Architectural Design for Earthquake

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Architectural Design for Earthquake

A guide to the design of non-structural elements

Published by the New Zealand Society for Earthquake Engineering

First edition (1992) authored by Warwick Massey assisted by Les Megget.

Second Edition (2007) revised and updated by Andrew Charleson, School of Architecture, Victoria University of Wellington.

Preface

This publication is intended to promote adequate performance of non-structural elements in earthquake - to reduce the risk of injury to people, to reduce damage and to avoid adverse structural effects.

Recognition of the need for a New Zealand guide to the architectural design of non-structural elements first arose out of meetings, discussions and enquiry conducted by a NZ National Society for Earthquake Engineering Study Group. Most engineers, some architects and a few other specialist designers understand the principles of designing for the protection of non-structural elements, but many others, who are directly concerned with detailing, specifying and constructing buildings, do not appreciate the effects of earthquake shaking.

In 1992 *Architectural Design for Earthquakes: A guide to the design of non-structural elements* was published by the NZNSEE. This edition, published in 2007 on the internet has been revised and updated. It incorporates developments that have occurred over the past fourteen years. Most significant of these is the introduction of a new NZ earthquake loadings standard, NZ 1170 Part 5:2004 Earthquake Actions – New Zealand.

The publication provides an overview and most topics are at least summarised and references given to sources of further information. In no way does it replace involvement by professional engineers and architects in appropriate aspects of design. On the contrary, it is intended to heighten awareness of the need for engineering involvement in the design of non-structural elements.

Given the difficulty of producing, cost effective architectural details that meet New Zealand earthquake code requirements the information provided will help architects and engineers to work together to produce designs which are functional, aesthetic and achieve a high standard of earthquake performance.

Acknowledgements

The assistance provided by NZSEE members in providing images and comments is appreciated.

Chris Greenfield undertook background research, formatted the publication and redrew most of the original diagrams where they did not warrant updating.

Unacknowledged photographs have been taken by Andrew Charleson.

Contents

This publication is about design of non-structural elements - that is, those parts of buildings which do not or are not intended to resist earthquake loads applied to the primary structure of the building. These include:

Cladding panels of various materials
Windows and exterior walling systems
Internal walls and partitions
Suspended ceilings
Stairways
Equipment items
Building services

In this text only brief reference is made to the behaviour of building services in earthquake.

1 Introduction

Design of non-structural elements is important because:

Non-structural parts of a building have the potential to modify earthquake response of the primary structure in an unplanned way. This can lead to severe structural damage or even collapse.

Damage to non-structural elements themselves may prevent the building from functioning after an earthquake, or make it useless, even though the structure remains sound.

Failure of non-structural components may cause death or injury from:

- falling panels, masonry or glass
- collapsed ceiling components
- falling fittings and fixtures
- debris blocking exitways, etc.

Evidence from earthquakes around the world shows that non-structural damage typically represents the greatest monetary loss in an earthquake (Figure 1.1). A survey of 355 high-rise buildings after the 1971 San Fernando earthquake showed that, in dollar value terms, 79% of the damage was non-structural.[1]

Figure 1.1
Interior damage to an office building, Mexico City, 1985 Mexico earthquake. (D.C. Hopkins)

New Zealand lies on the so-called ring of fire which encircles the Pacific and includes the Philippines, Japan, Alaska, the West Coast of USA and South America. The boundary between the Indian-Australian and Pacific tectonic plates passes through the length of the South Island and most of the North Island. As different parts of the earth's crust at the plate boundaries are trying to move in different directions there is an on-going cycle of stress build up followed by rupture and accompanying energy release. It is this process, sometimes gradual and sometimes sudden, that causes earthquakes.

Figure 1.2 shows how the Pacific Plate is subducting under the Australian Plate. Most of the earthquakes in New Zealand occur on the interface of the two plates when they rupture and move relative to each other.

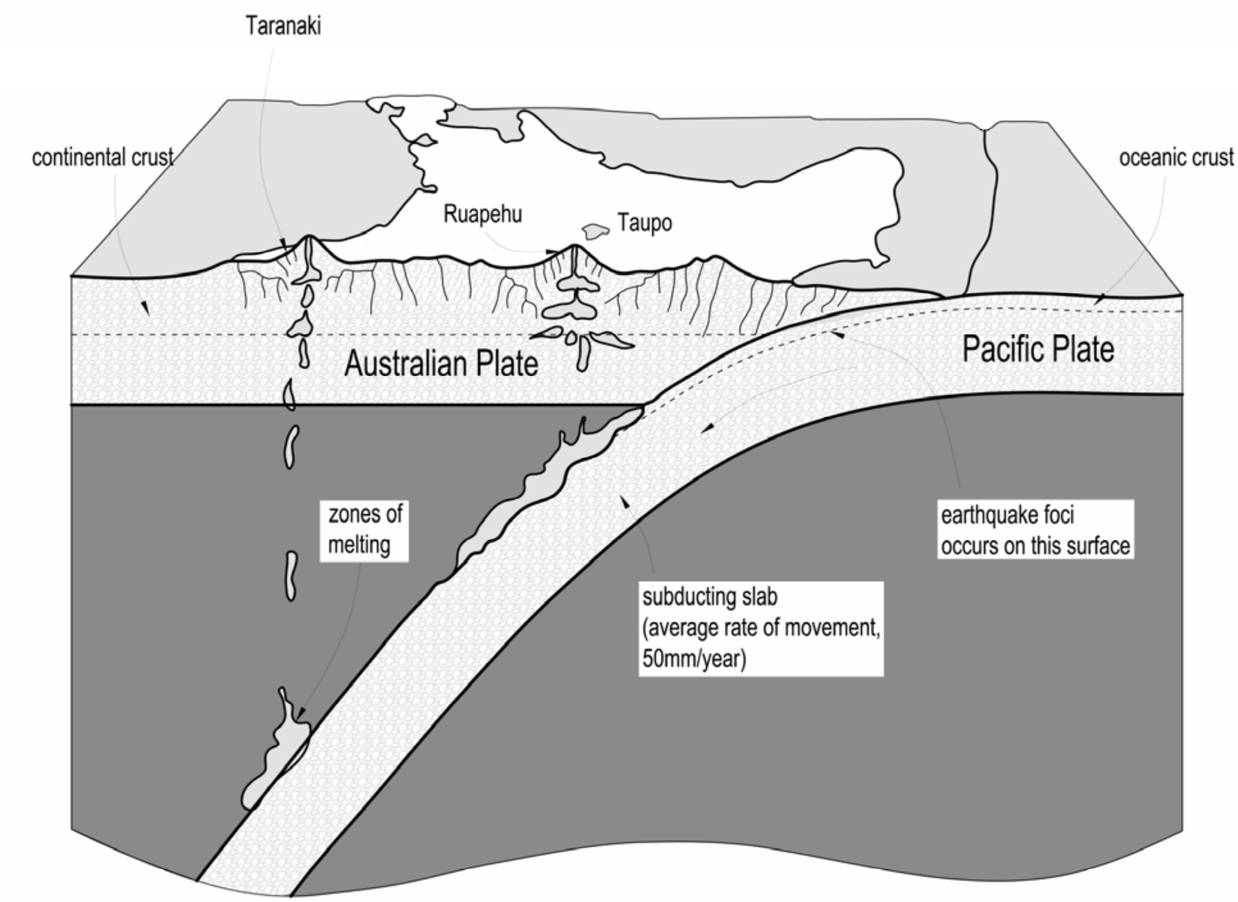

Figure 1.2
A cross-section through the middle of the North Island showing the Pacific plate subducting under the Australian plate. After "Caught in the Crunch" by Rebecca Ansell & John Taber.

Measuring Earthquakes

Two terms are frequently confused when talking about earthquakes. They are magnitude and intensity.

- The **magnitude** of an earthquake is a measure of its size and relates to the amount of energy released, usually by rupturing of the fault.
- The **intensity** of an earthquake is measured at a particular site and depends upon:
    - magnitude of the earthquake,
    - depth of the earthquake source,
    - distance from the epicentre (the point on the earth's surface directly above the source,
    - ground conditions at the observation site, and between there and the source,
    - duration of the shaking.

Magnitude is generally measured in terms of the Richter scale. Every time the Richter magnitude increases by one it represents a twenty-sevenfold increase in the size of the earthquake. In other words, a Richter magnitude 7 earthquake releases 27 times more energy than a magnitude 6 earthquake.

Intensity is often quoted in terms of the Modified Mercalli scale which is graded MM I to MM XII. Roman numerals avoid confusion with other measures of measuring earthquake magnitude. This scale is based on observed effects and as such is subjective. For instance MM VI shaking is described as:

> *Felt by all; many frightened and run outdoors; some heavy furniture moved; a few instances of fallen plaster or damaged chimneys; damage slight.*

Return Period

Figure 1.3 shows the epicentres of shallow earthquakes in New Zealand, of magnitude 6.5 and greater, since 1840. The greater concentration of earthquakes in some parts of the country is evident.

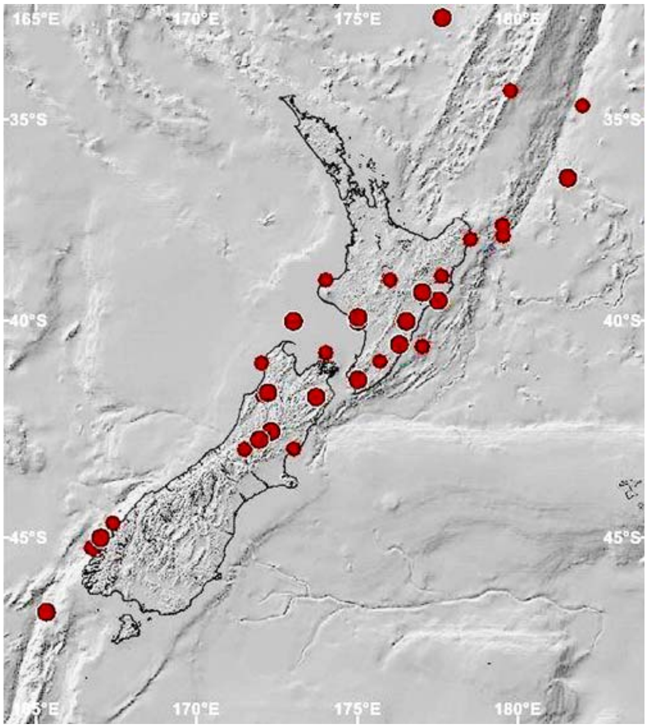

Figure 1.3
Epicentre of large shallow earthquakes in New Zealand since 1840: magnitude 7.0 and greater (large symbols) and 6.5 to 6.9 (small symbols). (Data courtesy of GNS Science, 2006)

From earthquakes felt in New Zealand over the period 1840-1997 the return period for upper MM intensities has been estimated.[3] As examples:

- For the Wellington area, on average ground:
  - MM V intensity every 3 years
  - MM VI intensity every 12 years
  - MM VII intensity every 53 years
  - MM VIII intensity every 79 years
  - MM IX intensity every 158 years

- In the Auckland area the predicted return periods are much longer:
  - MM V intensity every 158 years and higher intensities at considerably longer return periods.

The return period is a useful concept but it does not predict WHEN a particular earthquake will occur, only the likelihood of that event. So a designer in (say) Auckland cannot think, this building is only going to be used for 50 years at the most so there is no need to design for an earthquake. The earthquake predicted to occur within the return period might happen at any time.

Earthquake Zoning

The statistical probability of earthquake shaking of a given intensity occurring in a particular part of the country, within a given timeframe, is the basis of determining the earthquake hazard.

The contour lines in Figure 1.4 represent the peak horizontal ground accelerations at rock sites for a design earthquake with a return period of 500 years. Structural engineers use these values to determine the level of earthquake loading buildings must be designed for.

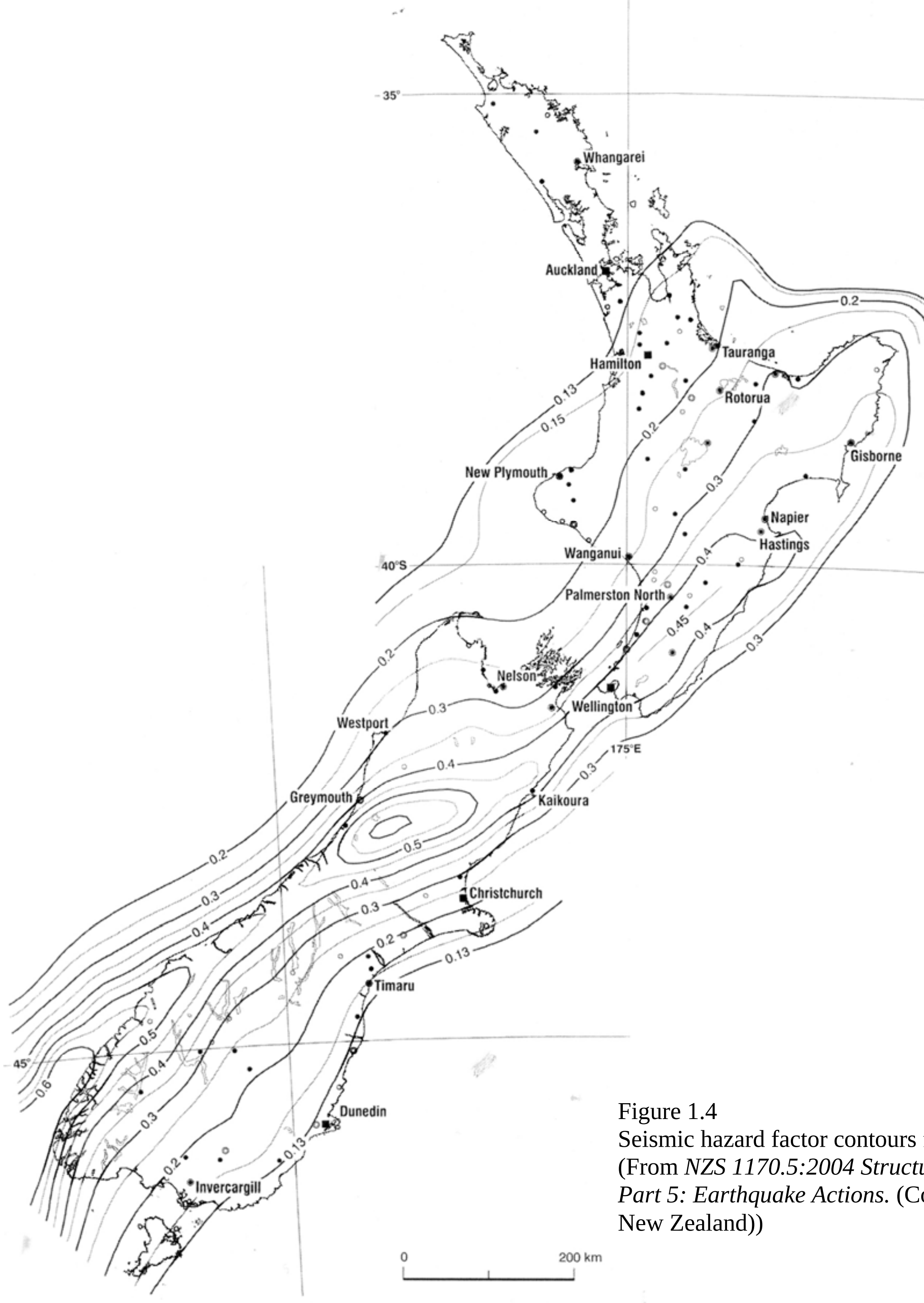

Figure 1.4
Seismic hazard factor contours for New Zealand.[2]
(From *NZS 1170.5:2004 Structural design actions, Part 5: Earthquake Actions.* (Courtesy of Standards New Zealand))

Earthquake risk to a building is determined by three factors:

- The likely frequency of an earthquake.
- The intensity of the resultant shaking at a particular location.
- The effect of that ground shaking on the building under consideration.

Ground Movement

The terms 'frequency' and 'intensity' have been noted. Return period predictions take both of these into account. But the way earthquake movement is propagated and the influence of differing ground conditions have an important bearing on ground motion at a particular site.

Earthquakes are transmitted through the ground in a complex way. Research has shown that four different types of wave motion may be involved. The primary wave accounts for the initial movement, the other three wave forms following, usually a few seconds later. Because of the interaction of these different types of movement the resultant ground displacement, at any particular site, is typically very erratic (but occasionally may be almost unidirectional). Also, while design codes emphasise horizontal forces there is usually a major vertical movement component as well.

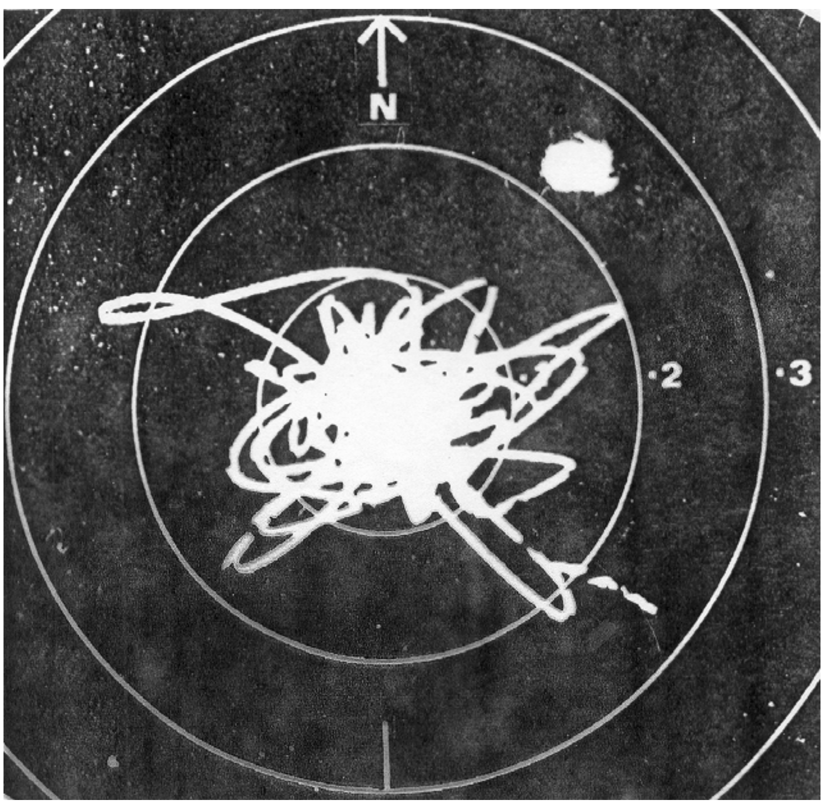

Figure 1.5
Record from a scratch-plate accelerometer at the Waipawa Post Office.

It shows directionally-random horizontal accelerations during the September 1982 earthquake. The numbered rings indicate acceleration as a decimal of the acceleration due to gravity. (Source unknown)

“Peak Horizontal Acceleration 0.239g

Epicentral Distance 61km

Bearing From Site to Epicentre S12W”

Building Response

The actual ground displacements involved are often surprisingly small - perhaps no more than ten millimetres or so, although in extreme cases the movement may be up to as much as 300 mm (or a great deal more where there is surface faulting). What can make earthquakes so devastating to buildings is the way some structures respond to particular types of ground motion - especially ground accelerations, the predominant frequency of the shaking, and its duration.

This was dramatically illustrated by the 1985 earthquake in Mexico City, where the soft soils of the old lake bed, on which major parts of the central business district are built, moved with a period of vibration close to that of some of the multi-storeyed buildings, thus causing resonance and collapse - especially those buildings designed in earlier years. (Figure 1.6)

Resonant response of structures is something that engineers try very hard to avoid. Hence the importance that is placed on a close understanding of soil conditions at specific sites and their response to a likely earthquake. To a reasonable extent, soil conditions are taken into account by structural engineers in the process of determining the earthquake design loads for a building.

Figure 1.6
Total collapse of a high-rise steel building in the foreground. Mexico City, 1985 Mexico earthquake. (D. C. Hopkins)

[1] Arnold, C., Hopkins, D. and Elsesser, E. (1987). Design and detailing of architectural elements for seismic damage control, Building Systems Development Inc, KRTA Ltd, and Forell/Elsesser Engineer Inc, p. 32.

[2] Standards New Zealand (2004). NZS 1170.5: 2004 Structural design actions, Part 5: Earthquake actions, Wellington.

[3] Dowrick, D. J. and Cousins, W. J. (2003). Historical incidence of Modified Mercalli Intensity in New Zealand and comparisons with hazard models, *Bulletin of the New Zealand Society for Earthquake Engineering*, Vol. 36, No. 1, pp. 1-24.

2 Configuration

The configuration of a building could be called its seismic form. Form to an architect means more than just shape and scale, but includes these qualities; so building configuration takes account of size and shape, but is also influenced by the location, size and nature of the structural elements, and of the non-structural elements as well.

An obvious example of poor seismic configuration is a U or L shaped building on plan, if it is not structurally divided into simply shaped blocks. Such a building may suffer damage in an earthquake because the 'free' ends on plan will sway in a different way to the corner section, which is stiffer. Columns on re-entrant corners are particularly prone to damage because of the concentration of forces at such points.

A building which has a simple plan form can nevertheless be badly damaged in an earthquake if it has abrupt changes in lateral stiffness, either on plan, or from one floor to the next. Take the case of a building in Mexico City that was nearly square on plan, but with glazing on two sides of a street corner and unseparated masonry panels on the other two sides. Severe damage, due to torsional effects, was predictable. (Figure 2.1)

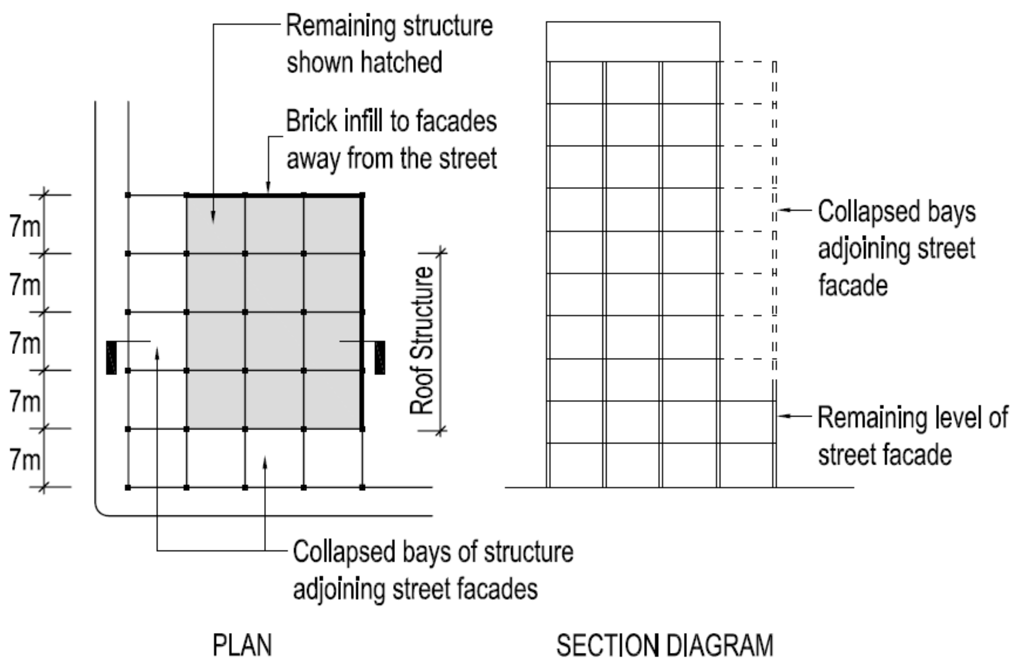

Figure 2.1
Diagrams of the Secretariat of Water Supply, Mexico City (cnr Juan a Mateus/Calz de Tlalpan). While the plan is symmetrical, unequal stiffness of street facades and rear walls means seismic configuration is very poor.

Readers are referred to the book "Building Configuration and Seismic Design" by Arnold and Reitherman[1] for full treatment of the subject of configuration. It has many illustrations to clarify the subject matter. One diagram is reproduced in Figure 2.2. It shows a range of irregular structures, or framing systems, which are typical of the types of configurations seen to have performed badly in recent major earthquakes.

To quote from an American directive to designers:

> "A great deal of a building's inherent resistance to lateral forces is determined by its basic plan layout. Engineers are learning that a building’s shape, symmetry, and its general layout developed in the conceptual stage, are more important, or make for greater differences, than the accurate determination of code-prescribed forces."[2]

This comment is confirmed by a conclusion reached after study of 178 different buildings in Vina del Mar, Chile, following a Richter magnitude 7.8 earthquake there on 3 March, 1985.

> "The correlations are sufficient to confirm that architectural configuration certainly justifies close architectural/ engineering attention at the outset of the design process. At the same time, poor configuration is no guarantor of bad performance, and good - configuration is no guarantor of impunity."[3]

Elements which adversely affect a structure's seismic performance have, in practice, contributed to building failures in earthquake. Often the position, form and type of these elements is decided by the architect before any engineering analysis or detailed design is attempted. Alternatively, stiff architectural elements that affect the seismic response are added after the engineering concept has been determined. Bad structural forms and poor non-structural element configuration are often irrevocably decided at the architect's sketch design stage. Interaction between architect and engineer is required as the concept is developed.

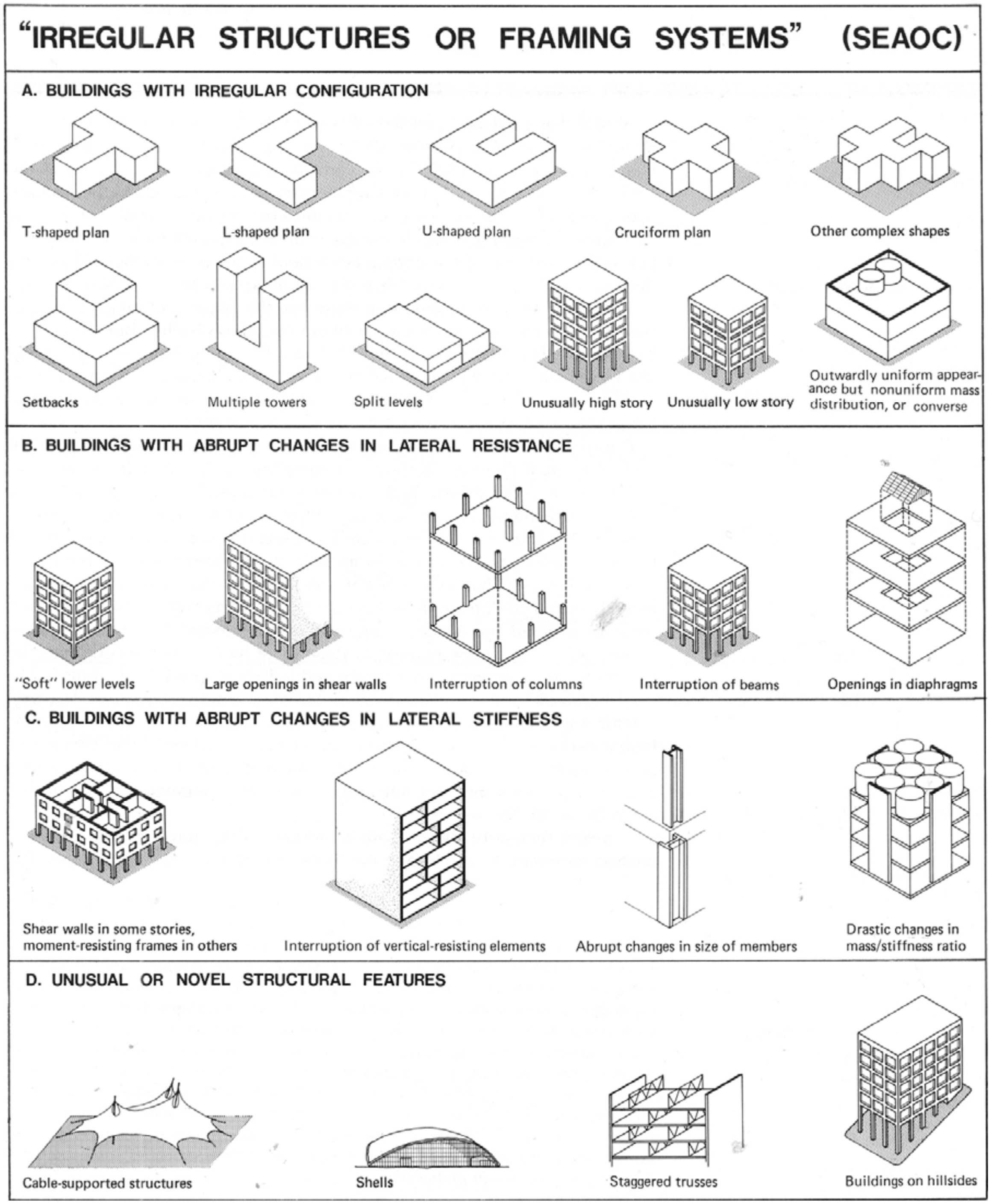

Figure 2.2
Graphic interpretation of irregular structures or framing systems from the Commentary to the SEAOC Recommended Lateral Force Requirements and Commentary.

"Seismic design, then, is a shared architectural and engineering responsibility. The earthquake attacks the building as a whole and does not distinguish between those elements conceived by the architect and those devised by the engineer." [4]

A designer should remember that a building's configuration will determine where seismic damage will occur - the earthquake will usually pick out poor aspects of configuration and detail and concentrate damage in those areas.

Figure 2.3
A stiff and strong masonry infill wall causing severe damage to the top of a column. Mexico City, 1985 Mexico earthquake. (D.C. Hopkins)

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[1] Arnold, C. and Reitherman, R. (1982). *Building configuration and seismic design*, John Wiley & Sons, New York, 269 pp.

[2] Ibid, page 5; from Tri-Services Design Manual, Washington DC: Dept of Army 1973, pp3-5 and 3-13.

[3] Arnold, C (1990).; *Architectural Configuration and Seismic Performance in Vina del Mar, Chile*, Building Systems Development Inc., Sept. , Preface p.iv.

[4] Arnold, C. and Reitherman, R. (1982). *Building configuration and seismic design*, John Wiley & Sons, New York, p. 5.

3 Implications of New Zealand Standards

The philosophy behind modern seismic standards is first and foremost to prevent serious injury to people within, or close to buildings, by preventing complete structural collapse. However, while buildings will remain standing in a major earthquake, considerable structural and non-structural damage will almost certainly occur.

Figure 3.1
Cladding damage to a multi-storey building. Mexico City, 1985 Mexico City earthquake. (R.B. Shephard)

The design of non-structural elements is important in two ways that are both recognised in New Zealand seismic design codes:

- Firstly, non-structural elements must be detailed so that they do not contribute in an unplanned way to the building's seismic response.
- Secondly, they should be detailed so that damage to the non-structural elements themselves is kept at acceptable levels.

What is acceptable in this context will vary according to building type, and can be open to some debate; although a clear distinction can be made between (say) a civil defence headquarters, which must remain functional in the period after an earthquake, and a typical office building, where the first concern is that people should be able to evacuate the building safely.

Loading Standard

The Loadings Standard[1] and especially the earthquake loadings section, NZS 1170.5: 2004 is a verification method for compliance with the New Zealand Building Code.

NZS 1170.5:2004 contains design load requirements for non-structural elements on, or in buildings, as well as inter-storey drift limits for the main lateral load resisting structure. Several aspects of the standard that relate to non-structural elements are reviewed briefly below.

Design Forces

Design forces on non-structural elements and their connections are addressed in Section 8- Requirements for Parts and Components.

The important thing for architectural designers to realise is that there are stringent requirements on the design of items such as exterior panels, veneers, and appendages (such as big signs, for instance). Therefore, the engineer needs to be consulted at an early stage in their design.

Figure 3.2
Storey-height precast panels on a Wellington office building. Note the elongated bolt holes to allow for relative interstorey movement.

There are also requirements for connections of elements, which affect fixings for curtain walls, for example, as well as the attachment of heavier items like precast concrete panels. Again, early engineering input is advisable.

Drift and Separation

Inter-storey drift and separation of non-structural elements is covered in Sections 2.5 and 7 of the Standard.

Drift is the result of a building swaying in an earthquake. It is defined as the horizontal movement at one floor level less the movement at the floor level beneath (Figure 3.3). The engineer calculates the amount of drift (or inter-storey deflection) for a particular building, from the design loads, taking into account a factor for the seismic hazard which recognises structures of special importance. The intention is that buildings housing special hazards and essential public facilities are afforded more protection so that they will remain functional even after a major earthquake.

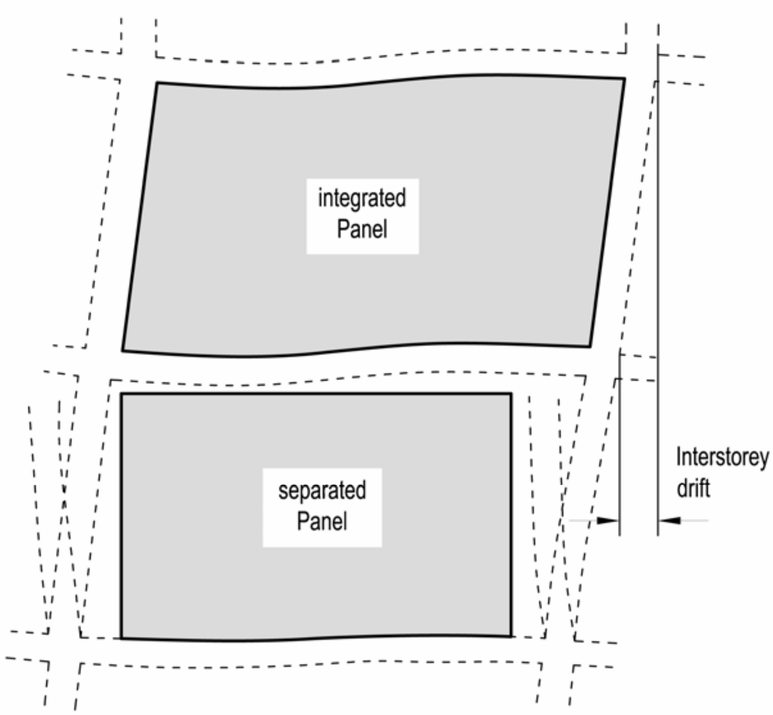


Figure 3.3
The diagram shows, in an exaggerated way the flexure of a framed structure under lateral loading and the clearances required around an infill panel to avoid it making contact with the structure.

Separation Limits and Application

The Loadings Standard requires that drifts are calculated for two earthquake scenarios. First, for the design earthquake that for normal buildings has a return period of 500 years (ultimate limit state), and secondly, for a smaller earthquake with a return period of 25 years (serviceability limit state).

For the ultimate limit state event the Standard limits the maximum interstorey drift to 2.5% of the interstorey height. For example, for a 3.5 m interstorey height, drifts up to plus or minus 88 mm are permissible. Under serviceability limit state conditions the permissible drift is 0.6%, or in this example, plus or minus 21 mm. Since the standard states the *maximum* permissible drifts, many buildings whose structural systems are stiffer than required against earthquake loads will experience lesser drifts.

At the ultimate limit state a building is not to pound into neighbouring buildings (by setting it back from all boundaries except at the street frontage), and all non-structural components must continue to be supported, ie not fall over or off a building. Also, all elements necessary for emergency evacuation are to continue to function. Although primary structure is likely to be damaged at the ultimate limit state, it is expected to be fully functional. Therefore stiff and strong non-structural elements like reinforced concrete masonry infill walls that could damage the primary structure or detrimentally affect its performance, need to be fully separated from it. The Standard accepts that weaker and more flexible non-structural components that will not affect the primary structure's ability to survive an earthquake will be damaged in the ultimate limit state.

The Standard requires that damage to non-structural elements be prevented during a small earthquake (the serviceability limit state). If elements can accommodate that level of drift there is no need to separate them from the floor or roof above. Take gypsum plaster partition walls as an example. The commentary to the Standard informs designers that this type of wall construction can sustain a drift equal to its height/300 before damage warrants repair. So, for a 3.5 m wall, the calculated serviceability limit state drift should not exceed 12 mm. Otherwise separation is required. If the wall above is located in the most flexible structure allowed that has a serviceability limit state interstorey drift of 21 mm, then at least ±9 mm separation must be provided.

For most buildings separation for drift is a normal requirement in the design of:

- Precast concrete claddings and other claddings of similar mass.
- Glass and other rigid, brittle exterior claddings (except in very low risk situations).
- Stairways
- Rigid partitions and infill panels - that is those that are sufficiently stiff that they are capable of altering the structural response of the building to a significant degree.

Details must allow twice the calculated separation distance since the structure will sway backward and forward.

Ductility

It is important to mention the significant differences between stiff and flexible structures, as this has a bearing on the selection of a structural system in the first place - as well as on the provisions that may have to be made for drift. Ductility is a word often used by engineers when talking about these matters. The Loadings Standard[2] defines member ductility as:

> *The ability of a member to maintain a capacity to carry certain loads, while exhibiting plastic deformations and dissipating energy when it is subjected to cyclic inelastic displacements during an earthquake.*

We are all familiar with the idea of elastic deformation. When we stretch a rubber band, or bend a thin rod (but not too much) it returns to exactly its original state when released.

Buildings too behave elastically, to some degree, but there are obvious practical limits to a building's flexibility. On the other hand, a building designed to be so stiff that it will not deflect beyond the elastic limit at all, even in a large earthquake, will usually be uneconomic.

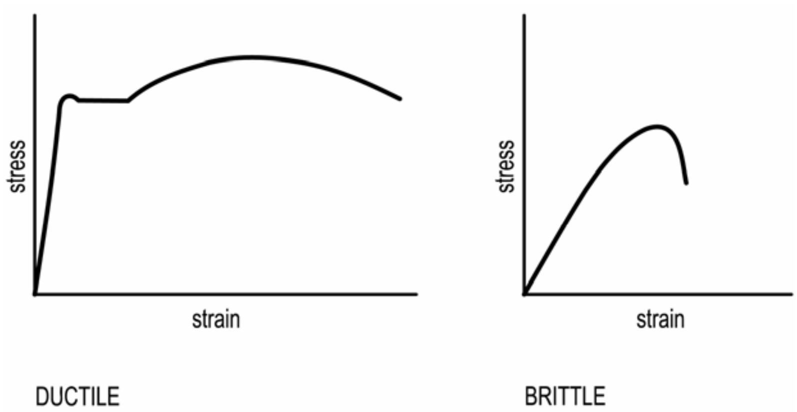


Figure 3.4
Variations in ductility: Steel is shown on the left and concrete on the right. Steel fails only after considerable inelastic deformation has occurred, whereas unreinforced concrete is a brittle material and fails suddenly when its elastic limit is reached. However, reinforcing steel contained in concrete can give the composite member considerable ductility. The act of deformation absorbs energy and defers failure of the concrete.

It is therefore likely that, for a real building in a moderate earthquake, structural deformations will enter the inelastic range, and some ductile yielding will occur. This is acceptable provided that the damage, if any, is limited and occurs in controlled locations, usually in the beams, at points away from their intersection with the columns, or possibly at the base of shear walls.

Why? Because experience has shown that, in a major earthquake, most catastrophic building failures occur when columns fail. Rarely do buildings literally fall over. Hence, the structural engineers' adage:

Strong columns and weak beams - not the other way around

Figure 3.5
Pancake collapse because the column and beam structure was not ductile. In a ductile frame building, columns need to be approximately as deep as the beams. Ironically, in this building the architect has ‘enlarged’ the weak structural columns. Mexico City, 1985 Mexico City earthquake. (R.B. Shephard)

In fact, ductility in the structure is most useful because inelastic yielding absorbs large amounts of energy. This means that the loads which the building is designed to withstand can be reduced without risking major failure or collapse - far better to have a building which yields in a designed way than a very stiff one which is subject to huge seismic loads and suddenly fails.

The importance of this, to architects in particular, is twofold:

- By designing a more ductile framed structure, that will absorb energy, the engineer can perhaps make that structure more economic than another stiffer and stronger frame would be; perhaps with smaller columns and beams.

  "Good", says the architect.

- But because the structure is more flexible the separations required for non-structural elements are much greater than for a stiffer building.

Provision of the necessary clearances can present numerous practical difficulties in detailing which add to the overall building cost.

Another downside of designing ductile buildings is that ductility is usually accompanied by structural damage. Architects, after discussion with structural engineers, should inform their clients of the damage that is likely in the event of the design earthquake. Clients need to be aware that in most cases they are not receiving an 'earthquake proof' building. If they are concerned about issues like business continuity after a moderate to large earthquake they might reconsider adopting the minimum requirements of the Standard that emphasises life safety above damage protection or post-earthquake function.

Figure 3.6
Non-structural ceiling damage. Los Angeles, 1994 Northridge earthquake. (A. B. King)

Other NZ Standards

"Seismic resistance of engineering systems in buildings, NZS 4219"[3] was introduced in 1983. The Standard specifies seismic design requirements for equipment and their fixings in buildings, with emphasis on services and other aspects not covered by this publication. For information and guidelines on protecting the contents of buildings refer to "Seismic restraint of building contents, NZS 4104:1994"[4].

[1] Standards New Zealand, (2002). *AS/NZS 1170 (Parts 0,1,2,3 & 5), Structural design actions*, Wellington.

[2] Standards New Zealand, (2004). *NZS 1170.5, Earthquake actions - New Zealand*, Wellington.

[3] Standards New Zealand (1983). *NZS 4219:1983, Specification for Seismic Resistance of Engineering Systems in Buildings*, Wellington.

[4] Standards New Zealand, (1994). *NZS 4104: 1994, Seismic restraint of building contents*, Wellington.

4 Structure and External Walls

In choosing the external cladding for a new building, todays designer has many options - from precast concrete and stone, to very lightweight composite panels of aluminium and synthetic resins. The choice is seldom made on engineering grounds, yet the interaction of cladding and structure can have a major influence on the behaviour of a building in an earthquake and, in consequence, the damage that may occur. Inherently, from a seismic engineering perspective, lightweight claddings mean less seismic mass and this is a desirable situation. Of course there are many other considerations.

Figure 4.1
Precast panels to a multi-storey building in Auckland.

Figure 4.2
Curtain wall incorporating glass and lightweight spandrel panels, Sun Alliance House, Wellington. Architects: Structon Group.

Structural Types

Just as the architect has a wide choice of materials to draw upon, so there are many options available to the engineer when designing the structure; choices between reinforced concrete and structural steel; between precast and insitu elements, and where to use each; the type of framing system, i.e. the disposition of columns and beams, cross-braced frames, shear walls - and so on.

But for simplicity this section mentions only three basic structural types:

- Stiff structures.
- Flexible structures.
- Special solutions.

Stiff Structures

All building structures are subject to some degree of lateral movement in a moderate earthquake but in a very stiff structure the degree of movement will be small.

In Section 3 it has already been seen that the Loadings Standard requires separation of non-structural elements if calculated interstorey drift in frequent earthquakes (serviceability limit state) will damage non-structural elements. Such small movement is uncommon, except in very stiff low-rise structures.

Many old buildings are rigid and brittle because their traditional construction, (thick masonry walls with small window openings) is initially unyielding. This makes them very vulnerable to the sort of earthquake shaking they are likely to experience in most parts of New Zealand. Very large loads seek out weak points - such as glazed shopfronts at street level, or cavity brick panels, which crack or are crushed.

Figure 4.3
Damage to external wall due to the incompatibility of a flexible steel frame and brittle cladding. Mexico City, 1985 Mexico earthquake. (R. B. Shephard)

Buildings constructed in the early part of this century often used a form of steel or reinforced concrete framing, but this was overlaid with traditional façade construction. Unless such buildings are strengthened they can be very vulnerable to earthquake attack due to inadequate toughness in the structural elements and connections, plus interaction between the frame and the façade elements.

Today, most structures possess ductility, so the risk of sudden failure is avoided. (A structure can be designed to remain elastic, but much greater seismic forces are then specified – up to 6 times those applied to fully ductile structures.)

A stiff well-designed building can normally be expected to perform well in an earthquake - and minimal drift between floors inherently reduces the risk of damage to non-structural elements. Some engineers consider that more emphasis should be placed on this type of structural solution. However, in most situations, stiffer structures must be designed for larger seismic forces.

Figure 4.4
Damage to glass panels on an office building due to structural flexibility and insufficient separation gaps around the glazing. Los Angeles, 1994 Northridge earthquake. (A. B. King)

Flexible Structures

Some medium and high-rise buildings are of this type. They consist of a framework of beams and columns along one or more major axes. Some times eccentrically braced steel frames might resist loads. In all cases the floors act as diaphragms to distribute horizontal loads. If shear walls, or coupled shear walls, are incorporated they will increase stiffness and such options need to be considered.

There may be pronounced drift between floors in a design earthquake (up to 90 mm in a 3.6 m interstorey height is allowed under the current Standard). Cladding must remain safely on buildings at these large interstorey drifts but damage is to be prevented during more frequent earthquakes when drifts of up to 23 mm can occur.

Flexible structures that are designed for ductility offer a wide range of opportunities to the architect in terms of planning and architectural treatment. They can be designed to produce daring architectural results **but early engineering consideration is a must.**

A disadvantage is that drift between floors can become increasingly difficult to accommodate. Even though earthquake damage may be avoided by separations that cope with the serviceability limit state, if movement is not provided for the ultimate limit state then damage will certainly result.

Cantilever shear walls and coupled shear walls are also usually designed for ductility so that plastic hinges can form at their bases, and in the coupling beams. The major advantage of ductile wall systems (compared with ductile frames) is that their inter-storey drifts are considerably less. However, because of their greater stiffness they attract greater earthquake loads and therefore their structural footprints (structural cross-sectional areas in plan) and foundation requirements are large.

Special Solutions

Seismic engineering research is on-going and new ways of protecting buildings are being developed.

Base-isolation, first introduced into a building in 1981 in Wellington, is a technique by which a structure can be separated from its foundations using special devices, such as a combination of lead and rubber called base isolators, or other forms of energy dissipator. Depending on site conditions these devices may greatly reduce the loads due to ground movement that are transmitted to the superstructure. Inter-storey drift may be reduced so that separation of non-structural elements is deemed unnecessary.

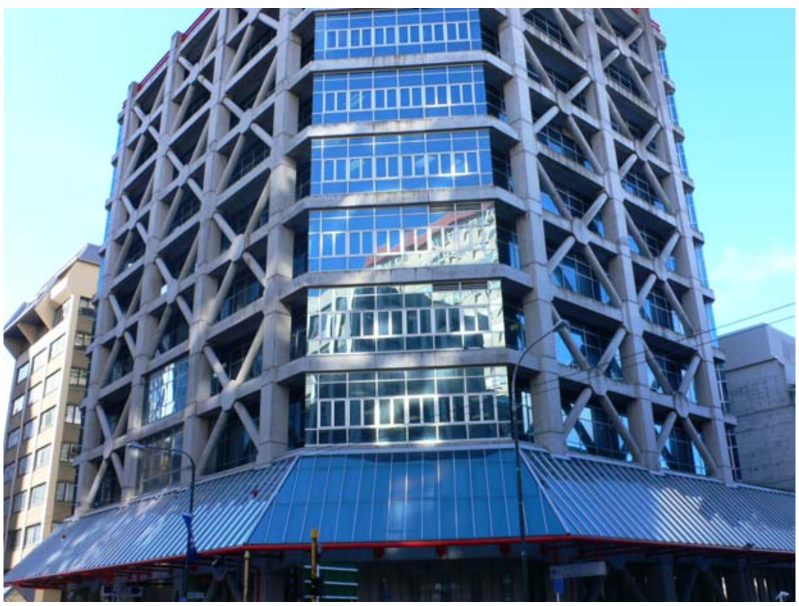


Figure 4.5
Base isolation has been used in the new Wellington District Police Headquarters and Central Police Station. The base isolation combines three components: long flexible piles standing within oversize casings; special spherical bearings at the pile tops; and lead extrusion dampers.
Architects: Works Corporation

Base isolation techniques have been used in over ten new buildings in New Zealand and on a number of other structures, such as railway viaducts and motorway bridges. Base-isolation has also enabled the economic preservation of historically important masonry buildings, such as Parliament Buildings in Wellington. It is an alternative to more extensive (and expensive) strengthening techniques, which may be unsuitable when trying to retain architectural and historical character.

Figure 4.6
Parliament Building, an unreinforced masonry building has been strengthened by the addition of structural walls and the whole building base-isolated.

Cladding Principles

These principles primarily relate to external cladding of ductile structures. Four levels of participation of the cladding in the seismic resistance of the building can be identified:[1]

- **Theoretically complete detachment** so that the cladding, usually lying outside the structure, does not contribute to its lateral stiffness at all: In practice, this would very rarely be the case. In a building with perhaps hundreds of cladding panels some transmission of forces from the structure to the cladding, and vice versa is likely, even if the cladding is comparatively lightweight, but this may not be significant in the overall structural response.

- **Accidental participation of cladding** in the seismic response: This can occur during an earthquake due to the separation distance being too small (if the cladding lies within the structural frame), or binding of supposedly free-moving connections of cladding to structure.

- **Controlled stiffening or dampening of the structure** by the cladding and its attachments: So far this approach has rarely been used, but it is the subject of research, especially in the United States. It could be a useful future development.

- **Full integration of the cladding into the structural system:**
  Where the cladding and the structure are homogeneous, as for instance when insitu concrete walls are used, the results are predictable and the cladding becomes part of a shear wall system. It is also technically possible to achieve integration using precast components, at least in low-rise situations. But in practice this approach has not been widely employed. It is seldom that the architectural cladding design is fully compatible with the structural concept: If it is not, then configuration problems can arise.

In practice, therefore, detachment of cladding from the structure has remained by far the most common approach, despite its inefficiency - in the sense that more economical and seismically efficient structures could be produced by integration.

Figure 4.7
Precast panels connected together to form a structural wall in an apartment building in Wellington.

[1] Arnold, C. (1990). Cladding Design: Recent Architectural Trends and Their Impact on Seismic Design" *Proceedings Architectural precast cladding - its contribution to lateral resistance of buildings*, Chicago, pp. 29-30.

5 External Wall Types

External walls can be:

- **Structural walls** - of reinforced concrete, precast concrete, masonry, timber, steel - or even rammed earth!
- **Integrated infill panels,** designed to be a part of the main structure.
- **Separated infill panels,** not considered part of the main structure.
- **Facing materials,** which clad the main structure but should be effectively detached from it for seismic design purposes.

This section deals mainly with facing panels, as it is their detailing that is most frequently of concern in the design of larger buildings for earthquake.

Infill Panels

Complete infill panels of rigid material, such as concrete block or precast elements, must be considered as part of the overall structural concept and not as isolated elements. Effectively they act as shear walls so engineering design of such panels is essential.

To be considered non-structural, infill panels must be constructed and connected so that they are not capable of altering the intended structural behaviour to a significant degree.

Generally, this is interpreted to mean that timber or light steel framing, lined with materials such as Gibraltar Board, need not be separated. BUT this should not be automatically assumed. In essential facilities, especially for central and local government, all infill panels and partitions may need to be separated to protect them from earthquake damage so that the building remains functional after the earthquake. Check this point with the design engineer.

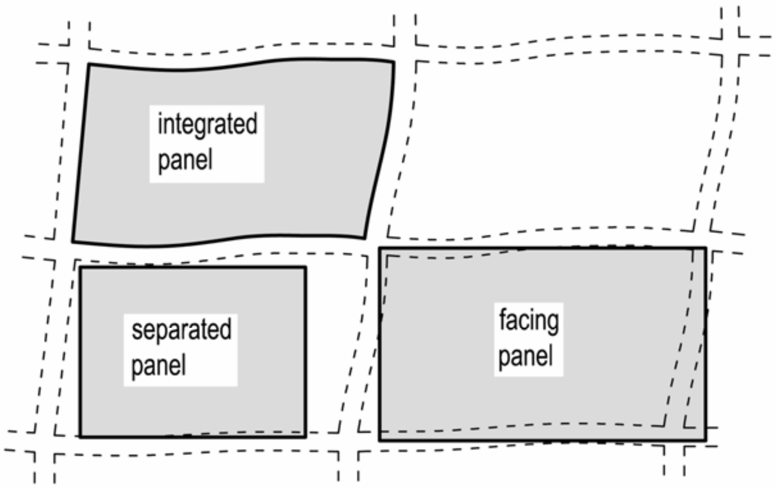


Figure 5.1
This diagram shows the basic options for cladding panels relative to the structure.

Heavy Facing Panels

Infill panels are usually built up from unit masonry (concrete block or brickwork), but facing panels are commonly large units, often covering the full width of a structural bay for a storey height. Construction handling is a major determinant in sizing such panels - either because weight must be limited (usually for ease of cranage), or because over-large panels become impractical to handle.

When large heavy facing panels are used, provision for seismic movement becomes critical. This is usually achieved by having fixed bearing connections at the top of the panel and providing for lateral movement in detailing the bottom fixings. But these locations are sometimes reversed. The fire rating of fixings can be an important consideration.

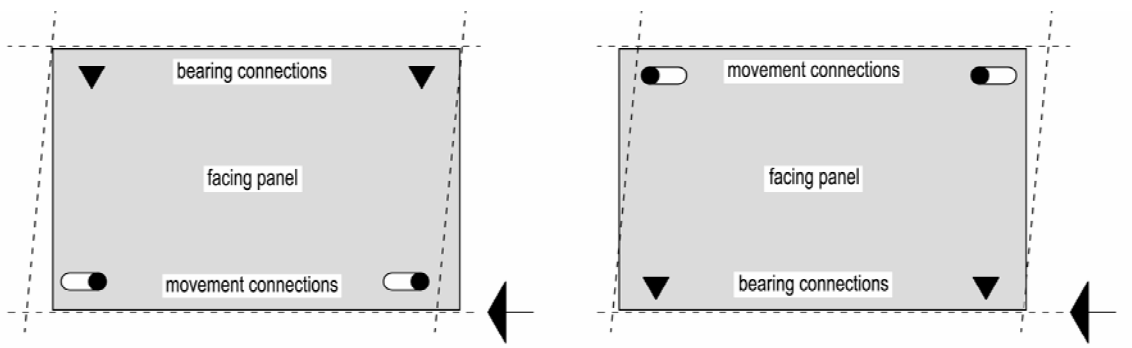


Figure 5.2
Top and bottom bearing connections for fixing facing panels.

Connections

Two common types of connection have been developed to allow for movement between heavy panels, such as precast concrete, and the main structure:

- Rod connections, which are the most common type in West Coast USA.
- Sliding connections, which have been widely used in New Zealand and elsewhere.

Neither approach is without disadvantage and, in each case, predicted performance is based on engineering principles rather than observed performance after an earthquake, or even extensive laboratory testing.

- **Rod connections.** These are commonly referred to in USA as ‘push-pull’ connections. The rod and connector details must be tough enough to withstand imposed loads, both on the face of the panel and ‘in plane’; yet the rod must be long and flexible enough that it will remain ductile over the predicted range of movement. If the panels are to be fixed close to the structure necessitating a relatively short rod, this may be difficult to achieve.

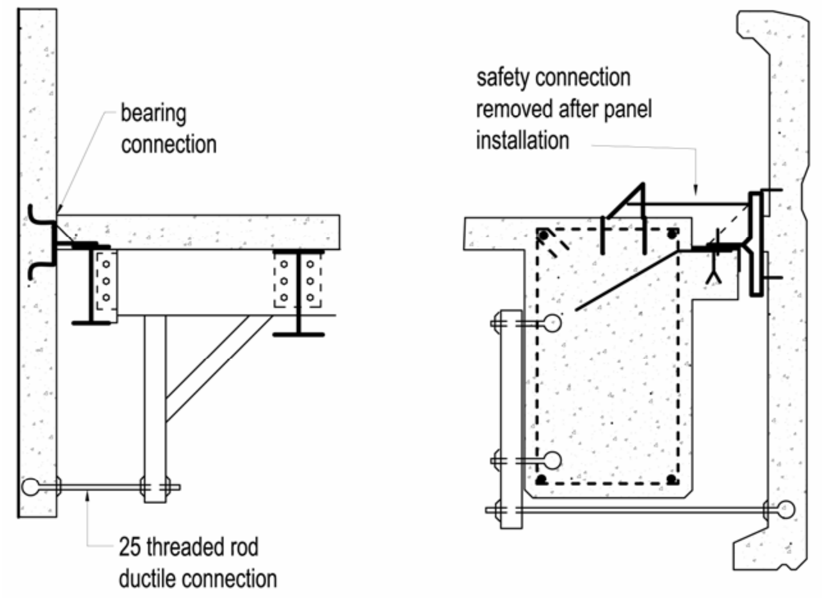


Figure 5.3
Rod (or 'push-pull') connections to provide for movement. Typical details for steel structure (on left), concrete structure on right. Note that fire protection of fixings is not shown on these details and may be required.
Redrawn with permission from "Seismic Design of Architectural Elements" Building Systems Development Inc., KRTA Limited, Forell/Elesser Engineers Inc., March 1987.

'Push-pull' connections seem to have performed well, but some queries about their long-term effectiveness have been raised. The connection of the rod to the panel is particularly critical.[1]

- **Sliding connections** are usually provided by using cleats to join the panel to the structure. Each cleat is bolted through a slotted hole to provide for movement. Disadvantages of this system are:

  - movement will not occur if the cleats 'bind' due to misalignment during construction or flexure of the components under load, or 'seizing' of the detail over time (due to rust).

  - bolts may be over-tightened so that lateral loads are transferred through the connection.

Sliding connections are best kept to situations in which the degree of lateral movement in each connection is small, e.g. stiffer structures, or panels of reduced height.

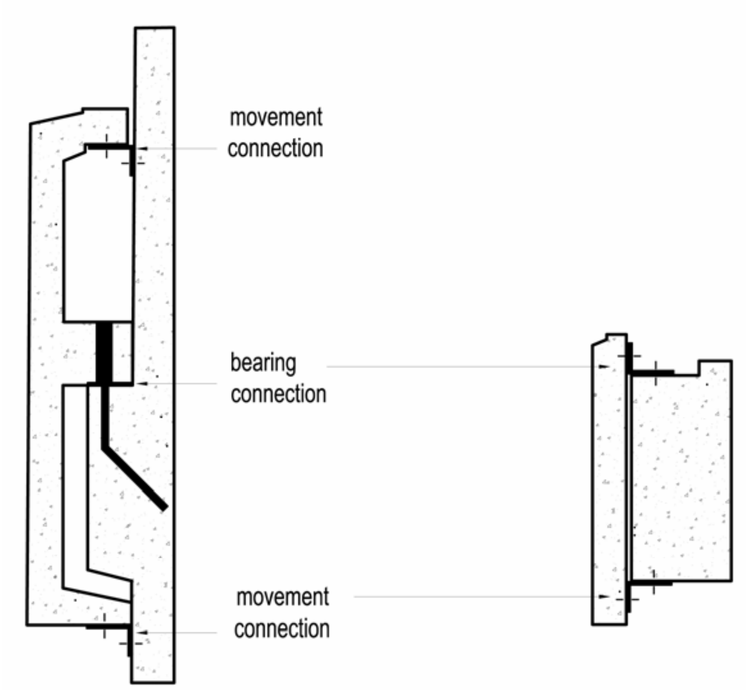


Figure 5.4
Two examples of sliding connections to precast panels. The example on the left has the panel bearing on a concrete corbel at mid-height, with movement connections at top and bottom of the panel. Movement in each connection is therefore reduced.
The example on the right is of a precast panel only 940 mm high, so provision for movement is limited.

Movement can also occur at right angles to the panel face (or at any other angle, depending on the direction of the drift in the structure). Connections must allow for this movement.

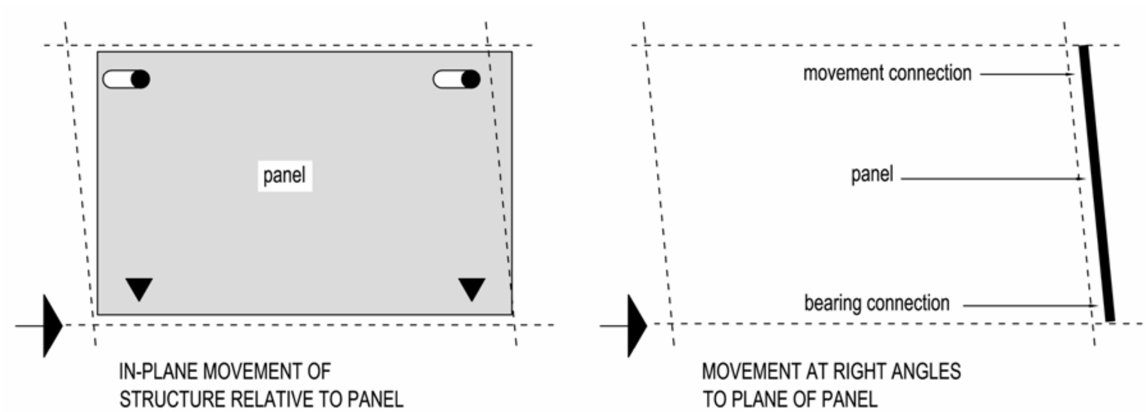


Figure 5.5
In-plane and out-of-plane movement of structure relative to panel.

Finally, the designer must be aware of the relative movement of panels at corners, both internal and external, so that drift does not lead to impact between panels at these locations.

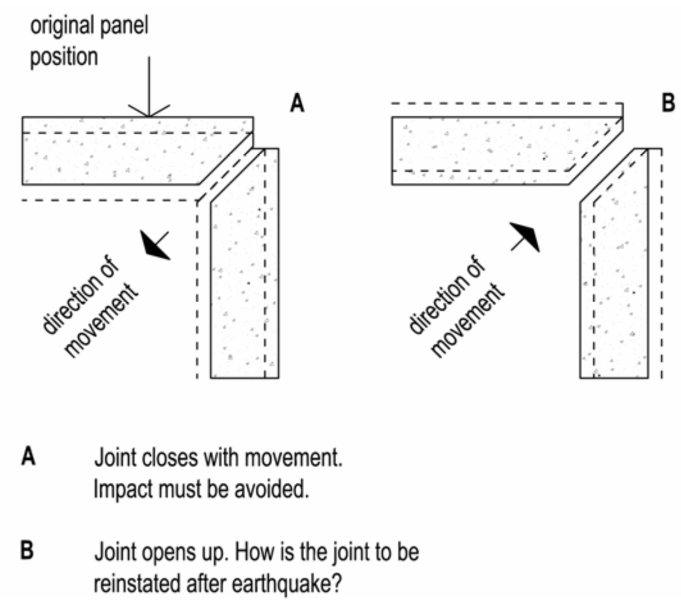


Figure 5.6
Movement of panels at external corner. Internal corners must be considered in the same way.

Panel Arrangement

Of the many different ways of arranging panels, four have been chosen as fairly typical. Other approaches are L or T-shaped panels, or even double-storey height arrangements, if heavy cranage is available.

- **Storey-height panels,** which may be continuously solid, or incorporate 'hole-in-the-wall' windows. There has been a return to this type of approach in recent years as architectural trends have changed.
- **Spandrel panels,** often approximately half storey height, from window head to the sill of the next storey, but can be no more than a beam facing where more glass is used.
- **Complete facing of columns and beams** using separate panels for each purpose, with movement joints between each panel.
  Note that this approach will reduce the amount of movement to be accommodated at each joint.

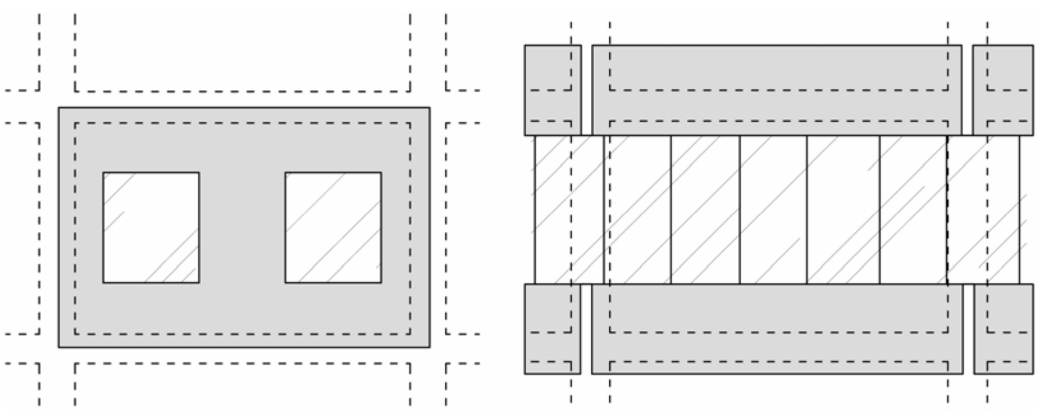


Figure 5.7 - Two typical arrangements of panels on a framed building structure.

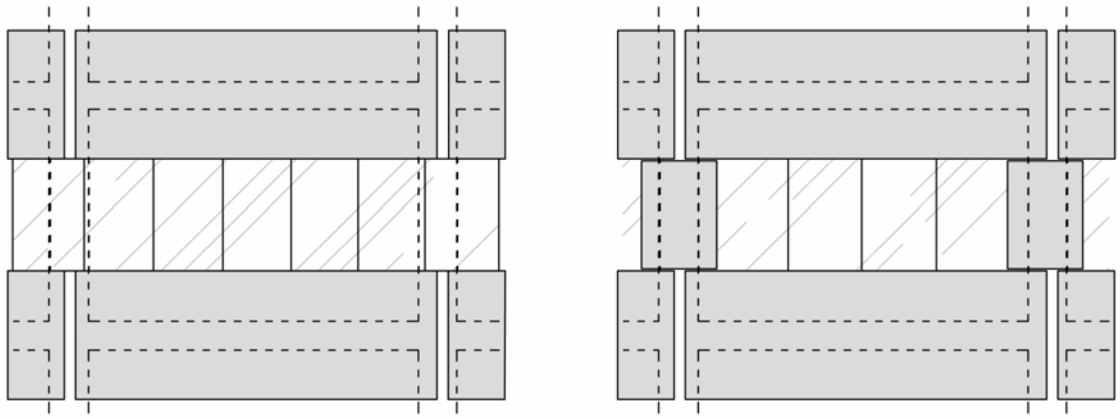


Figure 5.8
A further two common arrangements of facing panels.

Other Wall Materials

Windows and curtain walls are described in Section 6; but other wall materials (besides precast concrete and concrete blockwork) are also widely used in modern buildings.

They include:

- Stone slabs, such as granite and marble
- Ceramic tiles and thin stone tiles
- Insulated panels finished with specialised plasters
- Traditional plaster finishes
- Thin brittle sheet materials, such as fibre cement board
- Metal cladding in sheet and folded forms
- Traditional stonework and brickwork

and, most importantly in New Zealand:

- Brick veneer, chiefly on domestic construction.

This section now reviews some of these other claddings and related detailing to reduce earthquake damage.

Figure 5.9
The ASB Bank Head Office building has granite cladding to foyer levels, columns and penthouse level, attached to either a reinforced concrete or a steel framed substructure.
Architects: Peddle Thorpe Aitken

Stone Slabs

Granite, marble and other natural stone finishes have been specified again in recent years, especially for commercial projects. Prestigious buildings are clad in individual stone slabs, up to about 1.4 m x 1.2 m in face area and from 20-25 mm thick. The weight of this stonework can be supported in two ways:

- By attachment to a reinforced concrete or reinforced masonry substructure.
- By attachment to purpose designed steel framing.

In either case engineering design of the supporting structure is essential and must take seismic loads into account. Attachment of the stone slabs to their supports is carried out by specialist subcontractors and requires fine adjustment, sometimes using a one-way or two-way grid of lipped channels or a similar mechanism.

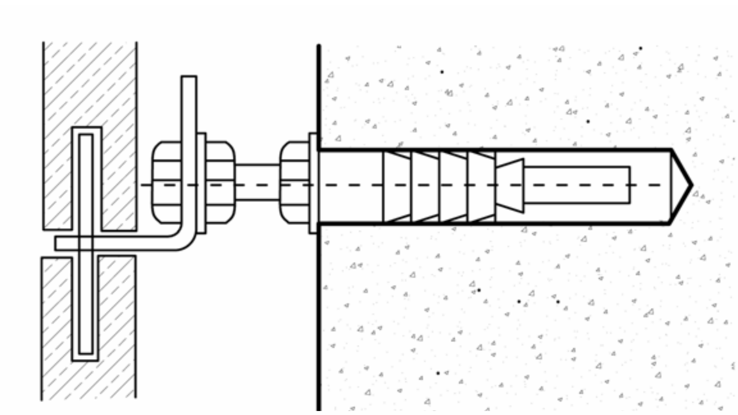


Figure 5.10
Typical stone slab fixing.

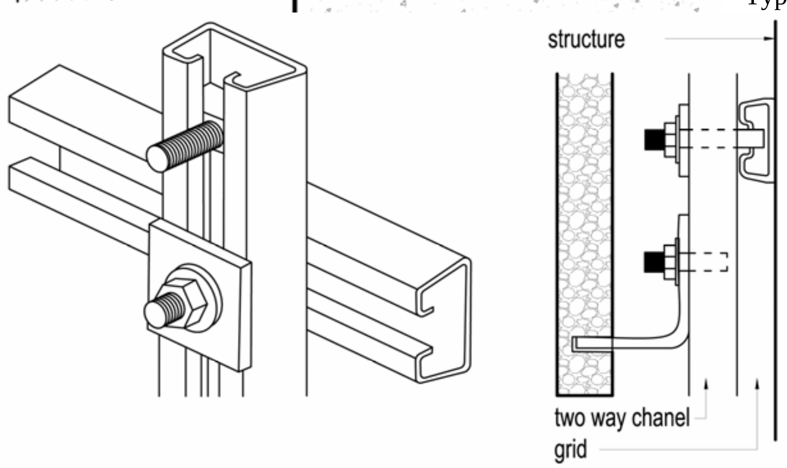


Figure 5.11

Two-way grid of lipped channels for adjustment of stone slab fixings.

The architect can therefore rely to a substantial extent on the knowledge of others, which must be sought at an early stage.

In the main, drift is provided for by assuming small incremental movements will occur in each horizontal joint. Joints are filled with a resilient sealant, such as polysulphide. Because there are a large number of joints, relatively closely spaced, and often a fairly stiff substructure, specially designed separation of panels of stonework may not be required, BUT consult the design engineer.

Ceramic Tiles and Thin Stone Slabs

Both these materials are supplied in small unit sizes, up to 300 mm x 300 mm x 12 mm thick. As a wall cladding they can be mounted in three ways:

- **Traditional mortar bed** over a rigid base (such as insitu concrete or masonry) with a good key. Because the base is rigid, joints between individual tiles can be grouted, but the base itself is often a non-structural element, e.g. a reinforced masonry infill wall. In that case, seismic movement must be provided for in tile joints over the separation gap. Flexible sealants are used for this purpose, over a backing rod.

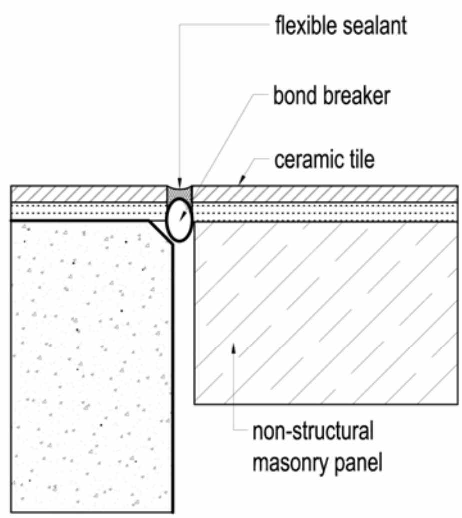
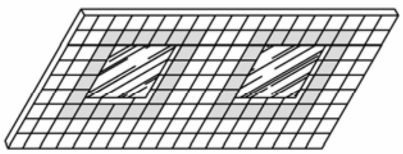


Figure 5.12
A flexible sealant joint of sufficient width to allow for drift is required at the junction of structural and non-structural elements.

- **Adhesive fixed** to a stable board substrate, which is in turn fixed to a metal or timber frame. If the framing is non-structural, then it must be separated from the main structure, and movement joints provided, similar to Figure 5.13.

- **Proprietary tile fixing systems.** When using these systems in New Zealand, the requirements for earthquake movement must be specified so that allowance for any special details can be made in pricing. Such systems have often been developed in countries that do not have earthquake design requirements.



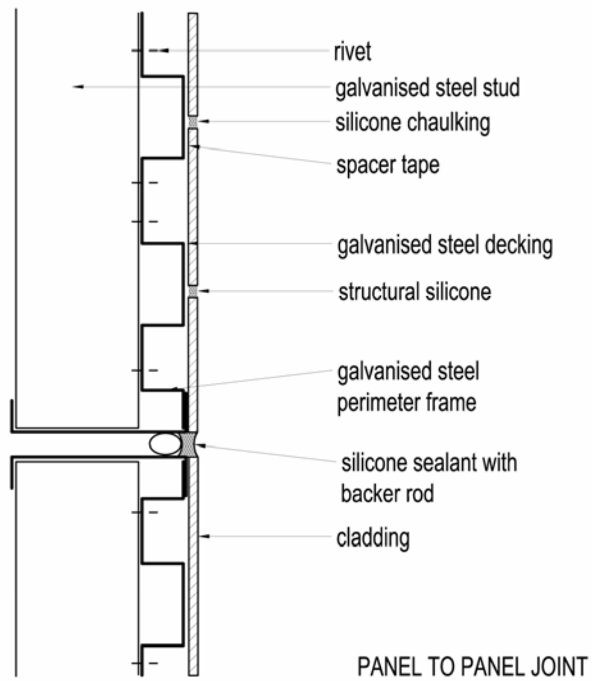


Figure 5.13
Manufacturer's literature on a proprietary tile fixing system. Note sealant in panel joint to allow for movement. The width of this joint must relate to ' drift' of the structure relative to height of the panel.
[Reproduced with permission from NZ Contracting Ltd.]

Plastered Wall Finishes

Whether traditional plastering techniques are used, or more recently developed proprietary systems, provision for movement needs to be made where framed panels are seismically separated from the main structure. There are no 'standard' details for such situations so the architect draws on good construction principles.

Thin Brittle Sheets

Materials such as fibre cement board are widely used for wall cladding in commercial, industrial and residential work. It is commonly assumed that no separation of such materials is required and on stiffer low-rise structures this approach is reasonable. Details often include open joints, or use PVC jointers, and some movement is provided for in this way if the framing behind is slightly racked.

Specific detailing for seismic movement becomes important on higher rise, more flexible structures, especially if joints are close butted or flushed up to provide a homogeneous finish. Clearly, reinstatement of such finishes could be required after a major earthquake but, more importantly, detachment of the cladding could occur if there are large inter-storey drifts.

Thin sheet cladding is often fixed to timber framing, which infills the main structure. Separation in this case is easily provided.

Note: The Loadings Standard may require separation of brittle exterior cladding in these circumstances depending on the flexibility of the main structure.

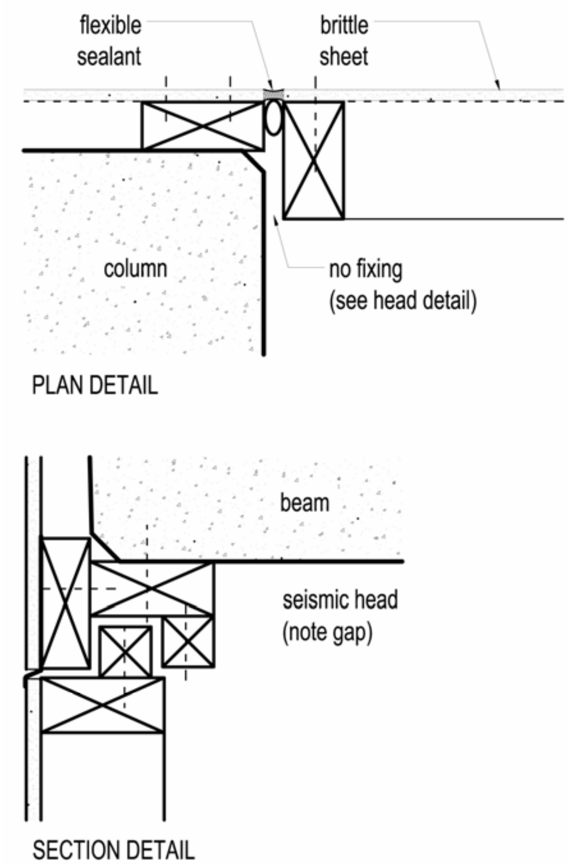


Figure 5.14
Seismic details to protect brittle cladding materials are not difficult to fabricate using conventional timber framing.

Sheet Metal Cladding

Sheet metal wall cladding seldom requires detailing for seismic drift (except at seismic breaks between structural blocks). The nature and fixing of long-run trough section cladding, corrugated iron and the like, tends to ensure that movement will be accommodated.

However, damage to one form of strip metal cladding, in the 1985 Mexico City earthquake, is a reminder that earthquake movement can produce unexpected results.

Figure 5.15
Strip metal cladding to the end of an office building, Wellington.

Masonry

Masonry construction can be used for wall cladding in two ways:

- As infill panels in a framed structure - separation is required.
- As a structural material - in which case engineering design is required.

In recent years little use has been made of free-standing reinforced brickwork but design techniques are well developed for buildings where fairfaced brick finish is required on both faces of a wall.

Reinforced blockwork of course continues to be a major structural material. **Examples of the use of this material for non-structural walls are given in Section 8 - Partitions.**

Brick Veneer

Brick veneer one storey in height and not requiring specific engineering design continues to be widely used in New Zealand. As documented in the literature, such veneers, constructed in accordance with accepted trade practice are likely to fail at openings and at corners under moderate earthquake attack. Brick veneers do not have a good seismic track record.

Figure 5.16
Brick veneer damage during 1987 Edgecumbe earthquake.

As its name implies, a veneer must be supported by internal structure. The two seismic design principles for achieving the best possible performance are:

- Tie the veneer strongly to the structure. In domestic construction, the veneer ties are screwed to wall studs at maximum specified horizontal and vertical spacing.

- Use veneer ties that are flexible in the direction of the plane of the veneer. This allows the interior load-bearing structure to move without transferring its load to the veneer which usually has more in-plane rigidity. This approach is explicitly stated in NZS 4230:2004[2] Design of reinforced masonry structures, clause F3.1:

  Wall ties should comply with the requirements of NZS 4210 and AS/NZS 2699: Part 1, and should be capable of accepting differential deflection, including seismic displacement, and imposed forces between the masonry veneer and the supporting structure in the plane of the veneer.

This approach of allowing flexibility between veneer and structural framing leads to a concentration of damage at corners. However damage prevention, achieved by wide vertical separation gaps near corners is unlikely to be deemed practical or aesthetically acceptable.

Prior to using building paper that was fixed to the outer edges of studs in the 1970s, ties were side stapled to studs. Up to 1995 most ties were nailed to the outer edges of studs through the building paper or wrapping material until it was discovered this method was unsafe. Research identified that the vibrations caused by the nailing loosed the bond between the ties and mortar already laid.[3] Now ties are screwed to studs.

Due to its high mass and potential danger if it were to fall from a building, the height of veneer panels is limited by NZS 3604 to 4 m excluding gable ends where veneer is supported by a timber framed wall. Two storey high veneer up to 7 m high is possible using one brickmaker's system provided a horizontal slip joint divides the wall into panels with a maximum 4 m height.[4]

Brick veneer can clad multi-storey buildings. In these situations steel shelf angles are used at each storey. High horizontal earthquake accelerations up the height of a building require closer than usual tie spacings and perhaps special reinforcement as well.

Figure 5.17
Brick cladding to the new addition of the Bayview Chateau Tongariro. The weight of each storey-height of veneer is supported by a steel angle fixed at floor level.

Where required, the tensile strength of panels may be increased through the use of horizontal joint reinforcement in the mortar bedding and by incorporating vertical steel in the ports of purpose made knock-out-end bricks. Special attention should be given to detailing at openings and at corners of reinforced veneers.

For more information about masonry veneer construction refer to *Good Practice Guide: Masonry Veneer.*[5]

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1 Rihal, S. S. (1989). Earthquake Resistance and Behavior of Architectural Precast Cladding and Connections. Proceedings *Architectural precast cladding – its contribution to lateral resistance of buildings*, Chicago, pp. 110 -140.

2 Standards New Zealand (2004). NZS 4230:2004 Design of reinforced masonry structures, Wellington.

3 Shelton, R. H. (1995). Seismic performance of masonry veneer and ties: Study Report No. 53, BRANZ, Building Research Association of New Zealand, Judgeford, 82 pp.

4 Oliver, J. (2000). The brick book, Lifetime Books, Auckland, 172 p.

5 BRANZ (2006). *Good Practice Guide: Masonry Veneer.* BRANZ, Judgeford.

6 Windows and Curtain Walls

This section deals with the design of windows and curtain wall systems, including non-glass cladding incorporated into curtain walls; glass assemblies and glass blocks.

When a building is shaken by an earthquake the structure typically deflects in a series of cycles whose period, duration and displacements are governed by the interaction of the particular building and the ground motion to which it is subject.

It *is* this movement that windows and curtain walls must be designed for to prevent damage in a minor earthquake and to ensure that during the design earthquake, the ultimate limit state, components of the window/wall system do not fall from the building.

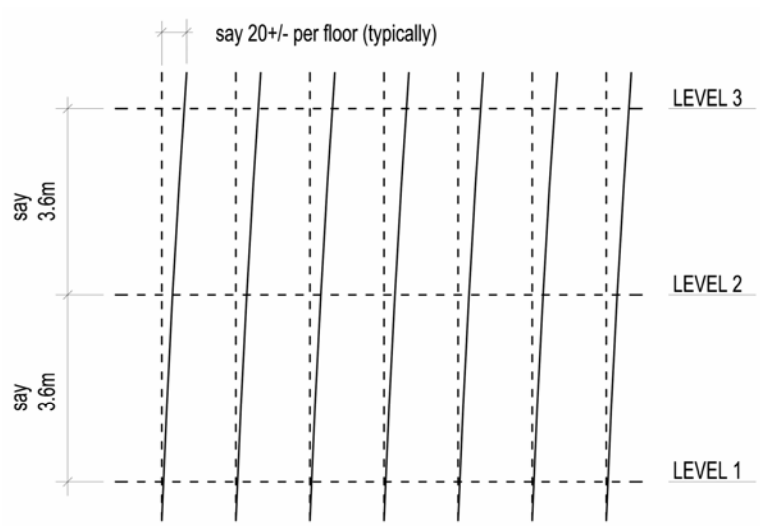

Figure 6.1
Diagrams of flexure of curtain wall mullions over 2 floors in an earthquake (not to scale).

It is rare for a building structure to be so rigid that it does not deflect to some degree. For very stiff structures (against horizontal loads) such as those with long shear walls, if deflections are very small (up to say 2 mm drift between floors) then no special seismic separation details may be required. But window details in most multi-storeyed buildings need to allow considerably more horizontal movement. Plus or minus 20 mm is fairly typical to accommodate movements from small earthquakes (as explained in Section 3). However glass panels must not fall out during a design level earthquake when interstorey drifts can approach 90 mm in a very flexible building. Provision for such large movements can pose practical and visual difficulties.

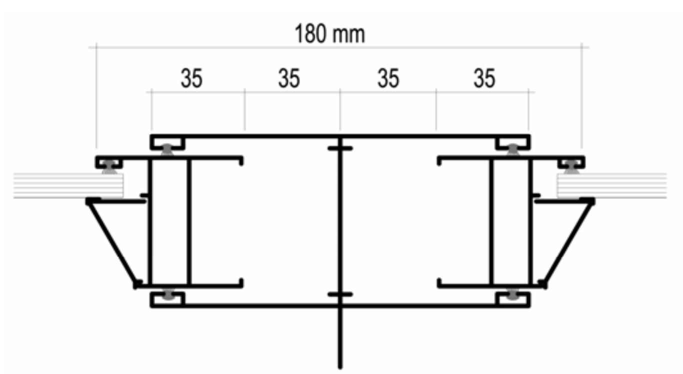

Figure 6.2
Detail of seismic mullion if 35mm drift is to be accommodated. Note overall width of mullion – 180mm MINIMUM.

Provision for seismic movement is, of course, but one requirement. Good details must also keep out the weather, allow for thermal movement, provide a satisfactory acoustic seal and be long lasting. Furthermore, loading requirements due to earthquake cannot be considered in isolation. Both dead loads and wind loads influence deflections and fixing details.

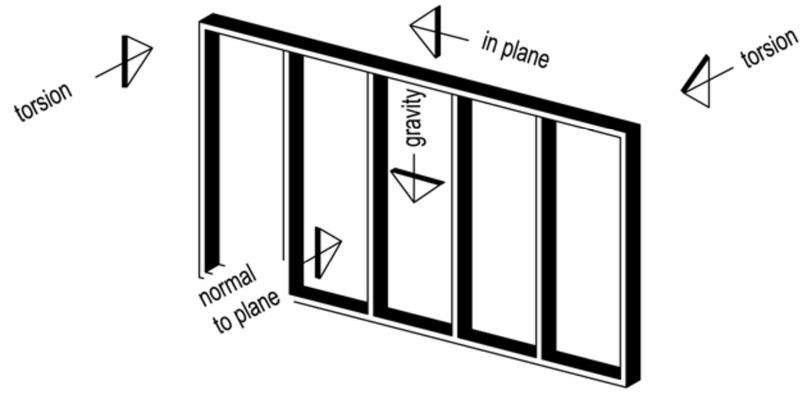

Figure 6.3
Types of load to which a window frame installed in a building may be subjected. All these loads may be reversing.

Design Criteria

It is therefore important that the design criteria be established at an early stage and then later clearly communicated to the contractors or sub-contractors concerned. This is best done by the building designer referring to the structural engineer early in the course of developing working drawings and specifications. The engineer will apply appropriate Standard requirements to the design and advise the degree of movement to be allowed in each direction, horizontally and vertically. The influence of these tolerances on the appearance and efficiency of window details can then be recognised by the designer. This may be so critical that basic redesign of some features is warranted.

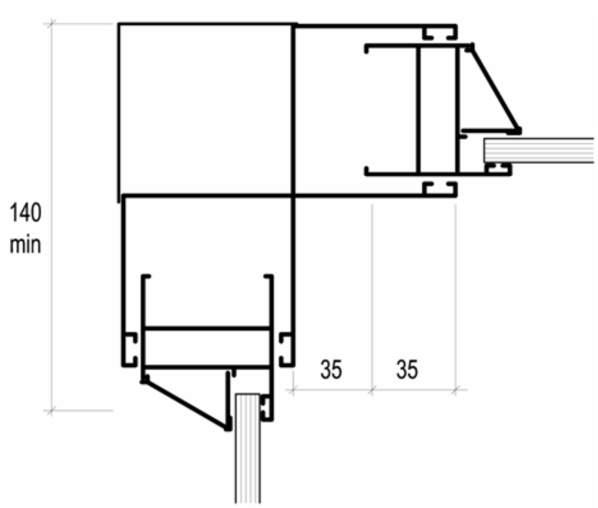

Figure 6.4
Would your client be happy with corner mullions like this? Should the structure be stiffer, or the fenestration concept be different?

Territorial Authority Requirements

In the past, architectural documentation required for permit purposes has mainly been concerned with bulk and location matters, fire and egress and building services. Engineering checks were made of the structural design but seldom extended to non-structural elements.

In recent years concern about the design of cladding systems has led some territorial authorities to require full details of the cladding and its attachments, either with the initial building permit or as a separate permit application. Structural silicone has also been the source of some misgivings.

Shop Drawings

It should be noted that not all trade suppliers are themselves equipped to prepare shop drawings that make adequate provision for seismic movement, but there are consultants who specialise in this type of work. For a major building it is essential that shop drawings be obtained and that the provision for seismic movement be carefully reviewed, along with other design features of the window systems.

Window Testing

For major projects, or those incorporating special details, physical testing may be called for. A number of test facilities are available in New Zealand, including that of the Building Research Association at Judgeford, near Porirua. Racking tests can therefore be carried out to ensure movement details will work.

Past Research

The conventional approach to allowing for seismic movement in window systems assumed that all ‘in plane’ drift needed to be accommodated by a gap between glazing members, or between the glass and those members, equal to the full calculated separation distance in each direction.

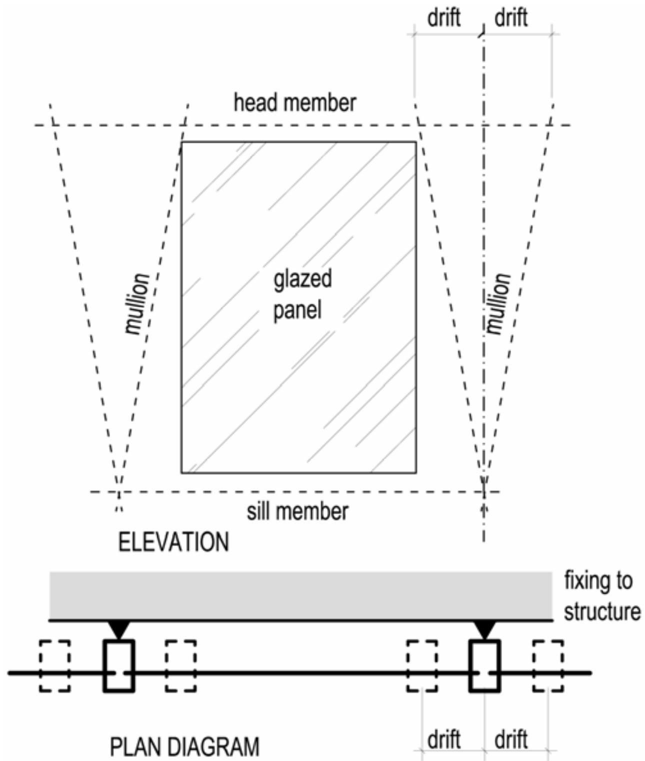

Figure 6.5
Diagram of a glazed panel showing the conventional approach to providing for 'drift' (i.e. in-plane displacement).

This is still a prudent approach in the absence of physical testing of particular systems. However, the relative lack of damage of some curtain walls and glazing in actual earthquakes has suggested that more complex movement of components, in relation to each other and the structure, can sometimes provide protection of the curtain wall and its glazing.

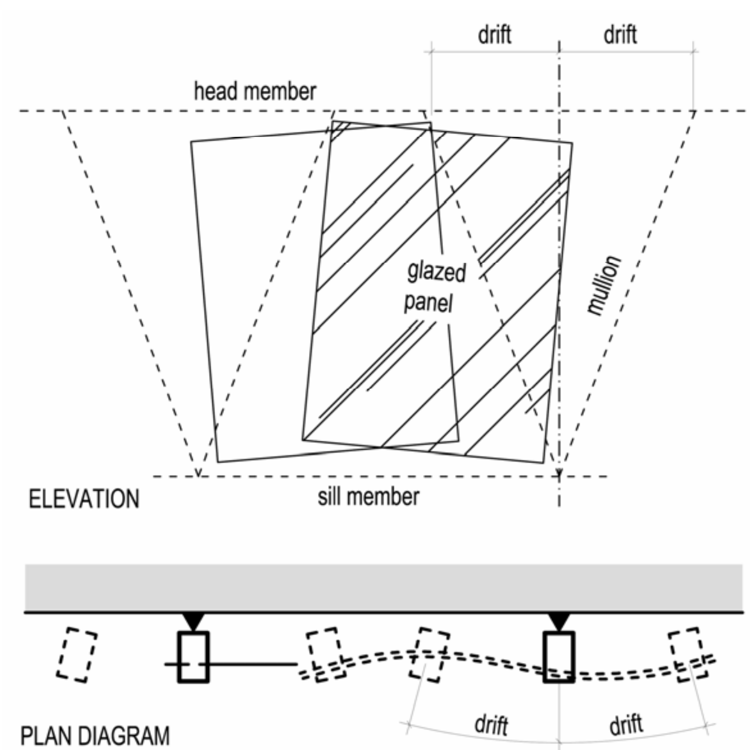

Figure 6.6
Diagram showing possible movement of a glazed panel relative to its frame and the structure. Note larger drift with the same size panel as Figure 6.5; also flexing of the glass as mullions are twisted. How far will rocking and twisting go before breakage?!
The diagram is indicative only and not to scale.

The ability of glazing, in some circumstances, to withstand larger than predicted movement without fracture is reassuring, but not guaranteed, and is dependent on many variables. Once the glass is restrained, or a corner impacts, or flexure is too great, then fracture will occur.

This has been positively demonstrated in tests by the Building Research Association[1] although it would be dangerous to generalise conclusions from this research.

Two of the preliminary conclusions from this study report are particularly relevant:

- All the generic types of glazing systems examined during the study demonstrated that they were capable of accepting inter-storey movements in excess of the maximum drift limits defined within the current New Zealand Standards.

- Seismic movement mechanisms require careful detailing to ensure that they are activated when required. In particular, care should be taken to ensure that where systems are designed to slide, this action is not hindered by tight fitting gaskets or other devices.

Figure 6.7
Badly damaged curtain wall on a hospital building in Mexico City, after the September 1985 earthquake.

Because tile faced spandrel panels stiffened the mullions for half their height all inter-storey drift occurred in the glazed section. Because opening sashes were "separated" their glazing suffered less damage than fixed glass.

A follow-up program involved two-dimensional cyclic racking of corner curtain wall installations.[2] Similar results to those previously obtained suggested that simple in-plane glazing tests can reliably predict how corner systems will perform. However it was found that the deflection capability of the tested panels was 40% less than that calculated using the conventional formula. This exemplifies the importance of full-scale testing to demonstrate adequate seismic performance.

Corners

Movement also occurs at junctions of planes, i.e. corners, curves, bay windows, steps, set backs. The effect varies with the direction of movement and can cause considerable damage, and falling glass. Internal corners pose similar problems.

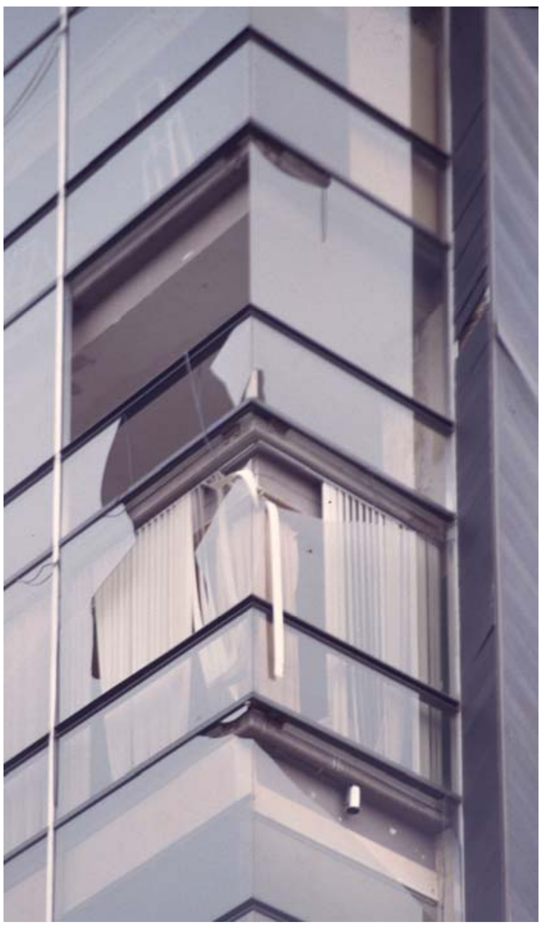

Figure 6.8
Broken glass in silicone jointed corner windows on three levels of an office building; Banco Confia, Mexico City; September 1985. Note that all breakages are at the top of the floor level where displacement was greatest.

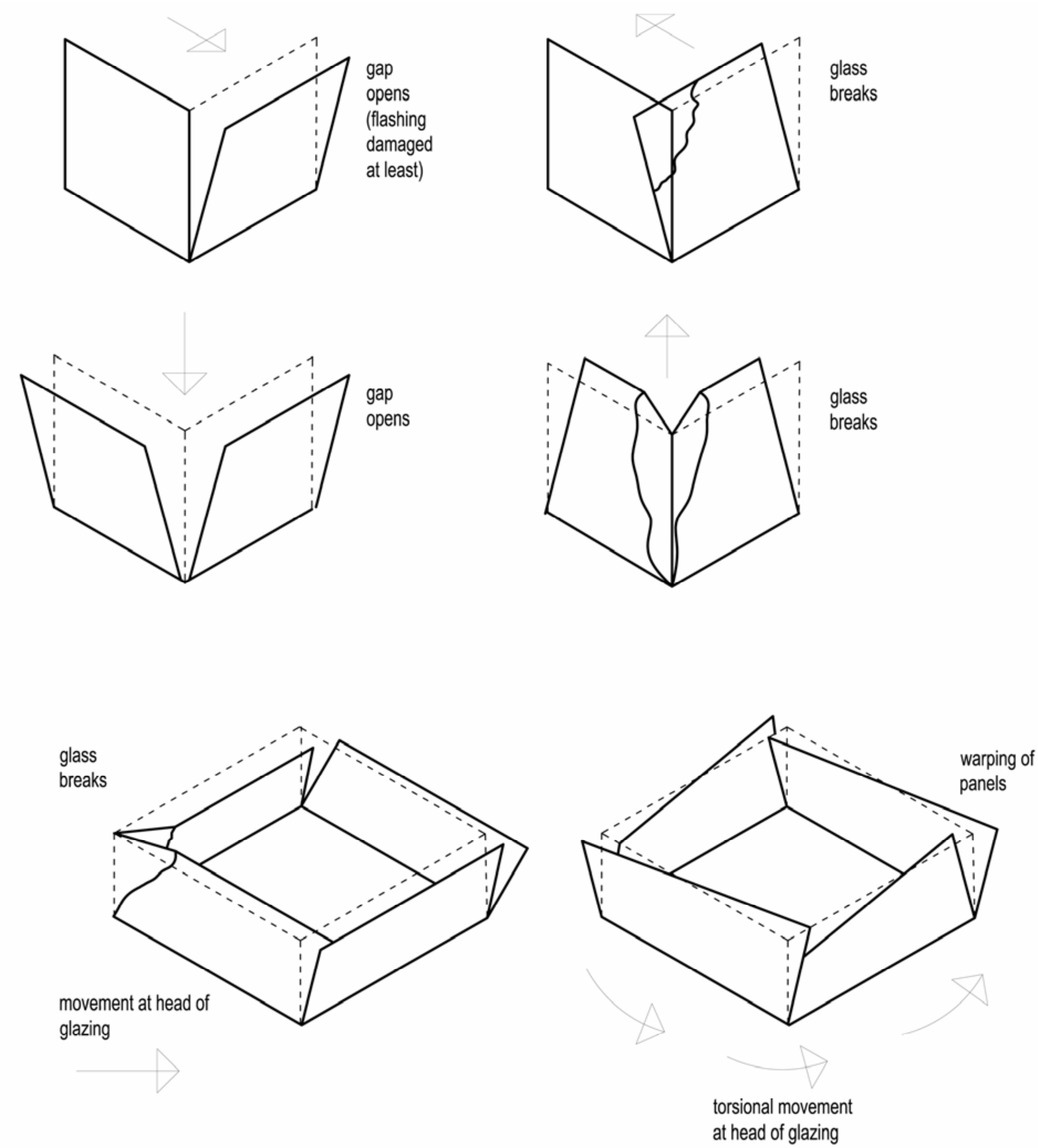

Figure 6.9
Typical diagrams of corner windows subject to deflection in an earthquake. Source: Drawing based on diagrams by E.B. Lapish.

Allowing for Movement: Four Approaches

Four generic approaches are shown but it is possible for different methods to be used in one glazing system or in one building.

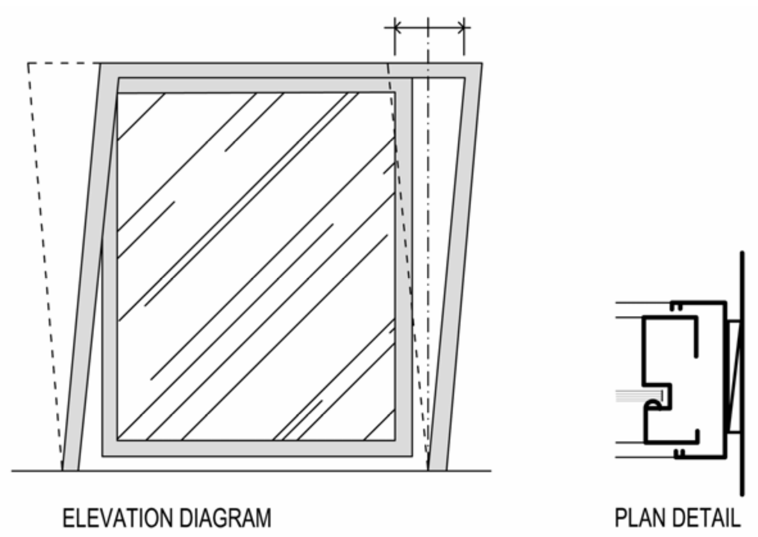

Figure 6.10
Seismic frame.
The glazed frame moves in a seismic frame, which moves with the building. The glazing frame is usually fixed at the sill.

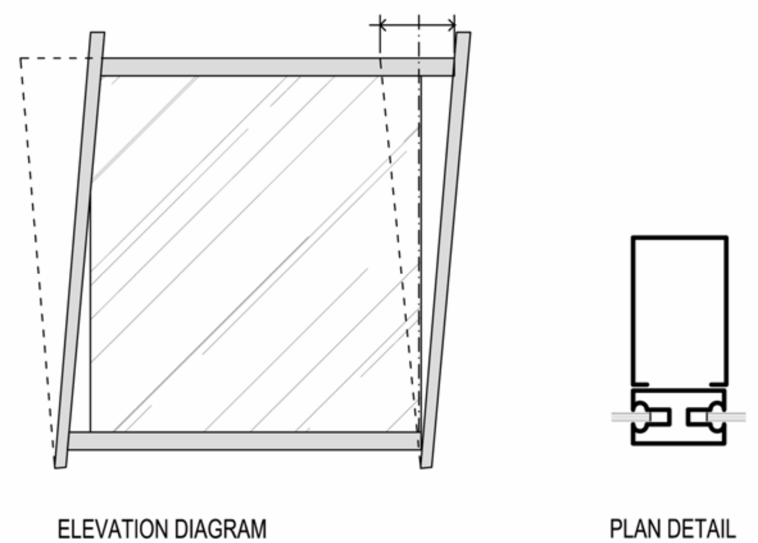

Figure 6.11
Glazing pocket.
The glass is usually gasket glazed direct into the frame with pockets around the glass sufficiently deep to admit movement. This is a common approach in 'stick' systems.

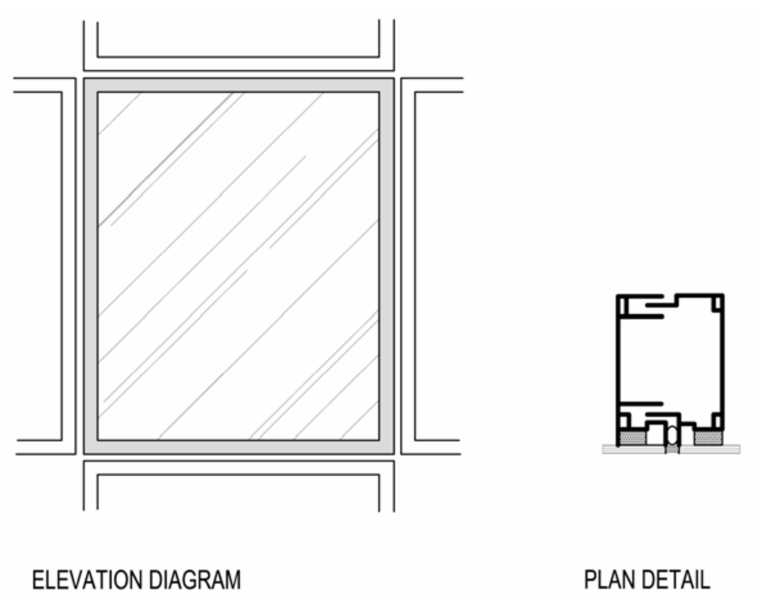

Figure 6.12
Unitised system.
Individual units interlock, with provision for movement between each unit, both horizontally and vertically. This approach has become very common in multi-storey work especially. Structural silicone is often used for fixing glass in unitised systems, but in this case the silicone itself is not required to accept deflections.

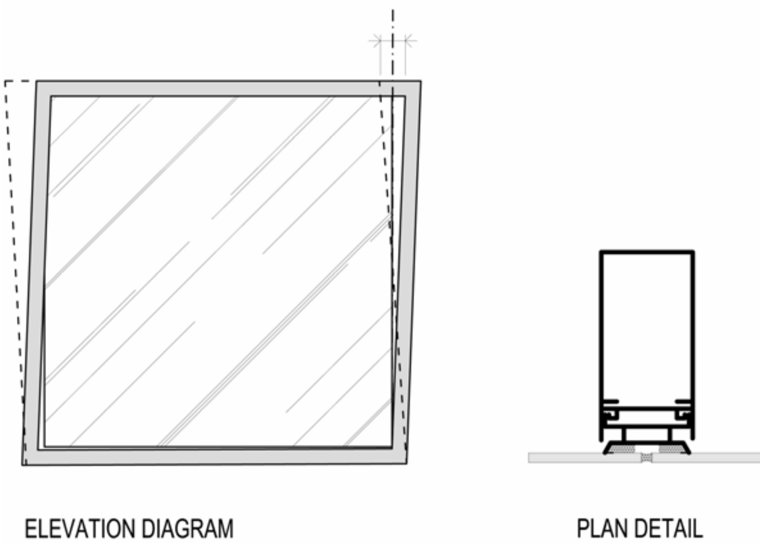

Figure 6.13
Structural silicone.
Where the other approaches provide a positive gap, in this case movement depends on elasticity of the silicone. This approach is often used in conjunction with 'stick' systems.

Sealants and Structural Silicone

The ready availability of sealants such as silicones, polysulphides, urethanes and others, has led to their increasing use in glazing systems; either alone or in conjunction with preformed gaskets, tapes, etc.

The chemistry and mechanical properties of sealants is a complex subject. Manufacturer and specialist literature should be consulted. Silicones that are commonly used in glazing systems have a range of physical properties. Only some are suitable as structural silicone, i.e. to fasten glass or other materials to the framing system, as the primary means of supporting and restraining the glass. High modulus silicones are commonly used for this purpose. They are not recommended for weather sealing the non-structural joint between adjacent units, or panes of glass because of their relatively limited movement capability.

The use of sealants in glazing systems, and of structural silicone in particular, is well covered in BRANZ Technical Paper P45.[3]

The application of silicone, especially for structural purposes, needs to be carried out under carefully controlled conditions. Factory glazing is much preferred to site glazing. Unitised window systems lend themselves to factory glazing.

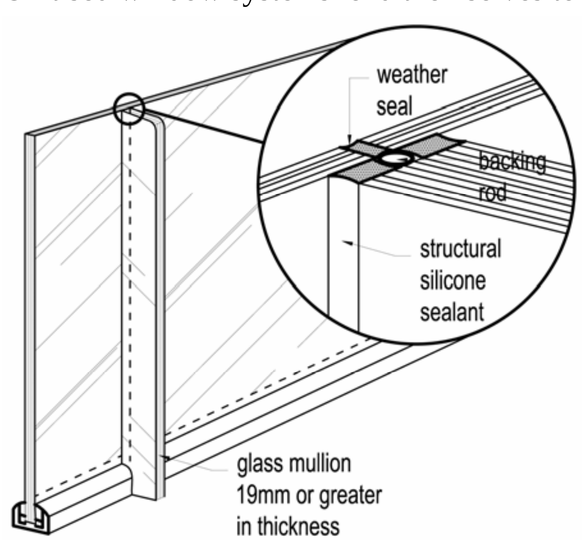

Figure 6.14
Glass mullion adhered with structural silicone to glass vision panel.
Illustration from BRANZ Technical Paper P45 : 1986, "External Flush Glazing Practices".

Allowing for Movement: Some Solutions

The solutions shown here are only a few examples. The aim is not to provide ready-made answers to every problem but to illustrate some ways in which manufacturers' details have been used, either in a particular job or in a type of window system. The details have been simplified to clarify the application of seismic movement principles. They are not working details.

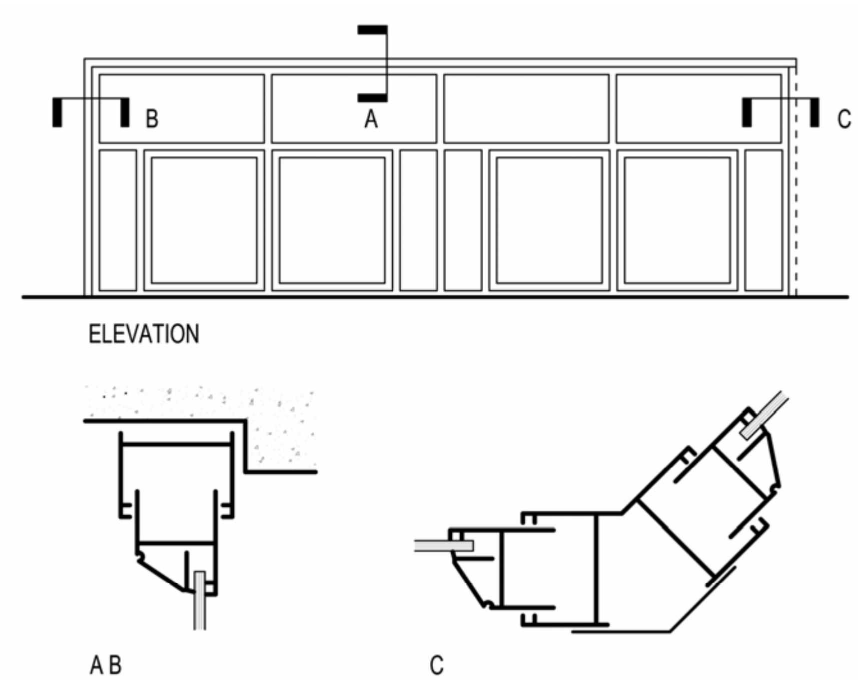

Figure 6.15
Typical seismic frame details for a commercial window suite used on a naturally ventilated building. The detail allows for a 20 mm positive separation gap over 2.1 m effective height.

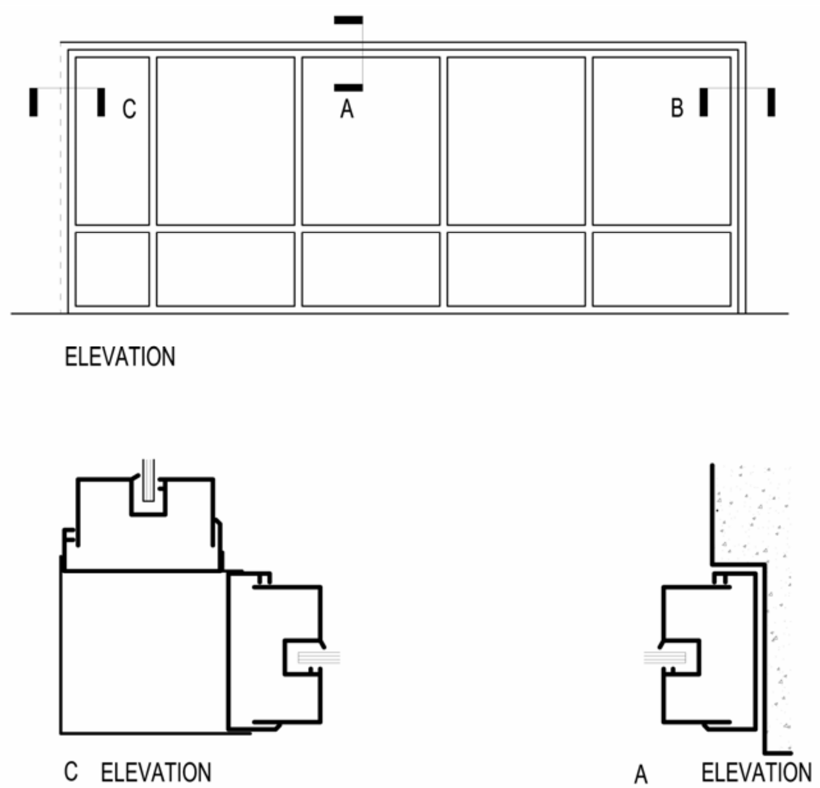

Figure 6.16
Aluminium box sections used in a seismic frame on a commercial office building. There is a 14 mm separation gap over 2.4 m effective height.

Stick Systems

The following two examples both illustrate the so-called stick system in which mullions, often running through two floors, are the sticks. In other respects the two examples are different.

In the first, the glass is gasket glazed into separate frames which float within H-section mullions. The frames meet at each transom level, spaced 750 and 1800 mm apart, where there is a small vertical gap. Because all the separation gaps are small, major seismic movement could require the floating frames to move sideways between the mullions, or rock slightly. This is a less positive approach than providing full separation on each side of the frame, but the effective height between frames is not great, being no more than half a storey height.

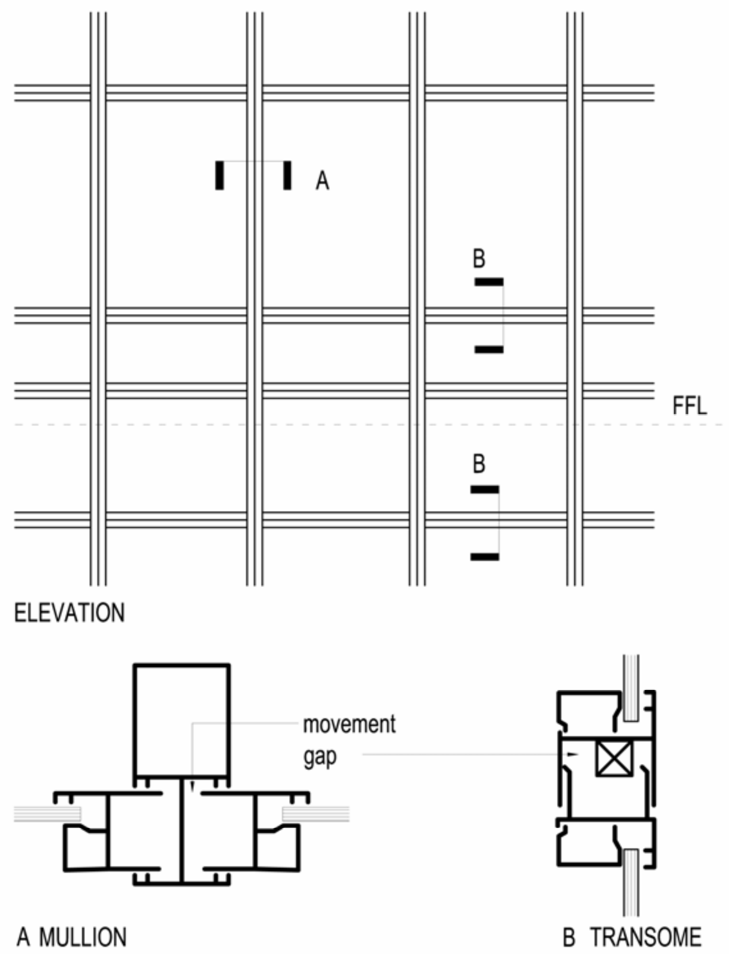

Figure 6.17
`Stick system' curtain wall with separate glazed frames 'floating' between mullions at each transome level. This is one approach to a stick system - Figure 6.18 shows another.

In the second example the glass is dry glazed directly into the stick mullions, with a much larger separation gap of 20 mm on each side and 25 mm vertical gap at each transom. The maximum height of any panel of glass is 1800 mm.

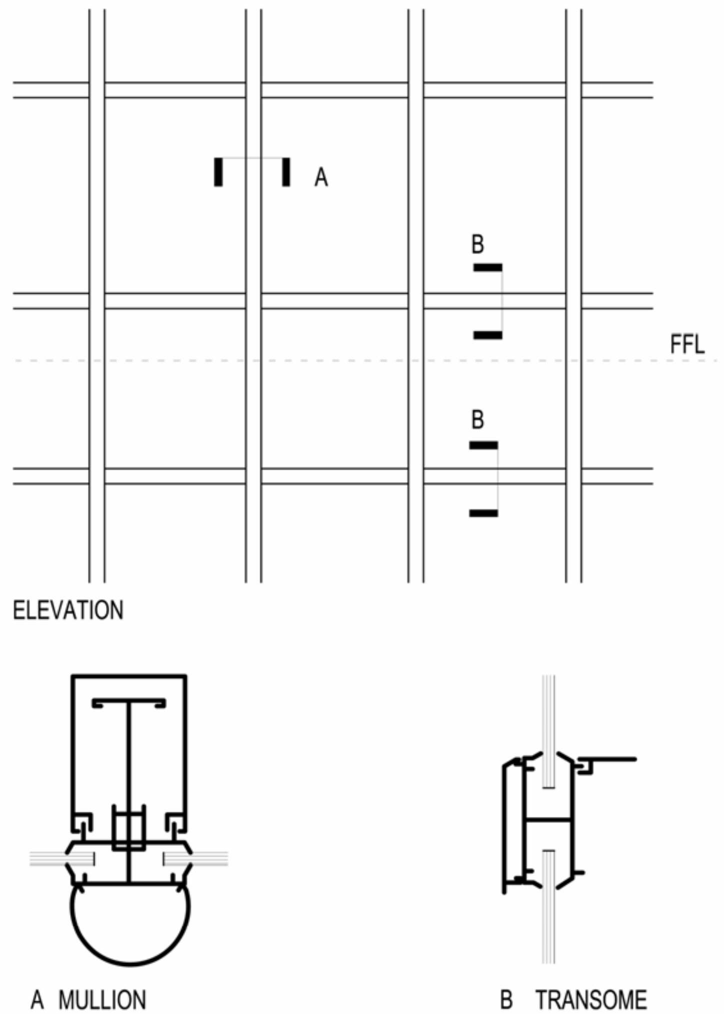

Figure 6.18
Stick system curtain wall with the glass dry glazed directly into the mullions and transomes with minimum 20 mm separation.

Unitised Systems

Two examples are shown: In both cases the same principles apply, although one building is a four storey speculative office block and the other a prestige double-glazed high-rise tower for an institutional client.

In both cases the individual units are storey height and factory glazed, using structural silicone. The framing members (mullions, transomes) which appear to be single sections are in fact comprised of two interlocking parts, each forming the side of a unit. Movement can thus occur between units. In both cases mullion divisions are not expressed on the exterior.

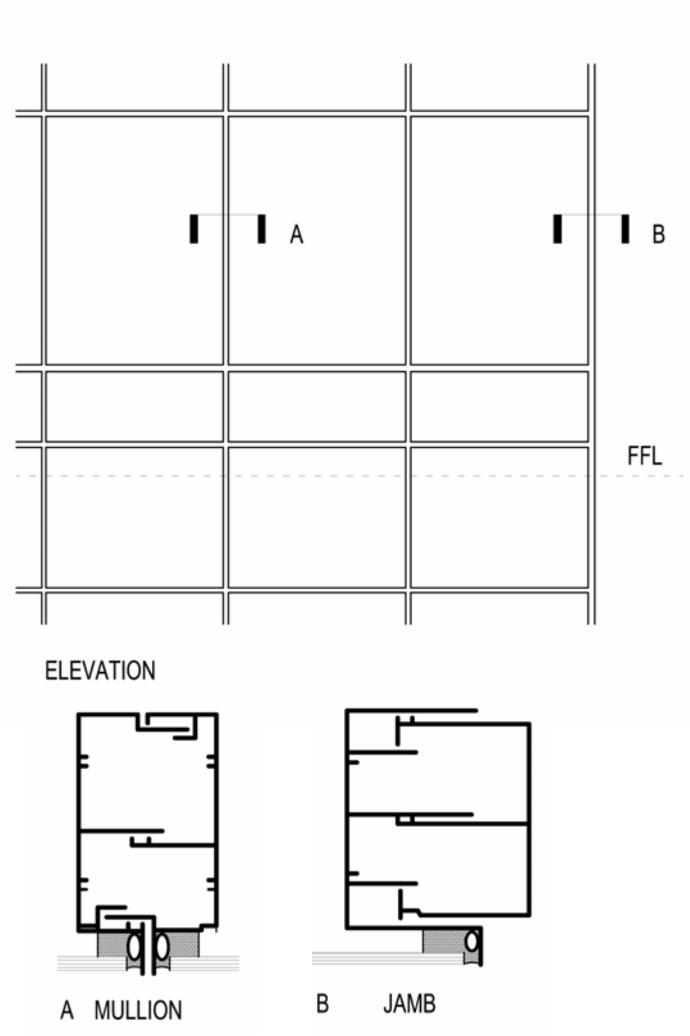

Figure 6.19
A unitised curtain wall system applied to a small office building. Structural silicone single glazing is used. An applied capping expresses the transome lines.

In this example (on a high rise tower) each unit is 3.6 metres high by 1.2 metres wide. A test assembly including a corner window was made up and subjected to a racking test to simulate earthquake loading. No failure of the system occurred.

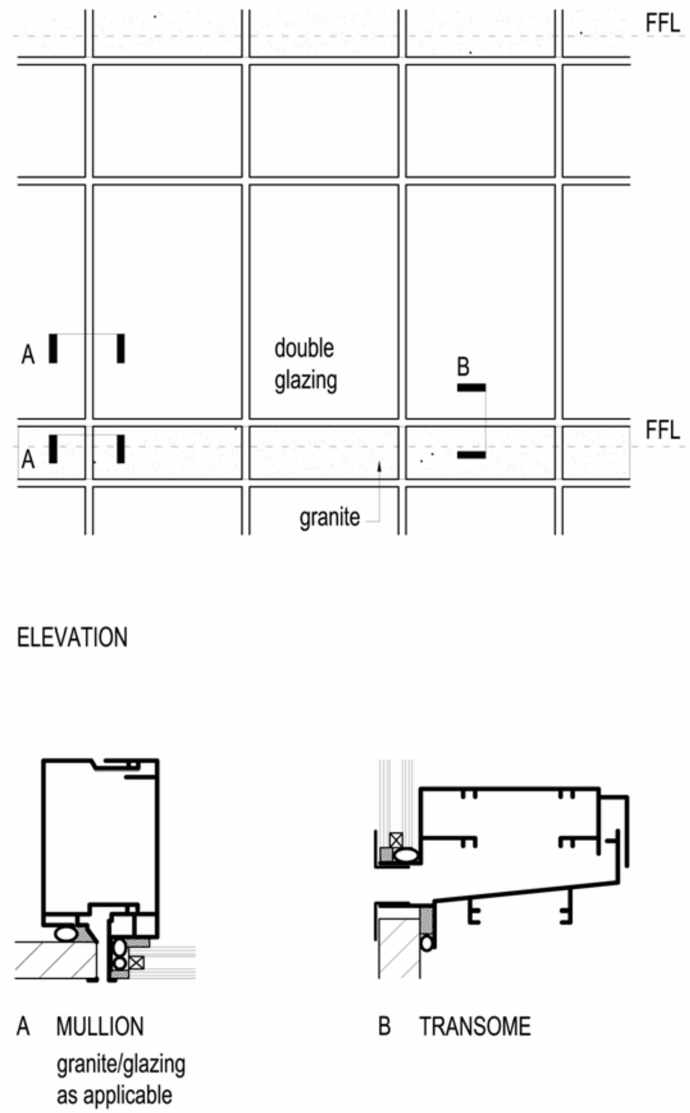

Figure 6.20
A unitised system incorporating double glazed units and granite spandrel panels. Whilst structural silicone is used a mechanical retaining angle is also provided at transomes.

All Glass Assemblies

Whilst silicone glazing systems have been touched on earlier in this section, nothing has so far been said about "all glass" assemblies, which have become increasingly common, especially for enclosing foyers of large office buildings and in atria etc. These assemblies can be hung from specially designed steel framing, the individual glass panes being stiffened by toughened glass fins and joined by proprietary stainless steel bolted connectors.

In principle such an assembly is a glass curtain which is not fixed at floor level and to that extent seismic movement is not difficult to accommodate. In detail such assemblies are special design exercises requiring early input from both the project structural engineer and a structural glazing specialist.

Glass Blocks

Two BRANZ Bulletins (No.s 281[4] and 282[5]) address selection, design and installation of glass blocks. Bulletin 281 makes the following comments relating to earthquake movement:

- Mortared block walls should be separated at the top and sides from the surrounding structure by a cushion material which protects the glass block wall from the effects of expansion, interstorey drift and building movement.
- The wall into which the glass blocks are inserted must be designed and constructed to prevent structural loads from the building being transmitted to the glass blocks.

---

[1] Lim, K.Y.S. and King, A.B. (1991). *Behaviour of external glazing systems under seismic in-plane racking: BRANZ Report No. SR39,* Building Research Association of New Zealand, Judgeford.

[2] Thurston, S. J. and King, A. B. (1992). *Two-directional cyclic racking of corner curtain wall glazing: Study Report No. 44 (BRANZ),* Building Research Association of New Zealand, Judgeford.

[3] Bennett, A.F (1986). *External flush glazing practices, BRANZ Technical paper P.45,* Building Research Association of New Zealand, Judgeford.

[4] (1991). *BRANZ Bulletin No. 281: Glass Blocks Selection and Design*, Building Research Association of New Zealand, Judgeford.

[5] (1991). *BRANZ Bulletin No. 282: Glass Blocks Materials & Installation*, Building Research Association of New Zealand, Judgeford.

7 Internal Elements

General Commentary

In the context of this guide, internal elements are part of the interior of a building but are not designed to be part of its primary load-bearing structure. For example, a shear wall is part of the structural design, but other concrete or masonry walls may be needed for fire rating purposes, or to provide acoustic separation. These walls may not be intended to affect the response of the structure in an earthquake.

Therefore any internal non-structural element that is rigid, or so stiff that it may alter the seismic performance of the building, should be separated from the structural elements.

Figure 7.1
Although this is an exterior infill wall, its damage is typical of masonry internal partition walls that are not separated with respect to inter-storey drift. 1990 Philippines earthquake. (D. C. Hopkins)

The design engineer should be made aware of such elements, whether they are part of the original design or later additions; for instance a new concrete block firewall installed as part of building refurbishment. It is important that such an additional wall is not built tightly between columns, without an engineering check being made.

Reference can be made to Section 3 of this handbook for a summary of NZ Standard requirements.

Rigid Partitions (other than shear or bracing walls)

Rigid partitions have negligible in-plane flexibility. They include concrete and masonry walls and panels, but can also be framed walls lined with continuous sheathing such as ply or securely fixed plasterboard, particularly if such partitions are extensive or are located where they can affect the structural performance of the building.

Further comments are given in Section 8.

Lightweight Partitions

Lightweight partitions that are not specially designed have limited bracing capability. They often finish at ceiling level and may either affect or be subject to the movements of the ceiling system.

Further comments are in Section 8.

Ceilings

Lightweight suspended ceilings are likely to be affected in an earthquake. They may support building services, such as lights and air conditioning outlets. Collapse can impede evacuation and might cause casualties.

Further comments are in Section 8.

Figure 7.2
Damage to an office suspended ceiling. 1985 Mexico earthquake. (R. B. Shephard)

Stairs

Unless stairwell partitions are designed to provide shear resistance, the stair flights and their enclosing partitions are usually non-structural. If separation joints are required in the stair enclosure then details must be devised that maintain fire ratings. Figure 7.3 shows one such situation.

Stair flights themselves, unless of lightweight construction, will probably require seismic separation at one end. This can also apply to open stairs to say a mezzanine. The separation detail normally takes the form of a simple sliding joint. Special arrangements may be needed to ensure clean and usable floor finishes at these locations. See Figure 7.4.

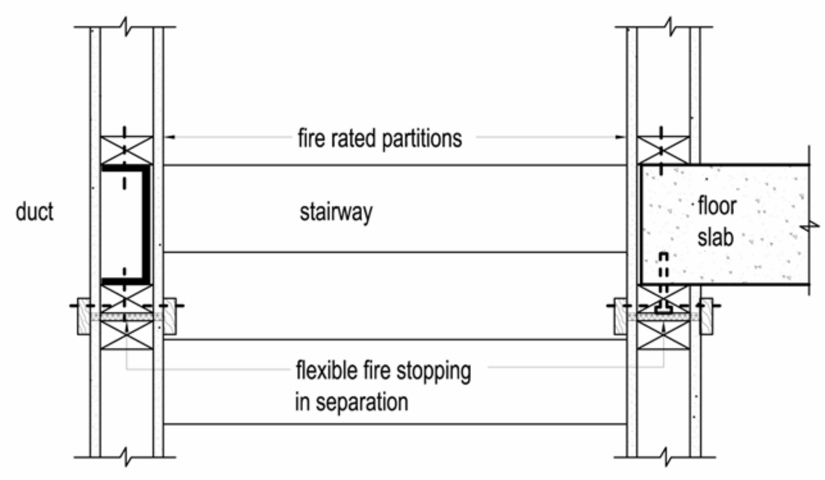

Figure 7.3
When separation details are required in partitions enclosing stairways fire ratings must be maintained.

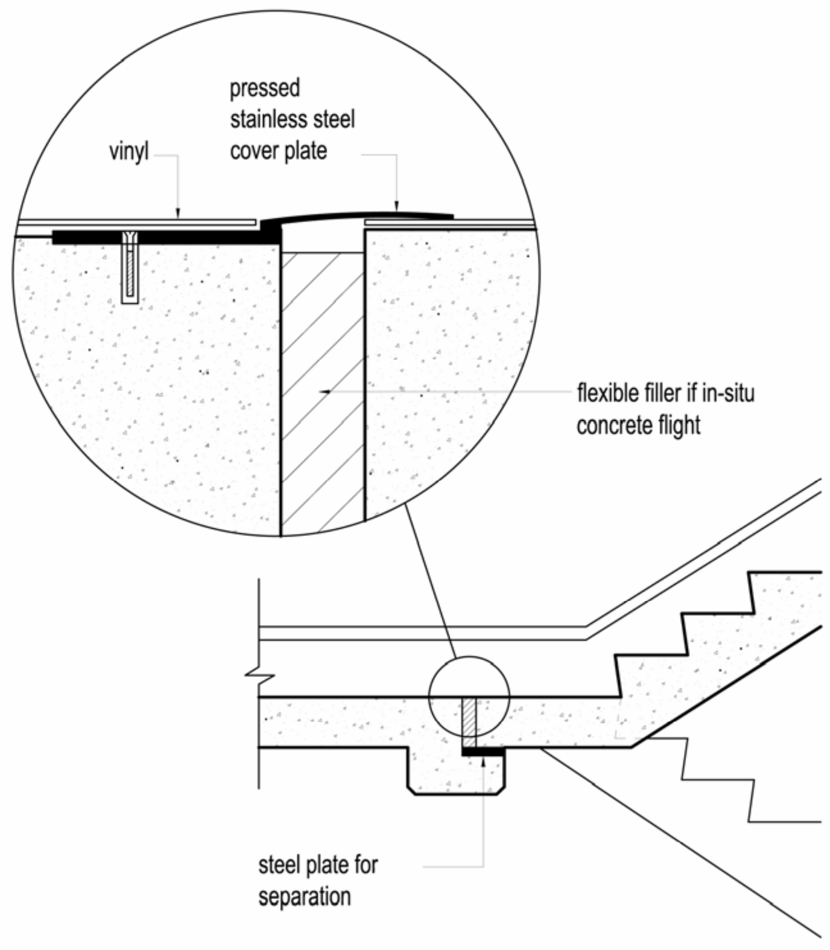

Figure 7.4
Separation of a stair flight at the landing. If a filler is used it must be flexible (or be removed after the slab is poured). Reinforcing omitted in this illustration.

Building Services

Building services plant and its supports need to be restrained against seismic movement to prevent damage and failure of the services. As large forces can be involved, specific structural design is often necessary. This is provided by either the building designer or the plant supplier.

Pipes, ductwork and wiring are usually adequately fixed, at least to resist gravity loads, but clearances from partitions etc. may be needed.

Building services fittings, such as lights, air conditioning units and heaters need support and restraint. Heavy fittings above or in the ceiling system must be suspended directly from the structure rather than supported by the ceiling.

Fittings

Fittings are items of furniture built into or fixed to the building. Usually no allowance for seismic movement is required and standard fixings are often satisfactory, but special attention is needed for tall or heavy items. They must be secured to the main structure.

Furniture

Furniture items are not attached to the building. While most furniture does not need special fixings, items such as shelving, computer equipment, filing cabinets, and the like, should be checked to ensure their stability in an earthquake.

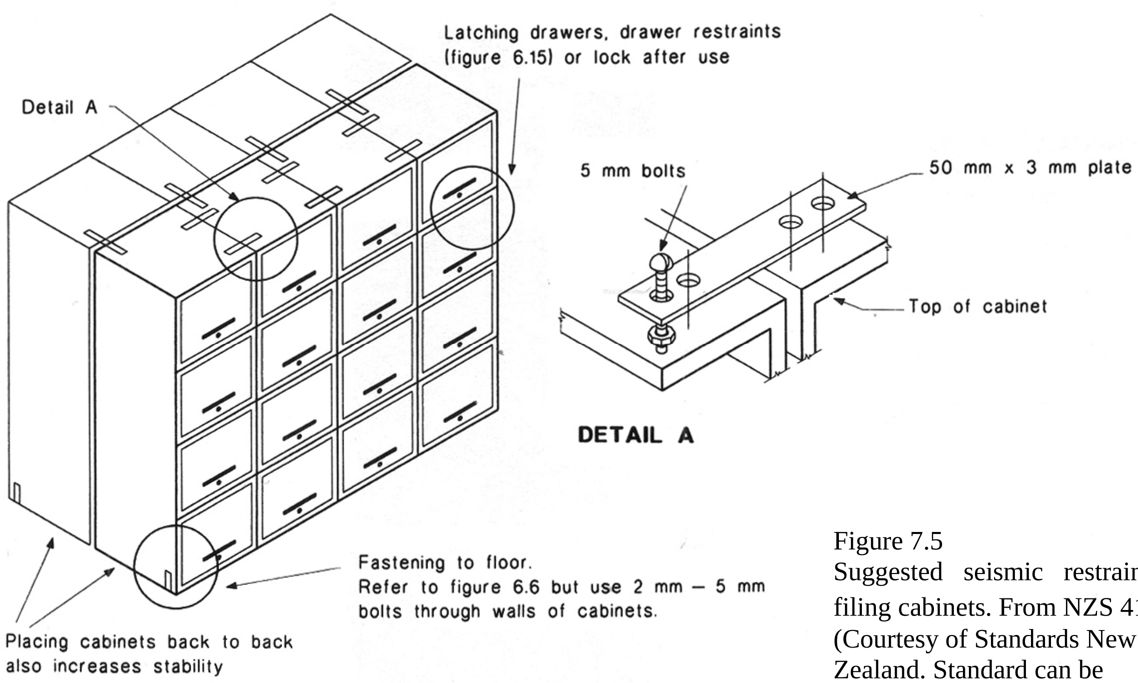

Figure 7.5
Suggested seismic restraint of filing cabinets. From NZS 4104.[1] (Courtesy of Standards New Zealand. Standard can be purchased from www.standards.co.nz .

Library Shelves

Library shelf units present a particular risk and should be fixed or supported so that they do not fall over in an earthquake. They can be braced one to another and to the building structure.

Storage Shelves

Shelves, racks and bins in offices and warehouses often need special restraint. They can be of considerable height, and support a substantial weight. This is easily overlooked.

Extensive shelving is often arranged as a separate or later contract. In this case it should be brought to the attention of the building designers that such items will be installed so that the effect of this loading can be taken into account.

Over recent years the public have expressed concerns about their safety in the vicinity of supermarket racks and designers have been unsure as to seismic design requirements. The Department of Building and Housing is currently deciding if supermarket racks are subject to the New Zealand Building Code and therefore require a building consent. Designers should refer to the BRANZ design guide.[2]

Figure 7.6
The design and day-to-day use of shelving requires careful attention to reduce potential hazards.

Raised Floors

Offices may include proprietary raised floors to allow access to building services. Such floors require restraint and allowance for movement at perimeters and around fixed items. The suppliers of proprietary types should provide seismic details.

Figure 7.7
An office raised floor during installation. Designers need to check that the lateral stability of a raised floor meets the requirements of the relevant New Zealand Standards.

[1] Standards New Zealand (1994). *NZS 4104:1994 Seismic restraint of building contents*, Standards New Zealand, Wellington.

[2] Beattie, G. J. and Deam, B. L. (2006). *Design guide: seismic design of high level storage racking systems with public access*, Building Research Association of New Zealand, Judgeford.

8 Partitions - Specifically

Rigid and lightweight partitions have been described briefly in Section 7.

Rigid Partitions

Rigid partitions, especially those of concrete or masonry construction can seriously affect the seismic performance of the building and therefore need to be separated from the building structure.

Usually, rigid partitions need to be anchored top and bottom to provide lateral support or stability, against toppling. To avoid stiffening the structure, upper anchors must accommodate both in-plane and vertical movement.

Separation details are usually designed to allow differential movement between partitions and structure in the plane of the wall. Movement normal to the wall is accommodated by allowing the partition to rotate within the structure when deflections occur under seismic loading.

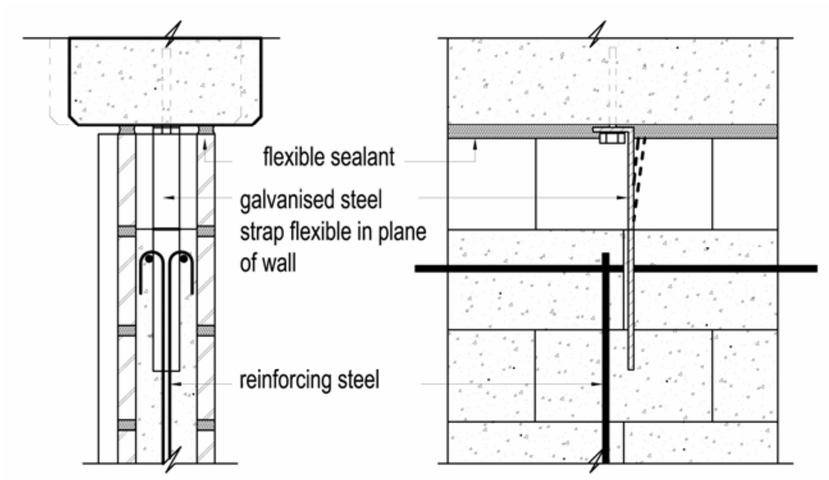

Figure 8.1
Separation detail at the head of a reinforced concrete block partition not requiring a fire rating.

In principle this is very simple, but in practice a variety of more complex situations arise. No general solution is available but each case can be approached from first principles in a logical manner to arrive at a cost-effective solution. Some examples of details that have been used are shown.

For the architectural designer the need to provide seismic separation is often in conflict with the day-to-day-requirement to maintain acoustic privacy and fire ratings. A further concern is to provide details that will require little reinstatement after an earthquake, particularly more frequent smaller seismic events.

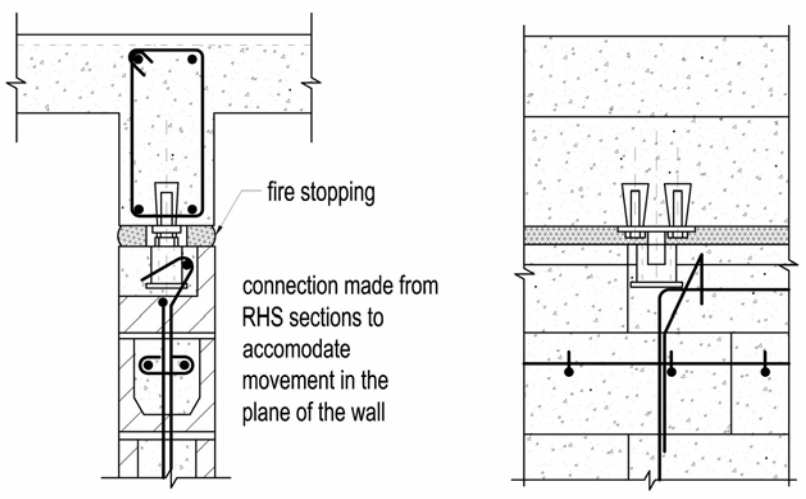

Figure 8.2
A more complex detail than Fig. 8.1 showing a way of maintaining the fire rating of a concrete masonry partition while providing for movement.

Lightweight (i.e. non-rigid) partitions can be of the traditional framed (timber or metal) type, lined with plaster board or other linings, or of the proprietary demountable type.

Lightweight (i.e. non-rigid) Partitions

If the interstorey drift during a small earthquake with a return period of 25 years (the serviceability limit state) would damage partitions, NZS 1170.5 requires they be separated from the primary structure. For specially important facilities, such as essential hospitals, non-structural damage must be prevented in considerably larger earthquakes (with much longer return periods) so that these essential facilities remain operational after an earthquake.

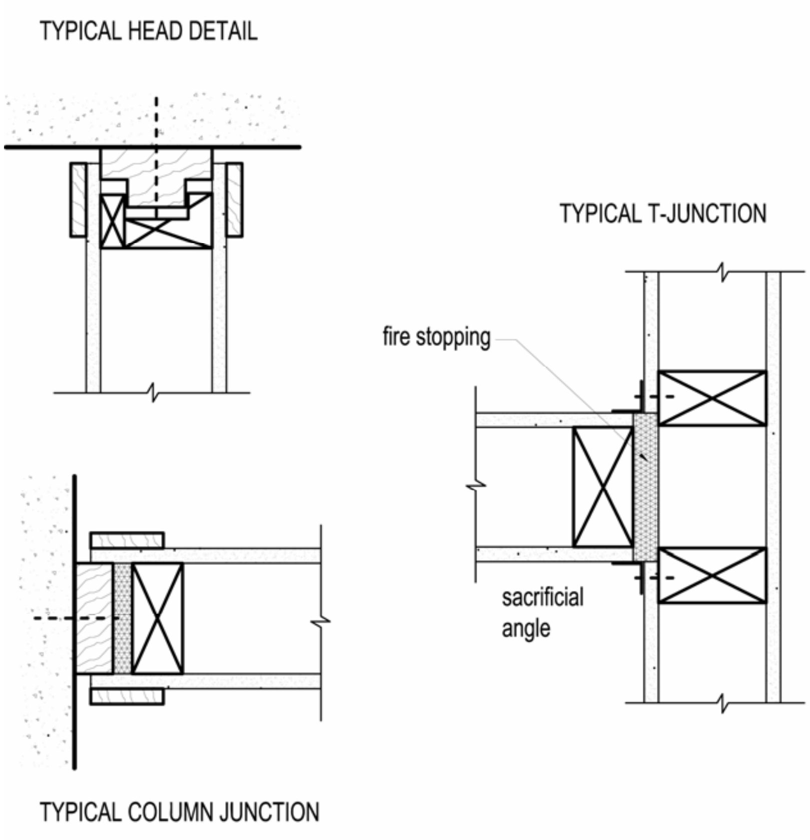

Figure 8.3
Typical details when timber framed partitions are required to be separated, e.g. in essential facilities.

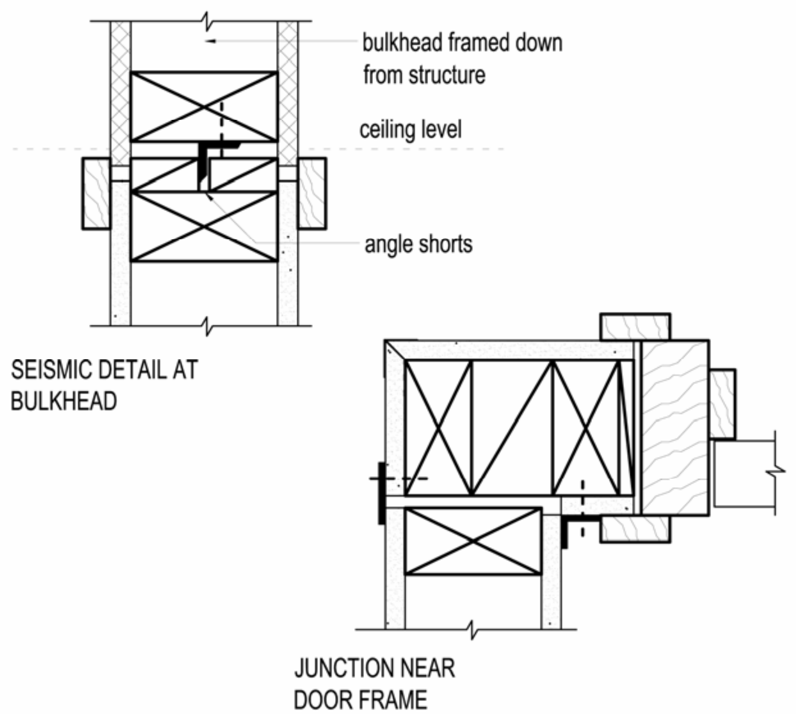

Figure 8.4
Further examples of separation of timber framed partitions.

Lightweight partitions have some flexibility, but this varies with the materials and details. Most traditionally framed and lined partitions can be considered lightweight, in a structural sense, but fire ratings may require thicker linings and closer finishes to the structure. Such partitions may initially stiffen the structure but will 'soften up' when subjected to successive cycles of seismic movement, as fixings work and linings are crushed at edges. This can be a bad situation in a major earthquake, leading to greater damage, unless separation details are provided that allow for movement whilst also maintaining fire ratings.

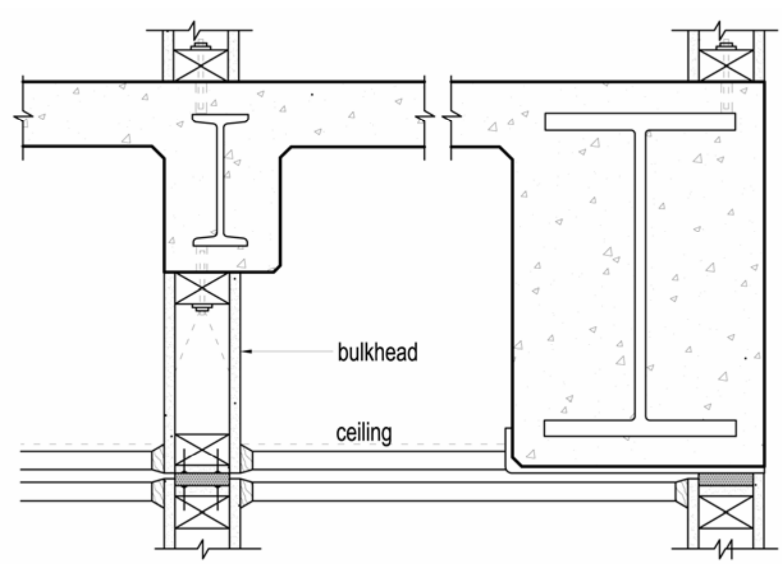

Figure 8.5
A more complex detail with fire rated partitions.

Recent research has shown that post-earthquake fire ratings of light partitions may be less than required if building occupants are to exit buildings safely.[1] Typical gypsum plasterboard partitions suffer damage at relatively low interstorey drifts – approximately ± 20 mm for a 3.5 m wall height. While this level of drift is greater than that allowed by the NZS 1170.5 during small earthquakes, is it far less than the ±90 mm drifts a flexible building may sustain during the design earthquake. In this case, it would be prudent to detail for ± (90-20) = ± 70 mm movement. NZS 1170.5 requires that fire-rated exit ways be protected from damage during the design earthquake. Therefore, in the realistic scenario of a post-earthquake fire and damaged sprinklers, a fire rated escape path would provide ensure safe egress for the duration of the evacuation.

Proprietary partitions normally have metal studs that are a friction fit in the top and bottom members. Caps are allowed at the head of studs, and there is thus some inherent flexibility in the partition system. These are commonly two types:

- "Demountable", where the linings are screw fixed and joints butted or covered with clipped cover strips. This type of partition has inherent flexibility.
- Flush lined, where joints in the linings are stopped flush. This type will have less overall flexibility.

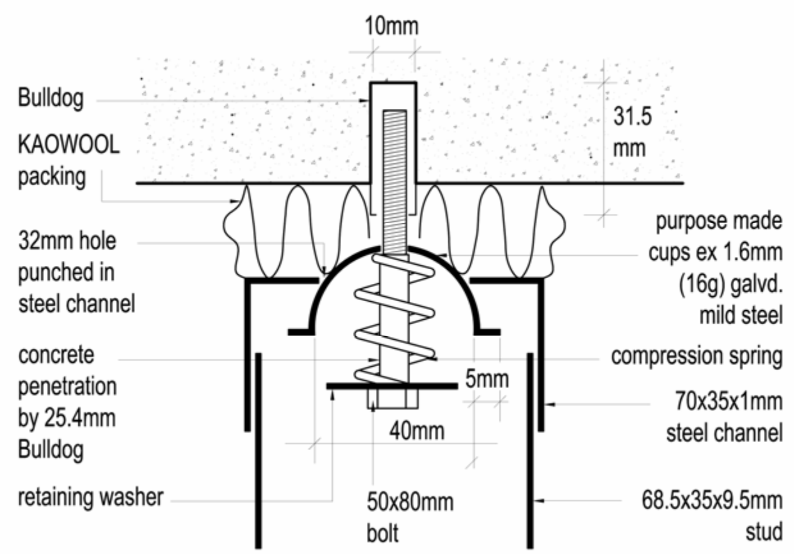

Figure 8.6
A seismic head detail for a proprietary walling system (Trend Walling Systems Limited).

In practice, lightweight proprietary partitions are usually fixed to ceilings, unless specified otherwise, and this is commonly considered acceptable except in essential facilities where separation should be considered.

In a lightweight partition system (of any type) it is recognised that corners and junctions are particularly liable to seismic damage unless partitions are either freestanding or detailed to provide separation and movement.

Glazed Partitions

Allowance for movement in glazed partitions may also need consideration.

Smaller areas of glass, gasket glazed into metal or timber sections, are generally acceptable. However, adequate gaps should be provided between the sections/fixings and the glass to prevent contact and damage.

Where large areas of glass are used, particularly when sheets of glass are butt joined with silicone, special allowances for movement may be required. Discuss with a structural engineer.

---

[1] Sharp, G. S. and Buchanan, A. H. (2004). *Earthquake damage to passive fire protection systems in tall buildings, Proceedings of the 2004 Conference of the New Zealand Society of Earthquake Engineering*, NZSEE, Paper No. 43.

9 Suspended Ceilings

The risk arising from suspended ceilings being damaged in an earthquake has already been noted. But suspended ceilings often cause damage. In many instances suspended ceilings, hung from small diameter wire ties, have swung about during an earthquake and damaged fire sprinkler heads rigidly attached to the structure above. The subsequent water flow has caused much damage. Lighting and other building services can also be affected if connected to, or supported by, the ceiling system.

Light fittings and other items weighing over 25 kg should be suspended directly from the building structure or be otherwise supported independent of the ceiling system.

The design and installation of suspended ceiling systems must comply with AS/NZS 2785:2000.[1] A structural engineer must specify the bracing for each ceiling that is determined by the requirements of NZS 1170.5: 2004[2] in conjunction with certified tests provided by the suspended ceiling manufacturers.

Lateral ceiling loads can be resisted by transferring loads to perimeter walls or structure, or by bracing from the structure above. Movement joints may be needed at the perimeter, and runners may need restraint to prevent them buckling upwards.

Tiles should be clipped in place to prevent them being dislodged, and to retain their diaphragm action.[3] This action is necessary both at the time of the initial installation and later on, when maintenance access to services, etc. is required.

Rigid items that pierce the ceiling, such as sprinklers, can cause damage to the ceiling installation, and more importantly suffer damage themselves, so allowance for movement should be made around such items.

The major suppliers of proprietary ceilings have developed details to provide for bracing and movement in compliance with the appropriate Standards. Their technical staff should be consulted at an early stage of the design if there are any special requirements.

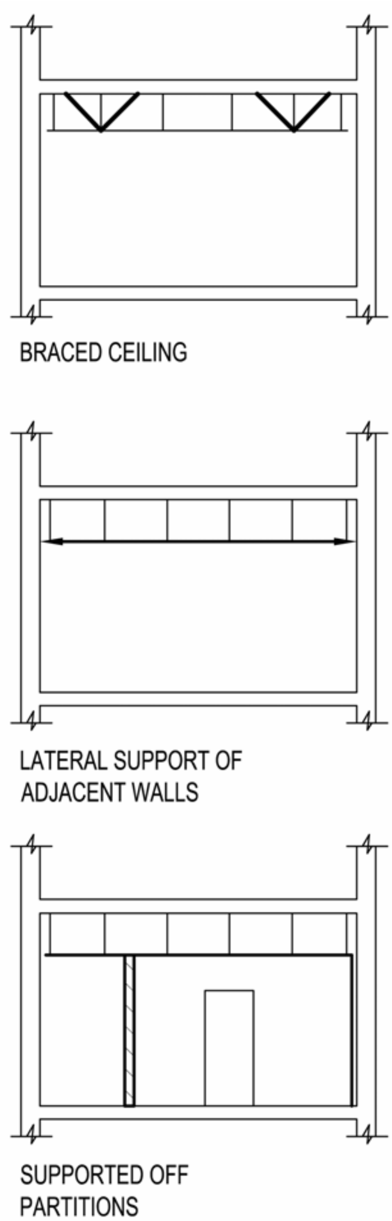

Figure 9.1
Three principles of support of suspended ceilings.

[1] Standards New Zealand (2000). *AS/NZS 2785: 2000 Suspended ceilings: design and installation*, Standards New Zealand, Wellington.

[2] Standards New Zealand (2004). *NZS 1170.5: Structural design actions: earthquake actions – New Zealand*, Standards New Zealand, Wellington.

[3] Badillo-Almaraz, H., Whittaker, A. S. and Reinhorn, A. M. (2004). *Seismic qualification and fragility testing of suspended ceiling systems, Proceedings of the 13th World Conference on Earthquake Engineering*, Vancouver, Paper No. 1053.

10 Miscellaneous

Building Separations

Building separations are the movement joints between buildings, or parts of buildings, required to ensure that adjacent structures can move separately and that damage is prevented when this happens.

Movement at building separations can be substantial, and in three dimensions. Details should allow for this. Such details may be different to those used elsewhere to accommodate inter-storey deflections.

Separations will usually need closing-in to maintain weatherproofing. Details should also:

- Keep the separation spaces between buildings clear of rubbish
- Enable the building to continue to function after an earthquake
- Improve the appearance of the separation.

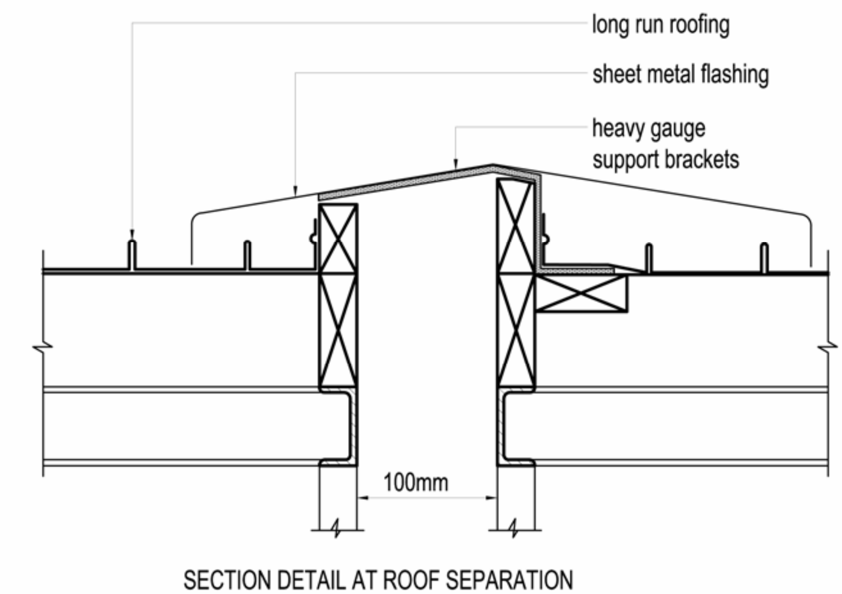

Figure 10.1
Roof separation between blocks of a Wellington building. Note the width of the flashing.

Where there is seismic separation, then there will also be thermal and other movements of the structure as well. Details should accommodate this. The amount of seismic movement to be allowed for increases with the height above ground level.

Details that permit easy inspection and repair are an advantage for building maintenance. Resistance to damage during normal building use should be considered.

A main requirement of roof separations is weather proofing. The visual aspect may not be as important as at wall junctions.

Flat roof details can incorporate either an upstand or a recess. With the use of upstands it is easier to protect against potential blockage and flooding. It is also easier to check and maintain such details.

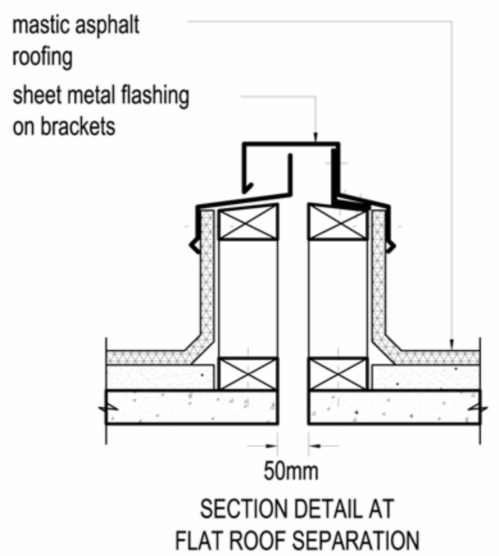

Figure 10.2
Seismic separation of a mastic asphalt roof. What happens to the flashing detail at each end needs thought. For instance: Will it still allow movement and keep out the weather where it meets a wall, or turns down into a gutter?

A recessed detail is not as reliable. If the recess acts as a gutter, then the possibility of water ingress into the building is increased.

Design for resistance to damage is particularly important when there is roof traffic.

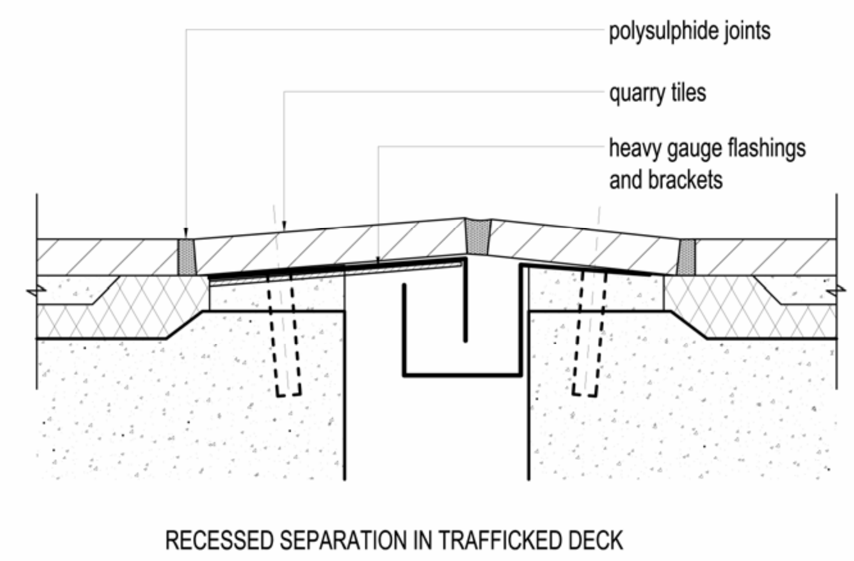

Figure 10.2
Seismic separation of a mastic asphalt roof. What happens to the flashing detail at each end needs thought. For instance: Will it still allow movement and keep out the weather where it meets a wall, or turns down into a gutter?

A recess detail can be more acceptable in a sloping roof as the slope assists drainage, and reduces the likelihood of blockage and flooding. Detailing of the outlet to the recess is important.

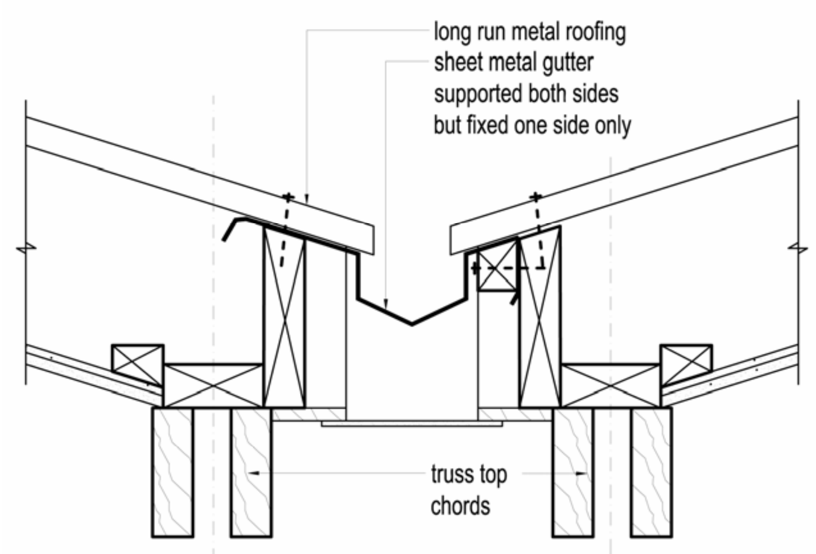

Figure 10.4
Seismic separation at a valley in a pitched metal roof. Note that fixings of the gutter and the internal cover strip are on one side only.

Simple overlapping of the roof materials is a good basis for movement details when this can be arranged.

External Claddings/Window Separations

In addition to the requirement for weatherproofing, appearance is likely to be important for separation details in exterior claddings/windows.

Normally, separation will be between adjacent structural elements, with external cladding stopping each side of the separation gap. It is preferable that claddings/windows are not taken across the seismic gap; this makes weathering and movement provision more difficult.

Weatherproofing details will most likely include flexible covers or flashings.

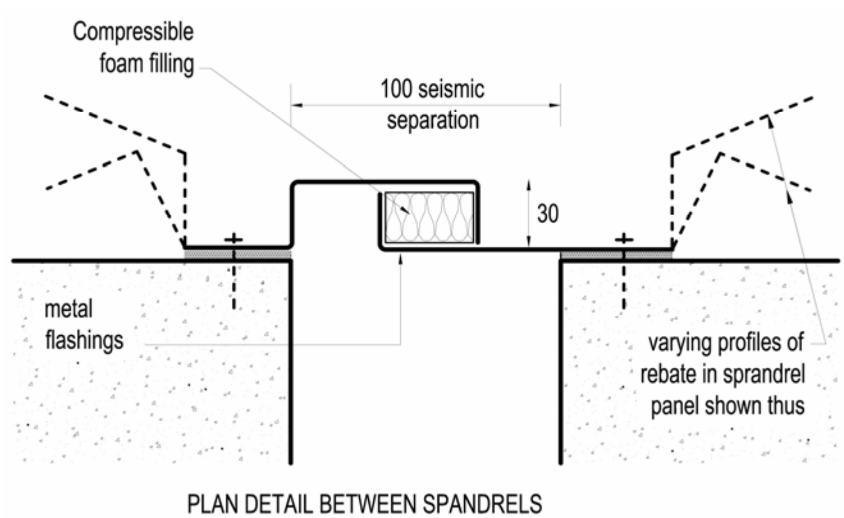

Figure 10.5
Overlapping flashings between spandrel panels at a separation gap.

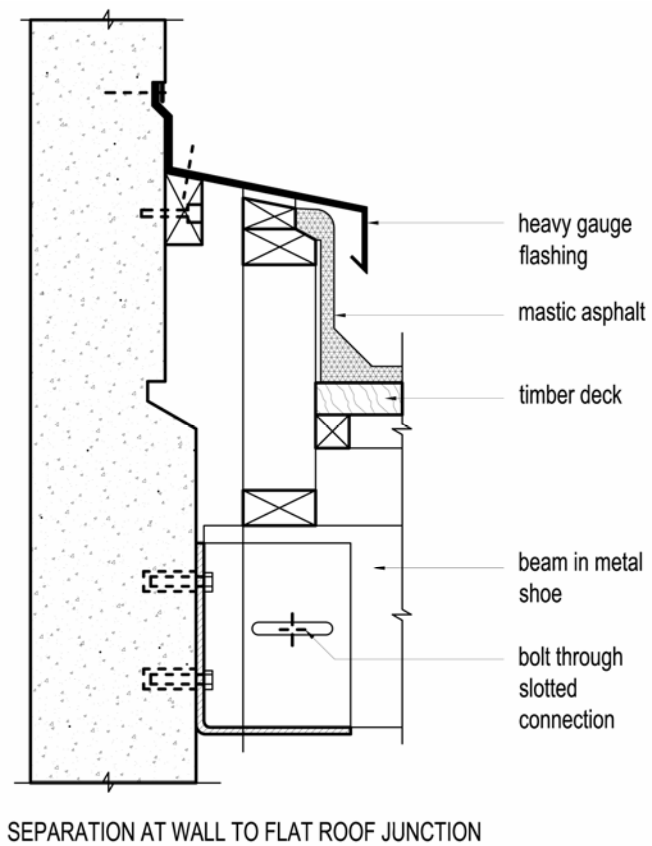

Figure 10.6
Each type of separation requires individual attention.

Internal Element Separations

To allow for expected movement, details are better provided at the separation space, rather than close to it.

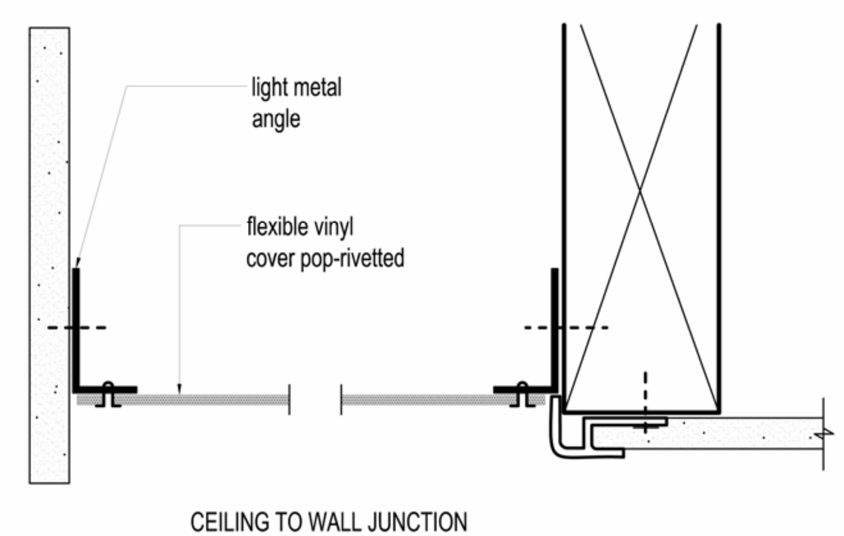

Figure 10.7
Internal separation details at a seismic gap can usually be quite simple.

Floors will require details to provide continuity of the surface without interfering with the traffic. The details may include sliding plates. The area of movement (generally a recess) can be filled in with a strip of the flooring material which will distort when there is seismic movement. Floor plates need to be sufficiently rigid, and adequately fixed, particularly if wheeled or heavy traffic is to be allowed for.

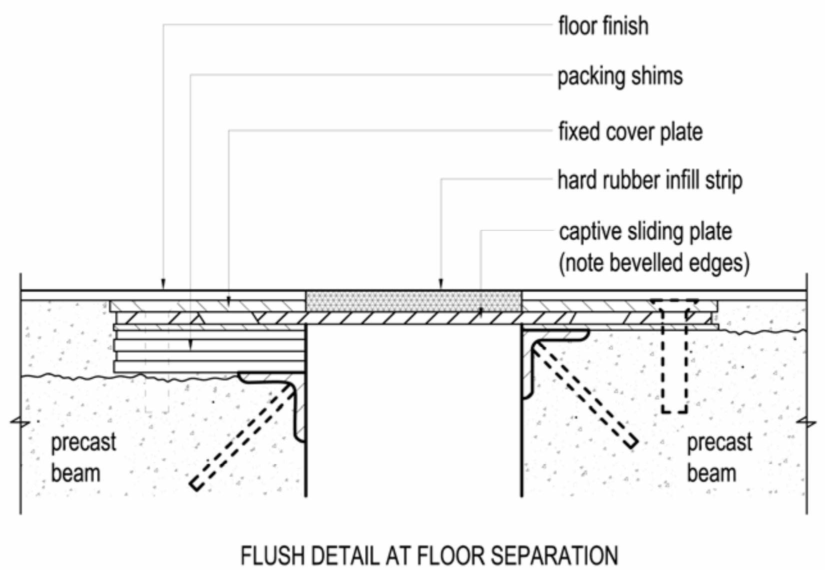

Figure 10.8
Details of this complexity may be warranted when a continuous floor finish is needed. In many cases a metal cover plate is adequate (See Fig 7.4)

Building Services

Building services pipes, ducts and wiring will need to allow for movement if they cross the separation. Such details should be designed by the services designer or supplier to meet specified performance standards, but are better avoided.

Access for inspection, and periodic checking and perhaps servicing of any movement points, should be included in the building design.

Other Items

Any substantial item in or on a building should be taken into account when considering allowances for movement or restraint during an earthquake. This can include signs, large works of art, etc.

Support systems that are bolted or screwed will usually provide better seismic resistance than those that are simply nailed together, unless nail plates or similar purpose-made devices are used.

Heavy items of equipment may need to have their own specially braced support systems off the structural floor.

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