BUILDING PERFORMANCE

Final report into the investigation of the collapse of a Balcony at 598 Castle Street, Dunedin

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MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
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New Zealand Government

Executive Summary

On the evening of 4 March 2016, a cantilevered balcony at 598 Castle St, Dunedin, collapsed during a music concert attended by up to 1500 people in a residential accommodation area. Eighteen students were injured as a result of the collapse, including two who received serious injuries.

The Minister for Building and Housing subsequently instructed the Ministry of Business, Innovation and Employment (MBIE) to investigate the cause of the collapse, and whether the balcony was designed, constructed and maintained to the required standards. The investigation was to establish whether there were failings and whether our building system processes and requirements are working as intended.

A Terms of Reference for conducting the investigation was developed and an MBIE investigation team was established. A site inspection was undertaken to analyse the balcony, the building that the balcony was attached to and the relevant documentation relating to the construction. A preliminary report into the investigation was issued by MBIE in March 2016 on which this final report is based.

The balcony was cantilevered from the first-level floor of a two-storey building that was part of a privately owned student accommodation complex designed in 1999, consented by the Dunedin City Council in December 1999 and constructed shortly after. The Code Compliance Certificate for the completion of the complex was issued by the Dunedin City Council in November 2003.

The conclusions of the investigation are:

- The primary cause of the collapse was the number of people congregated on the balcony at the time of collapse, which significantly exceeded the design capacity of the timber joists supporting the balcony.
- The structural design of the balcony met the standards of the day and its construction met Building Code requirements at the time.
- There were no observable defects or deterioration that would have contributed to the collapse.
- A design detail permitted at the time the balcony was constructed and which remains permitted under the current NZ Standard NZS 3604: 2011, namely the notching of the balcony timber joists at the step between the first floor and the balcony, was unlikely to be a contributing factor. This was validated by testing conducted by the University of Auckland.
- Design standards have changed since the balcony was constructed and the sizes of the timber cantilevered joists required for this type of structure were increased in 2011. It is therefore now less likely that a similar balcony built to current standards would collapse if it were subjected to the same level of overloading.
- This collapse highlights the brittle and sudden manner in which cantilevered balconies subjected to crowd loading can collapse. In this case they were designed for normal domestic use and not as public grandstands where higher design loads requirements apply.
- Design standards do provide for higher loadings for different circumstances such as domestic, public use and grandstands for large crowds. This balcony was effectively a domestic design that was subjected to grandstand level loadings. While there is an additional safety margin within the design loadings, the loads that this balcony experienced exceeded that.

- Designers need to be particularly vigilant when designing new cantilevered balconies to ensure they are designed appropriately to account for circumstances, particularly if there is any possibility of crowds gathering, or other forms of dynamic loading.
- Homeowners need to ensure that exiting cantilevered balconies are not overloaded. This means that for most domestic balconies the number of people using the balcony does not exceed two people for every square meter of surface area. Homeowners need to be aware of the circumstances when these design loads might be exceeded, for example large gatherings at special events with loading beyond domestic use. If homeowners have any concerns about the condition of their balcony or its safe use, they should seek professional advice.

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Introduction

On the evening of 4 March 2016 a cantilevered balcony at 598 Castle St, Dunedin, collapsed during a music concert attended by up to 1500 people in a residential accommodation area. Eighteen people were injured as a result of the collapse, including two individuals who received serious injuries. The collapsed balcony was one of several similar elevated balconies that cantilevered from a group of buildings that surrounded the area where the concert was held. It was located in a privately owned student accommodation complex designed in 1999, consented by Dunedin City Council in December 1999. A Code Compliance Certificate was issued after the construction was completed in November 2003.

The Minister for Building and Housing subsequently instructed the Ministry of Business, Innovation and Employment (MBIE) to investigate the cause of the collapse, and whether the balcony was designed, constructed and maintained to the required standards. Because structural failures are rare in New Zealand buildings, every incident of this nature needs to be thoroughly investigated to establish whether there were failings and whether our building systems are working as intended.

A Terms of Reference for this investigation is included in Appendix A.

This report takes into account the following:

- Video and photographic evidence of the collapse
- Building consent documentation held by the Dunedin City Council
- Information gained from an on-site inspection of the balcony by MBIE Engineers
- Laboratory testing of the existing timber joists.
- Laboratory testing of new timber joists to understand the effects of notching joists

This report provides findings about the causes of the collapse and recommendations for further action.

Investigation Methodology

This section outlines the methodology and procedures adopted for the investigation. This includes the establishment of an investigation team, the physical inspections that were conducted and the information collected.

Investigation team

The MBIE investigation team comprised the Chief Engineer, the Manager Engineering Design and Science, the Manager Building Systems Control, the Deputy Chief Engineer, the Team Leader Consent System and structural engineers from the Building System Performance Branch within MBIE. The team was selected on the basis of their experience and expertise, and had no conflicts of interest with the investigation.

External experts were consulted to provide advice on technical aspects of the investigation.

Inspections

Two members of the MBIE team visited Dunedin on Tuesday 7 March 2016 to:

- Obtain relevant documentation from the Dunedin City Council, as the Building Consent Authority.
- Visit the building site to photograph and record physical details of the remains of the balcony attached to the building. A sample of timber was taken from the balcony remains for further analysis.
- Inspect, measure and photograph the remains of the collapsed balcony that had been removed from the building site and placed in storage by the New Zealand Police.

Information collected

Documentation

The following design documents and reports were obtained for the investigation:

- Dunedin City Council Consent number ABA 993045 issued on 9 December 1999 for 8 units to be constructed at 820 Cumberland Street, between Castle and Cumberland streets. The collapsed balcony in unit 6 was constructed under this consent.
- Dunedin City Council Consent number ABA 3156 for an additional 5 units at 598 Castle Street, which also provides access to the other 8 units.
- Dunedin City Council Code of Compliance Certificate for consents ABA 993045 and ABA 3156, issued 24 November 2003.
- DCL Consulting report "598 Castle Street, Dunedin: Investigation into balcony collapse" commissioned by the Dunedin City Council.

The following design standards were used to assist with analysing the balcony:

- NZ Standard NZS 3604: 1990 – the timber framed buildings standard cited in ABA 993045.

- NZ Standard NZS 3604: 1999 – the timber framed buildings standard at the time of construction.
- NZ Standard NZS 3604: 2011 – the current version of the timber framed buildings standard.
- NZ Standard NZS 4203: 1992 – the loadings standard for buildings at the time of construction.
- NZ Standard NZS 3603: 1993 – the timber structures standard at the time of construction and the current standard.

Video photography

Dunedin Police supplied MBIE with video footage of the collapse that was recorded by Taylormade Productions. This video footage was intended to record the band's performance in the courtyard.

Physical evidence

The Balcony

The balcony remnant comprised a complete balcony floor with all the joists severed at the wall face. The balustrade along the front and one side of the balcony had broken away. No evidence of decay or deterioration of the wood in any of the joists in the vicinity of the fractures was observed during the 7 March 2016 site visit by MBIE.

The cantilever span of the balcony was measured as 1230 mm from the outside of the wall panel to the outside of the boundary joist. The joist spacing was nominally 400 mm. The overall plan dimensions of the balcony were measured as 1230 mm x 4000 mm.

The Building

At the time of the MBIE site visit to the building at 598 Castle Street a temporary piece of cladding had been installed to cover the failed ends of the joists over half the balcony length. In the remaining uncovered part of the wall where the balcony had been located, the ends of the failed joists were able to be inspected. Through openings in the blocking between the failed joists, colour flashes observed along the length of the joists indicated they had been machine stress graded.

General investigation procedures

Analysis was undertaken to determine the principal causes of the failure, taking into account the information and evidence collected. The design and construction of the balcony were checked for compliance with the construction standards of the day and with current standards. Laboratory testing was subsequently commissioned to verify the strength of the joists within the balcony remnant and the effects of notching timber joists. Expert opinions were also sought on several technical aspects of the investigation.

Review and Analysis of the Balcony

This section assesses the Building Code compliance of the balcony, the actions that resulted from the crowd loading and assesses the effects of the loading on the joists supporting the balcony.

Building Code compliance

A review of the relevant consent drawings (Appendix C) indicates the balcony was designed with 11 cantilevered joists spaced at 400 mm centres, projecting 1200 mm from the external face of the building framing and extending 1800 mm into the floor to double floor joists running at right angles to the balcony's joists. The drawings show the joists as continuous nominal 200 mm x 50 mm members. The finished size of the joists was measured as 190 mm x 45 mm with a 50 mm step down that reduces the size to 140 mm x 45 mm.

The designed joist dimensions comply with Table 7.2 of the Timber Framed Buildings Standard NZS 3604: 1990. The on-site observations of the joists suggest that they were machine stress graded *radiata pine*. At the time of construction, machine stress graded timber was commonly substituted for the No. 1 Framing grade specified in NZS 3604: 1990.

As the structural design followed a cited standard, there was no requirement for a structural review of the design and there was no evidence in the documentation that a structural review was undertaken. The design standard of the day anticipated a loading of 10 to 12 people distributed evenly over the balcony.

The Timber Framed Buildings Standard was revised in 2011 and Table 7.2 of NZS 3604: 2011 requires the net depth of supporting joists to be 190 mm x 45 mm for a balcony span of 1200 mm. The balcony design would not comply with the current Timber Famed Buildings Standard NZS 3604: 2011.

Balcony collapse – review of video footage

The video supplied to the investigation team was analysed to better understand the collapse mechanism. It appears there were approximately 18 people standing on the balcony at the time of collapse. More individuals were crowded at the right hand end (as viewed) of the balcony, which was closer to the location of the band.

Shortly after the headlining band started playing, it was observed at the crowded right-hand end of the balcony that people were moving up and down in time with the music. There is no evidence this was to the extent of jumping so their feet left the deck. Soon afterwards, the front right-hand corner of the balcony dropped and then the whole balcony rotated approximately 45 degrees before separating from the building and dropping vertically to the ground. Collapse was rapid and neither the people on the balcony nor those underneath it were able to take evasive action.

Balcony loading at the time of collapse

The balcony was significantly overloaded as a result of the number of people occupying the structure at the time of its collapse and the way they were moving. The weight of 18 people, including an allowance for dynamic loading due to their movement , is calculated to be on average - over the whole deck area - approximately double the specified design loading (a 2.0 kPa live load is used as the basis of design in the Timber Framed Buildings Standard NZS 3604:1990). Additionally, more people were observed to be crowded towards the right hand end of the balcony, closer to where the band was playing, and some of these joists may have therefore supported nearly four times the design loading. Because of uncertainty of the weights of the occupants and their distribution across the balcony, it is not possible to be more precise about the actual loading.

Fracturing of the joists supporting the balcony

It is unlikely that the notches in the joists at the junction between the floor of the building and the balcony contributed to the failure of the balcony joists. The joists fractured at the location of the step change in the depth of the joist, from 190 mm deep beneath the flooring inside the building to 140 mm beneath the balcony deck. This step or notch detail is permitted by the Timber Framed Buildings Standard NZS 3604: 1990, although there are no explicit criteria or guidance on the permissible depth of the notch for cantilevered floor joists supporting a balcony. The current NZS 3604:2011 also permits this detail, with no explicit guidance on permitted notch dimensions.

The provisions of the Timber Structures Standard NZS 3603:1993 for the strength of notched beams were applied to the balcony joists to determine the potential effect of the notches on their capacity to carry loads. Calculations based on the NZS 3603 provisions indicated the notches may have significantly reduced the capacity of the balcony's cantilevered joists.

Laboratory testing of notched joists

To better understand the effects of notching, the University of Auckland was commissioned to compare the joist strengths for the two alternative details permitted by the NZS 3604:1990, using the same span and cantilever as the Dunedin building and its balcony. One set of 190 x 45 mm timber joists was notched to 140 mm deep like those used for the balcony and a second set was stock 140 x 45 mm joists that were tested for comparison.

The joist strengths were found to be very similar for both sets of joists. This suggests that the notch detail permitted by NZS 3604:1990 was unlikely to have contributed to the failure. This also suggests that the provisions within the NZS 3603:1993 are conservative for the dimensions of the building and its balcony.

Testing of existing timber joists

Two timber samples and a series of photos were sent to SCION Research Institute to try and identify the grading and treatment properties of the timber joists from the recovered remains of the balcony. Black and green flashes observed at regular intervals along the joist faces indicated the joists had been machine stress graded and would be designated as equivalent to No. 1 Framing grade at the time they were graded. Chemical analysis of the samples concluded that the treatment most likely conformed to the specifications for external use (H3.2).

Five of the 11 joists removed from the collapsed balcony remnant were sent to BRANZ to determine whether the timber was correctly graded. The BRANZ strength test results provided no evidence that the joists used to construct the balcony would have been graded as less than No. 1 Framing Grade timber.

Investigation Results

The main findings of this investigation into the collapsed balcony at 598 Castle Street in Dunedin are as follows.

- **The balcony was overloaded**

The balcony was significantly overloaded by a combination of the number of people occupying the balcony at the time of its collapse and the dynamic effects of their movement. The live and dynamic loads resulting from the 18 people observed on the balcony at the time of its collapse was at least double the design load of 2.0 kPa used to design the balcony. Some of the joists at the end where failure originated could have been supporting up to four times the design load. This was the primary cause of the collapse.

- **Code compliance, condition of balcony joists and design standards**

The balcony was Building Code complaint at the time of its construction and there were no observable deterioration or unpermitted defects that would have contributed to its collapse. The balcony would not be compliant with the current requirements of the Timber Framed Buildings Standard NZS 3604: 2011. Changes have been made to Timber Framed Building Standard NZS 3604 in 2011. It is now less likely that a similar balcony built to current standards would collapse should it be subjected to the same level of overloading.

- **The effects of notching cantilevered timber joists**

The results of the University of Auckland tests replicating the Dunedin balcony design indicate that the notching does not reduce the joist strength.

- **Safe use of cantilevered balconies**

This collapse highlights the brittle and sudden manner in which cantilevered balconies subjected to crowd loading can collapse. In this case they were designed for normal domestic use and not as public grandstands where higher design loads requirements apply.

Designers need to be particularly vigilant when designing new cantilevered balconies to ensure they are designed appropriately to account for possible circumstances, particularly if there is any possibility of crowds gathering or other forms of dynamic loading occurring.

Homeowners need to ensure that exiting cantilevered balconies are not overloaded. This means that for most domestic balconies the number of people using the balcony does not exceed two people for every square meter of surface area. If homeowners have any concerns about the condition of their balcony or its safe use, they should seek professional advice.

Acknowledgements

MBIE would like to thank the owner of the building and the various agencies for providing their time and information to allow MBIE to conduct the investigation.

Appendix A Terms of Reference

The investigation is to be conducted under the following terms of reference.

Scope

The scope of the investigation by the Ministry of Business, Innovation and Employment (MBIE) includes:

- Liaise with Dunedin City Council, New Zealand Police, WorkSafe New Zealand, the building owner and other interested parties to inform them of our investigation;
- Ensure that evidence is kept secure so as to enable future testing, detailed studies, etc.;
- Review media reports, photographs and video evidence from eyewitnesses;
- Review video evidence supplied by Animation Research Ltd;
- Carry out a site visit to record details of the physical state of the collapsed balcony and its fixing to the supporting structure;
- Determine and review the method used in the structural design of the balcony;
- Review the design drawings and specification for the balcony;
- Determine whether the balcony was designed in accordance with the standards of the day and complied with the Building Code;
- Determine whether the balcony was constructed in accordance with the design drawings and specifications;
- Determine whether the design used the correct permanent and imposed design actions and combined them correctly;
- Determine whether the balcony was strong enough to resist the design actions at the time of its construction;
- Identify any possible deterioration of structural elements at the time of the collapse;
- Test, if possible, the timber properties (strength, stiffness) of the cantilevered joists to determine whether they met the assumed design properties;
- Identify the history of changes to design standards since the balcony was designed and determine the effect of changes in standards on how the balcony would be structurally designed today and in the intervening years;
- Conduct structural analyses of the as built and design cases, including allowable loading and likely actual loading;
- Establish whether the imposed design actions adequately represented the weight of balcony occupants;
- Establish whether movement of the balcony occupants could have contributed to the collapse;
- Identify causes of the collapse;
- Determining whether the same situation could cause balconies constructed with other materials to collapse in a similar manner;

- Recommend any changes to building regulations for new balconies or other possible uses where similar detailing might have been used; and
- Recommend any remedial actions for existing balconies.

Report

A draft report on the findings of the investigation will be prepared for the Minister by MBIE by the 31 March 2016. The report may be subject to peer review by independent experts.

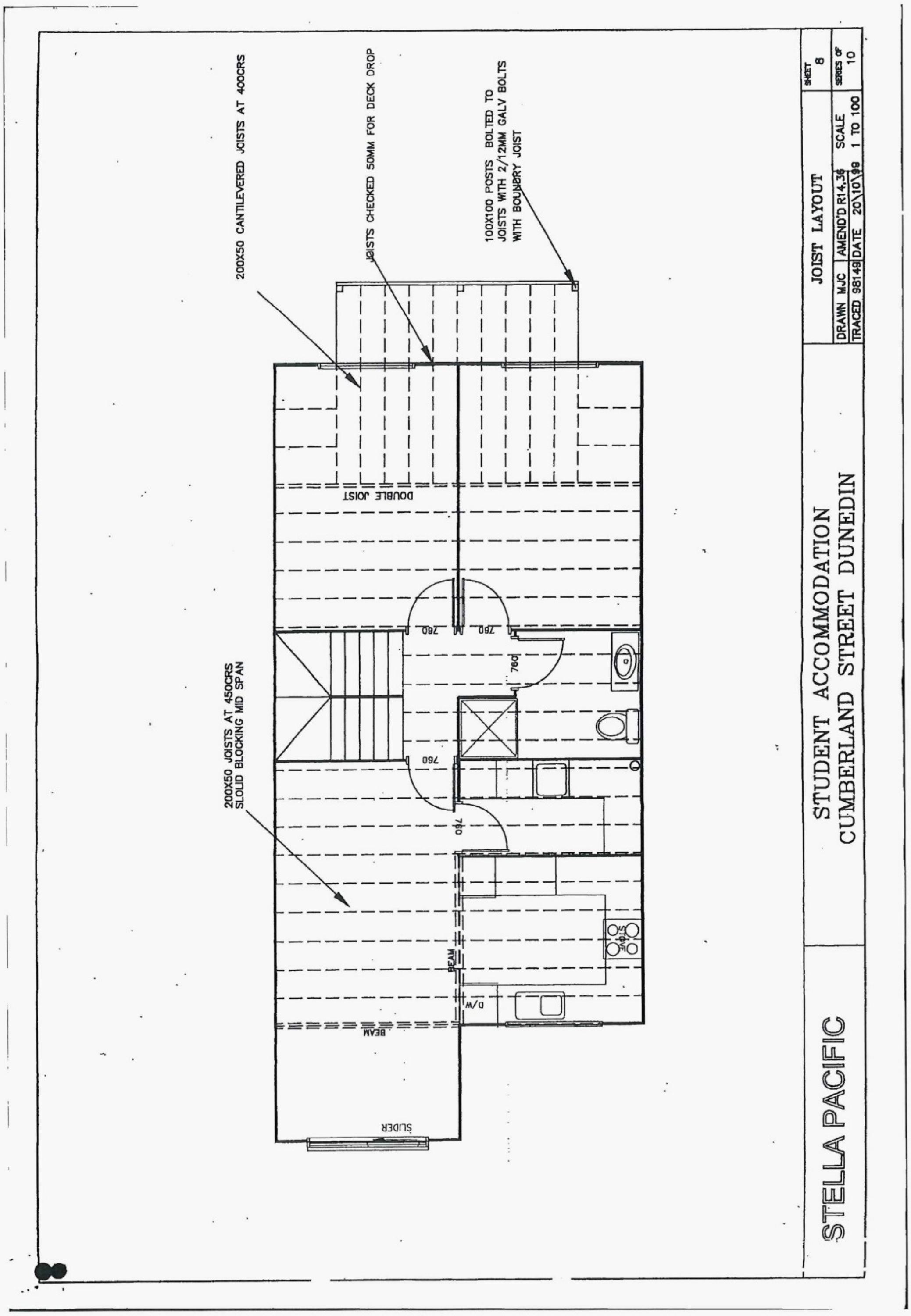
A communications plan on the release of the report will be developed.

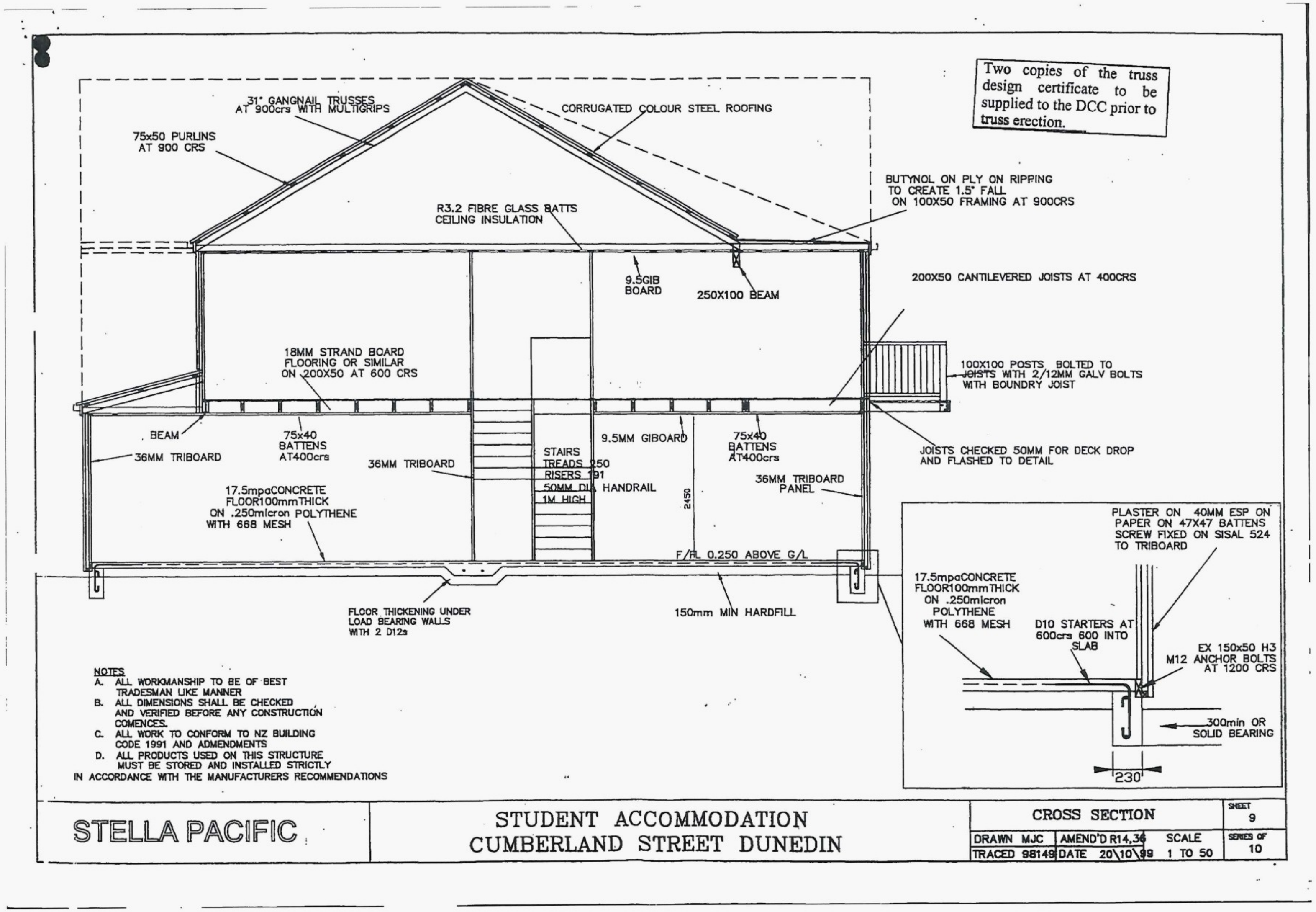
Management

The manager responsible for this investigation is Dr. Larry Bellamy, Manager Engineering Design and Science, MBIE, with technical assistance provided by Mike Stannard, Chief Engineer, MBIE.

Appendix B Selection of Photographs

Appendix C Relevant Drawings of Balcony




Two copies of the truss design certificate to be supplied to the DCC prior to truss erection.
31° GANGNAIL TRUSSES AT 900crs WITH MULTIGRIPS
75x50 PURLINS AT 900 CRS
CORRUGATED COLOUR STEEL ROOFING
R3.2 FIBRE GLASS BATTS CEILING INSULATION
BUTYNOL ON PLY ON RIPPING TO CREATE 1.5° FALL ON 100X50 FRAMING AT 900CRS
9.5GIB BOARD
250X100 BEAM
200X50 CANTILEVERED JOISTS AT 400CRS
18MM STRAND BOARD FLOORING OR SIMILAR ON 200X50 AT 600 CRS
100X100 POSTS BOLTED TO JOISTS WITH 2/12MM GALV BOLTS WITH BOUNDRY JOIST
BEAM
36MM TRIBOARD
75x40 BATTENS AT400crs
36MM TRIBOARD
STAIRS TREADS 250 RISERS 191 50MM DIA HANDRAIL 1M HIGH
9.5MM GIBOARD
75x40 BATTENS AT400crs
JOISTS CHECKED 50MM FOR DECK DROP AND FLASHED TO DETAIL
36MM TRIBOARD PANEL
2450
17.5mpaCONCRETE FLOOR100mmTHICK ON .250micron POLYTHENE WITH 668 MESH
F/FL 0.250 ABOVE G/L
FLOOR THICKENING UNDER LOAD BEARING WALLS WITH 2 D12s
150mm MIN HARDFILL
PLASTER ON 40MM ESP ON PAPER ON 47X47 BATTENS SCREW FIXED ON SISAL 524 TO TRIBOARD
17.5mpaCONCRETE FLOOR100mmTHICK ON .250micron POLYTHENE WITH 668 MESH
D10 STARTERS AT 600crs 600 INTO SLAB
EX 150x50 H3 M12 ANCHOR BOLTS AT 1200 CRS
300min OR SOLID BEARING
230
NOTES
A. ALL WORKMANSHIP TO BE OF BEST TRADESMAN LIKE MANNER
B. ALL DIMENSIONS SHALL BE CHECKED AND VERIFIED BEFORE ANY CONSTRUCTION COMENCES.
C. ALL WORK TO CONFORM TO NZ BUILDING CODE 1991 AND ADMENDMENTS
D. ALL PRODUCTS USED ON THIS STRUCTURE MUST BE STORED AND INSTALLED STRICTLY
IN ACCORDANCE WITH THE MANUFACTURERS RECOMMENDATIONS
STELLA PACIFIC
STUDENT ACCOMMODATION
CUMBERLAND STREET DUNEDIN
CROSS SECTION
SHEET 9
DRAWN MJC
AMEND'D R14,36
SCALE 1 TO 50
SERIES OF 10
TRACED 98149
DATE 20\10\99