

ARCHITECTURAL ELEMENTS IN EARTHQUAKE A REVIEW OF DESIGN AND CONSTRUCTION PRACTICE IN NEW ZEALAND

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ABSTRACT

The paper describes the results of a survey of New Zealand and Californian designers, contractors, approving authorities and fabricators, conducted during 1984 as part of a research project for the National Science Foundation of USA. The emphasis was placed on protection of architectural elements themselves, although inevitably the question of risk to people was addressed.

The main sources of information were the responses to a questionnaire sent to selected members of each affected sector and the material offered by those respondents who were interviewed.

A clear picture of the New Zealand state-of-the-art emerged and a number of noteworthy examples of separation of architectural elements were identified.

Recommendations for further research are made, particularly to improve knowledge of behaviour, and of the economics of special protective measures.

It is concluded that although New Zealand practice is advanced, there are important aspects which require attention.

INTRODUCTION

This paper describes research project sponsored by the National Science Foundation (USA) into concepts and practice for the reduction of seismic damage to architectural elements in buildings. The NSF report resulting from this project will provide a basis for the preparation of codes of practice and guidelines for the design and construction of architectural elements in buildings in the USA.

It has been increasingly recognised in recent years that design and detailing to safeguard architectural elements should receive equivalent attention to that currently paid to the design of the major structural elements. In the seismic regions of the USA, there is a growing awareness that more attention should be paid to the behaviour of architectural elements in earthquakes.

The New Zealand building industry has had considerable experience with these detailing problems and has developed and implemented design recommendations and construction practices to deal with them. It was therefore seen as desirable to draw on New Zealand's accumulated knowledge and experience so as to provide a background for recommended practices in the USA.

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The focus of the study was on approaches to design, construction and installation of architectural components that will reduce economic loss due to earthquake damage. The architectural aspects studied in detail were:

- ceilings
- partitions
- windows and glazing
- external cladding systems, including precast concrete
- fire protection considerations, arising from the seismic separation of non-structural elements.

Reviews of literature and codes of practice in USA and New Zealand were carried out by researchers in the respective countries. Current practice was assessed by sending a specially compiled questionnaire (see Appendix 1) to architects, consulting engineers and approving authorities. These questionnaires were followed up by interviews and site visits.

The full findings of the research project will be published as a National Science Foundation report, which is currently in preparation.

REVIEW OF NEW ZEALAND PRACTICE

1. INTRODUCTION

The review involved surveys of literature and codes of practice together with analysis of the responses to questionnaires sent to a range of designers, approving authorities, contractors and

fabricators. The questionnaire was intended to gauge the importance that different sectors of New Zealand's building industry place upon seismic design of architectural components. Respondents were encouraged to expand on aspects in which they held particular expertise or knowledge. Twenty-seven questionnaires were completed and returned, along with many examples of current design and detailing practice. A broad consensus emerged on most significant issues.

The research team interviewed many questionnaire respondents and accompanied them on visits to construction sites, manufacturing premises, completed buildings and research laboratories. An appreciation was gained of the difficulties encountered and successes achieved in the practical application of code provisions and designer's intentions.

2. TYPICAL SOLUTIONS

Protection of architectural elements against earthquake damage generally requires the provision of separation joints between these elements and the main structural frame of a building. The integrity of the supporting systems must be maintained throughout the range of possible movement. Basic methods commonly used in New Zealand to provide such separation and support are given in figures 1 to 6 which show each of the architectural elements considered.

3. REVIEW OF NEW ZEALAND CODES

The basic objective of the review was to outline the requirements of New Zealand codes and to summarise the points made in various technical papers. This review provided a reference point from which to view New Zealand practice. Codes reviewed were:

a) NZS 4203:1976 General Structural Design and Design Loadings for Buildings

This standard sets out requirements for general structural design and design loadings for buildings. It does not cover the detailed design appropriate to particular construction materials. In relation to the protection of non-structural elements against earthquake damage, the code gives requirements.

- i) Separation of Non-Structural Elements
- ii) Forces on Parts and Portins of Buildings
- iii) Special Requirements for Suspended Ceilings

b) Code of Practice PW 81/10/1 - Seismic Design of Public Buildings:1976 - Ministry of Works and Development, New Zealand

This code applies to all buildings designed by the MWD and all other buildings commissioned by Government departments and any others in which the Government has a financial interest. There is a need for many Government services to

continue with the least possible interruptions in the event of a seismic disaster. A greater emphasis is placed on minimising non-structural damage on the basis that this represents the greatest monetary loss and is the most common cause of essential facilities being unable to function immediately following a seismic disaster.

The objective of the requirements is to avoid material damage and to stop buildings from causing damage to adjacent properties during moderate earthquakes. In addition, the requirements are intended to ensure practicality and economy of restoration if damage occurs.

c) Code of Practice for Structural Design and Construction of Suspended Ceilings and Associated Fittings and Fixtures Ministry of Works and Development, May 1980, corrected May 1983

This code sets out minimum requirements for the design, supply and construction of suspended ceilings for compliance with the MWD Code of Practice for Seismic Design of Public Buildings:1976 (PW 81/10/1).

A combined suspension and bracing system is required to be designed to carry gravity loads, wind uplift, horizontal and vertical components of seismic loads and any reactions induced on the system by partitions or services connected to it.

d) Design Guides for Proprietary Systems

Manufacturers of suspended ceiling systems have produced detailed design guides to assist in the selection of their components. These design guides clearly set out the requirements of NZS 4203:1976 and PW 81/10/1, highlighting where the latter specifies more stringent levels of seismic restraint. Methods for calculating design loads are given, followed by selection charts for ceiling components.

4. REVIEW OF NEW ZEALAND LITERATURE AND RESEARCH

Literature and research by New Zealanders has not been extensive. Such papers as have been published tend to concentrate on the analysis of likely effects and possible solutions. These are based in part on the reports of performance of buildings in earthquakes overseas.

Although there is only a small amount of published literature it is significant that the requirements for non-structural elements have been included in New Zealand codes.

The papers reviewed were references 4 through 11. It was found that many of the papers covered similar ground. This was taken as an indication of the general consensus on the need for careful consideration of non-structural elements in design.

The paper by Toomath (4) indicates

the result of early thinking and practice by a very limited number of designers, and describes design solutions which are still specified, though in slightly different forms.

The papers by Blakeley (5), Glogau (6) and McKenzie (7) are all derived from research and development of ideas within the New Zealand Ministry of Works and Development, as a result of its wide-ranging responsibilities for Government-owned buildings.

Blakeley's paper was published at a time when revisions to the New Zealand Loadings Code had been issued in draft form for comment. Emphasis was placed on explaining the implications of the proposed new requirements.

Glogau's comprehensive paper deals more with the reasons for the proposed changes and the very limited background of (mainly overseas) experience which provided the justification. Because it provides this background and identifies a wide range of recommended sound practices, Glogau's paper may be considered as a benchmark in the development of the engineering design of non-structural elements in earthquakes.

The New Zealand Loadings Code, NZS 4203:1976, which incorporated many of Glogau's recommendations, represented a significant departure from the previous code, especially in the detailed provisions for ductility, in the introduction of capacity design, and for requirements to separate non-structural elements. These new concepts proved difficult to apply consistently throughout the profession and a study group was set up by the New Zealand National Society for Earthquake Engineering to reach a consensus of interpretation and application. The paper by Allardice (8) was one of a number which were published as a result of deliberations by this study group on a variety of subjects related to the design of ductile frame buildings. The paper summarised fundamental considerations for the sound design of non-structural elements, and reflected the views of leading practitioners at that time.

McKenzies' paper was presented to a National Science Foundation workshop at Berkeley and not only covered the desirable design principles but also presented some practical measures to achieve the necessary separation in exterior walls (precast panels and glazing), interior walls (partitions) and stairs. It is indicative of the practical approach adopted by New Zealand designers to achieve effective separation.

Development of design ideas and construction practice has continued as evidenced by Clark and Glogau's paper (9) on ceiling requirements and by the recent Ministry of Works and Development design guide on the support of precast concrete panels.

5. DESIGN AND CONSTRUCTION PRACTICE IN NEW ZEALAND

The state of New Zealand design and construction practice is described in this section under the headings of the questionnaire. As such it is a summary of the response to the questionnaire and interviews.

Design Approach (Question 1): It was generally considered uneconomic to limit deflections in major high rise structures. All respondents said they accepted the need to allow for seismic movement in the design of architectural elements, where this was required by New Zealand design codes. A large number of replies noted a preference for reducing deflections, where it was practicable to do so. Examples of this were base isolated structures and low rise structures using strategically placed shear walls, or bracing.

Codes Followed (Question 2): All respondents quoted New Zealand Standard 4203 "Code of Practice for General Structural Design and Design Loadings for Buildings". Other documents mentioned were the Prestressed Concrete Institute design handbooks (modified for New Zealand conditions) and New Zealand Standards for light timber framed buildings (NZS 3604), aluminium windows (NZS 4211) and particularly the New Zealand Ministry of Works and Development "Code of Practice for Seismic Design of Public Buildings" (PWS1/10/1). The MWD "Code of Practice for Structural Design and Construction of Suspended Ceilings and Associated Fittings and Fixtures" is used extensively. Proprietary design guides developed to meet MWD requirements were frequently used, particularly for ceilings placed by specialist designers/manufacturers/installers.

Awareness of Requirements (Question 3): Awareness and competence were both considered to vary greatly, being most developed amongst structural engineers, especially those concerned with major buildings. There was thought to be negligible awareness or interest at present amongst main contractors involved in general low risk commercial work.

Acceptability of Requirements (Question 4): Acceptance is general by structural engineers and experienced architects who have been involved with seismic movement considerations. Designers, manufacturers and contractors generally accept specification requirements when they are obliged to do so, but in some cases will quote precedents or economic reasons as justification for not meeting requirements fully.

A significant point to emerge was the existence of a strong streak of scepticism about details based on theory, rather than practical testing,

conveyed in comments such as "Will these details work as intended in an earthquake?" and "Is there economic justification when elaborate solutions have to be devised to meet 'one-off' problems?"

Degree of Application (Question 5):

Precast concrete panels are widely used as the primary exterior claddings. Once the formal concept of the exterior building treatment has been resolved, the structural engineer tends to take over from the architect by designing the structure of the panels, erection methods, fixing methods and provision for movement. Precast manufacturers are often consulted on practical aspects but do not generally carry out detailed design. Although there are some exceptions, which are cause for concern, precast concrete elements are competently handled by designers, manufacturers and constructors, in a wide variety of applications. In spite of the widespread use of precast elements there is a total lack of test or analytical data on the effectiveness of the solutions as built.

Windows: In a very competitive industry the detailed design of aluminium windows for major high rise or institutional buildings has devolved on a few manufacturers who serve the whole country. These firms are conversant with seismic code requirements and it is usual for these manufacturers' details to meet a performance specification written by the building designer. The need for separation is virtually taken for granted and installations appear to be effective in achieving the necessary clearances. An exception to this is at some corners and junctions where it is recognised that premature damage could occur at low levels of earthquake. Manufacturers are normally responsible for installation on major buildings.

Ceilings: The detailing and installation of ceilings in commercial and institutional buildings is often let to specialist suspended ceiling subcontractors. The major firms have engaged their own structural engineering consultants, or are taking steps to do so, and in some cases have commissioned extensive testing of their systems, modified to meet seismic code requirements. These firms are in a position to comply with performance specifications for suspended ceilings.

Test data on the behaviour of ceiling systems, particularly those of large area, is limited.

Partitions: There is a well developed awareness amongst New Zealand engineers of the potentially detrimental effects of connecting rigid partitions to the main structure. These elements, commonly of concrete block,

are detailed by the engineer and usually incorporate separation details. However a number of respondents acknowledged the difficulties of achieving practical "head" details and of maintaining fire ratings, which are frequently required in conjunction with masonry walls.

Accommodation for seismic movement in the design of lightweight partitions is regarded as being required only for certain public buildings, such as those housing essential facilities, or for other Government buildings, under certain conditions. Hence there is no general awareness in the building industry, amongst architects, manufacturers or builders of the need to detail for partition movement, or the means of achieving this.

Frequent comment was made on the lack of information on the cost-benefit of preventative measures.

Reactions to Requirements (Question 6):

A number of architects said they had doubts about the cost benefit of allowing for movement to protect damage to property. Some engineers shared this view. Two specific comments from experienced Wellington-based designers represent the general doubt. They described their reactions as follows:

"I agree with the principle and hence my reaction is obviously positive. It is important however to keep the provision of seismic separation in perspective and not have it dominate all other considerations, otherwise detailing can become very complex and costs go up accordingly. In addition, if the details get too complex then there is an increasing chance that the workmen will misunderstand and frustrate the designer's best intentions." (Engineer)

"Willing, in relation to major repetitive components where advantages are clearly evident; less willing in minor areas where the compliance entails costly expenditure of design time on complex solutions. Resistant where the demands exceed a sensible acceptance of a certain degree of risk." (Architect)

Design of Workable Details (Question 7):

Many noted that there had been very little physical testing, and negligible experience of the operation of seismic details in a moderate earthquake.

Cost Implications (Question 9):

No respondent had been involved in cost studies on this topic.

Informed guesses by some respondents tended to be in the range 3% to 10%. There was general agreement that co-ordination between architect and engineer early in the design stage,

and the production of well designed details, took time, but reflected in fewer problems and less cost at later stages. The least costly solutions came from architects and engineers who had developed an awareness of the implications of the code requirements.

Examples of New Zealand Practice (Question 10): A number of designers offered details, covering the range of aspects studied. A selection of these is given in Appendix 2 - New Zealand Case Studies.

Fire Rating of Seismic Separations (Question 11): There appears to have been no testing relating to this situation. Consequently answers depended on subjective personal experience - from "very onerous" to "not a problem". Most respondents had specified movement joints to be packed with asbestos rope or more recently with ceramic fibre. Overlap details had also been used where practicable. Most concern related to the effectiveness of packings such as ceramic fibre, given the problems of adequate supervision - proper placement and gap filling - and adequate long-term resilience.

A common view was that a small inadequacy in the fire stopping material would have less effect on fire resistance and smoke stopping than the inadvertent connection of a rigid partition to the floor above. That is, seismic separation should take precedence. However it was recognised that little test data was available to support this view.

Further Comments (Question 13): General comments received reflected a widespread recognition of the merits of the code provisions in separating non-structural elements, at least in the engineering profession. Some engineers consider that the current separation requirements should be increased in order to avoid costly damage and improve life safety at moderate levels of earthquake and higher.

Many respondents commented on the lack of "hard" information to justify the effort and expense of special detailing. The desirability of research and testing to provide this information was evident.

However, it is apparent that little change in attitudes will result until there is more evidence to demonstrate the cost benefit of more stringent measures.

CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

- In comparison with structural aspects the subject of non-structural elements in earthquake has received scant attention in recent years. It is important that this imbalance

be redressed as quickly as possible. The small amount of test results used to develop design criteria for New Zealand codes is an indication of this need and is a source of concern.

- There is a need to clarify the drift provisions in codes of practice and to relate the performance in practice with a particular code provision. Code provisions in turn should relate to expected actual displacements. Practitioners in New Zealand and California had varying understanding of the relationship between calculated and expected drift. This must surely be a point of basic concern.
- A concerted effort is required to improve the awareness within the industry, particularly amongst architects, of the implications of drift on the design of architectural elements both for life safety and damage control. Studies of cost-benefit are needed to assist in establishing relevant criteria.
- There is a need for definitive testing on external wall elements, particularly glazing and precast panels. This needs to be done on a rational and scientific basis so as to relate it to code provisions. The results of racking tests which have been carried out need to be assembled and their relevance established in the overall context. It is disturbing to see the amount of potentially brittle and heavy material being placed on buildings when there is apparently little evidence of the performance of such materials in real earthquakes, or indeed in laboratory testing.

2. RECOMMENDATIONS

The main recommendation resulting from the survey is that the behaviour of architectural elements in earthquake should receive its proper attention. Universities and research organisations are urged to take note of the importance of this subject. The following are suggested as specific research topics, to initiate a major effort in this area:

- Survey available literature involving tests on architectural elements. Seek out results obtained from tests commissioned specifically for actual buildings.
- Examine and analyse available data. Rationalise and interpret it in relation to the parameters relevant to earthquake forces and movements. Draw conclusions as the value of the test results in establishing design requirements. Identify aspects which require further investigation and/or testing.
- Review available data on the performance of architectural elements in earthquakes in relation to current code provisions for drift limitations.

- Extend past investigations into response of yielding structures, to allow consideration of the effect on architectural elements. Such effects as damping provided, building period, height and mass, earthquake ground motion record and of course drift will be relevant.
- Conduct a series of tests on window frames and precast exterior cladding panel assemblies to verify the effectiveness of commonly used details in providing freedom of movement.
- Conduct some large-scale tests on suspended ceiling assemblies. Test panels/configurations should be large enough to incorporate 'rogue' features such as sprinkler heads, which may represent a stiff element in an undesirable position.
- Survey representative buildings to check the separations actually achieved in practice. Attempt to draw conclusions on required construction tolerances for glazing and precast elements.
- Review current code provisions in the light of information obtained and revise the provisions as necessary.

ACKNOWLEDGEMENTS

Financial assistance provided by the National Science Foundation is gratefully acknowledged.

A feature of this research project which forms the basis of this paper was the contribution made by questionnaire respondents, particularly those who were subsequently interviewed by the research team, and those who provided photographs, drawings and articles for the case studies. The degree of enthusiasm, interest and cooperation shown by the people and organisations contacted was outstanding. Their contributions are gratefully acknowledged.

REFERENCES

1. NZS 4203:1976 - Code of Practice for General Structural Design and Design Loadings for Buildings.
2. PW 81/10/1:1976 - Code of Practice for Seismic Design of Public Buildings - Ministry of Works and Development.
3. Suspended Ceilings and Associated Fittings and Fixtures: Code of Practice for Structural Design and Construction - Ministry of Works and Development.
4. Toomath S W, Architectural Detailing for Earthquake Movement - NZSEE Bulletin Vol 1, No 1, June/July 1968.
5. Blakeley R W F, A Review of the Code Provisions for Separation of Elements & Buildings - NZSEE Bulletin Vol 7, No 3, September 1974.
6. Glogau O A, Separation of Non-Structural Components in Buildings - NZSEE Bulletin Vol 9, No 3, September 1976.
7. McKenzie G H, Problem of Damage to Non-Structural Components and Equipment: Walls and Stairs.

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8. Allardice N W, Parts, Portions and Secondary Elements - NZSEE Bulletin Vol 10, No 2, June 1977.
9. Clark W D and Glogau O A, Suspended Ceilings - The Seismic Hazard and Damage Problem and Some Practical Solutions - Ministry of Works and Development Report 80-1. Also NZSEE Bulletin Vol 12, No 4, December 1979.
10. Brookes A J, Cladding Methods in New Zealand - A State of the Art Report - BRANZ Technical Paper, page 40, 1984.
11. Smith A W, Some Aspects of Seismic Damage - NZ Engineering, 15 September 1961

APPENDIX 1 - QUESTIONNAIRE

DESIGN AND CONSTRUCTION OF ARCHITECTURAL ELEMENTS TO REDUCE DAMAGE BY EARTHQUAKES - CONCEPTS AND PRACTICE

Please respond to the questions as fully as you can and include as much factual material as possible. If your reply to any question exceeds the space allowed, please add supplementary pages, diagrams, photos, trade literature etc.

If possible, please consider all types of construction and materials with which you are familiar, under the broad headings listed below.

Please answer the questions as they apply under each of the following headings according to your experience.

- Partitions
 - Windows and glazing
 - External cladding systems generally
 - Precast concrete cladding
 - Ceilings
 - Fittings and furniture
1. In general, what design approach do you consider most appropriate to reduce earthquake damage to architectural elements in modern buildings:
 - a) Prevention of the problem by appropriate design of the major structural elements. If so by what approach?
 - b) Acceptance of seismic deflections and provision for these in non-structural elements.
 - c) Other? (Please specify)

2. Which codes of practice or recommended guidelines have you used and has been your experience in using them in the design, detailing, manufacture and installation of architectural elements to reduce earthquake damage?
3. How much awareness of these seismic considerations is there in your section of the building industry? How would you rate the general level of competence in providing effective, workable solutions?
4. How readily accepted by other sections of the building industry have you found your ideas, requests or requirements for seismic movement considerations?
5. To what degree do you think methods of accommodating movement are applied in today's design and building practices?
6. What is your reaction to requirements placed on you to allow for movement, or to provide for earthquake forces in non-structural components?
7. How successful have designers been in devising workable details?
8. How successful do you believe builders and manufacturers to have been in achieving workable details?
9. In cost terms, how significant do you rate the provision for earthquake movement or restraint on non-structural elements to be, when applied to the following facets of the building process:
- Design
 - Shop drawings
 - Approvals
 - Manufacture
 - On-site construction
 - Other (please specify)
10. Can you give any examples (illustrated if possible) of good and bad practice in dealing with the potential effects of earthquakes on non-structural elements?
11. There is an inherent conflict between the requirements for seismic separation of non-structural elements and fire protection requirements, in that points of separation are potential weak spots in fire ratings.
- How onerous have you found this in practice?
 - What approach have you taken to the problem?
 - What specific materials have been used to maintain fire ratings at points of separation?
12. Do you know of any good examples that could be inspected by a visiting research team from the USA as part of this study? If so please indicate where the examples may be seen and provide a contact phone number for arranging an appointment. If possible give the name of the architect or engineer.
13. Do you have any further comments or pointers that you feel should be covered in the report?

APPENDIX 2 - NEW ZEALAND CASE STUDIES

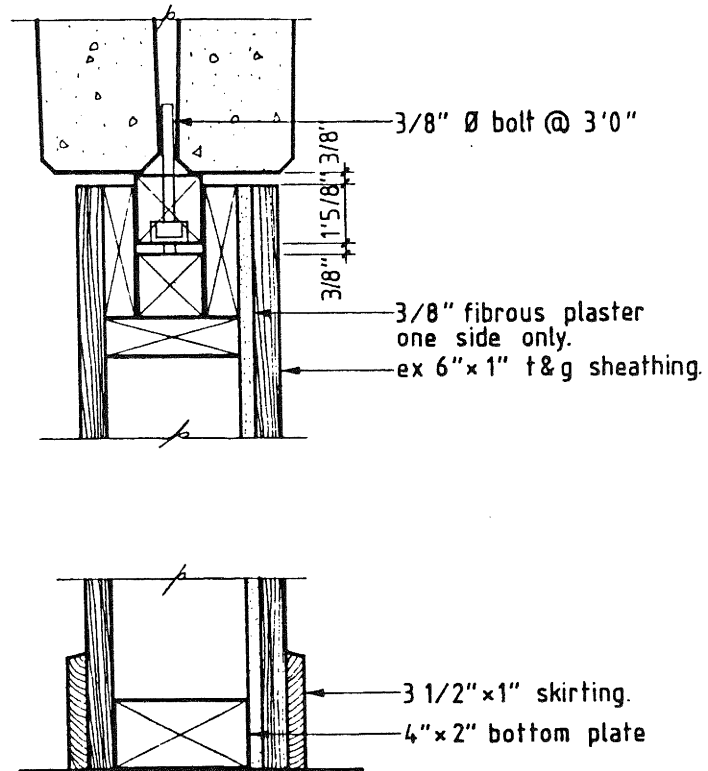
Some noteworthy examples of design for protection of architectural elements are described in this Appendix.

Illustration of the examples is strictly limited, but will be presented more fully in the final report.

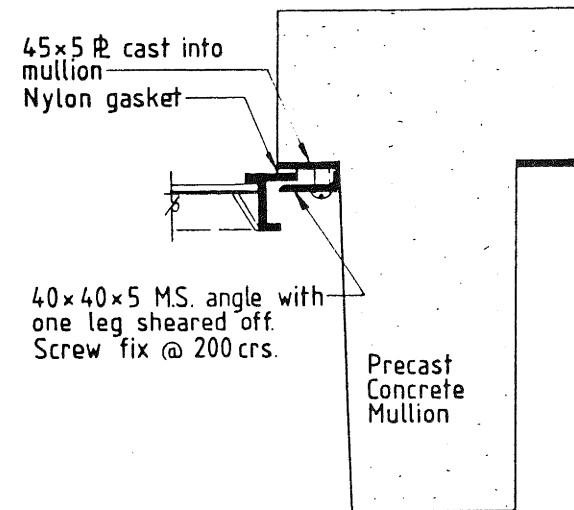
Examples have been selected to cover a range of applications and completion dates.

NEW ZEALAND CASE STUDY No 1 - Rankine-Brown Library

Owner:	Victoria University of Wellington
Architects:) Kingston Reynolds and Thom
Structural Engineers:) (now KRTA Limited)
Date completed:	1964
Building features:	A 10 storey precast concrete frame building with normal reinforced concrete columns, partially pre-stressed precast concrete floors consisting of trough sections with integral diaphragms which form a waffle slab.
Non-structural features:	<ul style="list-style-type: none"> - External walls - Windows - Staircases - Internal partitions <p>External reinforced block and brick masonry walls, precast mullions and concrete spandrel perimeter walls, external glazing, stairs and internal subdivision, have separation movement joints to prevent these secondary elements participating significantly with the frame in resisting seismic loads and by minimising induced loads, reduce the risk of seismic damage to such secondary elements.</p>
Description of approach to non-structural elements in earthquake:	<p>External walls and internal partitions are fixed to floors and incorporate head details with the waffle slab ceiling, which stay the partition against face loads, but permit relative movement at the head in the plane of the partition.</p> <p>Window frames are fixed to sills but float in channel sub-frame members at end mullions and at heads. Each stair flight is detailed to be anchored at one floor and to move at the adjacent floor.</p>
Remarks:	<p>This is probably the earliest example of provision for earthquake movement in the design of architectural elements for a New Zealand building.</p> <p>The concept of waffle slab separated from the partitions provides an unobtrusive effect.</p>



PARTITION DETAIL

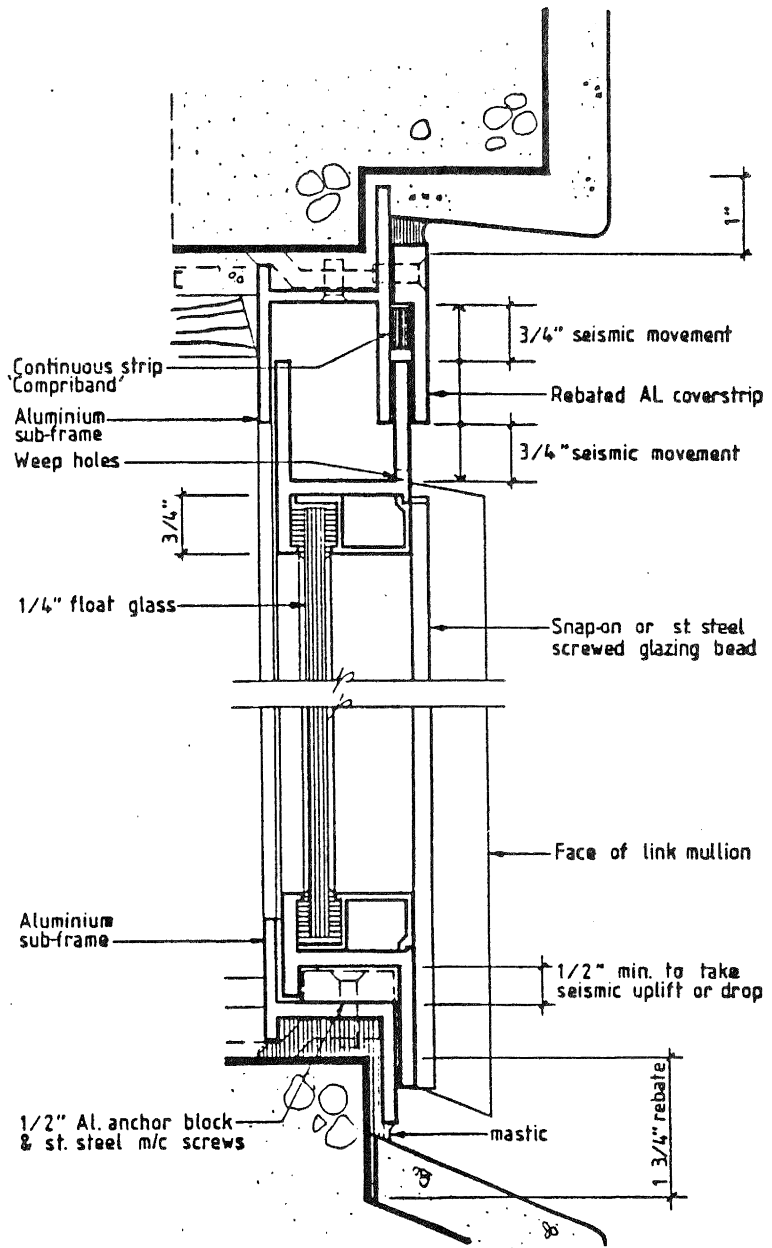


WINDOW SEPARATION DETAIL

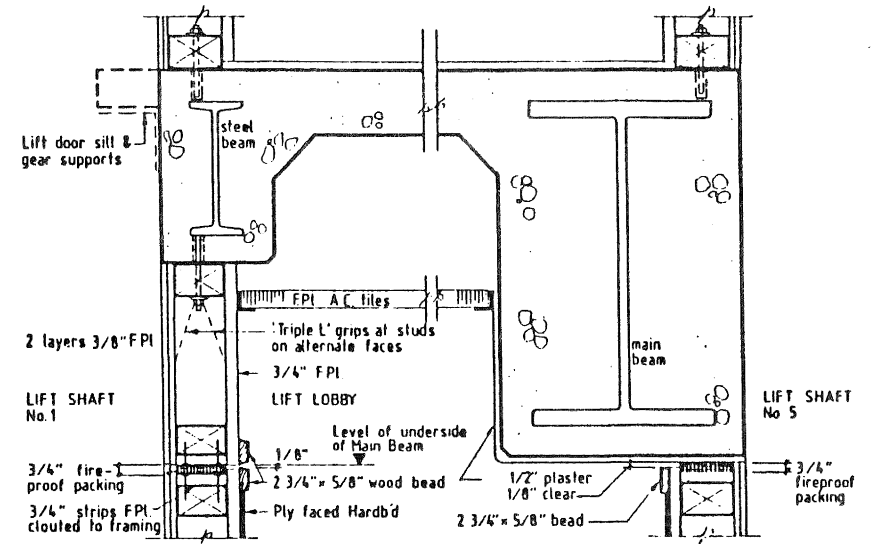
RANKINE BROWN BUILDING - WELLINGTON

NEW ZEALAND CASE STUDY No 2 - Aurora House, Wellington

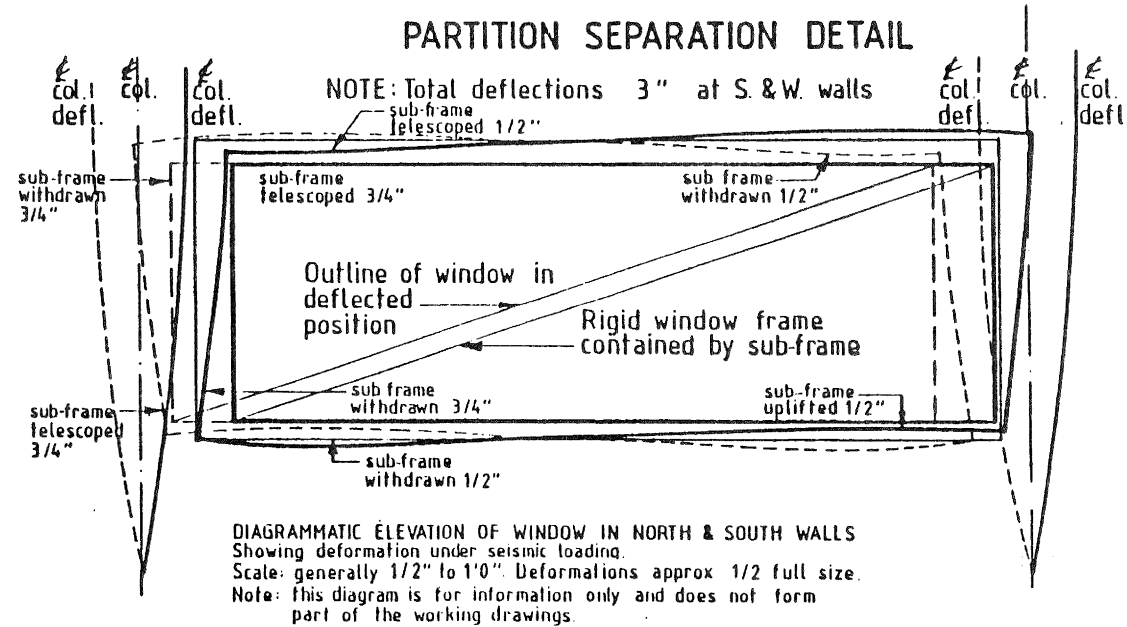
Owner:	Mayfair Limited
Principal Consultants & Structural Engineers:	Morrison Cooper and Partners
Architects:	Structon Group
Date completed:	1968
Building features:	A 19 storey steel frame building with floor to floor curtain wall type windows to the front and rear facades with all other windows in the side walls set in the plane of the exterior column faces and spandrels.
Non-structural features:	<ul style="list-style-type: none"> - Permanent partitions - Windows - Stairs - All subdividing partitions
Description of approach to non-structural elements in earthquake:	<p>Separation of partitions and windows was seen as a measure to reduce hazard and in particular to minimise damage to these elements in moderate earthquakes. Details were devised to allow movement in the aluminium windows by incorporating them in seismic sub-frames and to separate all permanent and all subdividing partitions throughout the building.</p> <p>For permanent fire-rated partitions in the service core, a separation gap was established at the soffits of the main beams.</p> <p>All subdividing partitions throughout were formed with separation gaps generally at ceiling level or beam soffit level and at all vertical junctions at structural columns. There were sufficiently frequent returns not to require special detailing for restraint at ceiling level.</p>
Remarks:	This is one of the earliest examples of detailing for earthquake movement in a major building in the central business district. Subsequent developments have followed similar principles.
References:	<p>G Cooper "A 19 Storey All-Welded Structure Utilising Rolled Section to BS 968:1962, Part 1: The Design Conception" - New Zealand Engineering, June 1967</p> <p>G Cooper "A 19 Storey All-Welded Earthquake Resisting Frame in Steel to BS 968:1962" - The Australian Welding Journal, Vol 11, No 1, September 1967.</p>



WINDOW SEPARATION DETAIL



PARTITION SEPARATION DETAIL



EXPLANATORY SKETCH FROM WORKING DRAWING

AURORA HOUSE - WELLINGTON

NEW ZEALAND CASE STUDY No 3 - Wellington Teachers College

Owner:	New Zealand Government
Architects:	Toomath & Wilson (now Toomath Wilson Irvine & Anderson)
Structural Engineers:	Hollings & Ferner (now Beca Carter Hollings & Ferner Limited)
Date completed:	1968
Building features:	The complex comprises six buildings generally of two or three storeys, with the common structural concept of reinforced concrete frames in both directions, supporting precast prestressed double T floors. Extensive use of prefabricated elements is made in forming the facade, including mullions, sun screens, exposed aggregate wall and spandrel panels.
Non-structural features:	<ul style="list-style-type: none"> - Partitions - Windows - Precast cladding
Description of approach to non-structural elements in earthquake:	<p>The structural framing system was seen as being relatively flexible. Consistent and thorough efforts were made to separate non-structural elements from the structural framing. Interstorey movements of at least 12 mm were provided for.</p> <p>Most details are based on sliding brackets and/or resilient members. The details were devised with the clear objectives of minimising hazard to people and of avoiding secondary damage at moderate levels of earthquake.</p>
Remarks:	In spite of the modest height of these buildings, the separation of the non-structural elements was carried out as thoroughly and effectively as in any building in New Zealand. Because it was an early example and it has been well documented and described, concepts used have been used and improved in later buildings.
Reference:	<p>S W Toomath "Architectural Detailing for Earthquake Movement" - NZNSEE Bulletin, Vol 1, No 1, June/July 1968.</p> <p>(Also published in New Zealand Institute of Architects Journal, March 1970)</p>

NEW ZEALAND CASE STUDY No 4 - National Provident Fund Building, Wellington

Owner: New Zealand Government

Architects:) Kingston Reynolds Thom & Allardice Ltd
 Structural Engineers:) (now KRTA Limited)

Date completed: 1980

Building features: A 16 storey reinforced concrete frame building above a 2 storey reinforced concrete shear wall podium.

Floors are shallow precast concrete units having composite action with a reinforced concrete screed which also acts as a diaphragm for seismic loads.

Lateral resistance is provided by the six perimeter frames which incorporate closely spaced columns and relatively short span beams.

Non-structural features: - Partitions
 - Windows
 - Stairs
 - Ceilings

Description of approach to non-structural elements in earthquake: Although designed in the early 1970s, this building anticipated NZS 4203 which was finally published in 1976.

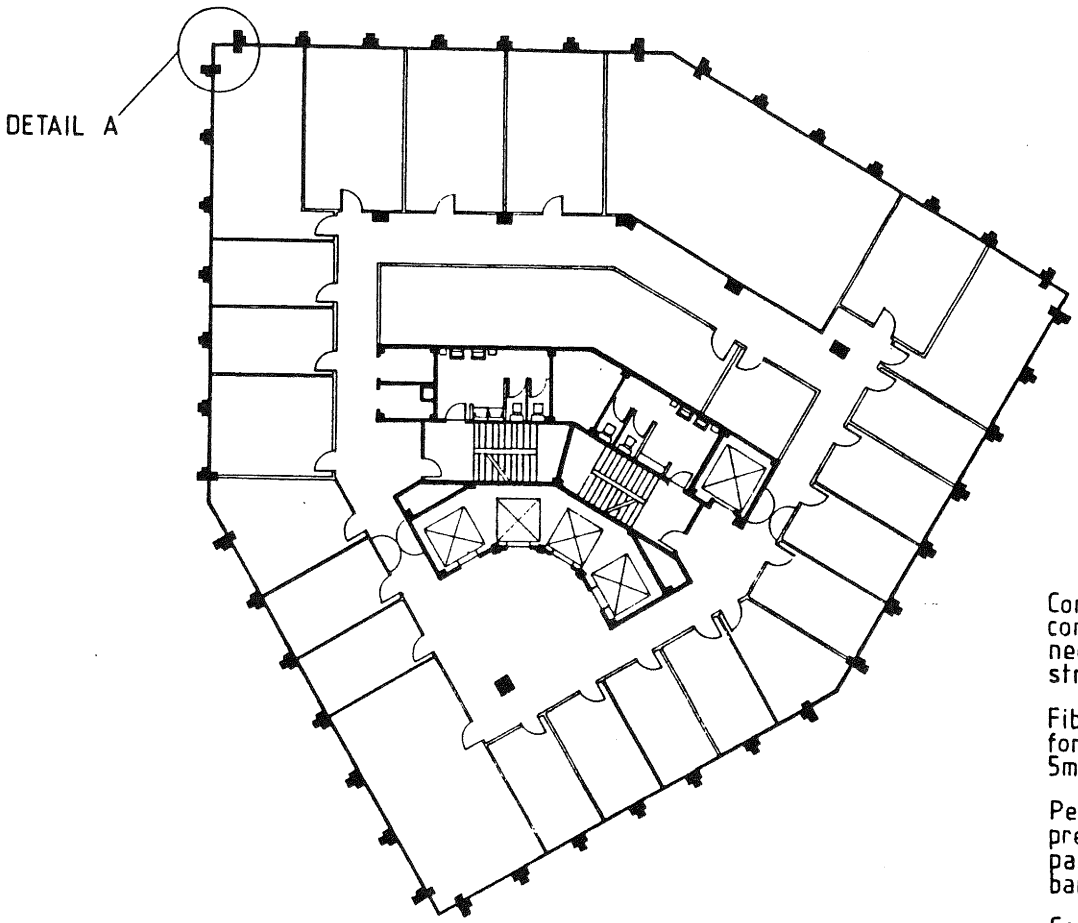
Partitions to the service core are timber framed, internal subdivision partitions are steel-framed, with vinyl covered gypsum board sheathing. All partitions are carefully detailed to accommodate interstorey drifts.

Junctions between window frames and partitions are detailed to accommodate interstorey drifts but right angle intersections between internal partitions have sacrificial joints which would require some repair after a moderate earthquake.

Special attention was paid to the anchorage of light fittings, fixings and ceiling panels.

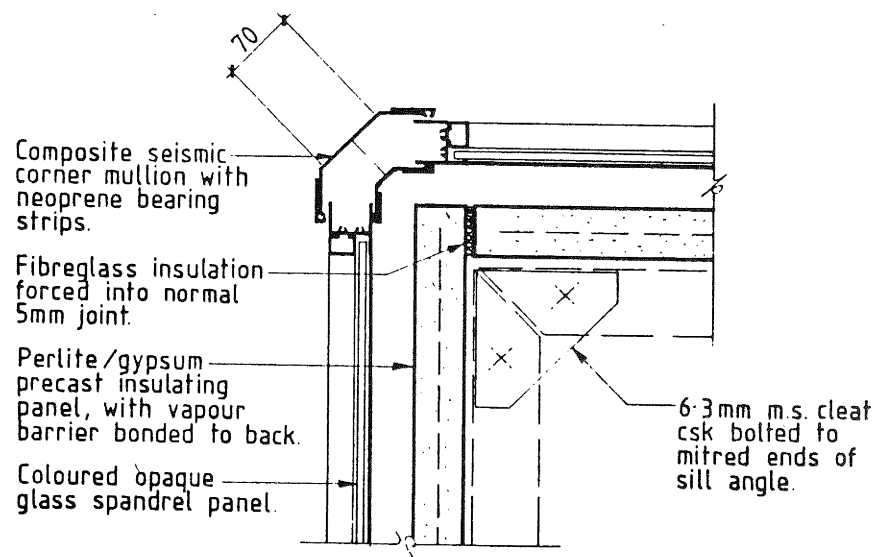
The window elements incorporated aluminium seismic subframes including special corner details.

Remarks: This is an example of a recent major building in which particular attention was paid to the protection of non-structural elements in earthquake.



DETAIL A

FLOOR PLAN



Composite seismic corner mullion with neoprene bearing strips.

Fibreglass insulation forced into normal 5mm joint.

Perlite/gypsum precast insulating panel, with vapour barrier bonded to back.

Coloured opaque glass spandrel panel.

6.3mm m.s. cleat csk bolted to mitred ends of sill angle.

DETAIL A

NATIONAL PROVIDENT FUND BUILDING - WELLINGTON

NEW ZEALAND CASE STUDY No 5 - William Clayton Building, Wellington

Owner:	New Zealand Government
Architects and Structural Engineers:	Ministry of Works and Development
Date completed:	1982
Building features:	Low-rise reinforced concrete ductile frame totally supported on lead-rubber base isolation devices. Exterior cladding comprises precast panels attached to the frame plus glazing, set back from the edge of the slab floors. New Zealand's first base isolated building.
Non-structural features:	<ul style="list-style-type: none"> - Base isolation - Windows - Ground floor partitions
Description of approach to non-structural elements in earthquake:	The incorporation of base isolation was used in part to reduce the damage to non-structural elements. All features, structural and non-structural at the ground level were carefully detailed to avoid unwanted ground coupling. Basements cantilever into oversize cavities, services are detailed to absorb the large differential movements at this level, ramps into the building have expansion joint covers; and stairs in ground contact are isolated to move freely in relation to the ground. Separation gaps are ± 150 mm.
Remarks:	Glazing to the lower storey is stopped short of the ground leaving an air gap. This building demonstrates that base isolation can be used to limit interstorey drifts and seismic forces on non-structural elements.
Reference:	L M Megget "Analysis and Design of a Base-Isolated Reinforced Concrete Frame Building" - NZNSEE Bulletin, Vol 11, No 4, December 1978

NEW ZEALAND CASE STUDY No 6 - BNZ Centre, Wellington

Owner: Bank of New Zealand

Architects: Stephenson & Turner

Structural Engineers: Brickell Moss Rankine & Hill
(now Brickell Moss & Partners)

Date completed: 1984

Building features: Thirty storey steel framed structure with floors comprising steel deck and concrete topping. Seismic resistance is provided by a perimeter frame with internal columns for gravity support only.

The external facade comprises precast concrete units supported outside the column line. Windows are built into the precast units which are detailed for interstorey drifts. It is one of the largest buildings of its type in New Zealand.

Non-structural features: - Precast panels/windows
- Partitions

Description of approach to non-structural elements in earthquake: This building is a dominant feature in the Wellington central business district. Provision for earthquake movement in its facade elements was a prime consideration.

Detailed analyses were carried out on the nature and magnitude of the relative displacements of the precast concrete/window units and the structural frame, including tilting due to vertical movement of the supporting beams.

The exterior precast concrete/window panels are designed to cater for 38 mm of interstorey drift, which is three times the computed interstorey drift under code loadings.

All internal partitions are lightweight in order to accommodate seismic movement (and to reduce weight). A clearance of at least 12 mm was provided between the partitions and the columns.

Special attention was also paid to the attachment of the stone facings.

Remarks: Although completed in 1984, this building was designed in the late 1960s. It is therefore an early example of specific detailing for seismic movement in a major building.

NEW ZEALAND CASE STUDY No 7 - Union House, Auckland

Owner: Union Steamship Company of New Zealand

Architects: Warren & Mahoney

Structural Engineers: Holmes Wood Poole & Johnstone Ltd

Date completed: 1983

Building features: A 12 storey reinforced concrete building with an external cross-braced frame and employing energy dissipators and long piles to achieve base isolation.

Non-structural features:

- Base isolation
- Partitions
- Stairs
- Lift enclosure

Description of approach to non-structural elements in earthquake:

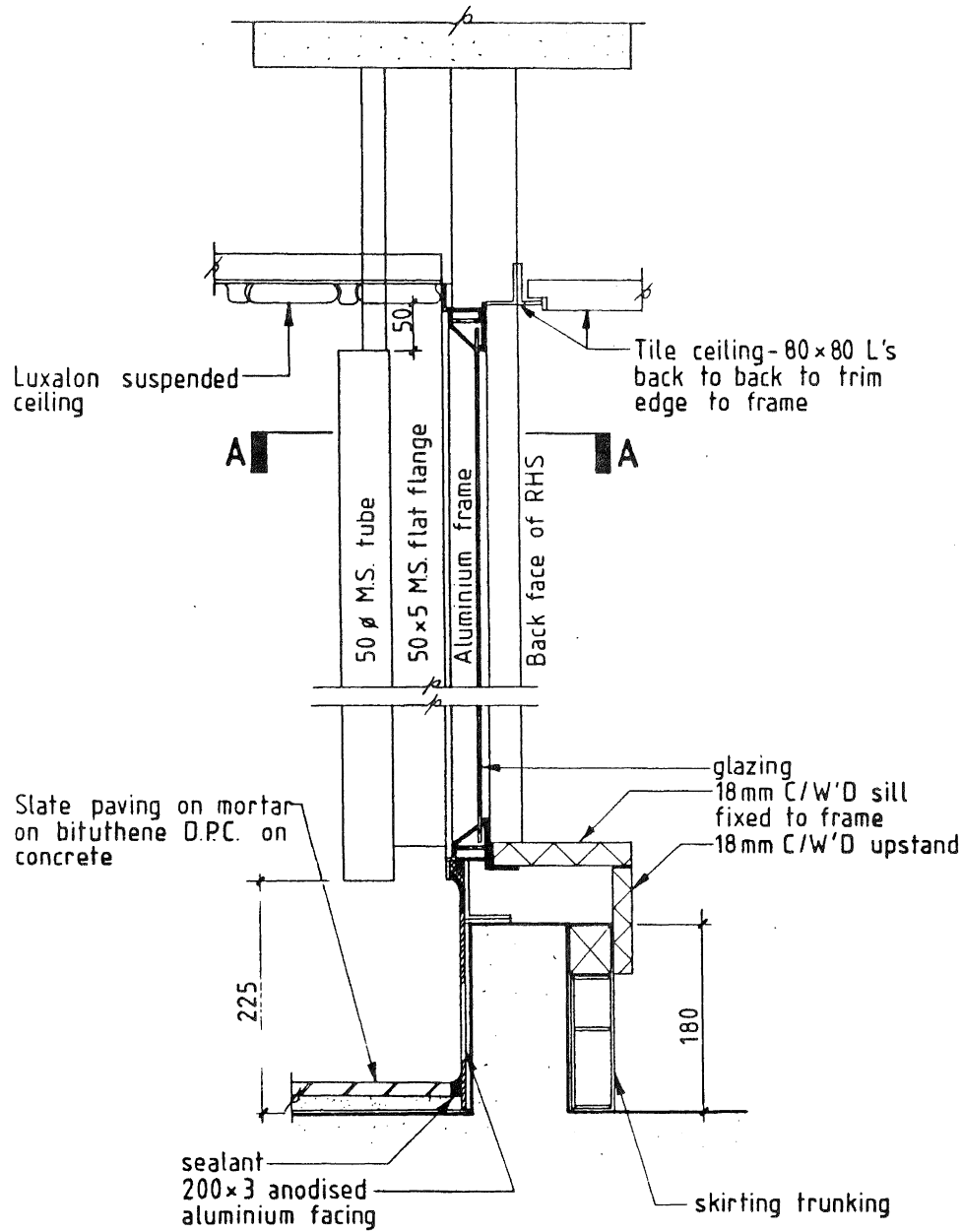
The cross bracing in the superstructure served to reduce interstorey drifts so that special treatment of non-structural elements was not required. However, relative displacements were concentrated between first and ground floors, requiring 150 mm of movement in both directions.

The lift enclosure cantilevers down from the first floor and is separated from the ground and basement slabs. Stairs are detailed to move relative to the supporting ground floor slab.

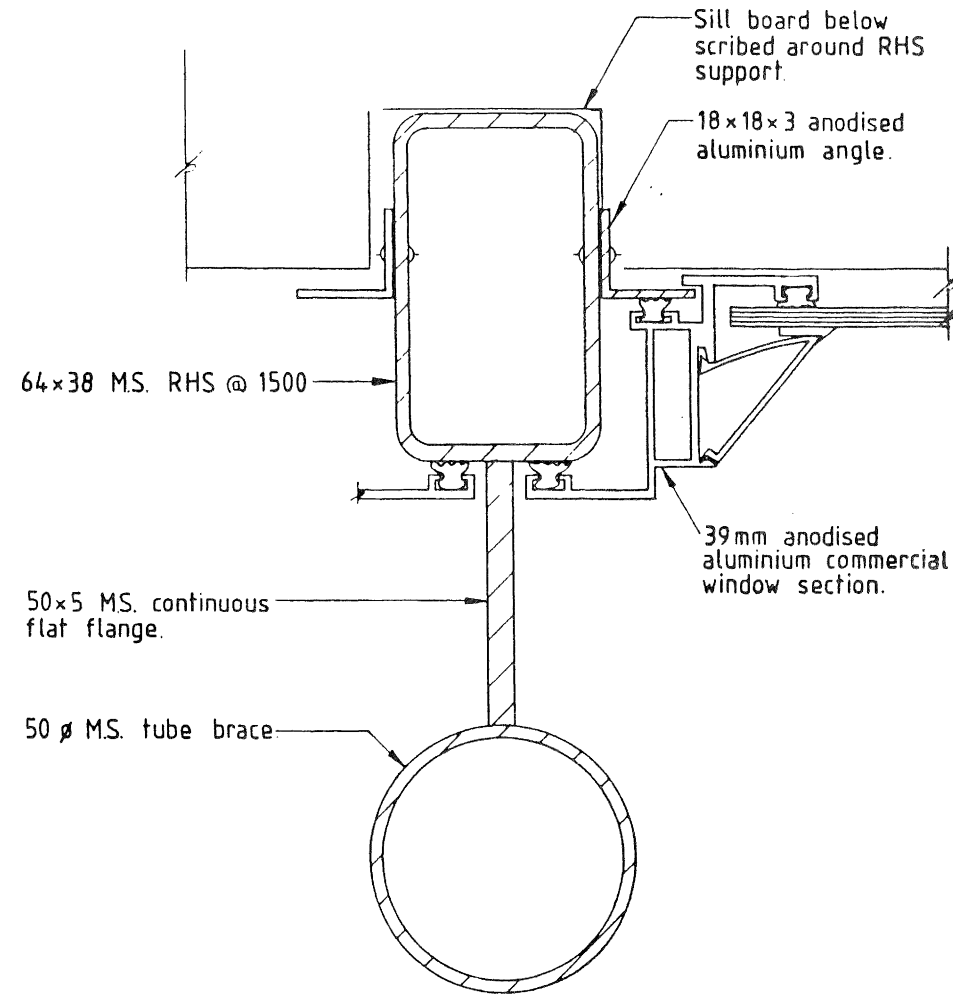
A most interesting feature is the treatment of the partitions at ground floor level. These curved, glazed shopfronts cantilever down from the slab above and finish clear of the ground floor. A sacrificial skirting is used to cover the gap.

Remarks: This is New Zealand's second major building to incorporate base isolation techniques, and relies totally on this form of earthquake protection. Although the unusual foundation conditions allowed easy isolation in this case, this building points the way to a viable and effective way of protecting non-structural elements from earthquake damage.

Reference: P R Boardman, B J Wood, A J Carr "Union House - A Cross Braced Structure with Energy Dissipators" - NZNSEE Bulletin, Vol 16, No 2, June 1983.



CROSS SECTION-GROUND FLOOR PARTITION



DETAIL SECTION AA

UNION HOUSE - AUCKLAND

NEW ZEALAND CASE STUDY No 8 - Great Northern Centre, Auckland

Owner: AMP Society

Architects: Peddle Thorp & Aitken

Structural Engineers: Beca Carter Hollings & Ferner Ltd

Date completed: Scheduled for 1985

Building features: A 19 storey reinforced concrete building with insitu columns and beams and precast flooring. Seismic resistance is provided by a perimeter frame which has columns set back from the corner. The main tower has curtain wall glazing on all four sides. Suspended ceilings are included on all floors to conceal services.

Non-structural features:

- Curtain wall glazing
- Ceilings

Description of approach to non-structural elements in earthquake: Glazing frames fit into proprietary mullions and achieve code separation requirements.

Proprietary suspended ceilings are braced to the floor above and are designed and constructed to conform with recognised (Ministry of Works) recommendations.

Remarks: This commercial development meets code requirements for protection of non-structural elements economically by use of a simple concept which allows maximum use of proprietary components. As such, it illustrates the degree of development of glazing and ceiling systems over the last decade.

