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SIMULATED WIND LOAD STRENGTH TESTING OF ENTRANCE DOORS

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1 Introduction

Damage investigations following cyclonic events have shown failure of doors and windows as illustrated in Figure 1 and Figure 2. Failure of such elements leads to further damage to the building by allowing rain and wind to enter the house. In addition to water damage to contents and internals, this creates increased stress to the building envelope due to the increased internal pressure as illustrated in Figure 3, which can lead to further failure such as roof failure.

Small weaknesses can therefore lead to large failures.

The study *"Design of Potential Dominant Opening to Resist Cyclonic Winds"* by Nicoline Thomson, David Henderson and John Ginger highlights the under design of a standard external door for cyclonic conditions. Following this study, additional tests were conducted, replacing the timber doorframe with a steel doorframe and assessing various types of doors and lock mechanisms under cyclonic conditions.

The aim of this test programme was to perform full-scale simulated wind load strength testing of these different configurations of entrance doors. The *AS 4040.2* static and *AS 4040.3* cyclic simulated wind load strength test regimes were used as guides to load the test doors.

The simulated wind load strength tests were conducted in the airbox testing facility located in the Wind Tunnel Building at James Cook University.

Figure 1: Failure of Glass Sliding Doors

Figure 2: Failure of External Door

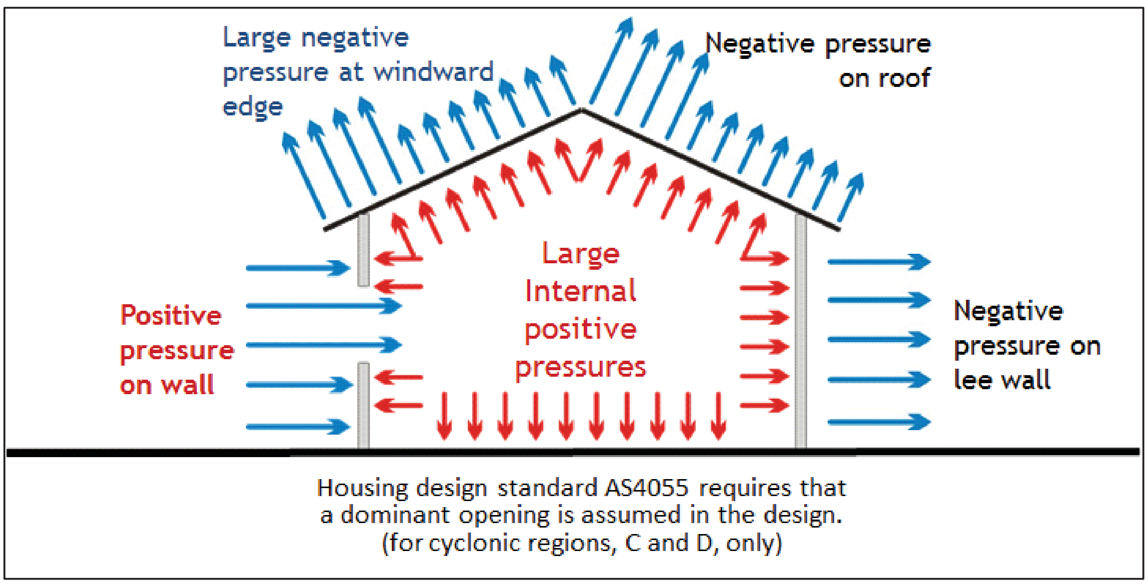

Figure 3: Schematic of Pressures in Presence of a Dominant Opening

2 Test Programme

A programme of seven (7) static and three (3) cyclic simulated wind load strength testing was conducted. A summary of the test programme is provided in Table 1.

Table 1: Test Programme Summary

<table>
<tr><th>Trial No</th><th>Test regime</th><th>Door Thickness (mm)</th><th>Door Core</th><th>Barrel Bolt</th><th>Lock</th></tr>
<tr><td>SS2</td><td rowspan="2">Static</td><td rowspan="5">35</td><td rowspan="5">Hollow</td><td rowspan="5">-</td><td rowspan="5">Budget</td></tr>
<tr><td>SS2a</td></tr>
<tr><td>SS2a_cyc</td><td rowspan="3">Cyclic</td></tr>
<tr><td>C1</td></tr>
<tr><td>C1a</td></tr>
<tr><td>SS3</td><td rowspan="5">Static</td><td>35</td><td>Hollow</td><td>Top of Door</td><td>Budget</td></tr>
<tr><td>SS4</td><td>35</td><td>Hollow</td><td>Top and Bottom of Door</td><td>Budget</td></tr>
<tr><td>SS5</td><td rowspan="2">35</td><td rowspan="2">Solid</td><td rowspan="2">-</td><td rowspan="2">Mid-range</td></tr>
<tr><td>SS5a</td></tr>
<tr><td>SS6</td><td>40</td><td>Hollow</td><td>-</td><td>Mid-range</td></tr>
</table>

3 Door Details

Three types of doors were used:

- 35 mm hollow core door
- 35 mm solid core door
- 40 mm hollow core door

Two types of lock mechanisms were used:

- A budget, entry lever lock mechanism
- A mid-range lock mechanism

3.1 Installation details

The doors were mounted onto a steel door frame.

Note that the strength of neither the fasteners nor the frame were being evaluated in this programme.

4 Test Apparatus and Procedure for Simulated Wind Load Tests

4.1 Test Set Up in Airbox Test Facility

The test specimens were installed in the Cyclone Testing Station's airbox test facility. The airbox is an open-topped pressure chamber with a maximum test width of 2040 mm and an adjustable length of up to 10 m. For this testing programme, the door assembly was installed to become the top (horizontal) surface of the chamber. Plywood infills were used to seal the gaps between the door frame and the walls of the airbox test rig.

4.2 Simulated Wind Load Strength Testing

A uniform pressure was applied to the internal face of the doors by two large centrifugal fan(s) blowing air into the airbox chamber. This pressure simulated the combined effect of both the outward pressure and the internal pressure acting on the doors. A pressure transducer measured the applied load on the test door.

4.3 Allowance for Self-Weight of Doors

The doors are normally mounted vertically but were tested in a horizontal position Therefore, the indicated test pressure applied was adjusted to compensate for the self-weight of the doors. All test pressure figures stated subsequently are net pressures that allow for the self-weight of the system.

4.4 Static Simulated Wind Load Strength Testing

The static simulated wind load strength testing was performed in accordance with *AS 4040.2-1992, "Methods of Testing Sheet Roof and Wall Cladding, Method 2: Resistance to Wind Pressures for Non-Cyclone Regions"*. The test specimen was subjected to increasing pressures in appropriate increments and each pressure was held constant for a period of 1 minute. This procedure was repeated until failure of the test specimen.

Note: This testing method was used as a guide only for consistency of testing. It is normally intended for testing of wall cladding. The standard acceptance criteria was not used, the reported maximum pressure held is the maximum pressure recorded before door failure.

4.5 Cyclic Simulated Wind Load Strength Testing

The cyclic simulated wind load strength testing was performed in accordance with *AS 4040.3-1992, "Methods of Testing Sheet Roof and Wall Cladding, Method 3: Resistance to Wind Pressures for Cyclone Regions*". Cyclic loading was achieved by opening and closing pressure dump valves.

The cyclic loading sequence used in this test programme was performed in accordance with the cyclic testing regime specified in the *AS 4040.3-1992*, *"Methods of Testing Sheet Roof and Wall Cladding, Method 3: Resistance to Wind Pressures for Cyclone Regions*". The loading sequence is presented in Table 2, where P_t is the test pressure.

Table 2: *AS 4040.3* Fatigue Loading Sequence

No. of Cycles	Load
8000	0 to 0.40 P_t
2000	0 to 0.50 P_t
200	0 to 0.65 P_t
1	0 to Ultimate Load

Note: This testing method was used as a guide only for consistency of testing. It is normally intended for testing of wall cladding. The standard acceptance criteria was not used. None of the specimens tested completed the entire fatigue loading sequence and therefore P_t was not used. Instead, for trials C1 and C1a, the reported cycle pressure is the pressure at which the specimen were cycled before failure; and for trial SS2a_cyc, the reported cycle pressure is the maximum pressure recorded before failure since the door failed during the first cycle.

5 Results

5.1 Static Simulated Wind Load Strength Testing

Seven static simulated wind load strength test were performed. A summary of the test results is provided in Table 3. Figure 4 shows a lock mechanism failure. Additional photographs of damages are provided in Appendix A.

Table 3: Static Simulated Wind Load Strength Testing Results

Trial No	Door Thickness (mm)	Door Core	Barrel Bolt	Lock	Max. Door Deflection (mm)	Max. Pressure Held (kPa)
SS2	35	Hollow	-	Budget	N/A	1.93
SS2a					20	2.09
SS3	35	Hollow	Top of Door	Budget	-	2.11
SS4	35	Hollow	Top and Bottom of Door	Budget	20	3.18
SS5	35	Solid	-	Mid-Range	35	4.22
SS5a					30	3.96
SS6	40	Hollow	-	Mid-Range	40	3.82

5.2 Cyclic Simulated Wind Load Strength Testing

Three cyclic simulated wind load strength test were performed. A summary of the test results is provided in Table 4. Photographs of damages are provided in Appendix A.

Table 4: Cyclic Simulated Wind Load Strength Testing Results

Trial No	Door Thickness (mm)	Door Core	Barrel Bolt	Lock	Number of Cycles completed	Cycle Pressure (kPa)
C1	35	Hollow	-	Budget	100	1.73
C1a					8	1.93
SS2a_cyc*					1	2.10

*Note: Trial SS2a_cyc was conducted on the same door as trial SS2a, with a new lock. Therefore the door was already weakened by trial SS2a. In addition the desired pressure value for the cycles was 1.8kPa. However, the airbox immediately ramped to 2.10kPa.

Figure 4: Lock Mechanism Failure

6 Determination of Ultimate Limit State Design Wind Capacities

The Ultimate Limit State design wind pressure capacities can be back calculated from the static test results by dividing the lowest of the highest test pressures held by each specimen by the factor to allow for variability of structural units (k_t).
Table B1 of *AS/NZS 1170:2002, "Structural design actions, Part 0: General principles"* was used to determine k_t.
The tests were full-scale test of timber and timber composite doors in metal frame; therefore, a coefficient of variation of structural characteristics (V_{sc}) of 15% was chosen to determine k_t.

None of the specimens tested cyclically completed the entire fatigue loading sequence, however, trial C1 completed 100 cycles at a lower pressure. Therefore, the result of trial C1 was not used and the results of trials C1a and SS2a_cyc were used as static results and combined with trials SS2 and SS2a since those four trials were done with the same configuration. Therefore, for these tests, k_t = 1.50.

Two static strength wind load tests were conducted for SS5/SS5a set up, in this programme, and therefore k_t = 1.64 for those tests.

One static strength wind load tests was conducted for all other set ups, in this programme, and therefore k_t = 1.79 for those tests.

Important note: The design values are indicative only as this study was conducted for informative purposes. These values should NOT be used to design buildings. The specimen were selected due to their easy availability in a hardware store and they may not be representative of other doors from different manufacturers.

The ultimate limit state design wind capacities are summarised in Table 5. Note that these design capacities are only applicable for the doors, geometry, frame types and support details, as used in this testing programme.

Table 5: Ultimate Limit State Design Wind Capacities

Door Thickness (mm)	Door Core	Door Frame	Barrel Bolt	Lock	Ultimate Limit State Design Wind Capacities (kPa)
35	Hollow	Steel	-	Budget	1.28
35	Hollow	Steel	Top of Door	Budget	1.17
35	Hollow	Steel	Top and Bottom of Door	Budget	1.77
35	Solid	Steel	-	Mid-Range	2.41
40	Hollow	Steel	-	Mid Range	2.13

7 Ultimate Limit State Design Wind Capacities from Previous Study

A summary of the ultimate limit state design wind capacities obtained in *"Design of Potential Dominant Opening to Resist Cyclonic Winds"* by Nicoline Thomson, David Henderson and John Ginger is provided in Table 6. Photograph of damage is provided in Appendix B.

Table 6: Ultimate Limit State Design Wind Capacities from Previous Study

Door Thickness (mm)	Door Core	Door Frame	Barrel Bolt	Lock	Ultimate Limit State Design Wind Capacities (kPa)
35	Hollow	Timber	-	Budget	1.06
35	Hollow	Timber	Top of Door	Budget	1.23

8 Recommended Ultimate Limit State Design Wind Capacities

From *Table 3.3* of *AS 4055-2012, "Wind loads for housing"*, shown in Figure 5, the ultimate strength design pressure on a wall of a standard residential building is 2.68 kPa inwards at any position of the wall for a wind classification C2. Note: the outwards value is 2.68 kPa away from corners and 4.02 kPa within 1200 mm of corners. External doors are generally installed such as they open inwards (the door opens inside the house). However, for a door mounted in the opposite direction (opening outside the house), consideration would have to be made on the door location to choose the appropriate ultimate strength design pressure for the door.

TABLE 3.3

ULTIMATE STRENGTH PRESSURES (kPa) FOR WIND CLASSIFICATION FROM THE NET PRESSURE COEFFICIENTS GIVEN IN CLAUSE 3.2

Wind class	Walls			Roofs			
	Any position	Away from corners (see Note 3)	Within 1200 mm of corners (see Note 3)	Any position	General away from edges (see Note 2)	Within 1200 mm of edges (see Note 2)	At corners (within 1200 mm of both edges) (see Note 2)
Pressure Zone	G, SC Figure 3.2	G Figure 3.2	SC Figure 3.2	G, RE, RC Figure 3.1	G Figure 3.1	RE Figure 3.1	RC Figure 3.1
$K_C.C_{p,n}$	**+0.9**	**−0.77**	**−1.35**	**+0.63**	**−0.99**	**−1.8**	**−2.61**
N1	+0.62	−0.53	−0.94	+0.44	−0.69	−1.25	−1.81
N2	+0.86	−0.74	−1.30	+0.60	−0.95	−1.73	−2.51
N3	+1.35	−1.16	−2.03	+0.95	−1.49	−2.70	−3.92
N4	+2.01	−1.72	−3.01	+1.41	−2.21	-4.02	−5.83
N5	+2.96	−2.53	−4.44	+2.07	−3.25	−5.91	−8.58
N6	+3.99	−3.42	−5.99	+2.80	-4.39	−7.99	−11.58
$K_C.C_{p,n}$	**+1.2**	**−1.2**	**−1.8**	**+0.95**	**−1.44**	**−2.25**	**−3.06**
C1	+1.80	−1.80	−2.7	+1.43	−2.16	−3.38	−4.59
C2	+2.68	−2.68	−4.02	+2.12	−3.21	−5.02	−6.83
C3	+3.94	−3.94	−5.91	+3.12	−4.73	−7.39	−10.05
C4	+5.33	−5.33	−7.99	+4.22	−6.39	−9.98	−13.58

Figure 5: Table 3.3 of AS 4055-2012, "Wind loads for housing"

9 Comments on Results

The ultimate limit state design wind capacities of all the door configurations tested and reported in Table 5 and Table 6 are lower than the recommended ultimate limit state design wind capacities from *Table 3.3* of *AS 4055-2012, "Wind loads for housing"*.

The combination of a better lock and more rigid door significantly improves the wind load capacity of the system. Indeed, conducting multiple repeats of configurations used for trial SS5 or SS6 would lower the k_t factor and as a result, the ultimate limit state design wind capacities of these systems could increase and potentially reach the recommended value of 2.68 kPa for an inward door installation. Note: the value of the k_t factor decreases with the number of repeat tests, however the lowest test result is used to determine the ultimate limit state design wind capacities of the system.

From the results obtained in this study, none of the tested configurations are able to reach the design value of 4.02 kPa required for an outward installation within 1200 mm of corners.

10 Conclusions

A programme of simulated wind load strength testing was performed on several configurations of entrance doors.

The methods of testing (with *AS4040.2-1992* and *AS4040.3-1992* as guide testing methods) have been presented.

From the comparison between static and cyclic tests, it can be noted that similar pressures are achieved independently from the loading sequence.

Table 5 outlines indicative design values for entrance doors. However, these values are obtained from static tests, which does not reflects the forces imposed to building during a cyclone as well as cyclic test.

Those results show that the door configurations tested are inadequate for use in cyclonic regions on building with wind classification C2 or above. Note based on these results, only configurations of tests SS5 and SS6 could be suitable for wind classification C1, in inward direction only.

As pointed in section 9, only the best two configurations tested in this study have the potential to be suitable for cyclonic regions, up to wind classification C2 in the inward direction only. However, they are also the most expensive combinations and therefore less likely to be chosen by customers in the absence of standard to regulate the use doors in cyclonic regions.

Failure of a door on a windward wall during a cyclone will create a dominant opening, resulting in an increase of internal pressure and subsequently increased stress on the building envelope and the likelihood of building failure.

It is recommended that the design of door systems as well as selection of these systems would be framed by appropriate standards.

Appendix A – Photographs of Damage

- **Trial SS2**

35mm hollow core door with budget lock.

Pressure held 1.93 kPa
Observation: Lock released from strike plate with lock mechanism jammed in. Strike plate is bent, not much damage to door except skin started to separate from core at the lock.

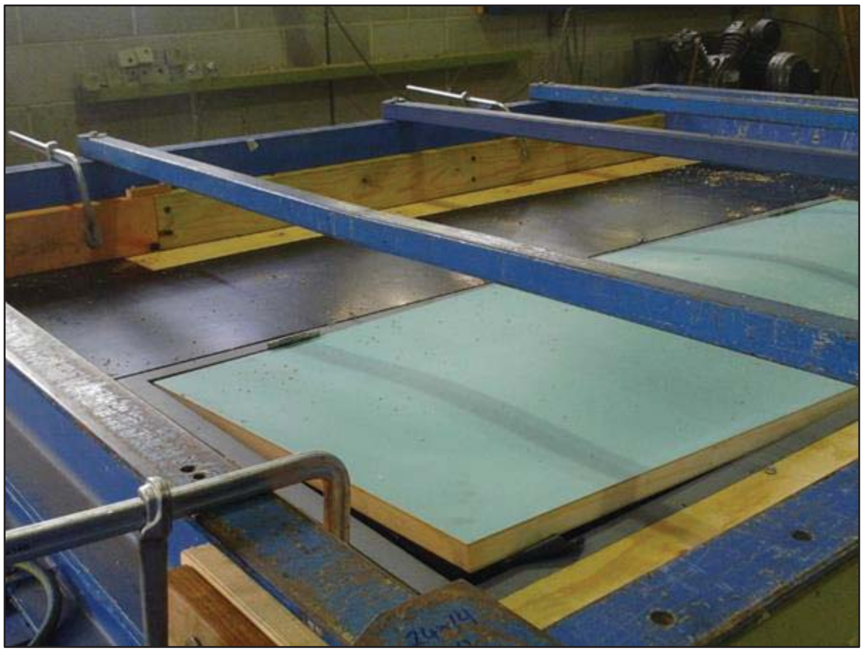

Figure 6: Trial SS2 door deflection during test

Figure 7: Trial SS2 Lock Jammed

Figure 8: Trial SS2 Strike Plate Bent

- **Trial SS2a**

35mm hollow core door with budget lock.

Held 2.09kPa.
Observation: The lock mechanism bent and released from strike plate.

- **Trial SS3**

35mm hollow core door with budget lock and a barrel bolt fitted to the top of the door.

Held 2.11kPa
Observation: The latch from the lock mechanism released from the strike plate.

Figure 9: Trial SS3 Door Deflection During Test

Figure 10: Trial SS3 Damaged Lock Mechanism

- **Trial SS4**

35mm hollow core door with budget lock and a barrel bolt fitted to the top and bottom of the door.

Held 3.18kPa
Observation: The bottom barrel bolt catch broke and then the lock latch pulled out of strike plate.

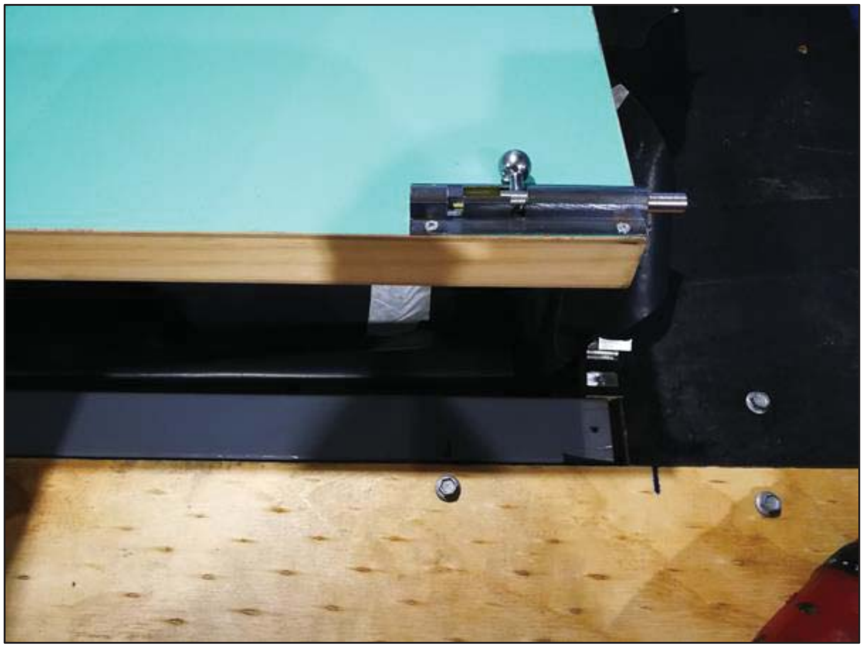

Figure 11: Trial SS4 Broken Barrel Bolt

Figure 12: Trial SS4 Top Barrel Bolt Undamaged

Figure 13: Trial SS4 Jammed Lock Mechanism

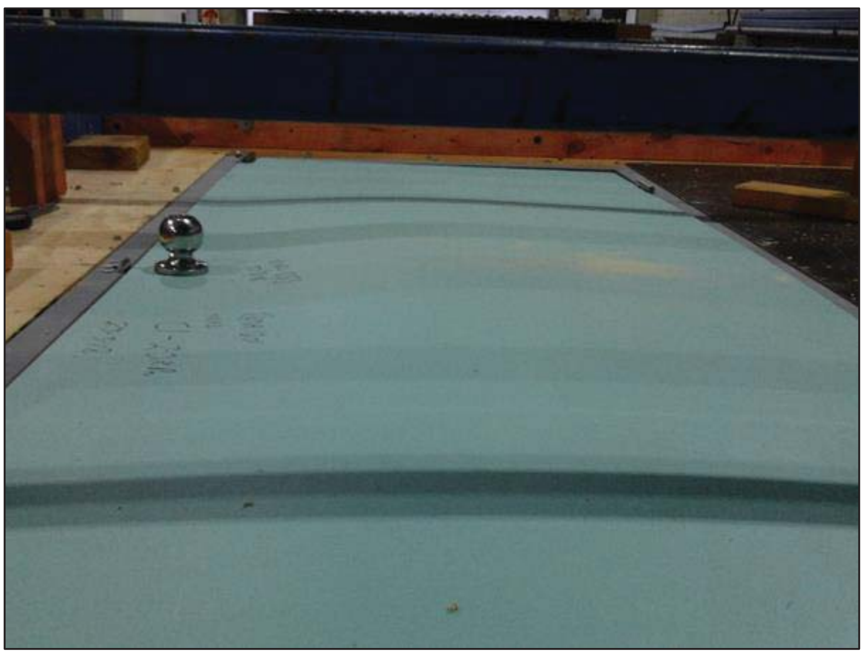

Figure 14: Trial SS4 Door Deflection during Test

Figure 15: Trial SS4 Door Deflection during Test

- **Trial SS5**

35 mm solid core door and mid-range entrance lock.

Held 4.22kPa
Observation: The latch released from strike plate and split across.

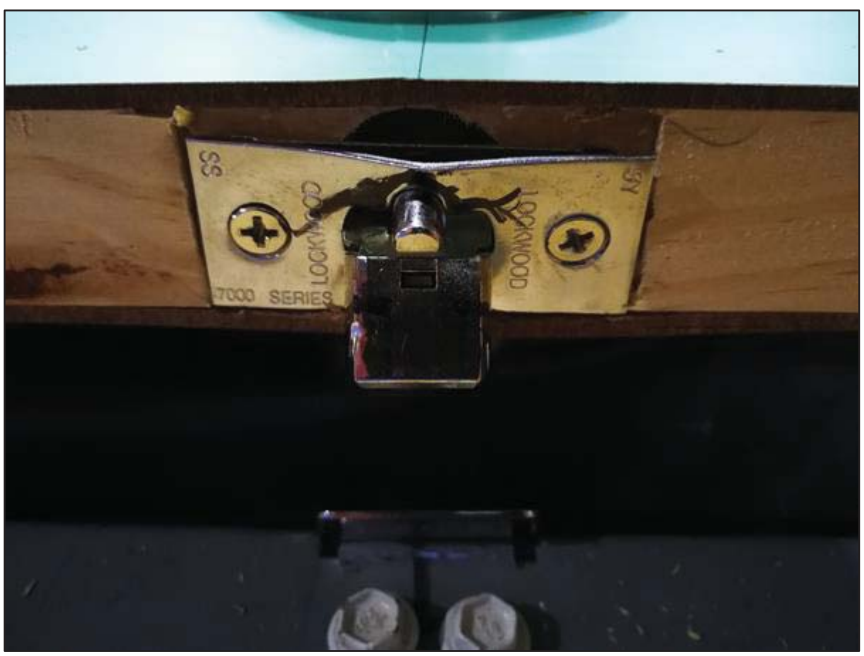

Figure 16: Trial SS5 Broken Lock Mechanism

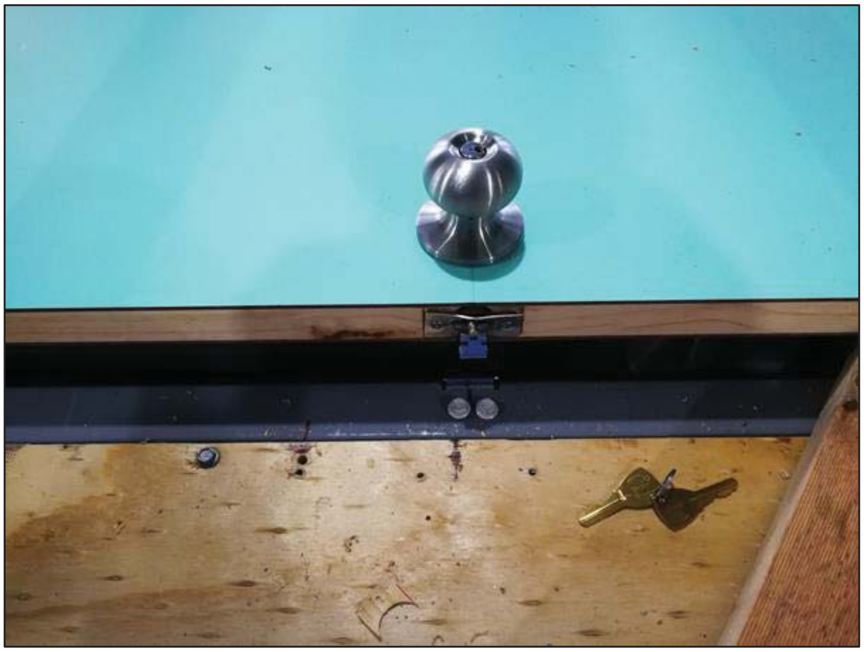

Figure 17: Trial SS5 Broken Lock Mechanism

Figure 18: Trial SS5 Broken Lock Mechanism

Figure 19: Trial SS5 Broken Lock Mechanism

- **Trial SS5a**

35 mm solid core door and mid-range entrance lock.

Held 3.96kPa
Observation: The edge of the door failed and the latch fell out of the lock completely. The edge of the door fractured.

Figure 20: Trial SS5a Broken Lock Mechanism and Damaged Door

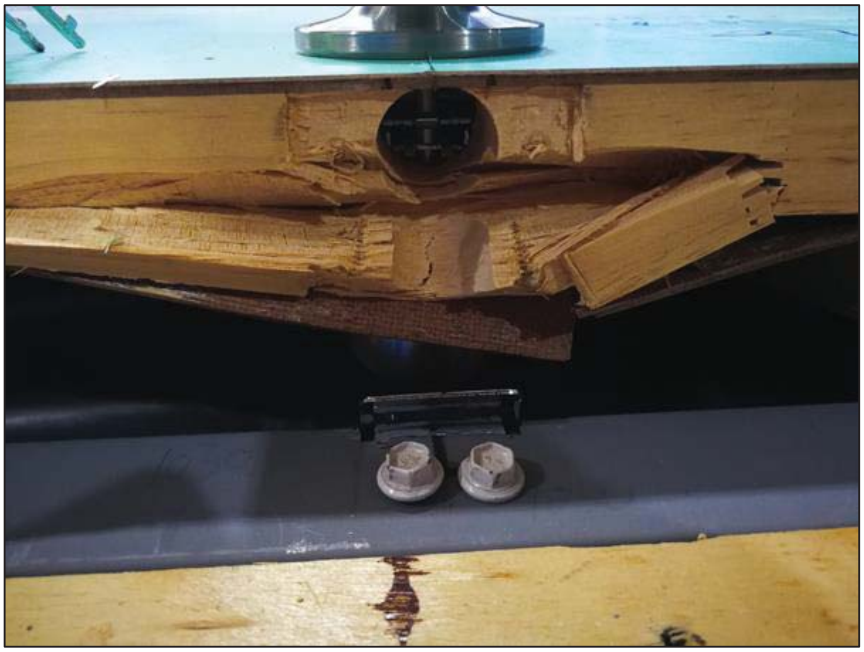

Figure 21: Trial SS5a Broken Lock Mechanism and Damaged Door

Figure 22: Trial SS5a Broken Lock Mechanism

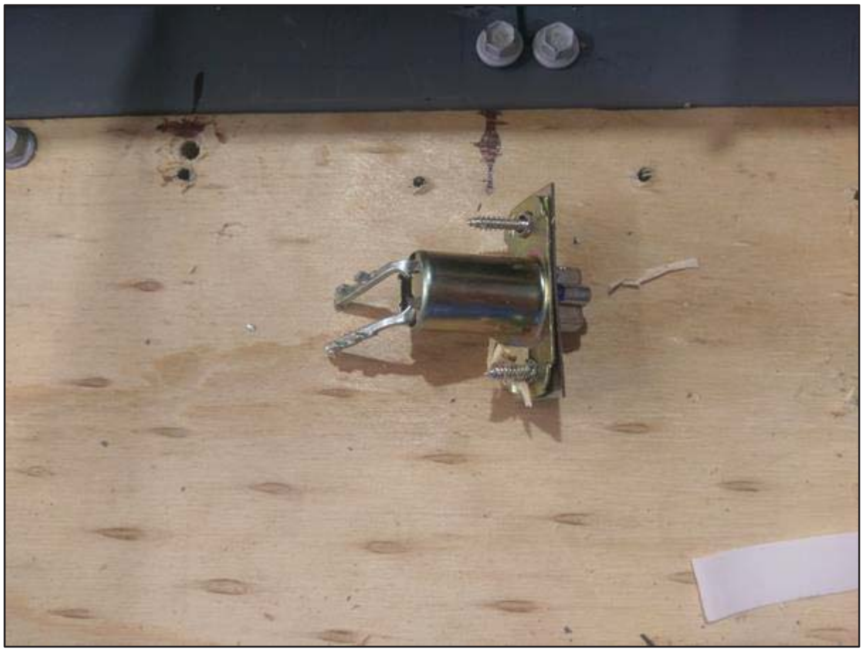

Figure 23: Trial SS5a Broken Lock Mechanism

- **Trial SS6**

40mm hollow core door with mid-range lock.
Maximum door deflection measured: 40mm.

Held 3.82kPa
Observation: The lock mechanism broke, the latch split across and bent down releasing from strike plate. Small split in door edge at lock.

Figure 24: Trial SS6 Damage to Lock Mechanism

Figure 25: Trial SS6 Damage to Lock Mechanism

Appendix B – Photograph of Damage from *"Design of Potential Dominant Opening to Resist Cyclonic Winds"* by Nicoline Thomson, David Henderson and John Ginger

35mm hollow core door with budget lock.

Pressure held 1.90 kPa
Observation: Door handle loosened and sheared door.

Figure 26: Photograph of Damage from *"Design of Potential Dominant Opening to Resist Cyclonic Winds"* by Nicoline Thomson, David Henderson and John Ginger