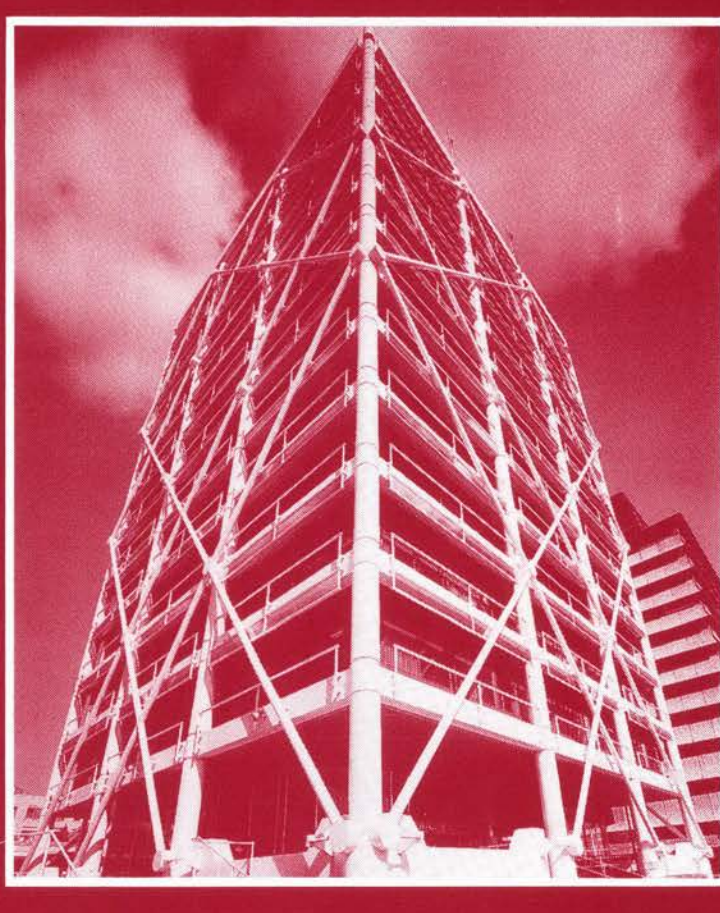
Architectural Design for Earthquake



A guide to the design of non-structural elements

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Architectural Design for Earthquake

A guide to the design of non-structural elements

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Preface

This book is intended to promote adequate performance of non-structural elements in earthquake - both 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 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.

This book 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.

As one architect who has recognised the need for, but difficulty of producing, cost effective details that meet New Zealand earthquake code requirements I hope 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.

Warwick Massey
May 1992

Acknowledgements

The genesis of this handbook was in meetings of a NZNSEE Study Group in 1986-1987. Recognition is due to the members of that group, which included: Adrian Bennett, John Christianson, Laurie and David Hayes, Henry James, Andrew King, Ernest Lapish, Les Megget, Ken Muholland, Geoff Sidwell, Maurice Tebbs and the writer.

I am grateful to those who have read and commented on parts of the text, including Chris Arnold, David Hopkins, Alan Perry and Andrew Charleson; also to Mark Smith and Peter Weston for their background research. In particular my thanks to Silva Bassett for her desk top publishing skills.

Finally I acknowledge the help of Les Megget; his major contribution to the text and his essential engineering advice.

WEM

Contents

This handbook is about design of non-structural elements - that is, those parts of buildings which do not or are not intended to resist loads applied to the structure of the building. This may 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. (Figure 2.1)

- 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. (Figure 3.1)

- 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)

Figure 1.1
Damage to partitions and ceilings in DDF Water Supply Secretariat, Mexico City. September 1985.

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)

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 earths 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.

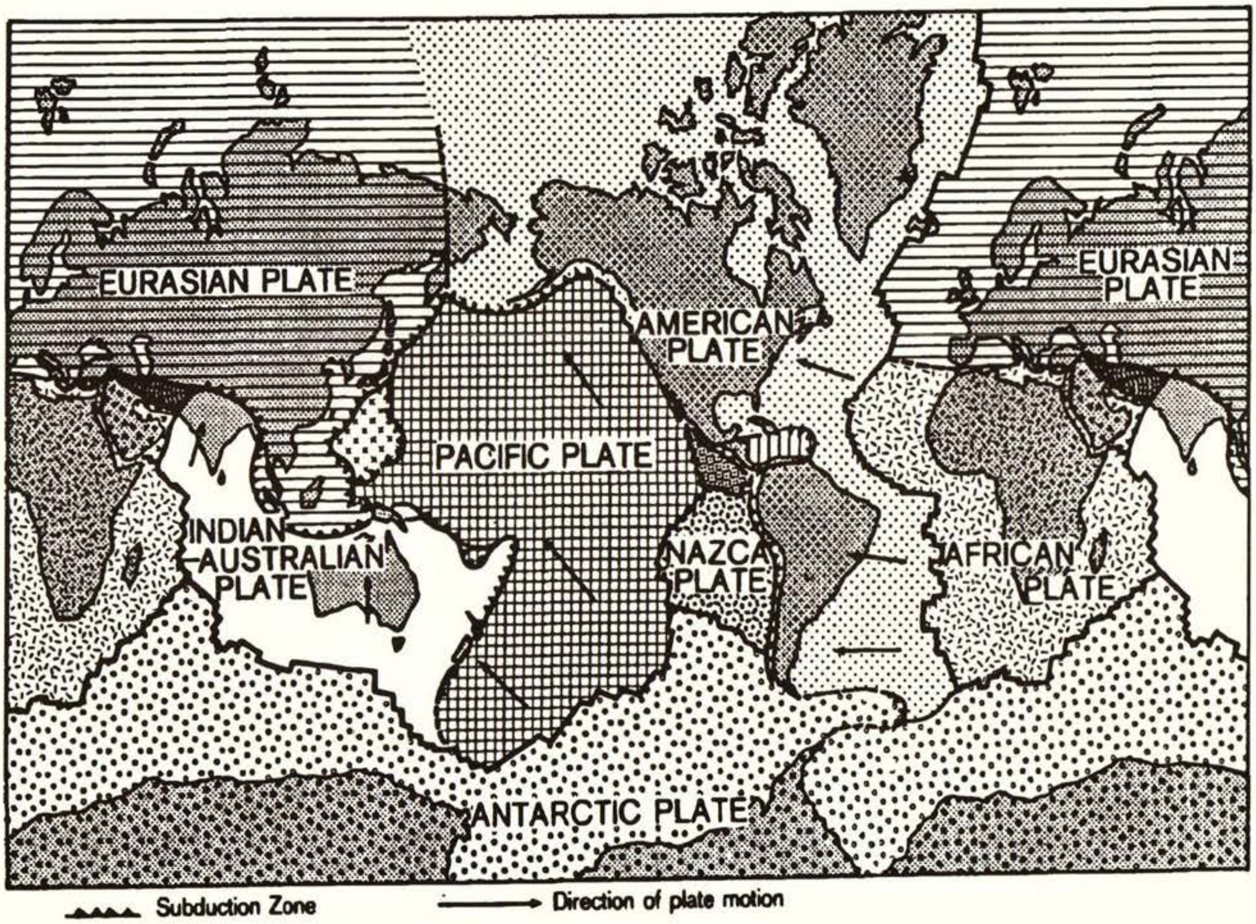


Figure 1.2
The earth's crust is composed of at least 15 rigid virtually undistorted slabs or plates of lithosphere, 7 of which occupy considerable areas of the globe and are shown on this map. Boundaries of plates are of four principal types: divergent or spreading zones, where plates are separating and new plate material is being added; subduction zones, where plates converge and one plate is being consumed; collision zones, former subduction zones where continents riding on plates are colliding; and transform faults, where two plates are simply gliding past one another, with no addition or destruction of plate material.

Almost all the earthquake, volcanic, and mountain-building activity which marks the active zones of the earths crust closely follows the boundaries of plates and is related to movements between them. As may be seen from the diagram, New Zealand straddles one such active zone, astride the boundary between the Indian-Australian plate and Pacific plate.

[Reproduced with permission from Lands in Collision: Discovering New Zealand's past geography, Graeme Stevens, Wellington, NZ: SIPC.]

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 earths 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 MM1 to MM12. This scale is based on observed effects and as such is subjective. For instance MM6 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.

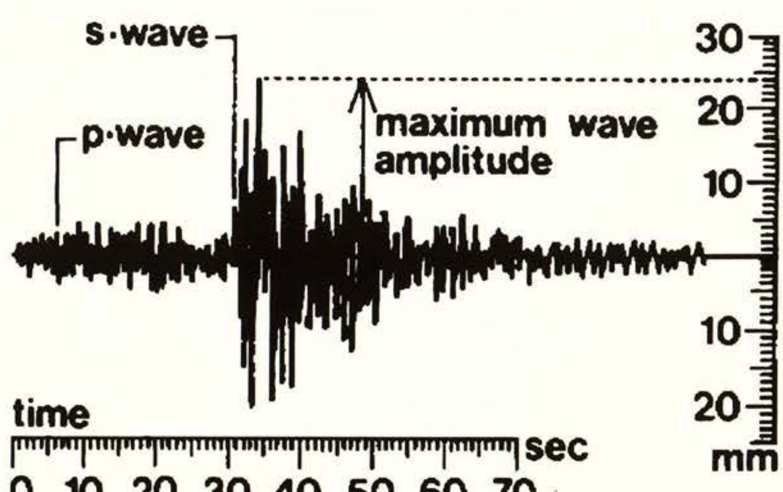


Figure 1.3
The accelerogram provides a picture of the ground shaking from which the magnitude of the earthquake can be derived.
Reproduced with permission from Bruce A. Bolt, Earthquakes: A Primer [San Francisco: W.H. Freeman and Company 1978].

Return Period

Figure 1.4 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.

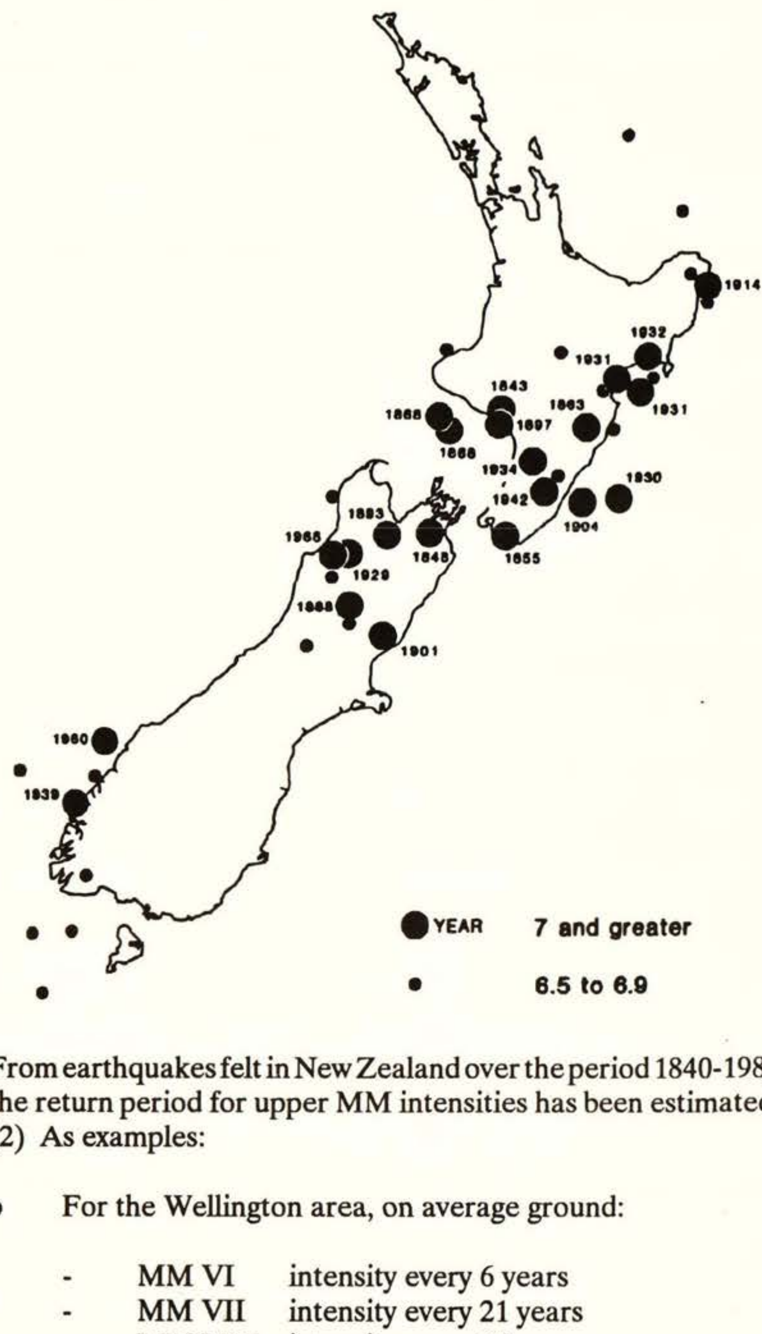


Figure 1.4
Epicentres of shallow earthquakes of magnitude 6.5 and greater, since 1840.
Reproduced with permission from Smith W.D., "Revised Estimates of Earthquake Hazard in New Zealand" Bull. NZNSEE, Vol. 16 No. 4, December 1983, p.263

From earthquakes felt in New Zealand over the period 1840-1987 the return period for upper MM intensities has been estimated. (2) As examples:

- For the Wellington area, on average ground:
  - MM VI intensity every 6 years
  - MM VII intensity every 21 years
  - MM VIII intensity every 67 years
  - MM IX intensity every 220 years

- In the Auckland area the predicted return periods are much longer:
  - MM VI intensity every 48 years
  - MM VII intensity every 200 years
  - MM VIII intensity every 990 years

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 earthquake zoning. Zoning is taken into account in seismic engineering design and is embodied in the New Zealand Standard (NZS 4203) commonly referred to as the Loadings Code. Both the present code and a proposed new version (DZ 4203 : 1989) make provision for zones of risk. There are three zones in the present code; the redraft is somewhat more sophisticated but the principles are the same.

Figure 1.5
Seismic Zonings of New Zealand from NZS 4203 : 1984.

Earthquake risk to a building is determined by three factors:

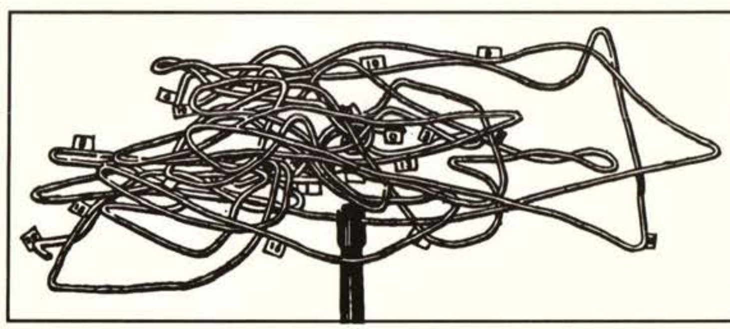
- The likely frequency of an earthquake.
- The intensity of the resultant shaking at a particular location.
- The effect of that ground shaking on the building under consideration.

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 1.6
Diagram of the motion of an 1887 earthquake in Japan enlarged 13 times. (Actual motion full size in diagram to right.)
Reproduced with permission from Arnold, Christopher and Reitherman, Robert: "Building Configuration and Seismic Design" from Transactions of the Seismological Society of Japan, Vol. XI, 1887.



Building Response

The actual ground displacements involved are often surprisingly small - perhaps no more than a centimetre or two, 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 1.7)

Resonant response of structures is something that engineers try very hard to avoid. Hence the importance that is placed on close understanding of soil conditions at specific sites and their response to a likely earthquake.

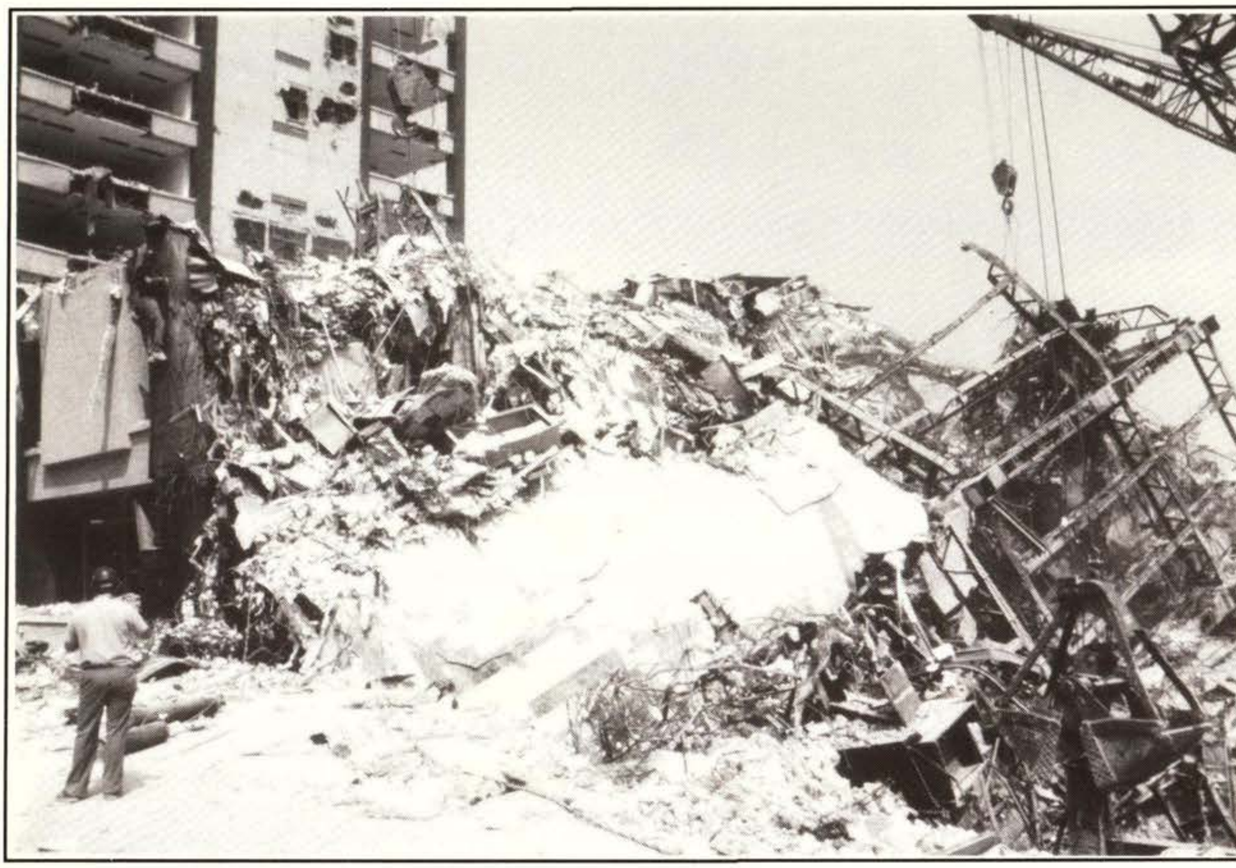


Figure 1.7
Total collapse of two steel-framed high-rise buildings (14 and 22 storeys) in the Mexico City earthquake Sept 1985.

(1) Source: Arnold, Christopher; Hopkins, David and Eric Elsesser: "Design and Detailing of Architectural Elements for Seismic Damage Control," Building Systems, Development Inc., KRTA Ltd, and Forell/Elsesser Engineer Inc., March 1987 : Page 32.

(2) Source: Smith, W.D., "Earthquake Hazard in NZ: Some implications of the Edgecumbe Earthquake, March '87", Bull. NZNSEE, Vol. 23 No. 3, Sept. '90, p.216.

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. (Figures 2.1 and 2.2.)

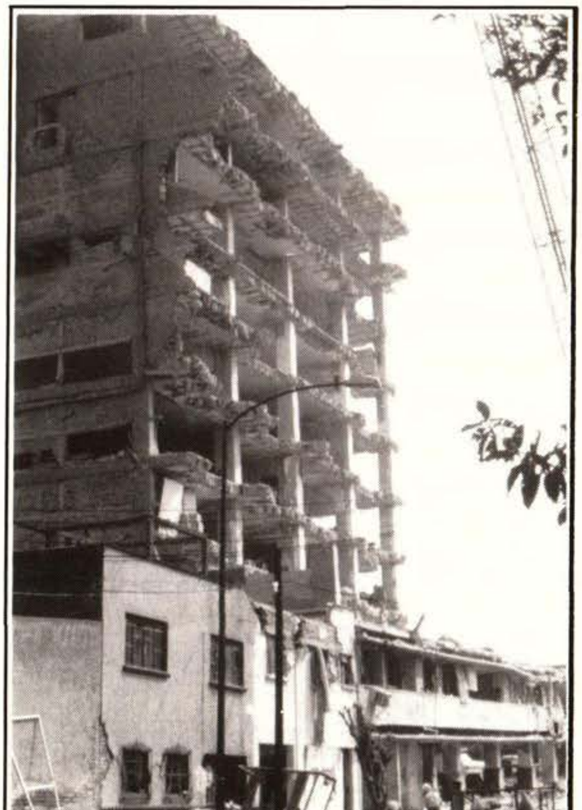


Figure 2.1
Secretariat of water supply, Mexico City, after collapse of the top 8 storeys of the first bay adjoining street facades.

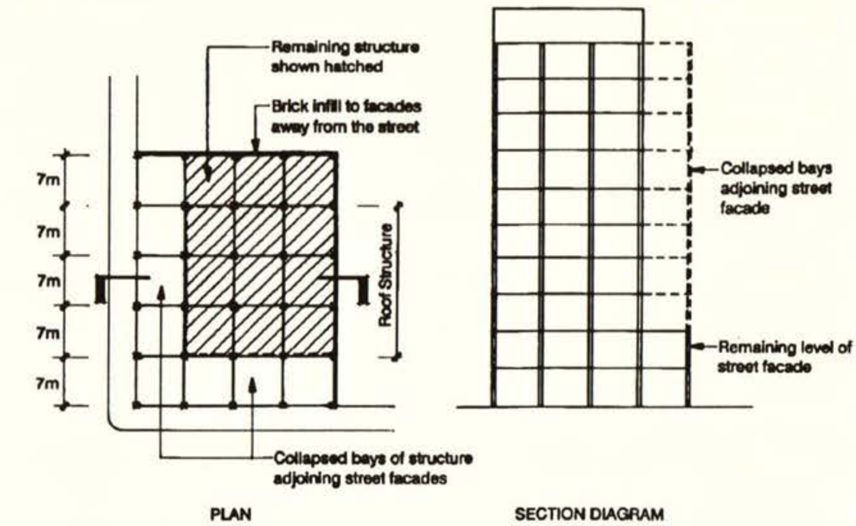


Figure 2.2
Diagrams of the Secretariat of Water Supply, Mexico City (cnr Juan a Mateus/Calz de Tlalpan). While the plan is symmetrical unequal stiffness of street facades and rear walls means seismic configuration is very poor.

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 on the facing page. 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. (Figure 2.3)

Key Points

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 buildings 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 the 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.

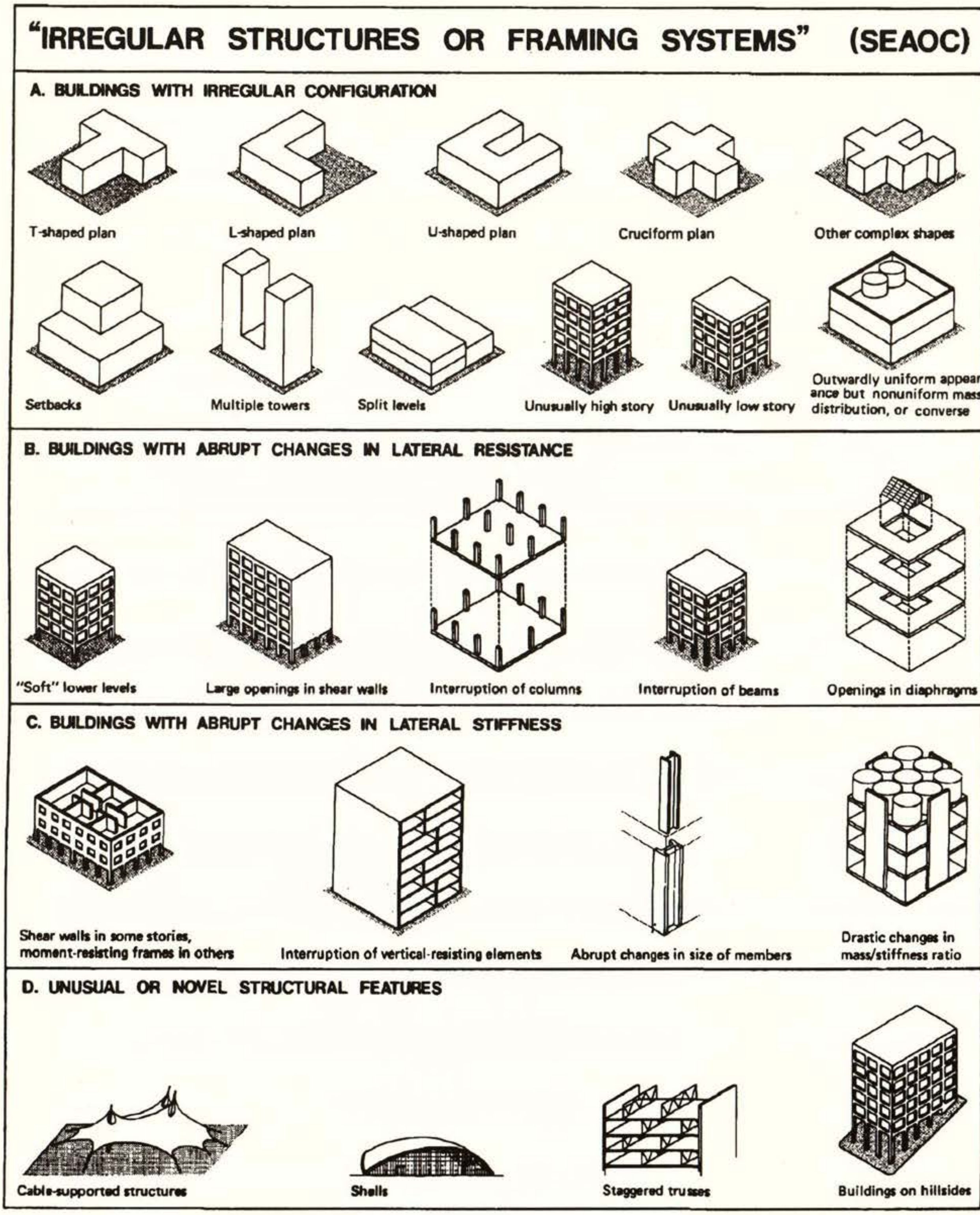


Figure 2.3
Graphic interpretation of irregular structures or framing systems from the Commentary to the SEAOC Recommended Lateral Force Requirements and Commentary.

> "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 the buildings 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 2.4
Hotel Intercontinental, Mexico City. Two narrow 15-storey blocks, separated structurally, but each block still flexible in the longitudinal direction. Collapse of the top 9 storeys of the right hand block was due to impact of one block with the other because the separation gap was insufficient. Both structures required demolition.

(1) Arnold, Christopher and Reitherman, Robert: Building Configuration and Seismic Design, John Wiley & Sons, New York, 1982, 296p.
(2) Ibid, page 5; from Tri-Services Design Manual, Washington DC: Dept of Army 1973, pp3-5 and 3-13.
(3) Arnold, Christopher: "Architectural Configuration and Seismic Performance in Vina del Mar, Chile", Building Systems Development Inc., Sept. 1990, Preface p.iv.
(4) Arnold, Christopher and Reitherman, Robert: "Building Configuration and Seismic design", John Wiley & Sons, New York, 1982, p. 5.

3
Implications of New Zealand Codes

The philosophy behind modern seismic codes of practice 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
Exterior non-structural damage to 22-storey steel-framed office building which was one of five towers forming the Pino Suarez complex in Mexico City.

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 buildings 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.

Loadings Code

At the time of writing NZS 4203 : 1984, the Loadings Code, (1) is used by all local authorities in New Zealand as their bylaw for earthquake resistant design. While the control regime will change once the new Building Act is in force, a version of the code will continue to be the principal verification method for seismic design under the proposed new national Building Code.

NZS 4203 : 1984 contains design force requirements for non-structural elements on, or in buildings, as well as inter-storey drift limits for the main lateral force resisting structure. Minimum separations between buildings are also included, and there is a special section on suspended ceilings. Each of these requirements is briefly reviewed below.

Design Forces

Design forces on non-structural elements and their connections are addressed in section 3.4.9 of the code - Parts or Portions.

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.

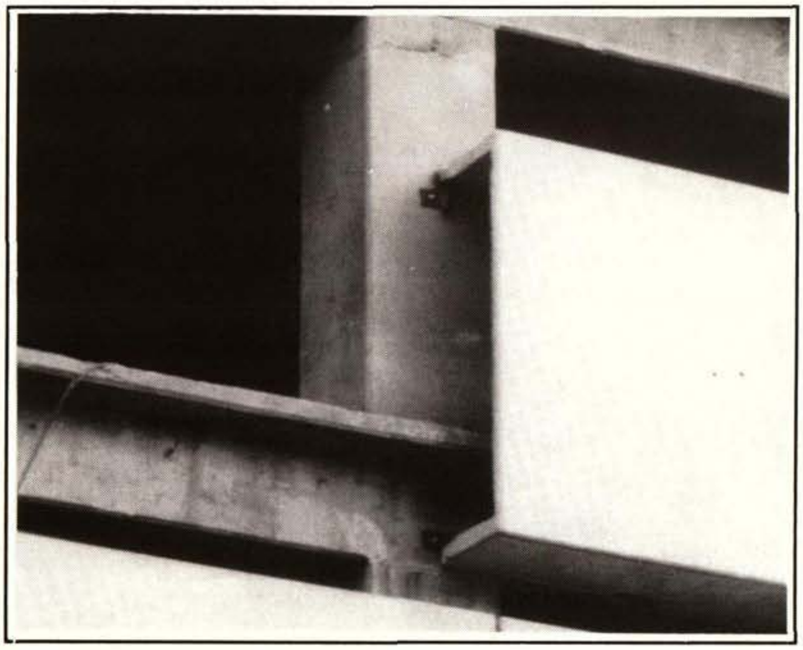


Figure 3.2
Precast concrete cladding panels being erected in Mexico City, 1985. This photo shows how NOT to do it! The poorly engineered details makes no provision for lateral movement in either the top or bottom fixing. Refer section 5 for information about how to do it.

There are also code requirements for connections of elements, which affects 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 3.8.3 and 3.8.4 of the code.

Drift is the result of swaying of a building in an earthquake. The engineer calculates the amount of drift (or inter-storey deflection) for a particular building, from the design forces, taking into account a factor for the seismic zone and a Risk Factor 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.

CATEGORY	DESCRIPTION	R	EXAMPLES
1	Structures containing highly hazardous contents	2.0	Highly toxic or corrosive products, or molten metal
2a	Buildings which are intended to remain functional in the Emergency Period for major earthquakes	1.6	Civil emergency centres; essential hospital and medical facilities; ambulance centres, fire stations; radio and television stations; telephone exchanges
2b	Buildings whose failure could cause high loss of life in the surrounding area	1.6	Fuel storage and distribution facilities for LPG, CNG or poisonous materials
3a	Buildings which should be functioning in the Restoration Period for major earthquakes	1.3	Central and local government facilities such as those for defence, non-essential hospital and medical facilities, electricity and gas supply authorities; prisons, post offices (major); air port buildings
3b	Buildings whose contents have a high value to the community	1.3	Major art galleries, museums, libraries and archives; buildings of cultural significance
4	Buildings with normal occupancy or usage	1.0	All other buildings.

Figure 3.3
Table 4, Risk Factor categories, with typical examples; from NZS 4203:1984 page 40.

The application of zoning makes a significant difference to the allowable drift. For example:

- if an office building in Auckland has an inter-storey drift allowance of (say) 20 mm,
- the same structure in Wellington would have an allowance of 30 mm.

Separation distance is the distance that the code requires between non-structural elements and the main structure so that they do not make contact with each other when drift occurs during an earthquake.

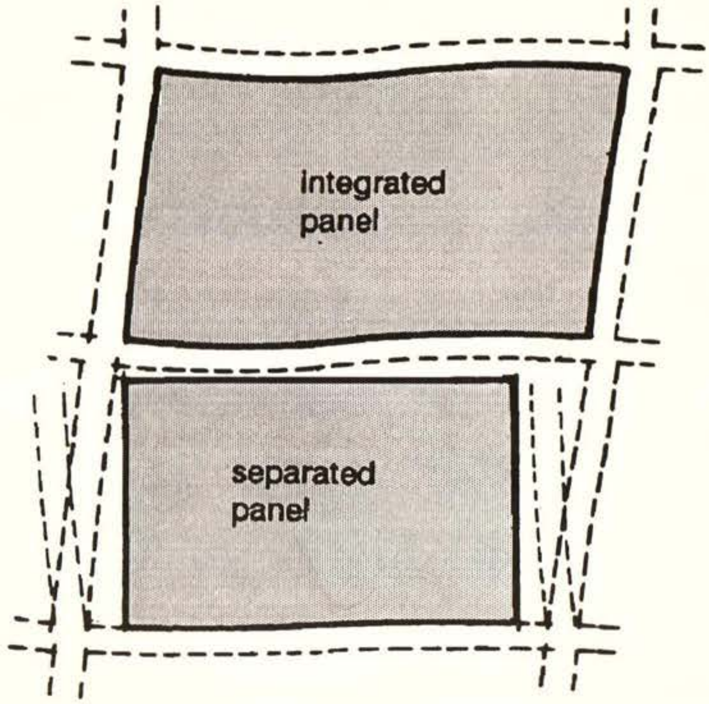


Figure 3.4
The diagram shows, in an exaggerated way, the flexure of a framed structure under lateral loading and the clearances required around an infill panel to avoid it making contact with structure.

Separation Limits and Application

When drift is less than 0.006 times the storey height, then no separation is required. This typically allows only 2 mm of movement between floors and in practice only applies to very stiff low-rise buildings

Drift of more than 0.010 times the storey height is not permittedin the highest risk zone, i.e. more than 36 mm in a building having 3.6 m between floors.

Most buildings fall between these limits and so separation for drift needs to be seen as 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.

In practice most buildings in which seismic drift is significant require at least 20 mm separation, plus and/or minus, i.e.

Details must allow for a total of 40 mm movement, in this case, as the structure sways 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.

> Ductility means the ability of the building or a member in a building to undergo repeated and reversing in-elastic deflections, beyond the point of first yield, while maintaining a substantial proportion of its initial maximum load carrying capacity. (2)

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 buildings 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.

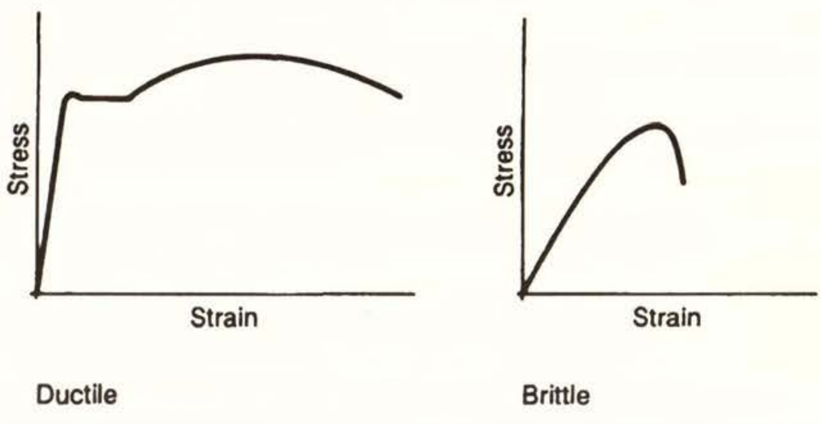


Figure 3.5
Variations in ductility: Steel is shown on the left and concrete on the right. Steel fails only after considerable in-elastic deformation has occurred, whereas unreinforced concrete is a brittle material and fails suddenly when its elastic limit is reached. However, reinforcing steel contained 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 in-elastic 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 seismic engineers adage:

> **Strong columns and weak beams - not the other way around**

Figure 3.6
Pancake collapse of a manufacturing building in Mexico City because the columns did not match the requirement for ductile behaviour.

In fact, ductility in the structure can be most useful because inelastic yielding absorbs large amounts of energy. This means that the forces 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 frame would be; perhaps with smaller columns and beams.

  "Good", says the architect.

- But because the structure is more flexible the separation 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.

The intention of the NZ code is to approximately equalise damage protection of all buildings in a moderate earthquake. The "flexible v. stiff" building debate therefore requires consideration of relative costs of earthquake protection under each option.

Ceilings

In New Zealand ceilings should be designed for horizontal accelerations and mention is also made in the code of vertical accelerations, which are often nearly as large. Thus, heavy ceiling tiles can be dislodged. Suspended ceiling hangers are not required to be designed for compression caused by upward accelerations but connections must be able to sustain upward movements without disengagement. The connection of light fittings to ceiling systems must provide positive anchorage. (3)

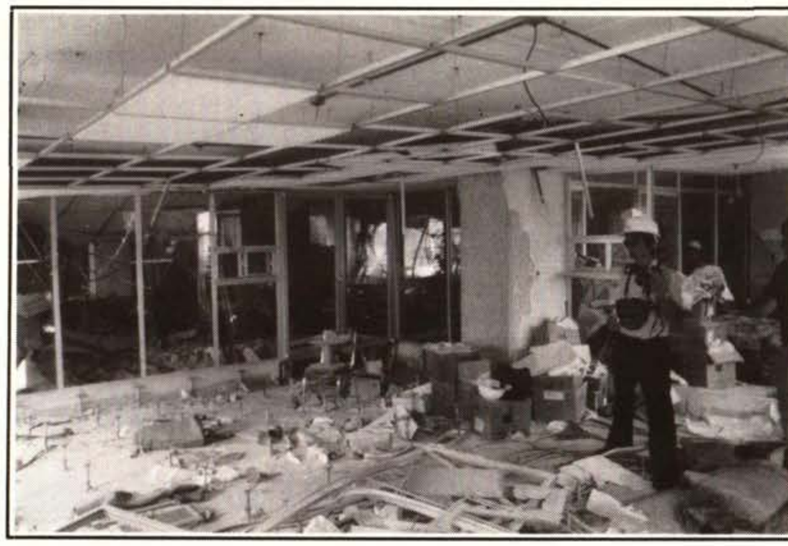


Figure 3.7
Failure of a very lightly framed suspended ceiling system in the Secretariat of Water Supply, Mexico City. Note the inadequate wire hangars.

Other NZ Codes

The code Seismic Resistance of Engineering Systems in Buildings, NZS 4219,(4) was introduced in 1983. The code specifies seismic design requirements for equipment and their fixings in buildings, with emphasis on services and other aspects not covered by this handbook.

The former Ministry of Works had their own Public Building Seismic Design Code, PW 81/10/1,(5) which contained special seismic requirements for buildings funded by Government. The code contained more stringent requirements than NZS 4203 for the protection of non-structural components, including exterior elements, windows, heavy rigid and lightweight partitions, suspended ceilings and stairs. Recommendations on materials best suited for element connections were included. At the time (1976) this code was more detailed than any other with regard to non-structural element design and detailing.

A more thorough review of the New Zealand code recommendations and their derivation is given in an article in the Bulletin of the NZ National Society for Earthquake Engineering, March 1985, by Hopkins, Massey and Pollard.(6)

(1) NZS 4203:1984, Code of Practice for General Structural Design and Design Loadings for Buildings

(2) Ibid, Definitions, page 12.

(3) Ibid, cl. 3.6.5, P56.

(4) SANZ, NZS 4219:1983, Specification for Seismic Resistance of Engineering Systems in Buildings, 37p.

(5) Ministry of Works and Development NZ, Code of Practice-Seismic Design of Public Buildings, Office of the Chief Structural Engineer, PW 81/10/1, 1976.

(6) Hopkins, D.C.; Massey, W.E.; Pollard, J.L.: Architectural Elements in Earthquake, A Review of Design and Construction Practice in New Zealand, Bull. NZNSEE, Vol. 18, No. 1, March 1985, pp21-40.

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
The choice of cladding and its interaction with the structure ...

Precast cladding, the Park Royal Hotel, Christchurch. Architects: Warren & Mahoney. *Photo reproduced with permission from Architecture New Zealand, May/ June 1989, p64.*

Figure 4.2
... can have a major influence on seismic response.

Curtain wall incorporating glass and lightweight spandril panels, Sun Alliance House, Wellington. Architects: Structon Group. *Photo reproduced with permission from Architecture New Zealand May/ June 1989, p67.*

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, 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 code requires separation of non-structural elements if calculated lateral movement is more than 2 mm floor to floor. 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.

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 facade 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 facade elements.

Figure 4.3
Partially collapsed older building in Mexico City. Note the very light columns encased in masonry. Interaction between a relatively flexible r.c. frame and more rigid traditional masonry construction probably contributed to failure.

Today, the Code requires most structures to possess ductility, so that the risk of sudden failure is avoided. (A structure can be designed to remain elastic, but much greater seismic forces are then specified - 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.

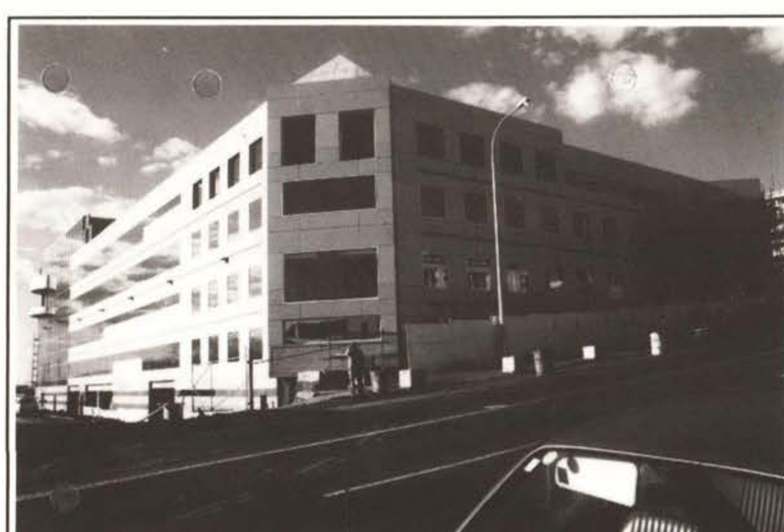


Figure 4.4
NZ Post Mail Centre in Auckland has a lightweight exterior cladding but large internal shear walls in association with a low-rise structure make it very stiff. Separation of non-structural elements was not required. *Architects: KRTA Ltd.*

Flexible Structures

Nowadays most medium and high-rise buildings are of this type and usually consist of a framework of beams and columns along each major axis. Lateral stiffness is generally provided by frame action, with the floors acting as diaphragms to distribute horizontal loads. If shear walls, or coupled shear walls, are incorporated they will add stiffness and such options need to be considered.

There may be pronounced drift between floors in an earthquake (up to 36 mm in a 3.6 m interstorey height is allowed under the current code). Potentially greater movement will occur if future codes allow even more flexibility, especially in steel structures, in the interests of lighter sections and hence structural economy.

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. If movement is not provided for then earthquake damage will certainly result.

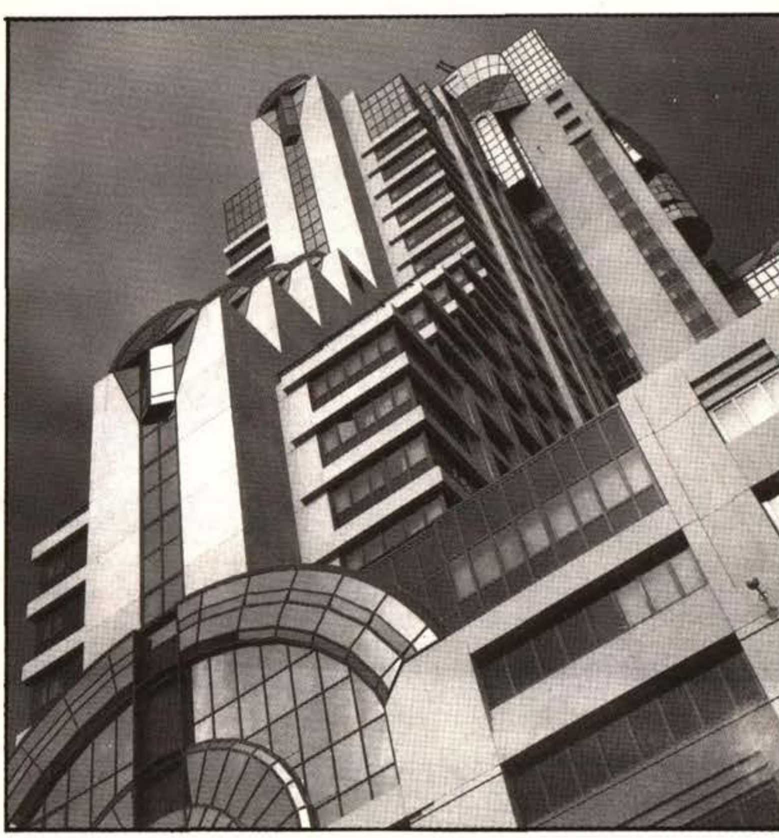


Figure 4.5
The 40 storey Marriott Hotel, San Francisco, in the soft soil area south of Market Street, covers most of a city block and has enormous four storey high reflective glass decorative fans at roof level. It suffered one broken pane of glass during the 17 October 1989 Loma Prieta earthquake (Richter magnitude 7.1). *(Source: Perry, Alan San Francisco Earthquake Report, Architecture New Zealand, May/June 1990, pp 89-90.)*

Architects: DMJM, San Francisco
Photo: Peter Leach, Philadelphia

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 forces.

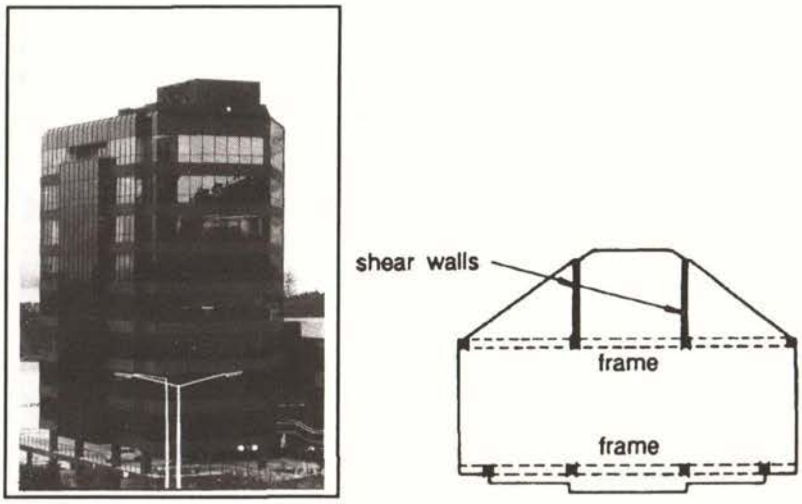


Figure 4.6
NEC House in Grafton Road, Auckland uses a combination reinforced concrete shear walls and beam/column frames. It is typical of many medium rise office buildings erected in the 1980s. Seismic movement was allowed for in both the curtain wall and precast concrete spandrels. Architects: KRTA Ltd.

Special Solutions

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

A relatively new approach (at least in actual application in buildings) is base isolation, 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.

Base isolation techniques have been used in a few buildings in New Zealand and on a number of other structures, such as railway viaducts. In the future base isolation offers promise for the economic preservation of historically important masonry buildings. It could be an alternative to more extensive (and expensive) strengthening techniques, which may be unsuitable when trying to retain architectural and historical character.

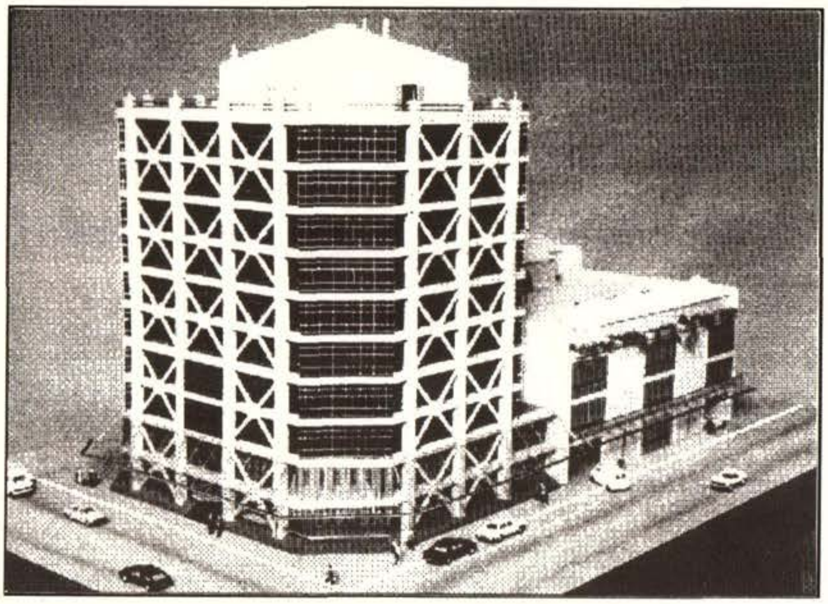


Figure 4.7
Base isolation has been used in the new Wellington District Police Headquarters and Central Police Station. The base isolation combines three components: long flexible piles standing within oversize casings; special spherical bearings at the pile tops; and lead extrusion dampers.
Architects: Works Corporation

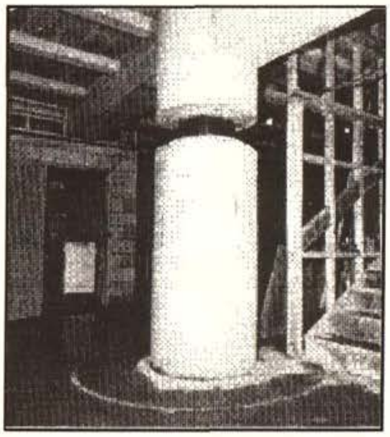


Figure 4.8
Spherical bearing positioned between the pile and the column downstand in the basement. Note cover plate over movement gap and horizontal seismic break in timber framing.

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)

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.

2. **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.

3. **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.

4. **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 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.

(1) Source: Arnold, C. "Cladding Design: Recent Architectural Trends and Their Impact on Seismic Design" Proceedings, "Architectural precast cladding - its contribution to lateral resistance of buildings" Chicago, Nov. 1990, p.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. (Refer Section 2: Configuration.) 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 (refer Fig. 3.3), 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.

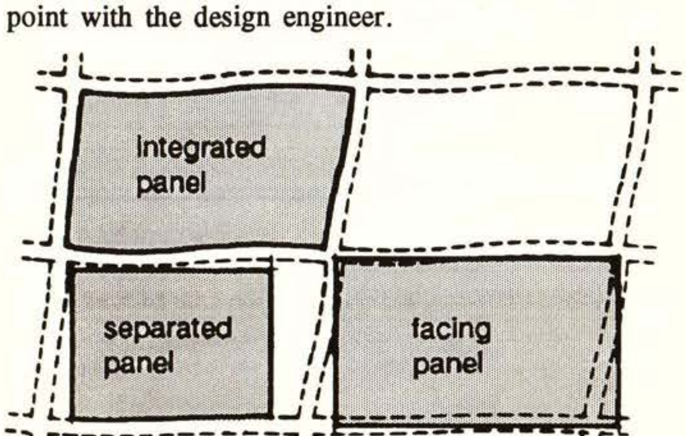


Figure 5.1
This diagram shows the basic options for cladding panels relative to the structure.

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.

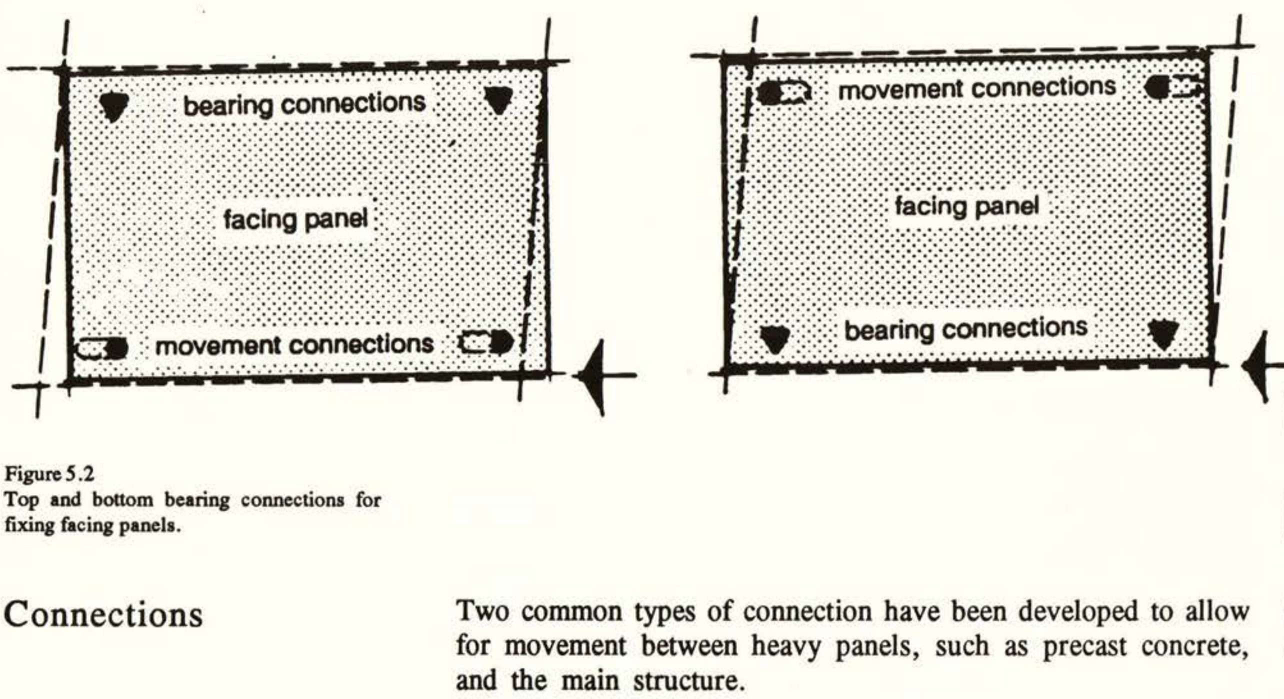


Figure 5.2
Top and bottom bearing connections for fixing facing panels.

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 this may be difficult to achieve.

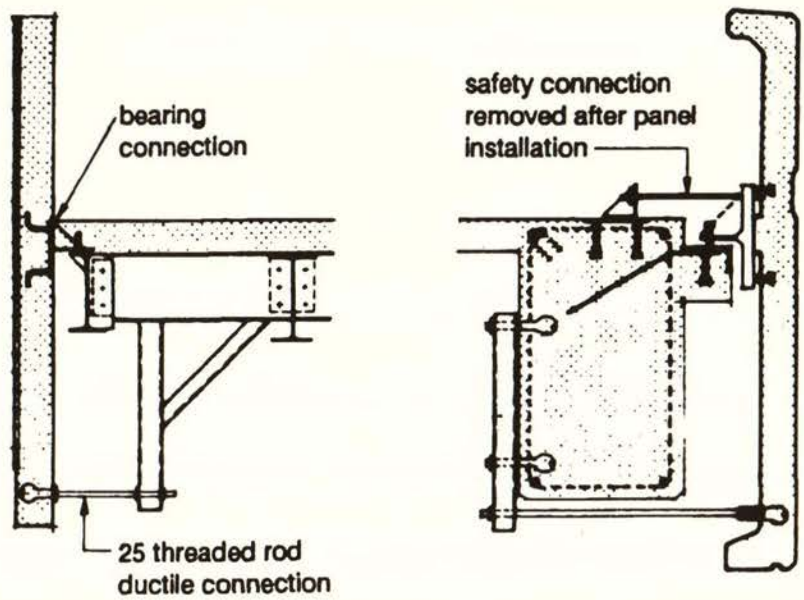


Figure 5.3
Rod (or `push-pull') connections to provide for movement. Typical details for steel structure (on left), concrete structure on right. Note that fire protection of fixings is not shown on these details and may be required.

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 overtightened 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.

(1) Rihal, Satwant, S.: ``Earthquake Resistance and Behaviour of Architectural Precast Cladding and Connections''. Proceedings; ``Architectural precast cladding - its contribution to lateral resistance of buildings''; Chicago, Nov. 1989, pp110-140.

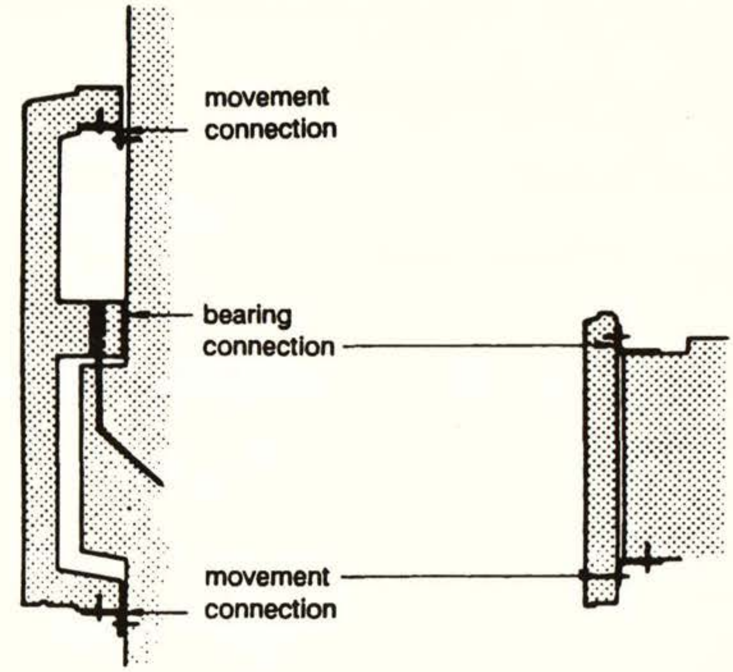


Figure 5.4
Two examples of sliding connections to precast panels. The example on the left has the panel bearing on a concrete corbel at mid-height, with movement connections at top and bottom of the panel. Movement in each connection is therefore reduced.

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.

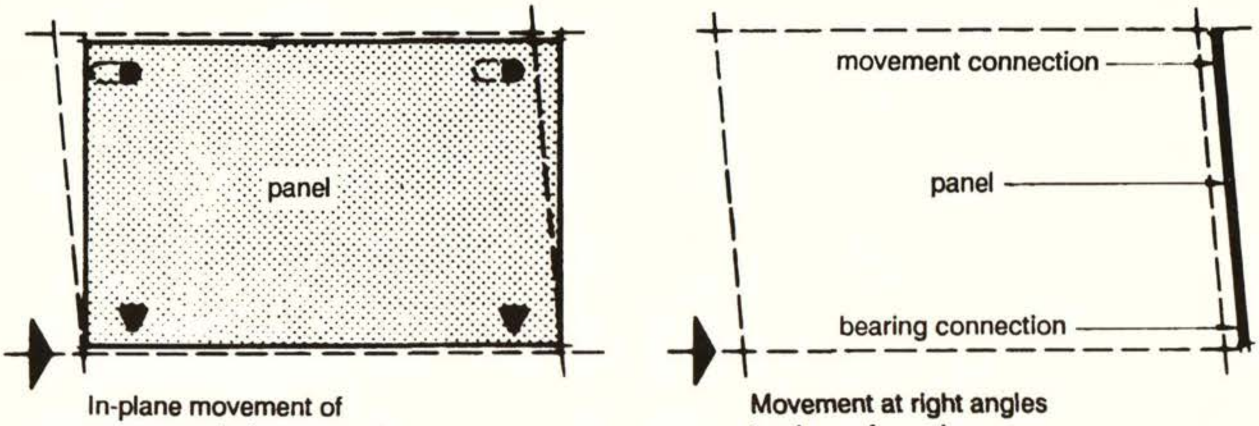
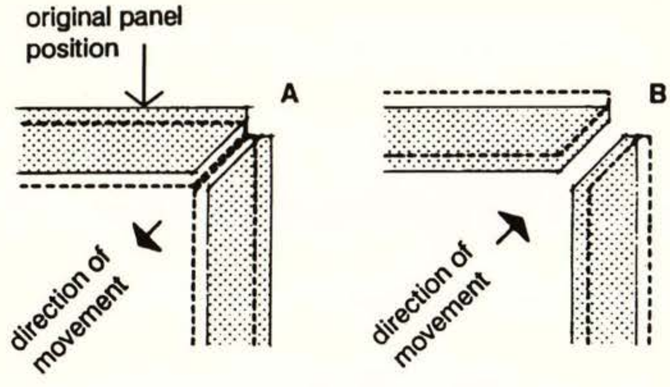


Figure 5.5
In-plane and out-of-plane movement of structure relative to panel.

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.



A Joint closes with movement. Impact must be avoided.

B Joint opens up. How is joint to be reinstated after earthquake?

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

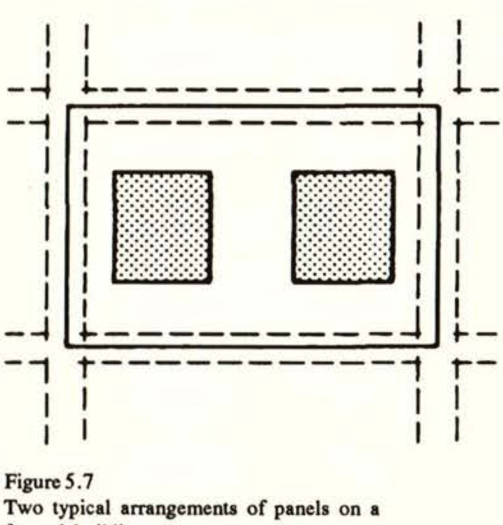
Panel Arrangement

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 may reduce the amount of movement to be accommodated at each joint.



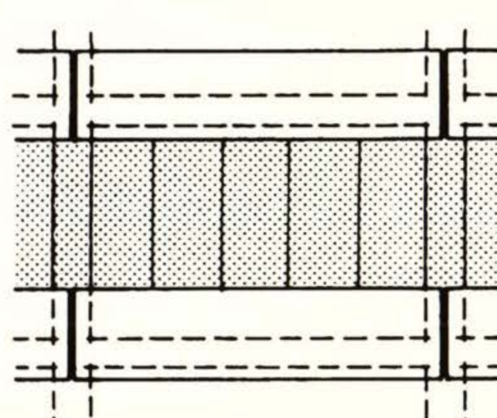


Figure 5.7
Two typical arrangements of panels on a framed building structure.

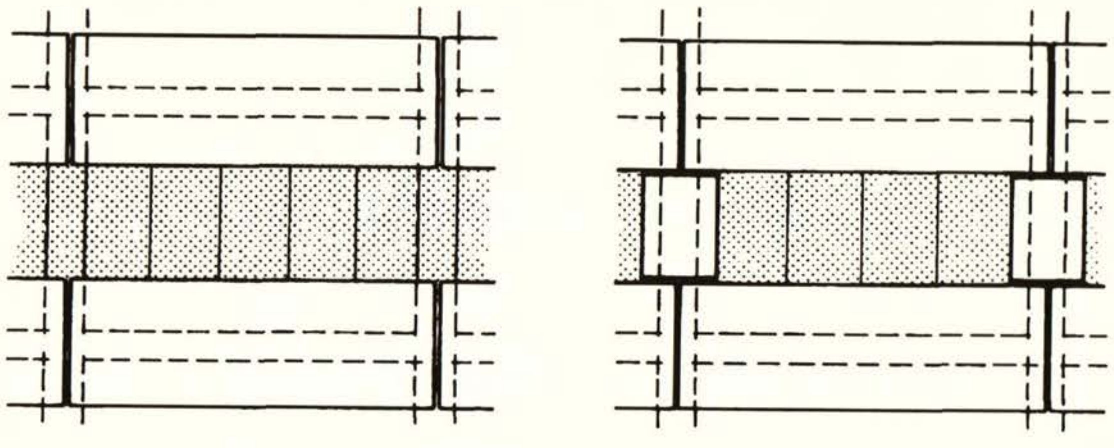


Figure 5.8
A further two common arrangements of facing panels.

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.

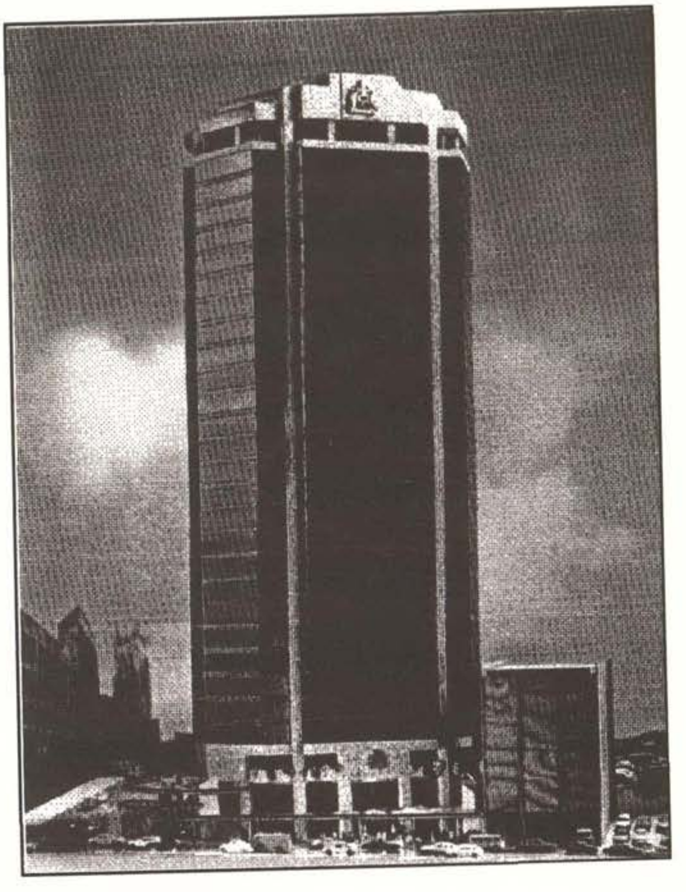


Figure 5.9
The ASB Bank Head Office building has granite cladding to foyer levels, columns and penthouse level, attached to either a reinforced concrete or a steel framed substructure.
[Architects: Peddle Thorpe Aitken. Reproduced with permission.]

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:

- o By attachment to a reinforced concrete or reinforced masonry substructure.
- o 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.

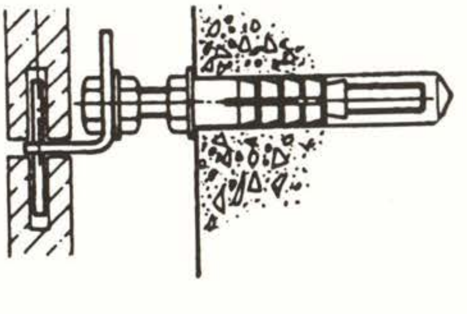


Figure 5.10
Typical stone slab fixing.

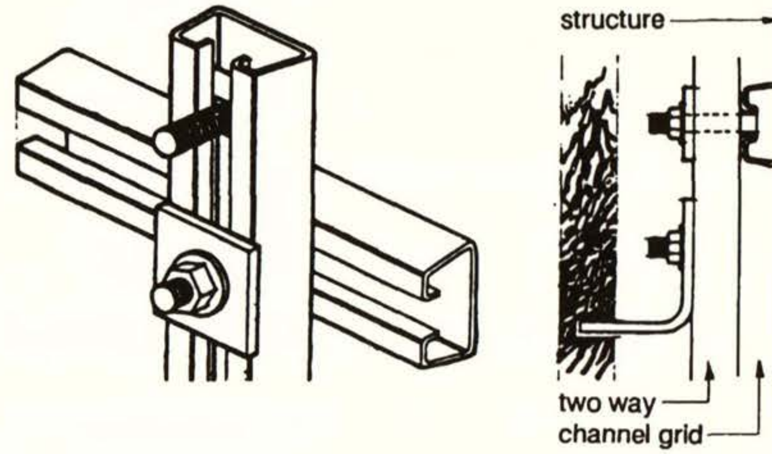


Figure 5.11
Two-way grid of lipped channels for adjustment of stone slab fixings.

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 closed spaced, and often a fairly stiff substructure, specially designed separation of panels of stonework may not be required, BUT consult the design engineer.

Figure 5.12
An Auckland office building clad in ceramic tiles mounted on panels.
[Architects: Andrews Scott Hill. Reproduced with permission.]

Ceramic Tiles 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.

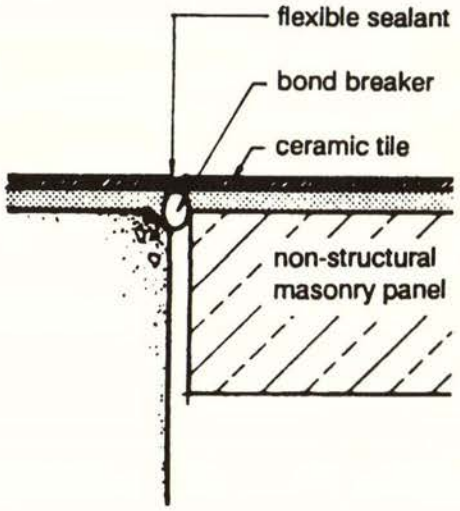
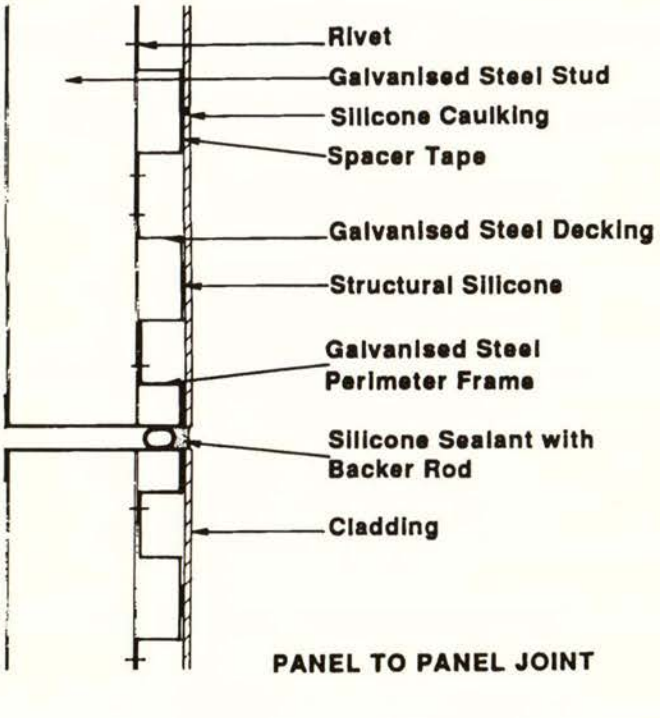


Figure 5.13
A flexible sealant joint of sufficient width to allow for drift is required at the junction of structural and non-structural elements.

- **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.

FLOOR TO FLOOR PANEL
-Set Back Windows



PANEL TO PANEL JOINT

Figure 5.14
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: NZS 4203 requires separation of brittle exterior cladding in these circumstances.

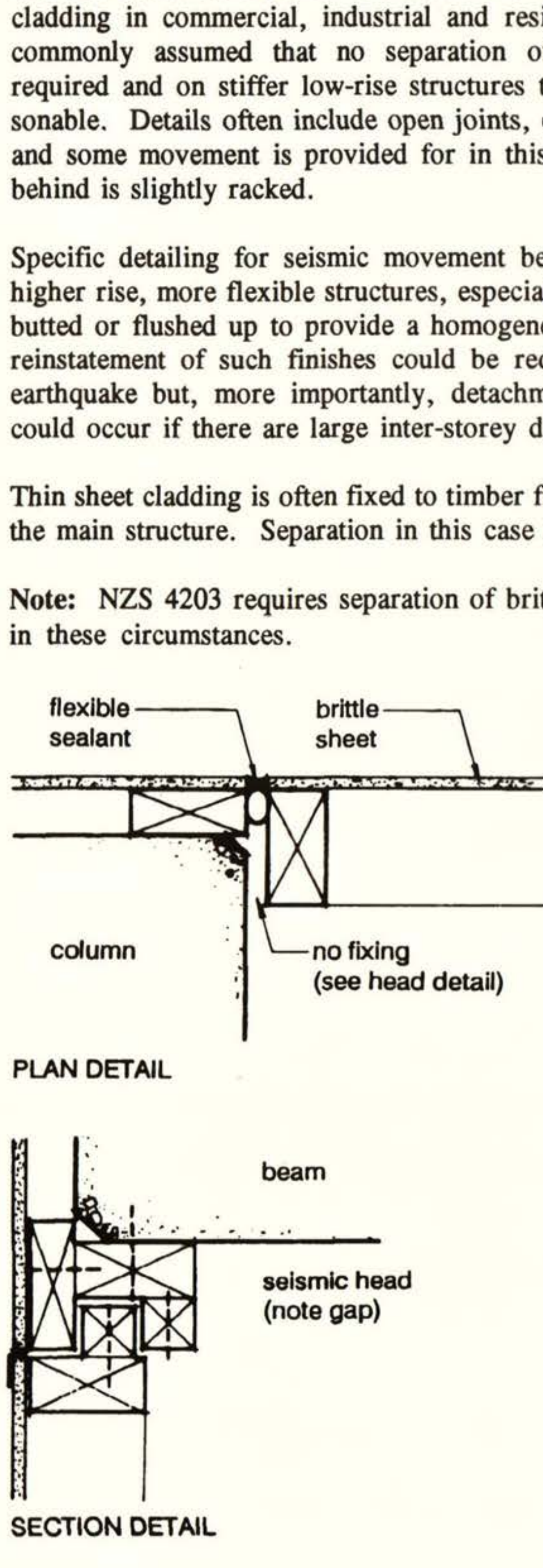


Figure 5.15
Seismic details to protect brittle cladding materials are not difficult to fabricate using conventional timber framing.

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.

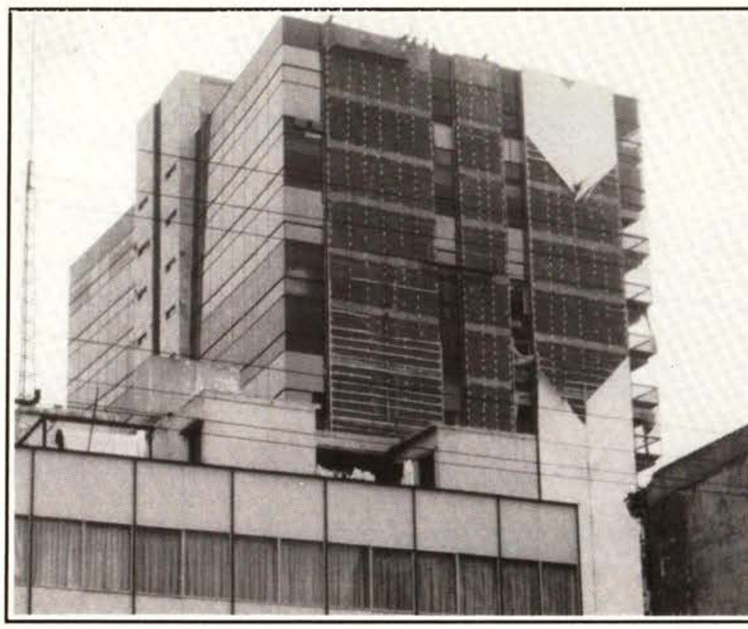


Figure 5.16
Strip metal cladding was lost from this bank building during the September 1985 earthquake in Mexico City, even though the unseparated panels of brickwork did not collapse.

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 freestanding 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 built to fail at openings and at corners under moderate earthquake attack.

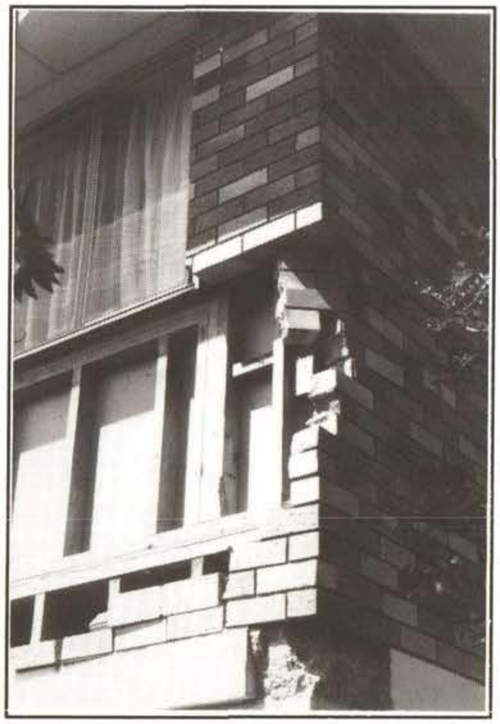


Figure 5.17
Corner damage of brick veneer after Edgecumbe earthquake on 2 March 1987. This house, built in the early 1960s, used twisted wire ties that are no longer allowed in veneer construction.

Veneer performance has been investigated by Lapish and other researchers (2), resulting in Monier Brickmakers Limited publishing a 20-page booklet offering guidelines for the design and construction of specifically designed veneer claddings extending above one storey in height. (3)

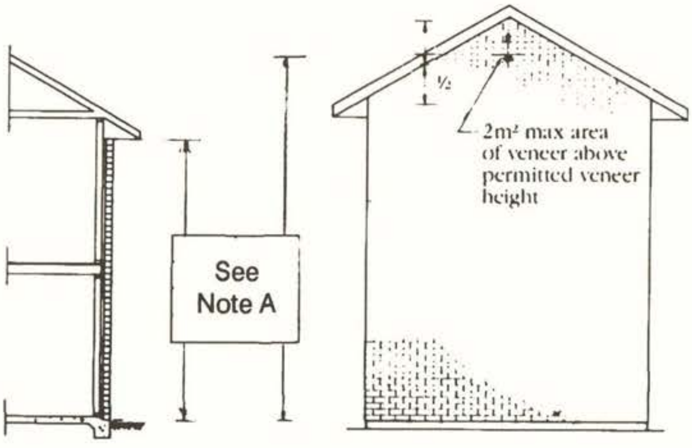


Figure 5.18
One diagram from Brickmakers Ltd Design Note 1A (June '87). Other diagrams and details are included.

Veneer, wall ties and supporting structures are subject to specific design and detailing procedures in compliance with NZS 4203 and NZS 4230, NZS 3603 for timber, AS 1538 for steel studs. **[Note A: Refer Table 11.2 in NZS 4230: Part 1: 1990 for current requirements.]**

Past deficiencies in the performance of brick veneers can be attributed to the common use of inadequate wall ties. The La Palle tie connector transfers face loads from the veneer to the structure, while catering for horizontal and vertical in-service and short term deflections of the timber framing.

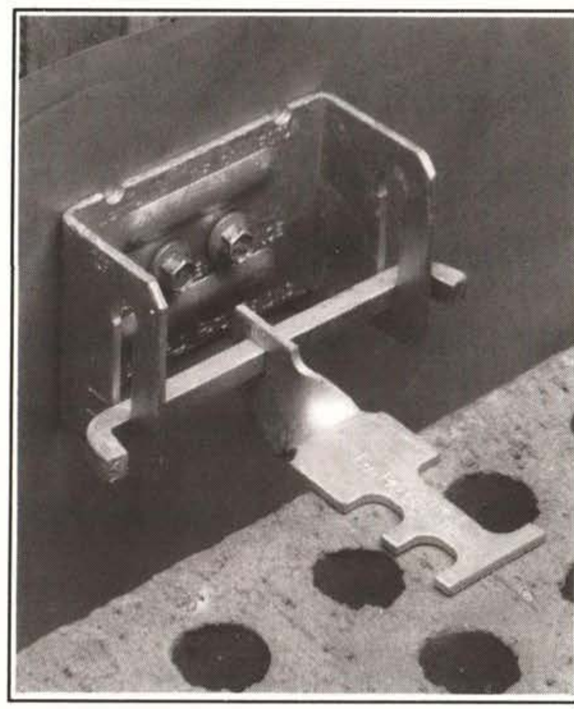


Figure 5.19
Illustration of the La Palle flexible tie connector.

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 attnetion should be given to detailing at openings and at corners of reinforced veneers.

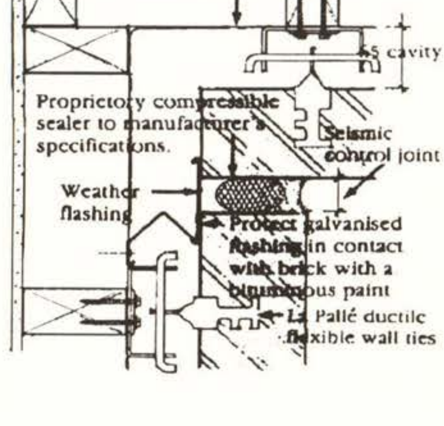


Figure 5.20
Re-entrant corner detail from Brickmakers Ltd Design Note 1A (June 1989).

(1) Rihal, Satwant, S.: "Earthquake Resistance and Behaviour of Architectural Precast Cladding and Connections". Proceedings; "Architectural precast cladding - its contribution to lateral resistance of buildings"; Chicago, Nov. 1989, pp.110-140.

(2) (a) Lapish E.B., Allen D. 1986. Variability of tie loads in Brick Masonry Veneer Construction. Proceedings 4th Canadian Masonry Symposium, Fredricton, Canada 1986.

(b) Allen, D. 1988. The La Palle Ductile Tie Connector. Proceedings 8th International Brick/Block Masonry Conference, Dublin, Ireland.

(c) Lapish, E.B. 1991. Aseismic Designs of Brick Veneer and the New Zealand Building Codes. Proceedings Pacific Conference on Earthquake Engineering, Auckland, New Zealand.

(d) Allen, D. 1991. Construction aspects of new masonry veneers. Proceedings Pacific Conference on Earthquake Engineering, Auckland, New Zealand.

(3) Monier Brickmakers Limited. Two Storey Brick Veneer Manual.

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 to accommodate to prevent damage in a minor earthquake; to reduce the risk of damage in a moderate earthquake; and to ensure, as far as is reasonable, that the total window/wall system does not fail no matter how major the seismic event.

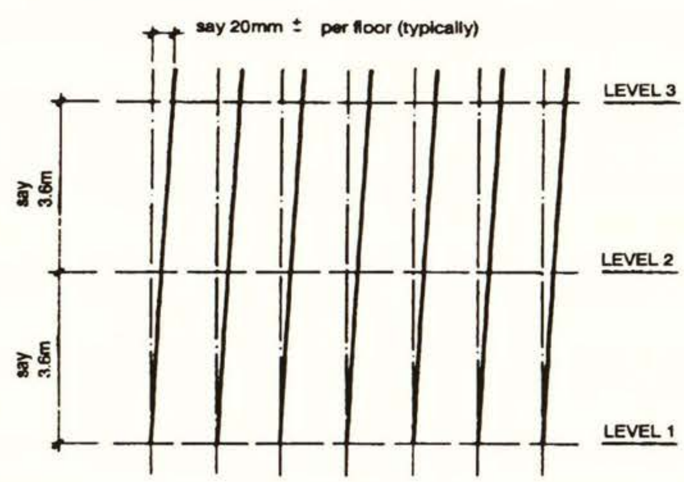


Figure 6.1
Diagram of flexure of curtain wall mullions over 2 floors in an earthquake (not to scale).

It is rare for a building structure to be so rigid that it does not deflect to some degree. Under current New Zealand code requirements if deflection is very small (up to say 2 mm drift between floors) then no special seismic separation details are required. But window details in most multi-storeyed buildings need to allow considerably more horizontal movement; plus or minus 20 mm is fairly typical and up to 35 mm (plus or minus) may be required. This can pose practical and visual difficulties.

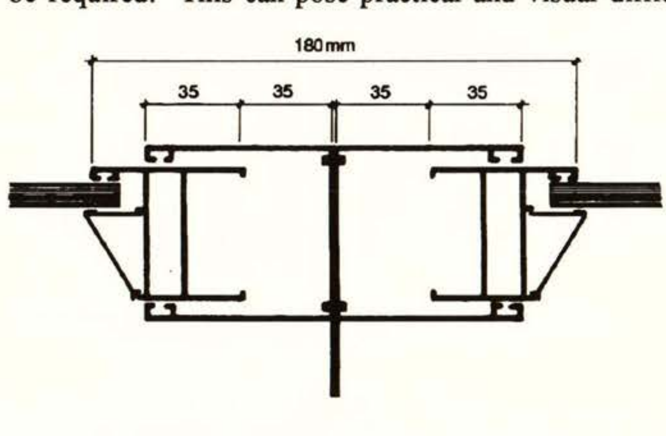


Figure 6.2
Detail of seismic mullion if 35 mm drift is to be accommodated. Note overall width of mullion - 180 mm MINIMUM.

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.

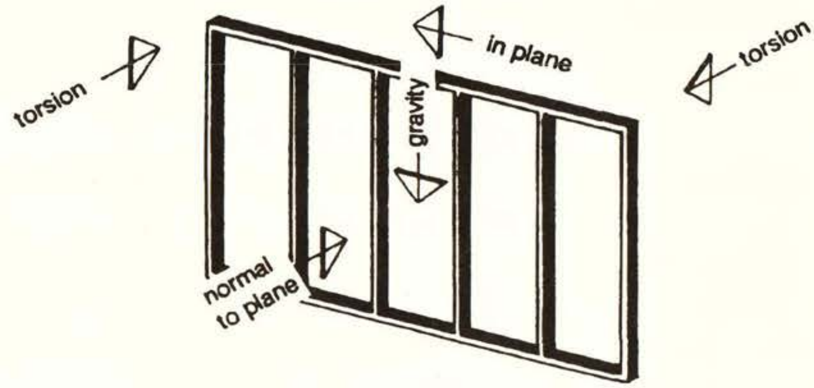


Figure 6.3
Diagram of types of load to which a window frame installed in a building may be subjected. All these loads may be reversing.

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 code 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.

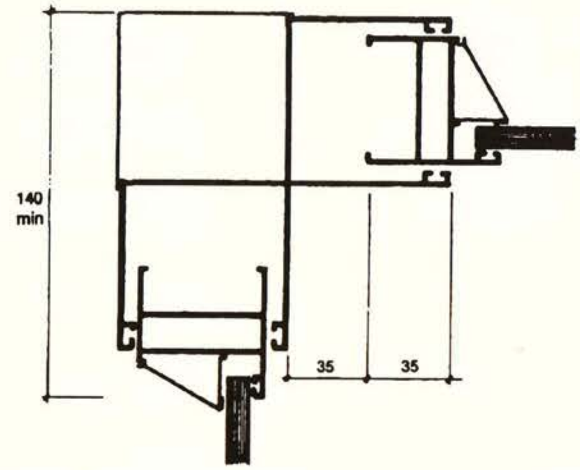


Figure 6.4
Would your client be happy with corner mullions like this? Should the structure be stiffer, or the fenestration concept be different?

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.

Any new building control regime, such as that envisaged in the Building Bill, will continue this surveillance of cladding design where safety is an issue.

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 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.

Recent 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.

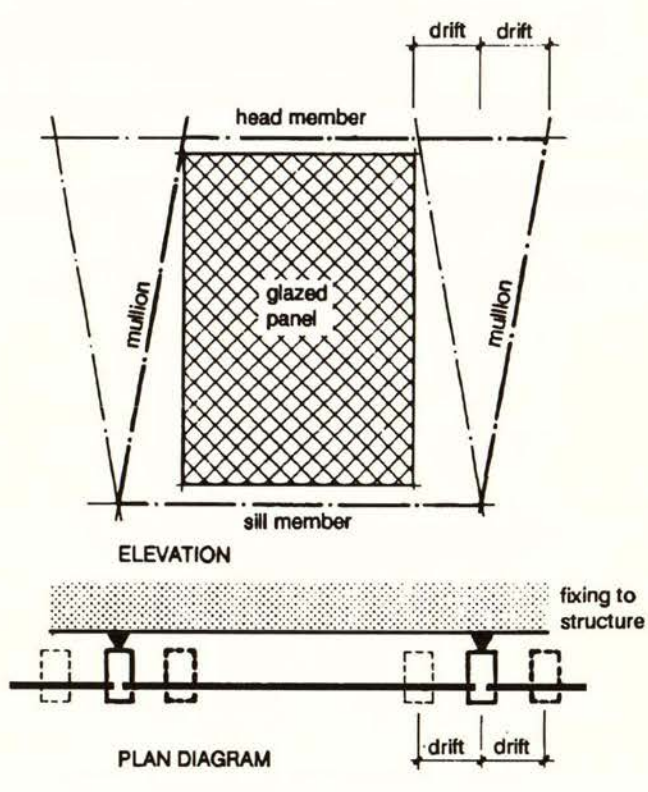


Figure 6.5
Diagram of a glazed panel showing the conventional approach to providing for `drift' (i.e. in-plane displacement).

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.

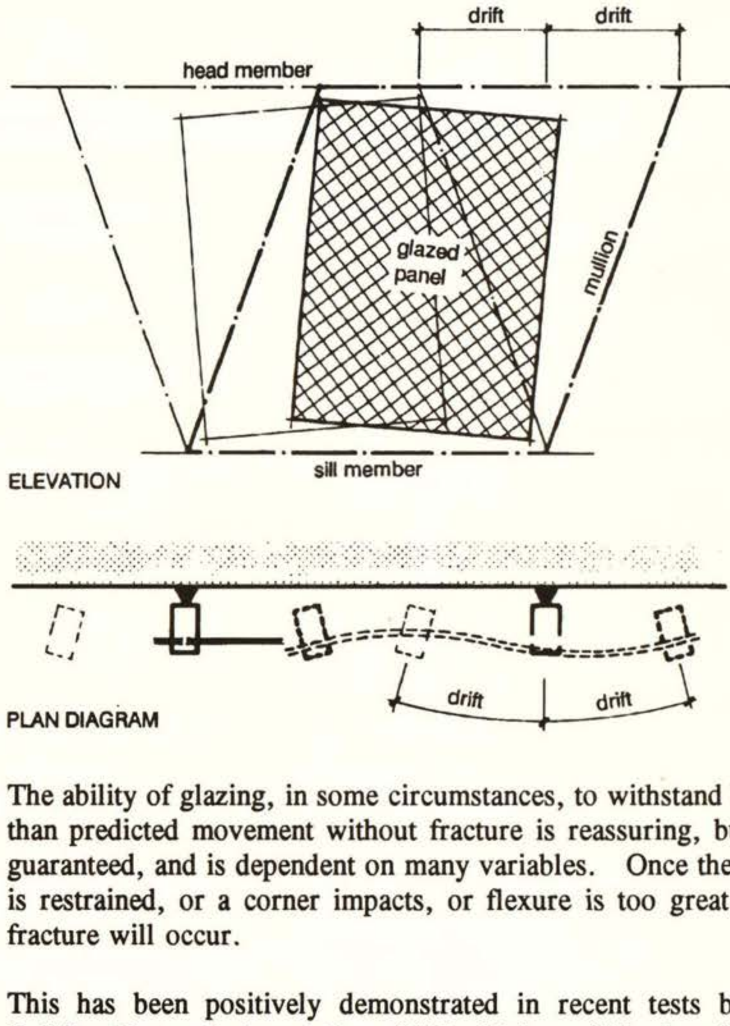


Figure 6.6
Diagram showing possible movement of a glazed panel relative to its frame and the structure. Note larger drift with the same size panel as Figure 6.5; also flexing of the glass as mullions are twisted. How far will rocking and twisting go before breakage?!

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 recent tests by the Building Research Association of NZ which are fully described in BRANZ Report No. SR39, ``Behaviour of External Glazing Systems Under Seismic In-plane Racking'' (1) It would be dangerous to generalise conclusions from this research, which is part of an on-going programme, and includes testing of corner assemblies.

However, 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 control documents.

- 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.

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.

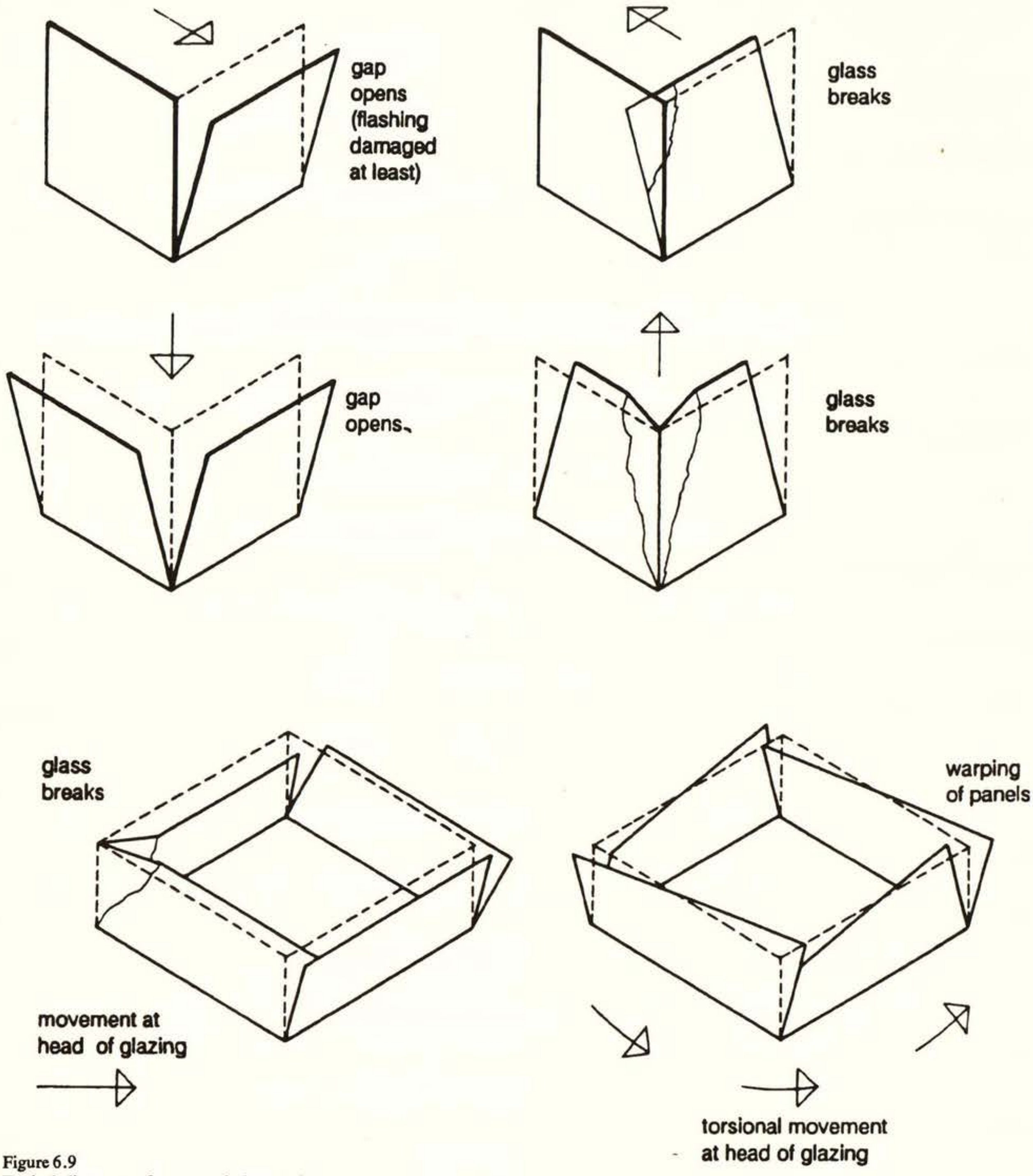


Figure 6.9
Typical diagrams of corner windows subject to deflection in an earthquake.
Source: Drawing based on diagrams by E.B. Lapish.

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.

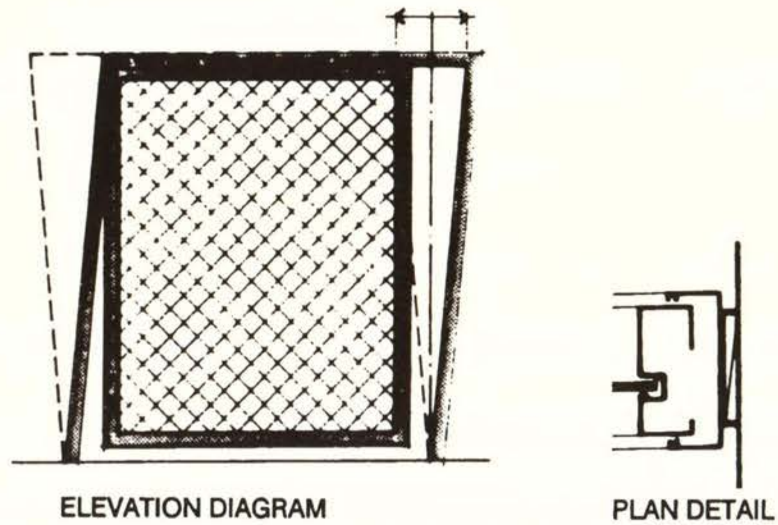


Figure 6.10
Seismic frame.
The glazed frame moves in a seismic frame, which moves with the building. The glazing frame is usually fixed at the sill.

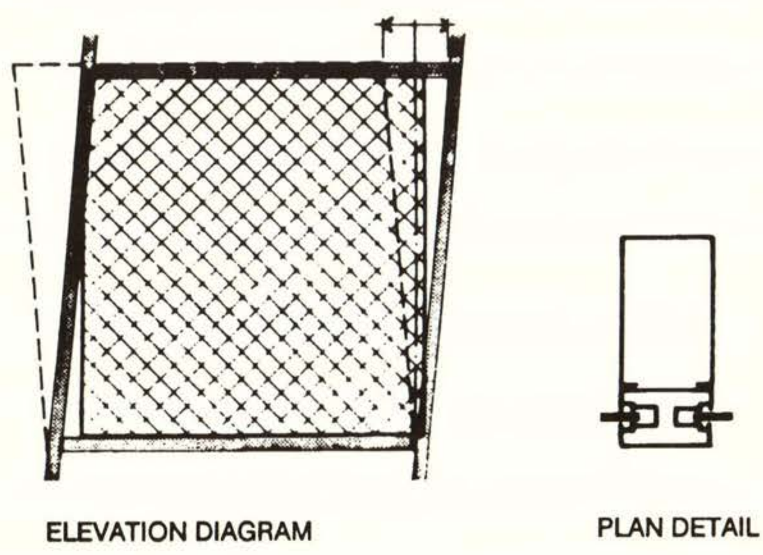


Figure 6.11
Glazing pocket.
The glass is usually gasket glazed direct into the frame with 'pockets' around the glass sufficiently deep to admit movement. This is a common approach in 'stick' systems.

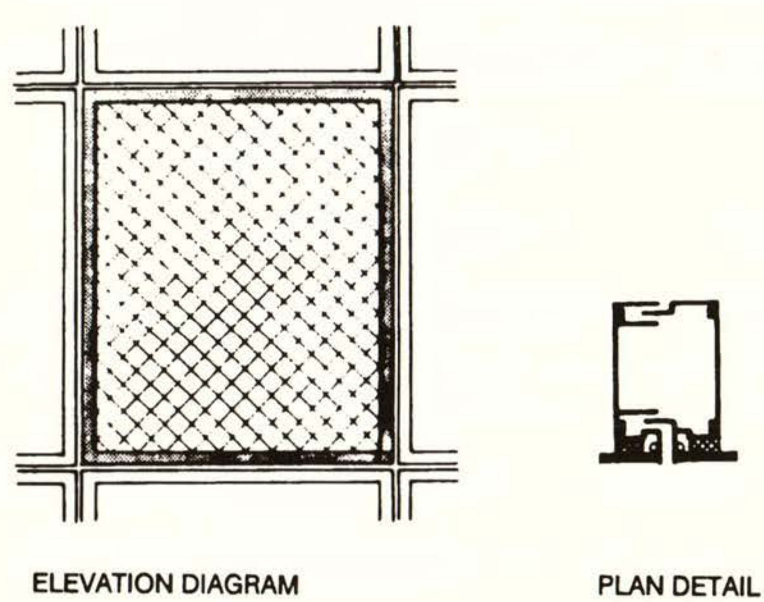


Figure 6.12
Unitised system.
Individual units interlock, with provision for movement between each unit, both horizontally and vertically. This approach has become very common in multi-storey work especially. Structural silicone is often used for fixing glass in unitised systems, but in this case the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

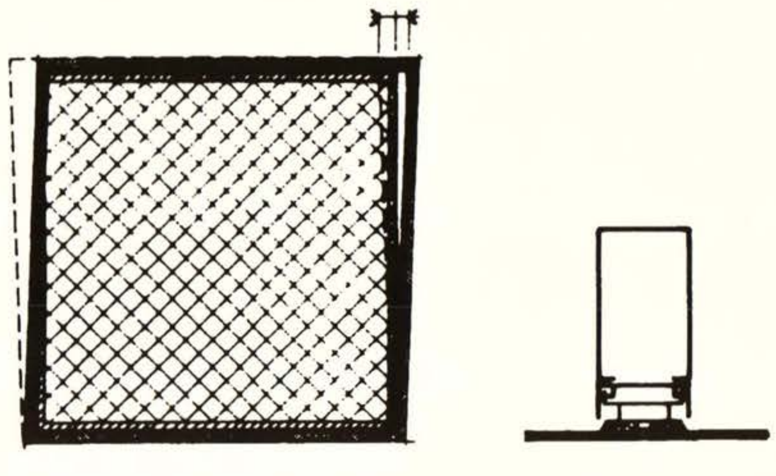


Figure 6.13
Structural silicone.
Where the other approaches provide a positive gap in this case movement depends on elasticity of the silicone. This approach is often used in conjunction with 'stick' systems.

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; 1986, ``External Flush Glazing Practices''.(2)

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.

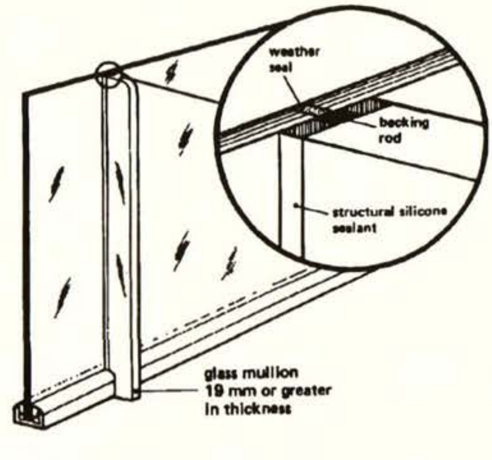


Figure 6.14
Glass mullion adhered with structural silicone to glass vision panel.
Illustration from BRANZ Technical Paper P45 : 1986, ``External Flush Glazing Practices''.

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.

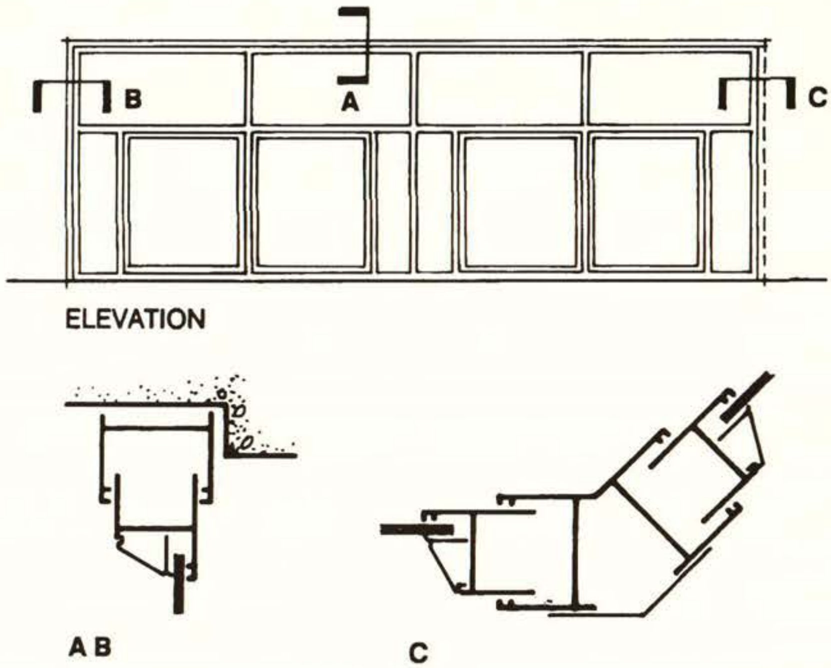


Figure 6.15
Typical seismic frame details for a commercial window suite used on a naturally ventilated building. The detail allows for a 20 mm positive separation gap over 2.1 m effective height.

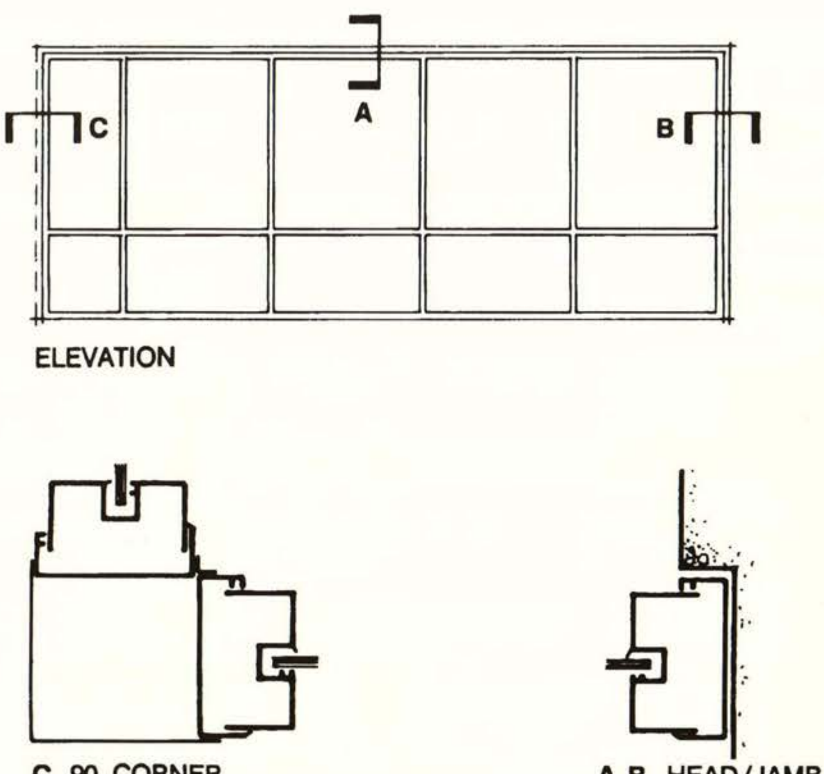


Figure 6.16
Aluminium box sections used in a seismic frame on a commercial office building. There is a 14 mm separation gap over 2.4 m effective height.

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.

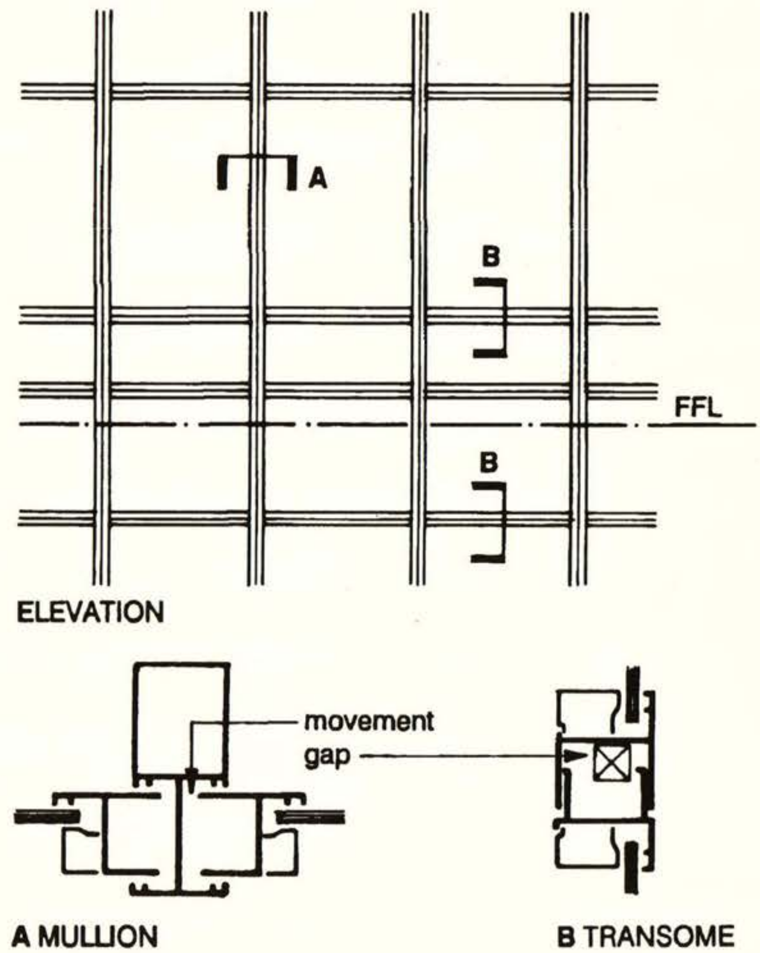


Figure 6.17
'Stick system' curtain wall with separate glazed frames 'floating' between mullions at each transome level. This is one approach to a stick system - Figure 6.18 shows another.

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.

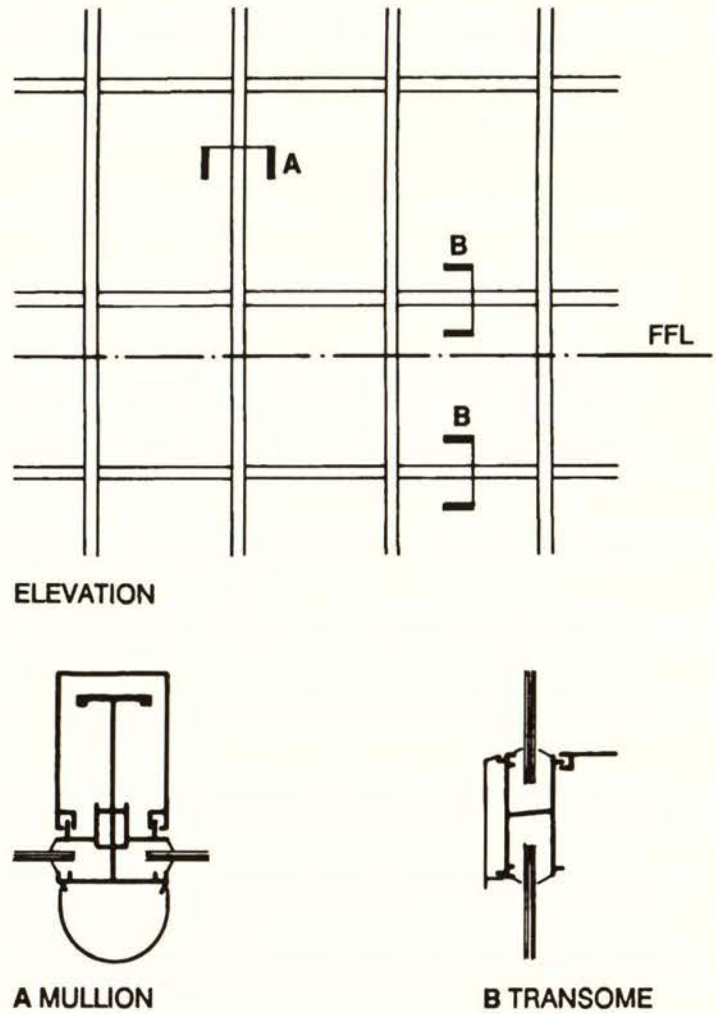
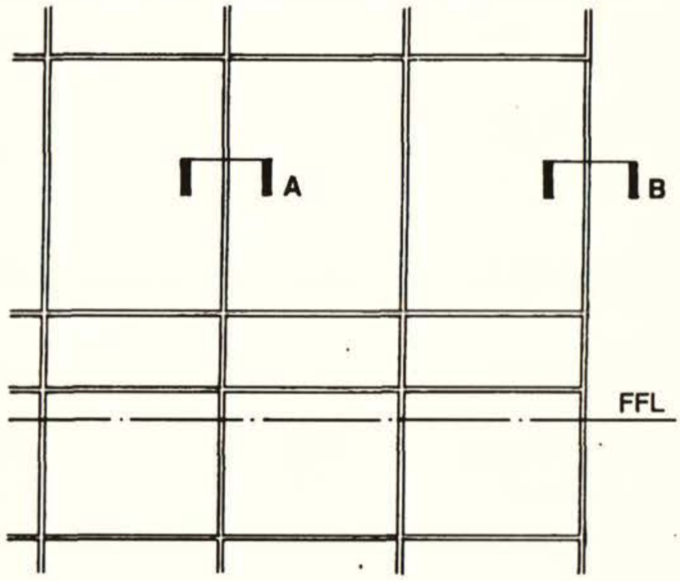


Figure 6.18
Stick system curtain wall with the glass dry glazed directly into the mullions and transomes with minimum 20 mm separation.

Unitised Systems

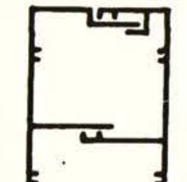
Two examples are shown: In both cases the same principles apply, although one building is a four storey speculative office block and the other a prestige double-glazed high-rise tower for an institutional client.

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.

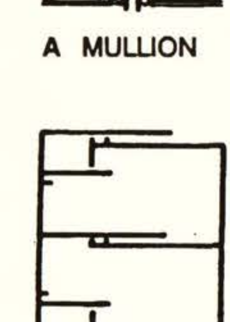


ELEVATION

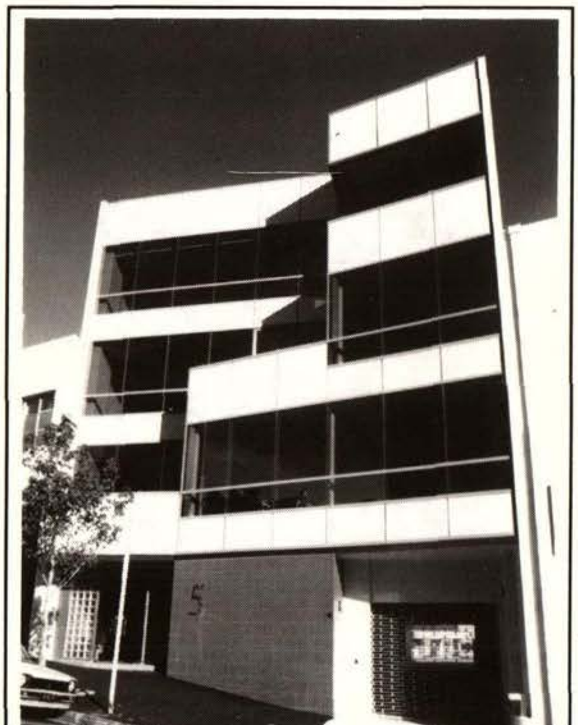
Figure 6.19
A unitised curtain wall system applied to a small office building. Structural silicone single glazing is used. An applied capping expresses the transome lines.



A MULLION



B JAMB



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.

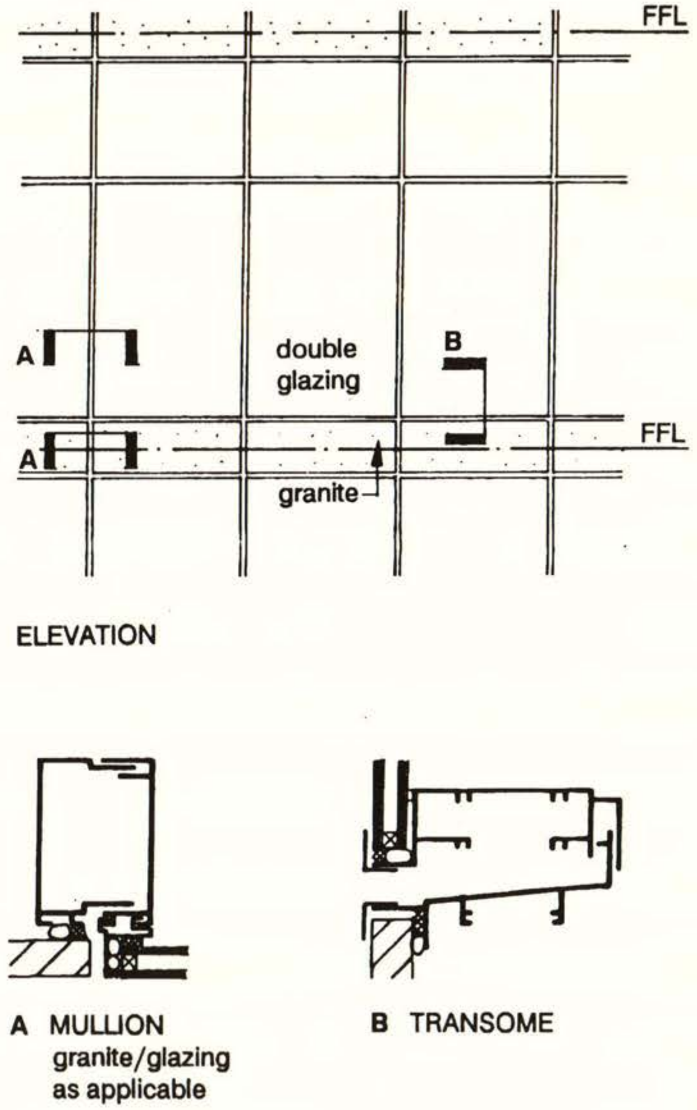


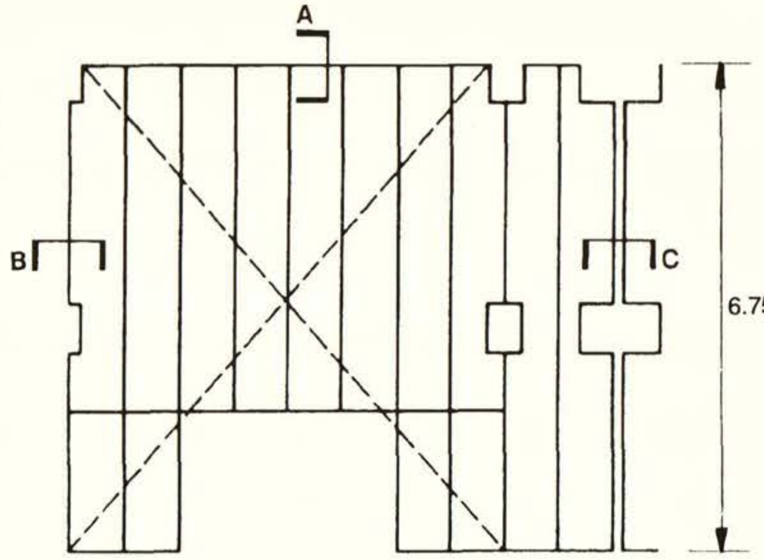
Figure 6.20
A unitised system incorporating double glazed units and granite spandrel panels. Whilst structural silicone is used a mechanical retaining angle is also provided at transomes.

Special Cases

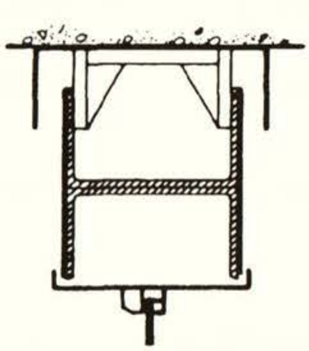
Three entirely different examples illustrate the range of complex situations that may arise:

Case 1

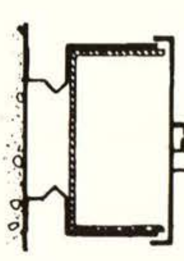
Figure 6.21
Details of the Studio windows in the School of Architecture, Auckland University. Each frame is nearly 7 metres square and made from welded steel, capped by aluminium glazing extrusions. The frame is stiffened by exposed bracing. Seismic movement is accommodated by using an enlarged purpose-made seismic frame.



ELEVATION



A HEAD



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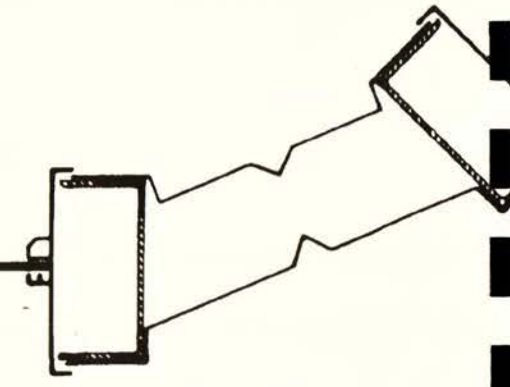
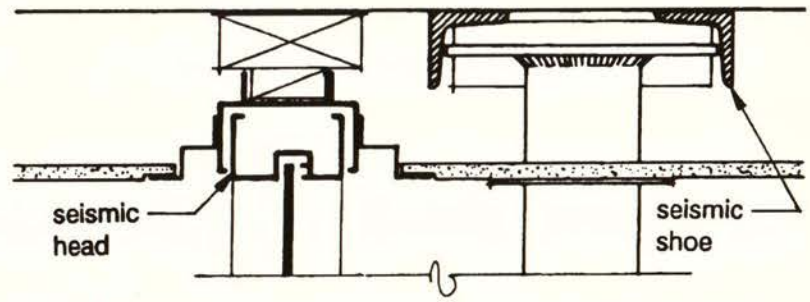


C SEISMIC SEPARATION
AT 45° CORNER

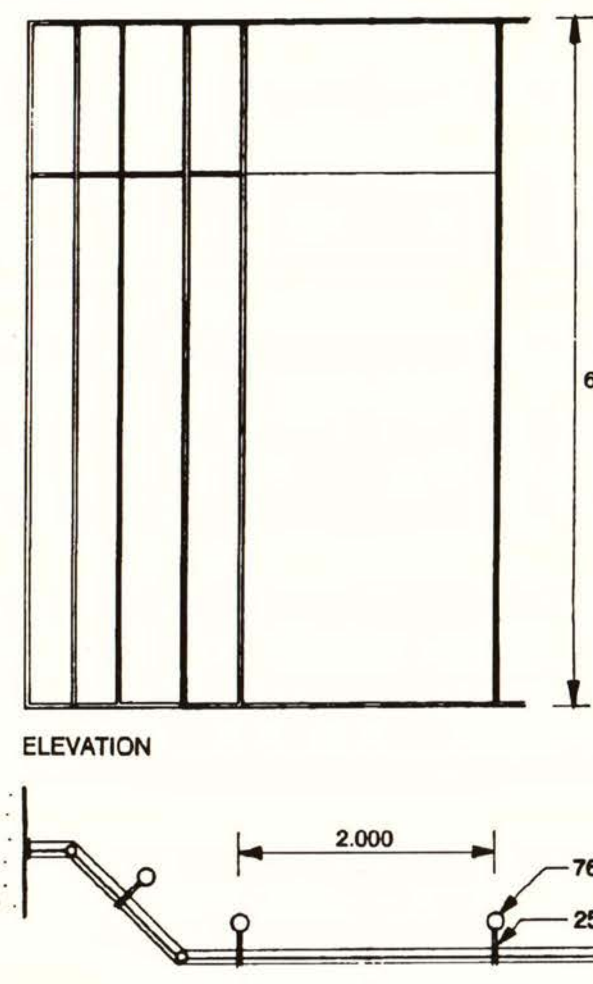
Case 2

Figure 6.22
The main glazing for Auckland's Aotea Centre required 10 mm thick toughened glass to be used in window panels sized up to 6 metres x 2 metres. Stiffened millions were required, with provision for seismic movement. Manufacturing restrictions also meant that horizontal silicone joints were required in the tall glass.

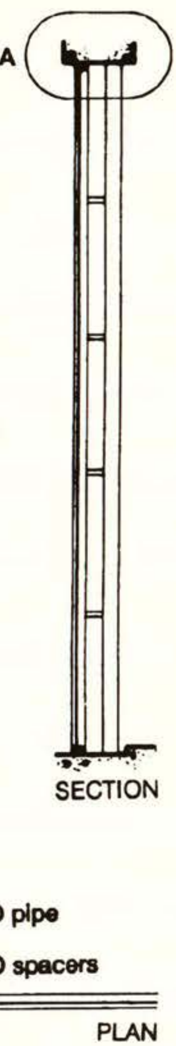
Where the glazing turns through 45¯ and 90¯ special details were developed at the corners using a tube mullions and H-section transomes. The detail supports the glazing under gravity, wind and impact loads but will accommodate interstorey drift in an earthquake.



A HEAD DETAIL

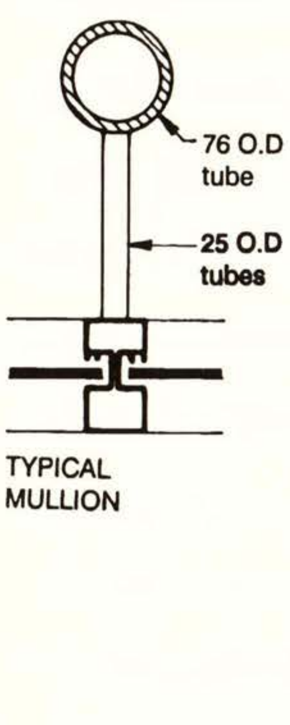


ELEVATION

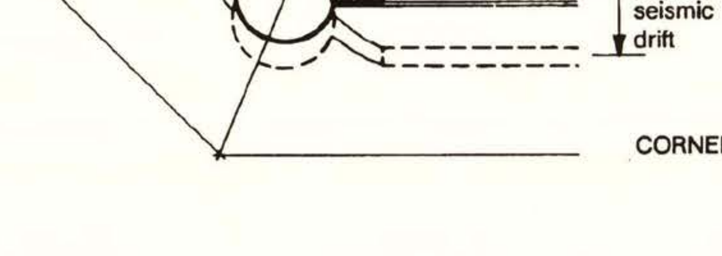


SECTION

PLAN



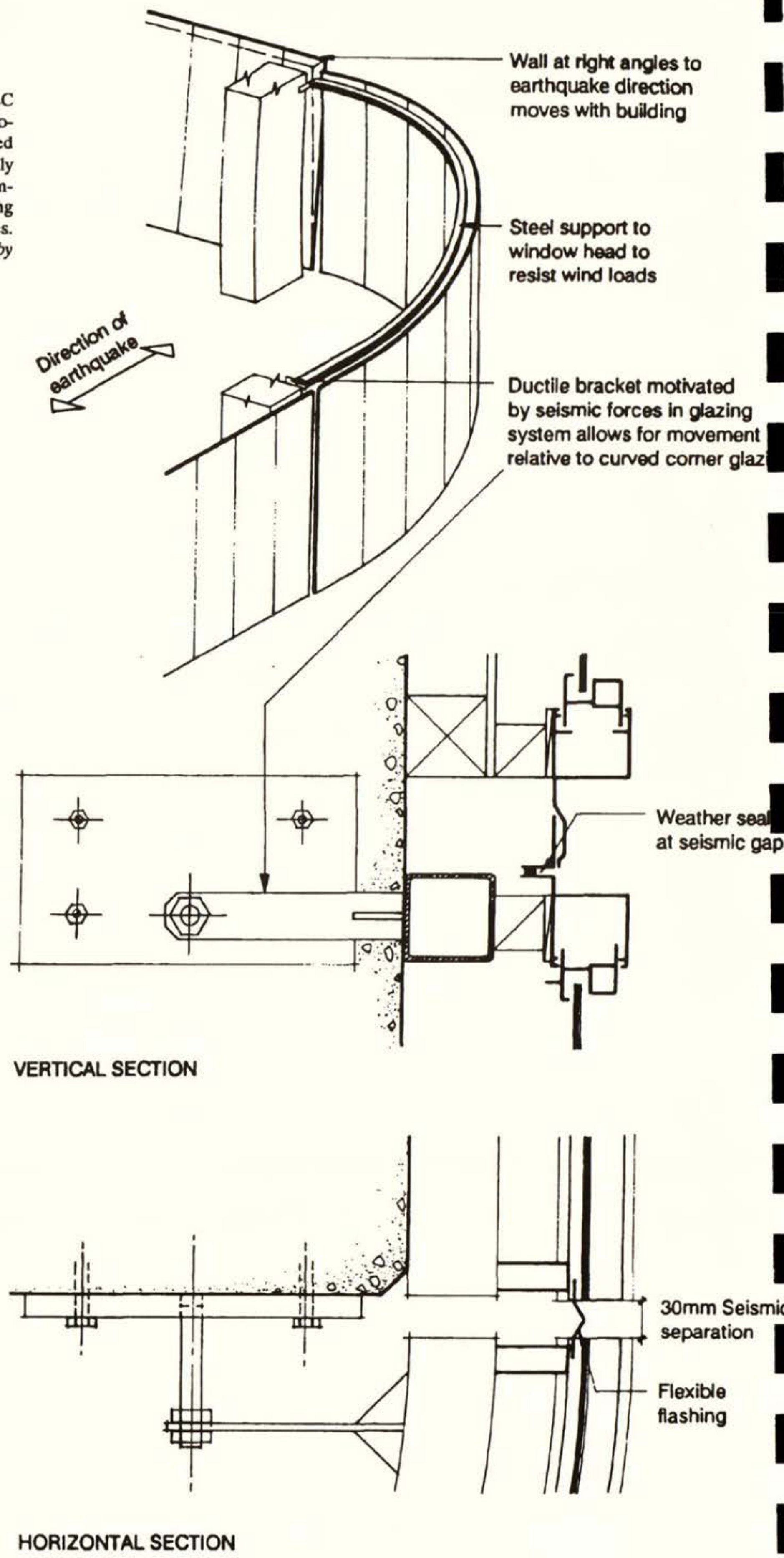
TYPICAL
MULLION



CORNER DETAIL

Case 3

Figure 6.23
These details were developed by CLC Consulting Group as a means of accommodating seismic movement in the curved corners of a multi-storey building. Only part of the detailing is shown. Such complex situations requiring clear thinking about both design and construction issues. *[Redrawn with permission from details by E.B. Lapish of CLC Consulting Group]*



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

Glass blocks are again popular and two recent BRANZ Bulletins (Nos 281 and 282) address selection, design and installation topics (3). Bulletin 281 includes comments (on page 3) that:

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.

It is also noted that:

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.

Both comments relate to earthquake movement.

(1) Building Research Association of New Zealand: Behaviour of External Glazing Systems under Seismic In-plane Racking, Lim, K.Y.S. and King, A.B., February 1991.

(2) Bennett, A.F.: External Flush Glazing Practices, BRANZ Technical paper p.45, 1986.

(3) BRANZ Bulletin No. 281, August 1991, Glass Blocks Selection and Design
BRANZ Bulletin No 282, August 1991, Glass Blocks Materials & Installation

7
Internal Elements

General Commentary

In the context of this handbook 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
Internal plastered brick partitions suffered extensive damage in Mexico City, September 1985. Usually no separation was provided.

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 in (say) a factory conversion, without an engineering check being made.

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

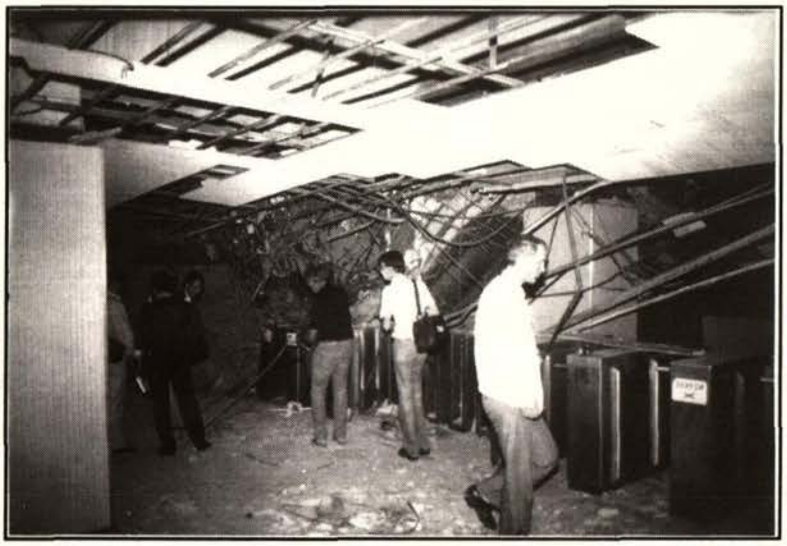


Figure 7.2
Ceiling collapse in the Pino Suarez Metro Station, Mexico City, September 1985.

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.

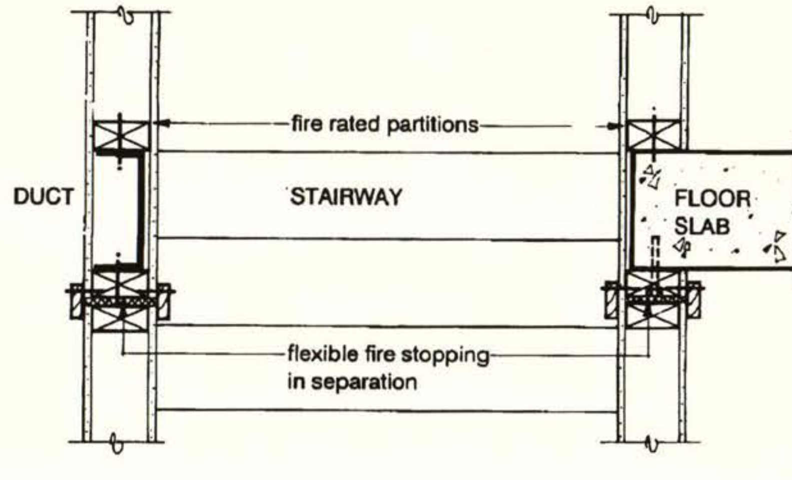


Figure 7.3
When separation details are required in partitions enclosing stairways fire ratings must be maintained.

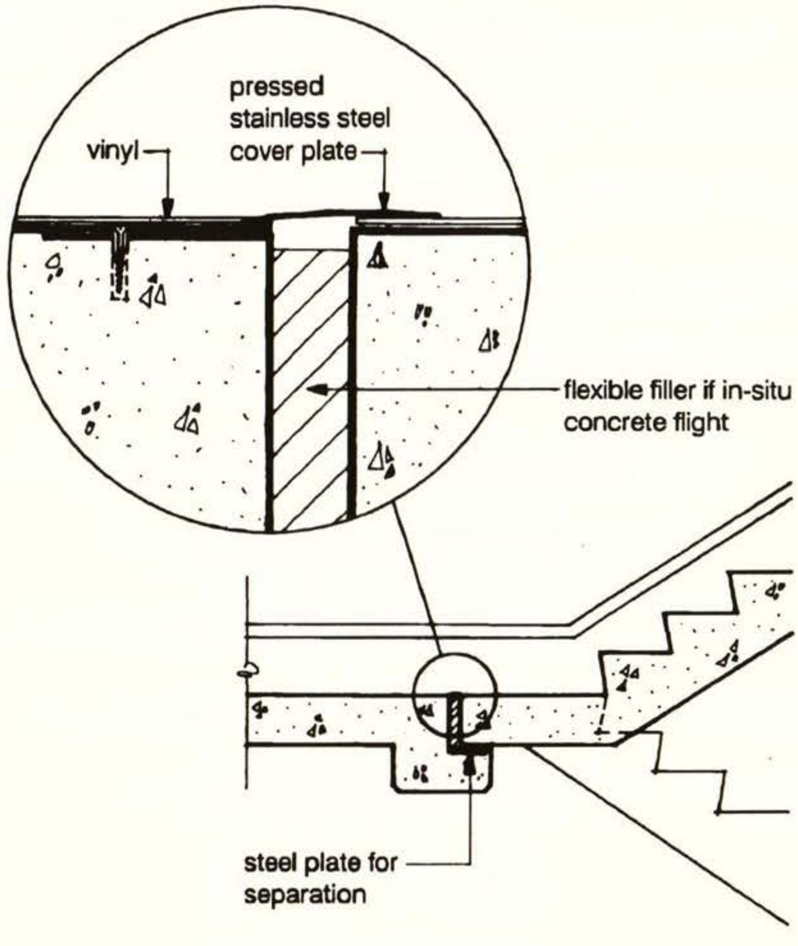


Figure 7.4
Separation of a stair flight at the landing. If a filler is used it must be flexible (or be removed after the slab is poured). Reinforcing omitted in this illustration.

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.

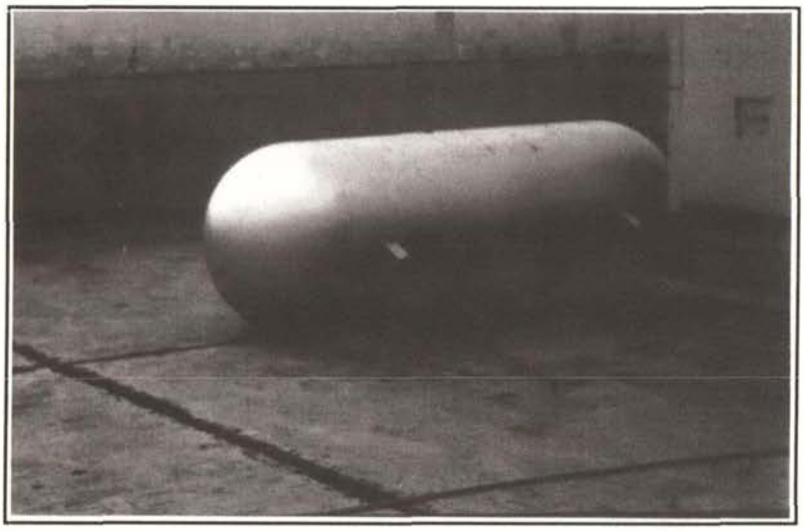


Figure 7.5
This gas tank rolled off its support during the Mexico City earthquake.

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.

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. Research on this and related topics has been described by A.W. Charleson. (1)

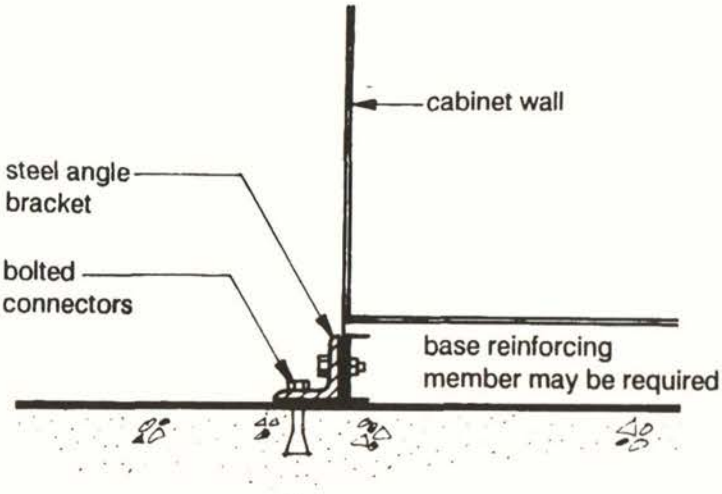


Figure 7.6
Bolt on fixing of a freestanding cabinet. *[Redrawn from "Earthquake Protection of Chattels and Light Office Equipment" by A.W. Charleson (1)]*

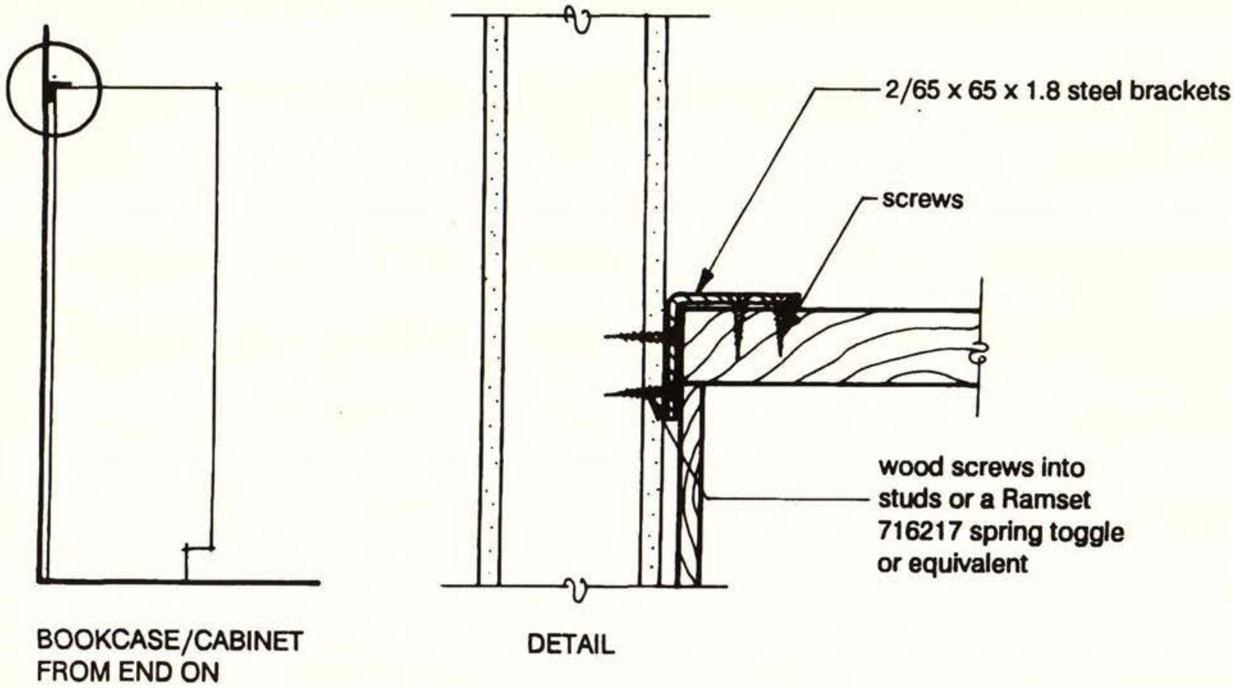


Figure 7.7
Restraint to top of storage unit against wall
[Source as Fig. 7.6]

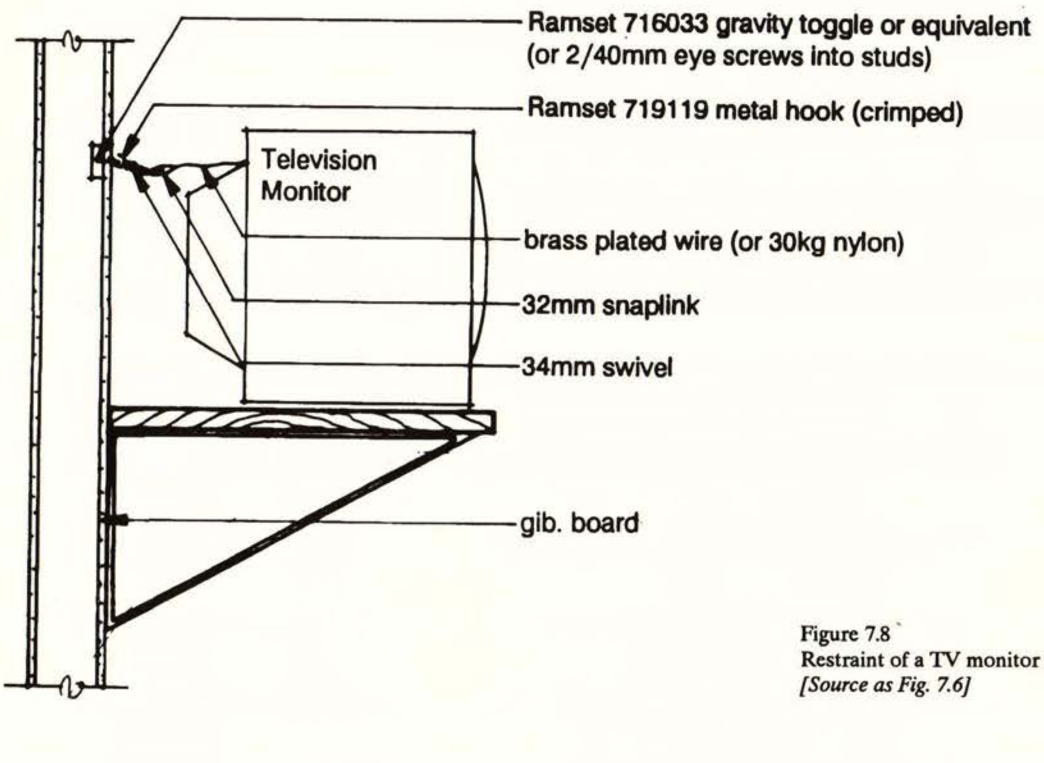


Figure 7.8
Restraint of a TV monitor on a high level shelf.
[Source as Fig. 7.6]

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.

Figure 7.9
Note the height of these storage units in an Auckland warehouse and their substantial loading. Clearly stability in an earthquake is in question.

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.

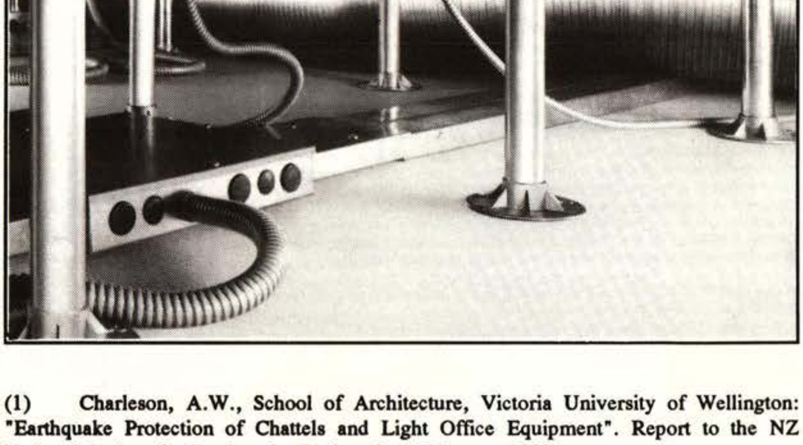


Figure 7.10
Pedestals supporting 600 mm x 600 mm floor panels (Cemac Access Floor system illustration)

(1) Charleson, A.W., School of Architecture, Victoria University of Wellington: "Earthquake Protection of Chattels and Light Office Equipment". Report to the NZ National Society for Earthquake Engineering, February 1989.

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.

NZS 4203 also requires that rigid partitions be anchored top and bottom, where this is required to provide lateral support or stability. To avoid stiffening the structure, the anchors must be able to 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 sway with the structure when deflections occur under seismic loading.

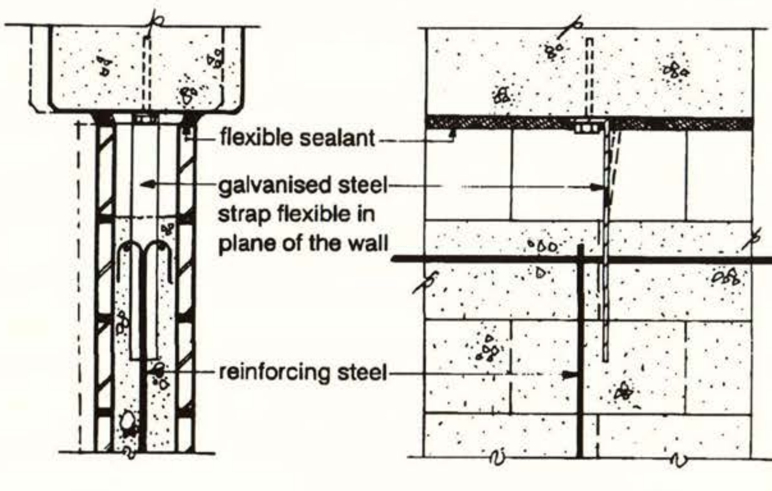


Figure 8.1
Separation detail at the head of a reinforced concrete block partition **not** requiring a fire rating to be maintained.

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.

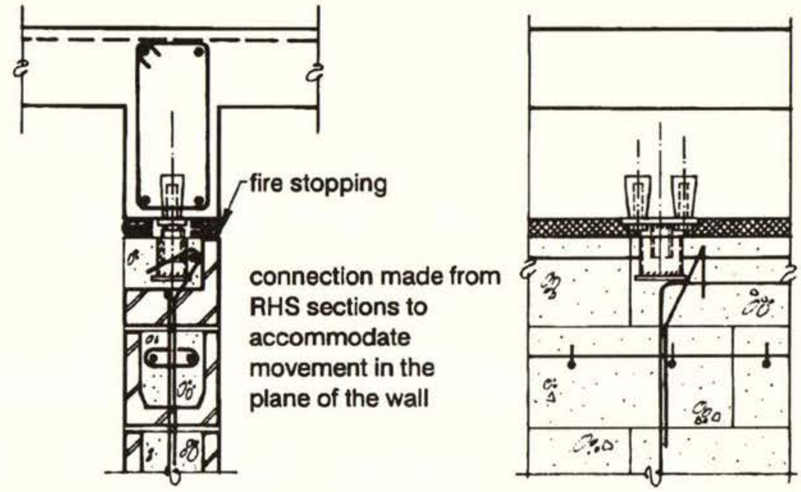


Figure 8.2
A more complex detail than Fig. 8.1 showing a way of maintaining the fire rating of a concrete masonry partition while providing for movement.

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

NZS 4203 does not refer to lightweight partitions. However, the former Ministry of Works Code PW 81/10/1 required that they be separated in all but the lowest risk seismic areas. For specially important facilities, such as essential hospitals, it may be appropriate to follow the approach adopted in PW 81/10/1 although this is no longer mandatory. The purpose would be to limit non-structural damage so that essential facilities remain operational after an earthquake.

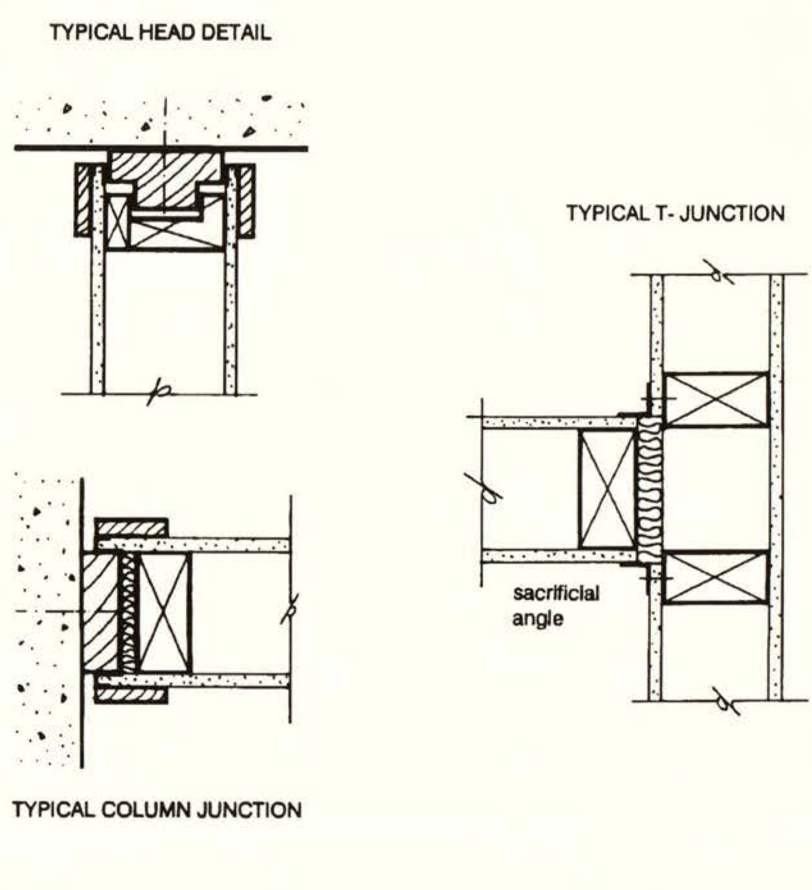


Figure 8.3
Typical details when timber framed partitions are required to be separated, e.g. in essential facilities.

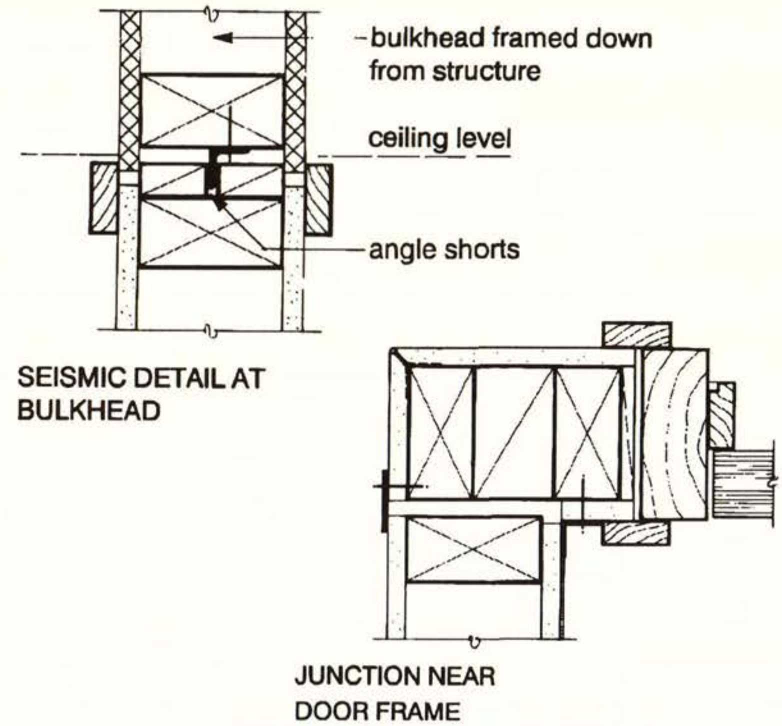


Figure 8.4
Further examples of separation of timber framed partitions.

Lightweight partitions have some flexibility, but this will vary 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.

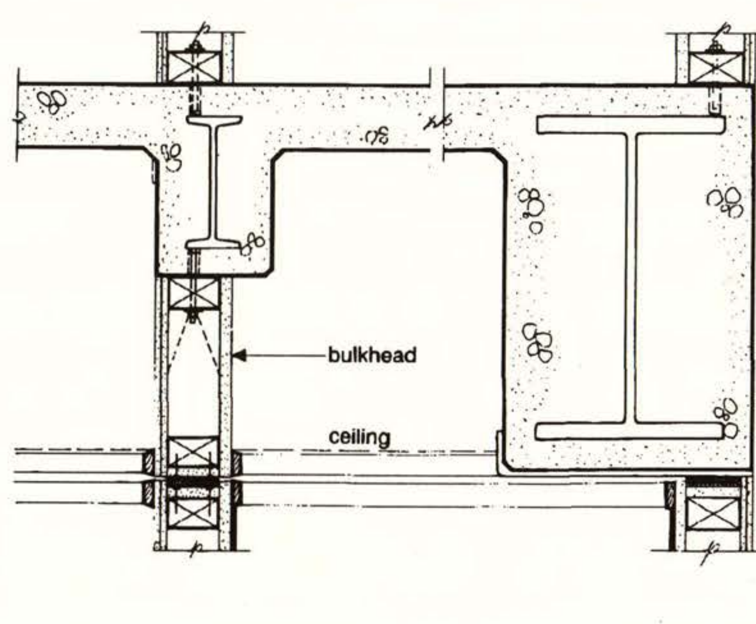


Figure 8.5
A more complex detail with fire rated partitions.

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:

(a) ``Demountable'', where the linings are screw fixed and joints butted or covered with clipped cover strips. This type of partition has inherent flexibility.

(b) Flush lined, where joints in the linings are stopped flush. This type will have less overall flexibility.

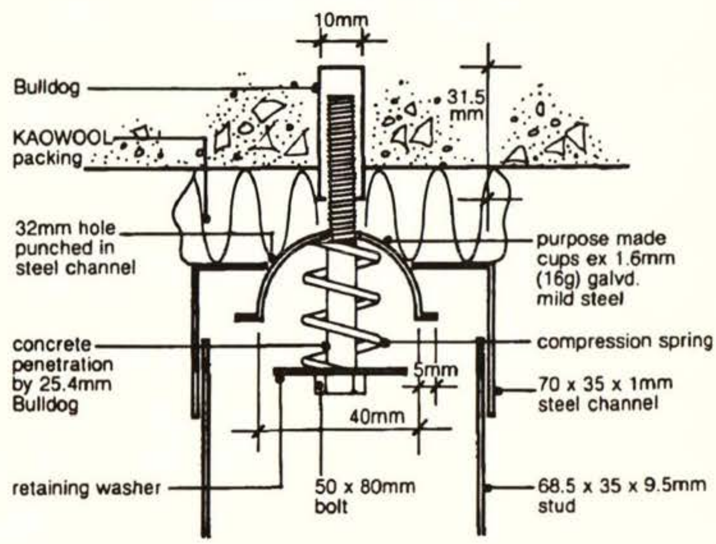


Figure 8.6
A seismic head detail for a proprietary walling system (Trend Walling Systems Limited).

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.

9
Suspended Ceilings

The risk arising from suspended ceilings being damaged in an earthquake has already been noted. Lighting and 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.

In New Zealand, the seismic design of ceilings is covered by NZS 4203, the Loadings Code (Refer Section 3 of this handbook). The former Ministry of Works Codes PW 81/10/1 and Code of Practice for Structural Design of Suspended Ceilings may also be applied in some cases.

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. However, a recent survey has identified that few recent commercial buildings observe this requirement. The subject requires further research and development to provide cost effective clipping, 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 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 codes. Their technical staff should be consulted at an early stage of the design if there are any special requirements.

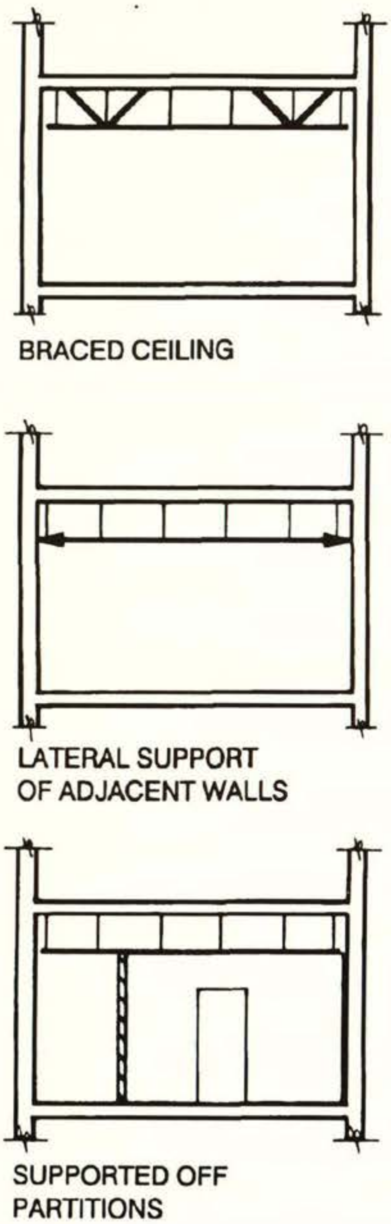


Figure 9.1
Three principles of support of suspended ceilings.

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 weather-proofing. Details should also:

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

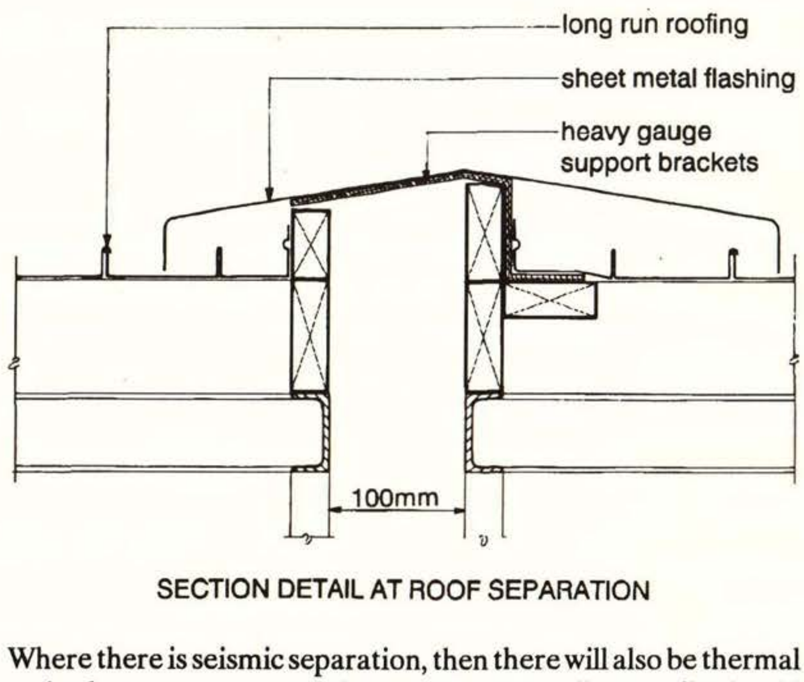


Figure 10.1
Roof separation between blocks of a Wellington building. Note the width of the flashing.

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 may increase 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.

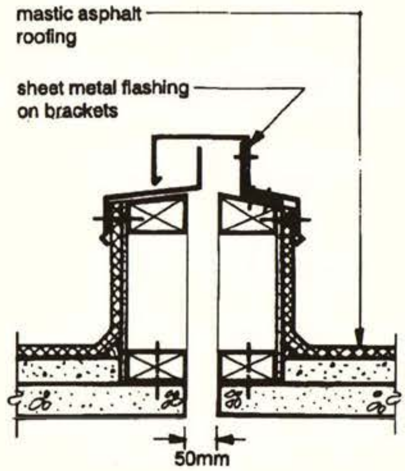


Figure 10.2
Seismic separation of a mastic asphalt roof. What happens to the flashing detail at each end needs thought. For instance: Will it still allow movement and keep out the weather where it meets a wall, or turns down into a gutter?

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 the roof is trafficked.

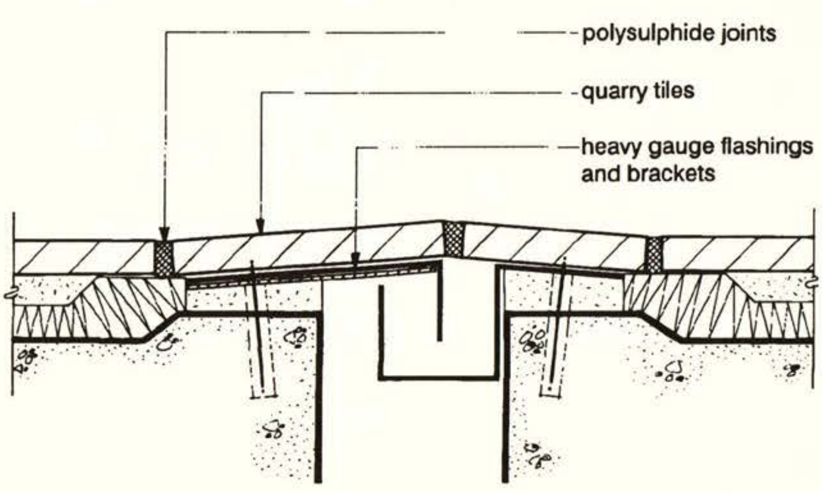
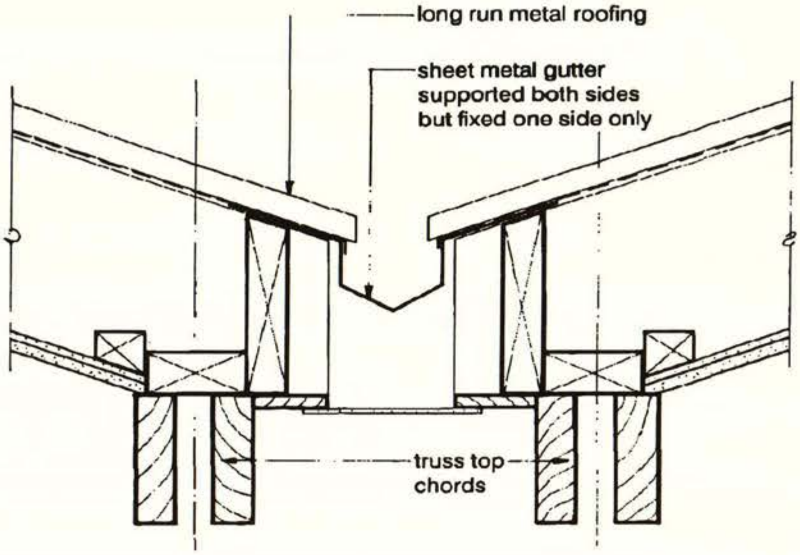


Figure 10.3
A detail to allow pedestrian traffic to cross the separation gap between two blocks on an external deck. Such situations are best avoided by very early consideration of seismic separation in conjunction with planning of the building.

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.



PITCHED ROOF SEPARATION AT VALLEY

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.

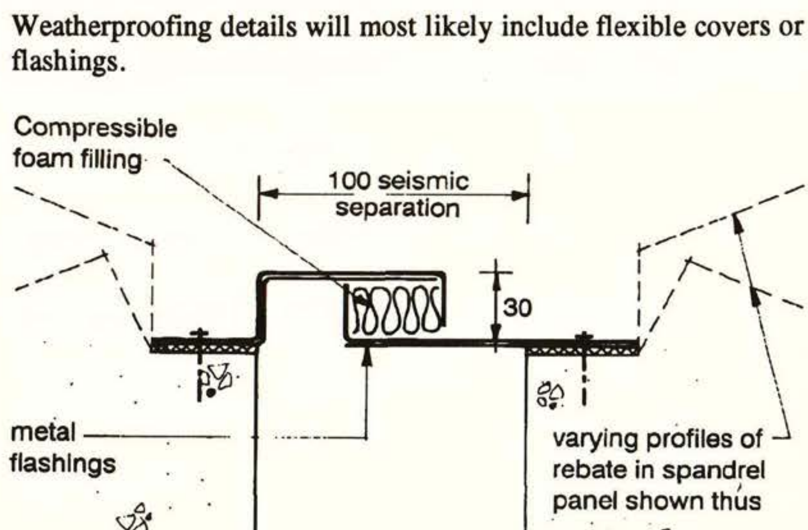
Simple overlapping of the roof materials is a good basis for movement details when this can be arranged.

External Claddings/ Window Separations

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

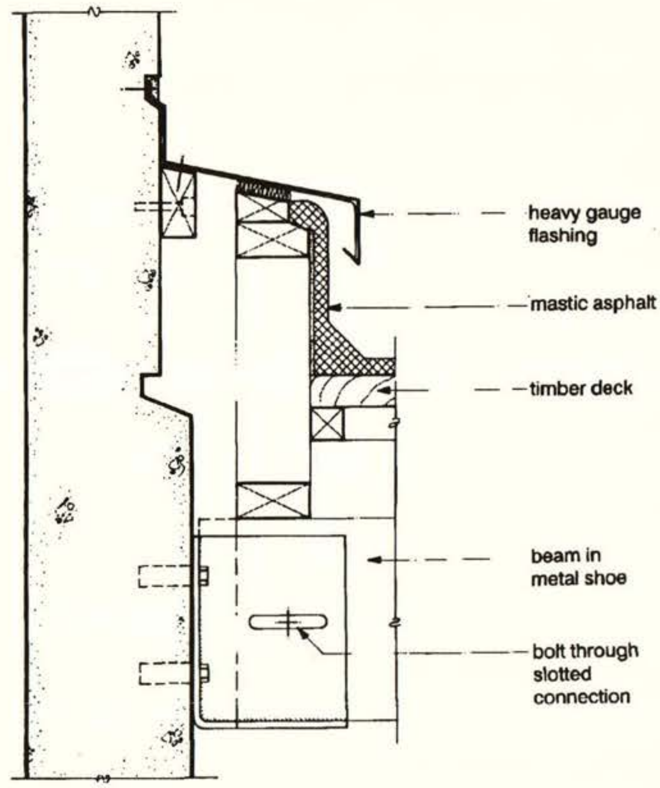
Normally separation will be between adjacent structural elements, with external cladding stopping each side of the separation gap. It is preferable that claddings/windows are not taken across the seismic gap; this makes weathering and movement provision more difficult.

Weatherproofing details will most likely include flexible covers or flashings.



PLAN DETAIL BETWEEN SPANDRELS

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

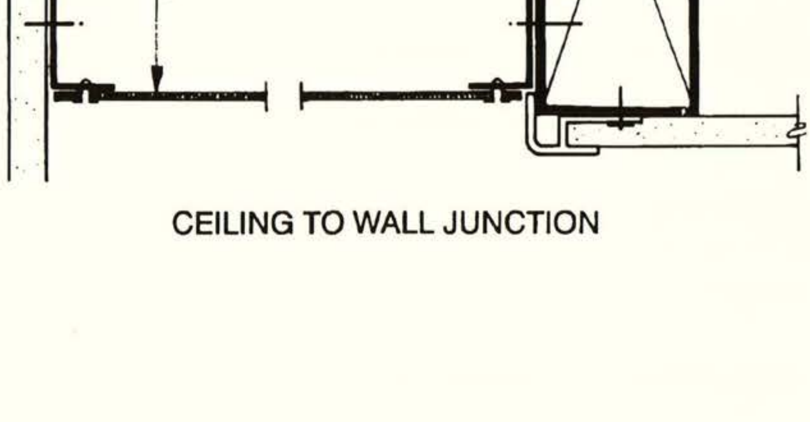


SEPARATION AT WALL TO FLAT ROOF JUNCTION

Figure 10.6
Each type of separation requires individual attention.

Internal Element Separations

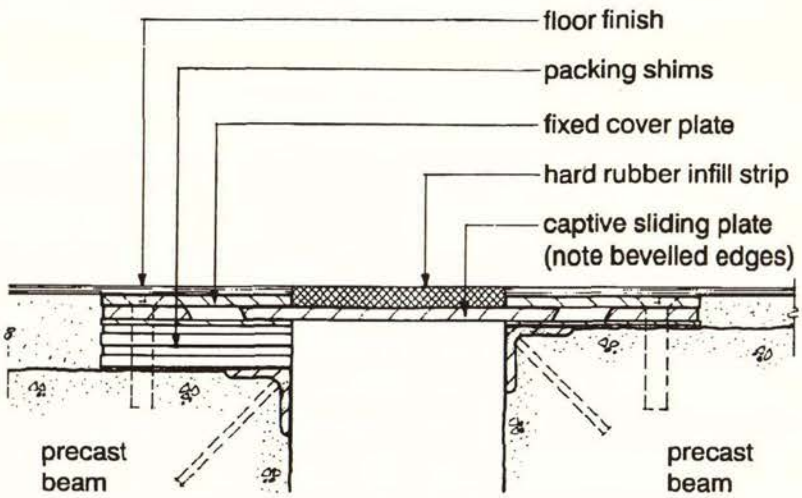
To allow for expected movement details are better provided at the separation space, rather than close to it.



CEILING TO WALL JUNCTION

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.



FLUSH DETAIL AT FLOOR SEPARATION

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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