EARTHQUAKE RISK BUILDINGS – LESSONS FROM EXPERIENCE

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SYNOPSIS:

The seismic provisions of the New Zealand Loadings Code are regarded as providing an acceptably low risk to life and property. However, the majority of existing buildings do not meet these requirements, some to a disturbing degree. The paper describes a selection of buildings both pre- and post- 1935 which were assessed by the authors' firm for earthquake risk. On the basis of this experience recommendations are made for the expansion and rationalisation of the present guidelines for assessment and structural upgrading of existing buildings.

1. INTRODUCTION:

When faced with a proposal to amend or upgrade an existing building a decision must be made early as to what standard the new structure is to meet. At the present time there is little regulation or guidance on this subject. It matters not whether it is unreinforced masonry, reinforced concrete or structural steel; if the building was designed prior to 1976 then it will not have been designed to NZS 4203 standards nor to the most up to date seismic detailing principles.

Owners of buildings and their architects have a right to demand a reasoned justification for spending money. It would help them to know that the requirements or recommendations for upgrading are in line with generally accepted principles which are applied consistently throughout the country as part of a well-reasoned strategy for the reduction of earthquake risks overall. There should be some commonly accepted, consistent and identifiable advantage in upgrading an existing building.

In the case of pre-1935 unreinforced masonry buildings we have legislation that sets out the means to determine which buildings require upgrading but regulations that define the standard that they are to be upgraded to are lacking. There is a growing awareness of deficiencies in post-1935 buildings, but as yet there is no regulation or guidance to cover these. The intention of this paper is to relate some of the difficulties experienced and to provoke thought and action towards achieving some sort of national guideline document.

2.0 CASE STUDIES

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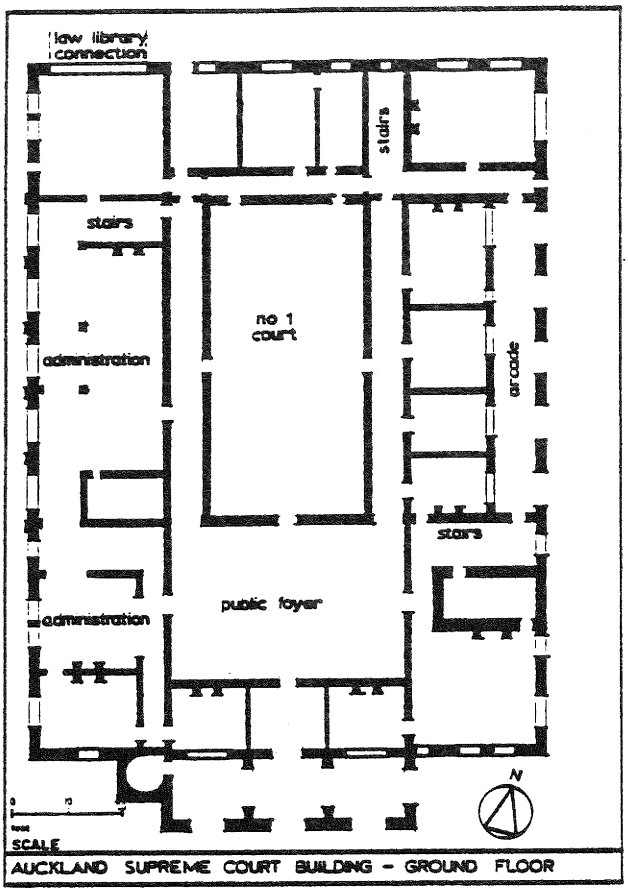
2.1 Pre-1935 Buildings -

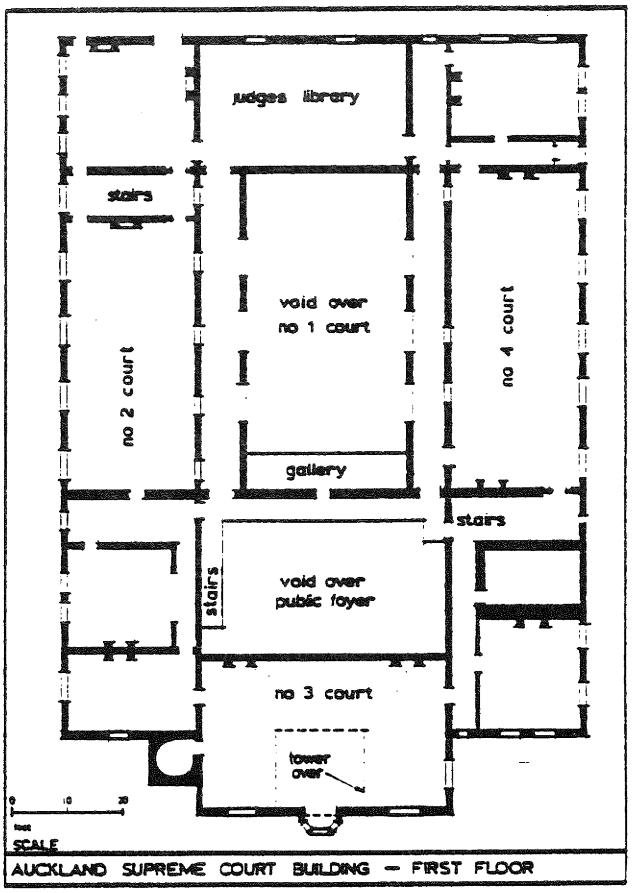
High Court Building (Auckland)
(Refer Figure 1)

Auckland's High (Supreme) Court building, built in 1868, is an unreinforced masonry two storey structure with two large double storey voids over the main court room and public foyer. The large tower over the main entrance is supported on three sides at roof level by steel portals and on the fourth by brickwork arches on the front facade. Arched cloisters run down the length of each of the longer sides and the rear wall has been penetrated by the more recent Law Library connection. The exterior features some rare hand carved stone gargoyles and figure heads depicting early Auckland notabilities.

The building is a fine example of 19th Century architecture and forms an important and valuable link in the heritage of Auckland. There was therefore no need to debate whether or not the building should be preserved, but rather to establish a basis for preservation and a corresponding level of structural upgrading. The project brief called for an investigation of requirements for both indefinite and short term lives.

A range of options was therefore examined, each option being upgrading to a different standard with consequential different usage, life and cost implications. The usage options ranged from the lowest standard of a monument to the highest standard of the continued use for an indefinite life as a Courthouse. The largest part of the investigation was devoted to this latter prospect. It was reasoned that a High Court is not just a public building and place of assembly, but it is a place of assembly where people are required to attend by legal summons, thus they are not there from free choice and in such a situation they should not be subjected to a level of risk in excess of that which they implicitly accept in modern public buildings.





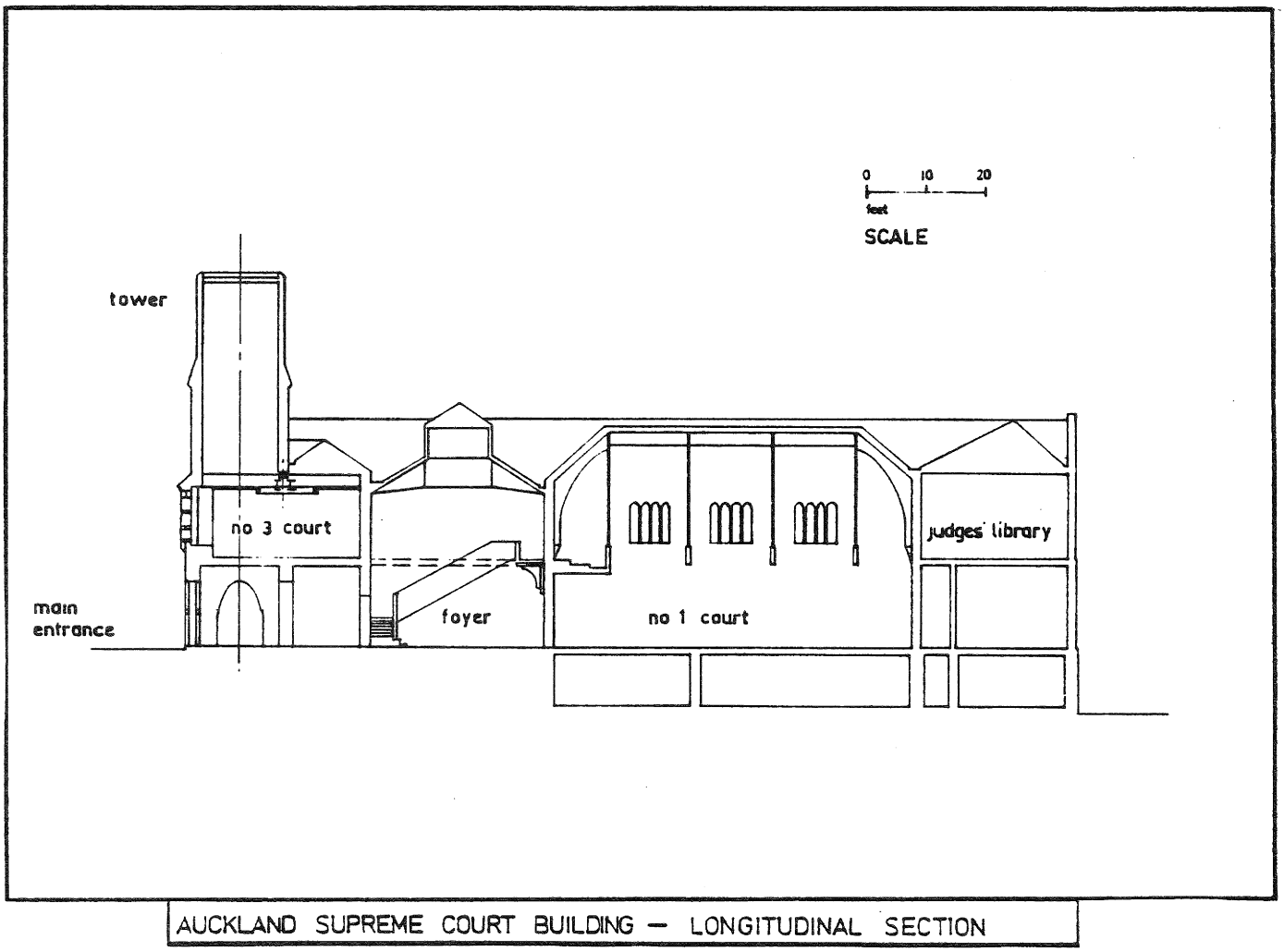


FIG. 1 HIGH COURT BUILDING LAYOUTS

Thus it was reasoned that if the building was to continue in its present usage as a Courthouse with indefinite life, the upgraded structure should comply with the spirit and intent of NZS 4203.

For the building to continue as a Courthouse for a limited period (say 15 years) would require an ultimate strength capacity (after securing particular hazards) equal to that given by Section 624 of the Local Government Amendment Act (formerly Section 301A of the Municipal Corporations Act) of half NZS 1900 Chapter 8 1965.

For an indefinite life as a monument a similar ultimate strength requirement would apply.

Our study also pointed out the need for a thorough revision of means of fire protection, egress, and an upgrading of building services.

In preparation for the design of the upgrading structure a programme of testing has been undertaken. The principal interest has been tensile and shear testing of anchors drilled into the brickwork, such as might be used to form a bond between a brickwork face and a concrete backing wall.

Old Choral Hall (Refer Figure 2)

When the old Choral Hall within Auckland University recently came due for redecoration and adaptation for new use it was recognised that the building would be classified as a High Earthquake Risk and that structural modifications would therefore be required.

The Choral Hall is an irregularly shaped conglomerate of several unreinforced masonry structures interconnected with rather tenuous brickwork links. The form of the building had long since become unsuitable as a teaching centre but it does present an imposing front facade to the Alfred/Symonds Streets intersection and is a well known and respected part of the University. It was considered however that, in view of the uncertain longterm future use of the building and the site, full structural strengthening was unwarranted. The decision was made therefore that only particular hazardous features would be secured so as to give the building an extended life of about 15 years. (Based on NZNSEE guidelines Reference 1).

The principal hazard was suspended concrete floors supported on masonry partitions and for these an independent steel support system was provided, cross braced to carry their own weight, seismic live load and upper partitions under an 8 per cent gravity earthquake. These are not specifically intended to hold the external walls intact. While a general tying together of components has been carried out no attempt has been made to bring the building as a whole up to 8 per cent gravity level. There was some deliberation on the strength levels required for the design of the new components for securing the hazards. In order to match the calculated strength of the rest of the building, a co-efficient of 4 per cent gravity was required. However, in order to increase the chances of mobilising the latent strength, the new components and connections were designed to the full value of Chapter 8 (i.e. 8 percent gravity).

Public Trust Site (Refer Figures 3 and 4)

Most developments of this nature involve the strengthening and rejuvenating of a single old building to suit its new life.

The investigation into the Public Trust site in Auckland presented a rare and exciting opportunity to investigate an entire city block of such buildings. There was therefore scope to consider not only the various levels of upgrading appropriate for each building but to investigate several combinations in arriving at a development plan for the site.

The site was one centrally located within Auckland's Central Business District fronting on to Queen Street and comprising six separate unreinforced masonry buildings. The brief was to explore all potential uses of the site from total rehabilitation to total replacement. Discussion here is concerned only with the rehabilitation part of the exercise. (Figure 3).

Three standards of upgrading were considered:

(i) A minimum standard to be applied to buildings being considered for demolition within about five years whereby particularly unsafe elements such as tall chimneys would be removed but the full requirements of the Act for securing hazards would not be met.

(ii) The second level of protection would be to secure all hazardous features with a moderate increase in strength as provided for in Section 624 of the Local Government Amendment Act. This would give the buildings a moderately extended life of 16 to 20 years before their condition was again reviewed.

(iii) The third level of protection would be to upgrade the structure to the full value of NZS 1900 Chapter 8 to give an indefinite life. To upgrade to this level was recognised as being both expensive and technically demanding.

Upgrading to the level of NZS 4203 was not even postulated and indeed, with some of the buildings up to five storeys high, such a standard would seem to be unachievable. Unlike the High Court, buildings on this site

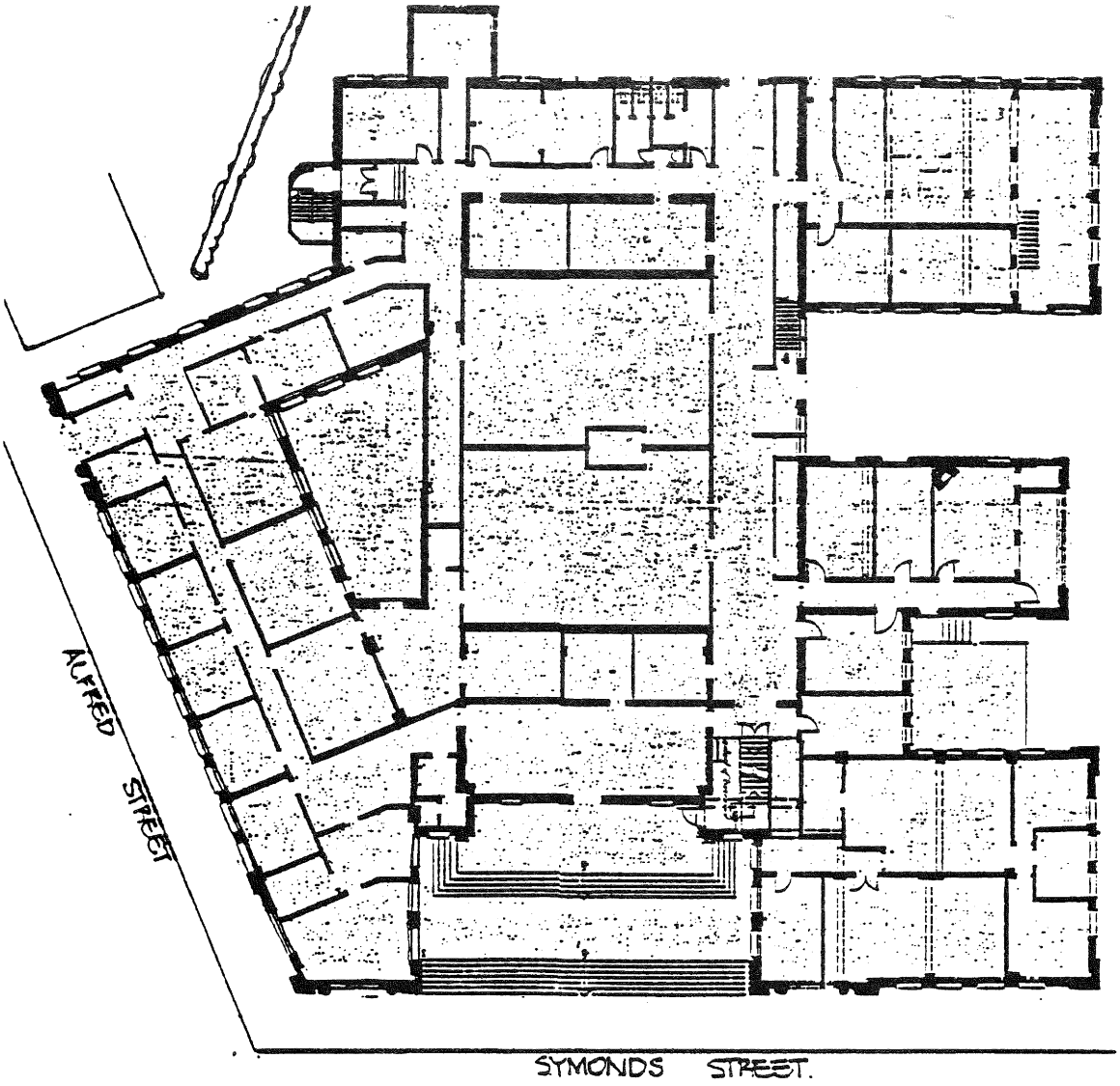


FIG. 2 OLD CHORAL HALL – GROUND FLOOR

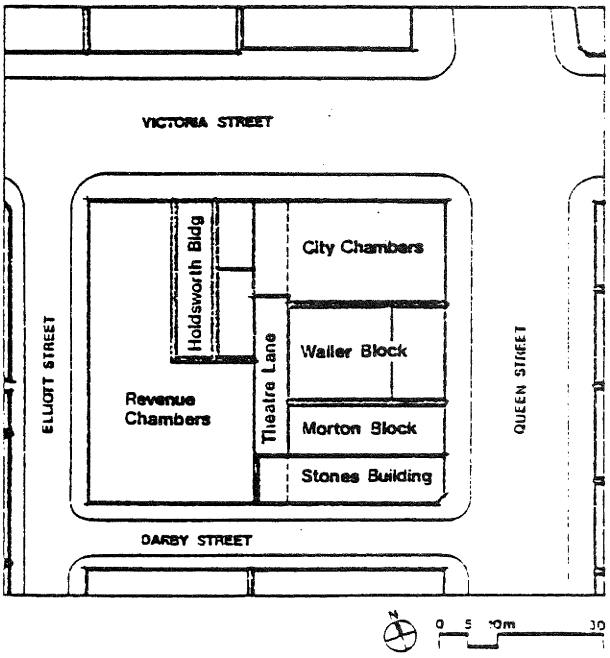


FIG. 3 PUBLIC TRUST SITE
EXISTING LAYOUT

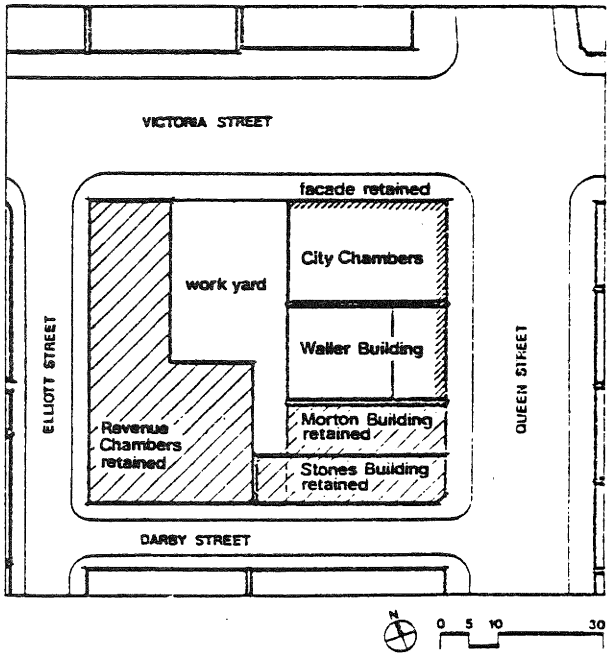


FIG. 4. PUBLIC TRUST SITE
POSSIBLE RETENTION PLAN

were neither public buildings nor places of assembly and certainly were buildings where people attended only of their own free will. A lower standard was therefore considered justified and appropriate.

Some of the buildings were not in any way suitable for permanent retention and for these an alternative third upgrading level was investigated of retaining only the front facade with a completely new structure behind. Each building on the site was considered for each of these levels of structural upgrading. Cost estimates were prepared allowing for appropriate levels of internal fitting out and upgrading of building services. Total site development schemes were then drawn up with each building being assigned what seemed to be the most appropriate upgrading standard. (Figure 4).

Unlike the High Court building or Old Choral Hall, these are commercial buildings and any development plan had to be justifiable as a sound investment proposition. It is of particular note that with present and foreseeable rental returns, full upgrading for indefinite life could not be justified for any of the six buildings on the site. The second level giving a 16 to 20 year life, however yielded a reasonable, though small, investment return on the larger structures.

Taking consideration of the fact that this site contained a representative range of unreinforced masonry buildings, from one storey to five, and that the forms of the structures led to a number of the usual methods of strengthening it is of particular significance that even though centrally placed in the Central Business District, thus gaining the benefit of high rental returns, an upgrading proposal for indefinite life could not show an economic return.

2.2 Post 1935 Buildings -

A number of recent commissions have required investigations and reports on post 1935 buildings, some as recent as the 1960's or even early 1970's.

It has been our experience that for the calculated initial elastic responses these buildings can display a strength inferior even to many of the unreinforced masonry structures that we so readily condemn. Certainly, being generally reinforced concrete or structural steel these recent buildings possess a measure of ductility; but in many cases this measure is only marginal on today's standards and it can often be demonstrated that their performance under moderate to severe earthquakes will be far from satisfactory.

Generally such buildings and their individual components are assessed in terms of an Rc value where

$$R_c = \frac{\text{actual ultimate strength}}{\text{required ultimate strength (NZS 4203)}}$$

It is quite usual to find Rc values as low as 0.1, though values of this order generally apply only to individual components. For the building as a whole however, Rc values of 0.25 or thereabouts are not uncommon, even for buildings designed as recently as 1972.

These buildings also provide classic examples of what would now be regarded as deficient structural and secondary element detailing.

Examples of such faults are:

- Highly torsional structures
- Exterior brick or blockwork built hard up to the structural framework
- Insufficient lap and anchorage lengths usually positioned within potential hinge areas
- Often strong beam/weak column detailing
- Lack of ductility

Even with relatively satisfactory existing buildings, problems related to code changes can occur.

A building designed in 1963 as a four storey building was built to three storeys only. In 1978 it was proposed to add the fourth floor. The building is regular, reinforced concrete with shear wall action in one direction and frame action in the other. What restrictions, if any should be imposed on the addition of the extra floor? Would it be necessary to upgrade the existing building or not?

The task of putting forward a rationale for any decision to this problem calls for an examination of the fundamental code philosophies, explaining them in simple terms, and relating them as far as possible to what is believed to be current thinking.

The original roof had been constructed with a thick non-structural topping screed laid to falls and it could be demonstrated that by removing this topping a lightweight fourth floor could be added without any overall increase in the ultimate loading on the building (gravity or seismic). On this basis it was argued that the structure would not be in any worse than its existing state. Note that this line of logic is independent of whatever ultimate strength the building possessed.

It could be argued that this was not a valid criterion to work to by claiming, for instance, that by increasing the occupation while not strengthening the original structure, the risk level would increase and that the structure should be upgraded so that the risk at least remained constant.

Alternatively it could be reasoned that the floor area was being increased by almost 33 per cent which must qualify

as a major alteration. With such an increase the building should be upgraded to modern-day standards.

Each of these arguments has its strengths and its weaknesses and each makes a valid point. The choice of argument will depend on the particular views of those involved in each instance.

3.0 Discussion -

These preceeding examples have one common factor in that it has been up to the investigators to decide the standard that was to govern the upgraded structure. This factor applied equally to pre-1935 buildings and to more recent ones, and applies throughout the country for existing buildings being considered for modification or upgrading.

While it can be reasonably assumed that consultants diligently endeavour to set standards that they believe are most appropriate and most in line with present legislature, it is nevertheless inevitable that different interpretations will be applied and different standards set.

Section 624 of the Local Government Amendment Act gives local authorities power to require owners to remove the danger from buildings which are "likely to be dangerous in earthquake". Buildings of unreinforced concrete or masonry are classified as such if they are not capable of withstanding half the loads specified in NZSS 1900 Chapter 8 1965. This code is now out of date and in particular does not require the application of structural type 'S' factors that are included in NZS 4203. What, therefore, is the spirit of Section 624 of the Local Government Amendment Act? Interpretations vary widely and local authorities have tended to set their own requirements to be enforced for restructuring of pre-1935 unreinforced masonry buildings.

The NZNSEE Draft Code of Practice (Reference 1), has been used to assess earthquake risk buildings and highlights critical factors contributing to earthquake risks in a building. Despite its shortcomings (which are increasing with time) this document has provided the means of achieving some uniformity of calssification and required upgrading. However, the life assessment provisions provide little benefit for securing of hazards (or other strengthening). Assessments may be made by means of a relatively superficial survey.

Local authorities were not bound by the Act to adopt the legislation and assume the right to order that hazardous buildings be strengthened or demolished.

There are three major factors which are contributing to the inconsistent approach to earthquake risk buildings in New Zealand.

- Some local authorities have assumed the powers afforded by the legislation; many others have not.

- Those that have adopted the legislation have found that the lateral force requirements defined in it serve only to determine whether or not a building should be classified as a "high earthquake risk". Each local authority is free to formulate its own requirements for structural upgrading. The lack of satisfactory guidelines has led to numerous anomalies.

- By definition the legislation restricts "high earthquake risk buildings" to those of unreinforced masonry or concrete. While this undoubtedly covers the majority of the seriously hazardous buildings, there is a need to develop a strategy which covers other more recent buildings, which can be shown to be hazardous in earthquake.

Studies of existing buildings in relation to the present loadings code showed that existing buildings both pre- and post-1935 exhibit deficiencies including:

- Lack of strength in relation to level of earthquake force attracted

- Lack of ductility

- Presence of hazards from non-structural components

- Conceptual defects or inadequacies - irregular plan shape, susceptibility to column hinging

- Lack of overall structural integrity - elements not well connected

- Lack of integrity in detailing

- Construction defects

Unreinforced masonry buildings lack strength, ductility, have non-structural hazards, and frequently lack overall and detailed integrity. However, plan shapes are commonly regular and the general disposition of lateral force resisting elements is usually satisfactory.

Buildings designed after 1935 may also lack strength in relation to present-day codes. Additionally they may lack ductility, contain hazards, lack integrity in their details and have constructional defects. Overall structural integrity is usually good but some of these buildings are not free of conceptual inadequacies when measured in present-day terms.

The deficiencies of post-1935 buildings highlight the need to avoid the temptation to assume that once all pre-1935 buildings have been identified, then all earthquake risk buildings have been listed. Many post-1935 buildings could also be classified as high earthquake risk.

In view of the seriousness of some of these deficiencies it is vital that the implications of these inadequacies in existing buildings be researched before making our requirements for new buildings even more sophisticated.

4.0 Recommendations -

It is recommended that a guideline document on earthquake risk buildings be prepared to help achieve a more uniform approach. With results of recent research in relevant areas, the profession has the means to produce a guideline document which is accepted nation-wide by engineers and owners. Such a document would deal with:

- Probability of earthquake and its intensity
- Structural integrity, both conceptually and in detail
- Common deficiencies
- Performance of non-structural elements
- Measurement of risk for a particular building on the basis of the above
- Classification of buildings according to this hazard analysis
- Definition of options for improving classification linked with benefits (e.g. increased life) with respect to statutory requirements and possibly insurance premiums

What is needed is a stepped scale of building performance expectation related to risk and calling for specific action for a range of circumstances. As far as possible this should be related to overseas practice and should be covered by enforceable legislation.

The consequences of taking specific action must be clearly defined so that an owner may choose an option which is appropriate to him in full knowledge of the consequences.

The document must seek to define an approach to cover all buildings not complying with present day codes. These approaches should be given in general terms initially, leaving sufficient flexibility to deal with the tremendous variety of buildings and circumstances. No attempt should be made to cover every aspect in detail.

This plea for a consistent and rational basis for dealing with Earthquake Risk Buildings should not be taken as a call for all-embracing legislation.

The variety of circumstances encountered requires a flexible approach within basic guidelines. The compilation of a useful guideline document is not a simple task and the following recommendations indicate the scope of work needed as background.

- A study of a cross-section of buildings to identify more closely those representing greatest threat and hence in need of most attention
- Development of analysis/assessment techniques for old masonry buildings
- Formulation of a rationale suitable for general issue but particularly to building owners
- Adoption of a policy of increasing public awareness of the assessed risks of earthquake damage
- Development of practical techniques for improving structural integrity. Testing programmes to verify the adequacy and performance of available strengthening details
- Investigation of some existing multi-storey frame buildings designed to Chapter 8 1965 using 2- or 3-dimensional, analysis programmes.
- In-situ tests on the strengths of materials particularly masonry. Where possible this should be extended to include tests of the strength and integrity of whole buildings due for demolition. Encourage dissemination of this information
- Further development of earthquake risk analysis in New Zealand

5.0 Conclusion -

The investigation of the risks of existing buildings measured against present day criteria is of great importance. After a major damaging earthquake in a main centre in which there was loss of life, injury and property damage, we as responsible engineers would like any Commission of Enquiry to say:

Earthquake engineers have maintained a balanced view in relation to the overall risks. They have responded sensibly to the changing attitudes of society and to the results of technical research and as a profession have done everything reasonable to reduce the hazard to life and property. Their attention has been appropriately divided between new and existing buildings and they have kept the public informed as to the level of risk and the extent to which it is feasible to reduce it.

When the identified deficiencies in existing buildings (and in the approach to dealing with them) are set alongside the general "state-of-the-art", it is surely questionable that such a conclusion would be reached. Action is required to rationalise the classification and upgrading of existing buildings.

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APPENDIX A:

Section 624 of Local Government Amendment Act

POWERS OF COUNCIL WITH RESPECT TO BUILDINGS LIKELY TO BE DANGEROUS IN MODERATE EARTHQUAKE - (1) In this section —

"Building" means a building constructed wholly or substantially of unreinforced concrete or unreinforced masonry; and includes any part of a building so constructed; but does not include any building used wholly or principally as a private dwelling, unless the building is of 2 or more storeys and contains 3 or more residential flats or apartments:

"Council" means a council to which this section applies pursuant to an Order in Council under subsection (2) of this section:

"Masonry" means any construction in units of burnt clay, concrete, or stone laid to a bond in and joined together with mortar:

"Moderate earthquake" means an earthquake that would subject a building to seismic forces one-half as great as those specified in New Zealand Standard Model Building Bylaw (N.Z.S. 1900, Chapter 8: 1965) for the zone (as described in that bylaw) in which the building is situated:

"Unreinforced masonry" means masonry classified as unreinforced masonry by Chapter 9.2: 1964 of the said bylaw.

(2) The Governor-General may from time to time by Order in Council made on the application to the Minister by the council concerned, declare that any specified council shall be a council to which this section applies.

(3) Where the council is satisfied that any building in the district (being a building to which this section applies), having regard to its condition, the ground on which it is built, its present and likely future use, and all other relevant matters, will have its ultimate load capacity exceeded in a moderate earthquake and thereby constitute a danger to persons therein or in any adjoining building or on any adjoining land or to passers-by, the council may, by notice in writing signed by the Chairman, or by the principal officer or Engineer or other authorised officer of the Council given to the owner, require the owner of the building within the time specified in the notice to remove the danger, either by securing the building to the satisfaction of the council or, if the council so requires, by taking down the building. The council shall also send a copy of the notice -

(a) To every person having an interest in the land on which the building is erected under any mortgage or other encumbrance, being an interest registered under the Land Transfer Act 1952; and

(b) To every person claiming an interest in the land which is protected by a caveat lodged under section 137 of the Land Transfer Act 1952 and for the time being in force; and

(c) Where the owner is not the occupier of the land within the meaning of the Rating Act 1967, to every occupier of the land within the meaning of that Act.

(4) Within 60 days after the notice is given to him, the owner or any person referred to in paragraphs (a) to (c) of subsection (3) of this section may object in writing to the council against the requirements of the notice, and the notice shall thereupon be deemed to be suspended pending the determination of the objection, or, where application is made to the Court to confirm the notice, pending the decision of the Court.

(5) Where any such objection is received by the council, the council shall as soon as practicable inquire into and dispose of the objection.

Provided that no objection shall be dismissed unless reasonable notice of the date and time when and the place where it is to be considered has been given to the objector, who, if present at the appointed time and place, shall be entitled to be heard and submit evidence and call witnesses in support of his objection. Any objector may be represented at the hearing by counsel or otherwise.

(6) Where on inquiry into the objection the council reaffirms its requirements, the council shall apply to a (District Court) for an order confirming the notice given by the council under sub-section (3) of this section.

(7) The Minister shall from time to time, by notice in the Gazette, publish a panel of persons of special skill or knowledge from whom assessors may be appointed under subsection (8) of this section.

(8) The Court hearing an application under subsection (6) of this section shall hear the application with the assistance of 2 assessors, to be appointed for the

purposes of that application by the Secretary from the panel of persons published under subsection (7) of this section. The sole function of the assessors shall be to assist the Court in determining the application, and the application shall be determined by the Court alone.

(9) If any assessor dies or is for any reason unable to act or to continue to act, an assessor may be appointed under subsection (8) of this section to act in his place, whether or not the hearing of the application has commenced.

(10) There shall be paid to assessors appointed under subsection(8) of this section, out of money appropriated by Parliament, remuneration by way of fees or allowances and travelling allowances or expenses in accordance with the Fees and Travelling Allowances Act 1951, and that Act shall apply accordingly as if those assessors were members of a statutory Board within the meaning of that Act.

(11) On the hearing of the application, the Court may -

(a) Confirm the notice without modification; or

(b) Confirm the notice subject to modification; or

(c) Extend the time specified in the notice for removing the danger; or

(d) Set aside the notice.

(12) Where -

(a) In any case in which no objection is made, the owner fails to do any act in compliance with the notice given under subsection (3) of this section within the time specified in that notice; or

(b) In any case in which objection is made, the notice is confirmed by the Court (whether with or without modification or extension of time), and the owner fails to do any act in compliance with the notice or with the notice as modified or extended, as the case may be -

the council may, by its officers or agents, enter upon the land and do that act and recover the cost thereof from the owner.

Cf. 1954, No. 76, s.301A; 1956, No. 64, s.318A; 1968, No. 123, s. 22; 1968, No. 124, s. 21; 1971, No. 62, s.28; 1971, No. 63, s.27

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Discussion -

B.H. Falconer, Auckland

The authors mentioned as a design objective the 'giving' of an extended building life of some target figure, e.g. about 15 years in one case (page 56).

Semantically would it be more effective to state a target period of years for acceptability of whatever level of residual risk there may be following upgrading, and for the authorities to grant the building an occupancy permit limited to that period of time, toward the end of which, obligatorily, there would have to be a review or the building emptied?

The approach suggested by Mr Falconer would suffer the same drawbacks of the present situation. Although his suggestion seems to provide a more reasonable basis for dealing with earthquake risk buildings, the acceptability of such a scheme will depend on the fundamental reasoning behind the techniques of classification, upgrading, risk analysis etc. Until these aspects are brought together to form a reasoned, consistent, and generally accepted approach, there will be little incentive for government and local authorities to adopt enforcing legislation.

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Discussion -

R.G. Taylor, Wanganui

With the selection of the appropriate load level for the High Court Building and the decision to adopt the full NZS 4203, did the client play any part in the final decision?

Yes, the client (who was the MWD) made the selection of load level to be applied. The consultants reports presented a range of options with appropriate life and occupancy implications. The consultants played no part in the final decision.