SINCLAIR KNIGHT MERZ

Building Industry Authority

Significant Design and Construction Issues arising out of a Review of the "Scarry Open Letter"

November 2003

SKM

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Executive Summary

Background

In September 2002 John Scarry presented an open letter to the Institution of Professional Engineers New Zealand (IPENZ) entitled "An Open Letter to IPENZ regarding the Parlous State of the Structural Engineering Profession and the Construction Industry in New Zealand". In December 2002 a revised version was presented to the Building Industry Authority (BIA). Sinclair Knight Merz Ltd. has been commissioned by BIA to report on the Scarry Open Letter to:

- Identify technical issues of major concern in relation to the safety of buildings.
- Comment on possible implications of these concerns.
- Comment on the likely extent of the issues of major concern.
- Make recommendations as appropriate on the short, medium and long-term actions required to address these concerns.

Critical Technical Issues

This report identifies four technical issues of major or significant concern where continuing investigation is required, arising out of the Scarry Open Letter. These four issues are:

- Performance of some precast concrete flooring systems, particularly hollow core precast systems.
- Use of cold worked brittle welded wire reinforcing mesh in areas of structures that are required to be ductile.
- Slender insitu and precast concrete walls.
- Performance of diaphragms.

The four issues are of concern only if the building incorporating the issue is subjected to a major earthquake. In other circumstances these issues are very unlikely to lead to inadequate building performance.

Other Technical Issues

There are many other issues raised in the Scarry Open Letter which fall into two categories:

- Technical issues that are not considered of major concern.
- Issues that do not directly influence the safety of buildings, but are more of a systemic nature in the process of building delivery.

Recommendations

The four specific issues noted above are discussed in this report and recommendations are made as follows:

- BIA issue a directive to the industry, and particularly consenting authorities, drawing attention to the concerns with hollow core flooring systems and cold worked welded wire reinforcing mesh, and gives interim guidelines on the use of these systems and materials in all new structures. A draft of such guidelines is given in Appendix B.
- BIA commission further investigation into perceived deficiencies in Grade 500E reinforcing bar with a view to confirming or otherwise its adequacy for use in ductile structures.
- BIA supports and encourages existing and new investigation and research into all four issues of concern discussed in Section 6 of this report.
- BIA conducts a survey to determine the extent of the hollow core deficiency that may lead to building failure in a major earthquake event. A survey of low, medium and high-rise building systems common in various parts of the country should be undertaken. The survey should be firstly on a sample basis, and depending on the results, on a more extensive basis.
- Where appropriate recommendations in the form of guidelines or advisory notes to industry should be circulated to alert them other issues raised in the Scarry open letter. It is suggested that a body such as "The Structural Engineering Society" with support from the BIA would be an appropriate organisation to undertake this.

These recommendations have two objectives:

- To reduce to an acceptable level the likelihood of failure of structures constructed in the future that have any of the issues of major concern incorporated into their design.
- To review and take action where necessary on the existing stock of buildings incorporating the issues of major concern.

The action in the second objective is shown to merit no higher priority than similar action on any other buildings that are vulnerable to major earthquake shaking[1].

Historically buildings that are very similar and have been subjected to the same major earthquake have shown a wide range of damage. Thus buildings that have similar characteristics of inadequate performance in a major earthquake event will exhibit widespread response to such an earthquake ranging from minor to serious damage, or possibly structural failure.

Systemic Issues

It is outside the direct scope for this report but some critical systemic issues that emerged from the preparation of this report are:

- Limited construction monitoring being provided by the structural design engineer on many sites.

[1] A major earthquake in the context of this report is one that has an average probability of occurring at a particular location every 500 years. As an example, a magnitude 7.5 earthquake that will be generated by movement on the southern sector of the Wellington fault is equivalent to the major earthquake for Wellington

- Structural designers with inadequate appreciation of site operations
- The need for improved training and practical education of designers

It is understood that these issues are being addressed through a special task force set up by the Institution of Professional Engineers New Zealand (IPENZ).

1. Introduction

About September 2002 John Scarry presented an open letter to the Institution of Professional Engineers New Zealand (IPENZ) entitled "An Open Letter to IPENZ regarding the Parlous State of the Structural Engineering Profession and the Construction Industry in New Zealand". There were some minor revisions made to this open letter in December 2002. The revised open letter was submitted to the Building Industry Authority (BIA) about that time.

In response to the Scarry Open Letter the BIA commissioned Sinclair Knight Merz Limited (SKM) to report on technical issues raised. At the same time IPENZ set up a Task Committee to investigate and report on issues raised by Scarry including systemic issues related to structural engineering practice, and related topics. It is understood that this report is in its final stages of preparation.

As required by BIA the SKM report is restricted to addressing technical issues so as to complement the IPENZ work. Even so a "Summary of all Significant Issues Noted in the Scarry Open Letter" as distilled from the review of the Scarry Open Letter required to prepare this report, is attached as Appendix A.

Based on the Scope set down by BIA this report:

- Identifies issues emerging from the review of the Scarry Open Letter that are, or could be, of major concern in relation to the safety of buildings as built.
- Comments on possible implications of those concerns in relation to the safety of building structures or parts thereof.
- Comments on the likely extent of any major concerns.
- Recommends actions:
  - Short, medium, or long-term, which are needed to address the major concerns for both existing buildings and new buildings.
  - Immediate steps or actions the BIA should take to address the major concerns.

The author has conducted a survey of opinion of some 29 people from various sectors of the building industry:

- Structural designers from consultant and academic backgrounds covering the regions of Auckland, Wellington and Christchurch
- Territorial Authority building consent structural reviewers covering Auckland and Wellington,
- Building Contractors covering Auckland and Wellington, although two of those surveyed have national coverage.

The survey has been informal inasmuch as there was no formal questionnaire followed, but relevant items from the Scarry Open Letter were discussed where the participant had appropriate knowledge. The results of the survey are not reproduced individually in this report, but rather as a majority view of the various views held by those surveyed.

An important aspect of the discussions with the structural designers was the assessment of the possible implications of "failure" of components and the likelihood, or otherwise, of these failures leading to building collapse.

This report addresses the issues in relation to existing buildings and new buildings.

Conclusions and recommendations are drawn from the study and presented at the end of this report.

2. Scope of this Study

The Scarry Open Letter identifies a range of issues that he claims to be contributing to the perceived poor state of the structural engineering profession. Many of the issues are non-technical in nature. Although the non-technical issues may have very significant indirect contribution to building safety, it is not within the scope of this report to pursue them. The IPENZ Task Committee has addressed the non-technical issues. Their report is shortly to be published.

The scope of this report is limited to those issues in the Scarry Open Letter that, after consultation with BIA, were considered worthy of further investigation as to whether they may contribute directly to building safety inasmuch as they may be deficiencies in design and/or construction practices. The issues being addressed are specifically:

- Deficiencies in reinforced concrete design practice. (Ref. Appendix A, item 6 for a detailed breakdown)
- Deficiencies in steel design practice. (Ref. Appendix A, item 7 for a detailed breakdown)
- Precast concrete not covered adequately in NZS 3101 (The Concrete Design Standard).
- Implications of the poor performance of precast concrete buildings in California.
- Designing and constructing unusual forms of construction before testing.
- Precast hollow core/end seating/brittle topping reinforcing concerns.
- The unacceptable construction practice of multiple rebending of reinforcing bars.
- Inability to form proper structural concepts and load paths by designers.
- Five specific technical issues noted in Section V of the Scarry Open Letter. (Ref. Appendix A for the five issues)
- Precast floor systems loading one side of a beam producing equilibrium torsion.

During consultation with interested parties in the building industry some systemic issues were identified as contributing to some of the perceived shortcomings in the building process. Some of these issues are discussed briefly in this report although they are not strictly of a technical nature and thus will be covered in the IPENZ Task Committee report. Selected issues are collected together for reference in Appendix C of this report.

3. Methodology

3.1 General

The methodology used to research this report and to arrive at the report conclusions is as follows:

- Review the Scarry Open Letter.
- Select with the assistance of the Building Industry Authority Project Manager the issues to be addressed in this report. The complete list of significant issues identified in the Scarry Open Letter has been itemised in Appendix A of this report.
- Survey the opinion of a cross section of senior practising structural design engineers and academics, structural reviewers of building consenting authorities, and building contractors about the issues raised in the Scarry Open Letter, and from this survey identify the issues of major concern.
- Report in tabular form on all the significant issues covered in this report.
- Report in more detail on the issues of major concern.
- Distil opinion from the surveyed design engineers, academics, reviewers, and contractors on the issues of major concern to understand the possible implications of these issues and the extent these issues may be present in the recently constructed building stock.
- Formulate a recommended course of action for BIA to deal with the issues of major concern in the short, medium and long-term cases.

Because of the nature of the survey of designers, academics, reviewers and contractors, and the variations in opinions held, this report is a distillation of these opinions to what may be considered a majority view.

This report has been peer reviewed in its draft form by a small group of senior structural designers. Where considered appropriate the content and/or methodology of the draft report has been modified to incorporate the views of the peer reviewers.

3.2 Assessment of Risk

In the assessment of the risk associated with each issue itemised in table 5.1, the risk analysis has been carried out along the lines of Appendix E of AS/NZS 4360:1999, "Risk Management". Each issue has been assessed on how widespread the issue (deficiency) occurs in recently constructed buildings, and the consequence of that deficiency being incorporated in the construction. These two assessments are then combined to provide a measure of risk associated with each issue. The risk assessment methodology is described in Section 5 of this report.

4. Survey of Opinion

4.1 Extent of Survey

The author interviewed several structural engineers practising in the field of design of commercial buildings, and academics with an expertise in concrete design and construction in an attempt to gauge the industry's considered response to the issues raised in the Scarry Open Letter. Those designers interviewed practise in Christchurch, Wellington, and Auckland although most also practise outside these geographic limits.

Senior structural engineers associated with or acting for Territorial Authority (TA) building consent departments have been surveyed. Three TA's from the Auckland and Wellington areas were chosen for this sample survey. As some of these TA's contract their structural assessments out to consultants the sample gives a broader perspective of the designers views as well.

Selected building contractors have also been surveyed. Two with national coverage and a medium sized Auckland contractor were those chosen for the survey in an attempt to get good coverage of what is a very diffused field of experience, market sector type, and geographic representation.

Most of the interviews were conducted in person. There was no formal agenda or questionnaire for the interview but rather each interview took a varied form depending on whether the person was an academic, a practising consultant, a building consent reviewer or a contractor.

It is considered that those interviewed gave a reasonable cross section of geographic opinion. All those mentioned as designers have extensive experience in the structural design, documentation and construction monitoring of commercial buildings.

A list of those interviewed with their affiliations follows:

Designers:

- Barry Ramsay (Managing Director, Powell Fenwick Consultants Ltd., Christchurch).
- Jason Milburn (Director and Wellington Manager, Holmes Consulting Group Ltd., Wellington).
- Geoff Sidwell (Senior Associate, Connell Mott MacDonald, Wellington).
- Len McSaveney (Market Development Engineer, Golden Bay Cement and Stresscrete, Auckland).
- David Bradshaw (Structural Department Manager, Sinclair Knight Merz Ltd., Auckland).
- Andrew Simpson (Project Manager, Meritec Ltd., Auckland).
- Murray Jacobs (Managing Director, Murray Jacobs Ltd., Auckland) and Ashley Smith (Senior Associate, Murray Jacobs Ltd.)
- Stuart George (Director, Buller George Engineers Ltd., Auckland).

- Victor Lam (Associate, Connell Mott MacDonald, Auckland).
  (Note that Victor Lam was until recently an employee of Stephen Mitchell Consulting Engineers in Auckland who specialise in highrise buildings)
- Richard Built (Technical Director Commercial Structures, Beca Carter Hollings and Ferner Ltd, Auckland)

Academics:

- Professor John Mander (University of Canterbury Chair of Structural Engineering)
- Dr. Jason Ingham (Senior Lecturer in Structural Engineering, University of Auckland).
- Professor Des Bull (Holmes Consulting Group, Christchurch, and Holcim Adjunct Professor in Concrete Design at the University of Canterbury).

(Des Bull and John Mander are the supervisors of the Jeff Matthews PhD research project that is the subject of Section Omega of the Scarry Open Letter).

Territorial Authority structural reviewers:

- Ian Garrett (Associate, Spencer Holmes Ltd, Wellington, acting as building consent structural engineering reviewer for Wellington City Council); Claire Stevens (Team Leader); Katharine Wheeler (Section Leader), (both of Environmental Control Business Unit, Building Permissions, Wellington City Council).
- Lian Ling (Structural Manager, GHD, Manukau, acting as building consent structural engineering reviewer for Manukau City Council).
- Hugh McNaughton (City Design, Senior Project Engineer – Structural Services, Auckland City Council LATE). (This LATE does not process the day to day applications but has the major applications referred on to it by the ACC consenting department.)

Building Contractors:

- Fletcher Construction and Stresscrete: Bob Hall (Regional Manager, Wellington), Nick Cater (Major Projects Manager, Wellington), Dave White (Regional Engineer, Wellington), Dave Gilmour (Construction Superintendent, Wellington), David Hunter (Construction Manager, Auckland), Robert Gibbes (General Manager, Stresscrete, Auckland), Keith Norgate (Manager, Professional Services, Stresscrete, Auckland.)
- Gibson O'Connor of Auckland: Don Savage (Construction Manager), and John Pye (Site Manager).
- Mainzeal Construction: Martin Fahey (Construction Manager), and John Hemi (Contracts Manager), both of Auckland

Len McSaveney is included in the designer's category as he is involved in product development and design.

4.2 Geographical Variations

It is considered that the range of opinions obtained from those surveyed will give a reasonable range of views geographically. Scarry practises predominantly in the Auckland area and it would appear from his open letter that the specific projects that he discusses are all in the Auckland area. This does not exclude the possibility that the issues that he raises occur in other areas, hence discussions with parties from Wellington and Christchurch.

It is apparent that the underlying issues that will be shown in subsequent sections of this report to be of major concern occur in all three areas. Thus it is reasonable to assume that they are nation-wide. There will be some limitations on the geographical spread depending on, for example, whether hollow core precast floor systems are manufactured in the vicinity. Hollow core is not manufactured south of Christchurch and hence it is not used extensively in the lower South Island. Another example is the differing details used at the base of precast concrete wall panels that are peculiar to specific regions and will influence the panel response differently.

Several issues brought up in the Scarry Open Letter appear to be peculiar to Auckland, but in general these issues are of minor importance.

5. Significant Issues Arising Out of the Scarry Open Letter

Scarry identifies many issues in the design and construction of buildings that he claims to be contributing to the vulnerability of structures particularly under major earthquake[2] loading. There is a general assertion in the Scarry Open Letter that there is a level of incompetence across the structural engineering industry, which seems to be based on his own experiences in the industry. A list of the significant issues he raises, as distilled from a review of the Scarry Open Letter required in order to prepare this report, is attached as Appendix A to this report.

The specific issues agreed with the BIA as the scope of this report are listed below. They do not include the systemic issues listed in Appendix A that are being addressed by the IPENZ Task Committee.

1. Deficiencies in reinforced concrete design.
   - 1.1 Beam bond and curtailment.
   - 1.2 Load paths through diaphragms.
   - 1.3 Steps in diaphragms.
   - 1.4 Shear calculations for beams supporting precast floor planks, and shell beams.
   - 1.5 Sawcuts in topping slabs cutting mesh.
   - 1.6 In cast insitu slabs M_{xy} is often ignored.
   - 1.7 Column head shear.
   - 1.8 Bursting forces at cranks in bars.
   - 1.9 Tying columns to slabs, particularly in precast floor slab situations.

2. Deficiencies in structural steel design
   - 2.1 Ignoring connection eccentricities.
   - 2.2 Lateral restraint against buckling and effective lengths.
   - 2.3 Connection design and detailing.

3. Precast concrete not adequately covered in NZS 3101 (The Concrete Standard).

4. Implications of the poor performance of precast concrete in buildings in recent earthquakes in California.

5. Designing and constructing unusual forms of construction before testing.

6. Precast hollow core end seating details and brittle topping reinforcing.

7. The unacceptable construction practice of multiple rebending of reinforcing bars.

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[2] A major earthquake in the context of this report is one that has an average probability of occurring at a particular location every 500 years. As an example, a magnitude 7.5 earthquake that will be generated by movement on the southern sector of the Wellington fault is equivalent to the major earthquake for Wellington

8. The inability of designers to form proper structural concepts and load paths.

9. Five specific technical issues noted in Section V of the Scarry Open Letter.
   9.1 The effective width of walls for in-plane shear design.
   9.2 The effective width of beams for shear design. (The same issue as 1.4 above).
   9.3 Precast floor units bearing on perimeter beams.
   9.4 Tack welded cold worked wire mesh reinforcing.
   9.5 Volcanic ash loads on roofs.

10. Precast floor systems loading one side of a beam producing equilibrium torsion.

Table 5.1 summarises all the significant issues in tabular form. It rates them in two categories:

- The likelihood of an issue leading to a detrimental effect when an event occurs,
- The consequence or impact of the issue in relation to the safety of the structure incorporating that issue.

These two categories are then qualitatively accessed against a risk analysis matrix. In the analysis the term "deficiency" rather than "issue" is used to better reflect the nature of the analysis.

Note. The event to activate the deficiency in all cases where the deficiency has been found to be of significant or major concern, is a major earthquake. In the table there is a very small risk that a deficiency is activated by some other event or loading condition and thus that risk has been eliminated from subsequent discussion in this report.

The descriptors of "consequence or impact", and "likelihood for a deficiency to be present to the extent that detrimental effects of that deficiency are activated by an event", are defined in Table 5.2. The risk analysis matrix is presented in Table 5.3. The risk analysis has been carried out along the lines set out in Clause 4.3.4(a) of AS/NZS 4360:1999, "Risk Management". The implications on the safety of the structure and a comment on how widespread the problem may be are given in brief narrative form in Table 5.1.

In Table 5.3 an issue of *major* concern is one that has been shown by test and/or experience to be reasonably likely to contribute to the collapse of a structure subjected to a major earthquake. An issue of *significant* concern is one that may contribute to serious damage, or in rare cases collapse, in a major earthquake, or one that is not well understood by the structural engineering profession. Issues of *minor* or *insignificant* concern are relatively less consequential.

Where the issue is of major concern it is covered in more detail in Section 6 of this report. There is one issue that does not fall into the category of being of major concern from the risk analysis that is also discussed further in Section 6. This is brought forward for further review in this report because, from those surveyed, it is generally agreed that there is ongoing research work that is urgently required to advance the structural engineering understanding to a satisfactory level.

All other issues that are identified in Table 5.1 are not discussed in more detail in the body of this report as their individual contribution to rendering a structure unsafe is recognised as not being significant. In rare circumstances any of these issues could contribute to serious damage to, or collapse of, a structure in a major earthquake. However this is considered an acceptable risk because of their rarity. Although covered in Table 5.1 the specific technical issues raised by Scarry in Section V of his open letter are also discussed in Appendix D.

Table 5-1 : Review of Issues Raise

Significant issues raised in the Scarry Open Letter and their contribution to rendering a building unsafe due to inadequate adherence to standards and design guidelines by structural designers

Column A	B	C	D	E	F	G	H	I
Item	**Issue**	**Reference in Scarry Open Letter**	**Likelihood (See table 5.2) (1 rare to 5 wide spread)**	**Consequence or impact (See table 5.2) (1 insignificant to 5 building collapse)**	**Risk (See table 5.3 for qualitative risk analysis matrix)**	**How covered in the relevant NZ standard**	**How wide spread**	**Implications for the safety of the structure**
1	Common deficiencies in reinforced concrete design	B.7						
1.1	Beam bond and curtailment	B.7.2 (b)	2	3	C	Adequately covered in NZS 3101 (The concrete standard). Section 7	Occurrences that may lead to serious consequences are uncommon.	Significant damage in a major earthquake but unlikely to lead directly to collapse of the structure.
1.2	Load paths through diaphragms and transfer diaphragms	B.7.2 (e)(i), B.7.6	4	2 to 4	C to A	Covered in NZS 3101. A complete section (13) is devoted to the design aspects of diaphragms.	In certain types of structures that are relatively common some deficiencies in the analysis of some diaphragms may be reasonably common.	Damage to diaphragms in a major earthquake may be significant but diaphragm failure leading to collapse is unlikely. The deficiencies in analysis noted are likely to lead to damage in a major earthquake but rarely to collapse.

Column A	B	C	D	E	F	G	H	I
Item	**Issue**	**Reference in Scarry Open Letter**	**Likelihood (See table 5.2) (1 rare to 5 wide spread)**	**Consequence or impact (See table 5.2) (1 insignificant to 5 building collapse)**	**Risk (See table 5.3 for qualitative risk analysis matrix)**	**How covered in the relevant NZ standard**	**How wide spread**	**Implications for the safety of the structure**
1.3	Steps in diaphragms	B.7.2 (e)(iii)	2	3	C	Not covered. An analysis consideration	Relatively few buildings have steps in major diaphragms and few of these would have poorly designed details leading to severe damage.	Significant localised damage to the diaphragm in major earthquake attack rendering the structure incapable of resisting diaphragm forces but unlikely to lead to collapse of the whole structure.
1.4	Precast beam and shell beam shear strength calculations.	B.7.4, B.7.5	2	3	C	Adequately covered in NZS 3101: Part 1 and 2 (The concrete standard and commentary). Clause 10.3.6 and C10.3.6.2	The problem structures are not wide spread.	In frames resisting horizontal earthquake loads not significant. In gravity load resisting elements unlikely to be of concern except where the structure is subjected to major earthquake forces. Localised serious damage in a major earthquake a possibility in flexible structures.
1.5	Saw cuts in slab toppings cutting mesh	B.7.6	1	3	D	Not covered in the concrete standard. A construction consideration.	Very unusual because if the diaphragm is a major structural element saw cutting would be very unlikely. Sawcutting of any suspended slab topping is unusual.	Not serious unless it is a major diaphragm. A very rare detail in a major diaphragm.

Column A	B	C	D	E	F	G	H	I
Item	**Issue**	**Reference in Scarry Open Letter**	**Likelihood (See table 5.2) (1 rare to 5 wide spread)**	**Consequence or impact (See table 5.2) (1 insignificant to 5 building collapse)**	**Risk (See table 5.3 for qualitative risk analysis matrix)**	**How covered in the relevant NZ standard**	**How wide spread**	**Implications for the safety of the structure**
1.6	M_{xy} in cast in situ slabs being ignored	B.7.8	3	1	D	Adequately covered in NZS 3101 : Part 2, Commentary (The commentary to the concrete standard). Clause C14.5	Some cases but not of a safety significance	A serviceability deficiency only. No significant threat to the safety of the structure
1.7	Column Head shear deficiencies	B.7.8	1	4	C	Adequately covered in NZS 3101 (The concrete standard). Clause 9.3.15	Where this structural configuration is encountered the instances of inadequate design are believed to be rare. This type of structure is generally confined to special structures. Unusual in modern commercial or domestic structures.	When ignored in design the situation could lead to partial collapse of a floor which could lead to overall collapse of the structure.
1.8	Bursting forces at cranked bar splices	B.7.9	2	2	D	Adequately covered in NZS 3101 (The concrete standard). Clause 7.3.16.7	Relatively rare as there are almost always ties or stirrups for other load conditions present that resist the forces from cranked bars.	Leads to damage under the ultimate limit state loading condition. Unlikely to result in more than relatively superficial damage.
1.9	Tying columns to slabs	B.7.11	4	3	B	Adequately covered in NZS 3101 (The concrete standard). Clause 4.3.6.7	Situations where there is no other reinforcing mechanism to resist the tendency for columns to move out from the frame would be very uncommon but such mechanisms have recently been shown to be relatively	If the required reinforcement is omitted then there may be substantial opening up of cracks in the adjacent slab at the ultimate limit state. Such damage is unlikely to lead to structural failure, as there are usually other mechanisms to

Column A	B	C	D	E	F	G	H	I
Item	**Issue**	**Reference in Scarry Open Letter**	**Likelihood (See table 5.2) (1 rare to 5 wide spread)**	**Consequence or impact (See table 5.2) (1 insignificant to 5 building collapse)**	**Risk (See table 5.3 for qualitative risk analysis matrix)**	**How covered in the relevant NZ standard**	**How wide spread**	**Implications for the safety of the structure**
							ineffective. Lack of ties from the actual column into the slab topping is not uncommon.	partly restrain the columns.
2	Common deficiencies in structural steel design	B.8						
2.1	Ignoring connection eccentricities	B.8.2(b), B.8.3	1 and 5	3 and 3	D and B	Adequately covered in NZS 3404 (The steel standard). Clause 9.1.5	Widespread for relatively minor bracing systems, the failure of which would not lead to collapse. Likely to be rare for major bracing systems where collapse may be brought about by the premature failure of the bracing connection.	Significant damage in the ultimate limit state but in usual structural configurations unlikely to lead to collapse. Major bracing systems are very likely to be given the required level of consideration for continuity of load path
2.2	Lack of lateral restraint for buckling and member effective lengths.	B.8.2(c)	1	5	B	Adequately covered in NZS 3404 (The steel standard). Clause 4.8	The bare structure as shown in the Scarry example (fig 25) is rare. Generally compression members being inadequately restrained is likely to be rare. Column lateral restraint is well understood by designers.	If the example as drawn by Scarry is real the structure could collapse. But in the majority of structural systems such compression members have more redundancy than the Scarry example.
2.3	Poor connection design and detailing	B.8.2(e), B.8.5	3	2 to 4	C to B	Adequately covered generically in NZS 3404 (The steel standard). Section 9.	Individually likely to be reasonably wide spread but combinations to cause structural collapse are not wide spread.	A wide range of consequences ranging from local dislocation to major damage.

Column A	B	C	D	E	F	G	H	I
Item	**Issue**	**Reference in Scarry Open Letter**	**Likelihood (See table 5.2) (1 rare to 5 wide spread)**	**Consequence or impact (See table 5.2) (1 insignificant to 5 building collapse)**	**Risk (See table 5.3 for qualitative risk analysis matrix)**	**How covered in the relevant NZ standard**	**How wide spread**	**Implications for the safety of the structure**
3	Precast concrete not covered adequately in NZS 3101	B.7.2(e)(ii) and B.10	3	2 to 4	C to B	Covered in general in NZS 3101 but except in a few specific areas precast is not separately identified. There is a widely used detailed NZ design guide available, "Guidelines for the Use of Structural Precast Concrete in Buildings", CAE, University of Canterbury, Christchurch, NZ. NZ is seen as a leader in earthquake resistant precast concrete construction. The revised NZS 3101, in preparation, will include a chapter specifically devoted to precast concrete.	Some precast concrete practice is outside the scope of the current version of NZS 3101 but it is covered by other well-recognised publications.	Generally the design outside the scope of the current version of NZS 3101 is recognised as being sound. But there are some issues, covered elsewhere in this table under items 6, 9.3, and 10, which are recognised to have safety implications.
4	A view that precast has performed poorly in recent earthquakes in California	B.10(d) and (e)	NA	NA		A general comment the implications of which are covered elsewhere in this table.	See respective issues discussed elsewhere in the table. The particular failures in California are not typical of construction types in New Zealand. Ref. J.A.Norton et al, Northridge Earthquake Reconnaissance Report, Bulletin of NZNSEE, Vol. 27, No. 4, Dec.1994.	There are serious implications for the safety of some structures but the particular poor performance evident in California is being addressed as part of; (a) the precast flooring issue item 6 in this table, and; (b) the slender wall issue item 9.1 in this table.

Column A	B	C	D	E	F	G	H	I
Item	**Issue**	**Reference in Scarry Open Letter**	**Likelihood (See table 5.2) (1 rare to 5 wide spread)**	**Consequence or impact (See table 5.2) (1 insignificant to 5 building collapse)**	**Risk (See table 5.3 for qualitative risk analysis matrix)**	**How covered in the relevant NZ standard**	**How wide spread**	**Implications for the safety of the structure**
5	Design and construction of unusual forms of construction before testing	B.11	3	3	C	The standards do not specifically cover the systems but provide very good fundamental guidance on design and detailing philosophy.	Some unusual structural systems have evolved this way but their design is usually given greater than normal care because the structure is unusual	Theoretically major but in practical terms minor
6	Precast hollow core/end seating/brittle topping rebar problem	B.13, V.4	5	4	A	Not adequately covered in NZS 3101 (The concrete standard)	Estimated up to 50% of two storey and above buildings constructed since 1980 will have some degree of exposure to the problem. Buildings of any number of floors have the flooring system that is being investigated.	From significant to precipitating structural collapse but only in a major earthquake. Most concern is with high rise flexible buildings. Stiff buildings are not so vulnerable.
7	Work practices	C.4						
7.1	Rebending rebar on site	C.4.5	4	3	B	Covered briefly in NZS 3101 (The concrete standard), Clause 3.8.4.2 and C3.8.4.2. Covered briefly but not adequately in NZS 3109 (Concrete Construction). Clause 3.3.5.	The practice is wide spread but it would not be evident from construction records or inspections	There could be some instances where serious damage at the ultimate limit state may occur. Possible collapse for some parts of structures that could lead to loss of life would be rare.

Column A	B	C	D	E	F	G	H	I
Item	**Issue**	**Reference in Scarry Open Letter**	**Likelihood (See table 5.2) (1 rare to 5 wide spread)**	**Consequence or impact (See table 5.2) (1 insignificant to 5 building collapse)**	**Risk (See table 5.3 for qualitative risk analysis matrix)**	**How covered in the relevant NZ standard**	**How wide spread**	**Implications for the safety of the structure**
8	Inability to form proper structural concepts and load paths - in detail and in structure overall	D to L	2	5	B	A fundamental analysis requirement. Not covered in standards.	Cases of poor selection of structural concepts and load paths leading to collapse in anything other than a major earthquake would be rare. Major buildings very unlikely to be affected. In major earthquakes this issue could be significant and is covered in item 1.2 of this table	If the structure was actually built with such a design deficiency undetected, results could be structural collapse, particularly under earthquake loading.
9	Section V of the Scarry report	V						
9.1	Effective width of walls for in-plane shear Design	V.2	5	3	B	Adequately covered in NZS 3101 (The concrete standard). Clauses 12.3.2.4 and 12.3.2.7. Some designers may be going outside the standard with insufficient attention to a special study	Widespread for certain types of structures mostly light industrial structures. Not normally an issue for office and accommodation structures.	Distress at ultimate limit state. Wall slenderness and specific details are both considerations. The industry has differing views on how serious the problem and hence the consequences are. The ongoing research needs to identify how slender walls may be before leading to potential partial collapse of some industrial structures.

Column A	B	C	D	E	F	G	H	I
Item	**Issue**	**Reference in Scarry Open Letter**	**Likelihood (See table 5.2) (1 rare to 5 wide spread)**	**Consequence or impact (See table 5.2) (1 insignificant to 5 building collapse)**	**Risk (See table 5.3 for qualitative risk analysis matrix)**	**How covered in the relevant NZ standard**	**How wide spread**	**Implications for the safety of the structure**
9.2	Effective width of beams for shear design when supporting hollow core precast floors.	V.3	2	3	C	Adequately covered in NZS 3101: Parts 1 and 2 (The concrete standard and commentary). Clauses 10.3.6 and C10.3.6.2	Serious cases not widespread.	Isolated shear failures but unlikely to lead to building collapse.
9.3	Precast floor units bearing on perimeter beams creating torsion out of balance.	V.4	4	3	B	Covered but not adequately in NZS 3101 (The concrete standard). Clauses 9.3.7 to 9.3.10. Nothing in Clause 9.4 (Additional design requirements for earthquake effects)	Wide spread in precast floor systems.	Some beam twisting in the ultimate limit state but unlikely to lead to major distress of beams. However this action may exacerbate the distress in some precast floor systems. See also item 6.
9.4	Cold worked wire mesh use where ductility may be required	V.5	5	4	A	Covered in NZS 3101 (The concrete standard) but only generically. The standard covering these meshes (NZS 3422) has been withdrawn but they are still available. Use of Grade 300E and 500E reinforcing meshes conforming to AS/NZS 4671 would mitigate against the problem arising but these meshes are not available in NZ at this time.	Widespread but use where it could lead to structural collapse less widespread but still very serious. The issue is generally limited to high strain demands at precast slab/beam junctions.	Serious damage in overload conditions and in major earthquakes. Could lead to some collapse of parts or complete structures. This issue is part of the broader issue noted in item 6.

Column A	B	C	D	E	F	G	H	I
Item	**Issue**	**Reference in Scarry Open Letter**	**Likelihood (See table 5.2) (1 rare to 5 wide spread)**	**Consequence or impact (See table 5.2) (1 insignificant to 5 building collapse)**	**Risk (See table 5.3 for qualitative risk analysis matrix)**	**How covered in the relevant NZ standard**	**How wide spread**	**Implications for the safety of the structure**
9.5	Volcanic ash load on roofs	V.6	1	4	C	Not covered in NZS 4203 (The Loading standard)	An Auckland and other isolated areas of the North Island issue. Buildings are very rarely designed for this load case and in NZ history few have been subjected to the loading.	Serious in isolated areas but other building responses are likely to overwhelm the consequences of excessive ash loading.
10	Precast floor systems loading one side of a beam only (See 9.3 above also)	Phi.4	4	3	B	Not adequately covered in NZS 3101 (The concrete standard)	Very wide spread in precast floor systems.	Some beam twisting in the ultimate limit state but unlikely to lead to major distress. See item 9.3 above

Table 5-2: Qualitative Risk Analysis

Qualitative measure of consequence or impact

Level	Descriptor	Detail description
1	Insignificant effect	No permanent damage to structure or injury to occupants expected
2	Minor damage	Some superficial damage to structure. Potential of some minor injuries to occupants
3	Moderate damage	Structural damage extensive but not severe. Injury to occupants may in some cases require hospital treatment
4	Major damage	Very severe structural damage with some partial collapse possible. Some fatalities can be expected
5	Building collapse	Structural collapse. Many occupants badly injured with a number of fatalities likely

Qualitative measure of the likelihood of an issue leading to a detrimental effect when an event occurs

Level	Descriptor	Description
1	Rare	Occuring in a very small number of structures and subjected to a rare event.
2	Uncommon	Present in a few structures or in a particular structural type that is unusual, and subjected to a rare event
3	Not wide spread	Occurs in a particular type of structure that is not common or is present in a confined geographical area, and subjected to a rare event
4	Reasonably common	Occurs in a significant number of structures over an extended geographical area, and subjected to a rare event
5	Wide spread	Occurs in a wide sample of structures or is common in many structures in most areas of the country, and subjected to a rare event.

Note: The rare event is in all cases a major earthquake.

Table 5-3: Qualitative Risk Analysis Matrix

Likelihood of activation		Consequences				
		Insignificant effect 1	Minor damage 2	Moderate damage 3	Major damage 4	Building collapse 5
Rare	1	D	D	D	C	B
Uncommon	2	D	D	C	B	B
Not wide spread	3	D	C	C	B	A
Reasonably common	4	C	C	B	A	A
Wide spread	5	C	C	B	A	A

<u>Legend</u>

A	Major concern
B	Significant concern
C	Minor concern
D	Insignificant concern

6. Issues of Major Concern

6.1 General

There are three issues arising from the Scarry Open Letter that are of major concern. Scarry identifies very specific issues that are part of more general concerns. These more general concerns are the issues that are discussed in this and subsequent sections of this report. The three issues are the main ones that the survey of structural designers indicated to be issues that need to be addressed by the industry. They were confirmed by the risk analysis carried out in the preparation of Table 5.1.

The three issues are:

- Performance of precast flooring systems in flexible structures, particularly the performance of hollow core precast systems.
- The use of cold worked relatively brittle welded wire mesh reinforcement.
- Both cast insitu and precast slender concrete walls, and the associated problems of eccentric joints in the precast walls.

There is an additional issue that the survey highlighted as being of concern to designers because of the general view that the issue needed extensive further investigation to give the profession a sound understanding of it.

This issue is:

- Performance of diaphragms.

Action is being taken by the industry to better understand and improve the state of the art of all the above issues of concern. The action includes testing of components and integrated parts of structures, assessment and recommending the direction of research needs by task groups set up by industry groups, and surveys of practical experiences of various practitioners in the industry.

6.2 Industry Advancement

One of the design professionals surveyed has written to a client to give his view of a NZ Herald article published in early April. He kindly provided a copy of the statement and a quote from that statement is relevant:

> *"Despite all of the above engineering is a conservative profession. When a critical report is written by an individual in the industry then it is looked at seriously. The basic system of designing and constructing buildings in NZ is sound. However, with any system there will be cases where mistakes or errors occur and if someone is aware of such problems, then they need to be raised so that corrective action can be taken. I believe this process is currently taking place and we totally support IPENZ in their response to the Scarry Report".*

This quote indicates the concern with which the industry regards the issues raised by Scarry. This is further evidenced by the work the BIA has initiated to make sure the issues are appropriately researched and addressed. What must also be understood is that the practice of structural engineering continues to evolve. The industry typically seeks to move forward on the basis of theoretical research supported by representative testing, but unforeseen consequences of advancement are always possible.

In the case of the issues of major concern identified in this report, the industry is taking a measured response. This response includes commissioning further research, setting up task committees to investigate the issues, and disseminating state of the art design guidelines to improve the use and practice of systems and details.

It is important that the industry allows itself sufficient time to properly investigate and research the issues of concern and to come up with measured and sound comments, procedures, and guidelines for corrective action, whilst not stifling innovation and the effective functioning of the industry. Feed back from the industry is that a reaction that may take the form of additional regulation and bureaucracy is to be avoided.

6.3 The Performance of Precast Flooring Systems

6.3.1 General

There has been significant use of precast flooring systems in industrial structures since the 1950's but the general use of such systems commenced about the mid 1970's. The common precast flooring systems are:

- Hollow core
- Single and double T's.
- Prestressed ribs with infill sections between them.
- Various flat plate systems.

The hollow core precast flooring system is of the most concern of these four systems in its overall performance in buildings. The other three systems have their own peculiarities which are reasonably well understood at the present time but require some codification of design methods, particularly at seatings to avoid significant, but not major, deficiencies in their use. Ongoing research is being undertaken at the University of Auckland to investigate other types of precast flooring systems at the present time. The reason that hollow core is of more concern than the other systems is related to its seating details, the stiffness of the seating, and the lack of a positive tie from the units into the insitu topping.

Therefore, the remainder of this subsection focuses on hollow core precast flooring systems.

6.3.2 Hollow Core

Hollow core was first introduced into New Zealand in the mid 1970's. It was a relatively new product worldwide and appeared to offer some major advantages for suspended floors in buildings. Its use became widespread quite quickly, and its popularity has been maintained until the present. From the discussions with the industry representatives (see section 4) it would appear that maybe up to 50% of all suspended floor slabs in commercial, institutional and apartment buildings built since about the middle of the 1980's are hollow core in the North Island. A significantly lesser proportion would be hollow core in the South Island as it is manufactured only in Christchurch in the South Island and hence it is not so widely used. The tradition in the South Island has been double T's.

The Northridge earthquake in Southern California in 1994 first alerted the industry in New Zealand that there might be some problems with hollow core seatings. However, the much-publicised spectacular failure of a hollow core floor in that earthquake was in a steel framed building which at that time was not typical of structures built in New Zealand. This did start structural engineers questioning exactly what was going on at the hollow core seatings. In New Zealand most of the hollow core was used in concrete framed or concrete shear wall buildings, not structural steel framed buildings.

As an ongoing understanding of hollow core performance evolved a PhD Research Project was set up at the University of Canterbury and testing was undertaken of an integrated flooring system of hollow core and ductile concrete frames. The thesis is still being written. The preliminary results of that test carried out at the beginning of last year pointed to deficiencies in the industry's understanding of the performance of hollow core. A technical advisory group of eminent members of the structural engineering profession was set up to guide and disseminate ongoing research on this problem. The technical advisory group represents:

- The Universities of Canterbury and Auckland
- The NZ Society for Earthquake Engineering
- The Structural Engineering Society, NZ
- The Concrete Society
- Precast NZ Incorporated
- Precast Floor Manufacturers
- Consulting Engineers
- Cement and Concrete Association of NZ

Many of the representatives on the Technical Advisory Group give their time voluntarily as they have the commitment to the profession and the community to improve the understanding and use of the particular flooring system.

A paper entitled "The Seismic Performance of Flooring Systems Executive Summary" was published in the Structural Engineering Society NZ (SESOC) Journal in September 2002 reflecting on the PhD Research Project and made interim recommendations on design details to mitigate against the most critical aspects of damage to the flooring system. Additional research is being carried out at the University of Canterbury to further the industry understanding of the performance of hollow core flooring systems. Some of this research has been reported for "Precast NZ Inc." by Bull, D., and Matthews, J., "Proof of Concept Tests for Hollowcore Floor Unit Connections", Department of Civil Engineering, University of Canterbury, Christchurch, NZ, Research Report 2003-1.

The major issue with the hollow core flooring is related to the stiffness of the hollow core itself in relation to the overall stiffness of the building. The failure mechanism of the hollow core system has been shown to be serious damage to the hollow core unit adjacent to the seating on the reinforced concrete beams, which could lead in some circumstances to collapse of the floor.

Damage associated with hollow core flooring systems in a major earthquake could range from minimal to building collapse. In shear wall buildings that are inherently relatively stiff the impact of a major earthquake on the integrity of the hollow core flooring system is likely to be minimal. As buildings become more flexible the likely impact will become more severe. At the extreme end of severity is successive collapse of floors but this depends on several characteristics of the hollow core flooring system used.

The above discussion is simplistic in that many flexible framed buildings may perform adequately in a major earthquake. The configuration of the floors of the structure, the relative stiffnesses of the beams and the columns of the lateral load resisting frames, the particular thickness of the hollow core units, the seating details of the hollow core on the beams, and other details, will all have influence on how the flooring system of a particular building performs.

There are no blanket criteria that can be applied to any particular class of buildings on whether the hollow core floor will perform adequately in a major earthquake.

Hollow core flooring systems are widely used internationally as well as in New Zealand. It is considered that there is a very low risk of damage to these floor systems except in a major earthquake event.

6.3.3 Geographic Variations in Performance

When hollow core was first introduced in about the mid 1970's it came as 150 mm and 200 mm thick. As more hollow core plants started up the available thicknesses increased to 300 mm with a 250 mm version being developed sometime after. In recent years there has been a 400 mm thick hollow core developed with very long span potential. Because of the relative earthquake design intensities varying from a maximum in Wellington to a minimum in Auckland and areas north of Auckland, the relative stiffness of buildings also varies.

Auckland buildings tend to be governed by serviceability considerations under earthquake loading and thus will deflect relatively less in the design earthquake than the equivalent Wellington building. Christchurch presents an intermediate stage between the two.

Hence the degree of concern varies for a particular style or type of building in Auckland as related to the equivalent buildings in other regions. The characteristics of each individual building need to be assessed on its merits.

6.4 Reinforcing

6.4.1 Cold Worked Welded Wire Mesh Reinforcing

Scarry identified problems with cold worked welded wire mesh. The traditional welded wire mesh used for many years in NZ has been known for some time to be insufficiently ductile to be used in situations where it could potentially yield. This problem has been well understood for a number of years and it is generally accepted by the industry that where there is potential for yielding of reinforcement in significant structural members, cold worked welded wire mesh should not be used. What has been less understood is the potential for the mesh to yield at precast slab/beam interfaces. There is now an alternative welded wire mesh available that is more ductile but is not in accordance with the new reinforcing steel standard AS/NZS 4671. It is manufactured from Grade 430 reinforcing that complies with a superseded standard NZS 3402 and it is supplied on the understanding that it is used as an alternative solution to the NZ Building Code requirements.

There is damage potential in slab structures that include cold worked welded wire mesh reinforcing where potential to yield in a major earthquake exists. Such potential to yield is almost exclusively associated with interfaces between precast floor toppings and adjacent structural elements where continuity cracking in the concrete can occur at the interfaces because of differing displacement and/or rotation characteristics of the elements.

The inability of the mesh to undergo significant post elastic deformation before it ruptures does not necessarily lead to severe damage or collapse. In the extreme case collapse of floors could occur, particularly if such a floor is a hollow core precast system that relies on cold worked welded wire mesh for continuity of the slab with the supporting beams. Many mesh failures are likely to cause relatively little damage. As with other major issues highlighted in this report there is a whole range of possible scenarios related to the use of the brittle meshes.

In the PhD Research noted in Section 6.3.2 above, the topping slab to the hollow core units was reinforced with cold worked welded wire mesh with conventional ductile starters from the beams. The performance of the hollow core precast flooring system has at least in part been influenced by the use of the cold worked welded wire mesh in the topping slab.

The majority of buildings constructed since the mid 1970's using precast concrete flooring systems will have cold worked brittle welded wire mesh reinforcement in the insitu floor toppings. They will include hollow core, double tee, and rib floor systems, and the relatively less frequently used flat plate type floor systems. How many of these buildings will exhibit significant distress under a major earthquake because of the use of cold worked brittle welded wire mesh in the slabs is much less clear.

6.4.2 Grade 500E Reinforcing

There also exists an issue with Grade 500E reinforcement. The reinforcement is manufactured to comply with AS/NZS 4671. The grade was introduced two years ago to replace Grade 430 and is now the only high yield reinforcing steel available. The industry has become aware that in isolated instances Grade 500E steel has suffered from abuse in bending and welding on site. It is noted that BIA has issued an advisory note cautioning against site welding and bending. Further investigations are ongoing.

6.5 Slender Concrete Walls

Slender walls do not fall into the category of being of major concern. They are classed in Table 5.1 as of being of significant concern and they are currently a controversial topic among structural design engineers. There is a wide divergence in views related to how conservative the current Concrete Design Standard requirements for these walls are.

There has been concern expressed by Scarry in the open letter about eccentric load paths at joints in precast concrete walls and similar types of panels. Scarry's concern about eccentric joint systems in precast concrete walls is specific and, although important, not the fundamental issue relating to walls. It is rather the issue of slenderness and consequent stability of walls.

There is a limitation in the NZ Concrete Standard, NZS 3101, on the unsupported height to thickness ratio of walls but the limit can be exceeded if

> *"…rational analysis or test shows adequate strength and stability at the ultimate limit state…".*

The limiting ratio is regularly exceeded in walls associated with particular types of structures. Although the Concrete Standard specifies a limit there is a considerable body of opinion that holds that the limit in the Concrete Standard is very conservative. Some testing done recently supports this view. (Beattie, G.J., "A Guide for the Designing and Detailing Slender Precast Panels for Earthquake Load Resistance", NZ Concrete Society Conference, 2002.)

There are two distinct situations where reinforced concrete walls are used. The first is in commercial buildings, including institutional and apartment buildings, where the walls extend between several floors. This is traditionally an insitu wall or a tilt up panel. These walls generally have an unsupported height to thickness ratio that complies with the non-specific design limitation in the Concrete Standard because restraint is provided at each floor level. There are some instances where timber floors are used in modern apartment buildings but well detailed timber floors provide sufficient restraint to the walls at floor level to enable them to comply with the Concrete Standard.

The other group of structures are primarily light industrial buildings and warehouses where walls are used effectively as cladding panels but also resist horizontal loads both in plane and out of plane. These are the walls that do not generally comply with the non-specific design limitation on unsupported height to thickness ratio provided in the Concrete Standard. Testing that has been undertaken recently to better understand the performance of these walls (some results have yet to be published) seems to be indicating that the Concrete Design Standard is very conservative with the limit set on the height to thickness ratio for these walls. In many cases these walls have low in-plane shear forces when subjected to major earthquake loading. They also show good stability characteristics and relatively good limited ductility. It is also apparent that geographic variations in base joint details have marked influence on wall performance.

Slender walls were identified by some of those surveyed as a major issue, and the industry continues to investigate these walls actively. There is a strong body of opinion that holds that slender walls will perform adequately under major earthquake loading. There is also a contrary view that slender walls will not perform as well as generally expected. The research into slender walls is focusing on, among other issues, reasonable slenderness ratios in various wall configurations.

The probability of slender walls causing building failure in commercial, institutional, and residential buildings is very low. The concern is with the slender industrial building walls. In these situations there may be cases where instability can occur and the consequences could be serious. It is unlikely that such wall failures would lead to collapse of the structure but they could precipitate partial collapse of a roof or wall.

6.6 Diaphragms

The diaphragms that are discussed in this section are generally floor diaphragms that, apart from supporting gravity loads, tie the various vertical structural elements of a building together at each floor level. Scarry has two particular concerns about diaphragms. These are the perceived inability of engineers to trace the load paths in the diaphragms and reinforce them accordingly, and a more specific problem with how vertical discontinuities in diaphragms are handled in design and detailing. Both of these concerns are part of a more general concern by many in the industry that the loads and actions of diaphragms, particularly in highrise buildings, is not well understood

The Loadings Standard Committee investigating the combined NZ/Australian seismic provisions for the proposed new Loading Standard have a concern related to diaphragms, but find that there is not enough research available to provide a definitive approach to diaphragm design. Understanding of these diaphragms starts with being able to model the diaphragms properly in the various commercially available analyses packages for multi-storey buildings. Until relatively recent years the standard analysis packages have not been capable of modelling diaphragms effectively. These packages are now available but reconciling the physical performance of diaphragms and their interaction with other elements of the building structure with the results of analysis requires extensive ongoing research effort. This will eventually lead to successful codification of diaphragm analysis and design.

All buildings of two or more storeys have diaphragms incorporated in them. Diaphragms associated with low and medium rise buildings are lightly stressed as the extent of the diaphragm, except for very unusual configurations, means that diaphragm forces are low. In highrise structures particularly of mixed shear wall and frame configurations, or structures of unusual shapes, the diaphragms can get very highly stressed and thus are much more prone to unpredictable response to a major earthquake. Diaphragm failure is a possibility but diaphragm failure does not necessarily lead to building collapse. A diaphragm may be classed as structurally failed but it may be still capable of performing most of its required functions. If several diaphragms in a multi-storey building were to fail then building collapse becomes more likely but this scenario is not likely except in isolated incidences.

7. Relative Risk

In this section there is a brief discussion on recently identified deficiencies in modern buildings (less than 25 years old) as opposed to deficiencies that have been identified in older buildings.

Issues of major concern highlighted in Section 6 of this report may, in some circumstances, lead to collapse of a building. The collapse will be the consequence of the response of the building to a major earthquake (an earthquake with the probability of occurring once in every 500 years). The argument to strengthen, or in the extreme case demolished, such a building because of the issues which are now being grappled with is only valid if buildings constructed in the past, say prior to 1976, are similarly treated. Many of these buildings may have critical structural weaknesses and thus some could potentially collapse in a major earthquake.

But the major earthquake event that could lead to the collapse of the pre-1976 buildings is also the event that could lead to the collapse of some of our modern buildings that incorporate the deficiencies outlined in this report.

Thus, there is no justification for dealing with these modern buildings with these deficiencies any more expeditiously than dealing with the pre-1976 buildings prone to brittle failure and collapse.

The earthquake is the same. The outcome is the same. The only issue as far as the building is concerned is the deficiencies that may lead to collapse.

8. Addressing the Issues

8.1 General

The issues arising out of the Scarry Open Letter discussed in Section 6 of this report are all related to reinforced concrete construction. All four issues are of significance only in the event of buildings being subjected to a major earthquake. It is anticipated that the level of earthquake loading required to produce possible failure of buildings because of the deficiencies identified in this report is the ultimate limit state design earthquake. This is the representative earthquake used for the design of structures to protect the lives of the occupants but accepting that the structure may sustain substantial non-repairable damage.

8.2 Existing Buildings

In Section 7 of this report the argument is presented that there is no justification for taking action on the existing stock of buildings in which the major issues of concern occur, if similar, and equally prompt action, is not taken on other existing buildings particularly those built pre-1976.

On a more pragmatic note, it may be appropriate that a survey of buildings vulnerable to the problems highlighted in Section 6.3 (precast hollow core floor systems) is undertaken so that the extent of the problem floor system and configurations can be assessed. If the BIA decide to undertake the review it is recommended that a selected number of Territorial Authorities in Auckland, Wellington and Christchurch make available Building Consent records for review. The review should extend to determining how extensive the use of hollow core in significant medium and highrise buildings has been, the general range of thickness of the hollow core, typical floor configurations, seating details, and the stiffness of the building.

If the assessment outlined above is undertaken then it should also include identifying whether cold worked brittle reinforcing meshes have been used in vulnerable parts of floor systems of these buildings so that the hollow core and brittle reinforcing mesh concerns can be addressed together.

It is important to appreciate that the level of damage that may occur to those buildings in a major earthquake that are identified as being vulnerable, will range from minor to very severe. Significant detailed work is likely to be required to quantify the extent of damage for specific buildings.

8.3 New Buildings

As part of the review of the Scarry Open Letter interim requirements have been formulated to address the precast hollow core floor system problems, and the use of cold worked brittle mesh reinforcement. These requirements are presented in Appendix B of this report. Some discussions are necessary with BIA to determine how they wish to disseminate this information to the industry, and particularly to consenting authorities. It must be stressed that this is an interim measure until the research has been completed and codified requirements have been included in NZS 3101 (the Concrete Standard) which is currently being revised.

Preparation and completion of standards of any description takes a significant amount of time and thus it is suggested that the interim requirements may be a suitable vehicle to mitigate the most obvious of the effects of the major concerns identified in this report. It must be clearly understood that the requirements are interim measures and are based on incomplete research findings. The Technical Advisory Group members looking into the seismic performance of flooring systems note the interim nature of these requirements in their paper in the SESOC Journal, Volume 15, Nº 2, September 2002.

The industry should take note of the concerns contained in the Scarry open letter. Where appropriate recommendations in the form of guidelines or advisory notes should be circulated to alert the industry, giving guidance on other important issues until they are addressed in the various standard documents. It is suggested that a body such as "The Structural Engineering Society" with support from the BIA would be an appropriate organisation to undertake this.

Note that a draft amendment to NZS3101 has been issued for public comment on 15 Sept. 2003, and to NZS3109 also on 15 Sept. 2003, covering aspects of hollow core precast floors and Grade 500 reinforcing steel.

8.4 Design Phase

It is generally believed among those surveyed that design practitioners are making genuine efforts to produce safe designs even under increasing pressure on fees and available time.

It is also clear from the survey that the thoroughness of design reviews undertaken by Territorial Authorities is variable throughout the country. Some authorities insist the designs of all significant buildings in their jurisdiction are peer reviewed. Others accept at face value Producer Statements from the designer. Even those peer reviews that are undertaken are variable in quality as the requirement by some Territorial Authorities that peer review fees are bid on a competitive basis may yield peer reviews of questionable quality.

It is clear from research done to produce this report that the standard of checking of designs by Territorial Authorities at the building consent stage varies from good to unsatisfactory. The adequacy of design reviews must be increased to a uniform and reasonable standard. This also extends to the role of building certifiers in reviewing designs.

8.5 Construction Phase

The level of construction monitoring of significant and major building projects varies from very good to unsatisfactory. Feed back from those surveyed indicated a level of concern that Territorial Authorities do not require sufficient construction monitoring to be undertaken by the design engineer, or do not provide enough construction monitoring from their own resources. Further, competitive fees and client attitudes are tending to drive down the scope of construction monitoring being provided by the design engineers.

Those interviewed considered construction monitoring for many buildings inadequate. Construction monitoring engineers, even at quite a junior level if they are properly supervised, provide a very acceptable method of identifying miscellaneous design and construction deficiencies. Where insufficient construction monitoring is undertaken these design deficiencies may not be picked up unless the contractor's staff on site are particularly experienced and well qualified.

The level of construction monitoring required is also related to the quality of the contractors QA procedures.

A mandatory requirement for construction monitoring at an appropriate level is desirable. A suggested scenario is that a building consent is not issued until a formal undertaking for a particular level of construction monitoring acceptable to the Territorial Authorities, and reflecting the requirements of the BIA and the community, is proposed. Then the actual construction monitoring being provided be regularly audited by the Territorial Authority so that they can be satisfied that the required input committed to at the building consent stage is being provided.

The profession needs to address this issue with BIA support. It is understood that the BIA has already set up a task force to improve compliance.

9. Conclusions

Conclusions drawn from this study and the research and interviews conducted as part of this study are as follows:

- Of the many issues raised by Scarry in his Open Letter, as related to technical design and construction issues, three are considered of major concern and one additional issue is of sufficient concern to designers as to require extensive ongoing investigation.
- The four issues of concern discussed in detail in this report are:
  - Hollow core precast flooring systems
  - Brittle cold worked reinforcing mesh
  - Slender walls
  - Diaphragms
- Scarry identifies several issues that are part of a more underlying concern about the performance of structures.
- Shearwall and stiff framed structures are unlikely to fail in a major earthquake because of deficiencies in hollow core seating and use of brittle cold worked reinforcing mesh. Very flexible framed buildings are most vulnerable to these deficiencies which in some circumstances could lead to failure in such an earthquake. See recommendation 1.
- Cold worked welded wire reinforcing mesh should not be used where there is potential for yielding. This tends to be concentrated at interface regions between precast floors and supporting structure. See recommendation 1.
- Grade 500E reinforcing is being subjected to continuing investigation into some of its characteristics, and handling on site. See recommendation 2.
- Although slender walls are identified as an issue of significant concern there is a wide diversity of views in the industry on their performance in a major earthquake. Very slender walls are generally used only in light industrial structures in situations that are highly unlikely to lead to failure of the entire structure if the wall collapses. Extensive further investigation is required.
- A significant amount of additional research needs to be carried out to improve the industry's understanding of the response of diaphragms to earthquake loading in multi-storey structures.
- Structural engineers have a good understanding of structural design and generally produce sound designs. But there is an increasing pressure on them to spend less time on design and construction monitoring.
- The level of design review by consenting authorities is variable, from adequate to poor.
- The level of construction monitoring of significant building construction varies from adequate to unsatisfactory. There appears to be no current mechanism that ensures that an adequate level of construction monitoring by the design engineer and/or territorial authorities is provided.

- Remedial action to buildings that are known to suffer from the issues of major concern identified in this report should not take priority over remedial work to older vulnerable buildings. The major concerns are related only to earthquake loading from a major earthquake. Many older buildings are equally or more vulnerable to the same event and thus should be treated similarly.
- There are some measures that can be brought to the attention of consenting authorities and disseminated to the design profession on an interim basis that are likely to improve the performance of new structures built. These requirements must be viewed as interim measures. They are detailed in Appendix B.
- Permanent measures to address the issues of major concern identified in this report will be codified in due course when the research has been completed and the new standards, particularly the new Concrete Standard and the new Earthquake Loading Standard, are issued.
- The practice of structural engineering continues to evolve. The industry typically seeks to move forward on the basis of theoretical research supported by representative testing, but unforeseen consequences of advancement are always possible.

10. Recommendations

Recommendations arising out of a review of the implications of the Scarry Open Letter and the four issues of concern discussed in section 6 of this report are itemised below. These recommendations are related to the specific issues noted in the scope of this report. All issues raised in the Scarry Open Letter are listed in Appendix A, but those associated with systemic issues are beyond the scope of this report.

1) BIA issue a directive to the industry, and particularly consenting authorities, drawing attention to the concerns with hollow core flooring systems and cold worked welded wire reinforcing mesh, and gives interim guidelines on the use of these systems and materials in all new structures. A draft of such guidelines is given in Appendix B.
2) BIA commission further investigation into perceived deficiencies in Grade 500E reinforcing bar with a view to confirming or otherwise its adequacy for use in ductile structures.
3) BIA supports and encourages existing and new investigation and research into all four issues of concern discussed in Section 6 of this report.
4) To determine the extent of the hollow core deficiency that may lead to building failure in a major earthquake event a survey of low, medium and high-rise building systems common in various parts of the country should be undertaken. The survey should be firstly on a sample basis, and depending on the results, on a more extensive basis.
5) Where appropriate recommendations in the form of guidelines or advisory notes to industry should be circulated to alert them to other issues raised in the Scarry open letter. It is suggested that a body such as "The Structural Engineering Society" with support from the BIA would be an appropriate organisation to undertake this.

Some issues have been briefly touched upon in this report that are not strictly within the scope of the report, but they are so important that they are the subject of the additional recommendations below:

6) BIA takes action to increase to a uniform and reasonable standard the design reviews by consenting authorities of all structures lodged for building consent.
7) BIA takes action to ensure that an adequate level of construction monitoring is carried out on all structures.

These recommendations do not purport to cover all the relevant issues that arise out of the Scarry Open Letter. There will be several other issues discussed in the IPENZ Task Committee Report.

Appendix A

A.1 Summary of all Significant Issues noted in the Scarry Open Letter

	Section Ref
1) Drastic decline in the standards of the structural engineering profession in NZ: - Unacceptable poor standards of practice - Unacceptable poor standards of training - Unacceptable poor standards of competence - Unacceptable poor standards of design - Unacceptable poor standards of documentation - Unacceptable poor standards of supervision	B1
2) Lowest fees, cheapest design, shortest design programme is the basis for competition between structural engineers	B3
3) Standard fee for a commercial building by one Auckland structural company is 0.6% of (presumably) building cost.	B3
4) Poor standard of design calculations	B4
5) Poor continuing education	B6
6) Deficiencies in Reinforced Concrete Design: - Beam bond and curtailment - Load paths through diaphragms - Precast concrete - Steps in diaphragms - Beam shear calculations supporting precast floor planks, shell beams. - Saw cuts in toppings cutting mesh - In cast-in-situ slabs M_{xy} is often ignored - Column head shear - Bursting forces at cranks in bars - Tying columns to slabs (precast toppings)	B7
7) Deficiencies in Structural Steel Design - Ignoring connection eccentricities - Lateral restraint for buckling and effective length - Connection design and detailing	B8
8) Stiffness incompatibility when strengthening masonry buildings	B9
9) Precast concrete not covered adequately in NZS 3101	B10

	Section Ref
10) A view that precast has performed poorly in recent earthquakes in California: - Rebending anchorage and continuity bars on site - Ultra thin wall panels	B10
11) Designing and constructing unusual forms of construction before testing	B11
12) The precast hollow core/end seating/brittle topping rebar problem (Matthews)	B13
13) Poor contract documents, specifications and drawings. Out of date drawings on site.	C3/C4.8
14) Unacceptable work practices generally (Section C4 highlights a few): - Poor pile construction - Rebending rebar on site - Drugs on site - Shop drawings not reviewed	C4
15) ISO 9001 does not achieve quality.	D1
16) Conflict of interest when acting as TA reviewer and undertaking work for the contractor.	E1
17) Inability to form proper structural concepts and load paths - in detail and in structure overall.	D to L
18) Low fees that bear no relationship to the input required for a proper design.	J1
19) Poor graduate training.	J2
20) Drafting in offices with no seismic experience, i.e. overseas drafting agencies.	J3
21) TA's not being aware of, or not prepared to pay appropriate fees for structural reviews.	M
Note: Section U – Suggested Corrective Action "Laws are put in place that will ensure the swift and effective maintenance of high standards throughout the entire profession"	UA1
22) A Register of Structural Engineers. If not on the register then unlawful to practice. A draconian body to enforce standards.	UA3 UA4

	Section Ref
Note: Section UA4 has a few useful ideas and clarifications for BIA such as item (p).	UA4
Section V – Specific Technical Issues Requiring Answers: V2 Effective width of walls for in plane shear design. V3 Effective width of beams supporting hollow core floors for shear design of the beams. V4 Precast floor units bearing on perimeter beams. V5 The use of tack welded cold worked wire mesh reinforcing. V6 Volcanic ash loading on roofs.	**V**
Miscellaneous Precast Concrete not adequately covered in 3101.	 Phi 2
The precast floor to one side of a beam torsion problem	Phi 4

Appendix B

B.1 Precast Floor Units Bearing Details

B1.1 Scarry highlights in his open letter in section V.4 precast floor unit bearing problems associated with perimeter beams. As a separate section in his open letter, section Ω, he reproduces a "Results Summary" of the testing undertaken by Jeff Matthews, as part of his PhD researched project, at the University of Canterbury.

The Matthews research has brought to the attention of the industry a series of problems associated with seating of precast floor units. Until very recently the details in question have had widespread acceptance in the industry as being sound. They have now been shown to be questionable in certain circumstances.

In response to the industry's concern about the problems raised by the Matthews research a "Technical Advisory Group" has been set up to 'disseminate the results from recent research to the industry, and provide input into the direction for future testing". This Group has published a paper "to assist in interpreting the results of testing recently completed,…". The reference to this paper is:

Technical Advisory Group of Precast Flooring Systems, "The Seismic Performance of Flooring Systems Executive Summary", Journal of the Structural Engineering Society New Zealand, Vol. 15, No.2, Sept 2002.

B1.2 The paper referenced above lists three recommendations as interim recommendations on the detailing of hollow core flooring systems. These recommendations are to be incorporated in the design of precast hollow core floor systems as a minimum, in conjunction with all of the relevant requirements of NZS 3101.

B1.2.1 The requirement of interim recommendation "2" in the above referenced paper is expanded as follows:

(a) The topping slab infill shall be designed to resist all relevant gravity loads plus the diaphragm forces imposed upon it. The adjacent precast floor unit, or units, shall be designed taking account of the extra gravity loads that may be applied to it (them) from the infill.

(b) The fire rating requirements of the infill shall be provided for.

B1.3 Seating details for precast concrete flooring systems, except hollowcore systems, are shown in figure 2 of the following reference.

McSaveney, L.G., "Precast Concrete Floor Systems Design and Detailing for Seismic Purposes", New Zealand Concrete Society Conference '97, Auckland, August 1997.

These details shall be used for the relevant precast flooring system design.

Note that amendment 3 of NZS3101 that will be issued shortly by Standards New Zealand will supersede the requirements of this recommendation.

B.2 Tack welded cold worked wire mesh reinforcing.

B2.1 Welded cold worked wire meshes are known to perform poorly where ductile behaviour of reinforced concrete members is required. The limited post-yield deformation capacity of cold worked wire meshes results in fracture of the mesh when located in regions of the structure where ductility is required. Therefore such meshes should not be used in earthquake resistant structures except in areas of the structure where there is no potential for post-yield behaviour.

Mesh manufactured from reinforcing steel of ductility class ‘E’ conforming to AS/NZS 4671 would be acceptable in areas of potential ductile behaviour but this is currently unavailable in New Zealand.

Specifications for the use of welded meshes should be written accordingly.

B2.1.1 Welded wire meshes in all locations of all structures where there is a requirement for potential or actual ductile behaviour shall be manufactured from ductility class ‘E’ reinforcement in accordance with AS/NZ5 4671, “Steel reinforcing materials”, or its ductile equivalent.

Welded wire mesh of a lesser ductility class, or cold worked welded wire mesh is expressly forbidden from use at any location in a structure where ductile behaviour may be required to occur by design or by deflection/rotation conformity.

Appendix C

C.1 Systemic Issues identified in the Consultation Process

During consultation with designers, academics, consenting authorities, and contractors undertaken as part of this report certain systemic issues were identified which have a very significant bearing on the perceived shortcomings of the building process, but which are not of a technical nature. Some of the more important of these issues are identified and briefly discussed below.

C.1.1 Limited Construction Monitoring

There was a general view among designers and contractors that there is insufficient construction monitoring being done by the designers' representatives on many construction sites. Contractors appreciate the input of designers on site. Feedback from designers noted that many commissions do not provide sufficient budget for appropriate construction monitoring, and in some instances the design consultant is not employed by the developer for any construction monitoring.

Increased input into construction monitoring by professionals involved in the structural design increases the chances of design and/or construction deficiencies being identified in a timely manner on site.

C.1.2 Structural Designers with Inadequate Appreciation of Site Operations

The contractors identified many construction detail problems emanating from designers with inadequate appreciation of site operations. Designers need to have construction monitoring experience so that they understand buildability, cranage restrictions, transportation restrictions, and other construction issues which influence how construction is undertaken. The corollary to this is that contractors may make changes to details as drawn to allow construction to proceed. Such changes may jeopardise the design intent.

Typical instances of this are:

- Rebending starter bars out of the way so that precast concrete units can be installed.
- Straightening starter bars bent because construction loads had been stacked one on the other and starters have been flattened.
- Starter bars being cut off or bent because of overwide loads for transport.
- Leaving stirrups out of beam column joints because of excessive congestion.
- Anchorage hooks being cut off reinforcing bars because of the impossibility of fitting the reinforcement cages together.

C.1.3 Training/Education of Designers

There is a "chicken and egg" situation related to designers and construction monitoring experience. Because of reduced construction monitoring involvement young engineers do not have the same access to adequate site experience that was available some years ago. Thus these young engineers do not have the site experience to be able to design buildable structures, and the designers of today tend to be less appreciative of good detailing so that the construction process can be undertaken without extensive site modification of details.

The overriding comment from many of the interested parties surveyed is that the level of construction monitoring by the design organisations needs to be increased substantially on many projects. This will benefit the integrity of the design and the ability of the contractors to construct according to the design intent.

Appendix D

D.1 Specific Technical Issues raised by Scarry in Section V of his Open Letter

Although the specific technical issues raised by Scarry in Section V of his Open Letter are covered in general in Table 5.1 of this report, and where appropriate expanded on in Section 6, the direct questions he asks are specifically answered here.

D.2 Effective Width of Walls for In Plane Shear Design

The question asked by Scarry is

> "In each case, for in plane shear design, what is the effective width of the wall?"

Strictly speaking the design of the wall for in plane shear is a diagonal tension question and local reduction in wall thickness of normal proportions does not significantly alter the diagonal tension capacity of such an element. The design criterion for the localised reduction in wall thickness at the precast concrete connections is shear friction. It would be very unusual if shear friction even on a reduced thickness of wall governed the overall in plane shear design of a wall. The governing criteria are almost certainly diagonal tension or compression. If shear friction were to govern or be close to governing then the majority of the diagonal tension would be carried by reinforcing in the wall. The design of the reinforcing is independent of wall thickness.

D.3 Effective Width of Beam for the Shear Design of Reinforced Concrete Beams supporting Hollow Core Floor Units

Scarry asked two questions in relation to this issue:

> "If Bull and Park are correct, why are calculations based on the gross width B not taken to be incorrect?"

And "If Bull and Park are correct, what are the effective widths to be used with other precast floor systems?"

The commentary to the Concrete Standard is quite clear on the effective width of composite concrete beams (shell beam and similar systems) for shear design. For beams such as sketched in drawing 8 of the Scarry Open Letter the relevance of the gross or nett effective beam width is less clear. To some extent the effective width is conservatively taken as the distance between the ends of the hollow core. However, the real situation also depends on the relative depth of the restricted beam width to the total depth of the beam. In almost all critical situations of shear, and all critical situations of shear in earthquake responding structures, the nett or gross beam width is irrelevant as the amount of shear reinforcement in the beam is independent of beam width.

D.4 Precast Floor Units Bearing on Perimeter Beams

Scarry asked two questions essentially related to continuity of bottom slab reinforcement where they intersect supporting beams.

> "Given these requirements of NZS 3101, and that over 100 years of sound engineering practice has been for the bottom reinforcement of cast insitu slabs to be developed into the edge beams past their shear centre, why is it that precast units supported by edge beams are not required to have minimum amounts of positive reinforcement anchored into the beam well past the shear centre?"

And "Why is it that apparently only one concrete building using hollowcore precast flooring units has been constructed in Auckland with hanger bars concreted into the floor units to maintain support should the frame dilate under seismic loading, as per the detail tested at the University of Canterbury?"

The answers to the issues highlighted by Scarry in this section are varied and complex and are beyond the scope of this appendix. Suffice to say that the Concrete Standard covers the issues raised in several places, some of which Scarry has identified. But the correct interpretation of these clauses is not necessarily as rigid as Scarry has portrayed.

The question of equilibrium torsion (Scarry refers to it as primary torsion) is an issue. It is adequately covered in the Concrete Standard in general terms but in seismic design, particularly in relation to capacity design, it is not specifically identified with design solutions. There is a complex interaction between equilibrium torsion and flexural capacity of members in post elastic response of reinforced concrete members. There is, in fact, no exact relationship between the torsional capacity of a member in primary torsion and the flexural capacity. Therefore, other mechanisms of resisting primary torsion are necessary. One of these is to have continuity of top and bottom reinforcing from slabs into the flexural member. However, this is not the only solution to the problem. A whole series of "arches" within the flexural member develops to resist equilibrium torsion where eccentric loading on the beam from precast elements is present. These arches are stable and thus the Concrete Standard has tended to not highlight the issue.

There does not appear to be any well documented cases of beam failure in primary torsion in earthquake loading conditions attributable only to the primary torsion problem. The Matthews test has identified some primary torsion interaction but it is heavily masked by the compatibility of the frame to building sway which is another issue.

The major vulnerability of structures from primary torsion is believed to be during construction rather than when the building is in service. Asymmetrical loading of precast floor systems on beams, particularly precast beams, must be addressed quite carefully as a temporary condition during construction. Once the building system is "locked" up with cast insitu floor toppings and other infills, the problem effectively disappears.

D.5 The Use of Tack Welded Cold Worked Wire Mesh Reinforcing for Major Seismic Resisting Elements and as Structural Reinforcement for Suspended Slabs, and the Damage to Reinforcement on Site

Scarry asked three questions related to the use of low ductility mesh and damage to reinforcement on site

> "Why is it that low ductility mesh is routinely used as the primary reinforcement in seismic transfer diaphragm, for even the tallest buildings?"

And "BS 5950 precludes the used of mesh as negative reinforcement in continuous composite slabs using profiled metal decking, because the mesh is not ductile enough, yet it is acceptable in NZ as suitable as the main negative and positive reinforcement for cast in-situ slabs?"

And "NZ technical articles and advertising consistently stress the need to use high ductility NZ made reinforcing because it is the only reinforcing that can be relied upon in earthquakes. Why is it then that virtually no one cares about how the same reinforcement is abused on site prior to encasement in concrete?"

These questions have been addressed in the body of the report but the specific answers are as follows:

a) Low ductility mesh should not be used as the primary reinforcement in seismic transfer diaphragms where there is a possibility that the reinforcement will be required to yield during a seismic event, or indeed any other event. This is also covered more fully in Appendix B.2.

b) The use of low ductility mesh is acceptable in slabs provided the reinforcement is not going to be required to yield when a slab for whatever reason may become part of a yielding response. The answer to this question is similar to a) above.

c) Abuse of reinforcement on site is a concern. It is a systemic problem and is related to appropriate education of contractors. Fuller construction monitoring should go part way to alleviating the problem.

D.6 Volcanic Ash Loads on Roof

Scarry posed the question

> "Should the loading standard be modified to include the effect of volcanic ash showers?"

The Loading Standard Committee has recently decided that the effect of volcanic ash showers will not be addressed in the Standard at this time.