

Design of Strong Rooms in Existing Houses for protection during tropical cyclones

Guide for Builders, Designers, Engineers and Building Certifiers

QUEENSLAND RECONSTRUCTION AUTHORITY
Queensland Resilience and Risk Reduction Fund

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Preface

In July 2021 the Cyclone Testing Station (CTS) at James Cook University (JCU) received funding through the Queensland Resilience and Risk Reduction Fund (QRRRF) to develop this Guide. The CTS invited representatives from key stakeholders to provide advice and support for the project. The Advisory Panel included representatives from:

- Queensland Fire and Emergency Services (QFES)
- Queensland Reconstruction Authority
- Queensland Government Department of Energy and Public Works (DEPW)
- Queensland Building and Construction Commission (QBCC)
- Australian Building Codes Board (ABCB)
- National Emergency Management Authority (NEMA)
- Western Australian Department of Fire and Emergency Services (DFES)
- Western Australian Department of Mines, Industry, Regulation and Safety (DMIRS)
- Northern Territory Government Department of Infrastructure, Planning and Logistics
- School of Psychology, James Cook University
- LGAs – Townsville City Council (Qld), Shire of Karratha (WA), Whitsunday Shire Council, Livingstone Shire Council, Gold Coast Local Government Authority.

This Guide is based on:

- the results of wind load and debris impact tests on construction materials and systems undertaken at the CTS
- investigations of damage from previous tropical cyclones
- the 'Design Guidelines for Public Cyclone Shelters'
- information provided by the Advisory Panel; and some builders, designers and certifiers from Queensland and WA
- design calculations from AS 1684.3, AS 4055 and AS/NZS 1170.2, and
- information obtained from other relevant research projects in Australia and the United States (refer to the References section).

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Introduction

A strong room is a strengthened compartment within a house where people can shelter during a tropical cyclone. They are designed to resist higher wind forces and larger wind-borne debris than the rest of your house and offer a higher level of protection from serious injury or death to you and your family. Strong rooms are designed to have a higher chance of remaining intact even if the rest of the house is severely damaged.

The objective of this document is to provide information about the selection, design and construction of strong rooms in existing houses in Australia. The document includes guidance on

- the selection of suitable rooms within a house
- the performance requirements for wind loads and impact from wind-borne debris
- the materials and systems that achieve the performance requirements.

The document includes:

- information for engineers, designers, and builders – mandatory technical design and construction specifications
- Deemed-to-satisfy solutions – materials and details
- Requirements for Performance Solutions.

Strong rooms should not be constructed in houses located in a 1:500 storm-tide area, or a riverine flood area. Refer to the local Council for maps.

The guide addresses the structural capacity of the strong room to resist wind and debris loads during tropical cyclones but does not address requirements for air changes and occupier comfort.

To claim compliance with this Guide, the requirements for design and construction in Sections 1 to 4 must be followed.

How to Use the Guide

This Guide provides information for builders, engineers, designers and building certifiers. It includes guidance for the design and construction of strong rooms into existing homes.

Sections 1 to 4 provide the technical requirements, and **Appendices A and B** provide links to the draft industry standards for wind-driven debris impact tests and bracing capacity tests. **Appendix C** includes an example of the label that indicates the strong room was designed and constructed to the requirements in this Guide and an annual maintenance checklist.

Homeowners are not legally required to build a strong room in their house – it is a personal decision. If they choose to build a strong room, it is recommended that this Guide is used.

If homeowners want to be able to claim that the strong room they have built complies with this Guide, then the designer and builder of the strong room **MUST**, as a minimum, follow the technical requirements in this Guide, and an engineer needs to certify that the strong room complies with this Guide. This Guide presents minimum requirements, and homeowners and designers can choose to use more stringent requirements.

Materials and products

The materials and products used in strong rooms need to meet the design criteria presented in Section 2.2. Make sure that:

1. For deemed to satisfy solutions, the products meet the requirements in Section 3.
2. For performance solutions, the suppliers of the materials are aware of the performance criteria in Section 4 using either calculations or test results as specified in APPENDIX A or APPENDIX B.

Useful Links

The following websites provide useful information about tropical cyclones, how they can damage buildings and information about building requirements in each state that has cyclone regions.

Also refer to the Guide for Homeowners.

<https://www.jcu.edu.au/cyclone-testing-station/education> under Strong Rooms

Information about tropical cyclones

Bureau of Meteorology –

<http://www.bom.gov.au/cyclone/tropical-cyclone-knowledge-centre/>

Cyclone Testing Station – Reports on previous cyclones and the damage they caused to houses

<https://www.jcu.edu.au/cyclone-testing-station/education/publications>

Information about building requirements

Queensland Government Department of Energy and Public Works (DEPW)

Advice for homeowners on building in Queensland

<https://www.qld.gov.au/housing/building-home>

Advice for the building industry on construction requirements in Queensland

<https://www.business.qld.gov.au/industries/building-property-development/building-construction>

Australian Building Codes Board (ABCB) – information on the National Construction Code

<https://www.abcb.gov.au/>

Queensland Building and Construction Commission – information on building regulations in Queensland

<https://www.qbcc.qld.gov.au/>

Western Australian Department of Mines, Industry, Regulation and Safety (DMIRS) – information on building regulations in Western Australia

<https://www.commerce.wa.gov.au/building-and-energy>

Northern Territory Government Department of Infrastructure, Planning and Logistics – information on building regulations in the Northern Territory

<https://nt.gov.au/property/building/build-or-renovate-your-home/building-and-renovating-a-home>

1. Design

This Guide applies to the design construction and installation of strong rooms constructed for the purpose of providing protection from tropical cyclones. The strong room is not designed as an emergency shelter after the storm, but it may provide a core for emergency accommodation.

The guide is to be used in addition to any requirements under codes and standards referred to in the Building Act.

Strong rooms should not be constructed in houses located in a 1:500 storm-tide area, or a riverine flood area. Refer to the local Council for maps.

1.1. Compliance

If it is claimed that the strong room satisfies this Guide, then the requirements of Sections 1, 2 and either 3 or 4 are mandatory.

Design of strong rooms shall adopt the enhanced design criteria presented in Section 2. Details for the structural design of the strong room shall comply with EITHER the provisions of the Deemed-to-Satisfy Solutions in Section 3 OR have demonstrated the performance requirements outlined in Section 4 for a Performance Solution.

1.2. Size and location of strong room

1.2.1. Size

- The floor area of the strong room shall be at least the number of bedrooms plus study/home office plus 2 m² including the bathtub, shower recess, toilet, and furniture.
- The minimum floor area of the strong rooms shall be 4 m².
- The maximum wall length of the strong rooms shall be 4 m.
- The minimum distance between any toilet pan and the door shall be sufficient to allow the door to not have to use lift-off hinges – NCC 2022 Volume 2 Cl. 3.8.3.3. (Lift off doors will not provide an adequate seal.)

It is recommended that if the house has been designed for universal access, the strong room should also contain features for universal access.

1.2.2. Location

Because the ceiling joists in the strong room will be located between roof trusses or joists, it can only be located where the roof trusses or joists are in the same direction over the roof of the room. Therefore, strong rooms should be located only under an area free of hips and valleys in houses with trussed hip roofs if the strong room ceiling is directly under the roof. A strong room could be located in any suitable room in a house under gable, flat or skillion roofs.

1.3. Record of compliance

1.3.1. Labels

A label that reads ‘This strong room complies with the Guide and can be used as shelter during tropical cyclones.’ should be clearly displayed in the strong room and a copy placed in the electricity meter box. This will indicate to future owners that the room can be used to shelter during a tropical cyclone. An example is provided in APPENDIX C.

1.3.2. Information provided to the owner

The following information shall be provided to the owner:

- Engineer’s Certification of the strong room
- Details of the design criteria used
- Date of construction
- Name and contact details of the builder.

2. Design criteria

Strong rooms should not be constructed in houses located in a 1:500 storm-tide area, or a riverine flood area. Refer to the local Council for maps.

Design requirements

- The strong room shall be designed as a stand-alone structure within the house (or on the property) and be able to resist the required debris and wind loadings.
- The strong room shall be designed to remain intact even if the rest of the house is destroyed. It therefore needs:
 - A false ceiling that is separated from the structure of the rest of the house and supported only on the strong room walls.
 - Separate tie-downs for the ceiling of the strong room.
- The walls, ceilings, doors, and windows shall be wind rated.
- The walls, ceilings, and doors shall be debris rated for the large debris item¹.
- Windows and other external glazing shall be debris rated or protected by debris-rated screens for both large and small debris items¹.
- Debris-rated screens or shutters shall be supported at a distance from the glass of more than 1.25 x the test peak instantaneous deflection from the large debris item tests¹.

¹Note the debris test items are defined in AS/NZS 1170.2 Clause 2.5.8, and the tests are described in CTS Tech Note 4 (a link to this document is provided in Appendix A).

The design of the strong room should also consider:

- **Water resistance of materials**
- **Insulation and condensation** – NCC insulation requirements for energy efficiency could be incorporated into wall and ceiling elements without compromising the resistance to wind-borne debris. Consider engaging an energy assessor to evaluate R-ratings for the recommended strong room systems.
- **Shower screens** – glass in shower screens must be safety glass to comply with the NCC. (If an existing screen is used in a retrofit, check that it meets the NCC requirements.)
- **Mirrors** – use laminated glass, vinyl-backed mirrors, acrylic mirrors, or a removable mirror that can be taken out of the room as part of the preparation for an approaching cyclone.
- In some cases, **universal design** that complies with AS 1428.1–2001 for people with special needs.
- In some cases, **earthquake resistance** that complies with Appendix A in AS 1170.4

Deemed-to-satisfy structural solutions are presented in Section 3.

Performance structural solutions are presented in Section 4.

2.1. Wind actions for the structural design of a strong room

The structure of the strong room shall be able to resist uplift and lateral wind effects calculated from $V_{10,000}$.

2.1.1. AS 4055 Wind classification

For houses designed using a wind classification derived from AS 4055, Clause 2.1 is satisfied by using a C wind classification with design criteria and details for the strong room that are at least one wind classification higher than the wind classification for the rest of the house. Table 2-1 summarises the wind classifications for the strong room given a classification for the rest of the house. AS 4055 Table 2.2 can be used to evaluate the wind classifications for most houses. Note that AS 4055 includes classifications up to C4, but if the house as designed is already a C4 building then a higher level must be included. Throughout this document, (C5) is used to designate the design level for a strong room in a C4 or N6 house. It only has meaning in the context of this Guide.

Examples:

- a) If the wind classification for a house in wind region C is C1, then the minimum strong room classification is C2.
- b) If the classification for a house in wind region B1 is N2, then the minimum strong room classification should be C1, which has a higher wind speed than N2.
- c) If the classification for a house in wind region B1 is N3, then the equivalent C classification is C1 (same ultimate wind speeds), so the strong room classification is C2.

Table 2-1 Wind classifications for strong rooms

House wind classification	Wind classification for strong room
N2	C1
N3	C2
N4	C3
N5	C4
N6	(C5)
C1	C2
C2	C3
C3	C4
C4	(C5)

2.1.2. AS/NZS 1170.2 wind speeds

For houses designed using AS/NZS 1170.2, the design wind speed used for structural elements in the strong room shall be calculated using $V_{10,000}$.

The internal pressure coefficient used in the design shall be 0.7 or -0.65.

The scenario used for this coefficient is illustrated in Figure 2-1. If a door or window is opened or the envelope is damaged to allow even a small opening on the windward wall of the strong room, the roof and walls must be designed to resist the combination of the external pressures and positive internal pressures. This is the +0.7 internal pressure coefficient. If, after the opening is created, the wind direction changes so that the opening is now on a side wall (not illustrated in Figure 2-1), then the internal pressure coefficient could be around -0.65.

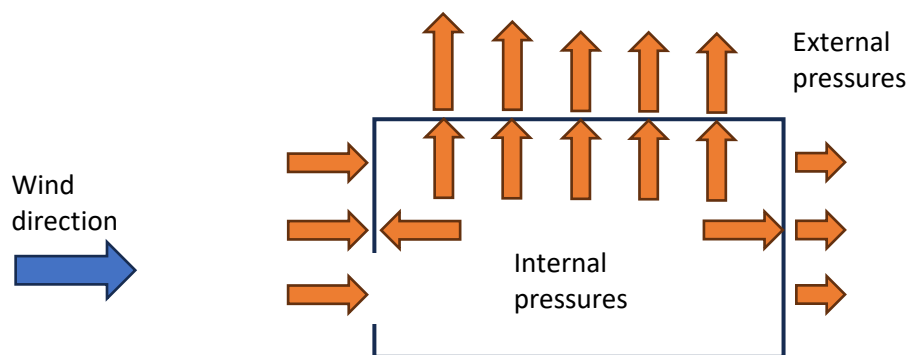


Figure 2-1 Internal pressures during tropical cyclones with a small hole in the envelope of the strong room

2.1.3. Wind-borne debris loads

The internal and external envelope of the strong room shall resist debris from the designated impact loadings for horizontal and vertical surfaces given in Clause 2.5.8 AS/NZS 1170.2 based on V_{500} .

Debris resistance is defined as preventing:

- penetration of the debris items defined in AS/NZS 1170.2 and
- spalling on the inside of the strong room that is large enough to cause injury to occupants

Where a performance solution is adopted, the test method referenced in APPENDIX A shall be used to demonstrate the required performance.

2.2. Design of specific elements

- *All strong room walls* shall be designed to function as external walls and satisfy the requirements for wind actions in Clause 2.1.1 or 2.1.2 for both in-plane loading as a bracing wall and out-of-plane loading; and for debris actions for vertical surfaces in Clause 2.1.3.
- *The strong room ceiling* shall be designed to be independent of the roof structure on the rest of the house and have the capacity to resist the differential pressure across a flat roof for the wind actions in Clause 2.1.1 or 2.1.2. The ceiling shall have debris resistance to the loadings defined in Clause 2.1.3 for horizontal surfaces.
- *The strong room door(s)* shall be inward-opening solid core doors with debris-resistant linings. They shall satisfy the wind and debris actions requirements in Clauses 2.1.1 or 2.1.2 and 2.1.3 for vertical surfaces. Doors shall be able to be opened after being subjected to wind and debris actions. The minimum width of the door shall comply with the NCC.
- *Any window in the strong room* shall be pressure-rated for the wind actions in Clause 2.1.1 or 2.1.2 and together with any protective screen, demonstrate resistance to the debris actions for vertical surfaces defined in Clause 2.1.3.
- *Foundations* shall be designed to resist uplift and bracing forces.

Note 1: Ceiling joists in false ceilings can be parallel to the roof trusses or floor joists above to have minimal effect on headroom. Non-habitable rooms such as bathrooms and laundries may have lower headroom requirements.

Note 2: Windows can be protected from the large debris test item (defined in AS/NZS 1170.2 Cl 2.5.8) by debris-rated screens and from the small debris item (defined in AS/NZS 1170.2 Cl 2.5.8) by debris-rated glass or glass coated with security film.

3. Deemed-to-satisfy solutions

Strong rooms should not be constructed in houses located in a 1:500 storm-tide area, or a riverine flood area. Refer to the local Council for maps.

Note: All of the DTS solutions satisfy the requirements for wind regions B and C. Any additional or different details to satisfy the requirements of wind region D are shown in (red) text. Any DTS that do not include red text also satisfy wind region D requirements.

3.1. Structural systems

3.1.1. Walls

Walls shall be constructed of either:

- **Reinforced concrete blockwork** (Wind regions B and C only – not applicable for wind region D) that complies with the following requirements:
 - Minimum block thickness 140 mm
 - Every core is filled with N20 concrete
 - 12 mm diameter vertical reinforcing at nominally 1200 mm centres
 - Bond beam bonded with each of the vertical reinforcements for 400 mm
 - 10 mm plasterboard or 6 mm fibre cement sheet glued to the strong room face of the wall at maximum 300 mm centres both horizontally and vertically. The lining prevents spalling of the blocks when hit by debris.

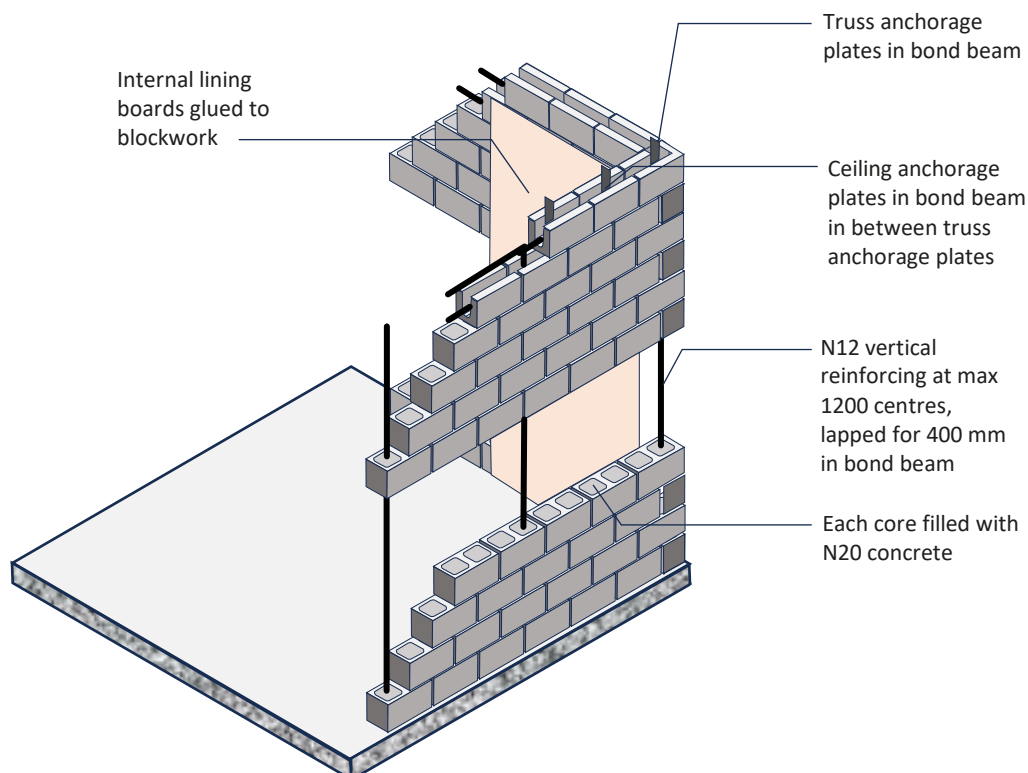


Figure 3-1 Reinforced concrete blockwork walls

- **Timber-framed construction** that complies with the following requirements (illustrated in Figure 3-2 and Figure 3-3):
 - Minimum 90 x 45 MGP12 studs at 600 mm centres fastened to 90 x 45 MGP12 top and bottom plates with two triple grips with 4 nails in each leg. Double studs shall be used at the end of each wall and adjacent to openings. Adjacent wall frames shall be joined using 100 mm #14 bugle head screws at 600 mm centres along the length of the join between the wall panels. Blocking shall be used at wall junctions where appropriate.
 - 0.55 mm G550 steel sheet glued between two layers of 12 mm plywood fastened to the frames with 75 mm 10-8 gauge rib head chipboard screws on either the inside or outside of the frame with respect to the strong room.

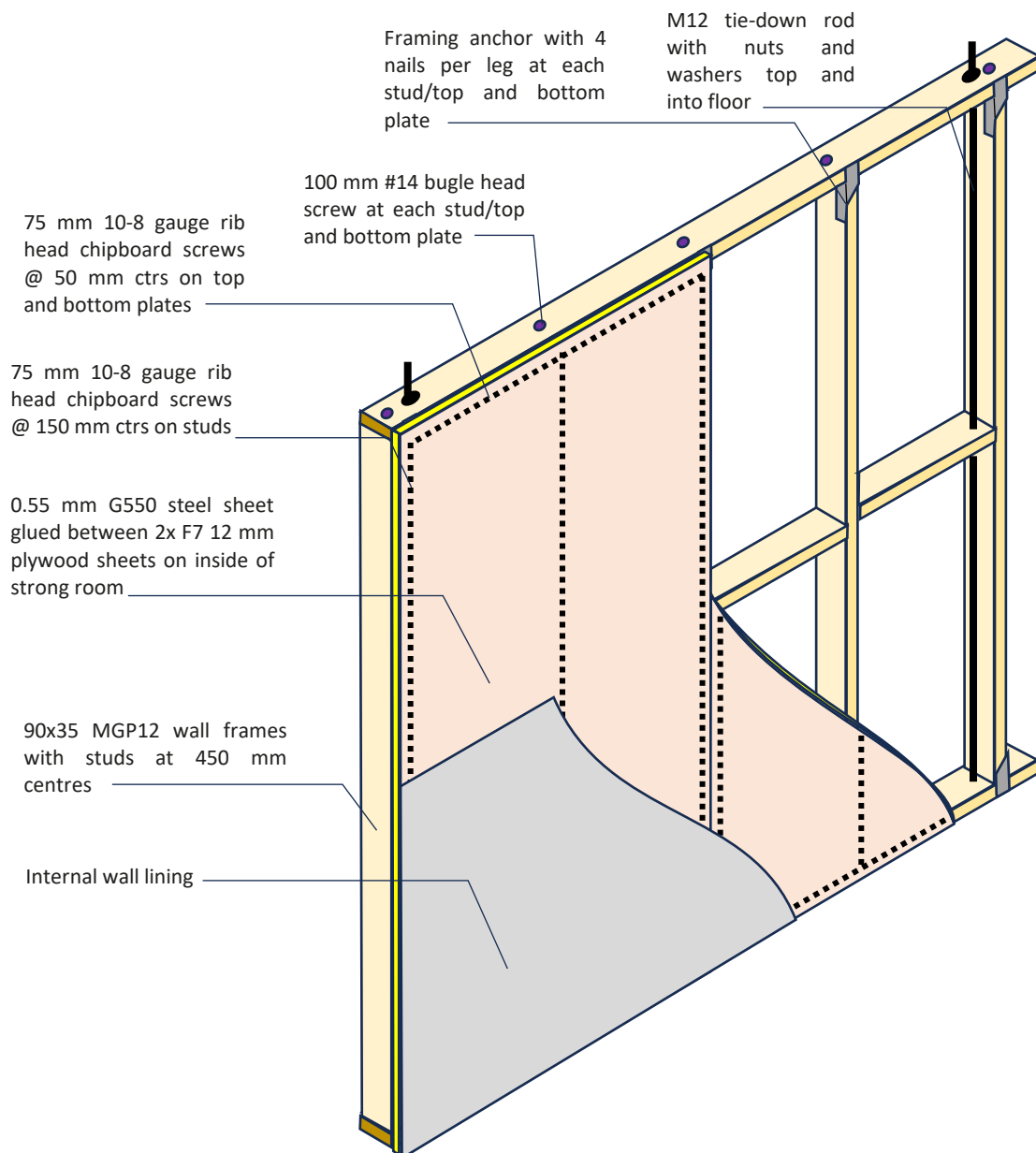


Figure 3-2 Timber framed walls

- Screw spacing between the plywood wall system and the frames to be:
 - 50 mm centres along top and bottom plates
 - 150 mm centres along studs
- M12 threaded tie-down rods with 60 mm x 60 mm x 5 mm washers under the nuts at each end of the wall and:
 - For walls on concrete slabs embedded into the reinforcing in the slab plus thickening; OR
 - For walls on framed flooring, fixed to the underside of the floor joists with nut and washer

The detail of the debris resistant wall linings for timber framed walls is shown in Figure 3-3. It can be fixed on either the inside of the strong room or on the outside face (opposite face to the strong room). If it is fixed on the outside face, the thickness of the lining may interrupt the cladding line if the wall continues past the strong room.

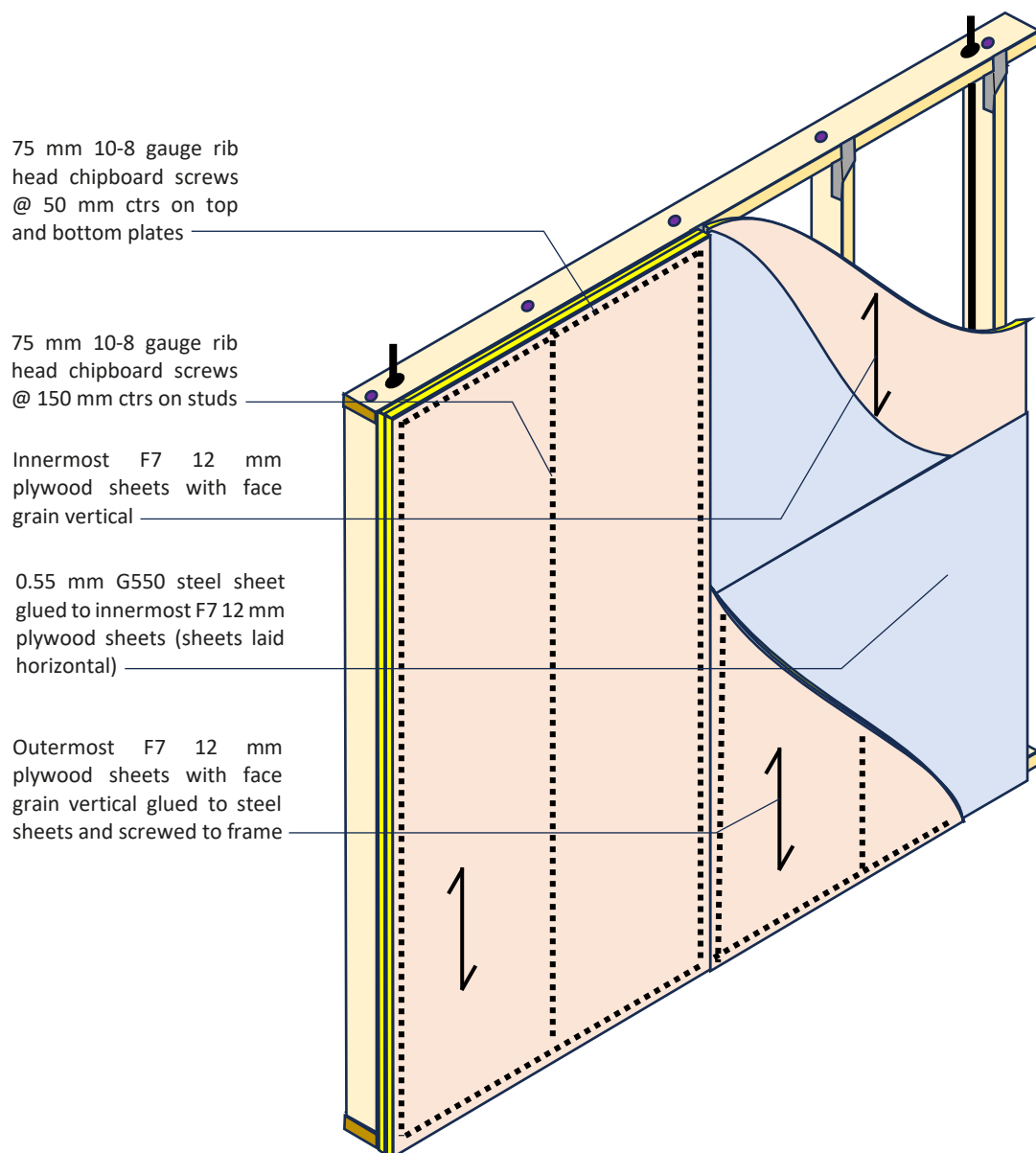


Figure 3-3 Layup of debris-resistant lining for both timber-framed and steel-framed walls

Walls constructed to these details have a bracing capacity in excess of 11 kN/m length.

- **Steel-framed construction** that complies with the following requirements (illustrated in Figure 3-3 and Figure 3-4):
 - Minimum 90mm x 1.2 studs at 600 mm centres fastened to 90mm x 1.2 top and bottom plates with M6 24x16 fasteners
 - 0.55 mm G550 steel sheet glued between two layers of 12 mm plywood fastened to the frames with 10-8 gauge x 40 mm zips
 - Screw spacing between the plywood wall system and the frames to be:
 - 50 mm centres along top and bottom plates
 - 150 mm centres along studs
 - M12 full height threaded tie-down bolts with 60 mm x 60 mm x 5 mm washers under the nuts at each end of the wall. Anchors with 60 mm x 60 mm x 5 mm washers every 600 mm along the bottom plate shall be embedded into the thickened slab.

The detail of the debris-resistant wall linings for steel-framed walls is the same as for timber framed walls as shown in Figure 3-3 but **it shall only be fixed to the outside of the frame (opposite side of the frame to the inside of the strong room)**. Walls constructed to these details have a bracing capacity in excess of 11 kN/m length.

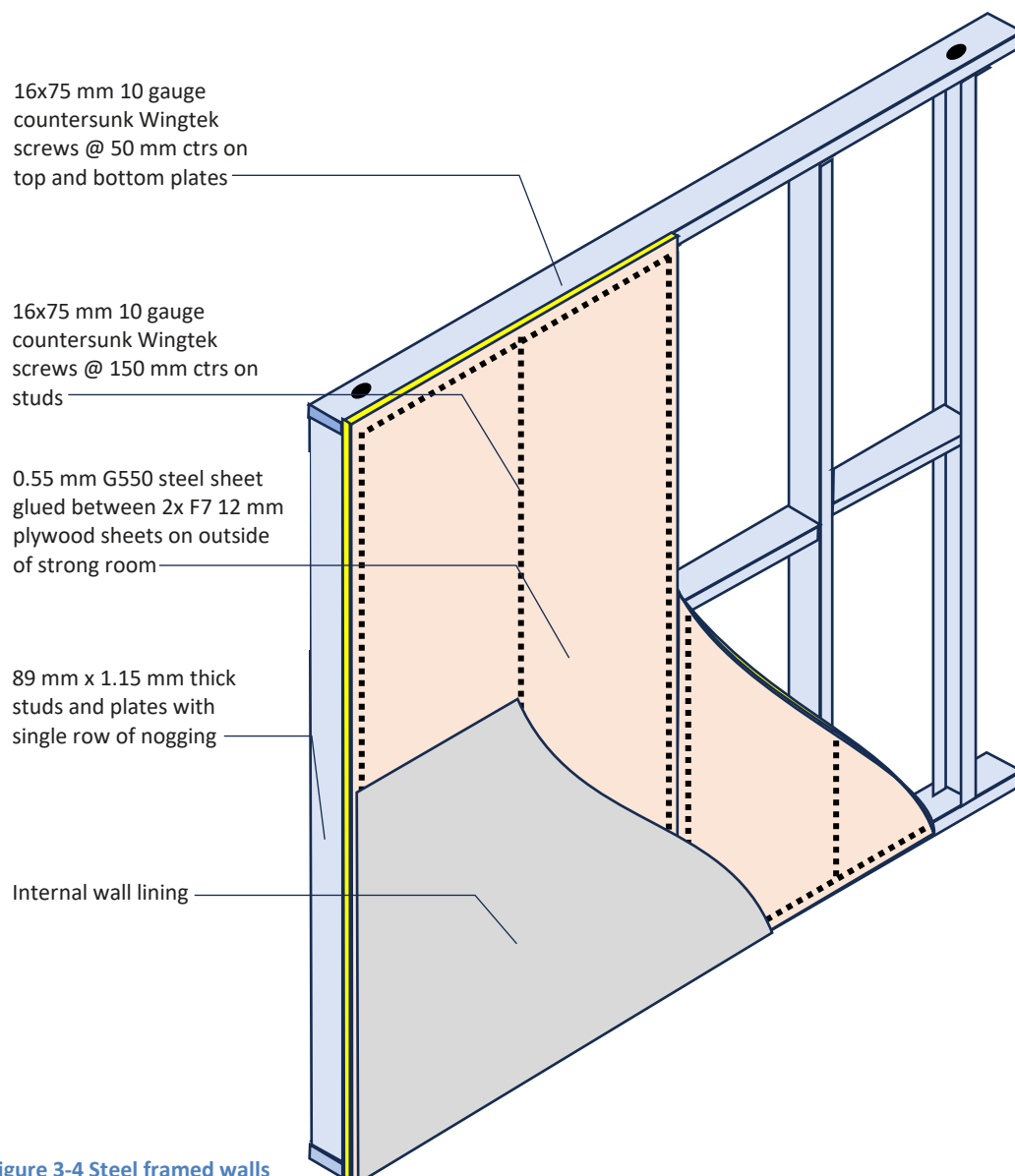


Figure 3-4 Steel framed walls

- **Cross Laminated Timber (CLT)**
 - 90 mm thick radiata pine three-ply CLT walls with face grain vertical
 - 70 kN capacity angle brackets with screws and masonry anchors that deliver the same capacity between the walls and the floor at the ends of each panel.
 - Wall junctions shall be joined with either 70 kN brackets screwed to each CLT panel with screws that deliver the same capacity or by M8 screws at 300 mm for the full length of the junction.

Silicone sealant shall be used between adjacent wall panels. Either silicone sealant or a sealing grout shall be used at the wall-to-floor junction under the panels.

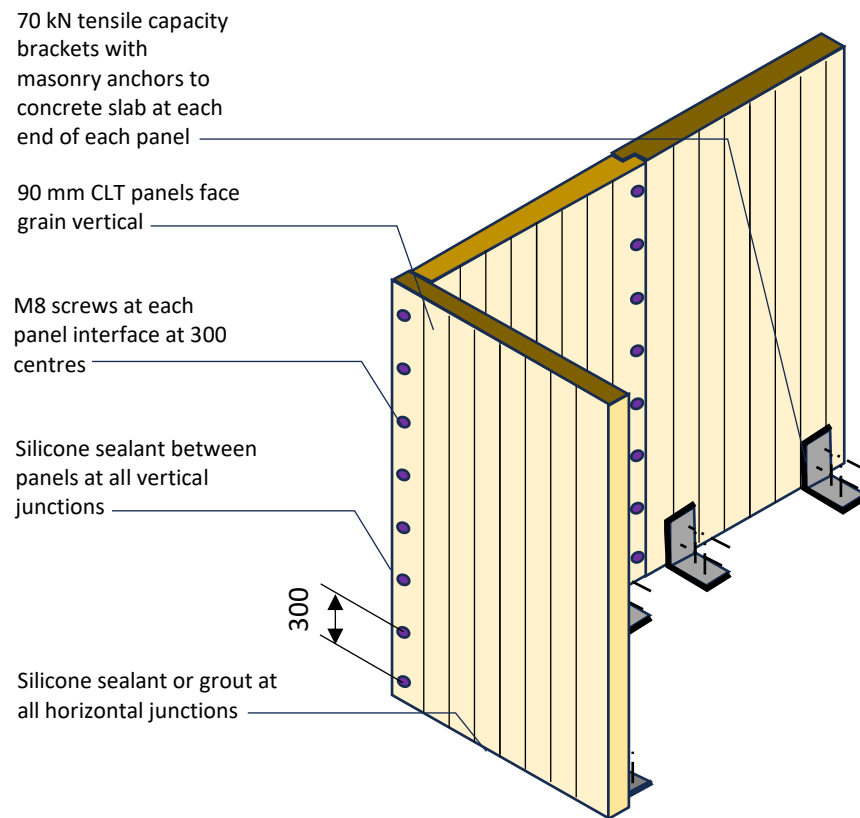


Figure 3-5 Connection of CLT panels within the room and between the room and the floor

3.1.2. Ceilings

A separate ceiling that spans the room (max. 4 m) shall be fabricated from 12 mm F11 plywood glued and screwed to LVL 15 ceiling joists with 75 mm 10-8 gauge rib head chipboard screws at 120 mm centres along the LVL 15 joists. Refer to Table 3-1.

Table 3-1 Span table for ceiling joists

Strong room wind classification	Span (mm)	2 m		2.5 m		3 m		3.5 m		4 m	
	Joist spacing	600	900	600	900	600	900	600	900	600	900
C1	Depth	90	90	90	90	90	90	90	90	90	90
	Screw spacing	300	200	300	150	250	150	200	100	150	100
C2	Depth	90	90	90	90	90	90	90	90	90	120
	Screw spacing	150	150	150	100	150	100	100	75	100	100
C3	Depth	90	90	90	120	90	120	120	120	120	140
	Screw spacing	150	100	100	100	100	75	100	75	100	75
C4	Depth	90	90	90	120	120	140	140	140	140	170
	Screw spacing	100	75	75	75	100	75	100	75	100	75
(C5)	Depth	90	120	90	120	120	140	140	140	170	190
	Screw spacing	75	75	75	50	75	50	75	50	100	50

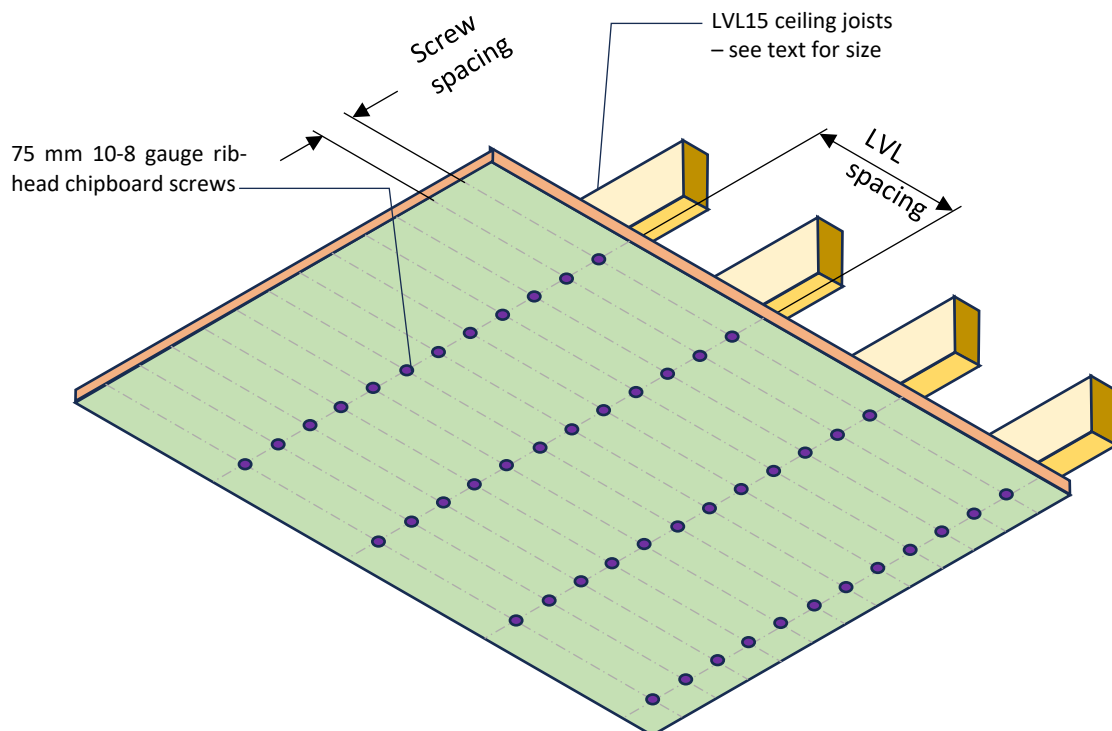


Figure 3-6 Construction of ceiling panels

The ceiling system for the strong room shall remain independent of the trusses or the roof frame. This can be achieved by orienting the LVL ceiling joists parallel to, and between the roof trusses.

The new LVL15 joists should be fitted to the top of the walls first and the plywood panels cut to fit inside the walls and glued and screwed to the joists with 75 mm 10-8 gauge rib head chipboard screws at 120 mm centres along the LVL 15 joists. Metal angle brackets shall be screwed to both top plate and each ceiling joist with two #14 bugle head screws per leg. The top plate shall be fixed to each stud with framing anchors with at least four nails per leg as shown in Figure 3-7. For ceilings fitted to blockwork walls, the angle brackets shall be bolted into the bond beam with two 12 mm masonry anchors.

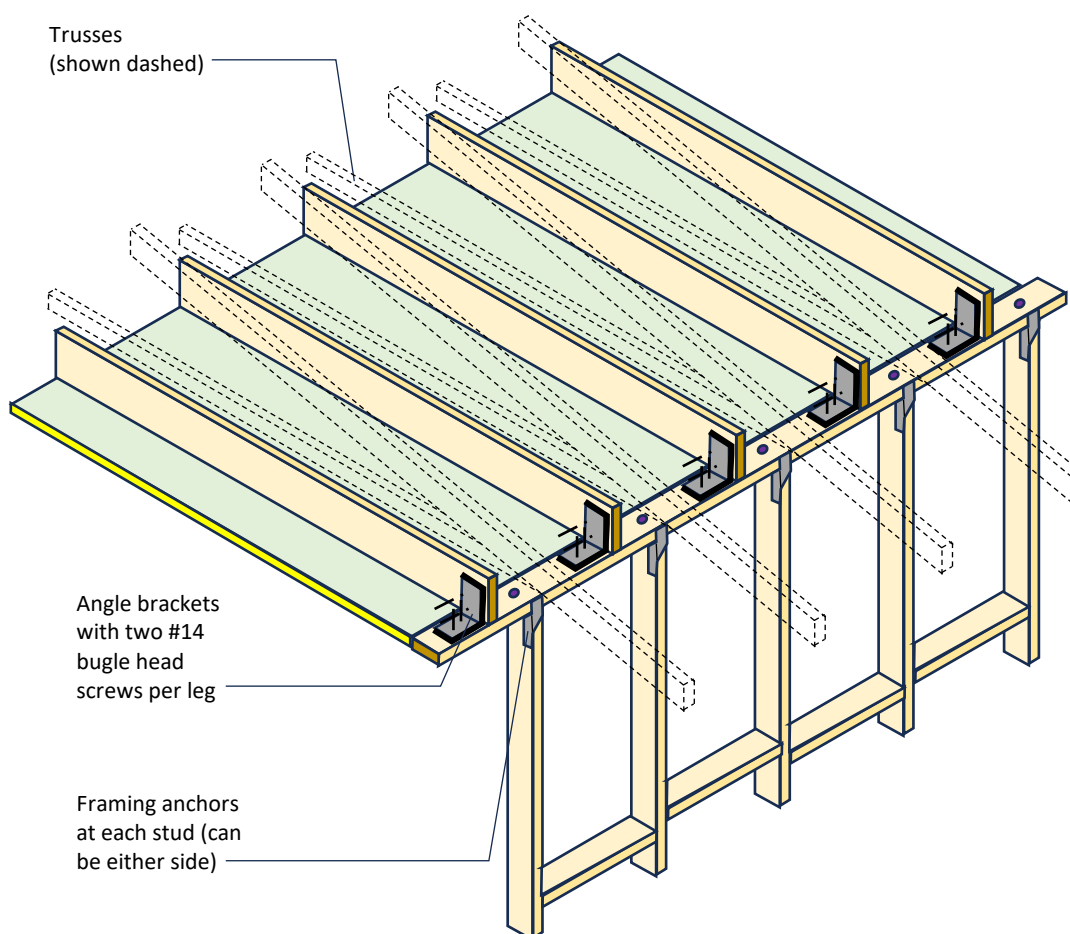


Figure 3-7 Ceiling connection to wall frames

The ceiling joists shall be directly connected to the top of the walls (either the top plate or the top of the wall panel) at each end of the joist using L-brackets with one M12 bolt into the ceiling joist and one into the top plate. At the ends of the walls, it is possible to use the M12 tie-down rods to anchor the L-bracket to the top plate.

3.1.3. Bracing systems

Walls that comply with Clause 3.1.1 are deemed to satisfy bracing requirements.

The contribution of the bracing for the strong room shall not be considered in the design of the total bracing in the house.

3.1.4. Doors

A performance solution shall be used for doors. Refer to Clause 4.1.4 for the requirements for a performance solution.

Security doors can usually achieve the performance requirements if the latches are augmented with “structural towel-rails” as illustrated in Figure 3-8 and Figure 3-9 provided adequate bolts are specified to absorb the impact of the loads on the rail as the door deforms under impact loads.

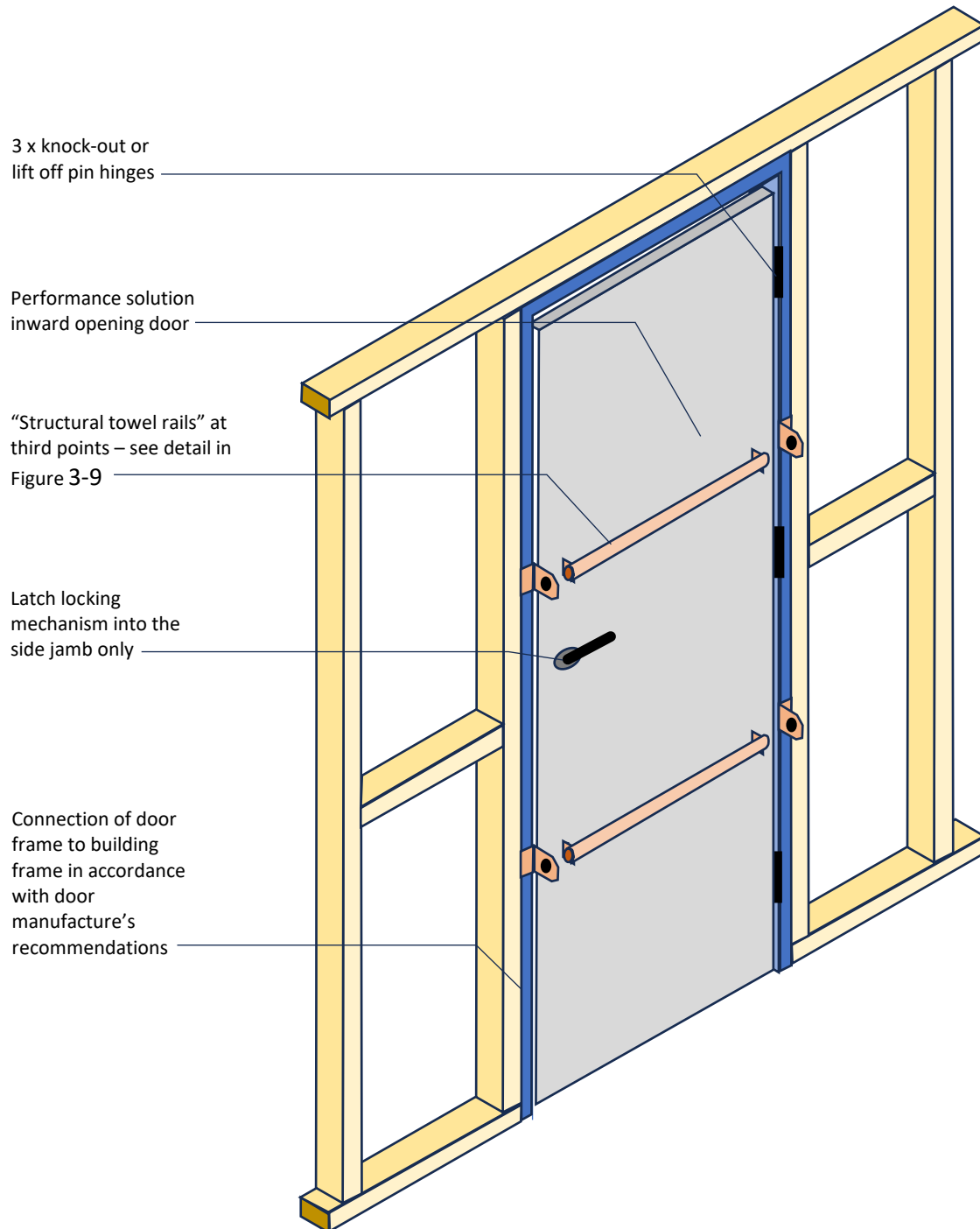
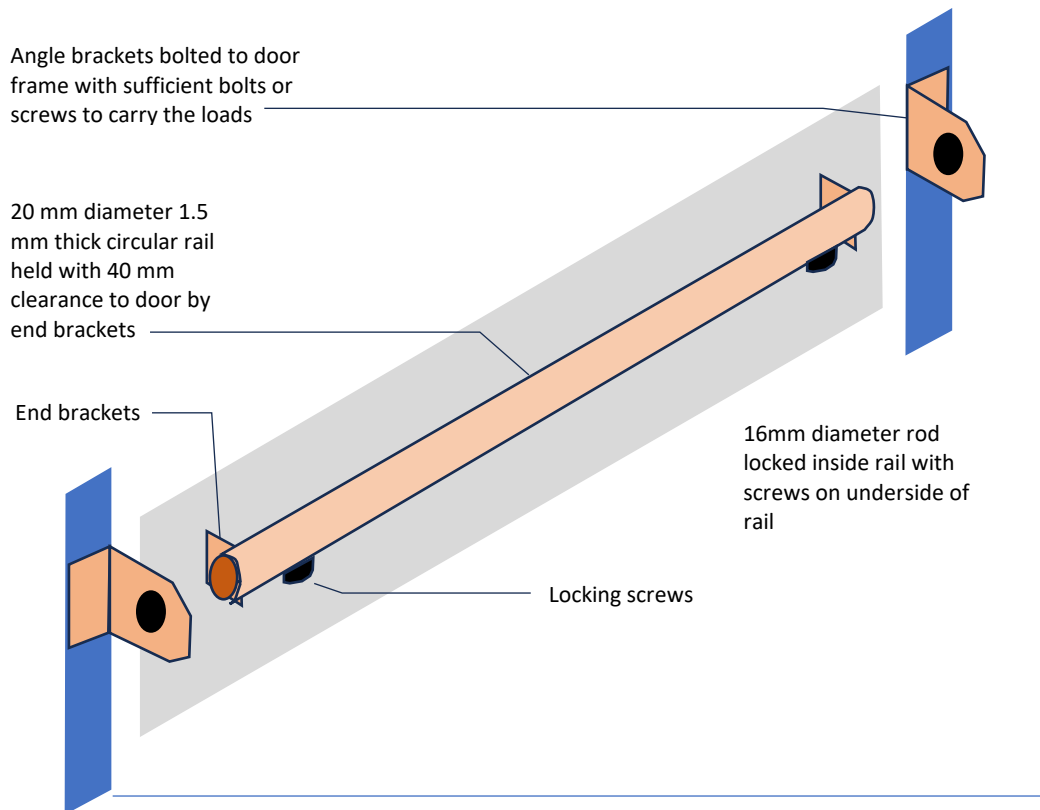
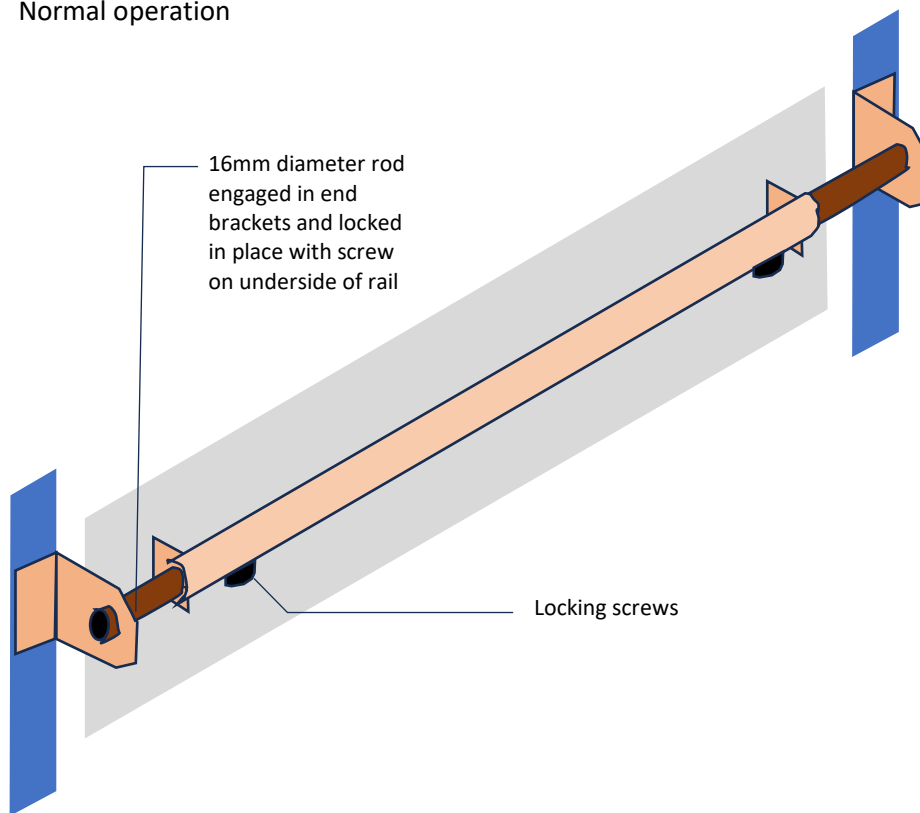


Figure 3-8 Door specification



- Normal operation



- Strong room operation

Figure 3-9 Detail of "structural towel rail"

Knock-out pin hinges shall be used to allow door to be opened even if locking mechanism has been damaged by debris. Three hinges shall be used to allow one to be damaged by debris and the door can still be supported by the other two.

Door frames shall be directly connected to either the door jamb studs or the wall panels using screws in accordance with the door manufacturer's performance solution.

Multi-latch systems can be used, but all latches shall be into the side jamb with no latches in the top or bottom of the door. This allows the door to be opened using the knock-out pin hinges even if debris has damaged the latches.

3.1.5. Foundations

The engineer must verify the adequacy of the existing concrete slab or sub-structure to resist the applicable loads.

3.2. Window systems

The window system in the strong room will need to be replaced.

Window systems shall comply with AS 2047 and have wind ratings defined as either a wind classification for the strong room as defined in Clause 2.1.1 OR a pressure rating as defined in Clause 2.1.2.

For example, if the wind classification for the rest of the house is C1, then the minimum wind classification used for the window in the strong room is C2.

The window system shall

- satisfy the requirements in Clauses 2.1 for the relevant V_{500} for debris resistance OR
- be protected by permanently installed cyclone-rated impact-resistant screens or shutters fixed with standoffs in accordance with the design information based on test results for the relevant wind region.

3.3. Waterproofing/water resistance

Details at the junction of walls, and the junction of walls and ceilings shall include water-resistant features including:

- Silicone sealant between wall panels, and between wall panels and ceiling and floor
- Corner flashings to extend at least 100 mm beyond the interface between the wall panels and bonded to both surfaces, and fixed with screws at 3 places per face of the flashing to hold it in place until after the debris-resistant lining is installed. The flashing is positioned under the debris-resistant lining, as shown in Figure 3-10 .)
- A waterproof membrane on the upper surface of the ceiling.

Note: Where the strong room is a wet space such as a bathroom, normal wet area waterproofing is required on the inside face of the internal lining.

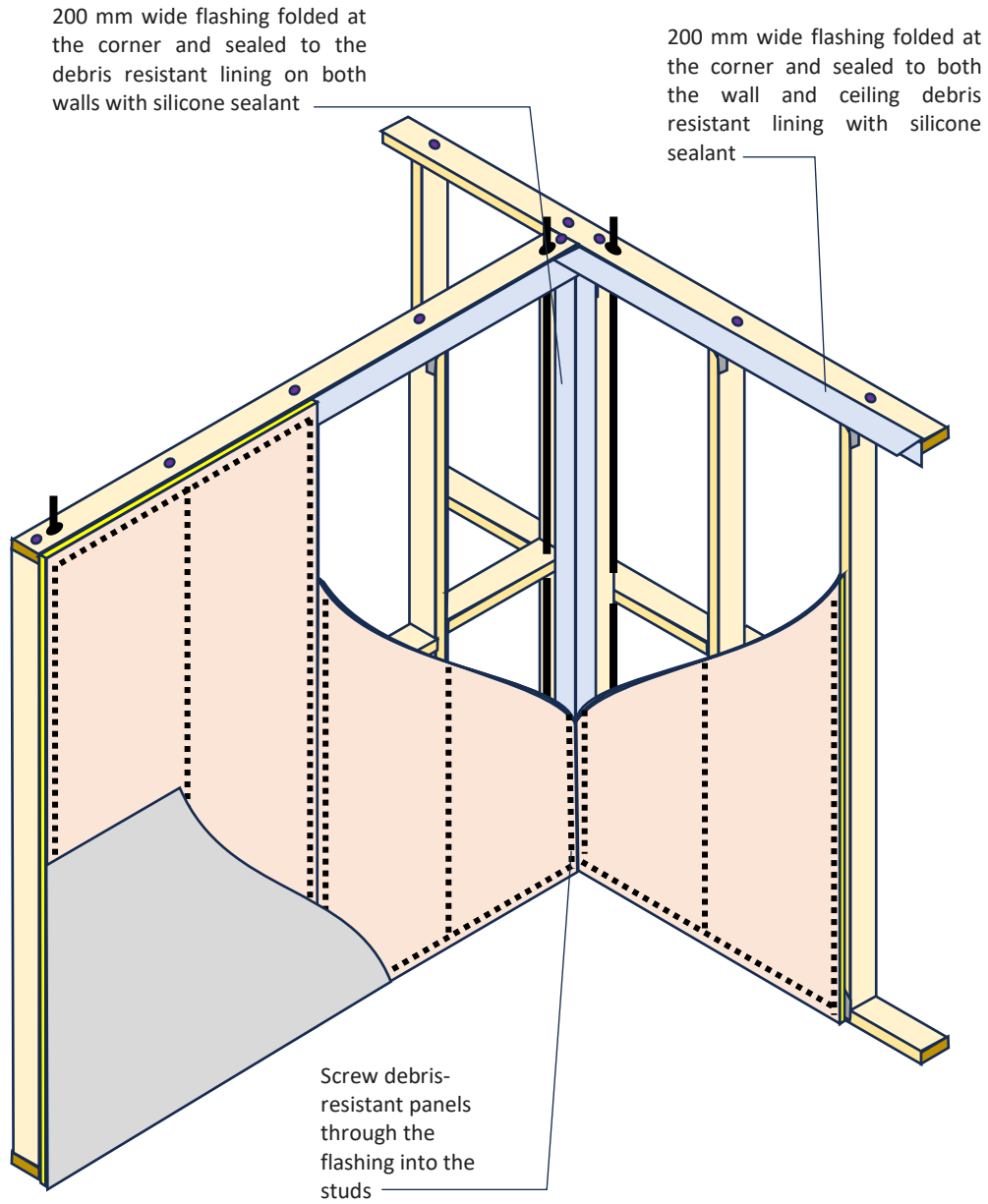


Figure 3-10 Flashing at wall junctions and wall to ceiling junctions

4. Performance solutions

Strong rooms should not be constructed in houses located in a 1:500 storm-tide area, or a riverine flood area. Refer to the local Council for maps.

Performance solutions shall demonstrate that they satisfy the design criteria in Section 2 by either or both:

1. Calculation using a design document referenced in the National Construction Code
2. Results from the tests referenced in APPENDIX A and/or APPENDIX B.

4.1. Structural systems

4.1.1. Walls

Wall systems shall demonstrate they satisfy:

1. Debris resistance, as specified in Section 2.1.3 for vertical surfaces using the test method referenced in APPENDIX A
2. Out-of-plane wind loads specified in Section 2.1.1 or 2.1.2
3. In-plane bracing capacity to carry wind loads specified in Section 2.1.1 or 2.1.2, or results from the tests referenced in APPENDIX B.

Deemed to satisfy walls detailed in Section 4.1.1 have a bracing capacity in excess of 11 kN/m length.

4.1.2. Ceilings

Ceiling systems shall demonstrate they satisfy:

1. Debris resistance, as specified in Section 2.1.3 for horizontal surfaces using the test method referenced in APPENDIX A
2. Out-of-plane wind loads specified in Section 2.1.1 or 2.1.2

4.1.3. Bracing

Bracing loads shall be evaluated using the wind actions for the strong room and either:

1. AS 4055 or AS 1684.3 using the length of the strong room wall perpendicular to the wind direction plus 3 m; OR
2. Pressures from AS/NZS 1170.2 using the length of the strong room wall perpendicular to the wind direction plus 3 m.

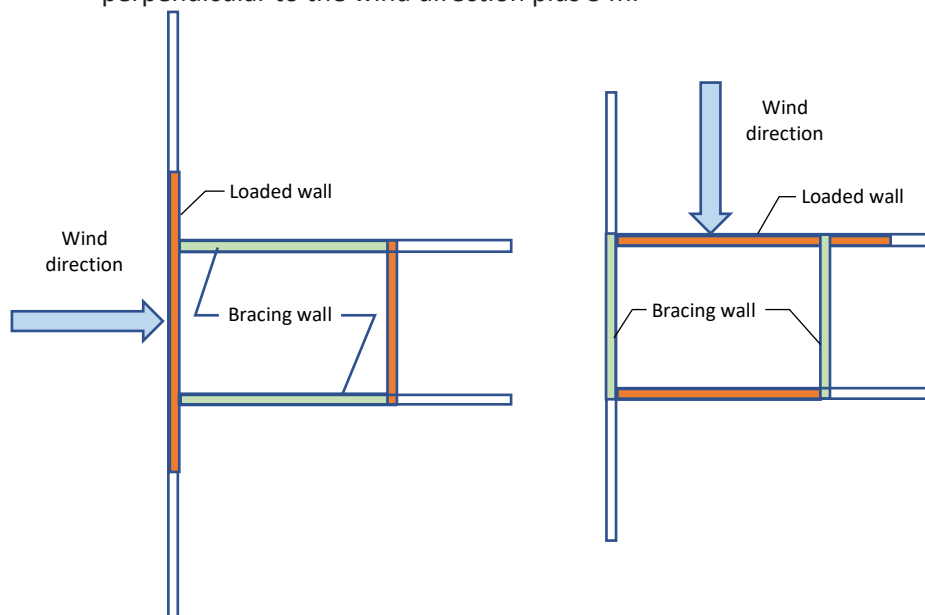


Figure 4-1 – Area used to calculate bracing loads

Bracing resistance shall be provided by walls parallel to the wind direction.

Bracing resistance shall be demonstrated by calculation of bracing capacity of the walls using a primary reference in the NCC or by testing using the test method referenced in APPENDIX B.

The contribution of the bracing for the strong room shall not be considered in the design of the total bracing in the house because the strong room walls are not structurally connected to the roof diaphragm of the rest of the house.

4.1.4. Doors

Strong room doors shall:

- (a) be inward opening
- (b) when fitted with hinges, locks and frames, meet the debris impact and wind load requirements in Clause 2.1 for the relevant V_R ($V_{10,000}$ for wind actions and V_{500} for debris resistance)
- (c) be easily latched and opened from both sides when undamaged and opened from the inside when damaged by wind-borne debris
- (d) have seals to minimise wind-driven rain entering the strong room.

Doors shall have the following attributes:

- Knock-out pin hinges shall be used to allow the door to be opened even if the locking mechanism has been damaged by debris. Three hinges shall be used to allow one to be damaged by debris, but the door can still be supported by the other two.
- Multi-latch systems can be used, but where they are used shall only latch into the side frame. (There shall be no latches in the top or bottom of the door.) This allows the door to be opened using the knock-out pin hinges even if debris has damaged some or all of the latches.

Components of a door assembly are not interchangeable with another door, frame, or components unless they are tested to the requirements in Clauses 2.1.1 or 2.1.2 and Clause 2.1.3 respectively for the relevant V_R ($V_{10,000}$ for wind actions and V_{500} for debris resistance). The wind-driven debris test shall be conducted in the same configuration as the door will be installed, i.e., the wind-driven debris test shall be undertaken with the door in an inward-opening configuration.

Installers shall follow the manufacturer's installation instructions precisely. The door and frame attachments shall be installed in the same way as the assembly was tested or evaluated by a building or engineering professional.

4.1.5. Foundations

The foundations shall provide resistance to combined wind uplift and overturning.

4.2. Window systems

Window systems shall demonstrate performance by meeting:

1. Wind pressure and rain penetration tests specified in AS 2047 for pressures that satisfy the design criteria specified in Section 3.
- Wind-driven debris tests referenced in APPENDIX A that satisfy the requirements in Clause 2.1.3 on either the window system or a protective screen or shutter.

4.3. Waterproofing/water resistance

A performance solution shall demonstrate that it meets or exceeds the water resistance performance of the measures specified in Clause 3.3.

APPENDIX A Wind-driven debris tests

Debris tests are based on the loads specified in Clause 2.5.8 in AS/NZS 1170.2. The test method and acceptance criteria are presented in Technical Note 4 available on the Cyclone Testing Station website.

<https://www.jcu.edu.au/cyclone-testing-station/education> under Technical Notes

APPENDIX B – Bracing test

Bracing tests are based on racking loads determined using AS 4055, AS 1684 or the NASH Standard. The test method is presented in Technical Note 7 available on the Cyclone Testing Station website.

<https://www.jcu.edu.au/cyclone-testing-station/education> under Technical Notes

APPENDIX C– Label and record of maintenance and changes to the strong room

Example of label

This strong room complies with the requirements in the ‘Guide for the design of strong rooms in houses for protection during tropical cyclones’.

Document number:

Subject to no evacuation orders, shelter in this room during a tropical cyclone.

Ensure the door and window are securely closed.

Room name:

Date strong room installed:

The homeowner will keep the following information for future building owners:

- Details of design criteria used.
- Date of construction.
- Name and contact details of the builder.
- Date and certification by an engineer
- Date and details (including contact details of the builder) of any alterations.
- Date and details (including contact details of the builder) of any repairs.
- Date and details (including contact details of the builder) of any major maintenance conducted.
- Date when the strong room was used during a cyclone, the number and ages of people who sheltered, and the length of time people were in the strong room. Note the performance of the strong room including any damage to the strong room. Also note any changes to what is brought into the room for next time.
- Building certification documentation

Annual Maintenance checklist:

The homeowner should check the strong room in October (before every cyclone season) and undertake maintenance if necessary.

Year	20__	20__	20__	20__	20__	20__	20__	20__	20__	20__	20__	20__	20__	20__	20__
Door frame in good condition															
Door in sound condition and latches and hinges lubricated & operational															
“Structural towel rails” are in good working order															
Window screen or protection is secure and undamaged															
Internal walls in good condition															
Ceiling in good condition															
External walls in good condition															
Any alterations since last year have been done using the design criteria															
Label visible and legible															
Items to take into the strong room are prepared & easily located refer to Section Error! Reference source not found.															

BIBLIOGRAPHY

Australian Codes, Standards and Guides

Australian Building Codes Board (2019) National Construction Code. Australian Building Codes Board, Canberra, Australia.

Cyclone Testing Station (2013) Technical Note No. 4 – Simulated windborne debris impact testing of building envelope components. Cyclone Testing Station, James Cook University, Townsville, Australia.

Darwin Reconstruction Commission (1976) Darwin Area Building Manual. Darwin Reconstruction Commission, Darwin.

Department of Public Works, Queensland (2006) Design Guidelines for Queensland Public Cyclone Shelters, Department of Public Works Brisbane, Australia.

Experimental Building Station (1978) Guidelines for evaluation of products for cyclone-prone areas. Technical Record 440 Experimental Building Station, Department of Construction, Sydney, 8.

Standards Australia (1989) AS 1170.2 Minimum design loads on structures Part 2: Wind loads. Standards Australia, Sydney.

Standards Australia (2002) AS/NZS 1170.2:2002 Structural design actions Part 2: Wind loads, Standards Australia, Sydney.

Standards Australia (2010a) AS 1684.3:2010 Residential timber framed housing, Part 3 Cyclonic areas. Standards Australia, Sydney, NSW, Australia.

Standards Australia (2010b) AS 1720.1:2010 Timber structures Part 1: Design methods. Standards Australia, Sydney, NSW, Australia.

Standards Australia (2011) AS/NZS 1170.2:2021 Structural design actions Part 2: Wind loads, Standards Australia, Sydney.

Standards Australia (2012a) AS4055:2021 Wind loads for housing. Standards Australia, Sydney, NSW, Australia.

Damage investigation reports

Boughton GN and Falck DJ (2007) Tropical cyclone George Damage to buildings in the Port Hedland area TR52. Cyclone Testing Station, James Cook University, Townsville.

Boughton GN, Henderson DJ, Ginger JD, Holmes JD, Walker GR, Leitch CJ, Somerville LR, Frye U, Jayasinghe NC, and Kim PY (2011) Tropical Cyclone Yasi – Structural damage to buildings TR57. Cyclone Testing Station, James Cook University, Townsville.

Boughton G, Falck D, Henderson D, Smith D, Parackal K, Kloetske T, Mason M, Humphreys M, Navaratnam S, Bodhinayake G, Ingham S, and Ginger J. (2017) Tropical Cyclone Debbie – Damage to buildings in the Whitsunday Region TR63. Cyclone Testing Station, James Cook University, Townsville.

Boughton G, Falck D, Parackal K, Henderson D, Bodhinayake G (2021) Tropical Cyclone Seroja – Damage to buildings in the Mid-West Region of Western Australia TR66. Cyclone Testing Station, James Cook University, Townsville.

Henderson DJ, Leitch C. (2005) Damage investigation of buildings at Minjilang, Cape Don and Smith Point in NT following Cyclone Ingrid. TR50. Cyclone Testing Station, James Cook University, Townsville.

Henderson DJ, Ginger, J., Leitch C, Boughton GN and Falck DJ (2006) Tropical Cyclone Larry – damage to buildings in the Innisfail area TR51. Cyclone Testing Station, James Cook University, Townsville.

Henderson DJ, Leitch C, Frye U, Ginger J, Kim P and Jayasinghe N (2010) Investigation of housing and sheds in Proserpine, Midge Point and Airlie Beach following Tropical Cyclone Ului TR56. Cyclone Testing Station, James Cook University, Townsville.

Leitch C, Ginger J, Harper B, Kim P, Jayasinghe N, Somerville L (2009) Investigation of Performance of Housing in Brisbane following storms on 16 and 19 November 2008 TR55. Cyclone Testing Station, James Cook University, Townsville.

Parackal K, Mason M, Henderson D, Stark G, Ginger J, Somerville L, Harper B, Smith D, Humphreys M (2015) Investigation of Damage: Brisbane, 27 November 2014 severe storm event TR60. Cyclone Testing Station, James Cook University, Townsville.

Reardon GF, Walker GR, Jancauskas ED (1986) Effects of Cyclone Winifred on buildings TR27. Cyclone Testing Station, James Cook University, Townsville.

Reardon GF, Henderson DJ, Ginger J. (1999) A structural assessment of the effects of Cyclone Vance on houses in Exmouth WA TR48. Cyclone Testing Station, James Cook University, Townsville.

Academic papers on debris tests and resilience of buildings to debris impact

Adams, K. (2001) Impact test criteria for flying debris in windstorms. Thesis submitted to James Cook University. Bachelor of Engineering.

American Institute Architects (2010). Comparing performance of fiberglass, wood and steel entry doors. AIA_HW_Course_Final_082410.ppt Continuing Education.

Baker CJ (2007) The debris flight equations. *Journal of Wind Engineering and Industrial Aerodynamics* 95, 329-353.

Bole, S., (1999) Investigation of the mechanics of windborne missile impact on window glass. MSc Thesis, Department of Civil Engineering, Texas Tech University, Lubbock, Texas.

Carter R (1998). Wind-generated missile impact on composite wall systems. Master's thesis, Department of Civil Engineering. Texas Tech University, Lubbock, Texas.

Chen W, Hao H, Du H (2014) Failure analysis of corrugated panel subjected to windborne debris impacts. *Engineering Failure Analysis* 44, 229-249.

Grayson JM, Pang W, Schiff S (2012) Three-dimensional probabilistic windborne debris trajectory model for building envelope impact risk assessment. *Journal of Wind Engineering and Industrial Aerodynamics* 102, 22-35.

Grayson JM, Pang W, Schiff S (2013) Building envelope failure assessment framework for residential communities subjected to hurricanes. *Engineering Structures* 51, 245-258.

Herbin AH, Barbato M (2012) Fragility curves for building envelope components subject to windborne debris impact. *Journal of Wind Engineering and Industrial Aerodynamics* 107-108, 285-298.

Holmes JD (1999) Debris Damage Criteria for Cyclone Shelter Buildings in Queensland, Report JDH 99/1, JDH Consulting.

Holmes JD (2001) Wind loading of structures. Spon Press, London. 16-23

Holmes JD (2004) Trajectories of spheres in strong winds with application to windborne debris. *Journal of Wind Engineering and Industrial Aerodynamics* 92, 9-22.

Holmes JD, Ginger JD (2012) Internal pressure – The dominant windward opening case – A review. *Journal of Wind Engineering and Industrial Aerodynamics* 100, 70-76.

Karimpour A, Kaye NB (2012) On the stochastic nature of compact debris flight. *Journal of Wind Engineering and Industrial Aerodynamics* 100, 77-90.

Leicester R, Reardon (1977) Wind-driven missiles, *Proceedings TR440 Workshop on guidelines for cyclone product testing and evaluation*. North Ryde, Sydney.

Lin N, Letchford C, Holmes JD (2006) Investigation of plate-type windborne debris. Part 1. Experiments in wind tunnel and full scale. *Journal of Wind Engineering and Industrial Aerodynamics* 94, 51-76.

Lin N, Holmes JD, Letchford C (2007) Trajectories of windborne debris in horizontal wind and applications to impact testing. *Journal of Structural Engineering ASCE*, Vol 133, 274-282

Lin N, Vanmarcke E (2008) Windborne debris risk assessment. *Probabilistic Engineering Mechanics* 23, 523-530.

McDonald J (1990). Impact resistance of common building materials to tornado missiles. *Journal of Wind Engineering and Industrial Aerodynamics*, 36. 717-724.

Peters S, Robertson I (2012). The effects of windborne debris on saferoom wall panels and fenestration systems. University of Hawaii, College of Engineering.

Salter T (2012) Implementing the 8 mm cyclonic debris test. Thesis, Curtin University Perth Western Australia.

Scheer D (2005). Large wind missile impact performance of public and commercial building assemblies. Florida State University. Tallahassee Florida USA.

Shah, N. (2009) Windborne debris missile impacts on window glazing and shutter systems. MSc Thesis, University of Florida, Gainesville Florida USA.

Starr, C., and Krauthammer, T., (2005) Cladding-Structure Interaction under Impact Loads, *Journal of Structural Engineering*, DOI: 10.1061/(ASCE)0733-9445(2005)131:8(1178), ASCE

Walker G (1991) the application of wind engineering technology to the mitigation of damage to housing from tropical cyclones – an Australian achievement. *Proceedings of the International Conference on Impact of Disasters* Los Angeles, California, USA.

Wind Science and Engineering Research Center (2003) A summary report on Debris impact testing at Texas Tech University. Texas Tech University, Lubbock, Texas.

Wind Science and Engineering Research Center (2004) Construction materials threshold testing at the Texas Tech University. Texas Tech University, Lubbock, Texas.

Wills JAB, Lee BE, Wyatt, TA (2002) A model of windborne debris damage. *Journal of Wind Engineering and Industrial Aerodynamics* 90, 555-565.

International Codes, Standards and Guides

American National Standard (2019) ICC 500–2020 ICC/NSSA Standard for the Design and Construction of Storm Shelters. International Code Council, Washington, D.C.

ASTM International (2012) E1996 Standards specification for performance of exterior windows, curtain walls, doors, and impact protective systems impacted by windborne debris in hurricanes. ASTM International.

ASTM International (2013) E1886 Standard test method for performance of exterior windows, curtain walls, doors and impact protective systems impacted by missiles and exposed to cyclic pressure differentials. ASTM International.

Federal Emergency Management Agency (FEMA) (2000) Performance criteria for compact debris IN: Design and construction guidance for community shelters. FEMA 361, 1st Edition, Chapter 6.

FEMA (2008). IN: Design and construction guidance for community shelters. Chapter 7. Performance criteria for debris impact. FEMA 361. 2nd Edition.

FEMA (2021) *Safe Room Publications and resources*, viewed 18 August 2021 <https://www.fema.gov/emergency-managers/risk-management/safe-rooms/resources>.

Florida Building Code Board (2010) Florida Building Code. Florida Building Code Board. Florida Department of business and Professional Regulation. Clause 1609.1.

International Standards Organisation (2007) ISO 13962:2007 Glass in building – destructive wind storm resistant security glazing – test and classification. International Standards Organisation Geneva.