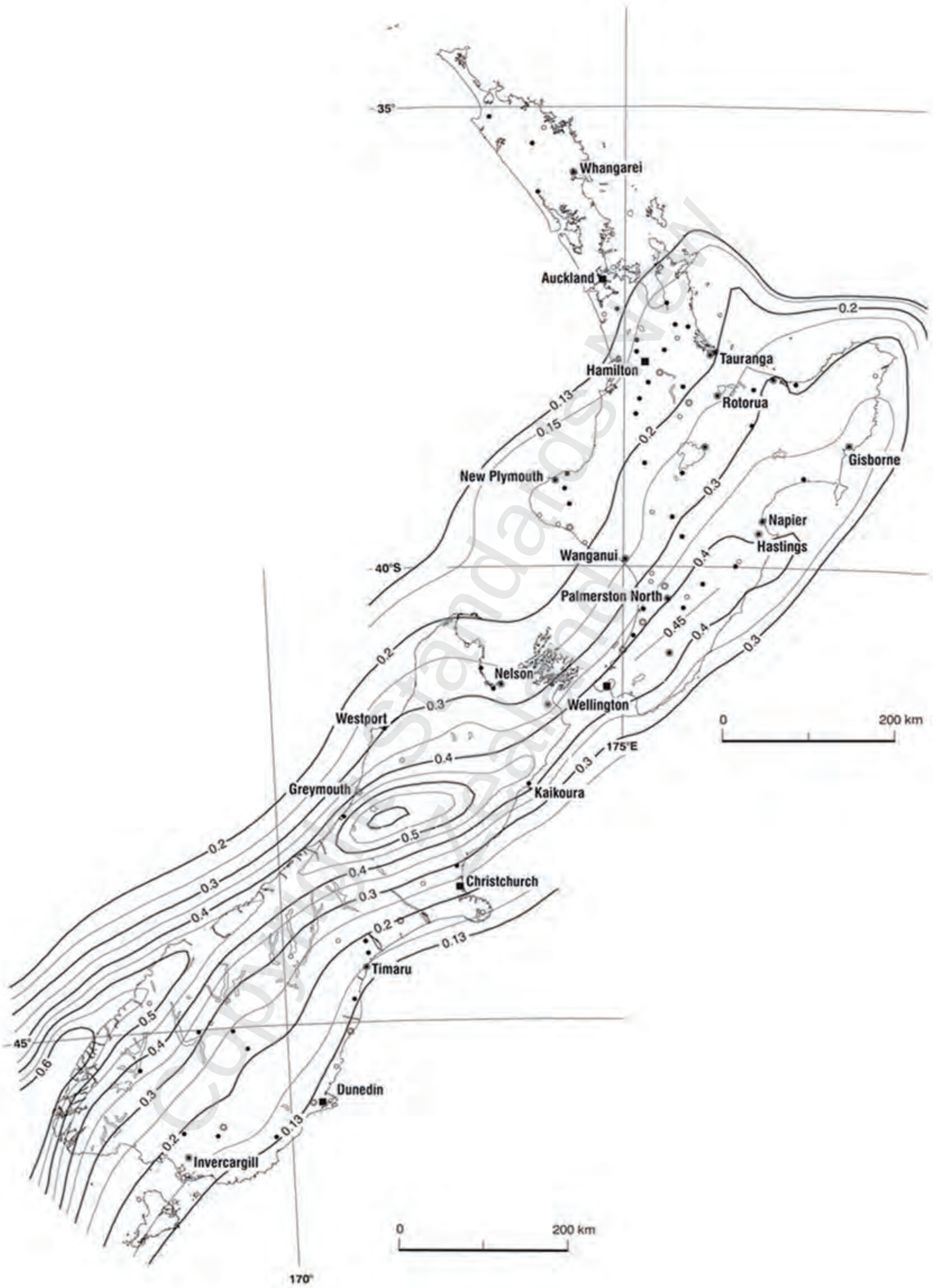


Figure 2 – Zone factor, *Z*

3.4.2 Performance factor

The value of C_p for each part of the seismic restraint system shall be used for determining the load in that part rather than taking the most severe applicable value and applying it to the whole system (see table 4).

Table 4 – Performance factors

Item	Building importance level	Category (limit state)	Component performance factor, C_p
Anchors, fixings and fasteners	1, 2, 3 or 4	All	0.85
Braces and supports	1, 2, 3 or 4	P1, P2, P3 or P4 (ULS)	0.85 or from Appendix C*
Braces and supports	1, 2 or 3	P6 or P7 (SLS1)	0.85
Braces and supports	4	P5 (SLS2)	0.85

* The lower of these values may be used.

3.4.3 Component risk factor

The component risk factor, R_c, shall be determined from table 5, using the importance level and category selected from 3.3.1 and 3.3.2.

Table 5 – Determination of component risk factor

Part category	Risk factor (R_c)		
	Building importance level		
	1 and 2	3	4
P1, P2, and P4	1.00	1.30	1.80
P3	0.90	1.20	1.60
P5	Not applicable		1.00
P6	0.50		
P7	0.25		

3.4.4 Operating weight

The operating weight of a component is its weight under normal operating conditions. It includes the weight of any contents (such as fuel) likely to be present under normal operating conditions. In the case of a non-pressure tank or pipeline the operating weight includes the contents up to the overflow level.

3.5 RELATIVE SEISMIC DISPLACEMENT

Components connected to the building structure at more than one level shall be able to sustain the relative seismic displacement, D, between the levels for the appropriate criterion (see 2.2) in accordance with either 3.5.1 or 3.5.2.

The displacement shall be determined from the building's calculated design displacement, where known. If the displacement is not known, the displacement shall be calculated using equation 3.3.

$$D = 0.025\, R_C\, H_Z \qquad \text{(Equation 3.3)}$$

where:

R_C = component risk factor from 3.4.3 (but not greater than 1.0)

H_Z = height between fixing points.

C3.5
For some components, such as piping, relative seismic displacements between support points are generally more significant than forces. The maximum displacement, as given in NZS 1170.5, is 0.025 times the storey height.

3.5.1 Flexible joints

Components may be attached to the supporting structure by flexible joints designed to accommodate the displacements prescribed in 3.5. Such joints shall be demonstrated by test or other means to be able to accommodate, by means of rotation or otherwise, the deflections associated with relative displacements between fixing points.

C3.5.1
Examples of flexible joints are rubber collars, grooved joints, ball and socket joints, and bellows joints.

3.5.2 Rigid joints

Components coming within the scope of 3.5, which are attached to the structure by joints not designed to allow for the required displacement, are not covered by this section. These components will require specific structural engineering design in accordance with section 4.

C3.5.2
Piping made of ductile materials such as steel or copper can accommodate relative displacements by local yielding but with strain accumulations well below failure levels. However, components made of less ductile materials, and some types of pipe joints (such as screwed), can accommodate relative displacement effects only by use of flexible joints, which would avoid local yielding.

3.6 LINEAR COMPONENTS

This clause applies to components with one significant linear dimension, such as pipes, ducts, cable trays, and so forth, running either horizontally, vertically or inclined.

Linear components shall be restrained in two orthogonal horizontal directions in addition to their normal gravity supports (see figure 3). For the direction perpendicular to the axis of the component, the maximum spacing between points of transverse restraint shall be taken from table 6. For the direction parallel to the axis of the component, the maximum spacing between points of longitudinal restraint shall be taken from table 7. The earthquake load demand, *F*, to be resisted at the maximum restraint spacing is given by table 6 or table 7 as appropriate. For restraints closer than the maximum spacing, *F*, may be reduced proportionately.

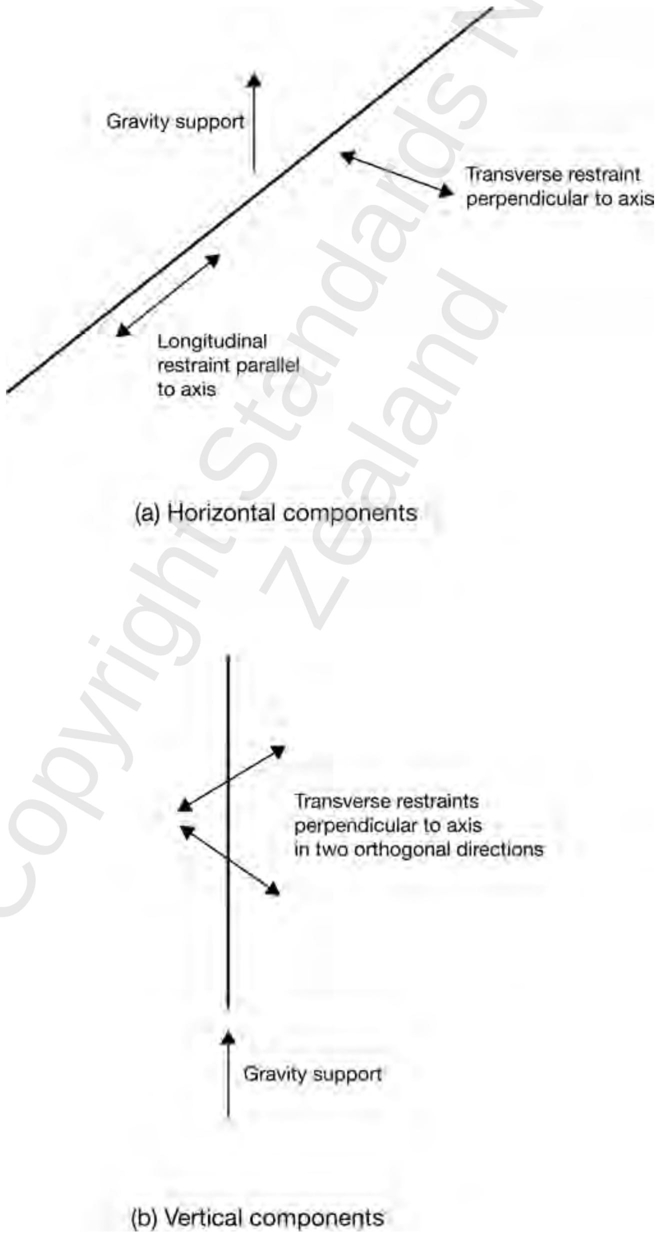


Figure 3 – Restraint of linear components

Table 6 – Spacing of transverse pipe restraints

(a) Steel pipes to BS 1387 or AS 1163 Grade C250 (or better)

Inside diameter (NB) (mm)	Min. wall (mm)	Lateral force coefficient					
		Where *C* = 1.0		Where *C* = 2.0		Where *C* = 3.6	
		Max. spacing (m)	Horizontal force, *F* (kN)	Max. spacing (m)	Horizontal force, *F* (kN)	Max. spacing (m)	Horizontal force, *F* (kN)
50	2.90	7.7	0.45	6.1	0.71	5.0	1.05
65	3.60	8.9	0.84	7.0	1.33	5.7	1.96
80	4.00	9.6	1.28	7.6	2.04	6.0	2.88
100	4.50	11.4	2.22	9.0	3.52	6.8	4.78
150	4.88	12.0	4.36	10.2	7.43	7.6	9.97
200	4.80	12.0	6.68	10.6	11.90	7.9	15.97

Where the lateral force coefficient, *C*, is determined from equation 3.2

(b) Copper pipes to NZS 3501

Nominal diameter (mm)	Min. wall (mm)	Lateral force coefficient					
		Where *C* = 1.0		Where *C* = 2.0		Where *C* = 3.6	
		Max. spacing (m)	Horizontal force, *F* (kN)	Max. spacing (m)	Horizontal force, *F* (kN)	Max. spacing (m)	Horizontal force, *F* (kN)
50	1.22	2.6	0.09	2.1	0.15	1.7	0.22
65	1.22	3.0	0.16	2.4	0.26	1.9	0.38
80	1.42	3.4	0.27	2.7	0.43	2.2	0.64
100	1.63	3.9	0.47	3.1	0.74	2.5	1.10

Where *C* is determined from equation 3.2

Table 7 – Spacing of longitudinal pipe restraints

(a) Steel pipes to BS 1387 or AS 1163 Grade C250 (or better)

Inside diameter (NB) (mm)	**Min. wall** (mm)	**Lateral force coefficient**					
		Where *C* = 1.0 (Max. offset* 0.9 m)		**Where *C* = 2.0 (Max. offset* 0.6 m)**		**Where *C* = 3.6 (Max. offset* 0.4 m)**	
		Max. spacing (m)	**Horizontal force, *F*** (kN)	**Max. spacing** (m)	**Horizontal force, *F*** (kN)	**Max. spacing** (m)	**Horizontal force, *F*** (kN)
50	2.90	23.0	1.32	18.0	2.07	15.0	3.10
65	3.60	26.0	2.45	21.0	3.95	17.0	5.76
80	4.00	28.0	3.73	22.0	5.86	18.0	8.63
100	4.50	34.0	6.61	27.0	10.50	20.0	14.00
150	4.88	36.0	13.07	30.0	21.79	22.0	28.76
200	4.80	36.0	20.04	32.0	35.62	23.0	46.09
* See figure 16.							

Where *C* is determined from equation 3.2

(b) Copper pipes to NZS 3501

Nominal diameter (mm)	**Min wall** (mm)	**Lateral force coefficient**					
		Where *C* = 1.0 (Max. offset* 0.9 m)		**Where *C* = 2.0 (Max. offset* 0.6 m)**		**Where *C* = 3.6 (Max. offset* 0.4 m)**	
		Max. spacing (m)	**Horizontal force, *F*** (kN)	**Max. spacing** (m)	**Horizontal force, *F*** (kN)	**Max. spacing** (m)	**Horizontal force, *F*** (kN)
50	1.22	8.0	0.28	6.0	0.42	5.0	0.63
65	1.22	9.0	0.48	7.0	0.74	5.0	0.96
80	1.42	10.0	0.79	8.0	1.26	6.0	1.70
100	1.63	11.0	1.31	9.0	2.15	7.0	3.01
* See figure 16.							

Where *C* is determined from equation 3.2

Forces in the restraint elements, such as braces, fixings, and anchors, shall be determined from figure 4 and equation 3.4, and the restraint systems designed in accordance with 3.10 and 3.11.

$$P = \frac{F}{\cos\theta} \quad \text{(Equation 3.4)}$$

where

P = brace force in the restraint element

F = horizontal force obtained from table 6 or table 7, as applicable

θ = angle of brace to horizontal (max. 60°).

Where the angle of the brace, θ, exceeds +/- 30°, the additional reaction in the vertical support system shall be considered.

Linear components attached to the supporting structure at more than one level shall also comply with equation 3.5.

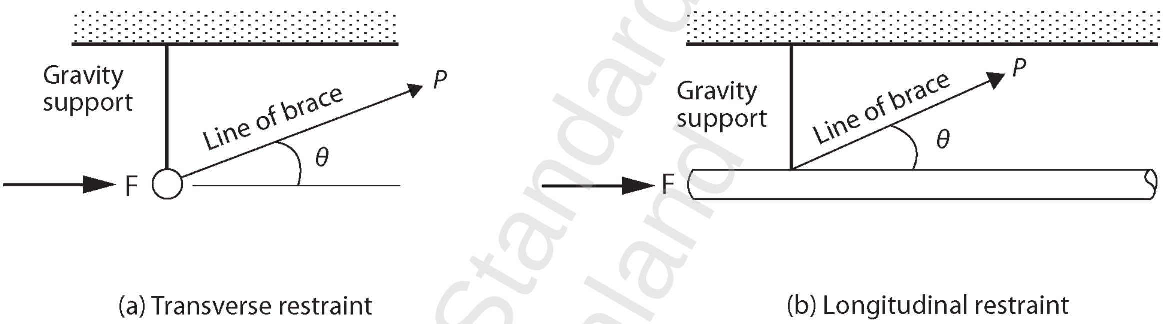


Figure 4 – Forces on linear components

C3.6

Distances between lateral restraints were derived using the following criteria:

(a) Seismic loads are based on pipes full of water;

(b) Deflection is limited to restraint spacing/300, with a maximum of 50 mm;

(c) Steel bending stress 100 MPa, E = 200,000 MPa;

(d) Copper bending stress 30 MPa, E = 17,000 MPa.

3.7 FLOOR-MOUNTED COMPONENTS

3.7.1 Rigidly mounted

3.7.1.1 Unbraced

This clause applies to rigid components with a single definable centre of gravity, and mounted either directly on a floor or on a plinth, and relying on their fixing to the floor structure for lateral restraint.

Forces on floor fixings or supports shall be determined from figure 5. Two orthogonal, horizontal directions shall be considered. Anchor forces determined for the two directions need not be considered concurrently. Anchors shall be designed in accordance with 3.10.

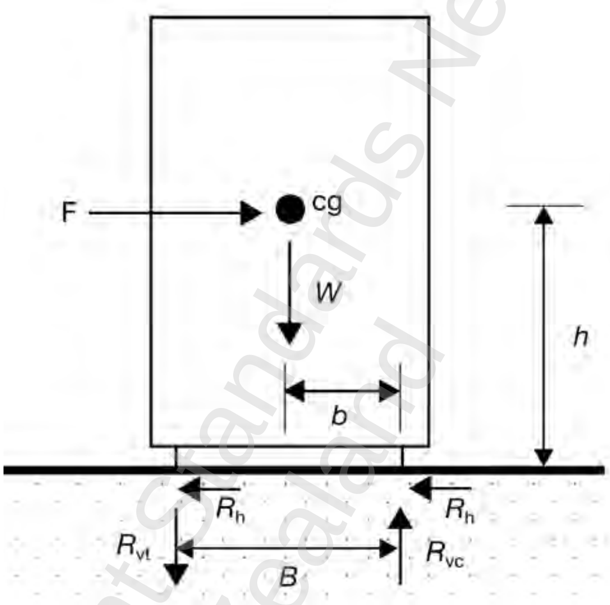


Figure 5 – Forces on floor-mounted components

Horizontal force on each support shall be taken as:

$$R_h = \frac{CW}{N} \quad \text{(Equation 3.5)}$$

Vertical force on each support shall be taken as:

$$R_{VC} \text{ or } R_{vt} = \pm\frac{CWh}{nB} + \frac{W}{N}$$ (positive equals compression, negative equals tension) .... (Equation 3.6)

where

C	=	lateral force coefficient, determined from equation 3.2
cg	=	centre of gravity
W	=	operating weight of the component
B	=	spacing of supports in the direction being considered
b	=	dimension from support to cg
N	=	total number of supports
n	=	number of supports acting in tension in the direction being considered
h	=	operating height of cg.

NOTE – This determination of horizontal and vertical forces applies only where $0.45B < b < 0.55B$ for each orthogonal direction.

C3.7.1.1
If the component is to be fixed at the base alone, without horizontal bracing, then the integrity of the component is to be sufficient to resist the resulting seismic actions.

3.7.1.2 Braced

This clause applies to components fixed to the floor with restraints attached part way over their height. If there is no single, easily defined, centre of gravity, they shall be considered by 3.9.

Braced components shall be restrained in two orthogonal horizontal directions (see figure 6). Restraining systems shall be disposed symmetrically about the centre of gravity of the component in each direction. Tension-only braces shall be arranged in opposing pairs. Where the angle of the brace exceeds +/- 30° to the horizontal, the vertical reaction on the component shall be considered.

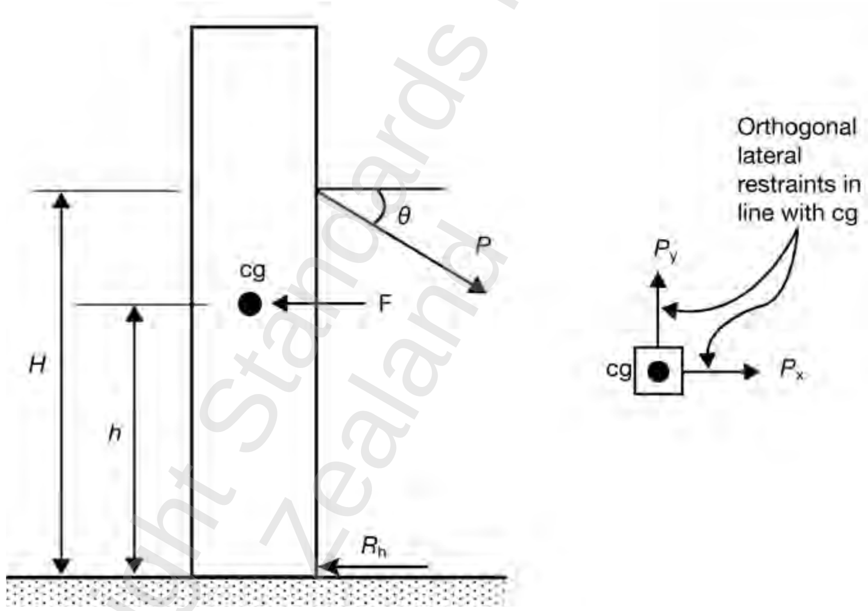


Figure 6 – Forces on tall braced components

The brace force shall be taken as:

$$P = \frac{CWh}{H\cos\theta} \quad \text{(Equation 3.7)}$$

The horizontal force on each floor support shall be taken as:

$$R_h = \frac{CW - P\cos\theta}{N} \quad \text{(Equation 3.8)}$$

where

C = lateral force coefficient, determined from equation 3

cg = centre of gravity

W = operating weight of the component

h = height to centre of gravity

H = height to brace fixing of the component

N = total number of supports

θ = angle of brace to horizontal (max. 60°).

3.7.2 Resiliently mounted

This clause applies to rigid components mounted to the floor via resilient mounts to isolate the transmission of vibration from the component to the structure and where snubbers may be used to limit the amount of movement of the component under seismic actions.

Forces on floor fixings and anchors for resilient mounts and snubbers shall be determined in accordance with the following procedures for each type of resilient mount as defined in 3.7.2.1.

Anchors and fixings shall be designed for the calculated forces in accordance with 3.10.

3.7.2.1 Resilient mount types

Resilient mounts can be categorised into two types.

A Type 1 resilient mount is defined as a system where the individual resilient mountings or vibration isolators have sufficient strength and stiffness to work as fixings for the restraint of seismic actions without the need for additional snubbers (see figure 7).

A Type 2 resilient mount is defined as a mounting system where the individual resilient mounts or isolators do not have sufficient strength or stiffness to work as fixings for the restraint of seismic actions and snubbers are required to limit the amount of movement of the component and restrain the component from the forces generated from seismic actions (see figure 8).

C3.7.2.1

Type 1 resilient mountings will often have snubbers incorporated or built into the vibration isolated mounting to provide the necessary strength and stiffness to restrain and limit seismic actions. In some cases snubbers may only be used to limit or buffer horizontal movements in which case they do not need to be designed to restrain vertically generated forces from the component.

3.7.2.2. Force calculations

The calculation of horizontal and vertical forces on mounts and snubbers shall be determined from figures 7 and 8 in accordance with 3.7.2.2.1 and 3.7.2.2.2.

3.7.2.2.1

Type 1 resilient mount – sufficiently strong and stiff to provide restraint to seismic actions without additional snubbers.

The fixing forces for type 1 resilient mounts shall be determined from figure 7. Loading along two orthogonal, horizontal directions shall be considered separately to determine the most critical load case on fixings. Anchors and fixings shall be designed in accordance with 3.10.

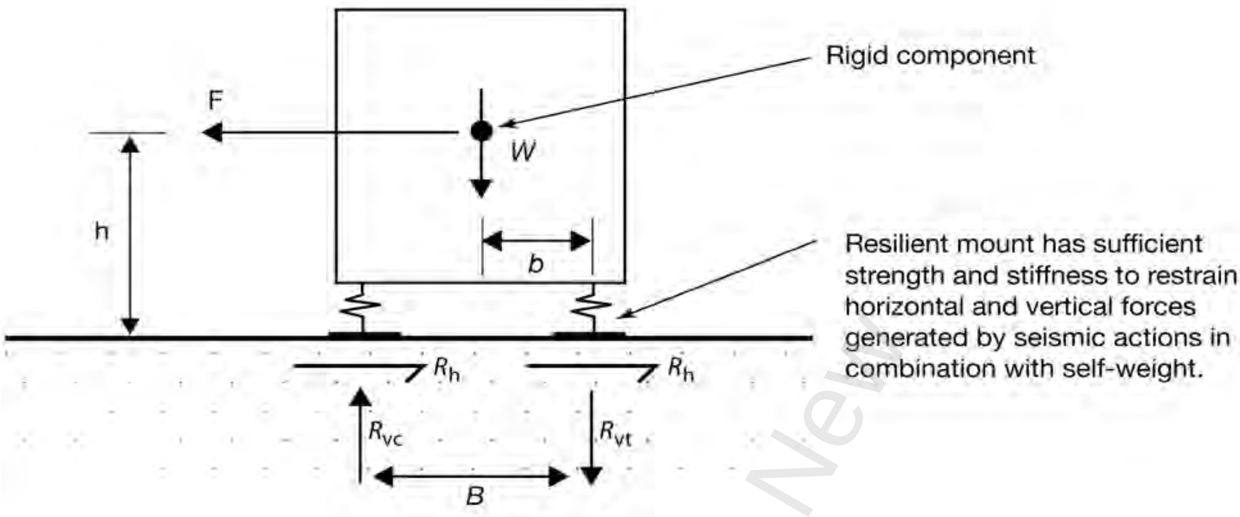


Figure 7 – Forces on floor-mounted components using type 1 mounts without snubbers

Horizontal force on each support or fixing shall be taken as:

$$R_h = \frac{CW}{N} \quad \text{(Equation 3.9)}$$

Vertical force on each support or fixing shall be taken as:

R_{vc} or R_{vt} $= \pm 1.3 \times \frac{CWh}{nB} + \frac{W}{N}$ (positive equals compression, negative equals tension) ....(Equation 3.10)

where

C = lateral force coefficient, determined from equation 3.2

W = operating weight of the component

B = spacing of supports or fixings in the direction being considered

N = total number of supports or fixings

n = number of supports or fixings acting in tension in the direction being considered

h = operating height of cg.

NOTE – This determination of horizontal and vertical forces applies only where $0.45B < b < 0.55B$ for each orthogonal direction.

C3.7.2.2.1

For equipment mounted with this type of resilient mount, the calculation of forces on the resilient mount includes the weight of the equipment as a restoring force when considering uplift of the fixing. The 1.3 multiplier allows for increased variation of the seismic force from concurrent loading in each orthogonal direction. (Refer to 5.3 of AS/NZS 1170.5.)

3.7.2.2.2

Type 2 resilient mount – utilising the isolator housing or supplementary fixings as snubbers to restrain and limit forces from seismic actions.

The fixing forces for snubbers of type 2 resilient mounts shall be determined from figure 8. Loading along two orthogonal, horizontal directions shall be considered separately to determine the most critical load case on fixings. Anchors and fixings shall be designed in accordance with 3.10.

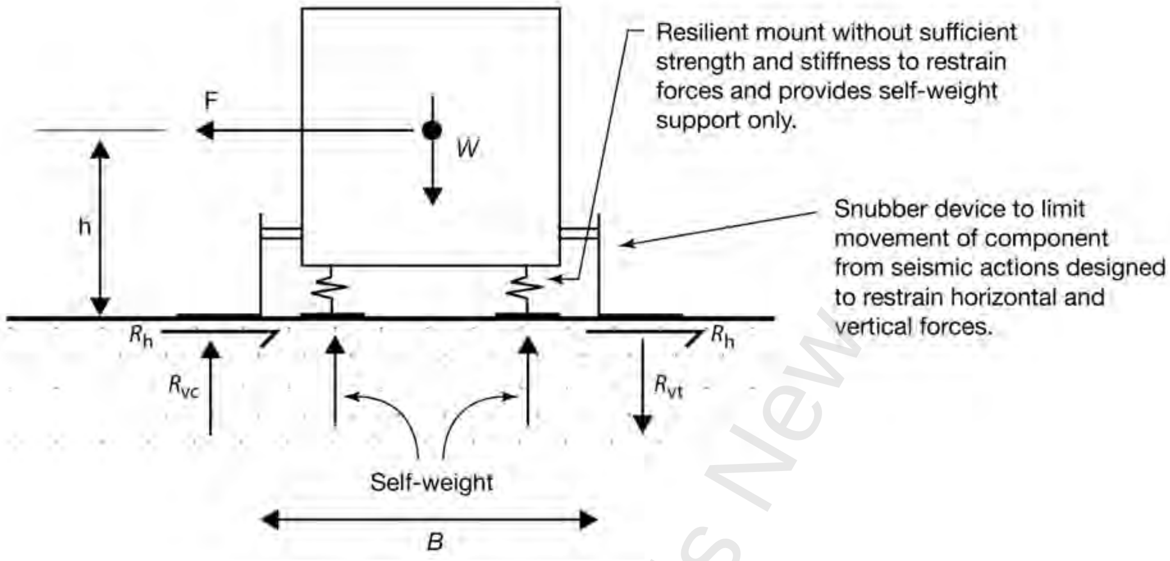


Figure 8 – Forces on floor-mounted components using type 2 mounts with snubbers

Horizontal force on each snubber support or fixing shall be taken as:

$$R_h = \frac{CW}{N} \times i \qquad \text{(Equation 3.11)}$$

Vertical force on each snubber support or fixing shall be taken as:

$$R_{vc} \text{ or } R_{vt} = \pm 1.3 \times \frac{CWh}{nB} \times i \text{ (positive equals compression, negative equals tension)} \qquad \text{(Equation 3.12)}$$

where

C = lateral force coefficient, determined from equation 3.2

W = operating weight of the component

B = spacing of supports or fixings in the direction being considered

N = total number of supports or fixings

n = number of supports or fixings acting in tension in the direction being considered

h = operating height of cg

i = impact factor:

1 for snubbers with resilient pads and less than 6 mm clearance between the component support frame and the snubber device in the direction being considered

1.5 for snubbers with less than 6 mm clearance and no resilient pads (metal on metal contact) between the component support frame and the snubber device in the direction being considered

2 for snubbers with more than 6 mm clearance and resilient pads between the component frame and the snubber device in the direction being considered

3 for snubbers with more than 6 mm clearance and without resilient pads (metal on metal contact) between the component support frame and the snubber device.

NOTE – This determination of horizontal and vertical forces applies only where $0.45B < b < 0.55B$ for each orthogonal direction. Forces on the resilient mounts need only be designed for self-weight only.

C3.7.2.2.2

For equipment mounted with this type of resilient mount using external snubbers, the calculation of forces on the snubber excludes the weight of the equipment as it is already supported by the resilient mountings. The 1.3 multiplier allows for increased variation of the seismic force from concurrent loading in each orthogonal direction. (Refer to 5.3 of NZS 1170.5.)

3.7.2.3 Anchor bolt force calculations

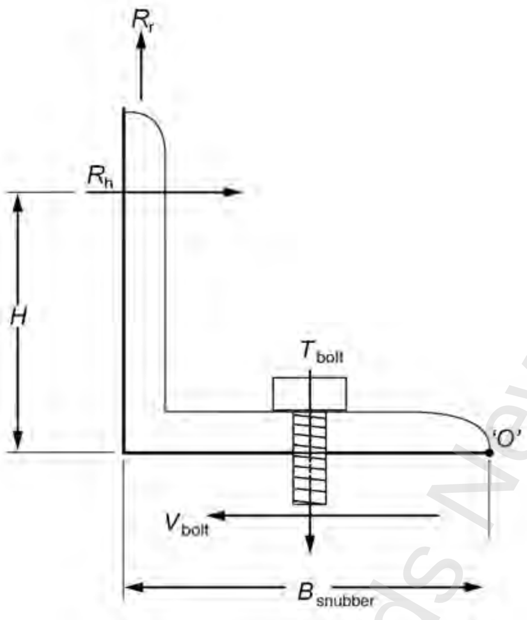
Anchor bolt forces for isolation or snubber fixings shall be calculated in accordance with 3.7.3.

3.7.3 Anchor bolt forces calculations for independent supports

Anchor bolt forces to resist the calculated fixing forces for independent supports not ridigly fixed to the component as in the case of an isolator or snubber fixing shall be determined based on the geometry of the fixing, taking into consideration the alignment of the applied forces. The specific case of a fixing with a single line of anchors resisting a vertical and horizontal action is provided in 3.7.3.1.

3.7.3.1 Equipment supported on independent supports such as vibration isolators and restrained with seismic snubbers

Anchor bolt horizontal and vertical forces for independent supports to resist seismic actions shall be determined from figure 9.



where

R_r = Maximum uplift (see equations 3.11)

R_h = Maximum shear (see equation 3.12)

H = Height to restraint connection

$B_{snubber}$ = Snubber width

n_{bolt} = Number of anchor bolts

T_{bolt} = Tension per anchor bolt

$$T_{bolt} = \frac{R_h H + R_r B_{snubber}}{n_{bolt}\left(\frac{B_{snubber}}{2}\right)}$$

V_{bolt} = Shear per anchor bolt

$$V_{bolt} = \frac{R_h}{n_{bolt}}$$

Figure 9 – Anchor bolt force calculation of independent fixings such as used for vibration-isolated components

3.8 SUSPENDED COMPONENTS

This clause applies to components suspended from the structure (floor slab or roof structure) above their centre of gravity, and requiring lateral bracing for seismic restraint. It also applies where linear components (see 3.6) are being considered in their axial direction.

Suspended components shall be restrained in two orthogonal horizontal directions. Restraining systems shall be disposed symmetrically about the centre of gravity of the component in each direction. Tension-only braces shall be arranged in opposing pairs. Where the angle of the brace exceeds +/- 30°, the additional reaction in the vertical support system shall be considered. Forces in braces shall be determined from figure 10. Braces and fixings shall be designed in accordance with 3.10 and 3.11.

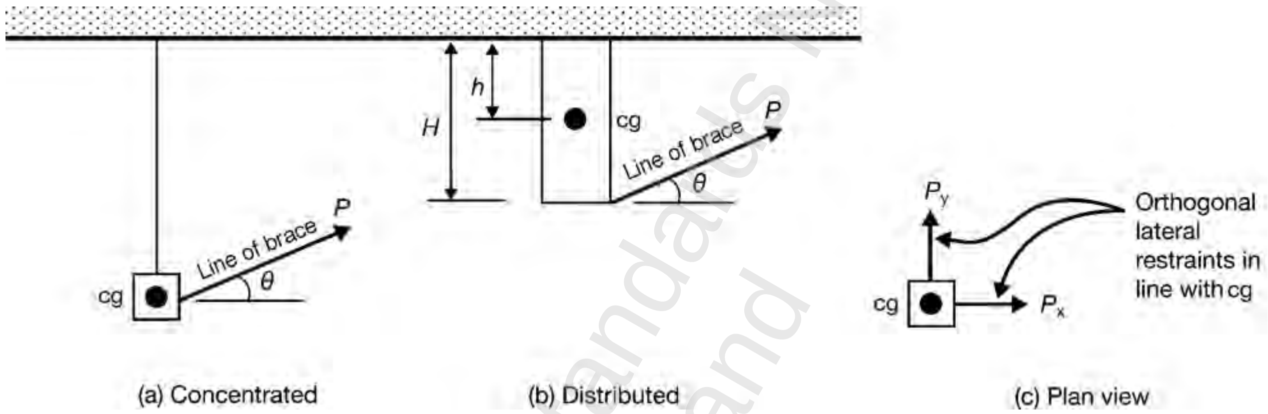


Figure 10 – Forces on suspended components

The brace force shall be taken as:

$P = \frac{CW}{\cos\theta}$ figure 10 (a)........(Equation 3.13)

$P = \frac{hCW}{H\cos\theta}$ figure 10 (b) ....(Equation 3.14)

where

C = lateral force coefficient from equation 3.2

W = operating weight of component

h = height from centre of gravity to upper support

H = height from lower fixing to upper support

θ = angle of brace to horizontal (max. 60°).

3.9 MISCELLANEOUS COMPONENTS

Components outside the scope of 3.6 to 3.8, such as wall-mounted components, are outside the scope of this section. They shall be designed using the provisions of section 4 or by testing in accordance with 4.5.

3.10 FIXINGS

All components, including their supports and restraints shall be attached to the building structure in accordance with the requirements of this section to match or exceed the load demand determined from 3.6 to 3.9, or to accommodate the displacements determined from 3.5.

Nuts on fasteners for rotating or oscillating equipment which may work loose during normal operation shall be locked in position.

C3.10
The locking device selected will depend on the fastener, but a locking type washer will normally be adequate.

Where components are fixed to non-structural elements of the building (such as timber-framed partition walls), such elements shall be checked to verify that their load carrying capacity is adequate. Such checking is outside the scope of this section.

3.10.1 Woodscrews

This clause shall be limited to steel woodscrews installed into the side grain of dry radiata pine framing timber. Screws shall be pre-bored to 0.8 × screw diameter, except for self-drilling screws.

Design strengths shall be obtained from table 8.

Table 8 – Woodscrew design strengths

Gauge	**Diameter** (mm)	**Minimum penetration** (mm)	**Tension** (kN)	**Shear** (kN)	**Minimum edge distance** (mm)	**Minimum end distance and spacing** (mm)
8	4.17	30	1.10	1.10	20	45
9	4.52	32	1.28	1.25	23	45
10	4.88	35	1.51	1.45	25	50
12	5.59	40	1.98	1.87	28	55
14	6.30	45	2.50	2.33	32	65

3.10.2 Coach screws

This clause shall be limited to coach screws installed into the side grain of dry radiata pine framing timber. Screws shall be pre-bored to 0.8 × screw diameter.

Design strengths shall be obtained from table 9.

Table 9 – Coach screw design strengths

Diameter (mm)	**Minimum penetration** (mm)	**Tension** (kN)	**Shear** (kN)	**Minimum edge distance** (mm)	**Minimum end distance and spacing** (mm)
8	80	5.38	3.54	40	80
10	100	7.49	4.42	50	100
12	120	9.91	7.28	60	120

3.10.3 Bolts

Design capacities to bolts connecting ends to steel components shall be obtained from table 10.

Table 10 – Capacities of bolts in shear

Bolt size	**Minimum end distance** (mm)	**Capacity for 1 bolt in single shear** (kN)
M8	16	6.1
M10	20	10.1
M12	24	15.1
M16	32	28.6
M20	40	45

C3.10.3
The capacities used in these bolts relate to root area.

3.10.4 Cast-in anchors

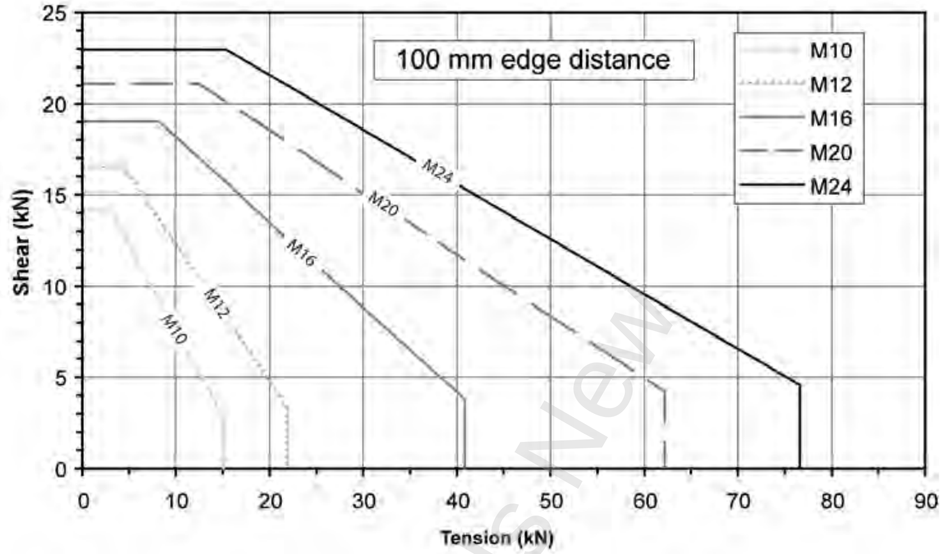
This clause applies to Grade 4.6 bolts or threaded rods installed into wet concrete or into concrete masonry before grouting. Specialty inserts, such as threaded sockets, and grouted anchors are outside the scope of this clause. However they may be used within the provisions of 3.10.5.

For the design of anchors, the performance factor, C_p, shall be 0.85 (see 3.4.2).

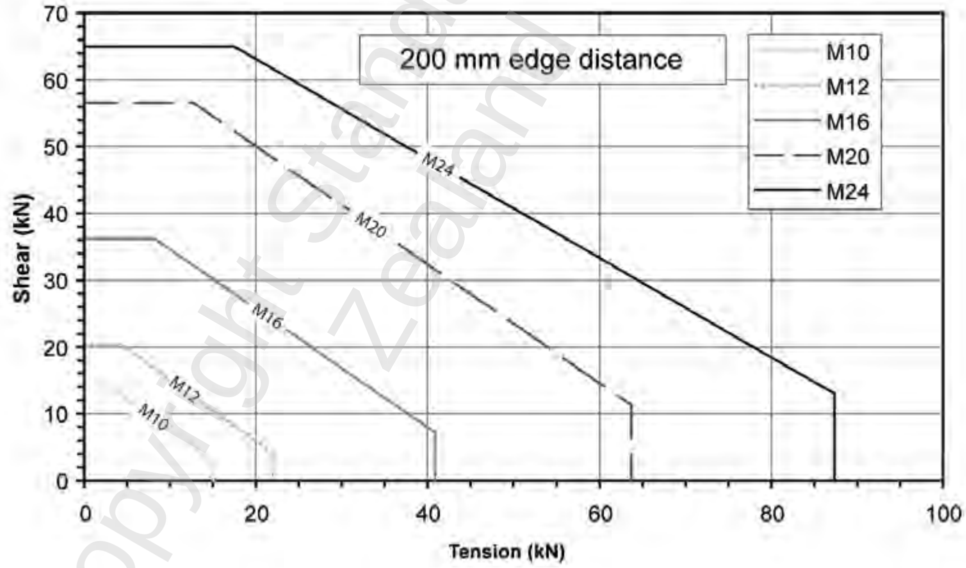
Anchors shall be provided with a positive means to prevent rotation while tightening the nut.

3.10.4.1 Cast into concrete

Design strength of anchors cast into concrete of specified strength 25 MPa or better shall be obtained from figure 11. Anchor edge distance, embedment, and spacing shall be in accordance with figure 11.



(a) 100 mm edge distance



(b) 200 mm or greater edge distance

NOTE – For both (a) and (b), the following shall apply:

Bolt size	**Minimum embedment** (mm)	**Minimum spacing** (mm)
M10	75	200
M12	100	300
M16	125	375
M20	150	450
M24	175	500

Figure 11 – Design strengths of bolts cast in concrete

3.10.4.2 Cast into concrete masonry

Bolts shall be embedded in grout in accordance with table 11, and as shown in figure 12.

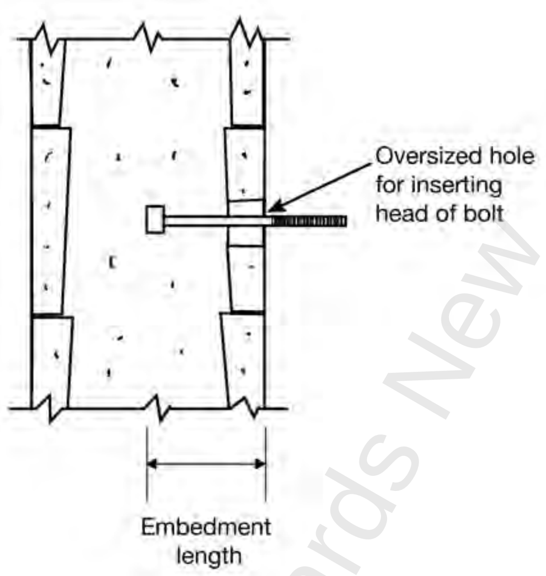


Figure 12 – Typical detail of bolt cast into concrete masonry

The minimum edge-distance, measured from the centre of the bolt to the outer face of the masonry, shall be not less than the embedment length, and spacing between adjacent bolts shall be not less than 2 × the embedment length.

The design strength of bolts imbedded in concrete masonry shall be obtained from table 11.

Table 11 – Design strength of bolts embedded in concrete masonry

Diameter (mm)	**Minimum embedment length** (mm)	**Tension and shear** (kN)
12	100	10
16	125	15
20	150	25
24	175	35

3.10.5 Post-installed and proprietary anchors

All post-installed and proprietary anchors used for restraint of engineering systems components shall have passed the seismic qualification test stipulated in ACI 355.2.

Expansion anchors shall not be used for non-vibration isolated mechanical equipment rated over 8 kW.

Design strength in tension and shear shall be obtained from manufacturer's data and shall comply with the requirements of this clause.

Manufacturers supplying anchors for use under this clause shall provide the following information on each package:

(a) Name and address of the manufacturer;

(b) Scope of application;

(c) Design strength of anchors in tension and shear, obtained using the provisions of ACI 355.2;

(d) Statement of compliance with ACI 355.2; and

(e) Installation instructions.

C3.10.5

Post-installed expansion and undercut anchors may be approved suitable for seismic applications using the testing procedures outlined in ACI 355.2.

No test Standard exists for chemical anchors.

Caution should be exercised during the use of the existing test results in earthquake environments. The effects on anchor capacity from earthquake-induced cracking of the concrete or masonry need to be considered.

3.11 BRACES

Braces used to provide seismic restraint to components of engineering systems shall be designed in accordance with this clause to equal or exceed the forces determined from 3.6 to 3.8.

3.11.1 Materials

All structural steel and fasteners coming within the scope of 3.11 shall, before fabrication, comply with the following Standards given in table 12.

Table 12 – Specification for brace and fastener materials

Brace or fastener type	Material Standard
Angles	AS/NZS 3679.1 – 300 (Grade 300)
Flats	AS/NZS 3679.1 – 300
SHS	AS 1163, Grade C350LO
Bolts	AS 1111.1, Property class 4.6
Threaded rods	AS 1111.1, Property class 4.6
Nuts	AS 1112.3

3.11.2 Braces in tension

Design capacities of braces in axial tension shall be obtained from table 13.

Table 13 – Capacity of braces in tension

Angles	Bolt size	Tension capacity (kN) for single leg connected by:			
		1 bolt	2 bolts	Welded	Fillet weld size and length (mm)
25x25x3EA	M8	6	12	32	3, 80
	M10	10	20	39	3, 100
40x40x3EA	M12	15	30	55	3, 140
50x50x3EA	M16	28	57	69	3, 170
50x50x5EA	M16	28	57	101	5, 150
50x50x8EA	M16	28	57	166	6, 200
65x65x8EA	M16	28	57	233	6, 280
75x75x8EA	M20	62	124	267	6, 330
75x75x10EA	M20	62	124	377	6, 460
90x90x10EA	M20	62	124	457	6, 550
100x100x8EA	M20	62	124	429	6, 520
Flats	**Bolt size**	**Tension capacity (kN) for flat connected by:**			
		1 bolt	**2 bolts**	**Welded**	**Fillet weld size and length (mm)**
20x3	M8	6	12	17	3, 50
20x5	M8	6	12	29	5, 50
20x6	M8	6	12	35	6, 50
20x10	M8	6	12	58	6, 70
25x3	M10	10	20	22	3, 60
25x5	M10	10	20	36	5, 60
25x10	M10	10	20	72	6, 90
25x12	M10	10	20	86	6, 110
40x3	M16	22	35	35	3, 90
40x6	M16	29	57	69	6, 90
40x10	M16	29	57	115	6, 140
40x12	M16	29	57	138	6, 170
50x3	M20	28	43	43	3, 110
50x6	M20	45	86	86	6, 110
50x10	M20	45	89	144	6, 180
50x12	M20	45	89	173	6, 210
75x6	M20	45	89	130	6, 160
75x10	M20	45	89	216	6, 260
75x12	M20	45	89	259	6, 320
100x6	M20	45	89	173	6, 210
100x10	M20	45	89	288	6, 350
100x12	M20	45	89	346	6, 420

Table 13 – Capacity of braces in tension (continued)

Threaded rods	**Tension capacity** (kN)
M10	18
M12	27
M16	50
M20	78
M24	113
Galvanised steel wire	**Tension capacity** (kN)
3.2 mm	1.5
NOTE – For angles, the configuration of bolts and welds to be as shown in figure 13.	

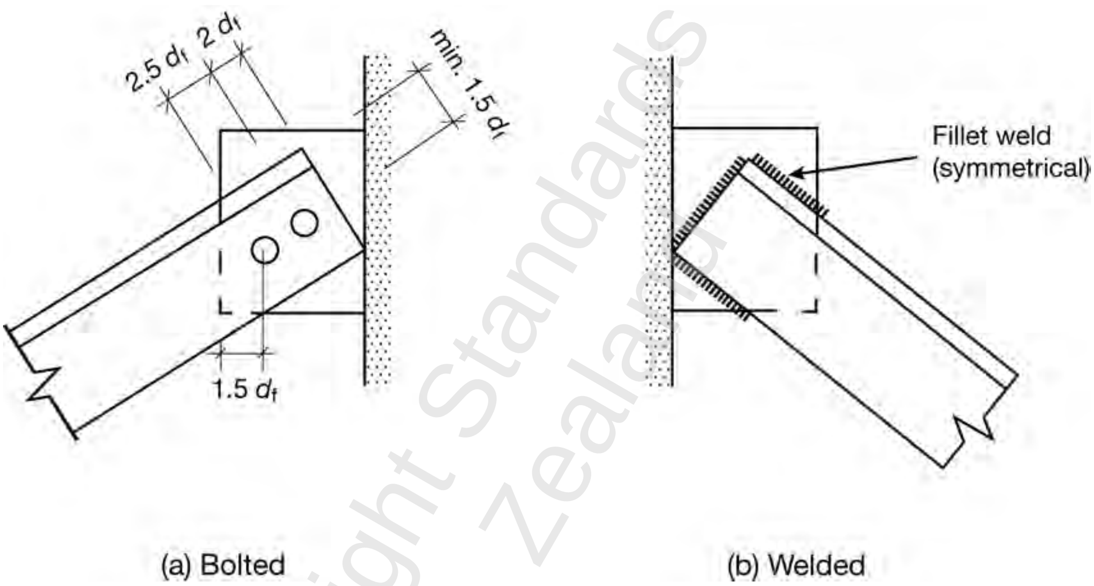


Figure 13 – Bolted and welded brace fixings

where

d_f = diameter of fastener

3.11.3 Braces in compression

Design capacities of braces in axial compression shall be obtained from table 14.

Table 14 – Capacity of braces in compression

(a) Angles	Bolt	Compression capacity (kN) (number of bolts) for length of:					
		0.5 m	1.0 m	1.5 m	2.0 m	2.5 m	3.0 m
25×25×3 EA	M8	7.4 (2)	3.5 (1)	1.4 (1)	0.8 (1)	0.5 (1)	–
30×30×3 EA	M10	11.2 (2)	4.8 (1)	2.4 (1)	1.4 (1)	0.9 (1)	0.6 (1)
40×40×3 EA	M12	17.5 (2)	10.0 (1)	5.7 (1)	3.4 (1)	2.4 (1)	1.6 (1)
50×50×3 EA	M16	23.7 (1)	15.4 (1)	11.5 (1)	6.5 (1)	4.4 (1)	3.1 (1)
50×50×5 EA	M16	37.7 (2)	25.6 (1)	15.4 (1)	9.5 (1)	6.3 (1)	4.6 (1)
50×50×8 EA	M16	61.9 (3)	41.0 (2)	25.2 (1)	15.6 (1)	9.6 (1)	7.2 (1)
65×65×8 EA	M16	93.0 *	69.5 (3)	47.2 (2)	33.7 (2)	23.6 (1)	16.9 (1)
75×75×8 EA	M20	100.0 (3)	72.6 (2)	49.1 (2)	34.9 (1)	23.2 (1)	16.8 (1)
75×75×10 EA	M20	134.9 *	100.8 (3)	79.9 (2)	57.4 (2)	42.9 (1)	30.1 (1)
90×90×10 EA	M20	173.3 *	161.5 *	132.1 (3)	106.9 (3)	87.3 (2)	70.8 (2)
100×100×8 EA	M20	145.2 *	137.3 *	116.4 (3)	98.8 (3)	80.3 (2)	64.1 (2)

NOTE –

(1) Bolts are assumed to be placed through only one leg of the angle (see figure 13).

(2) Values with an asterisk require a fully welded base plate fixing (see figure 14).

(b) Flats	Compression capacity (kN) for length of:					
	0.5 m	1.0 m	1.5 m	2.0 m	2.5 m	3.0 m
20×3	–	–	–	–	–	–
20×5	0.6	–	–	–	–	–
20×6	1.1	–	–	–	–	–
20×10	4.6	1.2	–	–	–	–
25×3	–	–	–	–	–	–
25×5	0.8	–	–	–	–	–
25×10	6.1	1.6	–	–	–	–
25×12	9.7	2.8	–	–	–	–
40×3	–	–	–	–	–	–
40×6	2.4	–	–	–	–	–
40×10	10.0	2.7	–	–	–	–
40×12	16.4	4.8	–	–	–	–
50×3	–	–	–	–	–	–
50×6	3.0	–	–	–	–	–
50×10	12.8	3.5	–	–	–	–
50×12	20.9	6.1	–	–	–	–
75×6	5.8	–	–	–	–	–
75×10	24.2	6.6	–	–	–	–
75×12	39.6	11.5	–	–	–	–

Table 14 – Capacity of braces in compression (continued)

100×6	8.5	–	–	–	–	–
100×10	35.6	9.7	–	–	–	–
100×12	58.2	17.0	–	–	–	–

(c) Hot rolled hollow sections	**Compression capacity for length of:** (kN)					
	0.5 m	**1.0 m**	**1.5 m**	**2.0 m**	**2.5 m**	**3.0 m**
25×25×3.0 SHS	35	17	7.7	4.1	2.6	1.8
40×40×3.0 SHS	116	95	61	36	21	17
50×50×3.0 SHS	152	138	107	72	49	34
50×50×6.0 SHS	259	227	164	103	69	48
65×65×3.0 SHS	202	194	176	143	108	78
75×75×3.0 SHS	238	231	215	191	157	119
NOTE – SHS shall have fully welded fixings at each end, with symmetrically placed fasteners.						

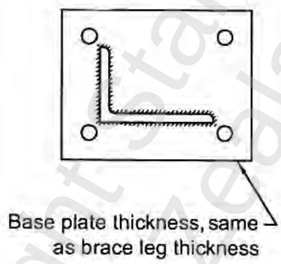


Figure 14 – Fully welded base plate fixing

4 SPECIFIC DESIGN OF RESTRAINT SYSTEMS

4.1 GENERAL

All components of engineering system equipment shall be verified as complying with the criteria of 2.2.

For components attached to only one level of the supporting structure, and subject to only inertial forces, verification may be in accordance with 4.2.1. Components which are attached to more than one level of the structure may be subject to forces caused by relative or differential deformations between fixing points as well as inertial forces. For those components, verification shall be in accordance with 4.2.2.

The design of a component, including its supports or restraints, may be verified by testing in accordance with 4.5. Fixings shall comply with 3.10.

4.2 EARTHQUAKE ACTIONS

4.2.1 Static forces

Earthquake actions shall be determined in accordance with AS/NZS 1170.0 and NZS 1170.5, for the limit state being considered, or 3.4 of this Standard where applicable.

4.2.2 Structural deformation

Forces on components of mechanical equipment, including restraints resulting from differential deformation of the supporting structure between their fixing points (where relevant), shall be determined in accordance with the principles of structural mechanics.

Deformation of the supporting structure at the points of fixing shall be determined in accordance with AS/NZS 1170.0 and NZS 1170.5, for the limit state being considered, or 3.5 of this Standard where applicable.

4.2.3 Combined actions

The forces on components resulting from the earthquake actions determined in 4.2.1 and the seismic displacement actions determined in 4.2.2 shall be combined:

where:

M^* = Total seismic action on component $= [\,(M_i)^2 + (M_d)^2\,]^{0.5}$

M_i = Design action resulting from earthquake load demand in 3.4

M_d = Design actions resulting from relative seismic displacements in 3.5.

4.3 DESIGN

Components of mechanical equipment, their restraints, and their fixings to the primary structure shall be proportioned for adequate strength, stiffness and ductility in accordance with the provisions of the appropriate material Standards.

Where the material Standard is in working stress format, or where the component design has been done in accordance with working stress Standards, the demand forces and actions determined from 4.2.1 may be reduced by the following factors:

Components requiring consideration at the ultimate limit state 0.80
Components requiring consideration at the serviceability limit state 1.0

In the absence of appropriate material Standards, the designer shall be responsible for specifying relevant material properties which are consistent with a limit state design philosophy. The performance factor C_p may be that given by 3.4.2.

C4.3
Appropriate material Standards include:

- *Steel (hot-rolled) NZS 3404*
- *Steel (cold-formed) AS/NZS 4600*
- *Stainless steel (cold-formed) AS/NZS 4673*
- *Aluminium AS/NZS 1664 Part 1*
- *Concrete NZS 3101*
- *Concrete masonry NZS 4230*
- *Timber NZS 3603.*

Different reduction factors are theoretically required for different actions and materials, as the reduction depends on the ratio between ultimate strength and allowable stress which are material dependent. For further information see ASCE 7-05.

4.4 FIXINGS

Fixings consist of bolts, welds, anchors, brackets, cleats, gusset plates, and so forth, which connect elements of the restraint system. They shall be positioned to transmit the calculated design actions in accordance with the requirements for connections in NZS 1170.5, and the appropriate materials Standards.

C4.4
Post-installed expansion and undercut anchors (but not chemical anchors) may be approved suitable for seismic applications using the testing procedures outlined in ACI 355.2. The design of qualified anchors in concrete is addressed in NZS 3101.

Anchors in masonry are rarely governed by steel capacity, and as such masonry anchors should in general be considered to be non-ductile.

For anchors that are not provided with a mechanism to transfer compression loads, the design for overturning is to reflect the actual stiffness of the base plate, equipment, housing, and so forth, in determining the location of the compression centroid and the distribution of uplift loads to the anchors.

While the requirements do not prohibit the use of single anchor fixings, it is considered good practice to use at least two anchors in any load-carrying fixing whose failure might lead to collapse, partial collapse, or disruption of a critical, inertial load path.

Depending on the design condition, ductile design of anchors in concrete or masonry may be intended to satisfy one or all of the following objectives:

(a) To ensure adequate load redistribution between anchors in a group;

(b) To allow for anchor overload without precipitous failure; and/or

(c) To dissipate seismic energy.

Unless specific attention is paid to the conditions necessary to ensure the desired hysteretic response (adequate gauge length, anchor spacing, edge distance, steel properties, and so forth), it is not recommended that anchors be relied upon for energy dissipation. An anchor may provide some transfer of load from a relatively deformable material (such as steel) to a low deformability material (such as concrete or masonry). To achieve a deformable, energy-absorbing behaviour in the anchor itself is often difficult.

On the other hand, the concept of providing a fuse, or deformable link, in the load path to the anchor is encouraged. This approach allows the designer to provide the necessary level of ductility and overstrength in the fixing while at the same time protecting the anchor from overload. It also eliminates the need to balance steel strength and deformability in the anchor with variable edge distances and anchor spacings.

4.5 TESTING

4.5.1 Scope

Testing may be carried out in accordance with the requirements of this clause as an alternative to calculation. This clause is not applicable to the establishment of general design criteria.

C4.5.1
Testing may be used as a means of verifying components of equipment not subject to any specific seismic assessment, for example, equipment sourced from overseas.

4.5.2 Test set-up

The component (or an appropriate sub-assembly) may be tested in situ in its final position in the building, or set up in a separate testing laboratory. Care shall be taken with the setup to ensure that no artificial restraints are applied by the loading system, and that boundary conditions are accurately replicated.

Loading and measuring systems shall be calibrated to BS EN ISO 7500-1 Grade 1 accuracy.

4.5.3 Load

The magnitude of the test load shall be the design load at the limit state being considered, as determined in 4.2. For components with a readily defined centre of gravity, the load application shall be as near to the centre of gravity as practicable. For a component with a distributed mass, such as a pipe, the load may be applied at third points, with the magnitude of the test load adjusted to most closely represent the action effect on the mode of failure being considered. For non-symmetrical components, the load shall be applied separately in two orthogonal horizontal directions.

4.5.4 Acceptance criteria

For the ULS, the specimen shall sustain the design load for five minutes without collapsing, releasing its contents, or becoming detached from its fixings.

At SLS1 the specimen shall sustain the design load for five minutes, without damage, while maintaining its operational continuity.

At SLS2 the specimen shall sustain the design load for five minutes, while maintaining its operational continuity.

4.5.5 Reporting

The test report shall contain the following information:

(a) The date and the name of the testing agency;

(b) Details of specimen construction and installation;

(c) The method of loading;

(d) All measurements recorded and observations made; and

(e) A statement as to whether or not the specimen satisfied the acceptance criteria.

5 SPECIFIC REQUIREMENTS

5.1 APPLICATION

The provisions of this section apply equally to sections 3 and 4.

5.2 INTERACTION BETWEEN COMPONENTS

5.2.1 Clearances

Unless otherwise specified, clearances shall be provided in accordance with table 15.

Table 15 – Clearances

Condition being considered	Minimum clearance (mm)	
	Horizontal	Vertical
Unrestrained component to unrestrained component	250	50
Unrestrained component to restrained component	150	50
Restrained component to restrained component	50	50
Penetration through structure (such as walls and floor)	50	50
NOTE – Ceiling hangers and braces are considered to be restrained components for the purposes of this table.		

C5.2.1
Flexible connections within the service may allow penetration clearances to be reduced.

5.2.2 Permitting independent movement

Where components are connected and their supports allow them to move independently of each other under seismic action, relative displacement between components shall be provided for.

C5.2.2
Relative displacement between components can be accommodated using flexible connections or by configuring pipework or ductwork to accommodate movement without fracture.

5.3 BRITTLE COMPONENTS

Brittle components shall be designed under the provisions of section 4 of this Standard.

5.4 PLINTHS

Where a component is mounted on a raised concrete plinth, the plinth shall be reinforced and anchored to the main floor slab. The plinth shall be designed to resist earthquake actions prescribed by this Standard, including overturning. Alternatively the details of figure 15 and table 16 may be used within the limits specified.

NOTE – Plinths may be designed using the provisions of NZS 3101.

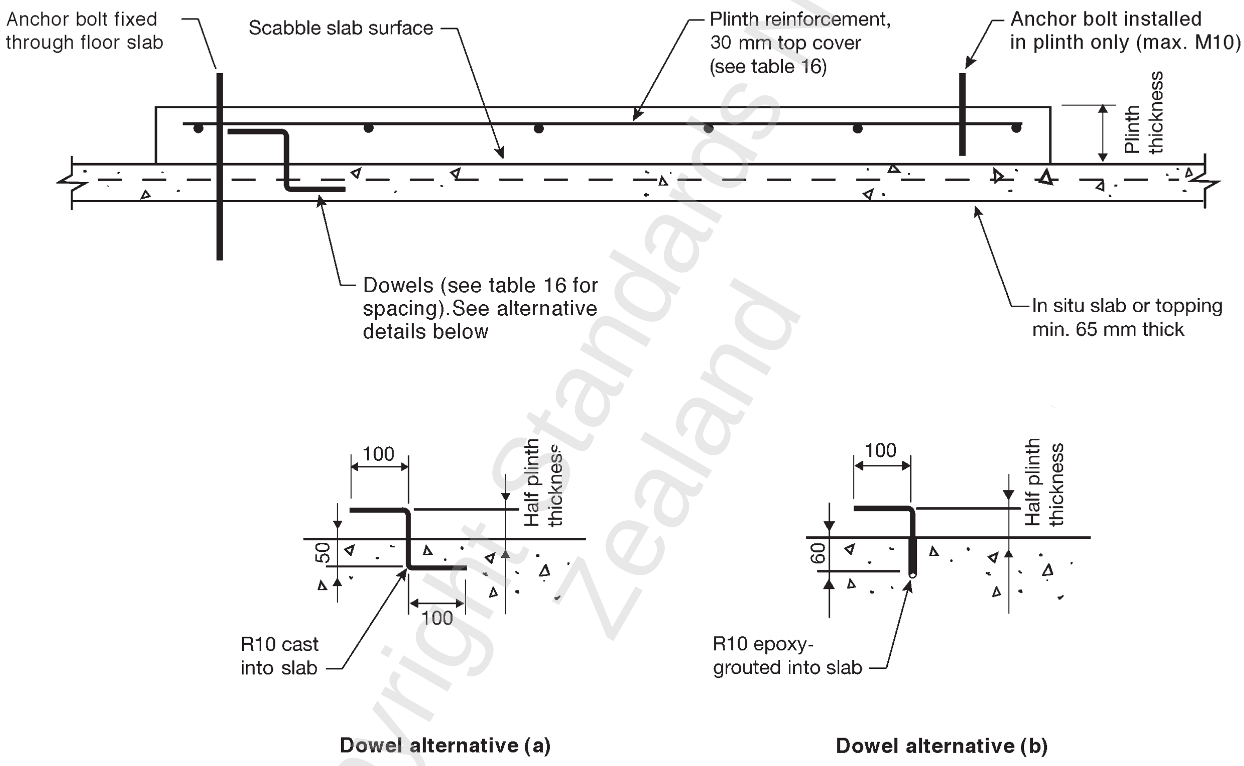


Figure 15 – Typical plinth details

Table 16 – Reinforcement requirements for plinths

Plinth thickness (mm)	**Plinth reinforcement**		**Dowels to main floor slab**	
	Option 1 MS bars (mm)	**Option 2 mesh** (mm)	**With M10 (max.) anchor bolts installed in plinth only** (mm)	**With anchor bolts fixed through the floor slab** (mm)
65 – 100	D10 at 300 each way	665	R10 at 300 each way	R10 at 600 each way
100 – 200	D12 at 200 each way	661	R10 at 300 each way	R10 at 400 each way

5.5 VIBRATION ISOLATED AND RESILIENT MOUNTINGS

Components mounted on vibration isolators shall have a bumper or snubber in each orthogonal horizontal direction, and vertical restraints shall be provided, where required, to resist overturning.

Isolator housings and mountings shall be constructed of ductile materials. Snubbers and fixings shall be designed for seismic forces induced by the dynamic impact of the component against the snubber.

The snubber shall be:

(a) A proprietary seismic snubber, meeting the performance requirements of section 3 or 4 of this Standard; or

(b) A fabricated snubber subject to the following criteria:

  (i) Where the clearance between components and the viscoelastic pad is between 3 and 6 mm, the pad shall have a thickness of at least 6 C mm but not less than 6 mm, where C is the lateral force coefficient as defined in 3.4 and impact is allowed for accordance with 3.7.2, or

  (ii) Where the clearance between components and the viscoelastic pad exceeds 6 mm, the pad shall have a thickness of at least 8 C mm but not less than 8 mm, where C is the lateral force coefficient as defined in 3.4 and impact is allowed for an accordance with 3.7.2.

Associated connections and piping shall be arranged to reduce potential damage to fuel, cooling water, and exhaust lines. Service connections shall be flexible and shall not form part of the restraining mechanism.

C5.5

Vibration isolators are used to prevent the transmission of vibration from rotating equipment to the building structure. Since isolated equipment has to be free to oscillate on the vibration isolators, seismic isolators should be installed with an air gap. The air gap allows the free vibratory oscillation of the equipment until seismic inertial forces cause temporary contact with the bumper or snubber, which limits overall displacement.

Anti-vibration mounts used to reduce the transmission of vibration from the equipment to the structure have often failed during earthquakes. Heavy inertia bases increase the seismic forces for which isolators need to be designed. Unless the forces are specifically evaluated, the snubbers should be designed for twice the forces that would apply for direct fixed components.

Captive type rubber mounts, which are unable to be pulled apart and are of sufficient strength, provide an adequate restraining system.

Steel spring and air bag mounts should be fitted with positive stops or snubbers to limit excessive movement. Such stops should be positioned clear of normal operating displacements and should have resilient surfaces to reduce shock loading.

All service lines should be kept as short as possible, while still providing adequate flexibility.

5.6 TANKS AND VESSELS

Tanks and fluid-containing vessels shall be restrained against seismic forces determined in accordance with this Standard. Tanks shall be designed and restrained in such a manner to prevent damage or loss of contents depending on the criterion being considered. Tanks shall be restrained to prevent sliding and over-turning failure. Resistance to sliding shall be by the fixings without dependence on friction between tanks and supporting pads.

Unless specifically designed, tanks and their contents shall be considered to respond as a rigid mass with restraint forces determined in accordance with section 3 of this Standard.

Tanks and vessels not attached to the building are outside the scope of this Standard.

C5.6

Pressure tanks, tanks holding highly viscous fluids, and completely filled tanks with fixed lids can be considered to respond as a rigid mass.

Open-topped tanks and partially-filled tanks with lids are subject to hydrodynamic action associated with the surface waves set up by an earthquake.

For vertical tanks, consideration should be given to the tie-down stresses around the periphery of the tank, horizontal shear at the base, overturning at the tank footing, and the compression buckling of the tank shell. Thin-walled tanks are likely to collapse at the bottom seam and rupture pipe connections, and ovalling of the tank sides at the top may also take place.

For horizontal tanks, the forces in the saddles and the base fixings should be considered. Hot water cylinders without rigid insulation can be damaged using a simple strap.

Loss of liquids could be reduced by containing the contents with specially made shallow containers. Alternatively, the containment can be achieved by extending the walls of the plant room or by bunding flat roofs and arranging for a controlled discharge. This method would be particularly applicable to water, but may not be safe for other liquids, especially if they are flammable or corrosive.

The relative movement between a tank and interconnected pipework may result in the failure of the pipe connections to the tank or adjacent fittings. Such pipes should be installed to move with the tank allowing the relative displacement to be taken up by flexible, less highly stressed sections of the pipe.

5.7 FLUES AND STACKS

Flues and stacks shall be restrained against seismic forces determined in accordance with this Standard. Flues and stacks not attached to the building are outside the scope of this Standard.

Flues and stacks emitting hazardous substances shall be located in a position accessible for inspection over their entirety so that they can be checked for damage after an earthquake. Provision shall be made for relative movement between plant structure and structural elements.

Flues and stacks shall allow for inter-storey deflection, determined from section 4 or from 3.5, in accordance with the criterion being considered.

Flues and stacks shall be restrained in two orthogonal horizontal directions and shall be designed to prevent slip joints and other flexible connections being pulled apart. Design of restraints shall be in accordance with sections 3 or 4 of this Standard.

C5.7

Light steel stacks (insulated and uninsulated) have performed better than masonry and refractory lined stacks and should be used wherever possible. Unreinforced masonry should be avoided. Masonry and refractory-lined stacks should have provision for inspection, particularly where a fire hazard could result from large cracks or damaged liners.

Stacks are continuous beams and, if supported or guyed, will respond as propped cantilevers. Modelling them as a point load on a cantilever will not accurately determine the fundamental period of the stack and, if in doubt, an assessment should be made of possible tuning with the building response, and the stack possibly analysed as being flexibly mounted.

5.8 PIPING SYSTEMS

5.8.1 General

All pipe systems shall be restrained against seismic forces determined in accordance with this Standard.

The following pipes need no specific seismic restraint unless otherwise specified in this Standard:

(a) Pipes less than 50 mm diameter; and

(b) Pipes suspended by individual hangers 150 mm or less in length from the top of the pipe to the supporting structure.

Pipes not requiring restraint shall be installed with a clearance of 150 mm from hangers and braces for suspended ceiling systems or other adjacent suspended components.

Restraints for pipes greater than 200 mm diameter shall be subject to specific design in accordance with section 4 of this Standard.

Pipework analysis based on recognised engineering principles meeting the criteria of 2.2 is deemed to comply with this Standard.

C5.8.1

Where small underground pipes run from storage tanks they should be installed inside larger diameter pipes that pass through the foundations.

For importance level 3 buildings that require fuel for temporary electric power or other essential operations, sufficient fuel should be stored on site for the immediate post-earthquake period, or where fuel cannot be stored, dual fuel equipment with storage of the secondary fuel should be considered. The point of delivery should allow easy access following an earthquake. An enclosed rear yard would not normally be as suitable as a street filling point because of debris.

5.8.2 Clearances

Sufficient flexibility shall be provided in vertical pipes to allow for the relative horizontal movement between floors, or fixing points, determined from 3.5.

Where vertical pipes pass through more than one floor and are more than 1 m from a column or shear wall, either the form of the fixing or the pipework flexibility shall allow for differential vertical movement between the floors.

Where pipes enter a building through the foundation, provision shall be made for relative movement between the pipe and building. Clearance of at least 25 mm between pipe and foundation shall be provided.

5.8.3 Pipes crossing structural separations or seismic gaps

Where pipes cross structural separations, an allowance shall be made for relative horizontal movement in two orthogonal directions. The allowance shall be either 160 mm per 4 m of height of the structural separation, or the building design movement, where known. Design of systems to achieve this shall be in accordance with section 4.

C5.8.3
Where a connection is necessary between two structural systems, it should be provided with adequate flexibility and be as close to ground level as possible. Bellows type expansion joints are usually unsuitable. Offsets, bends, and loops provide the best means of crossing seismic joints. Where thermal expansion joints are of the sliding or bellows type, suitable limit stops should be provided to prevent the joint pulling apart.

Flexibility may be achieved through piping flexibility or by the use of flexible grooved joints, providing axial and lateral pipe connection equivalent to the pipe strength.

Design and location of seismic restraints should take into account thermal expansion and control.

5.8.4 Restraints

Pipes shall be restrained at the points of: connection of branch pipes, connections to equipment, on at least one side of flexible couplings, and where the free swaying of the pipe may damage other building elements.

5.8.4.1 Horizontal pipes

Each straight length of horizontal pipe shall have at least two transverse restraints and one longitudinal restraint. Continuous lengths of pipe with an offset along the length (see figure 16) that is less than the corresponding maximum spacing given in table 6 may be considered as a single length of pipe for the purposes of longitudinal restraint.

Longitudinal restraint of a pipe length can be provided by transverse restraint of connected perpendicular pipes at elbows, bends, or tees, as long as the connected pipes are of the same size, or no more than one nominal size smaller, and the transverse restraint of the connected pipe is located within 600 mm of the elbow, bend or tee (see figure 16).

5.8.4.2 Vertical pipes

Each length of vertical pipe shall have at least two transverse restraints in each orthogonal direction (see figure 16).

Pipe restraints, including braces and fixings, shall be designed and installed in accordance with section 4, or 3.10 and 3.11, to resist the forces determined from 3.6.

All restraints shall be installed within two pipe diameters of a vertical support. Transverse restraints shall be installed perpendicular to the pipe axis, with the centreline as closely as practical intersecting with the pipe axis. Longitudinal restraints shall be aligned with the axis of the pipe. See figure 17 for examples.

5.8.5 Steam piping

Restraint of steam pipe networks exceeding the conditions in 5.8.1 shall be designed and installed in accordance with section 4 of this Standard so that the pipe network will meet the performance criterion of this Standard.

Steam piping shall be classified as P1, P2, or P3 as applicable (see table 2).

C5.8.5
For importance level 4 buildings, P5 may govern.

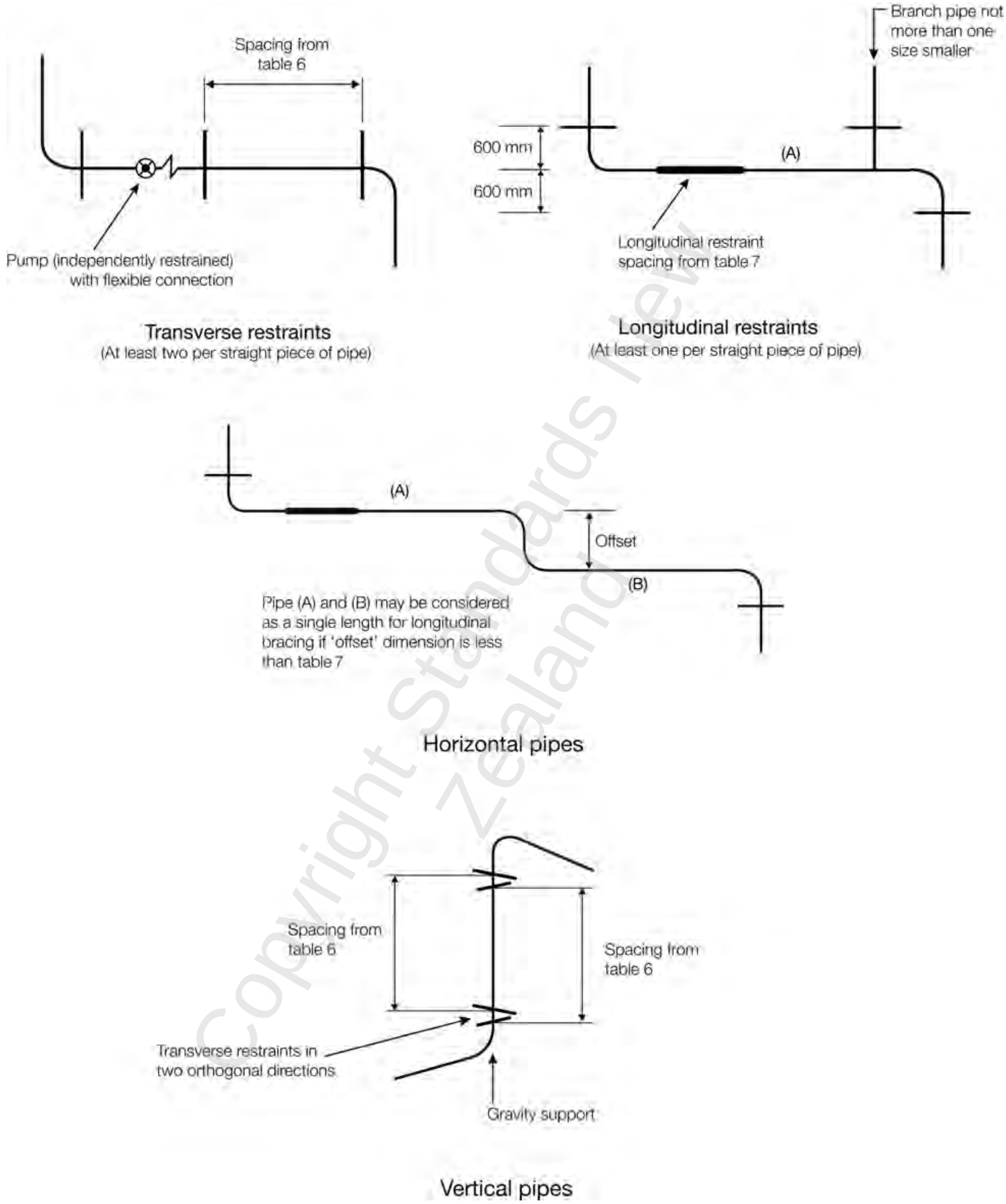


Figure 16 – Pipework restraints

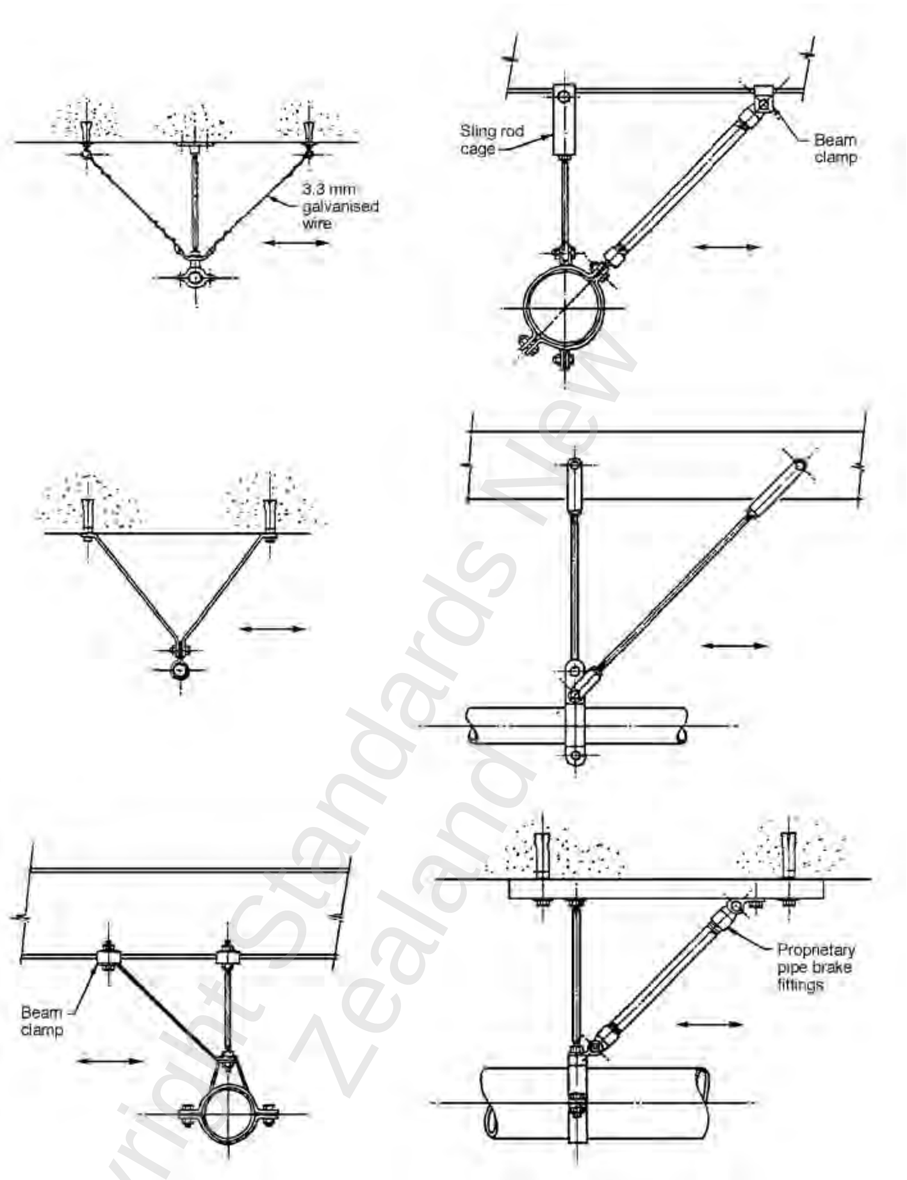


Figure 17 – Examples of pipework restraint

5.8.6 Gas piping

All gas pipework exceeding the conditions in 5.8.1 shall be designed and installed in accordance with section 4 of this Standard so that the pipe network will meet the performance criterion being considered.

Gas piping shall be classified as P1, P2, or P3 as applicable (see table 2).

The gas supply pipe passing from the ground into the building shall be designed to withstand the highest credible value of the seismic deflection of the building without rupture.

C5.8.6

For installations with a gas consumption exceeding 700 kW, consideration should be given to fitting a seismic shut-off valve. These devices are not recommended where numerous small appliances are used, because of the need to purge and recommission the system before the service is restored.

For importance level 4 buildings, P5 may govern.

5.8.7 Liquid fuel piping

All liquid fuel pipework exceeding the conditions in 5.8.1 shall be designed and installed so as to remain operational at the earthquake loadings specified in this Standard. Liquid fuel piping shall be in accordance with 3.3.

The installation shall be designed and installed to reduce fire and other hazards from earthquake damaged equipment.

C5.8.7

The risk of fire following an earthquake can be reduced by:

(a) Locating fuel-burning equipment where it is accessible, to facilitate fire fighting;

(b) Storing a minimum of fuel above ground and in buildings;

(c) Reticulation of fuel, outside the building; and

(d) The use of ductile (steel) flues and chimneys, rather than brittle masonry and brick construction.

For importance level 4 buildings, P5 may govern.

5.8.8 Water service

All water pipework exceeding the conditions in 5.8.1 shall be designed and installed so as to remain operational at the earthquake loadings specified in this Standard. Water supply piping shall be considered as at least category P5 (see table 2).

C5.8.8

Water distribution pipes and tanks essential for the continued functioning of the building should be designed and located to facilitate repairs.

The importance of water stored on site and available after an earthquake should be considered in all buildings, particularly those with a post-event function (importance level 4).

In importance level 4 buildings where water is essential to the continued operation, the quantity and security of on-site storage should be carefully assessed. Provision should be made for the delivery of water by mobile tanker, and, where possible, supplies should be available from two independent sources. In addition to normal restraints, tanks, pipes, and pumps should be located for reasonable access and provided with bypass connections and suitably labelled isolating valves. Isolating valves should be in easily accessible locations, and they should be provided for main branches at each floor in multi-storey buildings.

Tanks and pipes should be located so that any fracture or leakage would result in minimal water damage and would not affect safety operations. Except for fire services, pipe joints shall not be located over electrical equipment.

For importance level 4 buildings, P5 may govern.

5.9 DUCTING

Rigid ductwork, where the hanger length from the top of the duct to the structural support exceeds 200 mm, shall be restrained against seismic forces determined in accordance with this Standard.

Flexible ductwork greater than 1.5 m in length shall be restrained in accordance with this clause.

Ducting not requiring restraint shall be installed with a clearance of 150 mm from hangers and braces for suspended ceiling systems or other adjacent suspended components.

Duct restraints, including braces and fixings shall be designed and installed in accordance with section 4 or 3.10 and 3.11 to resist the forces determined from 3.6.

Suspended components that are installed in line with the duct system and have an operating weight greater than 10 kg, such as fans, heat exchangers and humidifiers, shall be supported and laterally braced independently of the duct system in accordance with 5.15.

Registers and grilles shall have positive fixings to the ducting. Ducting between ceiling mounted grilles and rigidly mounted ducting shall be flexible, or movement provision provided. Dampers, louvres and diffusers shall be positively attached to the duct with mechanical fasteners. Duct tape shall not be used to provide mechanical fixing or seismic resistance.

For installations where the failure of the service could result in the release of toxic fumes or gases, an installation complying with *A practical guide to seismic restraint* (Tauby et. al.), shall be deemed to comply with this Standard.

C5.9
In most installations, damage to ducting will present no particular hazard, but precautions need to be taken to prevent freely suspended ducts from damaging building elements (such as ceilings), or causing a hazard by falling. It is important that ducting supports and restraints do not come apart during earthquakes; open hooks and some slotted fixings are unsuitable. Split pins, bolts and nuts with spring washers, and welds provide positive fixings.

For importance level 4 buildings, P5 may govern.

5.10 HAZARDOUS SUBSTANCES

Mechanical components that contain hazardous material shall be classified as at least P3 in accordance with table 2 of this Standard for the purpose of design of restraints.

C5.10
For importance level 4 buildings, P5 may govern.

5.10.1 Operational plant and equipment

Plant and equipment that produces heat or contains hazardous substances shall be classified P1, P2, or P3 as applicable (see table 2).

Restraints and fixings shall be designed and installed in accordance with section 4 or 3.10 to resist the forces determined from 3.7 or 3.8.

Where interruption of the energy source could give rise to a fire hazard (immediately or on reinstatement of the building service), it shall incorporate an automatic shut down device and require manual restarting.

C5.10.1
The shutting down operation can be provided by a fuse, an automatic shut-off valve, or a seismically triggered device, but should operate if the appliance has been or is likely to be seriously damaged.

For importance level 4 buildings, P5 may govern.

5.11 NON-ESSENTIAL ELECTRICAL SERVICE

All components comprising the electrical supply and distribution system, including resilient mountings, shall be designed and installed in accordance with section 4 or 3.4 to resist the forces determined from 3.8.

Components of electrical supply shall be classified P7 as applicable (see table 2).

Electrical reticulation in the form of cable or busbar, together with associated ducting, conduit, or similar supporting methods, shall be designed and installed to allow relative movement of the building, or electrical apparatus to which it is connected, or both, without damage to the electrical reticulation apparatus or building.

Cable trays suspended more than 400 mm below their structural support shall be restrained against seismic forces determined in accordance with this Standard.

Cable trays not requiring restraint shall be installed with a clearance of 150 mm from hangers and braces for suspended ceiling systems or other adjacent suspended components.

Where a cable enters the building through a foundation, a sleeved penetration shall be used to accommodate movement of at least 25 mm in all directions.

Cables, conduit, and cable trays crossing a structural separation shall be provided with sufficient flexibility to accommodate horizontal and vertical movement determined in accordance with 4.2.2.

All electrical components contained within cabinets, shall be positively restrained with straps, bars, bolts, and similar devices.

Switchboards shall not contain mercury switches or other gravity-operated devices if their incorrect operation during an earthquake would cause danger to life or property.

Cabinets shall have hinged or sliding doors fitted with top and bottom catches.

C5.11
Electrical supply includes the main distribution board and all cables and equipment between the main distribution board and the supply point, considered to be 1 m from the building. These services provide a greater risk of hazard and therefore they require a high risk category.

Where it is necessary to cross building seismic joints with cables, the crossing should occur at the lowest possible floor. Additional draw-in boxes with sufficient flex should be provided in long conduit runs to avoid tensioning of the conductors.

Lift-off panels may fall on live terminals during earthquakes.

For importance level 4 buildings, P5 may govern.

5.12 EMERGENCY ELECTRICAL SYSTEMS

All of the components and cabling of emergency electrical systems shall be classified as category P4 (see table 2). Resilient mountings shall comply with 5.5.

Battery installations shall comply with the following requirements:

(a) All batteries in racks shall be strapped, or otherwise restrained, to prevent falling;

(b) Spacers shall be used between restraints and cells to prevent damage to cases;

(c) Racks and cabinets shall be fixed in accordance with this Standard; and

(d) Sufficient slack shall be provided in all connections to allow for any likely relative movement between components.

C5.12
For importance level 4 buildings, P5 may govern.

5.13 SUSPENDED CEILINGS, EQUIPMENT SUPPORTED BY THE CEILING, AND EQUIPMENT IN CEILING VOIDS

Suspended ceilings are outside the scope of this Standard. Where service loads are greater than 3 kg/m^2, the ceiling designer should be advised.

Equipment supported by the ceiling, such as air distribution grilles, diffusers, and other fittings not exceeding 10 kg mass, shall be positively fixed to the ceiling suspension system, but not supported by the ceiling panels or tiles. Service connections from ceiling supported equipment to ducts, pipes or cables, independently supported from the structure, shall be flexible. Where additional backup supports are used which are not normally under tension, they should not allow the equipment to drop more than 100 mm.

Equipment exceeding 10 kg mass in the ceiling void or at ceiling level shall be independently fixed to the structure in accordance with this clause.

Equipment supported independently of the ceiling, and in accordance with this clause, shall have a clearance of 25 mm all round to allow independent movement between component and ceiling.

Ceiling suspension systems (hangers, braces, and so forth) shall be located with a clearance in accordance with table 15 from all other services and equipment installed in ceiling voids.

Individual components with a mass exceeding 25 kg shall be designed in accordance with section 4 of this Standard.

Electrical (or other) cables/fixtures shall not be attached to suspended ceiling hanger supports, but shall be independently supported in accordance with clearances illustrated in table 15.

C5.13
Suspended ceilings should be designed and constructed in accordance with AS/NZS 2785. This Standard includes a seismic loading allowance of 3 kg/m^2 for distributed services supported by the ceiling.

Where resilient mountings are required they should employ restraining devices, bumpers or snubbers and connection piping should be arranged to reduce potential damage to fuel, cooling water, and exhaust lines. All service lines should be kept as short as possible, compatible with providing adequate flexibility.

For importance level 4 buildings, P5 may govern.

5.14 LUMINAIRES

All fixings, including those for detachable accessories (such as diffusers, light controllers), shall be of a positive locking type designed to prevent disengagement under earthquake action.

Where luminaires are recessed or surface-mounted on suspended ceilings, they shall be positively clamped to the ceiling suspension main runners (T-rails) or to cross runners having the same carrying capacity. Clamping shall be by means of screws and nuts or locking type clamping devices.

C5.14
For importance level 4 buildings, P5 may govern.

5.15 INDEPENDENTLY SUSPENDED CEILING COMPONENTS

Isolated ceiling components such as piping or light fixtures, lighted signs, and ceiling fans (not connected to ducts), that are supported by wires, chains or otherwise suspended from the structure, shall not be required to satisfy the seismic force and relative displacement requirements provided they meet all of the following criteria:

(a) The design load for such items shall be 1.4 times the operating weight acting down with a simultaneous horizontal load equal to 1.4 times the operating weight. The horizontal load shall be applied in the direction which results in the most critical loading for design;

(b) Seismic interaction effects shall be considered in accordance with 2.3.2; and

(c) The fixings to the structure shall allow a 360° range of horizontal motion.

All other suspended components shall be restrained in accordance with section 4 or 3.10 and 3.11 to resist the forces determined from 3.8.

C5.15
For importance level 4 buildings, P5 may govern.

5.16 COMMUNICATION, DATA, AND CONTROL SYSTEMS

Electrical control panels, computer equipment and other items with slide-out components, shall be classified as Category P6 (see table 2).

These items shall have a latching mechanism that restrains the item against a force of twice its own weight in the slide-in direction.

C5.16
For importance level 4 buildings, P5 may govern.

APPENDIX A – BUILDING IMPORTANCE LEVELS
(Normative)

This appendix provides a description and examples of building importance levels.

Importance level	Comment	Examples
1	Structures presenting a low degree of hazard to life and other property	Structures with a total floor area of <30 m^2 Farm buildings, isolated structures, towers in rural situations Fences, masts, walls, in-ground swimming pools
2	Normal structures and structures not in other importance levels	Buildings not included in importance levels 1, 3 or 4 Single family dwellings Car parking buildings
3	Structures that, as a whole, may contain people in crowds, or contents of high value to the community, or pose risks to people in crowds	Buildings and facilities as follows: (a) Where more than 300 people can congregate in one area; (b) Day-care facilities with a capacity greater than 150; (c) Primary school or secondary school facilities with a capacity greater than 250; (d) Colleges or adult education facilities with a capacity greater than 500; (e) Healthcare facilities with a capacity of 50 or more resident patients, without surgery or emergency treatment facilities; (f) Airport terminals and principal railway stations with a capacity greater than 250; (g) Correctional institutions; (h) Multi-occupancy residential, commercial (including shops), industrial, office and retailing buildings designed to accommodate more than 5 000 people and with a gross area greater than 10 000 m^2; (i) Public assembly buildings, theatres, and cinemas of greater than 1 000 m^2. Emergency medical and other emergency facilities not designated as post-disaster Power-generating facilities, water treatment and waste water treatment facilities, and other public utilities not designated as post-disaster Buildings and facilities not designated as post-disaster containing hazardous materials capable of causing hazardous conditions that do not extend beyond the property boundaries

4	Structures with special post-disaster functions	Buildings and facilities designated as essential facilities Buildings and facilities with special post-disaster function Medical emergency or surgical facilities Emergency service facilities such as fire and police stations, and emergency vehicle garages Utilities or emergency supplies or installations required as backup for buildings and facilities of importance level 4 Designated emergency shelters, designated emergency centres and ancillary facilities Buildings and facilities containing hazardous materials capable of causing hazardous conditions that extend beyond the property boundaries
5	Special structures (outside the scope of this Standard – acceptable probability of failure to be determined by special study)	Structures that have special functions or whose failure poses catastrophic risk to a large area (such as 100 km^2) or a large number of people (such as 100 000) Major dams, extreme hazard facilities

APPENDIX B – COMPONENT CLASSIFICATIONS
(Normative)

This appendix provides component classifications for specific components.

Component or system	Category	Comment
Air conditioning systems (distributed)	P7	–
Air conditioning systems (self-contained)	P7	If able to fall > 3 m category is P3. If the unit is also over a publicly accessible open space, category is P1
Boiler	P3	See 5.10
Building maintenance unit	P1	–
Communication equipment (phone, data, security, control systems)	P7	–
Computer equipment	P7	–
Electrical distribution	P7	–
Electrical supply	P7	See 5.11
Emergency lighting	P4	See 5.12
Emergency power supply	P4	See 5.12
Fire door	P4	–
Fire fighting system other than sprinklers (including smoke extraction)	P4	–
Hazardous materials systems (including gas, steam and so forth)	P3	See 5.8.5, 5.8.6, and 5.8.7
Lighting systems (non-emergency)	P7	–
Solid fuel heater	P3	–
Suspended ceilings	P2, P3, P4, and P5	Any one or more of these apply subject to the building importance level and occupancy type, (such as a Level 2 could require a P3 and P4 category, a Level 3 could require a P2, P3 and P4 category, and a Level 4 would require a P5 category).
Ventilation systems (including extractor fans)	P7	–
Waste disposal system	P7	–
Water heater (low/mains pressure)	P3	–
Water storage tank	P7	Roof mounted tanks adjacent to public open spaces, category is P1
Water supply system (non-fire suppression)	P7	Where a leak could affect critical contents below, category is P6
NOTE – If the listed components are essential to the continued operation of an importance level 4 building (buildings with a special post-disaster function), they will be category P5.		

APPENDIX C – PERFORMANCE FACTORS
(Normative)

This appendix provides performance factors for specific components and their specific type of installation.

Component	**Type**	**Restraint**	**Performance factor**, C_p
Horizontal or vertical piping	Steel, flanged joints Steel, welded or grooved joints	Suspended and braced to the structure	0.45
	Steel, screwed joints		0.65
	Copper, brazed joints		0.55
	Polypropylene		0.25
Horizontal or vertical rigid ducting (including in-line components)		Suspended and braced to structure	0.45
Rigid metal exhaust flue		Braced to the structure	0.45
		Cantilevered from its base	0.55
Cable tray		Suspended and braced to the structure	0.45
Tank (non-pressure)	Floor mounted	Ductile base fixing	0.55
		Limited-ductile base fixing	0.85
		Braced to structure	0.55
		Direct attached to timber or steel wall (such as hot water cylinder)	0.55
		Direct attached to concrete or masonry wall	0.85
	On a stand	2-way moment resisting stand	0.45
		Braced to structure	0.55
Pressure tank (for example LPG tank)		Floor mounted cradle	0.85
Compact component (boiler, pump, solid fuel heater)	Floor mounted	Ductile base fixing	0.55
		Limited-ductile base fixing	0.85
		Vibration isolated	0.75
		Braced to structure	0.55
	Suspended	Suspended and braced to the structure	0.55
Non-compact component (such as chiller or cooling tower)		Floor mounted	0.45
Metal cabinet (such as electrical, communication, rack mounted computer equipment)		Floor mounted	0.45
		Braced to structure	0.55
Light fitting (excluding lights mounted in suspended ceilings)		Direct fixed to structure	0.85
		Suspended and braced to structure	0.55

APPENDIX D – EXAMPLE CALCULATIONS
(Informative)

D1 LIST OF EXAMPLES

This appendix gives typical examples of using this Standard to calculate design solutions to restrain engineering systems. The following worked examples have been provided:

Description	Clause
Boiler	D2
Ventilation duct	D3
Pressure tank	D4
Fire hydrant pipe	D5
Thin-walled water tank on top of a multi-storey office building	D6
Thin-walled water tank on top of a multi-storey healthcare building	D7
Pipe loop crossing a seismic break	D8
Ceiling suspended 35 kg air conditioner (mounted 400 mm below concrete slab)	D9
Ceiling suspended 350 kg air conditioner (mounted 1000 mm below concrete slab)	D10
Oil supply service tank in a top floor plant room	D11
Oil supply service tank in top floor	D12
Plinth	D13
Electrical cabinet	D14

D2 BOILER

Given:

A boiler with a mass of 2000 kg (complete with water) is located on the top storey of a six-storey hospital building in the Hutt Valley and is required to be operational after an earthquake, see figure D1.

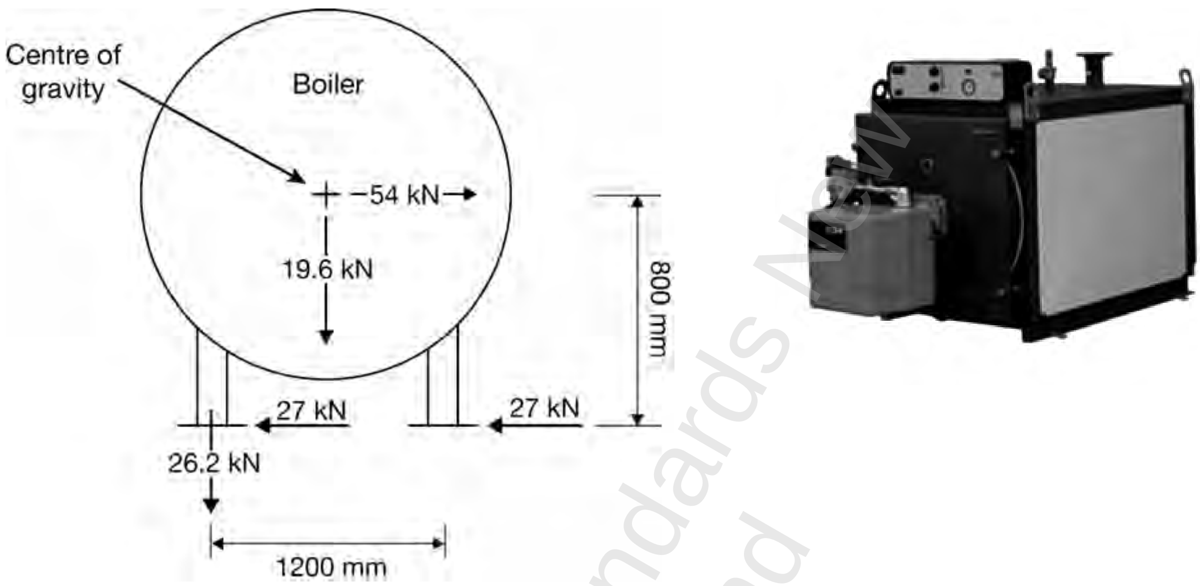


Figure D1 – Boiler example and force diagram

Required:

Determine the number and size of hold-down anchors

Solution:

Step 1 – Classify the building and the component

The building is required to be able to continue providing services after an earthquake. The importance level is 4 (see table 1).

The system is essential for the operational continuity of the functions carried out in the building.

The boiler is designed to be operated unattended and access to the plant room is restricted to authorised people and then only for routine maintenance and inspection, so failure of any part of the boiler does not present a hazard to life. The component category is P5 (see table 2). If the access restriction was not in place, thus allowing proximity to personnel, the component category would be P3, which would over-ride its load demand as a P5 component.

Step 2 – Determine the load demand (see 3.4)

The boiler is above ground floor,	C_H	=	3
Seismic zone factor,	Z	=	0.4 .... (see table 3)
Performance factor,	C_p	=	0.85 ......(see 3.4.2, or Appendix C)
Component risk factor,	R_c	=	1.0 (for IL4 and P5) ... (see table 5)

Hence, the seismic coefficient, $C = 2.7 \times 3 \times 0.4 \times 0.85 \times 1$
$= 2.75$

Weight of the boiler, $W = 2000\ \text{kg} \times 9.81\ \text{Nkg}^{-1}$
$= 19.62\ \text{kN}$

The lateral force on the boiler, $F = C \times W$
$= 2.75 \times 19.62$
$= 53.96\ \text{kN}$

The restraint system must be designed for a lateral force of 54 kN acting through the centre of gravity of the boiler. The boiler is supplied by the manufacturer as a floor-mounted component with a support near each corner. The hold-down anchors on the boiler legs are required to resist the resulting shear and tension forces.

The horizontal (shear) force on the anchors, R_h, may be found from equation 3.5.

$$R_h = \frac{54}{4} = 13.5\ \text{kN}$$

The tension force from overturning about the anchors on the opposite side is calculated from equation 3.6:

$$R_{vt} = -\frac{54 \times 0.8}{2 \times 1.2} + \frac{19.6}{4} = 13.1\ \text{kN}$$

Step 3 – Determine the arrangement of hold-down anchors to withstand these loads

The edge distance for the anchors is greater than 200 mm so figure 11(b) can be used to determine anchor arrangements.

An M16 bolt embedded 125 mm in the concrete will be acceptable for each leg base plate.

The legs or support system, including the fixing of the legs to the body of the boiler, needs to also be designed to be, or assessed as, capable of sustaining these forces.

D3 VENTILATION DUCT

Given:

A ventilation duct is suspended above a hospital operating theatre in Auckland. Ducting weighing 150 kg shall be seismically restrained at every third gravity support, see figure D2.

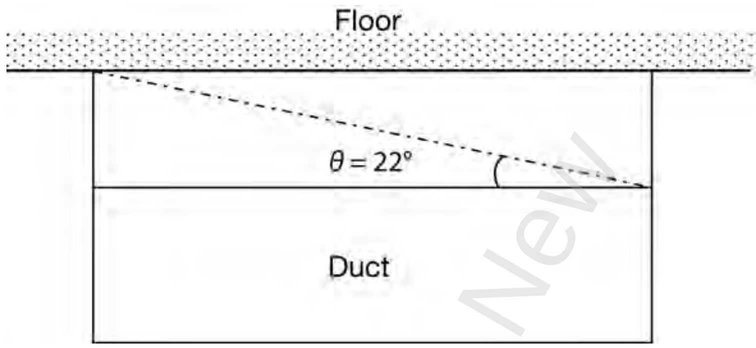


Figure D2 – Side elevation of ventilation duct example

Required:

Seismic loadings in supports, design of lateral bracing.

Solution:

Step 1 – Classify the building and the component

The hospital needs to be able to continue to provide services after an earthquake. The importance level is 4 (see table 1).

Seismic displacement need not be considered as unit is supported from one floor only.

A gravity support failure represents a falling hazard to individual lives within the building. The part category is P3 (see table 2).

The lateral supports are essential for the operational continuity of the functions of the unit. The part category is P5 (see table 2).

Step 2 – Determine the load demand (see 3.4)

The duct is above ground floor, C_H = 3

Seismic zone factor, Z = 0.13 .... (see table 3)

Performance factor, C_p = 0.45 ......(see 3.4.2, or Appendix C)

Component risk factor, R_c = 1.6 (for IL4 and P3) ... (see table 5)

NOTE – The higher risk factor between life safety (P3) and operational continuity (P5) has been used.

Hence, the seismic coefficient, $C = 2.7 \times 3 \times 0.13 \times 0.45 \times 1.6$

$= 0.758$

Weight of the duct, $W = 150 \text{ kg} \times 9.81 \text{ Nkg}^{-1}$

$= 1.472 \text{ kN}$

The lateral force on the duct, $F = C \times W$

$= 0.758 \times 1.472$

$= 1.12$ kN

Step 3 – Determine the arrangement of bracing layout

The bracing angle, $\theta = 22°$.

NOTE – As the bracing angle is less than 30°, in accordance with 3.8, no vertical hanger checks are required.

The brace loading, $P = \dfrac{CW}{\cos\theta}$

$= \pm \dfrac{1.12}{\cos 22}$

$= \pm$ 1.21 kN

Use 3.2 mm galvanised steel wire, opposing pair, tension bracing from table 13.

NOTE – Duct capacity to span horizontally between supports also needs to be considered.

Final layout of the duct and supports shown in figure D3.

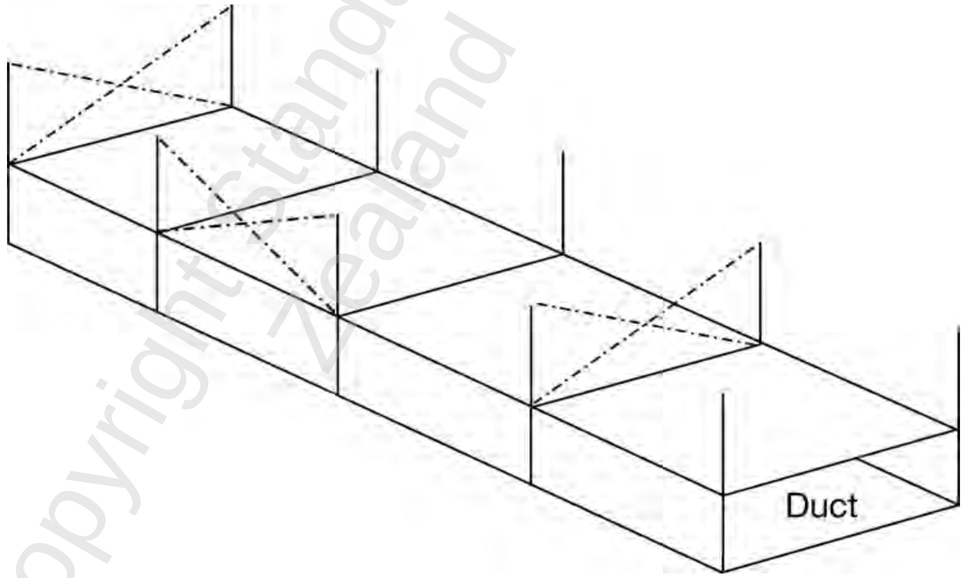


Figure D3 – Final layout of the duct and supports

D4 PRESSURE TANK

Given:

Pressure tank at ground level of a shopping centre building located in Wellington. Support by 4 braced RHS legs bolted to the floor with cast-in anchor bolts. Weight of full tank is 4,600 kg, see figure D4.

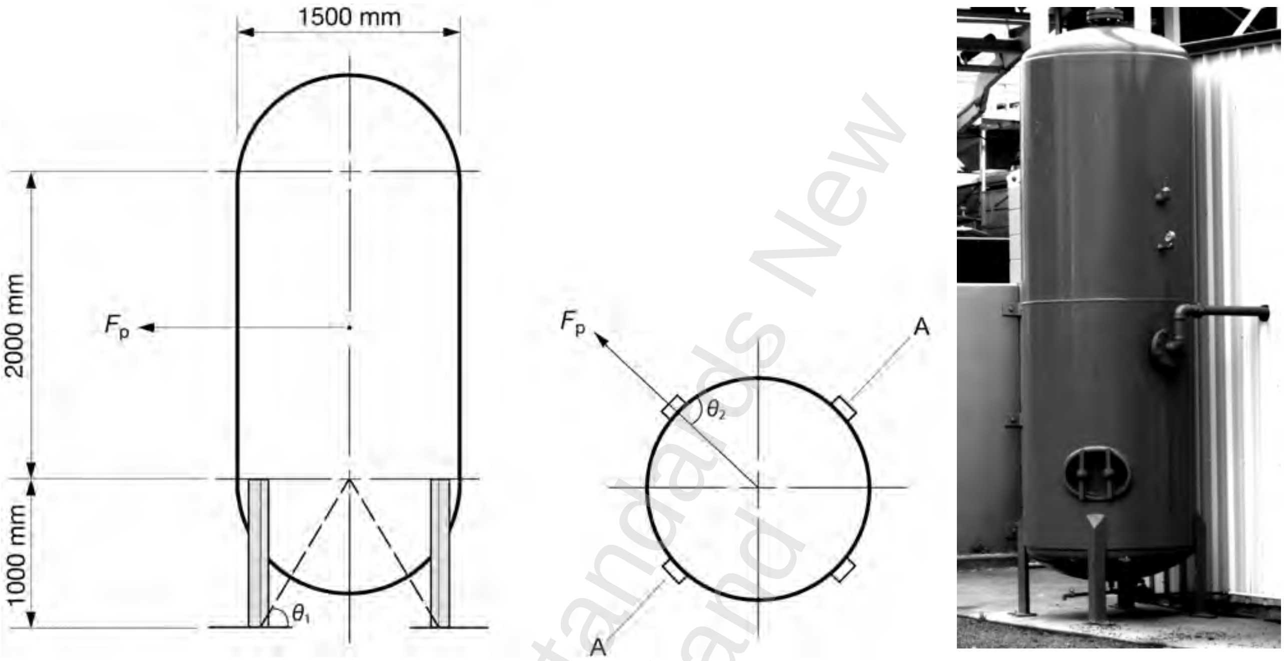


Figure D4 – Pressure tank example and force diagram

Required:

Size of legs and hold-down anchors.

Solution:

Step 1 – Classify the building and component

The building is not intended to accommodate more than 5,000 people, however, the total retail space exceeds 10,000 m^2. The importance level is 3 (see table 1 and Appendix A).

The pressure tank represents a hazard to a crowd of greater than 100 people within the building. The part category is P2 (see table 2).

Step 2 – Determine the load demand (see 3.4)

The pressure tank is at ground level, C_H = 1.0

Seismic zone factor, Z = 0.4............................ (see table 3)

Performance factor (for anchors), C_p = 0.85......(see 3.4.2 or Appendix C)

Component risk factor, R_c = 1.3 (for IL3 and P2).. (see table 5)

Hence C = 2.7 × 1.0 × 0.4 × 0.85 × 1.3

= 1.19 (less than 3.6)

Weight of the pressure tank, W = 4,600 kg × 9.81 Nkg^{-1}

= 45 kN

The lateral force on the tank, $F = C \times W$

$= 1.19 \times 45$

$= 53.55$ kN

Step 3 – Determine the arrangement of mounting

Design may be based on rigid mounting.

As this is a floor mounted component, figure 5 is appropriate.

Horizontal force at base of each leg may be evaluated using equation 3.5:

$$R_h = \frac{53.55}{4}$$

$$= 13.4 \text{ kN}$$

Vertical force in each leg may be evaluated using equation 3.6. The most critical situation is earthquake loading about the diagonal axis (A-A), where:

$$h = 1 + \frac{2}{2}$$

$$= 2$$

B = 1.5 (the diagonal distance between the legs)

$$R_V = \frac{53.55 \text{x} 2}{1 \text{x} 1.5} + \frac{45}{4}$$

$$= 71.4 + 11.3$$

$$= 82.7 \text{ kN}$$

These forces in the legs will result in a bending moment in the leg and a critical connection with the tank wall. This will require specific design using NZS 3404. An alternative solution is to add braces, as shown in figure D5.

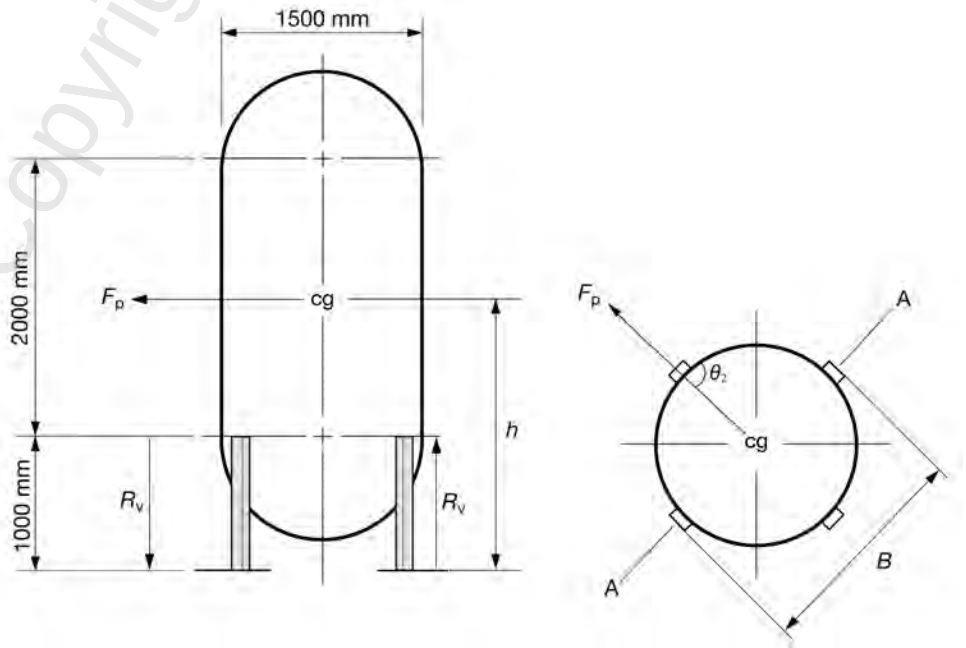


Figure D5 – Alternative solution for pressure tank bracing

where

$$\theta_1 = \tan^{-1}\frac{1}{\left(\frac{1.5}{2}\right)}$$

$$= 53^\circ$$

$$\theta_2 = 67.5^\circ$$

Force in each brace attached to one leg is:

$$P = \frac{13.4}{(2 \times \cos 67.5)\cos 53}$$

$$= 13.2 \text{ kN}$$

From table 14, for a brace length of 1.5 metres, a 50 × 50 × 5 angle acting in compression has a capacity of 15 kN and will need to be fitted and fully welded at each end.

Design of anchors to the slab. The anchors will have an edge distance greater than 200 mm, so select from figure 11(b).

For shear of 13.4 kN and tension of 82.7 kN, choose 2 × M20 cast-in anchors (or equivalent proprietary anchor selected from suitable manufacturers data prepared in limit state). The selected anchors may require a local thickening of the ground floor slab to accommodate the required embedment.

D5 FIRE HYDRANT PIPE

Given:

A wet riser is to be installed over the height of an elastically designed five-storey office building being constructed in Upper Hutt. The pipe is 150 mm steel pipe, with 0.38 kN/m weight (including the hydrants and water) and will have welded joints. The riser will be restrained against lateral loading at each floor of the building. The storey height (height between each of the floors) is 4 m.

Required:

The horizontal seismic force for all restraints needs to be determined.

Solution:

Step 1 – Classify the building and component

The building represents a normal building. The importance level is 2 (see table 1).

The component is part of the building's life safety system. The part category is P4 (see table 2).

Step 2 – Determine the load demand (see 3.4)

Seismic zone factor, Z = 0.42 .... (see table 3)

Performance factor (for steelpipe, welded), C_p = 0.45 ....(see 3.4.2 or Appendix C)

Component risk factor, R_c = 1.0................ (see table 5)

There are five acceleration coefficients, one for each floor.

Seismic height coefficient is as follows:

Floor	**Height from ground** (m)	**Floor height coefficient, C_H**
5	20	3.0
4	16	3.0
3	12	3.0
2	8	3.0
1	4	3.0
G	0	1.0

Hence, the seismic coefficient, $C = 2.7 \times C_H \times Z \times C_p \times R_c$

Floor	**Lateral force coefficient, *C***
5	1.53
4	1.53
3	1.53
2	1.53
1	1.53
G	0.51

At ground and roof level, the restraints support 2m of pipe:

Weight of the pipe full of water, $W = 0.38$ kN/m × 2 m

$= 0.76$ kN

For every other floor level, 4 m of pipe is supported:

Weight of the pipe full of water, $W = 0.38$ kN/m × 4 m

$= 1.52$ kN

The lateral force on the pipe is, $F = C \times W$

Floor	**Coefficient, *C***	**Weight, *W*** (kN)	**Restraint force, *F*** (kN)
5	1.53	0.76	1.16
4	1.53	1.52	2.33
3	1.53	1.52	2.33
2	1.53	1.52	2.33
1	1.53	1.52	2.33
G	0.51	0.76	0.39

Step 3 – Determine the relative displacement of the building between restraint attachment points

The calculated design displacement between floors is:

Storey	**Displacement** (mm)
4-5	25
3-4	30
2-3	45
1-2	65
G-1	80

These are less than the value given in 3.5.

Step 4 – Determine the arrangements of the restraints

At each floor level, two orthogonal restraints are required, as shown in figure 3(b) and figure 16. Restraints will be required to accommodate the displacements determined in step 3. A selection of MS flats from table 13 and table 14 will provide the necessary tension and compression resistance, with sufficient flexibility to allow for the displacements. Clearance must also be provided between the pipe and the penetrations through the concrete floor slabs. The penetrations must be fire rated if the pipe is not in a fire rated shaft.

D6 THIN-WALLED WATER TANK ON TOP OF A MULTI-STOREY OFFICE BUILDING

Given:

A thin-walled water tank with fixed lid and full mass of 5,140 kg is installed on the roof of a multi-storey office building. The building is located in Wellington.

The roof has perimeter parapet walls, which will contain any spillage and prevent the tank from falling off the roof should failure of the restraints occur. Failure of the component would not constitute a special hazard to life safety, or compromise the operational continuity of the building and the damage caused by its failure would not be disproportionately great, see figure D6.

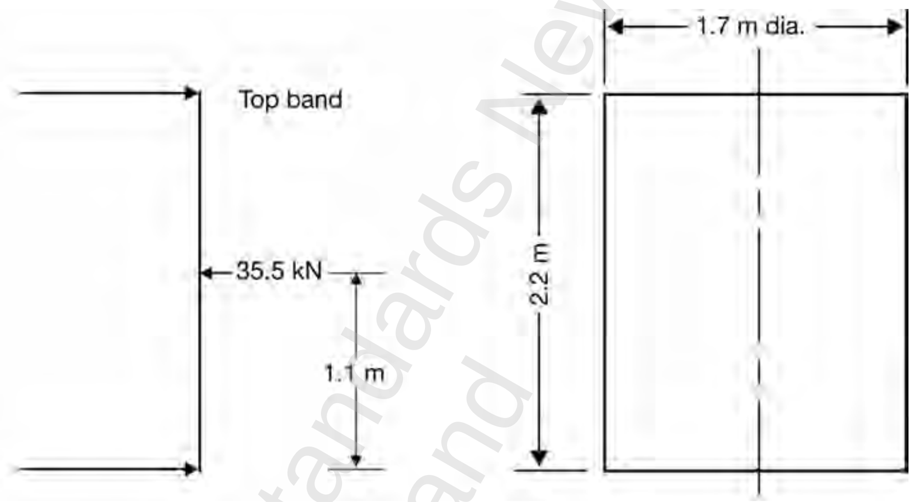


Figure D6 – Thin walled water tank force diagram

Required:

Seismic bracing without penetrating the safe tray.

Hydrodynamic effects and friction between the base of the tank and the safe tray may be disregarded. The tank mass is less than 20% of the building (within the limits of 1.1.2).

Solution:

Step 1 – Classify the building and component

The building is a normal office building. The importance level is 2 (see table 1).

The component represents a hazard representative of category P7 (see table 2).

Step 2 – Determine the load demand (see 3.4)

The water tank is on the roof,	C_H	=	3
Seismic zone factor,	Z	=	0.4 .... (see table 3)
Performance factor,	C_p	=	0.85 .... (see 3.4.2)

NOTE – The C_p is based on the tank being floor mounted and braced to the structure.

Component risk factor,	R_c	=	0.25 .... (see table 5)
Hence, the seismic coefficient,	C	=	2.7 × 3 × 0.4 × 0.85 × 0.25
		=	0.70

Weight of tank, W = 5,140 kg × 9.81 Nkg^{-1}

= 50.4 kN

The lateral force on the water tank, F = $C \times W$

= 0.70 × 50.4

= 35.3 kN

Step 3 – Determine the arrangement of bracing to withstand these loads. As the bracing arrangement is not covered in section 3, this will need to be a specific structural design using the verification procedures of section 4.

By taking moments about A, tension in band $= \dfrac{35.3 \times 1.1}{2 \times 2.2}$

= 8.8 kN

By taking moments about B, tension in wire $= \dfrac{8.8 \times 2.2 \times \sqrt{2}}{1.1}$

= 24.9 kN

NOTE – The tension wires are at a small angle to the orthogonal axes which will increase the load slightly. The effect of this will be small and for this example has been ignored.

Select a 12 mm diameter rod $f_t = \dfrac{24.9 \times 10^3 \times 4}{\pi \times 12^2}$

= 220 MPa (< 250 MPa therefore design is acceptable)

Compression in BB' $= \dfrac{24.9}{\sqrt{2}}$

= 17.6 kN

NOTE – The maximum capacity of angle brace (50 × 50 × 5) for a length of 1.1 m (by interpolation) is 24 kN (see table 14).

Bending moment at centre M = 8.8 × 1.1

= 9.7 kN/m

NOTE – Table 14, capacity of braces in compression, cannot be used because compression is combined with bending. The member size must therefore be determined by specific design.

Section modulus $Z_c = \dfrac{M}{f_y}$

$= \dfrac{9.7 \times 10^6}{350}$

= 27.7 x 10^3 mm^3

Consider a 76 × 76 × 4.9 SHS

$N^* < \theta N_S$; $N^* < \theta N_C$
where

$N^* = 17.6$ kN

$\theta N_S = 413$ kN

$\theta N_C = 379$ kN

Section conforms to the use of alternative design provisions from NZS 3404 and can be used.

$$M_{rx} = 1.18\, M_{sx} \left(1 - \frac{N^*}{\phi N_s}\right) < M_{sx}$$

Z_c = lesser of $S = 34.1 \times 10^3$ mm^3 or $1.5 \times Z = 41.9 \times 10^3$ mm^3

$M_{sx} = f_y \times Z_c = 350 \times 34.1 \times 10^{-3} = 11.9$ kNm

$N^* = 17.6$ kN, $\phi = 0.9$

N_s = 867 kN (from proprietary steel section tables)

$$M_{rx} = 1.18 \times 11.9 \times \left(1 - \frac{17.6}{413}\right) = 13.5 \text{ kNm } (>11.9 \text{ kNm})$$

$M_{rx} = M_{sx} = 11.9$ kNm > 9.7 kNm

Design is acceptable. The final layout of the thin-walled tank and bracing is illustrated in figure D7.

Top and bottom bands, stress $f_t = \dfrac{8.8 \times 10^3}{50 \times 6}$

$= 29.3$ MPa

Yield stress $= 250$ MPa

Weld SHS to band, assume 5 mm fillet weld, stress

$$f_w = \frac{8.8 \times 10^3 \times \sqrt{2}}{2 \times 50 \times 5}$$

$= 24.8$ MPa (<137 MPa $= 0.55\, f_{uw}$)

The bearing stress on the tank must be kept low to avoid local buckling. Select a 50 × 6 flat.

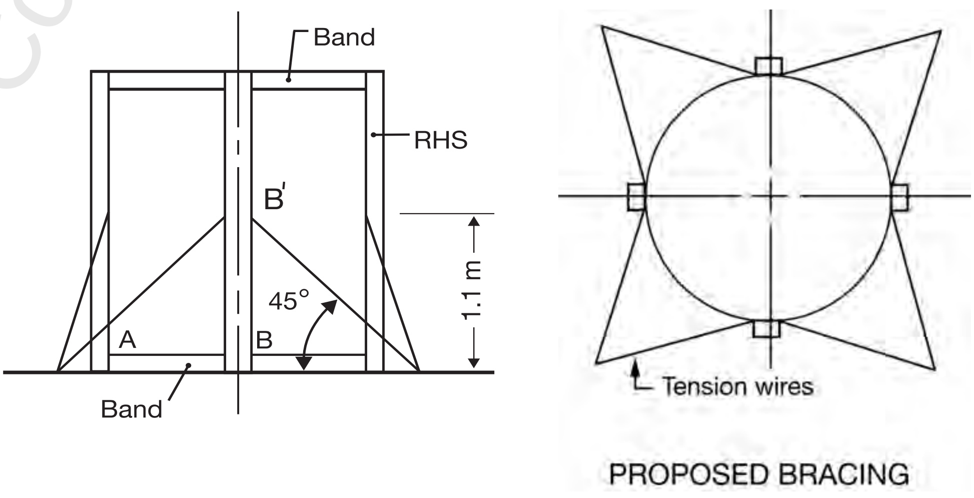


Figure D7 – Final layout of thin-walled tanks and supports

D7 THIN-WALLED WATER TANK ON TOP OF A MULTI-STOREY HEALTHCARE BUILDING

Given:

A thin-walled water tank with fixed lid and full mass of 8,000 kg is installed on top of a multi-storey healthcare building located in Wellington. The building contains 75 resident patients.

The tank is situated immediately adjacent to an opening in the roof which is directly over an open air area where patients spend time recuperating on fine days. While failure of the tank would not be likely to result in major life loss, its failure could still constitute a hazard to individual life in the building.

Required:

Seismic bracing without penetrating the safe tray.

Hydrodynamic effects and friction between the base of the tank and the safe tray may be disregarded. The tank mass is less than 20% of the building (within the limits of 1.1.2).

Solution:

Step 1 – Classify the building and component

The building is a healthcare building. The importance level is 3 (see table 1).

The component represents a hazard representative of category P3 (see table 2).

Step 2 – Determine the load demand (see 3.4)

The water tank is on the roof,	C_H	=	3
Seismic zone factor,	Z	=	0.4 .... (see table 3)
Performance factor,	C_p	=	0.55 ....(see 3.4.2 or Appendix C)

NOTE – The C_p is based on the tank being floor mounted and braced to the structure.

Component risk factor,	R_c	=	1.2 .... (see table 5)
Hence, the seismic coefficient,	C	=	2.7 × 3 × 0.4 × 0.55 × 1.2
		=	2.1
Weight of component,	W	=	8,000 kg × 9.81 Nkg^{-1}
		=	78.4 kN
The lateral force on the water tank,	F	=	$C \times W$
		=	2.1 × 78.4
		=	164.64 kN

NOTE – As with D6, section 3 cannot be used. The member size must therefore be determined by specific design using the verification procedures of section 4.

D8 PIPE LOOP CROSSING A SEISMIC BREAK

Given:

A steam pipe crosses the seismic gap between a podium and tower block. The project structural engineer has advised that the expected movements of the two parts of the building under ULS are as shown in figure D8. Vertical movement across the joint is insignificant.

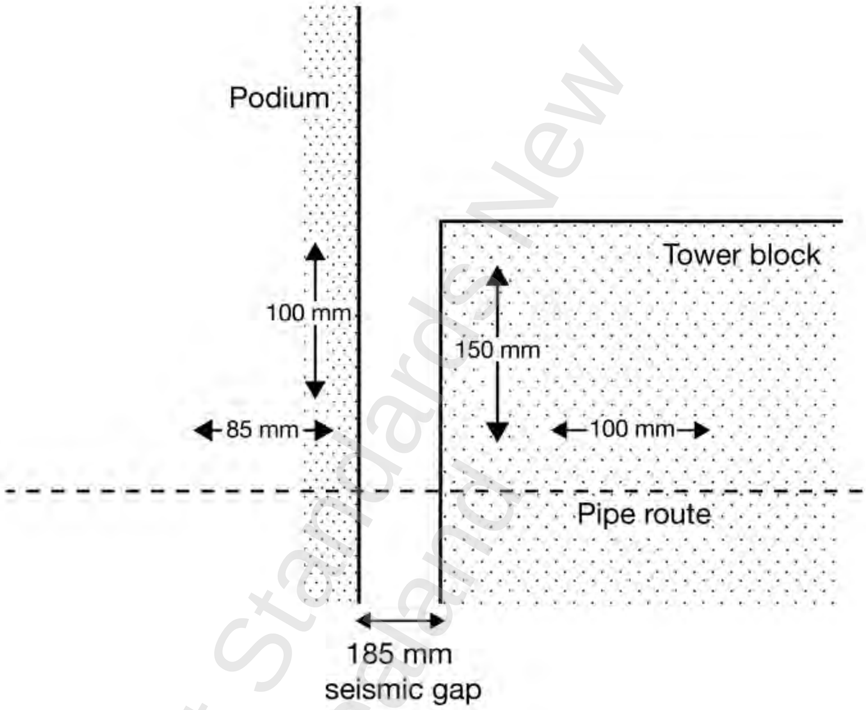


Figure D8 – Pipe loop crossing seismic break

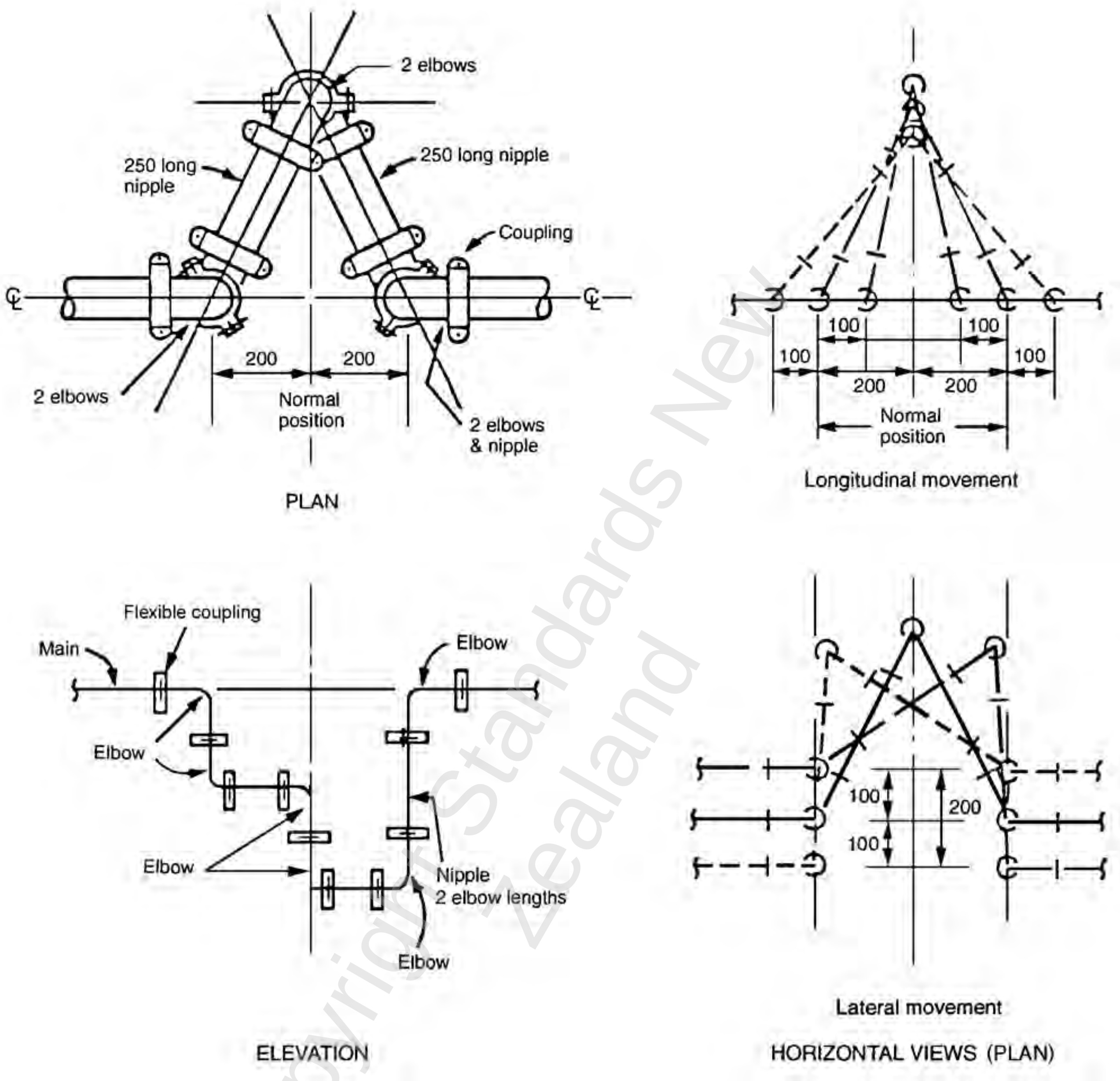
Required:

The seismic movement must be accommodated with a flexible loop or coupling.

Solution:

Total deflection along the pipe axis is 100 + 85 = 185 mm, and perpendicular to the axis is 100 + 150 = 250 mm.

The total seismic separation joint assembly as shown, made up of flexible couplings and suitable length nipples, can be used to accommodate the required movements, see figure D9 for examples of flexible couplings.



All measurements are in mm.

Figure D9 – Examples of flexible couplings

D9 CEILING SUSPENDED 35 kg AIR CONDITIONER (MOUNTED 400 mm BELOW CONCRETE SLAB)

Given:

A ceiling suspended 35 kg air conditioner in a Wellington office building mounted 400 mm below concrete slab (see figure D10).

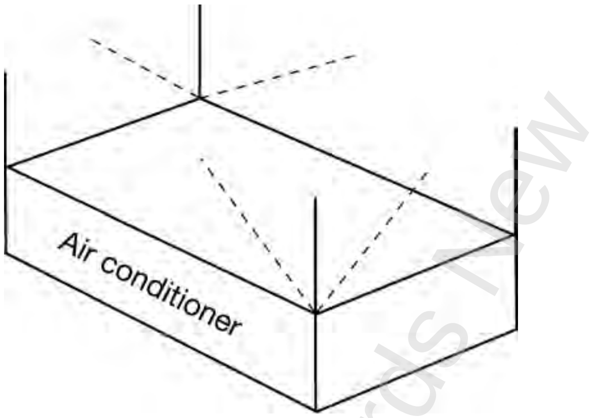


Figure D10 – Air conditioner suspended below a concrete slab

Required:

Provide lateral bracing, including anchors to slab.

Solution:

Step 1 – Classify the building and component

The building is a normal structure. The importance level is 2 (see table 1).

The component falling represents a hazard to an individual life. The category is P3 (see table 2).

Seismic displacement need not be considered as the unit is supported from one floor only.

Step 2 – Determine the load demand

The unit is above ground floor,	C_H	=	3
Seismic zone factor,	Z	=	0.4 .... (see table 3)
Performance factor,	C_p	=	0.55 ..... (see 3.4.2 or Appendix C)

NOTE – Compact component is braced to structure.

Component risk factor,	R_c	=	0.9 (for IL2 and P3) ... (see table 5)
The seismic coefficient for the brace design,	C	=	2.7 × 3 × 0.4 × 0.55 × 0.9
		=	1.60
Weight of the component,	W	=	35 kg × 9.81 Nkg^{-1}
		=	343 N
The lateral force on the component,	F	=	$C \times W$
		=	1.60 × 343
		=	549 N

Step 3 – Determine the arrangement of bracing and anchors to withstand these loads. Proposed bracing layout is shown in figure D11.

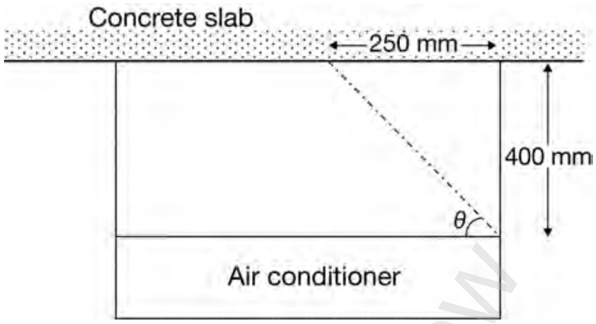


Figure D11 – Bracing layout for air conditioner suspended 400 mm below concrete slab

$$\theta = \tan^{-1}\left(\frac{400}{250}\right)$$

$$= 57.9° < 60°$$

This angle is acceptable (equation 3.30); however, vertical capacity of gravity hangers must be checked as, $\theta > 30°$ (see 3.8).

Consider loading on one side of unit. Forces are as described below in figure D12:

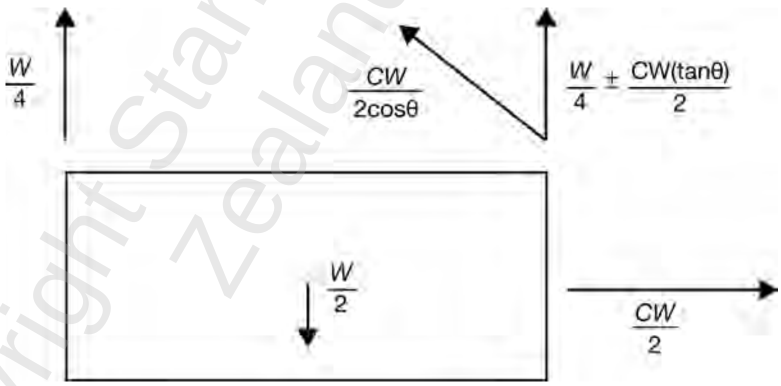


Figure D12 – Air conditioner (suspended 400 mm) force diagram

Brace axial load, $P = \frac{CW}{2\cos\theta}$

$$= \pm\frac{549}{2\cos 58}$$

$$= \pm 518 \text{ N}$$

From 3.11.3, a 25 x 25 x 3 EA (maximum of 0.5 m long), attached with an M8 bolt fixing will be satisfactory under compression.

Vertical hanger load. In the described configuration, two braces are attached to a single vertical hanger at 90 degrees to each other in plan, and the applied seismic loading can occur in any direction.

Seismic load must therefore be multiplied by 140% for the load in the vertical hanger.

Equation 3.13 may be used to determine this load, and the dead load of the component must also be included.

$$P = \frac{W}{4} \pm 140\% \times \frac{CW(\tan\theta)}{2}$$

$$= \frac{343}{2} \pm 1.4 \times \frac{549(\tan 58)}{2}$$

$$= 444 \text{ N or } 787 \text{ N}$$

From 3.11.2, a 25 × 25 × 3 EA or 12 × 3 flat, either one attached with an M8 bolt fixing will be satisfactory under tension (clearance for bolts will determine final size).

Step 4 – Determine anchor size (note that the seismic component of the forces on the anchor must be factored by 0.85/0.55 to allow for the differing performance factors), see figure D13.

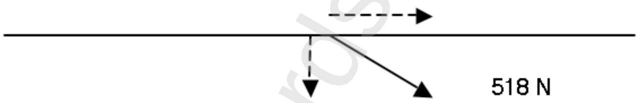


Figure D13 – Force diagram for air conditioner (suspended 400 mm) anchor size

For the brace anchors:

Shear force = 518 x cos58 x 0.85/0.55

= 424 N

Tension force = 518 x sin58 x 0.85/0.55

= 679 N

For the anchors to the vertical hanger:

Tension force $= \frac{343}{4} + 1.4 \times \frac{549(\tan 58)}{2} \times \frac{0.85}{0.55}$

= 1040 N

From figure 10(b), M10 cast-in anchors throughout will be satisfactory.

D10 CEILING SUSPENDED 350 kg AIR CONDITIONER (MOUNTED 1000 mm BELOW CONCRETE SLAB)

Given:

A ceiling suspended 350 kg air conditioner in a Wellington office building mounted 1000 mm below concrete slab, (see figure D10).

Require:

Provide lateral bracing, including anchors to slab.

Solution:

Step 1 – Classify the building and the component

The building is a normal structure. The importance level is 2 (see table 1).

The component falling represents a hazard to an individual life. The category is P3 (see table 2).

Seismic displacement need not be considered as the unit is supported from one floor only.

Step 2 – Determine the load demand (see 3.4)

The component is above ground,	C_H	=	3
Seismic zone factor,	Z	=	0.4 .... (see table 3)
Performance factor (for the anchor),	C_p	=	0.85 ......(see 3.4.2 or Appendix C)
Performance factor (for the compact component braced to the structure)	C_p	=	0.55 ......(see 3.4.2 or Appendix C)

NOTE – The air conditioner is a compact component braced to the structure.

Component risk factor,	R_c	=	0.9 (for IL2 and P3) ... (see table 5)
Hence, the seismic coefficient for the braces is,	C	=	2.7 × 3 × 0.4 × 0.55 × 0.9
		=	1.60
Weight of the component,	W	=	350 kg × 9.81 Nkg^{-1}
		=	3.43 kN
The lateral force on the component,	F	=	$C \times W$
		=	1.60 × 3.43
		=	5.49 kN

Step 3 – Determine the arrangement of bracing and anchors to withstand these loads. Proposed bracing layout is shown in figure D14.

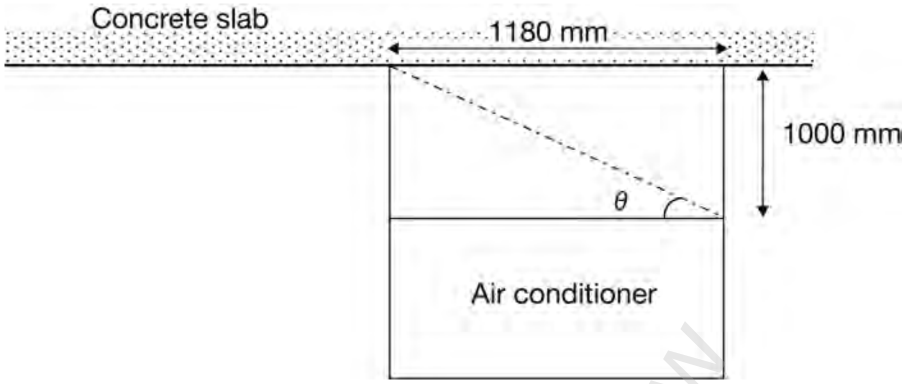


Figure D14 – Bracing layout for air conditioner suspended 1000 mm below concrete slab

$$\theta = \tan^{-1}\left(\frac{1000}{1180}\right)$$

$$= 40.2° < 60°$$

This angle is acceptable. However, vertical capacity of gravity hangers must be checked as, $\theta > 30°$ (see 3.8).

Consider loading of one half of unit. Loadings as described below in figure D15:

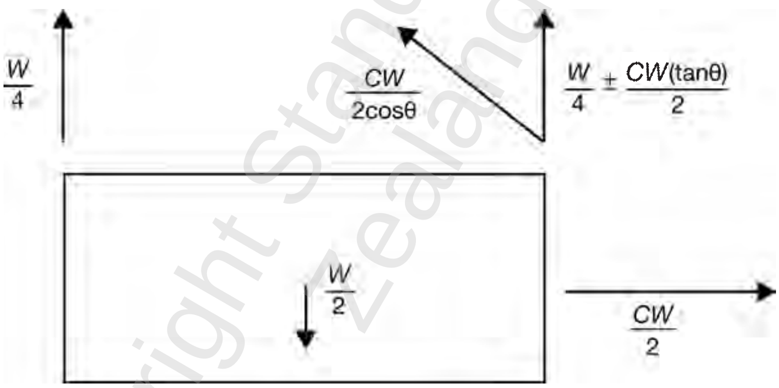


Figure D15 – Air conditioner (suspended 1000 mm) force diagram

Brace axial load, $P = \frac{CW}{2\cos\theta}$

$$= \pm \frac{5.49}{2\cos 40}$$

$$= \pm 3.59 \text{ kN}$$

Brace length is $\sqrt{1.0^2 + 1.18^2} = 1.55$ m

From 3.11.3, for a 2 m long brace, a 40 x 40 x 3 EA, attached with an M12 bolt fixing will be satisfactory under compression.

Vertical hanger load. In the described configuration, two braces are attached to a single vertical hanger at 90 degrees to each other in plan, and the applied seismic loading can occur in any direction. Seismic load must therefore be multiplied by 140% for the load in the vertical hanger. Equation 3.13 may be used to determine this load, and the dead load of the component must also be included.

$$P = \frac{W}{4} \pm 140\% \times \frac{CW(\tan\theta)}{2}$$

$$= \frac{3.43}{2} \pm 1.4 \times \frac{5.49\,(\tan 40)}{2}$$

$$= 4.9 \text{ kN (compression) or } 5.07 \text{ kN (tension)}$$

From 3.11.2 for a hanger of 1 m length, a 40 x 40 x 3 EA with an M12 bolt fixing will be satisfactory under tension and compression.

Step 4 – Determine anchor size (note that the seismic component of the forces on the anchor must be factored by 0.85/0.55 to allow for the differing performance factors), see figure D16.

Figure D16 – Force diagram for air conditioner (suspended 1000 mm) anchor size

For the brace anchors:

Shear force = 3.59 x cos40 x 0.85/0.55

= 4.25 kN

Tension force = 3.54 x sin40 x 0.85/0.55

= 3.57 kN

For the anchors to the vertical hanger:

$$\text{Tension force} = \frac{3.43}{4} + 1.4 \times \frac{5.49(\tan 40)}{2} \times \frac{0.85}{0.55}$$

= 5.84 kN

From figure 11(b), M10 cast-in anchors throughout will be satisfactory.

D11 OIL SUPPLY DAILY SERVICE TANK IN TOP FLOOR PLANT ROOM

Given:

An oil supply daily service tank, of 3000 kg total mass on a low cross-braced stand, is to be installed on the top floor plant room of a multi-storey telecommunications building. Located in Palmerston North, the building is designated as an essential emergency service communications facility. See figure D17.

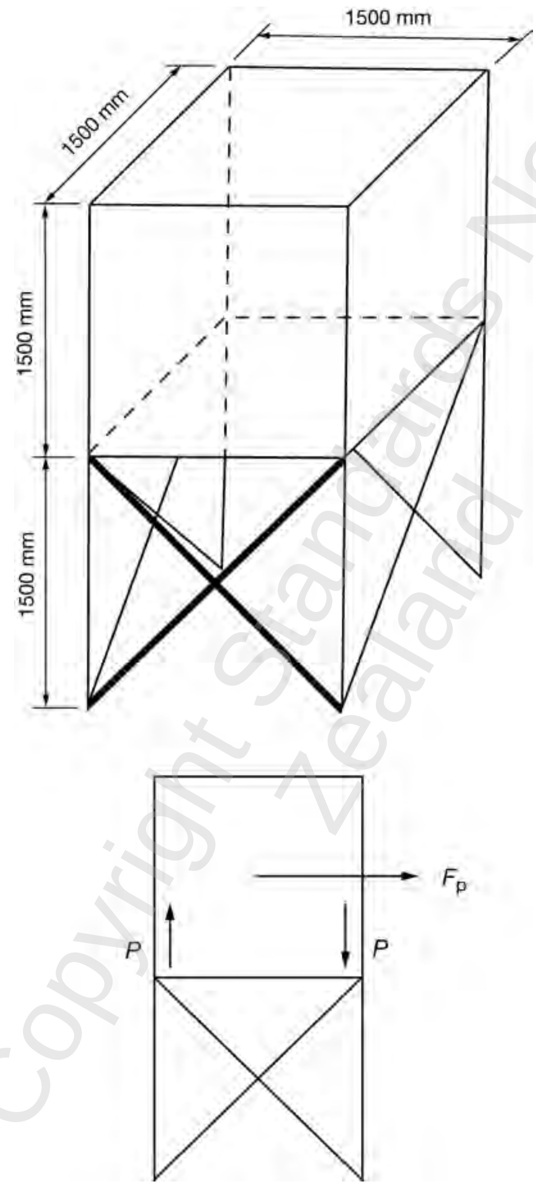


Figure D17 – Oil supply tank bracing layout

Required:

Determine the size of legs, cross-bracing and hold-down anchors.

Solution:

Step 1 – Classify the building and the component

The building must be able to continue providing services after an earthquake. The importance level is 4 (see table 1).

The component is essential for the operational continuity of the functions carried out in the building following a SLS2 earthquake. The category is P5 (see table 2).

The component presents a hazard as it contains oil, which could spill and pose a danger to building occupants. In this case the spill will be confined to the plant room so is not considered to represent a significant hazard, otherwise the category would be P2.

Step 2 – Determine the load demand (see 3.4)

The tank is above ground floor, C_H = 3

Seismic zone factor, Z = 0.38 .... (see table 3)

Performance factor (for P5), C_p = 0.85 .... (see 3.4.2)

Component risk factor, R_C = 1.0 (for IL4 and P5) ... (see table 5)

Hence, the seismic coefficient, C = 2.7 × 3 × 0.38 × 0.85 × 1 (for anchors)

= 2.6 (which is less than 3.6, so use C = 2.6)

Design bracing first to obtain anchor loads

Weight of the component, W = 3,000 kg × 9.81 Nkg^{-1}

= 30 kN

The lateral force on the tank, F = $C \times W$

= 2.6 × 30

= 78 kN.

Assume the stand is pin-jointed and that cross-bracing will only take load in tension.

Have two frames in each direction to share load.

Load per frame = $\frac{78}{2}$

= 39 kN

Taking moments about the top of the frame and assuming centre of mass of the tank is in the middle

$$P = \frac{39 \times 0.75}{1.5} = 19.5$$

Gravity load on each corner leg

Load = $\frac{30}{4}$

= 7.5 kN

Force in member AB = 19.5 – 7.5

= 12 kN

Force in member AC = $2 \times \frac{19.5}{\cos 45}$

= 55.2 kN

Force in member CD	=	19.5 + 7.5 + (55.2cos45)
	=	66 kN
Force in member BC	=	19.5 kN

For the anchor at A, the worst case is combined shear and uplift

shear	=	39 kN shear
uplift	=	12 + 55.2 cos45 = 51 kN uplift

The anchor at D will be the same with the seismic load direction reversed and tension only bracing.

The forces on the oil supply tank are shown in figure D18.

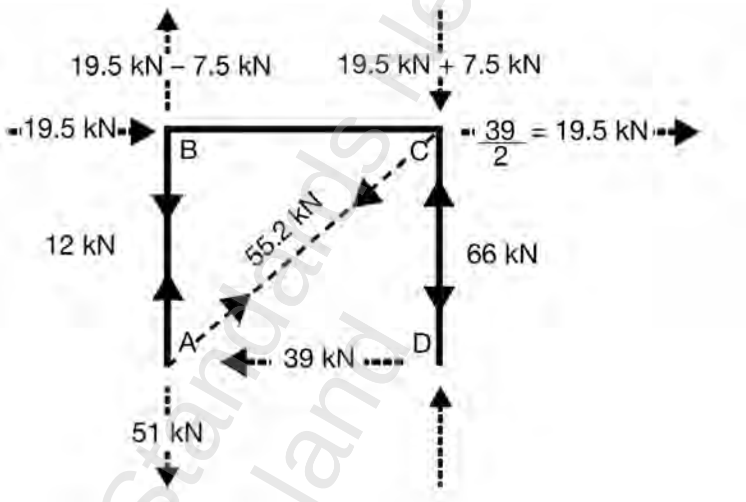


Figure D18 – Oil supply tank (plant room) force diagram

Step 3 – Determine the size of legs, cross-bracing and hold-down bolts

From table 14, consider 75 × 75 × 10 EA for member CD with 80 kN capacity over 1.5 m length.

From table 14 could use 50 × 50 × 8 EA for member BC with 25 kN capacity over 1.5 m length, but practically use 75 × 75 x 10 EA as for member CD.

From table 13 could use 40 × 40 × 3 EA welded for member AC with 55 kN tension capacity or equivalent sized flat of 20 × 10 mm or 40 x 5 mm.

For leg fixings, use one of the options below:

4 bolts per leg with combined 98 kN shear and 12.8 kN tension capacity. From figure 11, use 4 x M12 bolts with an assumed edge distance greater than 100 mm or 200 mm.

3 bolts per leg with combined 13 kN shear and 17 kN tension capacity. From figure 11, use 3 x M16 bolts with an assumed edge distance greater than 100 mm or 200 mm.

2 bolts per leg with combined 19.5 kN shear and 25.6 kN tension capacity. From figure 11, use 2 x M24 bolts with an assumed edge distance greater than 100 mm or 2 × M16 bolts per leg with an assumed edge distance greater than 200 mm.

Choose 2 × M16 bolts with an assumed edge distance of greater than 200 mm.

D12 OIL SUPPLY DAILY SERVICE TANK IN TOP FLOOR

Given:

An oil supply daily service tank, of 3000 kg total mass on a low cross-braced stand, is to be installed on the top floor of a multi-storey telecommunications building. Located in Palmerston North, the building is designated as an essential emergency service communications facility, see figure D17.

Required:

Determine the size of legs, cross-bracing and hold-down anchors.

Solution:

Step 1 – Classify the building and the component

The building must be able to continue providing services after an earthquake. The importance level is 4 (see table 1).

The component is essential for the operational continuity of the building following a SLS2 earthquake. The part category is P5 (see table 2). However, the tank potentially represents a hazard as it contains oil which could spill and pose a danger to building occupants. So the part classification is taken as P2.

The structural limit state is ULS. There will most likely be no need to check deflections under SLS2 for P5.

Step 2 – Determine the load demand

The tank is above ground floor,	C_H	=	3
Seismic zone factor,	Z	=	0.38 .... (see table 3)
Performance factor (for anchors),	C_p	=	0.85 .... (see table 5)
Performance factor (for cross-bracing),	C_p	=	0.55 .... (see table 5)
Component risk factor,	R_c	=	1.8 (for IL4 and P2) ... (see table 5)
Hence, the seismic coefficient,	C	=	2.7 × 3 × 0.38 × 0.85 × 1.8 for fixings
		=	4.7 (which is greater than 3.6, so use C = 3.6)
	C	=	2.7 × 3 × 0.38 × 0.55 × 1.8 for cross-bracing
		=	3.05 (which is less than 3.6, so use C = 3.05)

Design bracing first, then factor loads by to $\frac{3.6}{3.05}$ obtain fixing loads or alternatively recalculate using C = 3.6.

Weight of the component,	W	=	3000 kg × 9.81 Nkg^{-1}
		=	30 kN
The lateral force on the tank,	F	=	$C \times W$
		=	3.05 × 30
		=	91.5 kN.

Have two frames in each direction to share load.

Load per frame $= \dfrac{91.5}{2}$

$= 45.75$ kN

Taking moments about the top of the frame and assuming centre of mass of the tank is in the middle

$$P = \frac{45.75 \times 0.75}{1.5} = 22.9 \text{ kN}$$

Gravity load on each corner leg.

Load $= \dfrac{30}{4}$

$= 7.5$ kN

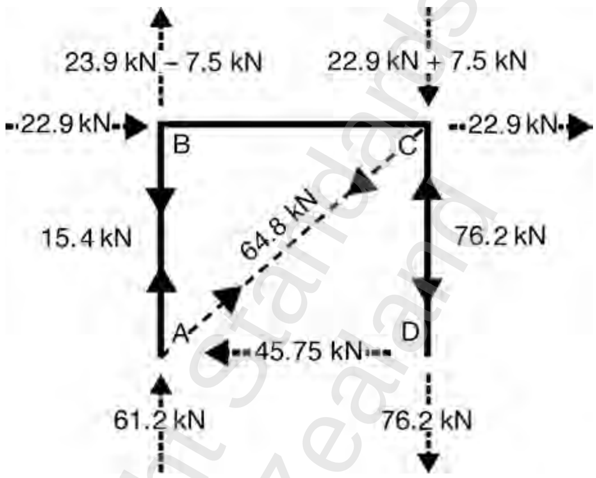


Figure D19 – Oil supply tank (not located in plant room) force diagram

Force in member AB $= 22.9 - 7.5$

$= 15.4$ kN

Force in member AC $= 2 \times \dfrac{22.8}{\cos 45}$

$= 64.8$ kN

Force in member CD $= 22.9 + 7.5 + (64.8\cos45)$

$= 76.2$ kN

Force in member BC $= 22.9$ kN

For the anchor at A the worst case is combined shear and uplift.

shear $= 47.75$ kN

uplift $= 15.4 + 64.8 \times \cos45 = 61.2$ kN

The seismic component of these loads must be factored by $\frac{3.6}{3.05}$ for anchor design because of the differing performance factors:

This gives (at A) shear $= 47.75 \times \frac{3.6}{3.05} = 56.4$ kN

uplift $= (61.2 + 7.5) \times \frac{3.6}{3.05} - 7.5 = 73.6$ kN

Step 3 – Determine the size of legs, cross-bracing and hold-down bolts

From table 14, consider 75 × 75 × 10 EA for member CD with 80 kN capacity over 1.5 m length.

From table 14 could use 50 × 50 × 8 EA for member BC with 25 kN capacity over 1.5 m length, but practically use 75 × 75 x 10 EA as for member CD.

From table 13 could use 50 × 50 × 3 EA welded for member AC with 69 kN tension capacity or equivalent sized flat of 50 × 6 mm.

For leg fixings, use one of the options below:

4 bolts per leg with combined 13.5 kN shear and 18.4 kN tension capacity. From figure 11, use 4 x M16 bolts with an assumed edge distance greater than 100 mm or 200 mm.

3 bolts per leg with combined 18 kN shear and 24.5 kN tension capacity. From figure 11, use 3 x M20 bolts with an assumed edge distance greater than 100 mm, or 3 x M16 bolts with an asurred edge distance greater than 200 mm.

2 bolts per leg with combined 19.5 kN shear and 25.6 kN tension capacity. From figure 11, use 2 x M24 bolts with an assumed edge distance greater than 100 mm or 2 × M16 bolts per leg with an assumed edge distance greater than 200 mm.

Choose 2 × M16 bolts with an assumed edge distance of greater than 200 mm.

D13 PLINTH

Given:

The boiler in example D2 needs to be mounted on a plinth, see figure D20.

NOTE – A specific design using section 4 is required because the boiler anchors are above the limits provided for in 5.4.

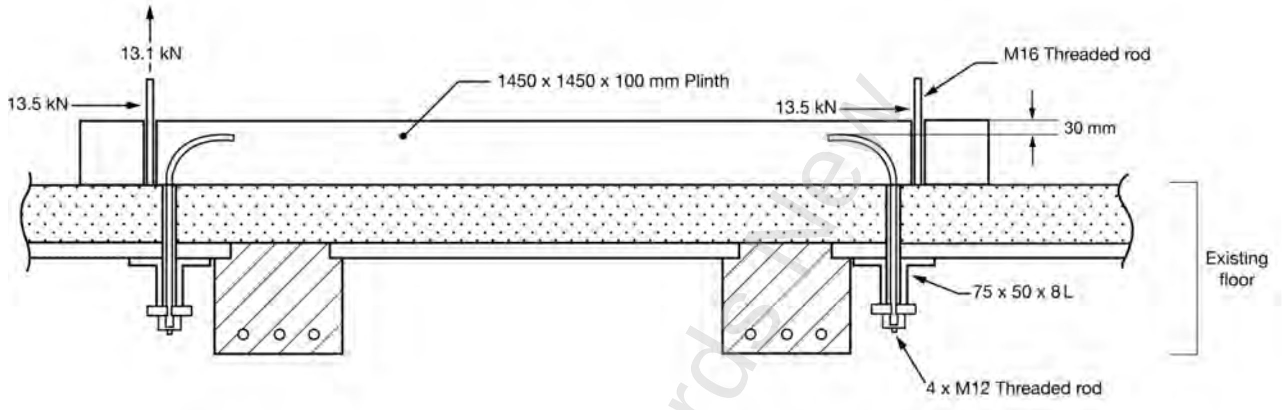


Figure D20 – Plinth layout and force diagram

Required:

Specific design of fixings and reinforced concrete plinth. The strength of supporting floor would also need to be checked (independently of this example).

Solution:

Step 1 – Design actions

The four boiler supports are to be ductile connections, with the connection over strength requiring anchors at each end of the boiler to restrain 13.1 kN uplift and 13.5 kN shear.

Step 2 – Selection of fixings

In accordance with figure 10(b), adequate anchorage will be provided by M16 bolts as cast-in anchors.

Step 3 – Plinth dimensions

A plinth is required, as the topping of the prestressed concrete flooring system is only 65 mm thick. The threaded rod anchors need embedding at least 200 mm into concrete (see figure 10(b)). The plinth needs to be at least 100 mm wider than the spacing between the boiler supports to accommodate the edge distance chosen for the anchors.

Step 4 – Plinth anchorage

The most expedient solution is to drill the floor slab and fix the boiler hold-down bolts through and underneath the slab. A pair of back-to-back angle sections beneath the slab may be used to distribute the concentrated overturning forces more uniformly. The timber beneath the topping concrete will distribute the pressure more uniformly. Alternatively, the plinth could be separately attached as shown in figure D20.

Step 5 – Plinth details

Provide plinth reinforcement and details in accordance with figure 14 with R10 at 600 mm each way selected from the column headed 'with anchor bolts fixed through the floor slab'.

D14 ELECTRICAL CABINET

Given:

A large freestanding electrical cabinet housing the main distribution board is located on the ground floor of an office building in Wellington. The cabinet is 2.2 m long, 2 m high, and 0.6 m deep. The mass of the cabinet is 600 kg, see figure D21.

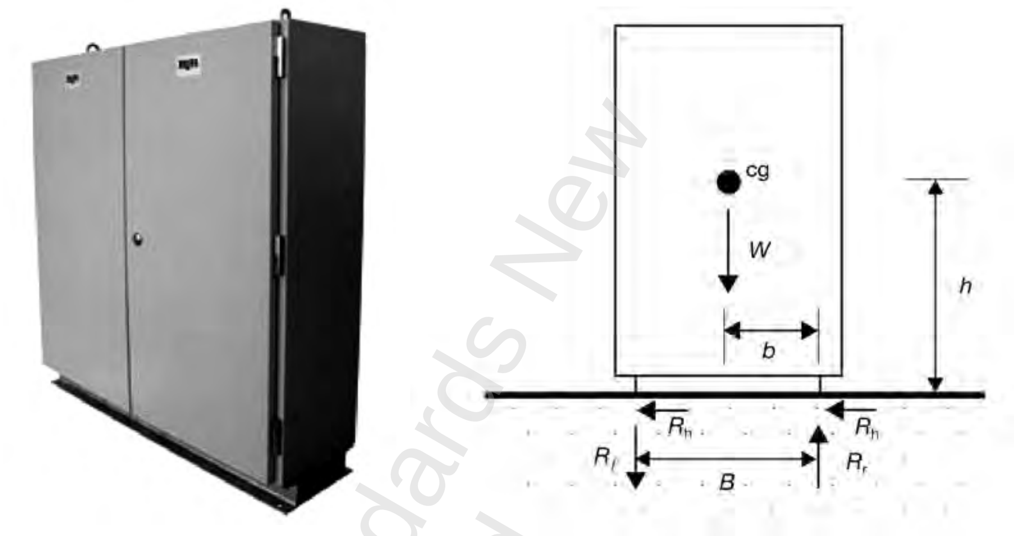


Figure D21 – Electrical cabinet example and force diagram

Required:

Determine the number and size of hold-down anchors. The cabinet structure will be designed by others.

Solution:

Step 1 – Classify the building and the component

The building is a normal office building. The importance level is 2 (see table 1).

The component poses a hazard to individual life within the building. The category is P3 (see table 2).

NOTE – In accordance with 5.12, components of electrical supply will be classified P1, P2, or P3 as applicable.

Step 2 – Determine the load demand (see 3.4)

The cabinet is on the ground floor,	C_H	=	1.0
Seismic zone factor,	Z	=	0.4 .... (see table 3)
Performance factor,	C_p	=	0.45 (floor mounted, metal).... (see Appendix C)
Performance factor,	C_p	=	0.55 (braced to structure, metal)... (see Appendix C)
Performance factor,	C_p	=	0.85 (anchors for component)... (see 3.4.2, or Appendix C)
Component risk factor,	R_c	=	0.9 (for IL2 and P3) ... (see table 5)

Hence, the seismic coefficient, $C = 2.7 \times 1.0 \times 0.4 \times 0.85 \times 0.9$

$= 0.83$

NOTE – The C_p value of 0.55 would apply for anchors if ductile fixings were used.

Weight of the cabinet, $W = 600 \text{ kg} \times 9.81 \text{ Nkg-1}$

$= 5.9 \text{ kN}$

The lateral force on the cabinet, $F = C \times W$

$= 0.83 \times 5.9$

$= 4.9 \text{ kN}$

Forces on the restraint anchors:

Floor mounted component (see 3.7)

The cabinet has the following dimensions:

$h = 1.1 \text{ m}$

$D = 0.6 \text{ m}$

$d = 0.3 \text{ m}$

Provide three anchors each long side (n = 3, N = 6) using equation 3.6

Horizontal force on each anchor:

$$R_h = \frac{CW}{N} = \frac{4.9}{6} = 0.82 \text{ kN}$$

Vertical tensional force on each anchor:

$$R_v = -\frac{CWh}{nD} + \frac{W}{N} = -\frac{4.9 \times 1.1}{3 \times 0.6} + \frac{5.9}{6} = 2.00 \text{ kN}$$

The edge distance for the anchors will be greater than 200 mm, so see figure 10(b) to choose M10 anchor bolts. Provide 3 M10 anchor bolts front and back of the cabinet.

It may be more suitable for this cabinet to be braced to the structure. Provide 3 horizontal braces to the top of the cabinet with bolt fixings to a structural wall behind the cabinet. Attachment height of the brace, H, is 2.0.

From equation 3.27:

$$P = \frac{CWh}{H\cos\theta} = \frac{4.9 \times 1.1}{2.0 \times 1.0} = 2.70 \text{ kN (0.9 kN per brace)}$$

Step 3 – Determine the fixings to withstand these loads

From table 11, one M12 bolt fixing embedded 100 mm into a masonry wall will be satisfactory. Alternatively, from table 8, a 10 gauge woodscrew penetrating 35 mm into a timber stud is an option.

NOTE – If the cabinet is fixed to a timber frame wall, the project structural engineer should check the wall capacity.

D15 VENTILATING FAN ON MULTI-STOREY BUILDING WITH ROOF PARAPET

Given:

A vibration-isolated ventilating fan is to be installed on top of a multi-storey office building in Christchurch. The roof has a parapet which is high enough and robust enough to prevent the fan from falling onto the public street below. The mass of the fan motor and base is 500 kg, see figure D22.

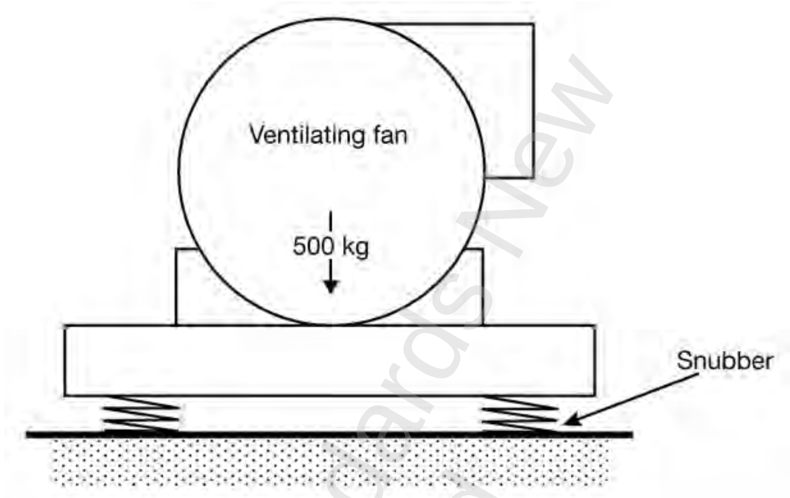


Figure D22 – Ventilating fan layout

Required:

Support type and horizontal design forces for the fan support system.

Solution:

Step 1 – Classify the building and the component

The building is a normal building. The importance level is 2 (see table 1).

The component would not pose a threat to life if supports were to fail.

The system is required for operational continuity, and its failure would have serious financial consequences for the owner. The category is P6 (see table 2).

Step 2 – Determine the load demand (see 3.4)

The fan unit is above ground floor,	C_H	=	3
Seismic zone factor,	Z	=	0.22............................ (see table 3)
Performance factor (for a vibration isolated, compact component),	C_p	=	0.75..... (see 3.4.2, and Appendix C)
Performance factor(for the anchor),	C_p	=	0.85..... (see 3.4.2, and Appendix C)
Component risk factor,	R_c	=	0.25 (for IL2 and P6) ... (see table 5)

For the design of the isolating structure:

The seismic coefficient, C = $2.7 \times 3 \times 0.22 \times 0.75 \times 0.5$

= 0.67

Weight of the component, W = $500 \text{ kg} \times 9.81 \text{ Nkg}^{-1}$

= 4.9 kN

The lateral force on the structure, F = $C \times W$

= 0.67×4.9

= 3.28 kN.

For anchors:

The seismic coefficient, C = $2.7 \times 3 \times 0.22 \times 0.85 \times 0.5$

= 0.89

The lateral force on the anchor, F = $C \times W$

= 0.89×4.9

= 4.4 kN.

Step 3 – Determine the support type and horizontal design forces for the fan support system

These horizontal forces should be used to evaluate ‘sliding’ and ‘overturning’ design actions for the ventilation fan support structure and fixings following the procedures in 3.7.

For the design of snubbers and their anchors, it is necessary to consider the seismic forces induced by the dynamic impact of the component against the snubbers (see 5.5).

This may be achieved by either:

(a) Providing snubbers complying with the requirements for the seismic restraints of vibration isolated equipment, such as:

(i) Proprietary seismic-rated snubbers, or

(ii) Fabricated snubbers with clearances of between 3 and 6 mm with neoprene pads. The neoprene pads need a thickness of 6 mm/g design load ($6 \times C$) and a minimum thickness of 6 mm. That is, $6 \times 0.33 = 1.98$ which is less than 6 mm, so use the minimum thickness of 6 mm;

(b) Providing snubbers with clearances greater than 6 mm and scaling the loads by a factor of 2.

Choose between the conforming snubbers, either suitably rated proprietary snubbers, or fabricated snubbers with a 6 mm clearance each side and 6 mm neoprene pads.

D16 VENTILATING FAN ON MULTI-STOREY BUILDING WITHOUT A ROOF PARAPET

Given:

A vibration-isolated ventilating fan on top of a multi-storey building in Christchurch. The roof does not have a parapet to prevent the fan falling onto a public street below. The mass of the fan motor and base is 500 kg, see figure D22.

Required:

Support type and horizontal design forces for the fan support system.

Solution:

Step 1 – Classify the building and the component

The building is a normal building. The importance level is 2 (see table 1).

The roof without a parapet means that the component could fall off the roof and hence pose a threat to life if supports were to fail. The category is P1 (see table 2).

Step 2 – Determine the load demand

The fan unit is above ground floor, C_H = 3

Seismic zone factor, Z = 0.22 .... (see table 3)

Performance factor (for a vibration isolated, compact component), C_p = 0.75 ... (see 3.4.2, and Appendix C)

Performance factor (for anchors), C_p = 0.85 ... (see 3.4.2, and Appendix C)

Component risk factor, R_c = 1.00 (for IL2 and P1) ... (see table 5)

For the design of the isolating structure:

The seismic coefficient, C = 2.7 × 3 × 0.22 × 0.75 × 1.00
= 1.34

Weight of the component, W = 500 kg × 9.81 Nkg^{-1}
= 4.9 kN

The lateral force on the component, F = $C \times W$ (supporting structure)
= 1.34 × 4.9
= 6.6 kN.

For the anchors:

The seismic coefficient, C = 2.7 × 3 × 0.22 × 0.85 × 1.00 (anchors)
= 1.51

The lateral force on the component, F = $C \times W$ (anchors)
= 1.51 × 4.9
= 7.4 kN.

Step 3 – Determine the support type and horizontal design forces for the fan support system

These horizontal forces should be used to evaluate 'sliding' and 'overturning' design actions for the ventilation fan support structure and fixings following the procedures in 3.7.

For the design of snubbers and their anchors, it is necessary to consider the seismic forces induced by the dynamic impact of the component against the snubbers (see 5.5).

This may be achieved by either:

(a) Providing snubbers complying with the requirements for the seismic restraints of vibration isolated equipment; such as:

(i) Proprietary seismic-rated snubbers, or

(ii) Fabricated snubbers with clearances of between 3 and 6 mm with neoprene pads. The neoprene pads need a thickness of 6 mm/g design load ($6 \times C$) and a minimum thickness of 6 mm. That is, $6 \times 1.34 = 8.04$, which is greater than 6 mm, so use the 8 mm;

(b) Providing snubbers with clearances greater than 6 mm and scaling the loads by a factor of 2.

Choose between conforming snubbers, either suitably rated proprietary snubbers, or fabricated snubbers with a 6 mm clearance each side and neoprene pads with an 8 mm neoprene pad.

NOTES

Approved by the Standards Council on 27 April 2009 to be a New Zealand Standard pursuant to the provisions of section 10 of the Standards Act 1988.

First published: 30 April 2009
Reprinted: August 2015

The following Standards New Zealand references relate to this Standard:

Project No. P 4219
Draft for comment No. DZ 4219
Typeset by: Standards New Zealand
Printed by: The Colour Guy

STANDARDS®
NEW ZEALAND
PAEREWA AOTEAROA