Department of
Building and Housing
Te Tari Kaupapa Whare

Technical investigation into the collapse of the Stadium Southland roof

DEPARTMENT REPORT TO THE MINISTER FOR BUILDING AND CONSTRUCTION

May 2012

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1. Background

The Stadium Southland building was constructed in 1999 to provide a new indoor sports facility for the Southland region. The facility included multi-purpose courts, events courts, a climbing wall, seating, full service amenities, lounge, bar, kitchen and off-street parking facilities. The design of the stadium featured clear spans over two large inter-linked spaces comprising the community courts area and the events courts area.

In November 1999, during construction of the stadium, excessive deflections were observed in the roof trusses that had been erected above the community courts area. Remedial works were necessary to address the deflections. A revised building consent was obtained for the revisions involved in the remedial works. The building opened in 2000.

Figure 1. Stadium Southland prior to collapse (the builder's website)

2. The collapse

The Stadium Southland roof collapsed at around noon on 18 September 2010 following a heavy fall of snow in the area. There were no injuries or loss of life. The only person in the building at the time of collapse was not in the area affected by the collapse. Tennis players who had just left the facility noted hearing a loud 'crack' or 'explosion' come from the building as it collapsed quickly and said they saw the doors at the eastern end of the community courts blow open and a roof panel fly past.

The main areas of the stadium that collapsed were:

- part of the end walls on the eastern and western sides of the stadium
- a large portion of the roof above the community courts
- the roof above the events court supported by the spine trusses
- the main roof 'spine' trusses located between the community courts and the events courts and their western supporting columns.

Figure 3 on the following page gives a schematic view of the stadium and the structural components. The photograph below in Figure 2 shows the collapsed stadium on 19 September 2010. The access stair to the eastern end of the spine trusses had been demolished for safety reasons by this time. Figure 3 will help understanding of the description of the structure and the collapse sequence.

Figure 2 Stadium Southland following collapse – 19 September 2010 (copyright The Southland Times)

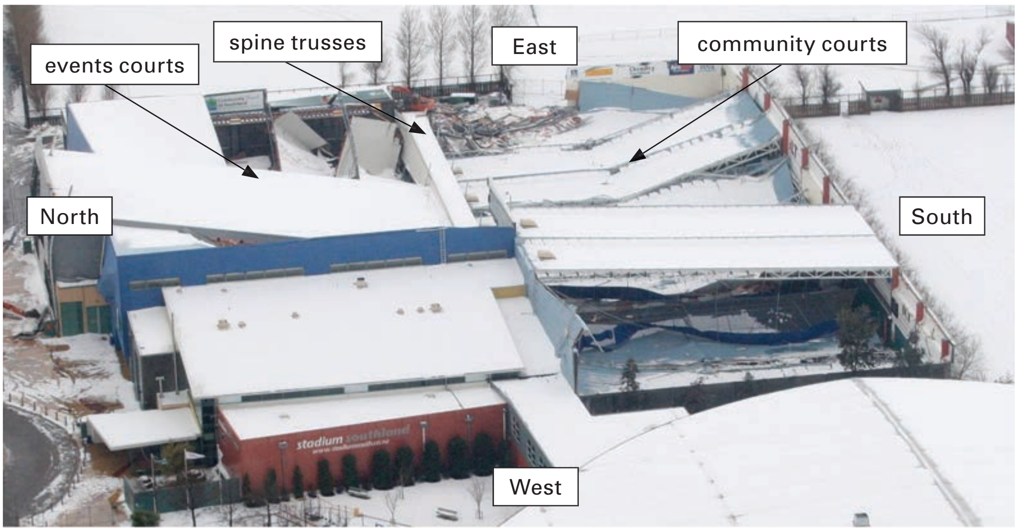
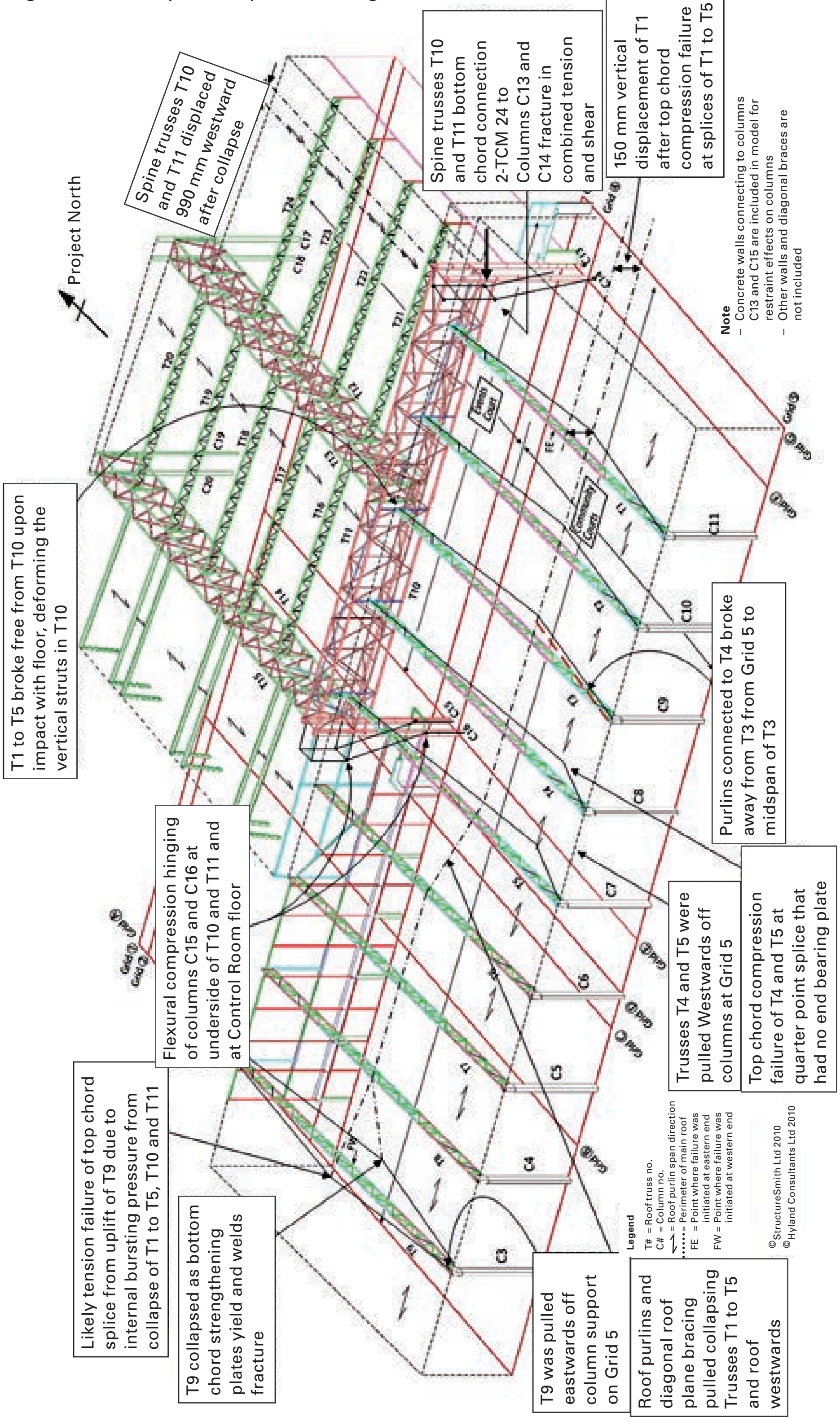


Figure 3 Collapse sequence diagram



3. Scope of the investigation

The Department of Building and Housing commissioned consulting engineers Ashley Smith (StructureSmith Ltd) and Dr Clark Hyland (Hyland Consultants Ltd) to investigate and report on the collapse of Stadium Southland.

The scope of work for the investigation included:

- determining the snow loadings required in the standards at the time of the design of the building and as amended in 2008 and comparison with the specific assessment of the snow load on the ground by the National Institute of Water and Atmospheric Research (NIWA)
- undertaking site visits and photographing the collapsed structure
- reviewing the design drawings and specification of the structure
- carrying out structural analysis to assess actions and calculate capacities of critical components in order to determine likely collapse mechanisms
- arranging laboratory testing of selected salvaged components and reporting on these findings, and
- recommending any changes as a result of the investigation:
  - to building design and construction practices and standards, and
  - to the Building Code and related documents.

The consultants undertook the work as specified in the brief and prepared a technical report.

The consultants developed a 3-D computer model to determine the loads on the structure and to help identify the relative demands on critical components of the structure at failure.

4. Findings of the investigation

4.1 COLLAPSE SEQUENCE

The main areas that collapsed were:

- part of the end walls on the eastern and western sides of the stadium
- a large portion of the roof above the community courts
- the roof above the events courts supported by the spine trusses
- the main roof 'spine' trusses located between the community courts and the events courts and their western supporting columns.

The stadium collapse is likely to have been initiated by the compression failure of the defective mid-span top chord splice in one of the roof trusses over the eastern end of the community courts (see Figure 3). The collapse then progressed through other roof trusses causing a westward displacement of the trusses and their supporting columns. As the building displaced westward, the bottom chord bolts that were connecting the spine trusses to the two easternmost columns fractured. The spine trusses then fell to the ground as the two westernmost support columns collapsed. At the western end of the community courts, one of the roof trusses fell to the floor soon after and in response to the collapse of the trusses at the eastern end. Welds failed and strengthening plates peeled away on some of the roof trusses.

4.2 CAUSES OF THE COLLAPSE

The stadium roof collapsed due to a combination of factors that included the heavy snowfall, and defects in the construction of the steel tube truss roof, particularly those portions that involved design and construction modifications and welding on site. These factors are outlined below.

a) Heavy snow fall

The snow load on the roof at the time it collapsed has been estimated to be 0.30 kPa (based on testing the critical truss top-chord compression splice capacity). The National Institute of Water and Atmospheric research (NIWA) calculated the average snow on the ground at 0.45 kPa on the day after the collapse event. Snow on ground loads are recognised in the loading standards to be higher than those on sloping roofs. It also appears that the snow load increased from the time of the roof collapse as sleet, rain and some snow had continued to fall as indicated by the collapse of a nearby shop roof the following day. The loading requirement for the stadium, when it was originally designed, was for a factored[1] roof snow load of 0.40 kPa which, when combined with a factored assessed dead load of 0.41 kPa, gave a total factored design load of 0.81 kPa. The actual self weight of the roof was calculated at 0.34 kPa at the time of collapse, allowing a snow load of 0.47 kPa to occur before the design was exceeded. At this self weight and attainment of this snow load an expected probability of failure is expected to be less than 1%.

Therefore snow load alone does not explain the roof collapse.

1 Factored as required by NZS 4203: 1992, the Verification Method at the time of design

b) Problems with design changes and remedial work during the construction process

Design modifications were made to the Stadium structure during construction to reduce the steel quantities in some of the community courts trusses. However an error in the calculation of the loadings used meant that at a late stage of construction additional design changes were required to address problems including:

- excessive deflections of the roof trusses
- the low design capacity of the community courts trusses
- inadequate south wall column head connections. The connections of the community courts trusses to the south wall concrete column heads were also found to be fragile and were unable to provide the moment fixity assumed in the original design
- inadequate spine truss connections to columns, and
- cracking of spine truss columns.

The remedial works were considered, in the opinion of StructureSmith Ltd and Hyland Consultants Ltd, to have been complex and difficult to achieve to the necessary level of quality without skilled and experienced steel construction personnel and appropriate supervision.

The modified design was compliant in terms of design for strength but susceptible to progressive collapse due to:

- site splices in the community courts trusses at the most highly loaded mid-span location
- the design modifications resulted in simply supported trusses over the community courts reducing redundancy
- the fragility of the connections of the community courts trusses to the south wall concrete columns
- the spine truss supporting structure did not have the lateral strength or stiffness to resist the westward drift imposed on it as the community courts trusses began to collapse.

c) Construction defects

The investigation found that aspects of both the off-site and on-site fabrication were not compliant with the drawings on the Council property file and/or the Steel Structures Standard and/or the Welding Standard.

Non compliant off-site fabrication included use in some instances of undersized sections and complete penetration welding without backing strips. Non compliant on-site fabrication included complete penetration welding without backing strips, insufficient weld thickness, missing welds, missing end bearing splice plates, inadequate three-sided end bearing at splices.

Construction defects were found to be critical in weakening the structure that would have otherwise been able to support the snow loads of 18 September 2010. Many, but not all, of these defects were associated with execution of design changes during construction. They included:

- *Connection of elements*
  The investigation identified defects in the community courts trusses and their connections, as well as the connections of spine trusses T10 and T11 to their supporting columns (C13 and C14). Some bolts appeared to be missing from the connections of the community courts trusses to the tops of the south wall columns.
- *Welding*
  A range of welding deficiencies were identified that weakened the stadium structure including:
  - the top chords of truss T1 to T5 (at the mid-splice locations) had insufficient end bearing and welding at the splice plates
  - the quarter point splices of trusses T4 and T5 had insufficient welding
  - there was no welding of the top surfaces of the top chords of the community court trusses at most splice locations
  - the top and bottom chord side strengthening plates were not joined by complete penetration welds
  - welds attaching the strengthening plates (to sides of top and bottom chords) were applied to painted rather than cleaned surfaces
  - bolted connection of spine truss T10 to column C14 and T11 to C13 had some unwelded packing plates increasing the stresses in the connectors
  - in all trusses examined, all the site welded splices had been incorrectly prepared and welded. No backing strips at the welds were evident as required by the structural Welding Standard.
- *Installation of strengthening and end bearing plates*
  The strengthening plates including the top chord side strengthening plates were not installed continuously past chord splice locations. Splices on trusses T4 and T5 did not have end bearing splice plates installed.

d) Site Supervision
The deficiencies identified above should have been picked up if there had been an adequate construction monitoring regime in place. The deficiencies were not identified and corrected.

e) Design and detailing shortcomings
Other design shortcomings included:

- non compliant steel shear reinforcement in the concrete columns (C13–C16) supporting main roof spine trusses T10 and T11 with the spacing of reinforcement less than that required in the applicable Concrete Structures Standard (NZS 3101: 1995). This may have reduced the column ductility, however the shear capacity was adequate for the snow design actions and would not have made the columns unfit for that purpose.

5. Implications for Building Code and Standards

Buildings are required to resist snow loads under the Building Code. The Stadium Southland building was designed according to snow load requirements that were first published in 1992 in NZS 4203. Snow load requirements were revised to a much higher level in 2008 following a major snow storm in South Canterbury in 2006. At the Department's request NIWA undertook research and provided information to the Department about significant snow events. The Department amended its Verification Method B1/VM1 to include a minimum ground snow load requirement in the south of the South Island. This effectively meant a substantial increase in design snow load in low altitude locations such as Invercargill.

Summary of current snow load requirements (since 2008):

- the design snow load at the time the Stadium was constructed (under the 1992 Standard NZS 4203) was 0.33 kPa (or a factored snow load of 0.40 kPa) on the community courts trusses
- the snow load on the Stadium roof was estimated to have been as low as 0.30 kPa at the time of the collapse based on failure capacity analyses of stadium components
- NIWA measured the average ground snow load at 0.45 kPa one day after the Stadium collapse, although it is also possible that the snow load increased from the time when the Stadium collapsed to when the NIWA measurement was taken as sleet, rain and some snow continued to fall in the day following
- the design roof snow load for this building, if it were built under the 2008 amendment to the Verification Method B1/VM1, would be 0.63 kPa
- the 2008 amendment to the Verification Method B1/VM1 provides a significant margin (60%) above the snow loads probably experienced in the Stadium Southland event

It is not therefore considered necessary to increase the design snow loads further. However it is considered necessary to follow up on recommendations to review the snow loading requirements, including review of the return period, snow density parameter for sub-alpine regions and reduction factors for snow loading on low pitched roofs.

CODE COMPLIANCE

There were three areas of non compliance with the Building Code and Standards referenced in associated compliance documents:

- the on site steel fabrication and welding for the remedial works were found to be not compliant with the drawings and/or the Steel Structures Standard (NZS 3404: 1997), and/or the Welding Standard (AS/NZS 1554)
- the spacing of the reinforcing ties in the concrete columns was found to be less than that required in the applicable Concrete Structures Standard (NZS 3101: 1995). This reduced the column ductility. However the shear capacity of the columns was found to be adequate for the design demands
- the wall thicknesses of some community court truss members were found to be less than specified.

6. Other issues for Department action

The public needs to be confident that new public buildings are not likely to collapse if designed and built according to the current design standards. The safety of structures is the key objective of the Building Act and Code.

The collapse has raised questions about the adequacy of steel fabrication along with concerns about the consistency of compliance with the standards for steel fabrication and welding. Site fabrication and welding should be supervised and executed by appropriately qualified personnel experienced in steel construction procedures. The steel construction supervisor needs to understand the risks, resources and skills required to achieve the welded construction quality required by the New Zealand Building Code.

The collapse has highlighted the importance of adequate construction monitoring. This is an issue identified in the Expert Panel report and recommendations from the investigation into the failure of four CBD buildings in Christchurch in the 22 February 2011 earthquake. The Department has work underway to improve the understanding of roles and accountabilities including construction supervision.

The Department will work with Steel Construction NZ to ensure that their practice notes address the issues identified in the Southland Stadium report.

As with the recommendations of the Expert Panel on the Department's technical investigation into four key buildings that failed in the Christchurch CBD, the Southland Stadium report also makes observations about the need for more quality assurance of commercial design and construction.

One of the initiatives to support this is the implementation of risk-based commercial consenting as provided for in the Building Amendment Act 2012 recently enacted by Parliament. Risk-based consenting will be brought into force once the regulations have been developed and certain pre conditions have been met, including industry readiness.

The Department has a comprehensive programme of work to address the recommendations made by the Expert Panel and following the Building Act review. This programme of work will be informed by the Canterbury Earthquake Royal Commission final reports parts one and two into the Canterbury earthquakes.

This investigation has raised concerns about the skills and competence of parties involved in the design and construction of the Stadium. Skills and competence are matters for the respective professional bodies (such as IPENZ, NZIA, Registered Master Builders and Steel Construction New Zealand). The Department, through the Building and Construction Productivity Partnership, has identified that work is required on skills including the need for more people capable of quality supervision of construction.

One of the recommendations from the Expert Panel report is the introduction of Design Features Reports. The purpose of these reports is to ensure that the approach to design is transparent, design intentions are clear and that important structural characteristics are known. These would be available at consenting stage, throughout construction and at Code compliance stage. The replacement stadium has a Design Features Report which describes how the building is designed to respond to critical events.

Other work the Department has underway has identified the need for more sector leadership. Critical to the quality of construction is the involvement of the designer, engineer or architect assisted by specialist inspectors, to carry out site observations during construction, which would be a change in approach for the sector.

The Department will release a Practice Advisory to building owners, territorial authorities and others, in case the issues revealed through the Stadium Southland report are present elsewhere.

An issue arising from this investigation, as for the investigation into the failure of the four buildings in the Christchurch CBD, is that some of the evidence relating to the collapse had been removed from site prior to the investigation. The Department will investigate the potential for greater legislative powers to assist the Department to:

- carry out building investigations
- restrict removal of debris, other than for search and rescue
- require documentation or photographic records of debris removal, and
- have right of access to relevant information to inform an investigation.

7. Consultants' recommendations and Department response

INTRODUCTION

The Department has a range of initiatives underway to improve the quality of the construction of commercial buildings in New Zealand. A multi-year work programme is underway arising from the Expert Panel report recommendations as a result of the investigation of the failures of four commercial buildings in the Christchurch earthquake sequence. This work programme will be revised in response to the Canterbury Earthquakes Royal Commission final reports part one and two and will also pick up the recommendations from the Southland Stadium investigation report.

DESIGNING BUILDINGS SUBJECT TO SNOW LOADINGS

Consultant recommendations

RECOMMENDATIONS 1 AND 2: RESEARCH INTO SNOW LOADINGS

Undertake research to improve the understanding of snow loadings for New Zealand coastal sub-alpine areas. In particular:

- the relationship between roof and ground snow loads due to the effect of roof slope
- review of the snow density parameter in subalpine regions
- the statistical reliability basis of snow loadings
- return periods and corresponding load and materials strength safety factors for the Loadings, and the Steel and Concrete Structures Standards.

Departmental response

The Department commissioned NIWA to undertake further research into snow loadings and their relationship with roof slope and building standards. The snow load factor was increased in 2008. B1 (the Building Code Clause for Structure) is under review and this will consider design for snow load. The overall design level now used in the NZ Loadings Standard appears to be adequate, but it and related parameters will be considered. The contract with NIWA is ongoing so that learning from new snow events can be built into requirements for construction where required.

The Practice Advisory on long (over 20 metres) span stadiums and exhibition centres will recommend that owners of existing buildings throughout New Zealand to which members of the public have access, particularly those subject to snow loads, and that have roof trusses fabricated from closed steel hollow sections such as circular and rectangular tubes, get a structural engineering assessment on the strength of their structure and whether any remediation is appropriate.

RECOMMENDATION 3: INSPECTION OF BUIILDINGS SUBJECT TO SNOW LOADINGS
Ensure that public buildings expected to be affected by snow loadings are not opened for public use until the adequacy of the construction of all roof structural components has been appropriately inspected and certified.

Departmental response

The Department is satisfied that this is provided for in the current regulatory system. Before issuing a code compliance certificate a building consent authority must be satisfied that the building work complies with the building consent. When the building consent is granted, the building consent authority must have been satisfied the plans and specifications will result in a building that complies with the Building Code. Further the Building Act requires (s 363) that buildings intended for public use must not be used until a code compliance certificate is issued (or a certificate for public use under s 363a).

The introduction of risk based consenting along with the proposed Design Features Reports will strengthen this assurance with the levels of risk matched with the appropriate quality assurance mechanisms.

RECOMMENDATION 4: SNOW LOAD ALARMS
Require snow alarms be installed in public buildings subject to snow load to warn occupants to exit buildings when snow loads exceed specified design limits

Departmental response

The Department will investigate the practicality of installing snow warning alarms (possibly linked through security monitoring or fire alarm systems) in large span public buildings where there is the risk of snow fall exceeding design specifications. The Practice Advisory recommends that owners of public buildings in snow-prone areas likely to have large numbers of occupants develop mitigation and evacuation procedures.

RECOMMENDATIONS 5 AND 6: DESIGNING BUILDINGS SUBJECT TO SNOW LOADINGS
Develop guidelines for the design of roof structures subject to snow loadings to prevent progressive collapse in the event of snow overload. Require the connections of roof rafters and trusses to the supports to be sufficient to prevent them being pulled from their supports should those members suffer overload failure. Require that columns and walls supporting roof structures subject to snow loading be sufficiently stiff, strong or braced to resist transverse drifts imposed by collapsing rafters under overload conditions, thereby preventing progressive collapse.

Departmental response

The Department will address the issues of buildings subject to snow loadings as part of the work already underway on the Structure Code Clause B1 and the associated Verification Method B1/VM1.

The Department will work with the Structural Engineering Society of New Zealand together with the building and construction sector to ensure the provision of revised standards and guidance on:

- design of roof structures subject to snow loading
- connections of roof rafters and trusses to supports subject to snow loading
- design of columns and walls supporting roof structures subject to snow loading
- identifying on drawings the collapse critical components of important roof structures subject to snow loading for particular attention by reviewing, construction and monitoring personnel.

This will be followed by:

- input to continuing professional development for practitioners in the sector
- promulgation of advice to owners, territorial authorities, New Zealand Property Council and building owner organisations.

RECOMMENDATIONS 7 AND 8: PROFESSIONAL COMPETENCY

Mandatory minimum levels of competency be set for companies and key personnel undertaking the construction of steel roof structures of public buildings subject to snow loadings.

Mandatory levels be set for independent third party design review and construction monitoring assisted by appropriately qualified people for steel roof structures of public buildings subject to snow loadings.

Departmental response

The Department has been working with the Building and Construction Productivity Partnership, as skills have been identified as a critical issue to improve the quality of construction and build it right first time.

The Department will be encouraging the sector to ensure they use Chartered Professional Engineers, that they actively assure themselves that welders are appropriately skilled, and that welds are routinely inspected with the assistance of appropriately qualified welding inspectors in the course of construction, both on site and in the workshop.

The implementation of risk based consenting will also provide assurance that the appropriate skills and quality assurance mechanisms are applied to projects consistent with their risk and construction complexity.

RECOMMENDATION 9: ROLE OF STRUCTURAL ENGINEERS
Structural engineers be required to identify on the drawings collapse critical components of important roof structures subject to snow loading for particular attention by reviewers, constructors and construction monitors.

Departmental response

The Department plans to develop and introduce Design Features Reports which would articulate how the design addresses the potential for critical events, enabling reviewers to see quickly the viability of the design for prospective events.

RECOMMENDATION 10: CONCRETE STANDARDS
Review the adequacy of the extent of concrete column buckling provisions in the Concrete Structures Standard NZS 3101.

Departmental response

The Department, in the work on the review of the Verification Method B1/VM1 and the Concrete Structures Standard NZS 3101, will ensure that this work addresses the column buckling issue.

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