bnhcrc.com.au

TESTING OF SIMULATED FLOOD EFFECT ON THE STRENGTH OF SELECTED BUILDING COMPONENTS

Tariq Maqsood[1], Martin Wehner[1], Mark Edwards[1], Simon Ingham[2] and David Henderson[2]
[1] Geoscience Australia
[2] Cyclone Testing Station, James Cook University

Version	Release history	Date
1.0	Initial release of document	23/06/2017

Disclaimer:
Geoscience Australia, James Cook University and the Bushfire and Natural Hazards CRC advise that the information contained in this publication comprises general statements based on scientific research. The reader is advised and needs to be aware that such information may be incomplete or unable to be used in any specific situation. No reliance or actions must therefore be made on that information without seeking prior expert professional, scientific and technical advice. To the extent permitted by law, Geoscience Australia, James Cook University and the Bushfire and Natural Hazards CRC (including its employees and consultants) exclude all liability to any person for any consequences, including but not limited to all losses, damages, costs, expenses and any other compensation, arising directly or indirectly from using this publication (in part or in whole) and any information or material contained in it.

Publisher:
Bushfire and Natural Hazards CRC

June 2017

Citation: Maqsood T, Wehner M, Edwards M, Ingham S and Henderson D (2017) Testing of simulated flood effect on the strength of selected building components

Cover: Flooding of selected building components (Geoscience Australia)

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This report presents the results of tests conducted to ascertain the resilience of selected building components to floodwater exposure. The experimental test programme was part of the Bushfire and Natural Hazards Collaborative Research Centre (BNHCRC) project entitled "Cost-effective mitigation strategy development for flood prone buildings".

The motivation for this project arises from the experience and observations made during the recent flooding in Australia in 2011 and 2013, which caused widespread devastation in Queensland. The objective of the project is to address the vulnerability of existing residential building stock in Australian floodplains and is targeted at assessing cost-effective mitigation strategies to reduce the vulnerability.

Geoscience Australia as the lead researcher for the project selected the Cyclone Testing Station at James Cook University in Townville, Queensland, to conduct the experimental tests. These tests aimed to address knowledge gaps in the areas of strength and durability implications of selected components of a typical brick veneer slab-on-grade house due to immersion.

The experimental programme was developed in consultation with insurance industry loss assessors from two major companies and was scoped in recognition of the available budget. The objective of the testing was to identify whether the selected components remain serviceable following inundation and subsequent drying or whether replacement was required.

The experimental programme examined the resistance to inundation of three common building components as outlined below. For each component, a number of samples were tested to attempt to provide some understanding of the variation of resistance. For each component some specimens were tested dry without wetting and some were tested after drying following inundation. For Component 3, some specimens were also tested wet immediately after inundation.

- Component 1 (6 specimens): Tiled surfaces within a typical brick veneer, slab-on-ground house. This test examined the bond strength of floor and wall ceramic tiles to their substrate with the objective of determining the necessity or otherwise of removing and replacing all tiles following inundation.
- Component 2 (20 specimens): Manufactured timber sheet wall bracing. This test examined the effect of flooding on the racking strength of Oriented Strand Board (OSB) and High Density Fibreboard (HDF) sheet wall bracing.
- Component 3 (48 specimens): Manufactured timber joists. This test examined the effect of flooding on the bending and shear strength of manufactured HJ20045 'I' section timbered joists with OSB webs.

The results of the tests showed that flooding did not have any significant effect on the pull-out strength of the bond of the ceramic floor and wall tiles to their substrate, nor on the racking strength of the OSB wall sheet bracing. There was a nominal strength reduction of 10% for the HDF wall sheet bracing when tested after wetting and drying cycle.

However, there was a significant reduction (~46%) in load carrying capacity of the timber joists when tested in the wet condition. These results suggest that the samples whilst in the wet stage may be compromised due to reduced strength capacity and stiffness. However, if allowed to dry then the specimen could recover to nominally 96% of average strength capacity and stiffness. Moreover, it was observed that the moisture content level after the test returned close to pre-inundation level within a week and therefore contributed to recover the strength and stiffness.

The results of the testing will inform recommendations on mitigation measures within the BNHCRC flood project. The results will also inform the selection of building materials for new construction in flood-prone areas.

PROJECT BACKGROUND

INTRODUCTION

Globally, floods cause widespread damage with loss of life and property. An analysis of global statistics conducted by Jonkman (2005) showed that floods (including coastal flooding) caused 175,000 fatalities and affected more than 2.2 billion people between 1975 and 2002. In Australia floods cause more damage on an average annual cost basis than any other natural hazard (HNFMSC, 2006). The fundamental cause of this level of damage and the key factor contributing to flood risk, in general, is the presence of vulnerable buildings constructed within floodplains due to ineffective land use planning. The National Strategy for Disaster Resilience (NSDR, 2011) which is the core of Australian Government's policy on the issue of natural disasters clearly acknowledges the role of individuals along with businesses, communities and government to enhance resilience and build capacity to mitigate flood risk.

The Bushfire and Natural Hazards Collaborative Research Centre project entitled 'Cost-effective mitigation strategy development for flood prone buildings' (BNHCRC, 2017) is examining the opportunities for reducing the vulnerability of Australian residential buildings to riverine floods. It addresses the need for an evidence base to inform decision making by individuals (home owners) and governments on the mitigation of the flood risk posed by the most vulnerable Australian building types.

To date, the project within the BNHCRC has developed a building classification schema to categorise Australian residential buildings into a range of typical storey types (Maqsood et al., 2014; Maqsood et al., 2015a). Mitigation strategies developed nationally and internationally have been reviewed (Maqsood et al., 2015b). Five typical storey types have been selected which represent the most common residential buildings in Australia. A floodproofing matrix has been developed to assess appropriate strategies for the selected storey types. All appropriate strategies have been costed for the selected storey types through the engagement of quantity surveying specialists (Maqsood et al., 2016a; Maqsood et al., 2016b). In the following years of the project vulnerability of predominant storey types will be assessed. The information on vulnerability is fundamental to evaluate mitigation strategies and to examine the opportunities for reducing the vulnerability. The research will include cost benefit analysis to find optimal mitigation strategies for selected storey types located within a range of catchment types.

The mitigation strategies to reduce the vulnerability of residential buildings have been categorised into five categories: elevation, relocation, flood barriers, dry floodproofing and wet floodproofing.

Elevation is traditionally considered to be an easier and effective strategy and is the one which generally results in incentives such as a reduction in insurance premiums (Bartzis, 2013). However it is difficult to implement for some construction types such as concrete slab-on-grade structures.

Relocation is the surest way to eliminate flood risk by relocating outside the floodplain but, as in the case of elevation, it becomes more difficult to implement for heavier and larger structures.

Flood barriers considered in this project are those built around a single building and are normally placed some distance away from it to avoid any structural modifications to the building. There are two kinds of barriers: permanent (flood walls) and temporary (metal fences, box barriers, PVC tubes). Flood barriers are generally restricted to a height of 2m because of their stability issues, cost and visual concerns (USACE, 1993).

Dry floodproofing requires portion of a structure that is below the expected flood level to be substantially impermeable to floodwaters. Such an outcome is achieved by using sealant systems, waterproofing compounds and impervious sheeting (FEMA, 2012). Dry floodproofing is generally not recommended for flood depths exceeding one metre based on tests carried out by the US Army Corps of Engineers as the stability of the building becomes an issue over this threshold depth (USACE, 1988; Kreibich et al. 2005).

Wet floodproofing requires modification of a structure. It typically involves three elements: allowing floodwaters to enter and exit to equalise the hydrostatic pressure on the interior and exterior of the building to minimise structural damage, using flood damage-resistant materials, and elevating utility service and equipment (FEMA, 2008; Maqsood et al., 2015b). Wet floodproofing is suitable in low to moderate depths of water and can only reduce loss from floods but cannot eliminate loss as some amount of cleanup and cosmetic repair will always be necessary (USACE, 1984).

TEST PROGRAMME

To assess the suitability of the wet floodproofing technique and to ascertain the resilience of selected building components to floodwater a testing programme was developed as part of the BNHCRC flood project. Geoscience Australia as the lead researcher for the project selected the Cyclone Testing Station at James Cook University in Townville, Queensland, to conduct the experimental tests. These tests aimed to address knowledge gaps in the areas of strength and durability implications of selected components of a typical brick veneer slab-on-grade house due to immersion.

The experimental programme was developed in consultation with insurance industry loss assessors and was scoped in recognition of the available budget. The objective of the testing was to identify whether the selected components remain serviceable following inundation and subsequent drying or whether replacement was required.

The results of the tests will inform the selection of appropriate building materials for the wet floodproofing strategy for both existing and new construction as part of the BNHCRC flood project.

LITREATURE REVIEW

According to FEMA (2008) flood damage-resistant material is defined by the U.S. National Flood Insurance Program (NFIP) as any building product (material, component or system) capable of withstanding direct and prolonged contact with floodwaters without sustaining significant damage. A number of studies have been conducted in the past to assess the resilience of building materials and to assess the regulation and practices for achieving building flood resilience in a number of countries. A summary of selected studies is presented below.

ARMY CORPS OF ENGINEERS (U.S.)

USACE (1988) conducted tests to assess building materials and systems that could protect buildings from floodwater. It was determined that brick-veneer and concrete block walls could withstand floodwater up to a metre depth without damage. It was also observed that liquid coatings such as epoxy, polyurethane or asphalt were not dependable in keeping water from penetrating the walls (dry floodproofing).

OAK RIDGE NATIONAL LABORATORY & TUSKEGEE UNIVERSITY (U.S.)

Aglan et al. (2004) conducted tests on prototype structures to identify materials and methods that would make the envelope of a building resistant to flood damage. Their first prototype module replicated slab-on-grade structure with commonly used residential materials utilised according to standard construction practices in the U.S. The second prototype module replicated a low-set structure and had two vents in the concrete block foundation. Each module had a window, an exterior door, asphalt shingle roof and consisted of two rooms with an interior partition and interior grade door between the two rooms. The third series of tests were conducted along with a supplementary test of the slab-on-grade module only.

The results indicated that plywood and hardboard wall linings maintained reasonable dimensional stability and mechanical properties after they were dried, but remained discloured. Fiber reinforced gypsum sheathing maintained its integrity and mechanical properties. Moisture levels in timber studs that were above the flood level returned to pre-flood levels within the drying period. Ceramic wall and floor tiles performed well under flood conditions, required only cleaning to be restored and showed no long-term deterioration. Exterior wood paneled doors in wooden frames were stained slightly, but were able to be washed and restored. All interior doors that were tested were severely stained and some were warped, split, and peeled. The sealed concrete floor slab in all slab-on-grade modules remained undamaged during and after flooding.

Further tests conducted by Aglan et al. (2004) to assess the effectiveness of dry floodproofing techniques showed that dry floodproofing was not successful. While the door and window dams were effective in preventing the entry of water through doors and windows, water entered the units through other paths, such as the joint between the interior partition and the exterior walls at floor level.

FEDERAL EMERGENCY MANAGEMENT AGENCY (U.S.)

FEMA (1993) discussed the impacts of flood duration, flood-borne contaminants, flood frequencies, and depth on buildings. It also presented engineering considerations for the primary elements (foundations, walls, floors, openings, electrical and mechanical systems) of selected building types (cavity wall and solid wall construction).

FEMA (2008) classified building materials (both structural and finish) into five classes according to their ability to resist flood damage. The classification was based on information in the U.S. Army Corps of Engineers' Flood Proofing Regulations (1995), and was updated based on additional information from studies and reports conducted by FEMA. However, it did not evaluate the performance of building components made from a combination of several of these materials.

Class 1, 2 and 3 materials were considered unacceptable in flood-prone areas for a number of reasons. The reasons included materials containing water soluble adhesives, materials that deteriorate or lose structural integrity, floor or wall coverings that restrict the drying process of materials they cover, materials that become dimensionally unstable when subject to wetting and drying, and materials that absorb and retain a high moisture content after flooding. Examples of these materials include hardboard, plasterboard and Oriented Strand Board (OSB).

Class 4 and 5 materials were considered acceptable in flood-prone areas as these materials were resistant to floodwater damage and could survive wetting and drying and could be successfully cleaned after a flood. Examples of these materials include concrete, brick, steel, structural timber and marine grade plywood.

FEMA (2012) discussed the engineering principles and practices for retrofitting floodprone residential structures. It presented various retrofitting measures which also included wet floodproofing. Moreover, the document also discussed the regulatory framework, parameters of retrofitting, analysis of flood hazards and general design practices along with a few case studies.

FLOODPROBE PROJECT (EUROPE)

Escarameia (2012) identified knowledge gaps after conducting a review of existing building resilience guidance in the UK, Europe and the United States. The gaps identified were lack of regulation at European (or at national) level to choose adequate building materials to minimise the impact of floods, lack of approved testing protocols, limited testing on building materials and limited examples of application of flood-resistant materials either for new buildings or retrofits.

SCOPE OF EXPERIMENTAL PROGRAMME

The experimental programme was based on the learnings from the literature review and was aimed to address key gaps in knowledge on resilience to floodwater exposure. The experimental programme was developed in consultation with insurance industry loss assessors where two workshops were conducted to seek feedback from two leading insurance companies on the proposed programme. Furthermore, the Cyclone Testing Station also provided input in finalising the experimental programme which was scoped in recognition of the available budget.

The primary aim of the experimental programme was to assess the strength and durability implications of immersion of key structural elements and building components in conditions of slow water rise. The test programme only tested the strength implications (degradation) that resulted from the wetting and drying cycle associated with flooding and did not address health implications associated with flooding such as development of mould due to dampness. Flood depth was limited to 600mm above floor level, which applied a pressure that was within the strength capabilities of typical timber frame construction. The tests also studied the degradation associated with the wetting and drying cycles of selected building components. The experimental testing was undertaken at a full scale component level. This arrangement permitted an enhanced understanding of, not only how individual materials performed, but also how they performed when combined into a building system.

Three test types (building components) were selected, and a number of samples were prepared and tested for each test type to attempt to provide some understanding of the variation of resistance. The scope of the tests included:

- Constructing samples for the three selected building components,
- Testing the samples for strength evaluation in a dry state,
- Immersing the samples in silt / clay-laden water for a specified period of time,
- Testing some samples immediately after immersion,
- Drying the samples using natural ventilation, and
- Testing the samples following drying.

Moreover, a technical specialist (loss assessor) from Insurance Australia Group (IAG) was requested to inspect the specimens visually and to assess the repair work the samples might require if they were part of a full size house. The technical specialists submitted a report on the observations made during the tests (Van Gender, 2017).

The test results will help to ascertain where deterioration due to wetting and subsequent drying needs to be addressed as part of repair strategies within the future research of the BNHCRC flood project (Maqsood et al., 2017).

TEST TYPE 1 (FLOOR AND WALL TILES)

Test type 1 was designed to test the bond of ceramic floor and wall tiles to their substrate along with wet proofing treatments (see Figure 1). The goal of this test was to determine if full removal of tiles was required following inundation.

The test examined the bond of:

- Floor tiles bonded to a concrete substrate with ordinary tile adhesive,
- Floor tiles bonded to a concrete substrate with wet-area adhesive,
- Floor tiles bonded to a shower floor screed with a wet-area adhesive,
- Wall tiles bonded to fibrecement sheeting with wet-area adhesive,
- Wall tiles bonded to a waterproof membrane with wet-area adhesive.

The test will enabled the performance of pine door framing to be assessed with two finish variations (primed all round with top paint coats and unprimed with top paint coats).

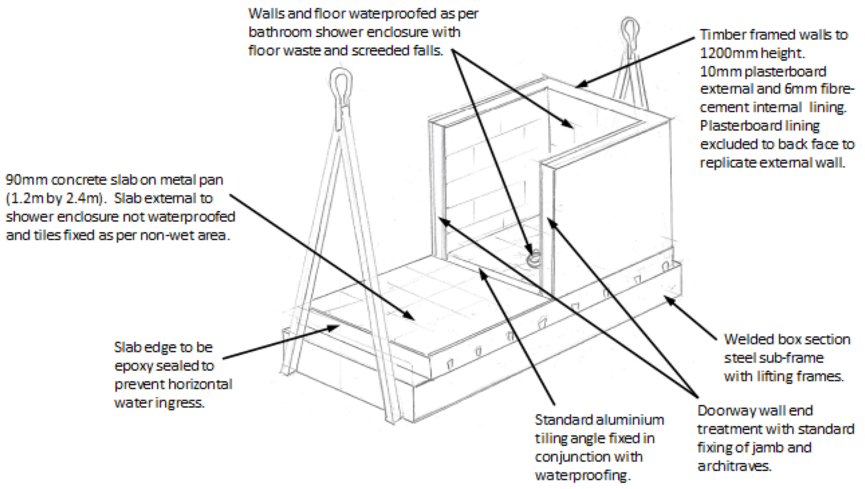


FIGURE 1: SCHEMATIC DIAGRAM OF TILED SURFACES WITHIN A TYPICAL BRICK VENEER, SLAB-ON-GROUND HOUSE

SCOPE OF WORK

The scope of work for this test is set out below.

- Construction of six samples and allowing at least 28 days for concrete to cure before tiling. Three samples were to have the enclosure finished as for a bathroom (Test Type 1A) and three samples were to have the enclosure finished as for a shower (Test Type 1B).
- Taking moisture readings at the top and bottom plates of the end wall for each sample prior to flooding.
- For the shower specimens, placing a temporary gate across the ends of the stud walls and flood the recess to a depth of 50mm. Visual checking for leaks and draining the recess.
- Immersing the samples for 4 days.
- Removing the samples from the immersion tank and transferring to a ventilated, sheltered drying space.
- Taking moisture readings at the top and bottom plates of the end wall for each sample immediately after removing the samples from the immersion tank.
- Inspection by an insurance loss assessor to visually assess the repair work the samples might require.
- After 4 days, removing the external plasterboard sheeting to facilitate drying.
- Air drying for a minimum of 6 weeks and to a timber framing moisture content of 20%.
- Taking moisture readings at the top and bottom plates of the end wall for each sample at frequent intervals during the drying period.
- From each sample, undertaking a tile pull-off test for 3 floor tiles from and 4 wall tiles.

TEST PROGRAMME

An overview of the test programme to evaluate the bond strength of wall and floor ceramic tiles to their substrate is provided in Table 1. Two types of samples were manufactured to perform this test. The first type simulated the general areas of a bathroom (refer to tests 1A_1 to 1A_3). The second type simulated the shower area of a bathroom (refers to tests 1B_1 to 1B_3). The tests 1A_1 and 1B_1 were not subjected to floodwater and were tested as control specimens.

TABLE 1: SUMMARY OF RESULTS OF STATIC PULL-OUT STRENGTH TESTING

Test	Simulation	Flood Exposure	Tiles Tested	Test Regime
1A_1	Bathroom	No	3 Floor Tiles 2 Wall Tiles on Back Wall 2 Wall Tiles on Side Wall	Hydraulic Pull-Out
1A_2		Yes		
1A_3		Yes		
1B_1	Shower	No		
1B_2		Yes		
1B_3		Yes		

Construction of Simulated Bathroom Samples (3 specimens)

Three simulated bathroom samples were manufactured. The samples comprised a concrete slab poured into a steel bed (Figure 2), on which three stud walls were built (Figure 3). Pine planks were used to simulate door jambs (Figure 4). The wall sides facing the inside of the samples were lined with fibrecement sheeting affixed with stud glue and nailed onto the studs at the joints. The wall sides facing the outside of the samples were lined with plasterboard using stud glue and no lining was used for the end wall (Figure 5). The plasterboard sheeting was primed and painted with two coats of anti-bacterial paint (Figure 6). The corners between walls and between walls and floor were then sealed and waterproofed (Figure 7 and Figure 8). Finally the floors and wall ceramic tiles were glued onto the floors and walls respectively (Figure 9, Figure 10, Figure 11 and Figure 12), grouted (Figure 15), and corner gaps were sealed with silicone (Figure 16 and Figure 17).

Construction of Simulated Shower Samples (3 specimens)

Three simulated shower samples were manufactured. The samples comprised a concrete slab poured into a steel bed, fitted with a PVC pipe to simulate the shower floor waste (Figure 18), on which three stud walls were built (Figure 19). Pine planks were used to simulate door jambs (Figure 20). The wall sides facing the inside of the samples were lined with fibrecement sheeting affixed with stud glue and nailed onto the studs at the joints. The wall sides facing the outside of the samples were lined with plasterboard using stud glue and no lining was used for the end wall (Figure 21). The plasterboard was primed and painted with two coats of anti-bacterial paint (Figure 22). The entrance of the shower enclosure was fitted with a screed angle (Figure 23 and Figure 24). The corners between walls and between walls and floor were sealed and the whole shower enclosure was waterproofed (Figure 25 and Figure 26). The shower enclosure was filled with a cement screed to create falls to the floor waste (Figure 27 and Figure 28). Finally the floors and wall ceramic tiles were glued onto the floors and walls, respectively, (Figure 29, Figure 30, Figure 31 and Figure 32), grouted (Figure 35), and corner gaps were sealed with silicone (Figure 36 and Figure 37).

FIGURE 2: STEEL BED FOR CONCRETE SLAB

FIGURE 3: TWO LATERAL AND ONE END STUD WALLS

FIGURE 4: PINE PLANKS USED TO SIMULATE DOOR JAMBS

FIGURE 5: STUD WALLS LINED AND DOOR JAMBS INSTALLED

FIGURE 6: PAINTING OF PLASTER BOARD

FIGURE 7: FILLING OF WALLS AND WALLS AND FLOOR CORNERS

FIGURE 8: WATERPROOFING OF CORNERS BETWEEN WALLS AND WALLS AND FLOOR

FIGURE 9: FLOOR TILING

FIGURE 10: WALL TILING

FIGURE 11: WALL TILING

FIGURE 12: WALL TILING

FIGURE 13: SAMPLES TILED

FIGURE 14: GAP BETWEEN TILES AT WALLS CORNERS

FIGURE 15: TILES GROUTING

FIGURE 16: GAPS FILLED WITH SILICONE

FIGURE 17: GAPS FILLED WITH SILICONE

FIGURE 18: STEEL BED FOR CONCRETE SLAB WITH PVC PIPE

FIGURE 19: TWO LATERAL AND ONE END STUD WALLS

FIGURE 20: PINE PLANKS USED TO SIMULATE DOOR JAMBS

FIGURE 21: STUD WALLS LINED AND DOOR JAMBS INSTALLED

FIGURE 22: PAINTING OF PLASTER BOARD

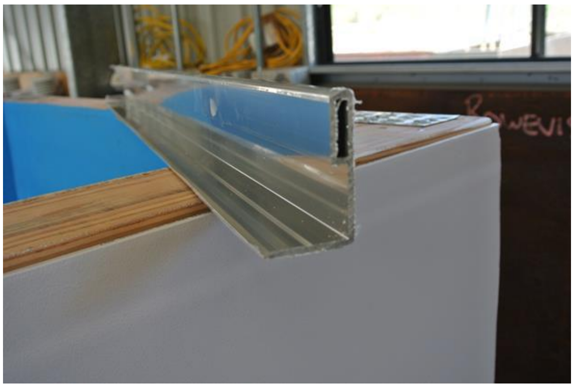


FIGURE 23: SHOWER SEAL

FIGURE 24: SHOWER SEAL FITTED TO ENTRANCE OR ENCLOSURE

FIGURE 25: FILLING OF CORNERS BETWEEN WALLS AND FLOOR

FIGURE 26: WATERPROOFING OF SHOWER ENCLOSURE

FIGURE 27: RECESSING OF SHOWER ENCLOSURE

FIGURE 28: SHOWER ENCLOSURE RECESSED

FIGURE 29: FLOOR TILING

FIGURE 30: FLOOR TILING

FIGURE 31: FLOOR TILING

FIGURE 32: WALL TILING

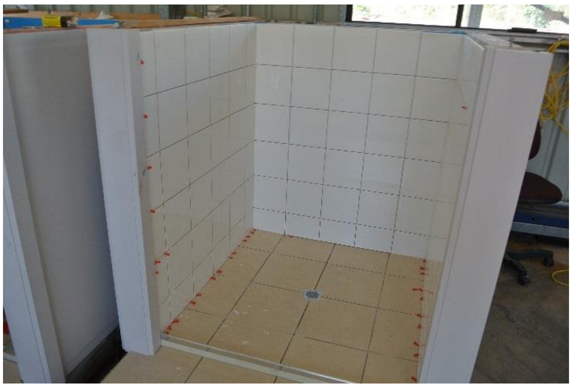


FIGURE 33: SAMPLES TILED

FIGURE 34: GAP BETWEEN TILES AT WALLS CORNERS

FIGURE 35: TILES GROUTING

FIGURE 36: GAPS FILLED WITH SILICONE

FIGURE 37: GAPS FILLED WITH SILICONE

Flooding of Samples

Two bathroom and two shower simulated samples were placed in a water tank and the water level was raised to 600 mm above the floor tiles for four days. Figure 38 shows two samples in the tank with water. Subsequently the water was drained out, the samples were removed from the tank and were placed in a ventilated sheltered drying area for a duration of six weeks.

Moisture readings were taken at the top and bottom plates of the end wall for each sample, prior to flooding, immediately after, and at frequent intervals during the drying period (see Table A1 to Table A4 in Appendix A).

FIGURE 38: TWO SAMPLES IN THE WATER TANK DURING THE FLOOD SIMULATION

Preparation of Samples for Tile Pull-Out Testing

For each sample a total of seven tile pull-out tests were performed, three on floor tiles and four on wall tiles (two on the end wall and two on the left side wall). Steel RHS sections were bonded to the surface of the tiles to be tested in order to provide an anchoring point to perform the testing. The same method was used for both wall and floor tiles, but using two different RHS sizes to accommodate the difference in size between wall and floor tiles. Figure 39 shows the locations of the seven RHS attachment points (F1, F2, F3, B1, B2, S1 and S2) bonded to the tiles of one sample. These locations were kept consistent across all samples.

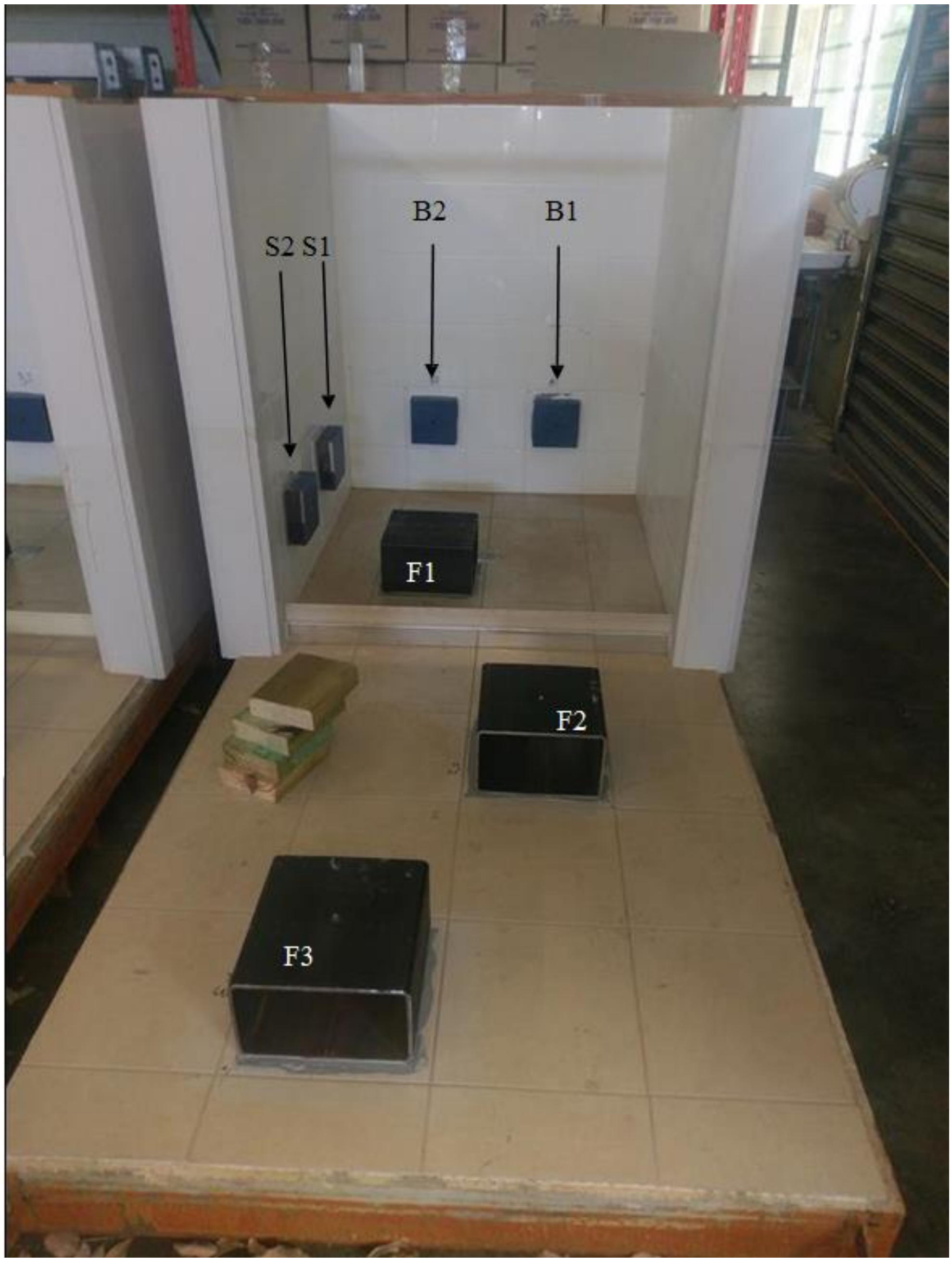


FIGURE 39: LOCATION OF TILES TO BE TESTED AND RHS ANCHORING POINTS BONDED ON TILES

APPARATUS AND PROCEDURE FOR TILE PULL-OUT TESTING

Floor Tile Hydraulic Test Set Up

To perform the floor tiles pull-out testing, the anchoring point was linked with a steel rod to a hydraulic ram mounted onto a steel frame. A load cell was placed directly in line between the hydraulic ram and the tested tile to record the pull-out force. The test samples were anchored down to the structural floor of the laboratory to ensure no lifting up of the sample could occur. Figure 40 shows the set-up for the floor tile test.

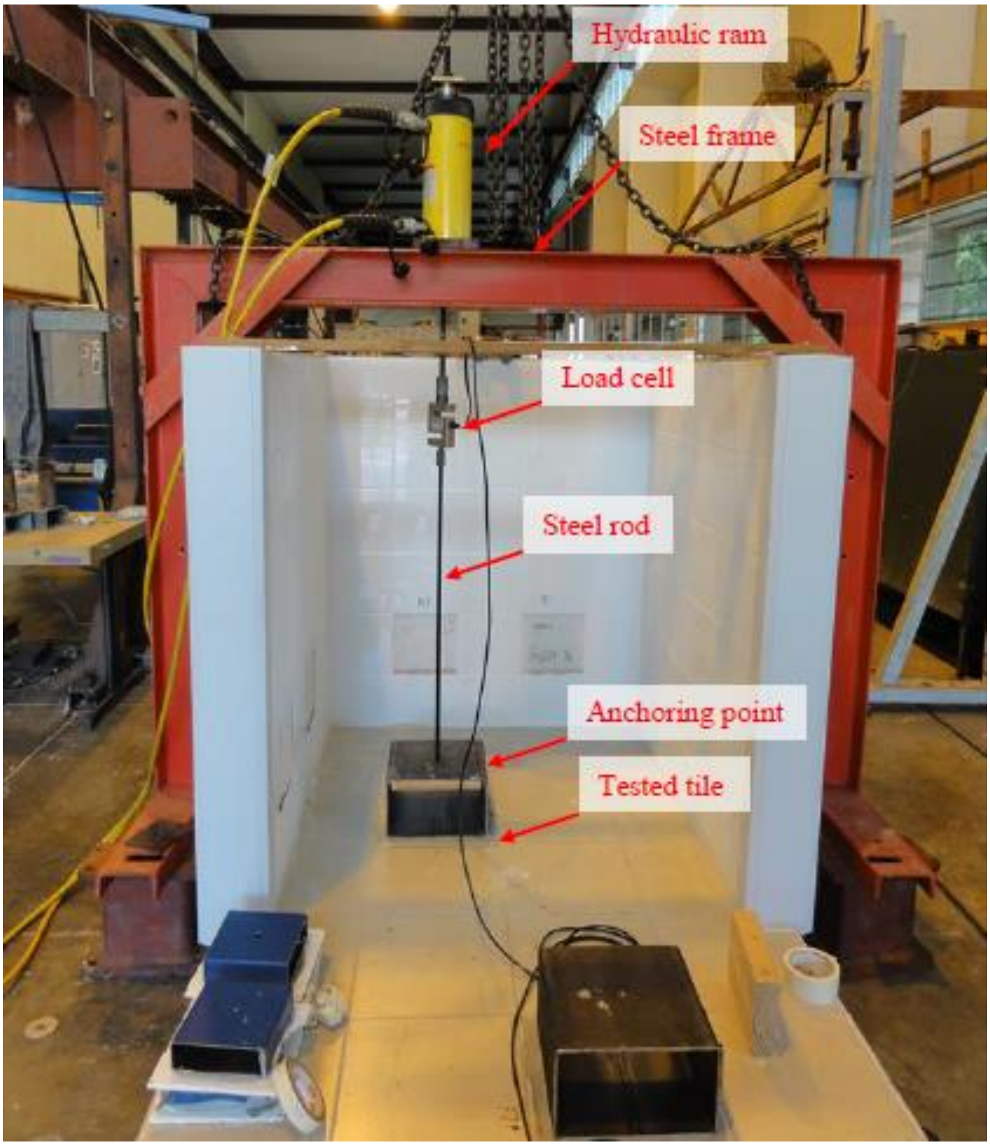


FIGURE 40: FLOOR TILE HYDRAULIC TEST SET-UP

Wall Tile Hydraulic Test Set Up

To perform the wall tiles pull-out testing, the anchoring point was linked to a hydraulic ram mounted onto a steel frame. The steel frame was custom built to spread the reaction of the pull-out force on the wall around the tested tile. A load cell was placed directly in line between the hydraulic ram and the tested tile to record the pull-out force. Figure 41 shows the set-up for the wall tile test.

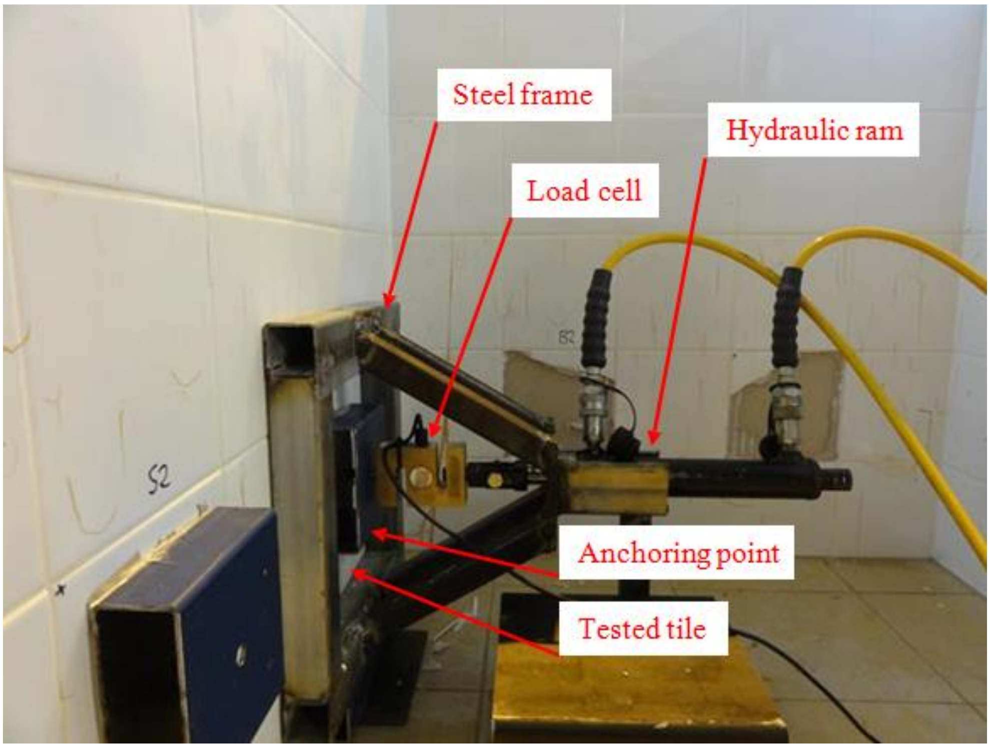


FIGURE 41: WALL TILE HYDRAULIC TEST SET UP

Test Procedure for Tile Pull-Out Testing

For both floor and wall tile pull-out testing the load was applied to the tested tile through the hydraulic ram by the laboratory technician actuating a manual hydraulic pump. The load was slowly increased until failure and the peak load was recorded for each test.

RESULTS

Floor Tile Test Results

A summary of the recorded static pull-out strength of the floor tiles is provided in Table 2. The failure load and the failure mechanism for each test were also recorded. Figure A3 in Appendix A provides the photographs of floor tile samples after completion of tests.

TABLE 2: STATIC PULL-OUT STRENGTH OF FLOOR TILES

Test	Simulation	Flooded	Date Tested	Tile Location	Floor Tile Failure Load (kN)	Comment on Failure Mechanism
1A_1	Bathroom	No	13/03/2017	F1	9.71	Tile released from adhesive.
				F2	8.39	Tile released from adhesive.
				F3	9.72	Tile released from adhesive.
1A_2	Bathroom	Yes	13/03/2017	F1	12.16	Most adhesive came off tile.
				F2	11.42	Most adhesive came off tile, broke tiles around it.
				F3	10.37	25% of tile broke off, glue failed on rest of platen.
1A_3	Bathroom	Yes	14/03/2017	F1	11.72	Most of adhesive stayed on floor.
				F2	13.74	Most of adhesive stayed on floor.
				F3	9.61	Most of adhesive stayed on floor.
1B_1	Shower	No	14/03/2017	F1	8.53	Adhesive broke, adhesive left on tile and floor.
				F2	8.99	Adhesive broke, adhesive left on tile and floor.
				F3	9.23	Adhesive broke, adhesive left on tile and floor.
1B_2	Shower	Yes	15/03/2017	F1	9.35	Tile separated from adhesive, broke tiles around it.
				F2	8.35	Adhesive failed, half left on tile and half left on floor.
				F3	9.17	Adhesive failed, half left on tile and half left on floor.
1B_3	Shower	Yes	15/03/2017	F1	9.56	Tile pulled away from adhesive.
				F2	10.24	Adhesive failed, half left on tile and half left on floor.
				F3	9.36	Adhesive failed, half left on tile and half left on floor.

Wall Tile Test Results

A summary of the recorded static pull-out strength of the wall tiles is provided in Table 3. The failure load and the failure mechanism for each test were also recorded. Figure A4 in Appendix A provides the photographs of wall tile samples after completion of tests.

TABLE 3: STATIC PULL-OUT STRENGTH OF WALL TILES

Test	Simulation	Flooded	Date Tested	Tile Location	Wall Tile Failure Load (kN)	Comment on Failure Mechanism
1A_1	Bathroom	No	13/03/2017	B1	2.94	Tile pulled off from wall. Adhesive left on wall and tile.
				B2	3.10	Tile pulled off from wall. Adhesive left on wall and tile.
				S1	2.89	Tile pulled off from wall. Adhesive left on wall and tile.
				S2	2.35	Tile pulled off from wall. Adhesive left on wall and tile.
1A_2		Yes	13/03/2017	B1	3.09	Fibre cement sheet delaminated under most of tile.
				B2	3.79	Fibre cement sheet delaminated under most of tile.
				S1	3.52	Half tile face delaminated & half adhesive broke.
				S2	4.22	Face of tile delaminated from rest of tile.
1A_3			14/03/2017	B1	3.78	Fibrecement sheet delaminated over most of tile area.
				B2	3.34	Fibrecement sheet delaminated over most of tile area.
				S1	4.48	Front skin of tile delaminated from tile.
				S2	2.94	Front skin of tile delaminated from tile.
1B_1	Shower	No	14/03/2017	B1	2.49	Tile pulled cement sheet apart & away from wall frame.
				B2	3.47	Tile broke, pulled away from wall.
				S1	4.38	Tile broke, pulled away from wall.
				S2	3.94	Tile broke, pulled away from wall.
1B_2		Yes	15/03/2017	B1	3.08	Tile broke, some adhesive remained on wall and on tile.
				B2	3.32	Tile broke, some adhesive remained on wall and on tile.
				S1	3.25	Tile broke, most adhesive remained on tile.
				S2	2.95	Tile broke, most adhesive remained on tile*.
1B_3			15/03/2017	B1	4.23	Tile broke, most adhesive remained on tile.
				B2	3.66	Tile broke, most adhesive remained on tile.
				S1	3.63	Tile broke, most adhesive remained on tile.
				S2	3.26	Wet seal pulled off of fibre cement sheet.

* Initial failure appears at water seal.

SUMMARY

This test examined the bond strength of floor and wall tiles following inundation with the objective of determining the necessity or otherwise of removing and replacing all tiles following inundation.

Six specimens were constructed. Three of them simulated a bathroom assembly while the other three simulated a shower assembly. For each simulation two specimens were subjected to floodwater while one remained dry in its original condition as a control sample.

Visual inspection of the specimens by an insurance loss assessor indicated that the depth of water the specimens had been submersed in was evident with discolouration of the tiles and sheet lining. No evidence of delamination of the adhesive of tiles causing lifting or popping was observed (Van Gender, 2017). Therefore, replacement of tiles after flooding was not considered to be necessary by this research.

Furthermore, the trims and jambs displayed little distortion. The timber frame appeared to have not moved or distorted from its original constructed state, with no further evidence of movement or cracking to the linings or paint. The discolouration and residue remaining on the tiled surfaces was removable, however, the grout required cleaning and further inspection to confirm the extent of damage (Van Gender, 2017).

Results in the testing conditions stated earlier indicated that flooding did not have any adverse impact on the bond strength of the ceramic floor and wall tiles to their substrate as shown in Table 4.

TABLE 4: SUMMARY OF RESULTS OF BOND STRENGTH TESTING

Test	Simulation	Flooded	Comment	Average Floor Tile Failure Load (kN)	Average Wall Tile Failure Load (kN)
1A_1	Bathroom	No	Control Specimens	9.27	2.82
1A_2		Yes	Tested after drying	12.44	3.66
1A_3			Tested after drying	11.69	3.64
1B_1	Shower	No	Control Specimens	8.92	3.57
1B_2		Yes	Tested after drying	8.96	3.15
1B_3			Tested after drying	9.72	3.70

TEST TYPE 2 (OSB AND HDF WALL SHEET BRACING)

Test type 2 was designed to test the structural adequacy of structural wall sheet bracing following inundation and subsequent drying (see Figure 42). Two types of wall sheet bracing (OSB and HDF) were tested for racking strength.

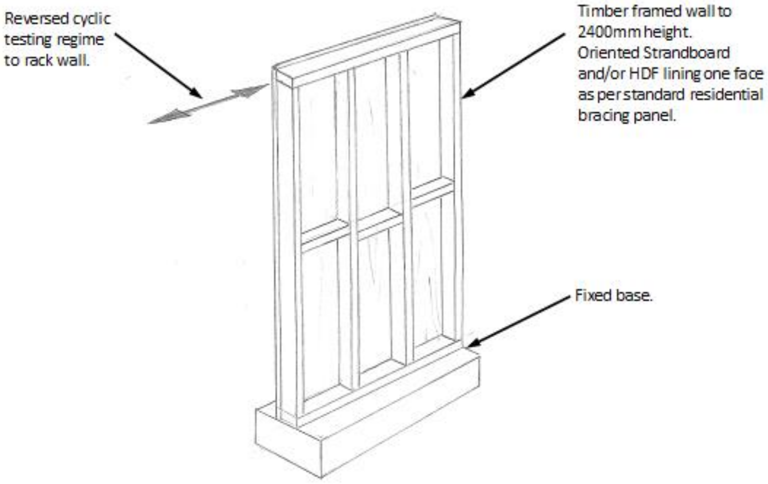


FIGURE 42: SCHEMATIC DIAGRAM OF MANUFACTURED SHEET WALL BRACING

SCOPE OF WORK

The scope of work for this test is set out below.

- Construction of 20 samples, 10 with OSB sheet bracing and 10 with HDF sheet bracing. Attachments to suit subsequent load cells and hold-down to be provided.
- Taking moisture readings on a stud at nominally 300 mm and 900 mm above the bottom plate prior to flooding.
- Testing 5 specimens of each bracing type for racking strength.
- Immersing the remaining 10 samples for 4 days.
- Removing the samples from the immersion tank and transferring to ventilated, sheltered drying space.
- Taking moisture readings on a stud at nominally 300 mm and 900 mm above the bottom plate immediately after removing the samples from the immersion tank.
- Air drying for a minimum of 6 weeks and to a maximum moisture content of 20%.
- Taking moisture readings on a stud at nominally 300 mm and 900 mm above the bottom plate at frequent intervals during the drying period.
- Testing 5 samples of each bracing type for racking strength.

TEST PROGRAMME

A test programme to evaluate the racking strength of two types of wall sheet bracing was conducted. This test was designed to assess the structural adequacy of structural wall sheet bracing following inundation and subsequent drying. The selected bracing materials were the OSB and HDF. Ten specimens were constructed for each bracing material. Five of them were tested in a dry condition without being flooded as control specimens and the other five were tested after a wetting and drying cycle. A summary of the test programme is provided in Table 5.

TABLE 5: SUMMARY OF RESULTS OF STATIC PULL-OUT STRENGTH TESTING

Test	Sheet Bracing Type	Flood Expsure	Test Regime
2A_1	OSB	Yes	TR440 Racking Pull Push Pull
2A_2			
2A_3			
2A_4			
2A_5			
2A_6		No	
2A_7			
2A_8			
2A_9			
2A_10			
2B_1	HDF	Yes	
2B_2			
2B_3			
2B_4			
2B_5			
2B_6		No	
2B_7			
2B_8			
2B_9			
2B_10			

Construction of Samples (20 specimens)

Two types of timber wall samples were manufactured to perform this test programme, the first type of wall frame was braced with OSB sheeting and the second type with HDF sheeting. The samples were comprised of MGP10 timber frames nominally 1,800 mm wide and 2,400 mm high with studs at approximately 450 mm centres. Either OSB or HDF wall sheet bracing was fixed to the frames using 2.5mm diameter by 32mm length electro galvanized head nails in accordance with the manufacturer's specifications. For the OSB samples the sheeting was fixed to the timber frame at the following spacings: to the top and bottom plates at nominally 80mm centres, to the other edge of sheet at nominally 150mm centers, to the internal studs at 300mm centres and at the vertical butt join at 80 mm centres (see Figure 43).

FIGURE 43: CONSTRUCTED OSB SAMPLE

For the HDF samples the sheeting was fixed to the frame at 100 mm centres in all locations as per the manufacturer's specifications. All nails were positioned at a minimum edge distance of 12mm. Figure 44 shows a constructed HDF sample.

Note that since the wall samples were wet in the vertical position and dried in the vertical position the 24mm CFC strip as noted on the specification sketch (Appendix B) was not installed.

FIGURE 44: CONSTRUCTED HDF SAMPLE

Flooding of Samples

Five OSB samples and five HDF samples were used as a control comparison and remained dry for the entirety of the testing programme. Moisture content was measured and ranged between 7.6% and 12.6% with an average of 10.3% for the OSB samples and the HDF samples ranged between 7.9% and 12.1% with an average of 9.8%.

Five OSB samples and five HDF samples were placed in an immersion tank and the water level was raised to 600 mm above the bottom plate of the samples. Each sample remained partially submerged for nominally four days. Subsequently the tank was drained and the samples were removed from the tank and were placed in a ventilated sheltered drying area for a duration of six weeks.

Moisture readings were taken on a stud at nominally 300 mm and 900 mm above the bottom plate, prior to flooding, immediately after, and at frequent intervals during the drying period. Moisture readings are provided in Table B1 to Table B4 in Appendix B.

Figure 45 shows the samples in the immersion tank filled with water.

FIGURE 45: SAMPLES AFTER PULL-OUT TESTS ON FLOOR TILES

APPARATUS AND PROCEDURE FOR RACKING TESTING

Racking Test Set Up

The test wall samples were installed in the racking test rig. Threaded rods were used to anchor the bottom plate of the wall down to a steel rail which was fixed to the concrete test floor of the laboratory. Two steel squares were used to further restrain the bottom plate from sliding on the rail. The hydraulic ram was mounted onto a steel post attached to the concrete structural floor and was linked to the top right corner of the walls to perform the tests.

A load cell was placed between the hydraulic ram and the wall connection and the load was recorded for the duration of the tests. Two horizontal gauges (labelled D1 and D2) and two vertical gauges (labelled D3 and D4) were installed to record the displacements of the samples. Figure 46 shows the test setup in the racking test rig.

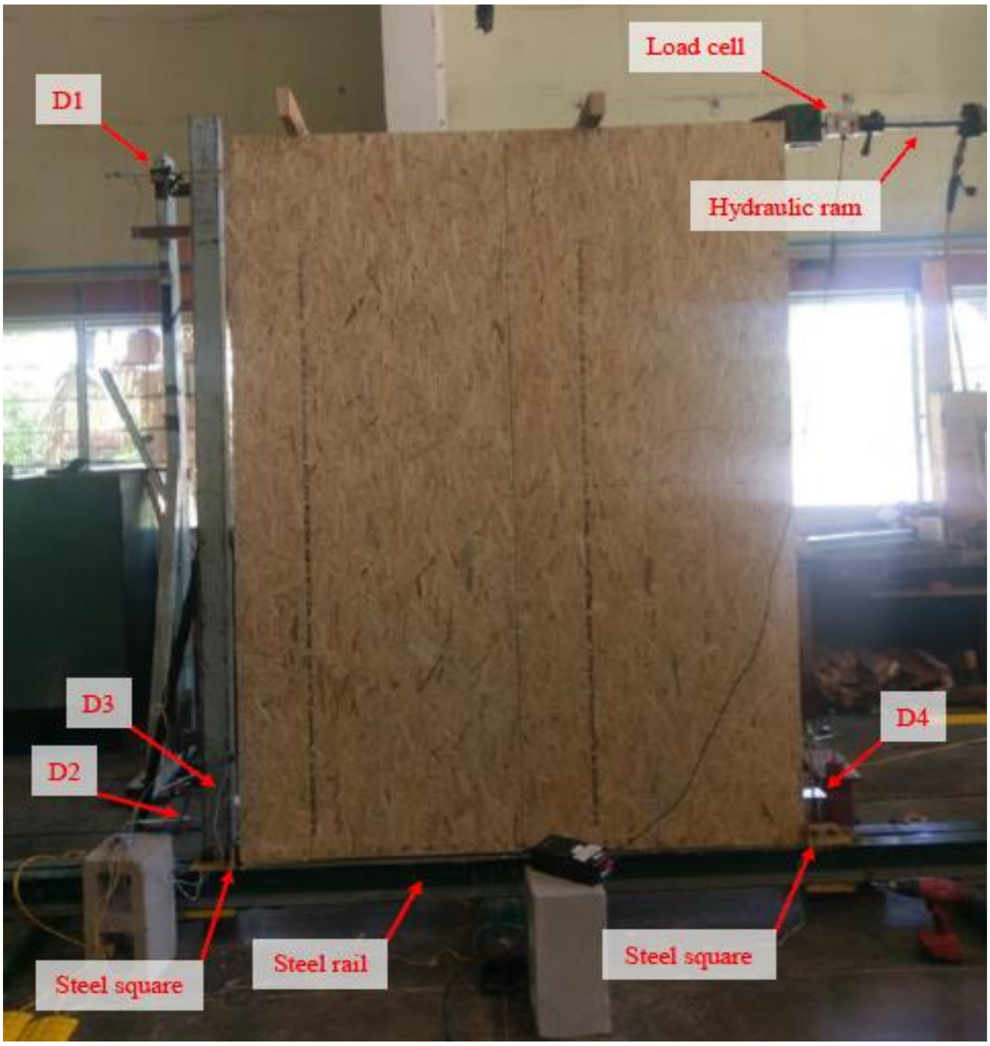


FIGURE 46: AFTER PULL-OUT TESTS ON FLOOR TILES

To ensure the wall remained in a vertical position at all times, two timber rafters were fixed to the top plate and attached to a supporting frame, which was fixed to the concrete structural floor. The timber rafters were free to rotate at their attachment points with the supporting frame to minimise their effects on the test results. Figure 47 shows the location of the timber rafters.

FIGURE 47: AFTER PULL-OUT TESTS ON FLOOR TILES

Test Procedure for Racking Testing

The racking tests were conducted in three steps in accordance with testing standard TR440 i.e. ‘pull’, ‘push’, ‘pull’. For all three steps, the load was applied to the wall sample through the hydraulic ram by the testing supervisor actuating a manual hydraulic pump.

For the first pull and the push tests the loads applied were within the serviceability limits of the samples. For the last pull test, the load was slowly increased until failure of the test specimen.

Failure was defined for this test programme as the maximum load able to be resisted by the wall.

For this test programme the largest deflection (D_1) was used as a comparison, however, to determine classical racking displacement (D_R) from the rigid body overturning component, the following formula is used:

$D_R = D_1 - D_2 - (D_3 + D_4) * (H/L)$

Where D_1 to D_4 are the measured displacements at the locations 1 to 4, H is the height of D_1 and L is the length between D_3 and D_4.

RESULTS

Control Specimens (Dry-Dry)

A summary of the recorded racking strength test results for the control specimens (i.e. specimens that remained dry (Dry-Dry)) is provided in Table 6. The failure load and the failure mechanism for each test were also recorded. Load versus displacement graphs are provided in Appendix B.

TABLE 6: RACKING STRENGTH TESTING RESULTS OF CONTROL SPECIMENS (DRY-DRY)

Test	Date Tested	Bracing Sheet	Failure Load (kN)	Comment on Failure Mechanism
2A_6	19/01/2017	OSB	6.54	Nail Failure: Slippage between adjacent sheets observed. Nails on lower edge of sheeting withdrawal from bottom plate. Studs withdrawal from bottom plate. Loss of load carrying capacity
2A_7	19/01/2017		4.94	Bottom Plate Failure: Slippage between adjacent sheets observed. Bottom plate cracked. Studs withdrawal from bottom plate. Loss of load carrying capacity
2A_8	19/01/2017		4.21	Bottom Plate and Sheeting Failure: Slippage between adjacent sheets observed. Bottom Plate cracked. Sheeting pulled over nails in lower edge of sheeting. Studs withdrawal from bottom plate. Loss of load carrying capacity
2A_9	20/01/2017		5.54	Nail Failure: Slippage between adjacent sheets observed. Nails on lower edge of sheeting withdrawal from bottom plate. Studs withdrawal from bottom plate. Loss of load carrying capacity
2A_10	20/01/2017		5.53	Nail and Sheeting Failure: Slippage between adjacent sheets observed. Nails on lower edge of sheeting withdrawal from bottom plate and torn sheeting. Studs withdrawal from bottom plate. Loss of load carrying capacity
2B_6	01/01/2017	HDF	8.57	Nail Failure: Slippage between adjacent sheets observed. Nails on lower edge of sheeting withdrawal from bottom plate. Studs withdrawal from bottom plate. Loss of load carrying capacity
2B_7	09/01/2017		6.14	Nail and Sheeting Failure: Slippage between adjacent sheets observed. Nails on lower edge of sheeting withdrawal from bottom plate and sheeting pulled over some nails. Studs withdrawal from bottom plate. Loss of load carrying capacity
2B_8	10/01/2017		6.96	Nail and Sheeting Failure: Slippage between adjacent sheets observed. Nails on lower edge of sheeting withdrawal from bottom plate and torn sheeting. Studs withdrawal from bottom plate. Loss of load carrying capacity
2B_9	10/01/2017		6.29	Nail Failure: Slippage between adjacent sheets observed. Nails on lower edge of sheeting withdrawal from bottom plate. Studs withdrawal from bottom plate. Loss of load carrying capacity
2B_10	10/01/2017		5.91	Nail Failure: Slippage between adjacent sheets observed. Nails on lower edge of sheeting withdrawal from bottom plate. Studs withdrawal from bottom plate and bottom plate cracked. Loss of load carrying capacity

Flooded Specimens (Wet-Dry)

A summary of the recorded racking strength test results for flooded specimens (i.e. specimens that were immersed in 600 mm of water and dried (Wet-Dry)) is provided in Table 7. The failure load and the failure mechanism for each test were also recorded. Load versus displacement graphs are provided in Appendix C.

TABLE 7: RACKING STRENGTH TESTING RESULTS OF FLOODED SPECIMENS (WET-DRY)

Test	Date Tested	Bracing Sheet	Failure Load (kN)	Comment on Failure Mechanism
2A_1	25/01/2017	OSB	5.75	Sheeting Failure: Slippage between adjacent sheets observed. Sheeting torn at nails in lower edge of sheeting. Studs withdrawal from bottom plate. Loss of load carrying capacity
2A_2	25/01/2017		5.76	Sheeting Failure: Slippage between adjacent sheets observed. Sheeting pulled over nails in lower edge of sheeting. Studs withdrawal from bottom plate. Loss of load carrying capacity
2A_3	24/01/2017		5.47	Nail Failure: Slippage between adjacent sheets observed. Nails on lower edge of sheeting withdrawal from bottom plate. Studs withdrawal from bottom plate. Loss of load carrying capacity
2A_4	24/01/2017		4.98	Sheeting Failure: Slippage between adjacent sheets observed. Sheeting pulled over nails in lower edge of sheeting. Studs withdrawal from bottom plate. Loss of load carrying capacity
2A_5	23/01/2017		5.40	Sheeting Failure: Slippage between adjacent sheets observed. Sheeting pulled over nails in lower edge of sheeting. Studs withdrawal from bottom plate. Loss of load carrying capacity
2B_1	01/01/2017	HDF	5.98	Nail Failure: Slippage between adjacent sheets observed. Nails on lower edge of sheeting withdrawal from bottom plate. Studs withdrawal from bottom plate. Loss of load carrying capacity
2B_2	09/01/2017		5.00	Nail and Sheeting Failure: Slippage between adjacent sheets observed. Nails on lower edge of sheeting withdrawal from bottom plate. Sheeting started to pull over nails. Studs withdrawal from bottom plate. Loss of load carrying capacity
2B_3	10/01/2017		5.64	Nail and Sheeting Failure: Slippage between adjacent sheets observed. Nails on lower edge of sheeting withdrawal from bottom plate. Sheeting started to pull over nails. Studs withdrawal from bottom plate. Loss of load carrying capacity
2B_4	10/01/2017		6.01	Sheeting Failure: Slippage between adjacent sheets observed. Sheeting pulled over nails in lower edge of sheeting. Studs withdrawal from bottom plate. Loss of load carrying capacity
2B_5	10/01/2017		5.35	Nail Failure: Slippage between adjacent sheets observed. Nails on lower edge of sheeting withdrawal from bottom plate. Studs withdrawal from bottom plate. Loss of load carrying capacity

SUMMARY

This test examined the strength of engineered timber structural sheet wall bracing. This test was designed to assess the structural adequacy of wall sheet bracing following inundation and subsequent drying. Two types of wall sheet bracing were tested for racking strength i.e. OSB and HDF.

Ten specimens were constructed for each bracing material. Five of them were tested in dry conditions without being flooded as control specimens and the other five were tested after wetting and drying cycle.

Failure modes observed were;

- Bracing failure: where the bracing sheeting had pulled over the nails in the lower edge of the sheeting or torn the sheeting at the nails,
- Nail failure: where nails withdrew from the bottom plate, and
- Nail and sheeting failure: where the nails withdrew from the bottom plate and the sheeting was torn at some nails.

In all cases slippage between adjacent sheets and stud withdrawal from the bottom plate was observed.

Appendix B provides comparative plots of top plate displacement of the test wall specimens. It could be seen that for the OSB wall samples there was minimal difference of performance between the Dry-Dry and Wet-Dry cases. For the HDF wall samples, a slight decrease in overall performance was observed for the re-dried wall bracing. However, more test samples would be required to determine if there was a statistically significant reduction in strength.

OSB Samples

There was an increase in the number of specimens that had a sheeting failure in the samples that had been exposed to flooding compared to those not flooded. However, the average failure load of Dry-Dry samples and Wet-Dry samples was nominally unchanged (5.35 kN and 5.47 kN) as shown in Table 8.

The load versus displacement graphs remained similar between flooded and non-flooded samples resulting in similar stiffness characteristics (see Appendix B).

Given no significant variation in maximum load and stiffness between Dry-Dry and Wet-Dry samples it was reasonable to deduce that the bracing capacity of OSB samples was not significantly affected by the 600 mm of simulated flooding.

HDF Samples

The average failure load of Wet-Dry samples and Dry-Dry samples was decreased by nominally 10% (6.23 kN to 5.6 kN) as shown in Table 8. Further, an increase in sheeting type failure mode was observed in the Wet-Dry samples.

There was no significant variation in stiffness of the HDF samples that were exposed to the flooding to those that were not exposed to the flooding.

Given there was a decrease in maximum load carrying capacity between Dry-Dry and Wet-Dry samples it was reasonable to deduce that the bracing capacity of HDF samples was affected by the 600 mm of simulated flooding.

TABLE 8: RESULTS OF RACKING STRENGTH TESTS

Test	Sheet	Flooded	Comment	Average Failure Load (kN)
A1 - A5	OSB	Yes	Tested after drying	5.47
A6 - A10	OSB	No	Control specimen	5.35
B1 - B5	HDF	Yes	Tested after drying	5.60
B6 - B10	HDF	No	Control specimen	6.23

The results of the load carrying capacity of HDF bracing sheets in this study were in line with the observation made by HNFMSC (2006) although the later recorded a strength reduction of about 30%. Similar failure mechanism of sheet bracing which was associated to failure around the nail fixing was also recorded by HNFMSC (2006).

Therefore, the loss of bracing capacity of HDF sheets indicated that additional bracing should be incorporated in the design of new construction to account for the loss of its effectiveness when saturated. However, the 10% loss of capacity is not considered to be severe enough to warrant retrofit existing structures unless substantial renovations are being carried out.

TEST TYPE 3 (TIMBER JOISTS)

Test type 3 was designed to assess the structural adequacy of manufactured timber I section joists following inundation and subsequent drying. Two types of joist were tested (H2 treated and untreated). Strength was tested at three stages: dry before immersion, wet immediately after immersion and dry after drying following immersion.

SCOPE OF WORK

The scope of work for this test is set out below.

- Construction of 48 samples, 24 with H2 treatment and 24 without.
- Taking moisture readings on the top flange of each sample prior to flooding.
- Testing 8 samples of each type for bending and shear strength using two point loads at the 1/3 and 2/3 span locations.
- Immersing 16 specimens of each type for 4 days.
- Removing the samples from the immersion tank and transferring to a ventilated, sheltered drying space.
- Taking moisture readings on the top flange of each sample immediately after removing the samples from the immersion tank.
- Testing 8 samples of each type immediately after removal from immersion for bending and shear strength using two point loads at the 1/3 and 2/3 span locations.
- Air drying for a minimum of 6 weeks and to a maximum moisture content of 20%.
- Taking moisture readings on the top flange of each sample at frequent intervals during the drying period.
- Testing 8 samples from each type for bending and shear strength using two point loads at the 1/3 and 2/3 span locations.

TEST PROGRAMME

A programme of four point bend strength testing was conducted on manufactured timber ‘I’ section joists with OSB webs (see Figure 48).

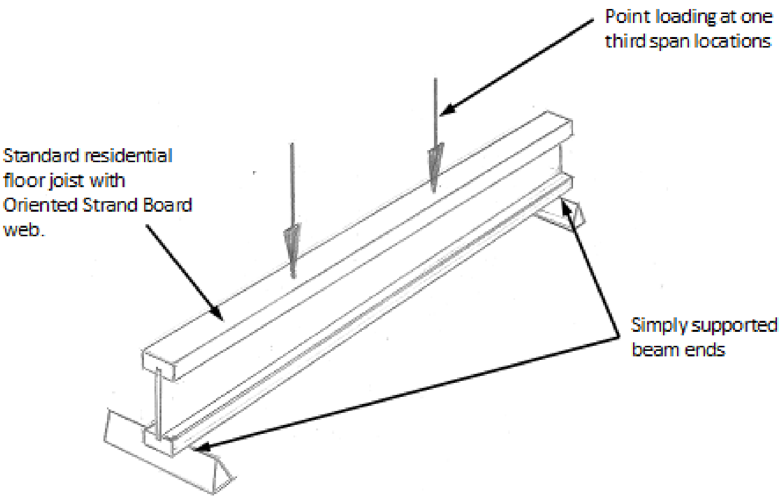


FIGURE 48: SCHEMATIC DIAGRAM OF ENGINEERED TIMBER JOISTS

A summary of the test programme is provided in Table 9. Twenty four H2 treated and twenty four untreated specimens were tested. For each treated and untreated type, 8 of them were tested in dry conditions without being flooded as control specimens, 8 were tested wet immediately after immersion and the last 8 were tested after a wetting and drying cycle. A summary of the test programme is provided in Table 9.

TABLE 9: SUMMARY OF RESULTS OF FOUR POINT BENDING STRENGTH OF MANUFACTURED TIMBER ‘I’ SECTION JOISTS WITH OSB WEBS

Test	Treatment	Flooded	Comment	Test Regime
3A_1 - 3A_8	H2	Yes	Tested after drying (Wet-Dry)	Four point bending test
3A_9 - 3A_16		No	Control specimen (Dry-Dry)	
3A_17 - 3A_24		Yes	Tested wet (Wet-Wet)	
3B_1 - 3B_8	Nil	Yes	Tested after drying (Wet-Dry)	
3B_9 - 3B_16		No	Control specimen (Dry-Dry)	
3B_17 - 3B_24		Yes	Tested wet (Wet-Wet)	

Sample Description (24 specimens)

Two types of HJ20045 samples were used in this test programme, the first type had treatment specified as H2 and the second type remained untreated. Note that the treatment process was completed prior to shipment of the samples for testing. The samples had an 'I' shape and were made with a top and bottom flange joined by the vertical web. Each sample was nominally 3,000 mm long and 200 mm high with each flange measuring approximately 45 mm wide.

The samples were prepared by drilling a 100 mm diameter hole into the web at a location approximately 1,350 mm from one end and a 40 mm diameter hole into the web at a location approximately 100 mm from the opposite end. The holing in the joists was as per limits specified by the manufacturer. Figure 49 shows the profile and bottom flange to web connection of a typical sample in this testing programme. The sample specification is provided in Appendix C.

(A) PROFILE

(B) DETAILED VIEW

FIGURE 49: PROFILE AND DETAILED VIEW OF BOTTOM FLANGE TO WEB CONNECTION OF A TYPICAL SAMPLE USED IN THIS TESTING PROGRAMME

Flooding of Samples

Eight H2 treated and eight untreated samples were used as a control comparison and remained dry for the entirety of the testing programme. Moisture content was measured and ranged between 9.2% and 14.5% with an average of 11.8% for treated samples and untreated samples ranged between 11.0% and 14.5% with an average of 13.5%.

Eight H2 treated and eight untreated samples were placed in an immersion tank and the water level raised to completely submerge the samples. Each sample remained submerged for nominally four days. Subsequently, the tank was drained and the samples were removed from the tank and placed in a ventilated sheltered drying area for a minimum duration of six weeks. Moisture readings were taken on the top flange of each sample, prior to flooding, immediately after, and at frequent intervals during the drying period. Moisture readings are provided in Table C1 and Table C2 in Appendix C.

Additionally, another eight H2 treated and eight untreated samples were installed in an immersion tank and the water level was raised to completely submerge the samples for a duration of nominally four days. Subsequently the tank was drained and the samples removed from the tank and immediately tested. Moisture was measured as 99.9% for all samples at the time of testing. Figure 50 shows a batch of samples submerged in the immersion tank.

FIGURE 50: SAMPLES SUBMERGED IN THE IMMERSION TANK DURING THE FLOOD SIMULATION

APPARATUS AND PROCEDURE FOR BENDING TESTING

Four Point Bending Test Set-Up

The test samples were installed in the four point bending test rig. When installed in the rig the test samples were free to rotate at the support (simply supported) and supported laterally at both ends. To prevent the samples from bowing laterally under load, three lateral supports were installed. Rollers were attached to the top flange of the samples and guided in the lateral supports. These rollers were used to minimise the friction between the samples and lateral supports and therefore minimise the effects of the supports on the load readings.

The load was applied at two locations along the top flange, each nominally 50 mm long across the width of the top flange. The load was applied by a hydraulic ram split by a whiffletree and was applied at approximately 1/3 span and 2/3 span locations. A load cell was placed between the hydraulic ram and the whiffletree to record the load for the duration of the tests. A horizontal gauge (D1) was installed under the bottom flange at mid-span to record the displacement of the samples. Figure 51 shows the test set-up in the four point bend test rig.

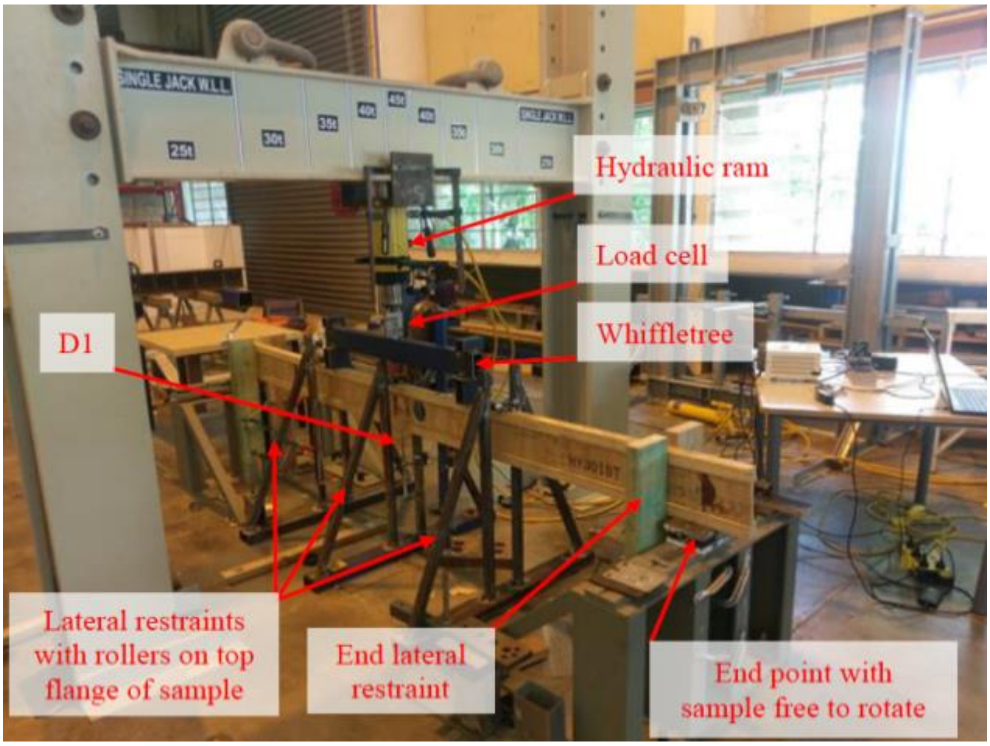


FIGURE 51: FOUR POINT TEST SET-UP

Test Procedure for Four Point Bending Testing

The load was applied to the sample through the hydraulic ram by the laboratory technician actuating a manual hydraulic pump. The load was slowly increased until failure of the test specimen. The load was recorded for the whole duration of the test, while the displacement at mid-span stopped being recorded before failure of test specimen in order to protect the measuring equipment.

RESULTS

Control Specimens (Dry-Dry)

A summary of the recorded four point bending strength test results for the control specimens (i.e. specimens that remained dry (Dry-Dry)) is provided in Table 10. The failure load and the failure mechanism for each test are also presented in the Table 10. Load versus displacement graphs are provided in Appendix C.

TABLE 10: FOUR POINT BENDING STRENGTH TESTING RESULTS OF CONTROL SPECIMENS (DRY-DRY)

Test	Date Tested	Bracing Sheet	Failure Load (kN)	Comment on Failure Mechanism
3A_9	01/02/2017	H2	14.89	Web and top flange buckled at loading point. No rupture.
3A_10	09/02/2017		21.18	Top flange shattered and bottom flange cracked at hole in web near the centre of the beam.
3A_11	10/02/2017		16.86	Web detached from top and bottom flange at join in web near end support. Top and bottom flanges ruptured.
3A_12	10/02/2017		13.53	Web snapped at join and detached from top and bottom flanges between loading point and end support.
3A_13	10/02/2017		17.76	Top and bottom flanges ruptured and web snapped between loading point and end support.
3A_14	10/02/2017		19.52	Top flange collapsed (localised buckling) between loading points.
3A_15	10/02/2017		18.68	Bottom flange ruptured and web snapped at loading point. Web disengaged from top flange.
3A_16	10/02/2017		15.24	Web detached from top and bottom flange at join in web near end support. Top and bottom flanges ruptured.
3B_9	06/02/2017	Nil	17.75	Bottom flange and web ruptured at join in web between load point and end support. Top flange cracked at loading point.
3B_10	13/02/2017		19.75	Top flange split across and longitudinally at centre of beam above defect in web.
3B_11	13/02/2017		18.79	Top and bottom flange ruptured adjacent web joint between load point and end support.
3B_12	13/02/2017		21.94	Top flange cracked across and longitudinally near centre of beam between loading points.
3B_13	13/02/2017		20.28	Top and bottom flange ruptured and web split between load point and end support. Web detached from flange.
3B_14	13/02/2017		17.83	Top and bottom flange ruptured near centre of beam. Web split in same location.
3B_15	13/02/2017		17.32	Beam snapped in two at join in web near centre of beam and load point.
3B_16	13/02/2017		15.44	Web detached from top and bottom flange at join in web near end support. Top and bottom flanges ruptured.

Flooded and Fried Specimens (Wet-Dry)

A summary of the recorded four point bending strength test results for the submerged and dried specimens (Wet-Dry) is provided in Table 11. The failure load and the failure mechanism for each test were also recorded and presented in the Table 11. Load versus displacement graphs are provided in Appendix C.

TABLE 11: FOUR POINT BENDING STRENGTH TESTING RESULTS OF FLOODED AND DRIED SPECIMENS (WET-DRY)

Test	Date Tested	Bracing Sheet	Failure Load (kN)	Comment on Failure Mechanism
3A_1	08/02/2017	H2	17.51	Top flange cracked and buckled across flange and longitudinally along centre of beam. Initial crack near loading point.
3A_2	08/02/2017		13.20	Top flange buckled at loading point
3A_3	08/02/2017		17.42	Web slippage on bottom flange. Beam snapped in two at centre of beam. Top and bottom flanges have ruptured along glue line.
3A_4	08/02/2017		15.51	Top flange collapsed (localised buckling) and split apart at centre of beam.
3A_5	08/02/2017		16.76	Top flange cracked and collapsed at loading point.
3A_6	08/02/2017		14.88	Web join split between loading point and end support. Web disengaged from top and bottom flanges.
3A_7	08/02/2017		18.38	Top flange collapsed (localised buckling). Web has buckled.
3A_8	09/02/2017		18.54	Top flange collapsed (localised buckling).
3B_1	06/02/2017	Nil	16.32	Top flange cracked between loading points.
3B_2	13/02/2017		17.77	Bottom flange cracked at join in web. Rupture of glue line.
3B_3	13/02/2017		16.18	Continual flexure of beam, no rupture but loss of load carrying capacity.
3B_4	13/02/2017		14.44	Web split at joint and pulled out of bottom flange near load point. Bottom flange cracked at end support.
3B_5	13/02/2017		16.22	Bottom flange cracked midway between load point and end support. Top flange cracked near top load point. Web has split (not a join).
3B_6	13/02/2017		16.47	Web split at join under load point. Web slipped out of bottom flange.
3B_7	13/02/2017		17.45	Top flange split longitudinally and bucked. Web no longer fixed to bottom flange.
3B_8	13/02/2017		14.81	Bottom flange and web rupture at join in web between load point and end support.

Flooded Specimens (Wet-Wet)

A summary of the recorded four point bending strength test results for the specimens that were submerged for four days then tested immediately (Wet-Wet) is provided in Table 12. The failure load and the failure mechanism for each test were also recorded and presented in the Table 12. Load versus displacement graphs are provided in Appendix C.

TABLE 12: FOUR POINT BENDING STRENGTH TESTING RESULTS OF FLOODED SPECIMENS (WET-WET)

Test	Date Tested	Bracing Sheet	Failure Load (kN)	Comment on Failure Mechanism
3A_17	15/02/2017	H2	9.94	Web split at join and bottom flange disengaged from web.
3A_18	15/02/2017		9.03	Top flange and web collapsed (localised buckling) near centre of beam.
3A_19	15/02/2017		9.31	Top flange and web collapsed (localised buckling) near loading point.
3A_20	15/02/2017		9.19	Top flange and web collapsed (localised buckling) near hole in web.
3A_21	15/02/2017		9.18	Web disengaged from top and bottom flanges at a join in web between loading point and end support.
3A_22	15/02/2017		8.70	Top flange and web collapsed (localised buckling) near loading point.
3A_23	15/02/2017		8.70	Top flange and web collapsed (localised buckling) above hole in web.
3A_24	15/02/2017		9.78	Top flange and web collapsed (localised buckling) above hole in web.
3B_17	13/02/2017	Nil	8.43	Top flange collapsed (localised buckling) near loading point.
3B_18	13/02/2017		10.18	Top flange collapsed (localised buckling) near loading point.
3B_19	14/02/2017		8.51	Top flange and web collapsed (localised buckling) near loading point.
3B_20	14/02/2017		9.47	Top flange and web collapsed (localised buckling) near loading point.
3B_21	14/02/2017		9.61	Top flange and web collapsed (localised buckling) near loading point.
3B_22	14/02/2017		9.88	Top flange and web collapsed (localised buckling) near loading point.
3B_23	14/02/2017		9.29	Top flange collapsed (localised buckling) near loading point.
3B_24	14/02/2017		9.02	Top flange and web collapsed (localised buckling) near loading point.

SUMMARY

This test examined the bending and shear strength of manufactured timber joists. This test was designed to assess the structural adequacy of manufactured timber I section joists following inundation and subsequent drying. Two types of joist were tested (H2 treated and untreated). Strength was tested at three stages: dry before immersion, wet immediately after immersion and dry after drying following immersion.

Results indicated that flooding did not have any adverse impact on the bending and shear strength of both types of joist when tested in re-dried condition as shown in Table 13. There was minimal reduction in average maximum load observed that reduced from 17.21 kN to 16.53 kN (nominally 4%) between H2 treated samples that remained dry to those that were inundated and then dried. There was a greater reduction in average maximum load observed that reduced from 17.21 kN to 9.23 kN (nominally 46%) between samples that remained dry to those that were inundated and tested whilst wet. Similar observations were made for the untreated samples (see Table 13).

From the load versus displacement curves given in Appendix C it was observed that the stiffness between dry samples and wet samples that had dried was nominally the same, however, the stiffness was significantly reduced when in the wet state.

The significant reduction in stiffness and load carrying capacity of saturated joists recorded in this study was also observed in the tests carried out by the Commonwealth Scientific and Industrial Research Organisation (HNFMSC, 2006). These results suggested that the joist samples whilst in the wet stage might be compromised due to reduced strength capacity and stiffness. Furthermore, the load on the joists could be increased substantially immediately after a flood when the building materials and contents supported by the joists become saturated. The situation could be exacerbated by overloading the saturated joists if additional contents would be moved on higher floors for protection.

However, if allowed to dry then the specimens could recover to nominally 96% of average strength capacity and stiffness. Moreover, it was observed that the moisture content level after the test returned close to pre-inundation level within a week which was much faster than what was assessed by HNFMSC (2006). Table C1 and Table C2 in Appendix C provide moisture meter readings.

TABLE 13: FOUR POINT BENDING STRENGTH TESTING RESULTS

Test	Treated	Flooded	Comment	Failure Load (kN)
A1 –A8	H2	YES	Tested after drying	16.53
A9 –A16	H2	NO	Control Specimens	17.21
A17 –A24	H2	YES	Tested wet	9.23
B1 –B8	NIL	YES	Tested after drying	16.21
B9 –B16	NIL	NO	Control Specimens	18.64
B17 –B24	NIL	YES	Tested wet	9.30

CONCLUSIONS

Flood damage resistance includes both physical and human health factors (Aglan et al., 2004). This experimental programme only tested the strength and some serviceability implications (degradation) that resulted from the wetting and drying cycle associated with flooding. Testing did not address the post-flooding mould growth or any other associated health impacts. Flood depth was limited to 600mm above floor level, which would apply a horizontal flow pressure that would be within the strength capabilities of typical timber frame construction.

It is to be noted that these conclusions should be viewed as preliminary since they are based on the results of the testing accomplished in this project and not on an accepted certifying test procedure as to the flood damage resistance of a particular material or system.

TEST TYPE 1 (FLOOR AND WALL TILES)

This test examined the bond strength of floor and wall tiles following inundation with the objective of determining the necessity or otherwise of removing and replacing all tiles following inundation. Six specimens were constructed: three of them simulated a bathroom assembly while the other three simulated a shower assembly. For each simulation two specimens were subjected to floodwater while one remained dry in its original condition as a control specimen.

Results indicated that flooding did not have any adverse impact on the pull-out strength of the bond of ceramic floor and wall tiles to their substrate. Furthermore, no evidence of delamination of the adhesive causing lifting or popping of tiles was observed. Therefore, replacement of tiles after flooding is not considered to be necessary by this research.

TEST TYPE 2 (OSB AND HDF WALL SHEET BRACING)

This test was designed to assess the structural adequacy of structural wall sheet bracing following inundation and subsequent drying. Two types of wall sheet bracing were tested for racking strength (OSB and HDF). Ten specimens were constructed for each bracing material. Five of them were tested in dry conditions without being flooded as control specimens and the other five were tested after wetting and drying cycle.

Failure modes observed during the tests were bracing sheet failure, nail failure, and nail and sheeting combined failure. In all cases slippage between adjacent sheets and stud withdrawal from the bottom plate were observed.

The average failure load and stiffness characteristics of flooded and non-flooded OSB samples remained similar. Therefore it is reasonable to deduce that the bracing capacity of OSB samples was not significantly affected by the 600 mm of simulated flooding.

The average failure load of flooded and non-flooded HDF samples was decreased by nominally 10%. However, there was no significant variation in stiffness of the HDF samples that were exposed to the flooding to those that were not exposed to the flooding.

Therefore, the loss of bracing capacity of HDF sheets indicated that additional bracing should be incorporated in the design of new construction to account for the loss of its effectiveness when saturated. However, the 10% loss of capacity is not considered to be severe enough to warrant retrofit existing structures unless substantial renovations are being carried out.

TEST TYPE 3 (TIMBER JOISTS)

This test was designed to assess the structural adequacy of manufactured timber I section joists following inundation and subsequent drying. Two types of joist were tested (H2 treated and untreated). Strength was tested at three stages: dry before immersion, wet immediately after immersion and dry after drying following immersion.

Results indicated that flooding did not have any adverse impact on the bending and shear strength of both types of bracing when tested in a dried condition. There was minimal reduction (nominally 4%) in average maximum load observed between H2 treated samples that remained dry to those that were inundated and then dried. There was a greater reduction in average maximum load observed (nominally 46%) between samples that remained dry to those that were inundated and tested whilst wet. Similar observations were made for the untreated samples.

These results suggest that the samples whilst in the wet stage may be compromised due to reduced strength capacity and stiffness. However, if allowed to dry then the specimen could recover to nominally 96% of average strength capacity and stiffness. Provided excessive permanent sag deflection had not been recorded, replacement is not considered to be necessary by this research.

REFERENCES

Aglan, H., Wendt, R., Livengood, S. 2004. Field testing of energy-efficient flood-damage-resistant residential envelope systems summary report. Oak Ridge National Laboratory, Tennessee, USA.

Bartzis, N. 2013. Flood insurance pricing. Proc. Floodplain Management Association National Conference, Tweed Heads, Australia.

BNHCRC. 2017. Cost-effective mitigation strategy development for flood prone buildings. Bushfire and Natural Hazards Cooperative Research Centre. http://www.bnhcrc.com.au/research/resilient-people-infrastructure-and-institutions/243.

Escarameia, M., Tagg, A.F., Walliman, N., Zevenbergen, C. Anvarifar, F. 2012. The role of building materials in improved flood resilience and routes for implementation. Proc. 2nd European Conference on Flood Risk Management, Rotterdam, The Netherlands.

FEMA. 2008. Flood damage-resistant materials requirements for buildings located in Special Flood Hazard Areas. NFIP Technical Bulletin 2. Federal Emergency Management Agency, USA.

FEMA. 2012. Engineering principles and practices for retrofitting flood-prone residential structures. FEMA P-259, Third Edition. Federal Emergency Management Agency, USA.

Jonkman, S. 2005. Global perspectives of loss of human life caused by floods. Natural Hazards, 34:151–175.

HNFMSC. 2006. Reducing vulnerability of buildings to flood damage: guidance on building in flood prone areas. Hawkesbury-Nepean Floodplain Management Steering Committee, Parramatta, June 2006.

Kreibich, H., Thieken, A., Petrow, T., Meuller, M. & Merz, B. (2005) Flood loss reduction of private households due to building precautionary measures – lessons learned from the Elbe flood in August 2002. Natural Hazards and Earth Systems Science, 5: 117–126.

Maqsood, T., Wehner, M., Dale, K. 2014. Cost-Effective Mitigation Strategy Development for Flood Prone Buildings. Preliminary building schema. Bushfire and Natural Hazards CRC, Melbourne, Australia. http://www.bnhcrc.com.au/research/resilient-people-infrastructure-and-institutions/243.

Maqsood, T., Wehner, M., Dale, K. 2015a. A schema to categorise residential buildings in Australian floodplains. Floodplain Management Association National Conference 2015; 12pp.

Maqsood, T., Wehner, M., Dale, K. 2015b. Cost-Effective Mitigation Strategy Development for Flood Prone Buildings. Report on literature review of flood mitigation strategies. Bushfire and Natural Hazards CRC, Melbourne, Australia.

Maqsood, T., Wehner, M., Dale, K. 2016a. Cost-Effective Mitigation Strategy Development for Flood Prone Buildings. Report on developing costing modules for implementing flood mitigation strategies. Bushfire and Natural Hazards CRC, Melbourne, Australia.

Maqsood, T., Wehner, M., Dale, K. , Edwards, M. 2016b. Cost-Effective Mitigation Strategies for Residential Buildings in Australian Floodplains. International Journal of Safety and Security Engineering, Volume **6**, No. 3, 550-559.

NSDR. 2011. National strategy for disaster resilience-building the resilience of our nation to disasters. Council of Australian Government. Australian Emergency Management Institute. ISBN: 978-1-921725-42-5.

USACE. 1984. Flood proofing systems and techniques; examples of flood proofed structures in the United States. Floodplain Management Services Programs. US Army Corps of Engineers. Washington D.C., USA.

USACE. 1988. Flood proofing tests; tests of materials and systems for flood proofing structures. Floodplain Management Services Programs. National Flood Proofing Committee. US Army Corps of Engineers. Washington D.C., USA.

USACE. 1993. Flood proofing; how to evaluate your options. National Flood Proofing Committee. US Army Corps of Engineers. Washington D.C., USA.Wehner, M., Maqsood, T., Corby, N., Edwards, M., Middelmann-Fernandes, M. 2012. Augmented vulnerability models for inundation. Technical report submitted to DCCEE. Geoscience Australia, Canberra, Australia.

USACE. 1995. Flood Proofing Regulations, Chapters 9 and 10, US Army Corps of Engineers, EP 1165-2-314, Washington D.C., USA.

Van Gender, N. 2017. Technical specialist assessment report. Insurance Australia Group. Sydney, Australia.

APPENDIX A

Figure A1 shows the construction details of the bathroom samples.

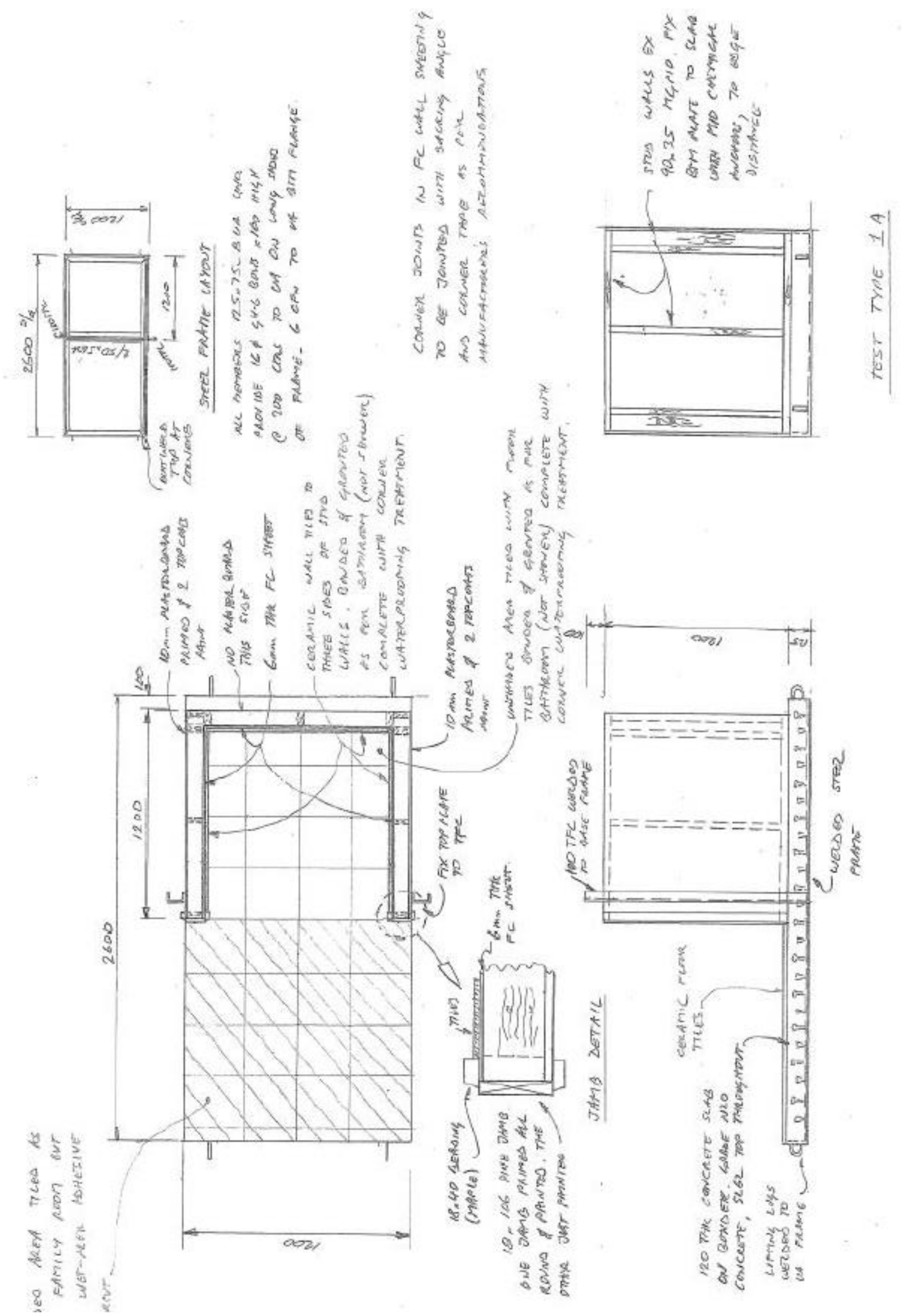


FIGURE A1: CONSTRUCTION DETAILS OF THE BATHROOM SAMPLES

Figure A2 shows the construction details of the shower samples.

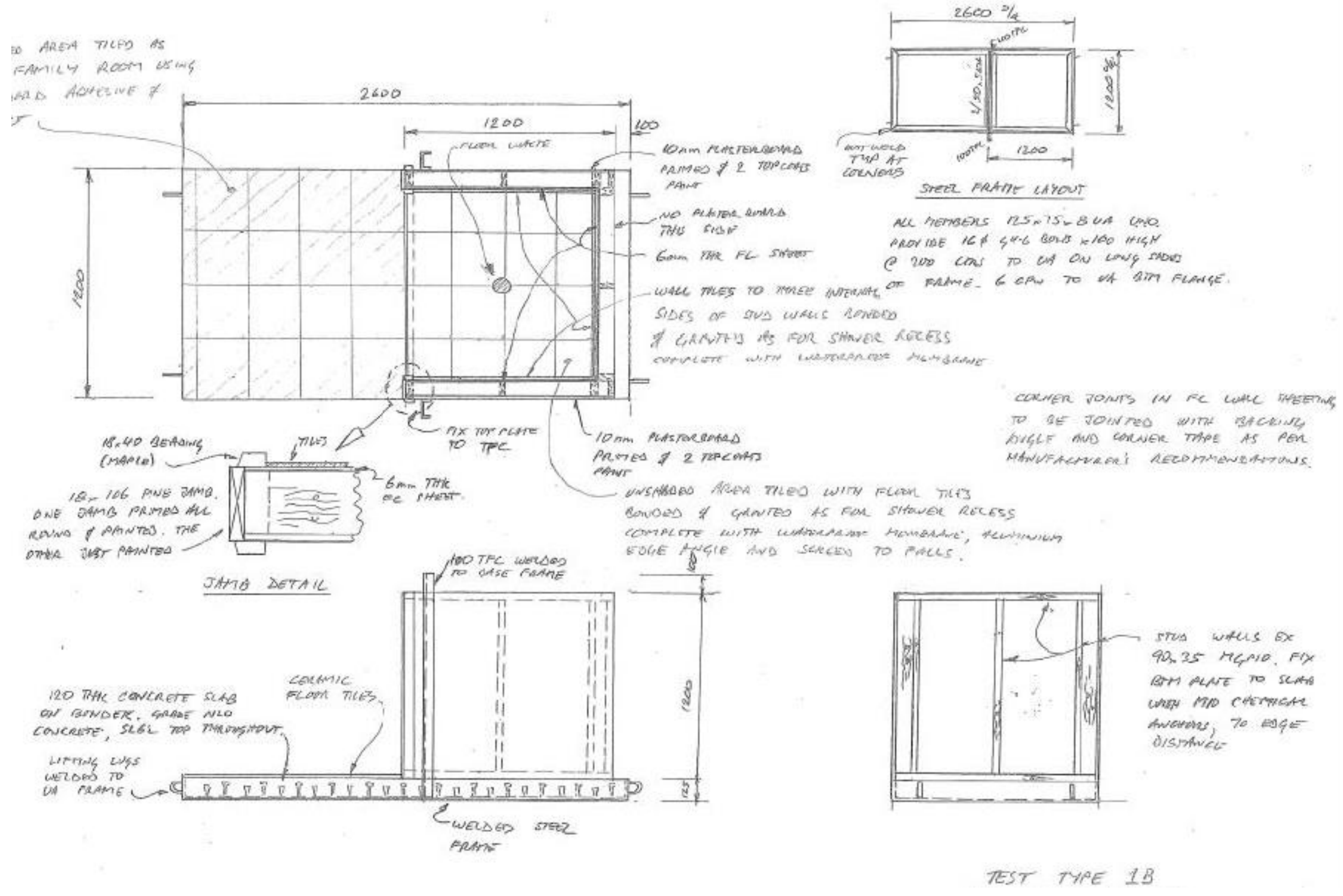


FIGURE A2: CONSTRUCTION DETAILS OF THE SHOWER SAMPLES

Table A1 to Table A4 show the moisture content readings for all the samples for Test Type 1.

TABLE A1: MOISTURE READINGS OF FLOODED SAMPLE (1A_2)

Location	Date	Moisture (%)	Location	Date	Moisture (%)
Top Plate	01/12/16	10.8	Bottom Plate	01/12/16	11.5
	Flooding			Flooding	
	06/12/16	9.8		06/12/16	99.9
	14/12/16	9.7		14/12/16	23.3
	20/12/16	11.5		20/12/16	25.4
	23/12/16	10.5		23/12/16	21.3
	09/01/17	11.4		09/01/17	15.6
	11/01/17	12.1		11/01/17	15.5
	16/01/17	12.7		16/01/17	16.8
	13/03/17	12.8		13/03/17	14.8

TABLE A2: MOISTURE READINGS OF FLOODED SAMPLE (1A_3)

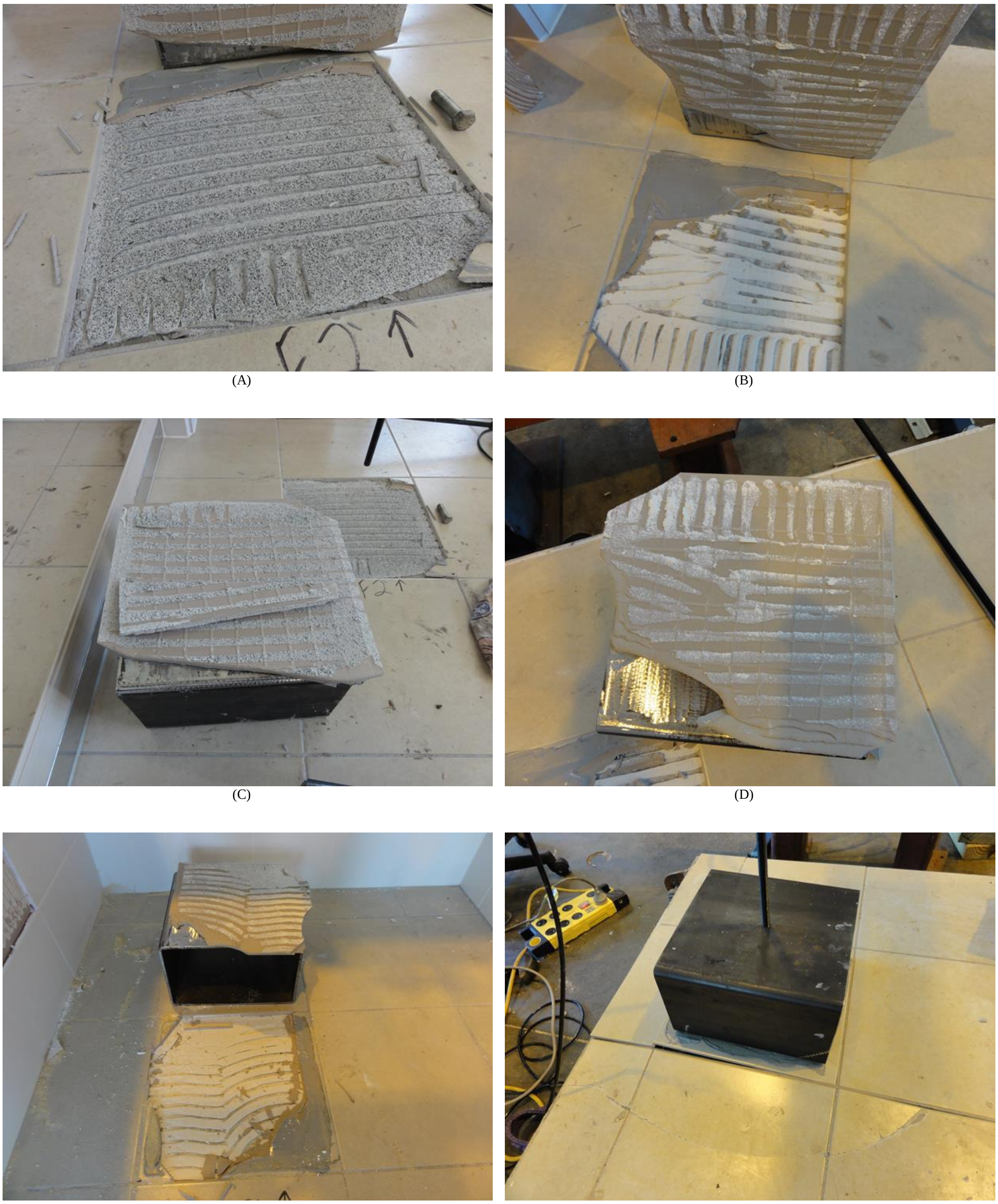
Location	Date	Moisture (%)	Location	Date	Moisture (%)
Top Plate	01/12/16	11.4	Bottom Plate	01/12/16	10.6
	Flooding			Flooding	
	06/12/16	10.4		06/12/16	99.9
	14/12/16	10.6		14/12/16	21.1
	20/12/16	12.7		20/12/16	21.0
	23/12/16	11.8		23/12/16	17.2
	09/01/17	12.2		09/01/17	15.0
	11/01/17	13.1		11/01/17	14.7
	16/01/17	14.2		16/01/17	15.5
	13/03/17	13.7		13/03/17	13.5

TABLE A3: MOISTURE READINGS OF FLOODED SAMPLE (1B_2)

Location	Date	Moisture (%)	Location	Date	Moisture (%)
Top Plate	01/12/16	11.0	Bottom Plate	01/12/16	11.8
	Flooding			Flooding	
	06/12/16	9.7		06/12/16	99.9
	14/12/16	9.8		14/12/16	16.8
	20/12/16	11.8		20/12/16	20.5
	23/12/16	10.7		23/12/16	21.5
	09/01/17	12.4		09/01/17	16.5
	11/01/17	12.4		11/01/17	15.0
	16/01/17	13.2		16/01/17	17.3
	15/03/17	13.9		15/03/17	14.3

TABLE A4: MOISTURE READINGS OF FLOODED SAMPLE (1B_3)

Location	Date	Moisture (%)	Location	Date	Moisture (%)
Top Plate	01/12/16	11.9	Bottom Plate	01/12/16	10.1
	Flooding			Flooding	
	06/12/16	9.8		06/12/16	99.9
	14/12/16	10.2		14/12/16	16.5
	20/12/16	12.1		20/12/16	19.7
	23/12/16	11.0		23/12/16	15.5
	09/01/17	12.4		09/01/17	13.8
	11/01/17	12.8		11/01/17	14.2
	16/01/17	13.6		16/01/17	15.0
	15/03/17	13.8		15/03/17	15.8

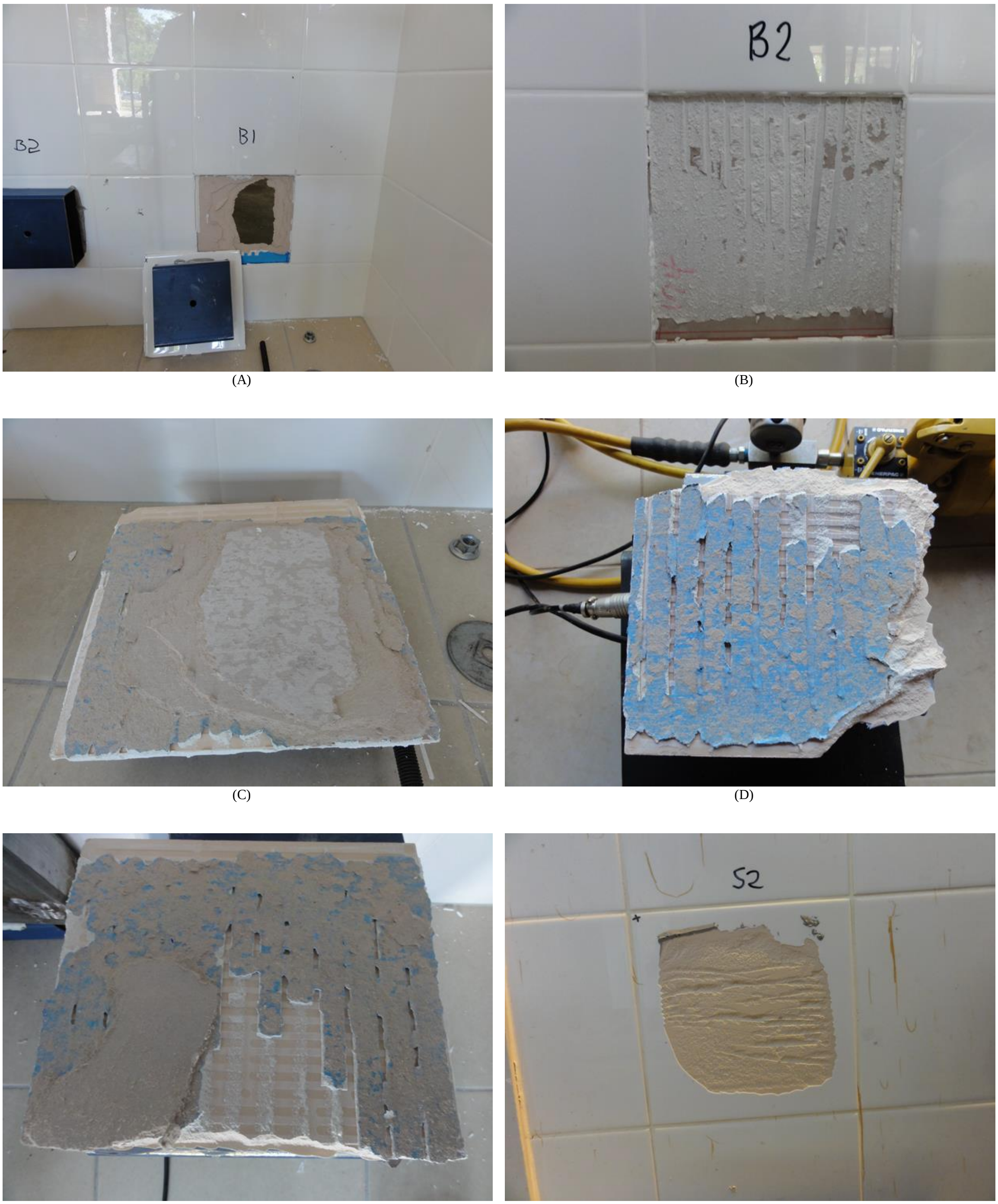


(A) (B)

(C) (D)

(E) (F)

FIGURE A3: SAMPLES AFTER PULL-OUT TESTS ON FLOOR TILES



(A) (B)

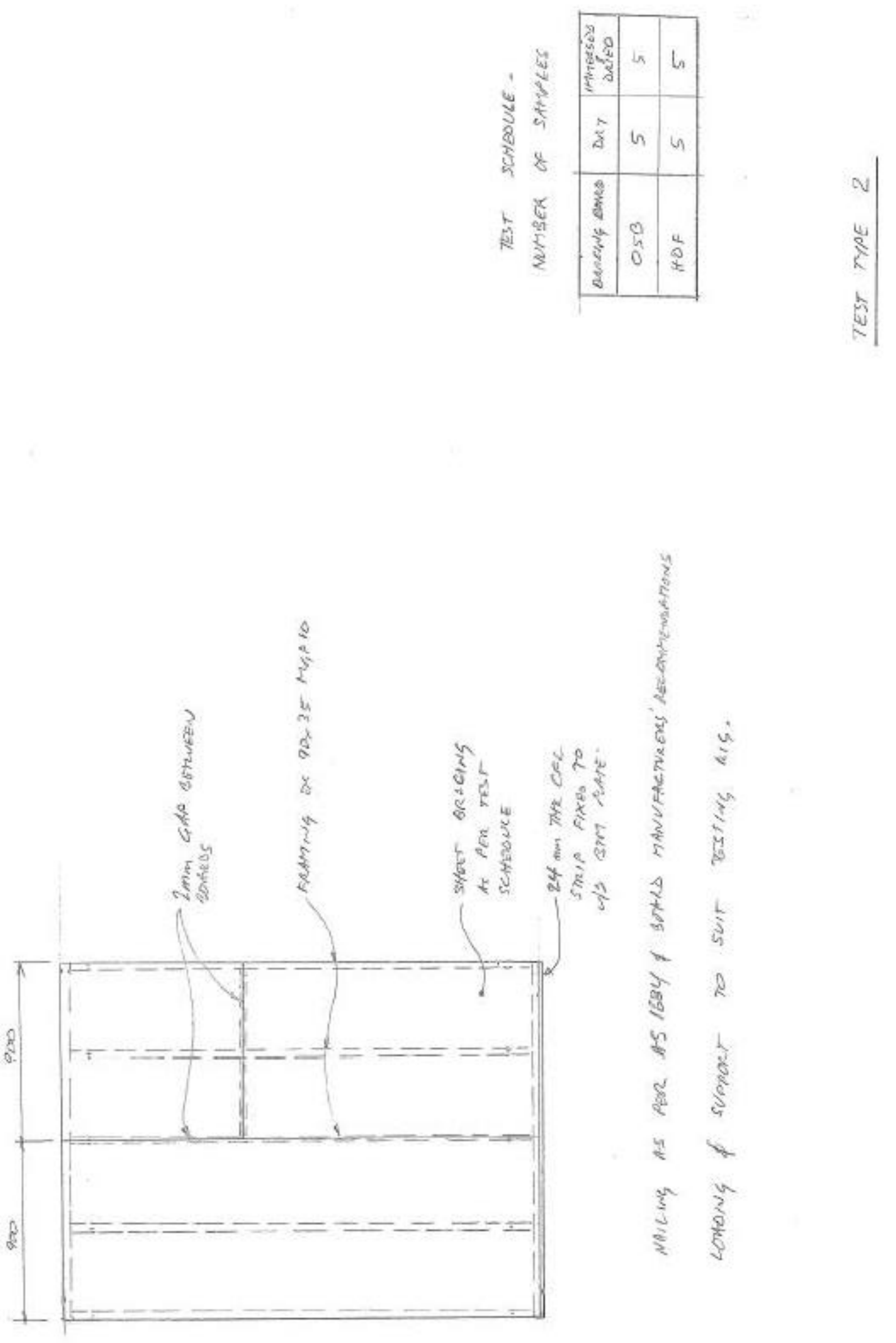
(C) (D)

(E) (F)

FIGURE A4: SAMPLES AFTER PULL-OUT TESTS ON WALL TILES

APPENDIX B

Figure B1 shows the construction details of the timber frame and wall sheet bracing.



TEST SCHEDULE -
NUMBER OF SAMPLES

BRACING BOARD	DRY	IMMERSED & DRIED
OSB	5	5
HDF	5	5

TEST TYPE 2

FIGURE B1: CONSTRUCTION DETAILS OF THE SHOWER SAMPLES

Figure B2 to Figure B7 show the load vs displacement graphs for all the samples for Test Type 2.

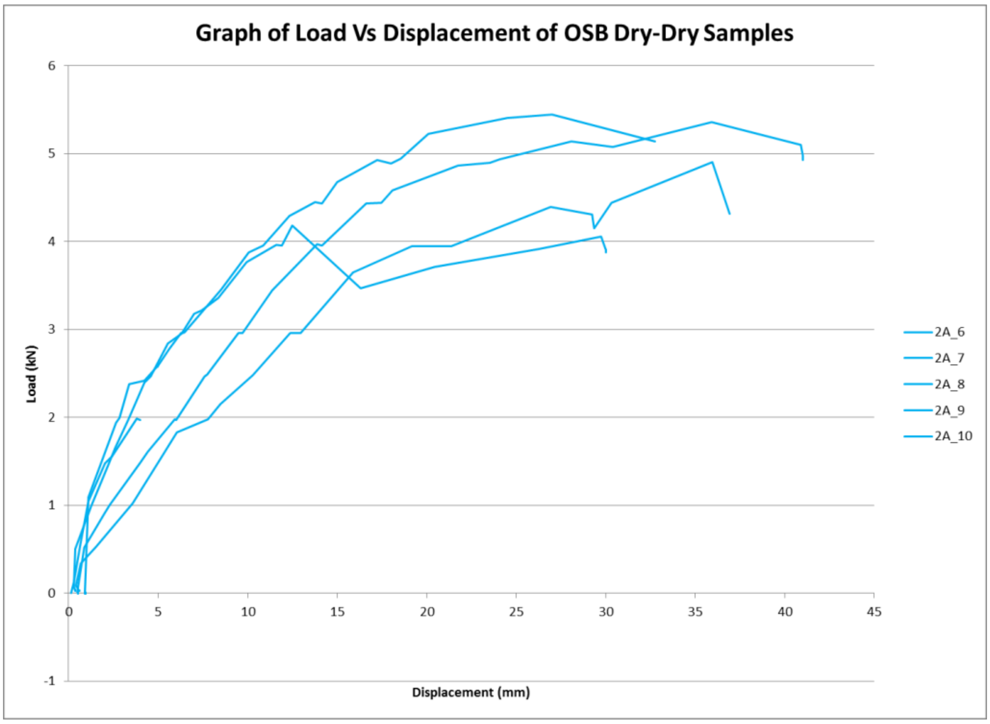


FIGURE B2: LOAD VS DISPLACEMENT GRAPHS OF OSB WALL SHEET BRACING (DRY-DRY SAMPLES)

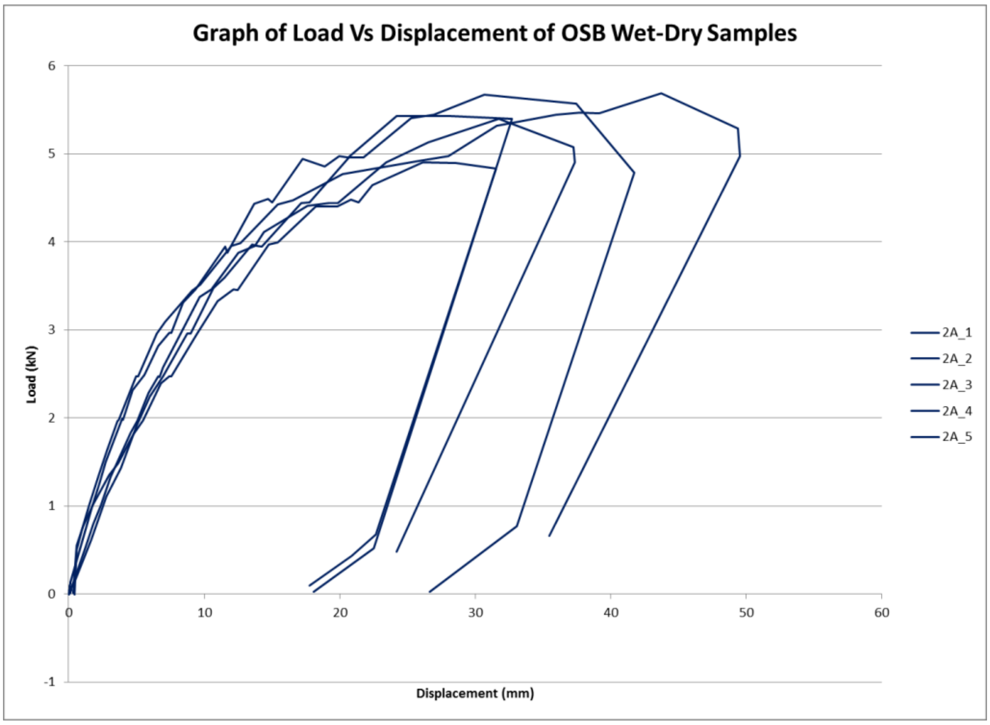


FIGURE B3: LOAD VS DISPLACEMENT GRAPHS OF OSB WALL SHEET BRACING (WET-DRY SAMPLES)

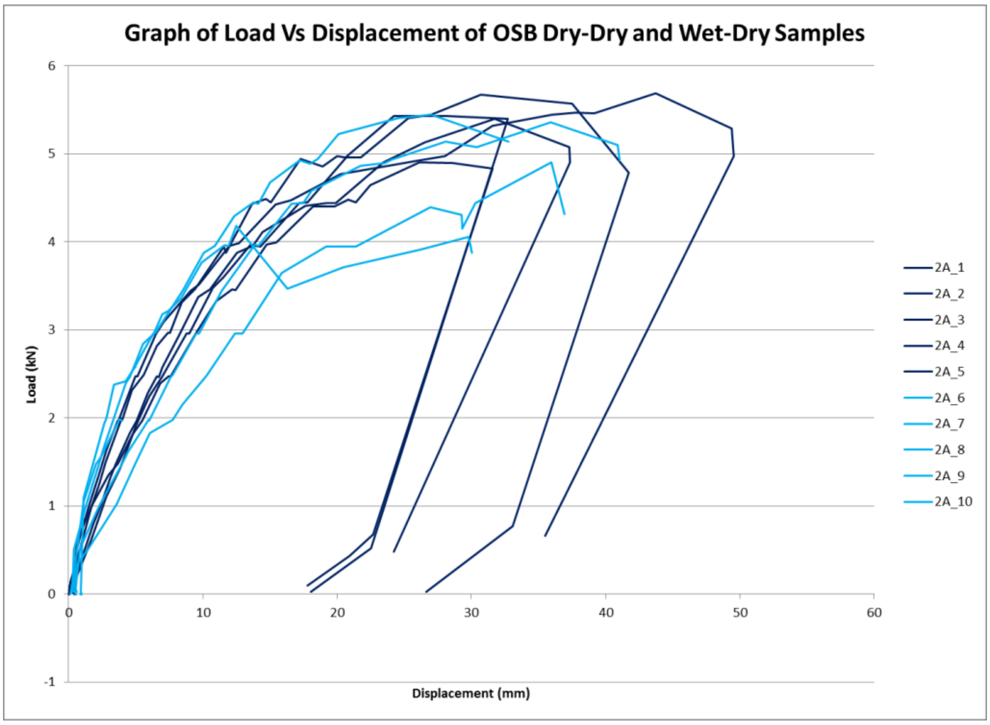


FIGURE B4: LOAD VS DISPLACEMENT GRAPHS OF OSB WALL SHEET BRACING (DRY-DRY AND WET-DRY SAMPLES)

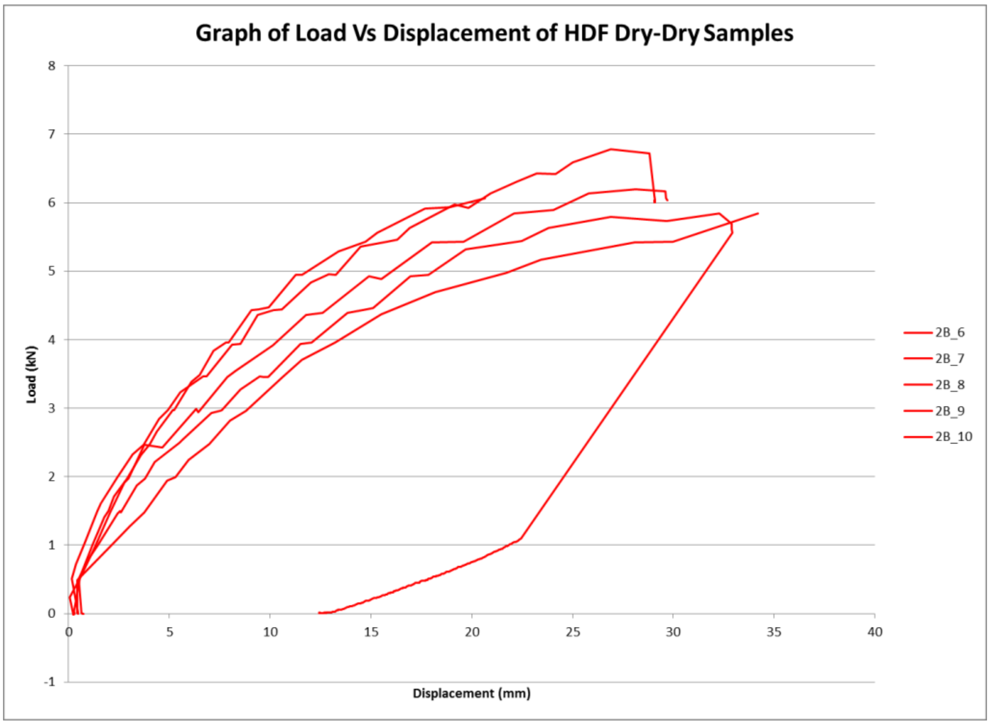


FIGURE B5: LOAD VS DISPLACEMENT GRAPHS OF HDF WALL SHEET BRACING (DRY-DRY SAMPLES)

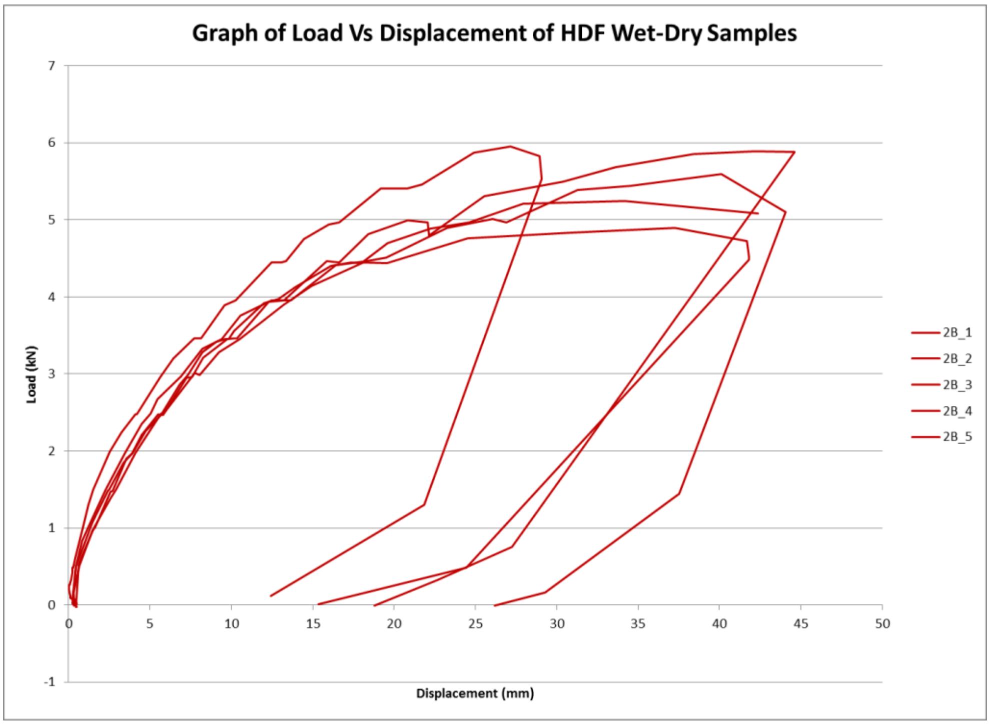


FIGURE B6: LOAD VS DISPLACEMENT GRAPHS OF HDF WALL SHEET BRACING (WET-DRY SAMPLES)

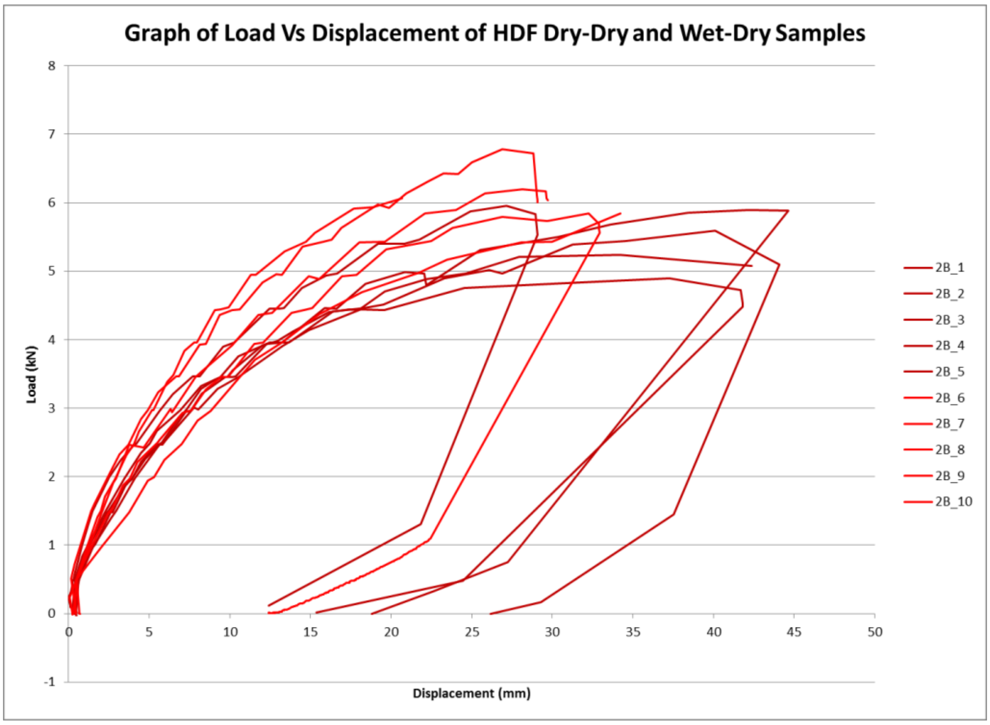


FIGURE B7: LOAD VS DISPLACEMENT GRAPHS OF HDF WALL SHEET BRACING (DRY-DRY AND WET-DRY SAMPLES)

Figure B8 to Figure B19 show the typical failure in all the samples for Test Type 2.

(A) OSB

(B) HDF

FIGURE B8: SLIPPAGE OBSERVED BETWEEN ADJACENT BRACING SHEETS

(A) OSB

(B) HDF

FIGURE B9: STUD WITHDRWAL FROM BOTTOM PLATE

(A) OSB: NAIL FAILURE

(B) OSB: NAIL FAILURE

FIGURE B10: NAIL FAILURE (DRY-DRY SAMPLES)

FIGURE B11: OSB BRACE SHEETING FAILURE (DRY-DRY SAMPLES)

FIGURE B12: OSB BOTTOM PLATE FAILURE (DRY-DRY SAMPLES)

FIGURE B13: OSB BRACE SHEETING FAILURE (WET-DRY SAMPLES)

FIGURE B14: OSB BOTTOM PLATE FAILURE (DRY-DRY SAMPLES)

FIGURE B15: OSB BRACE SHEETING FAILURE (WET-DRY SAMPLES)

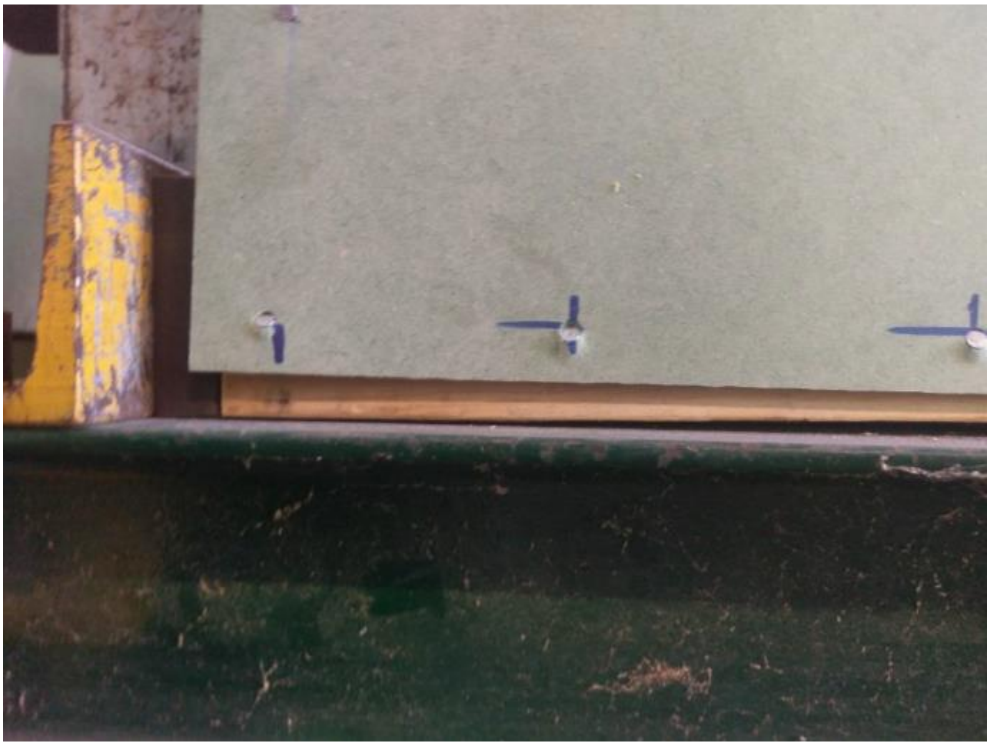


FIGURE B16: OSB BOTTOM PLATE FAILURE (DRY-DRY SAMPLES)

(A) HDF: NAIL FAILURE (B) HDF: SHEET FAILURE

FIGURE B17: NAIL FAILURE ON HDF (WET-DRY SAMPLES)

FIGURE B18: NAIL FAILURE ON HDF (WET-DRY SAMPLES)

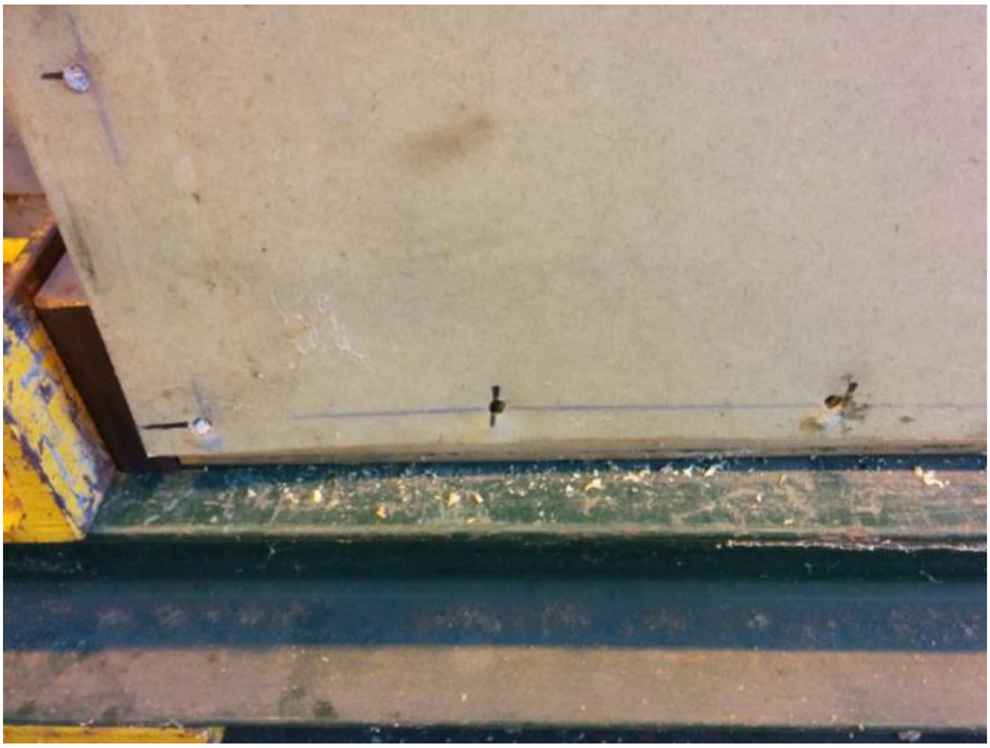


FIGURE B19: NAIL FAILURE ON HDF (WET-DRY SAMPLES)

Table B1 to Table B4 show the moisture content readings for all the samples for Test Type 2.

TABLE B1: MOISTURE READINGS OF FLOODED OSB SAMPLES AT 900MM UP FROM BOTTOM PLATE (2A_1 TO 2A_5)

Date	**Moisture (%)**				
	2A_1	**2A_2**	**2A_3**	**2A_4**	**2A_5**
01/12/16	7.8	8.4	7.2	8.6	8.8
Flooding					
06/12/16	7.1	7.7	7.1	8.0	8.2
14/12/16	8.7	8.8	8.0	9.1	9.4
20/12/16	8.7	9.1	8.4	9.4	10.0
23/12/16	8.1	9.0	7.9	8.9	9.9
09/01/17	8.7	9.0	8.4	9.4	9.7
11/01/17	9.1	9.5	8.7	9.7	9.9
16/01/17	9.7	9.8	9.0	9.9	10.2
25/01/17	9.0	8.9	8.5	10.1	9.2

TABLE B2: MOISTURE READINGS OF FLOODED OSB SAMPLES AT 300MM UP FROM BOTTOM PLATE (2A_1 TO 2A_5)

Date	**Moisture (%)**				
	2A_1	**2A_2**	**2A_3**	**2A_4**	**2A_5**
01/12/16	7.0	8.4	7.5	7.8	9.0
Flooding					
06/12/16	99.9	99.9	99.9	99.9	99.9
14/12/16	13.9	14.1	17.8	14.8	19.6
20/12/16	13.2	15.1	15.4	15.1	16.9
23/12/16	11.8	12.6	14.3	13.2	14.7
09/01/17	11.0	11.0	12.1	11.5	12.5
11/01/17	11.8	11.8	12.1	12.4	13.1
16/01/17	12.1	12.1	12.9	12.5	13.2
25/01/17	10.8	11.4	11.2	12.2	11.2

TABLE B3: MOISTURE READINGS OF FLOODED HDF SAMPLES AT 900MM UP FROM BOTTOM PLATE (2B_1 TO 2B_5)

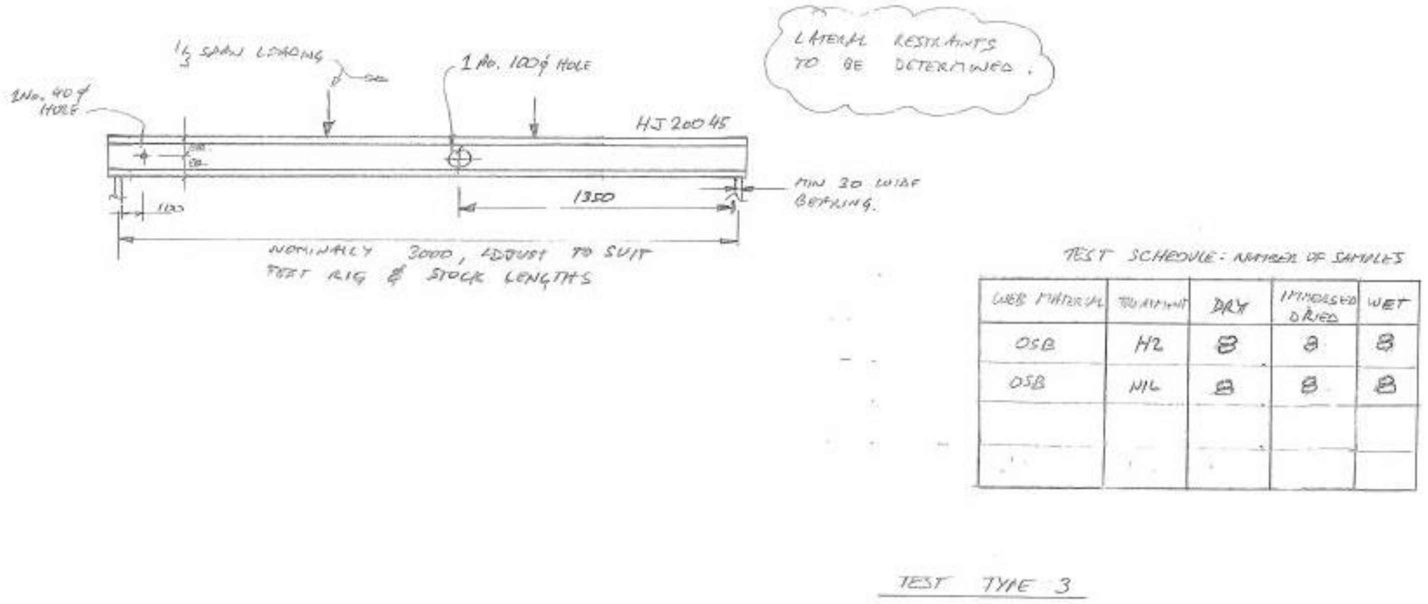
Date	Moisture (%)				
	2B_1	2B_2	2B_3	2B_4	2B_5
01/12/16	9.1	9.7	9.8	8.7	8.1
Flooding					
06/12/16	8.4	8.9	9.2	8.2	6.8
14/12/16	8.9	10.0	9.8	8.8	7.5
20/12/16	9.4	9.9	10.2	9.4	8.8
23/12/16	9.0	9.7	9.7	9.1	7.7
09/01/17	9.7	10.1	10.0	9.5	8.0
11/01/17	9.9	10.5	10.5	9.9	8.0
16/01/17	10.4	11.4	11.2	10.1	8.8
25/01/17	9.7	10.1	10.2	9.7	7.9

TABLE B4: MOISTURE READINGS OF FLOODED HDF SAMPLES AT 300MM UP FROM BOTTOM PLATE (2B_1 TO 2B_5)

Date	Moisture (%)				
	2B_1	2B_2	2B_3	2B_4	2B_5
01/12/16	8.8	9.2	10.1	8.5	7.2
Flooding					
06/12/16	99.9	99.9	99.9	99.9	99.9
14/12/16	15.1	14.8	15.2	13.5	10.0
20/12/16	14.1		17.9	13.4	12.8
23/12/16	12.2	12.7	12.6	12.4	9.4
09/01/17	11.1	11.5	11.8	10.9	10.8
11/01/17	11.8	11.8	12.4	11.8	10.8
16/01/17	12.4	12.7	12.7	11.8	9.0
25/01/17	11.2	11.4	11.5	10.8	7.7

APPENDIX C

Figure C1 shows the construction details of the manufactured timber joist.



TEST SCHEDULE: NUMBER OF SAMPLES

WEB MATERIAL	TREATMENT	DRY	IMMERSED DRIED	WET
OSB	H2	8	8	8
OSB	NIL	8	8	8

FIGURE C1: CONSTRUCTION DETAILS OF THE SHOWER SAMPLES

Table C1 and Table C2 show the moisture content readings for all the samples for Test Type 3.

TABLE C1: MOISTURE READINGS OF FLOODED AND DRIED H2 TEATED SAMPLES AT TOP FLANGE (3A_1 TO 3A_8)

Date	Moisture (%)							
	3A_1	3A_2	3A_3	3A_4	3A_5	3A_6	3A_7	3A_8
01/12/16	10.1	9.7	9.5	8.7	10.2	10.1	10.1	9.4
02/12/16	11.1	13.2	13.1	11.2	10.0	11.4	11.8	12.5
Flooding								
06/12/16	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9
14/12/16	14.2	12.9	13.4	15.1	12.8	14.3	15.0	15.2
20/12/16	16.5	17.7	18.7	18.8	17.7	17.5	17.5	18.7
23/12/16	13.7	15.1	13.1	12.9	14.2	14.3	15.0	15.0
09/01/17	14.0	12.8	14.0	15.1	15.0	15.0	14.8	15.2
11/01/17	13.8	13.2	13.5	14.0	13.6	14.0	15.6	15.9
16/01/17	15.2	15.0	15.5	15.7	14.8	15.7	15.7	15.0
08/02/17	14.3	13.7	14.8	14.0	13.8	15.6	15.6	16.0

TABLE B2: MOISTURE READINGS OF FLOODED AND DRIED SAMPLES AT TOP FLANGE (3B_1 TO 3B_8)

Date	Moisture (%)							
	3B_1	3B_2	3B_3	3B_4	3B_5	3B_6	3B_7	3B_8
01/12/16	8.9	9.2	9.6	10.6	9.0	9.7	10.0	13.0
Flooding								
06/12/16	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9
14/12/16	13.9	17.8	13.7	17.3	14.0	15.6	14.8	15.5
20/12/16	17.3	18.7	21.0	20.0	20.0	20.5	18.8	17.9
23/12/16	13.2	15.6	15.0	15.0	15.9	13.9	13.2	12.6
09/01/17	13.9	14.3	15.0	15.2	15.0	13.2	14.0	13.7
11/01/17	15.1	15.6	15.2	15.2	15.2	14.1	15.1	13.9
16/01/17	15.2	16.3	15.5	15.7	15.6	15.0	15.7	16.0
08/02/17	14.1	12.9	14.8	14.7	16.2	13.8	16.6	14.3

Figure C2 to Figure C16 show the load vs displacement graphs for all the samples for Test Type 3.

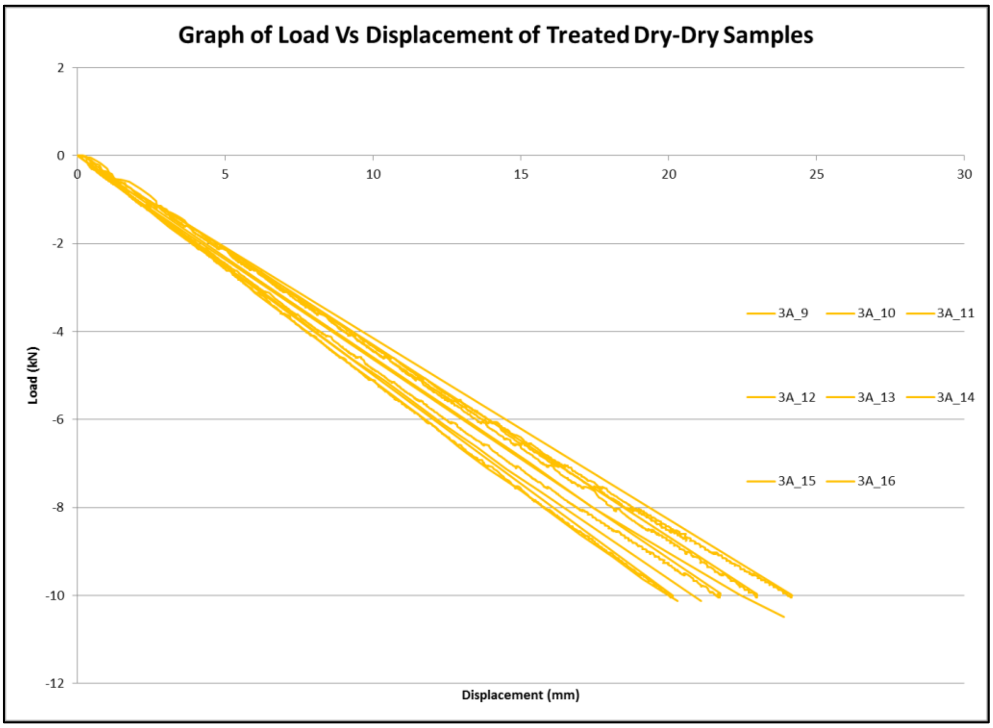


FIGURE C2: LOAD VS DISPLACEMENT GRAPHS OF H2 TREATED JOISTS (DRY-DRY SAMPLES)

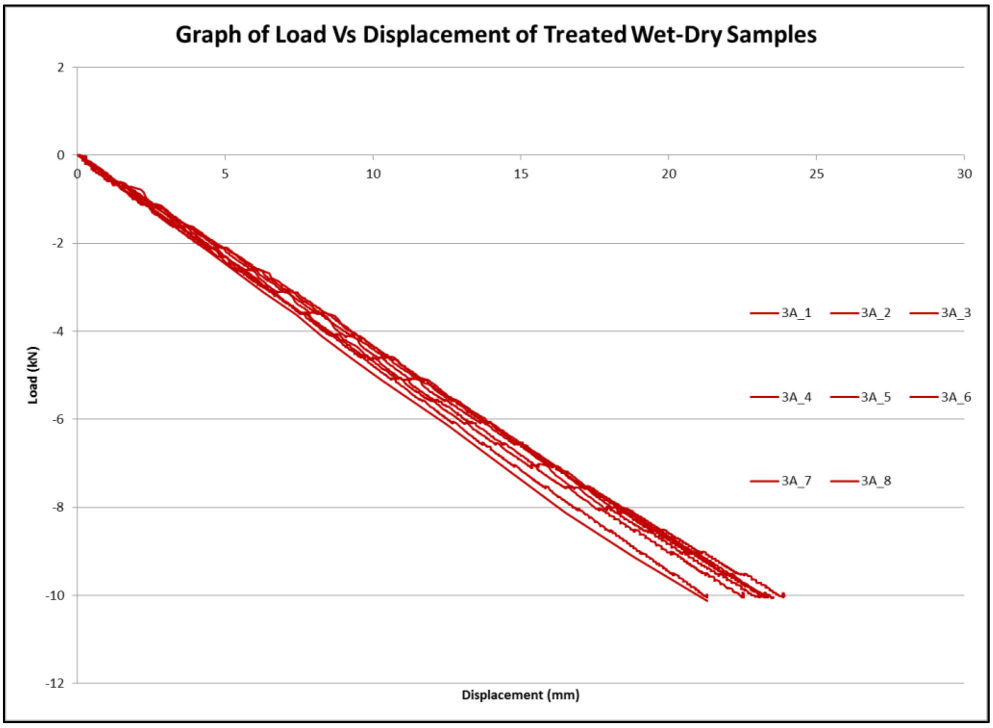


FIGURE C3: LOAD VS DISPLACEMENT GRAPHS OF H2 TREATED JOISTS (WET-DRY SAMPLES)

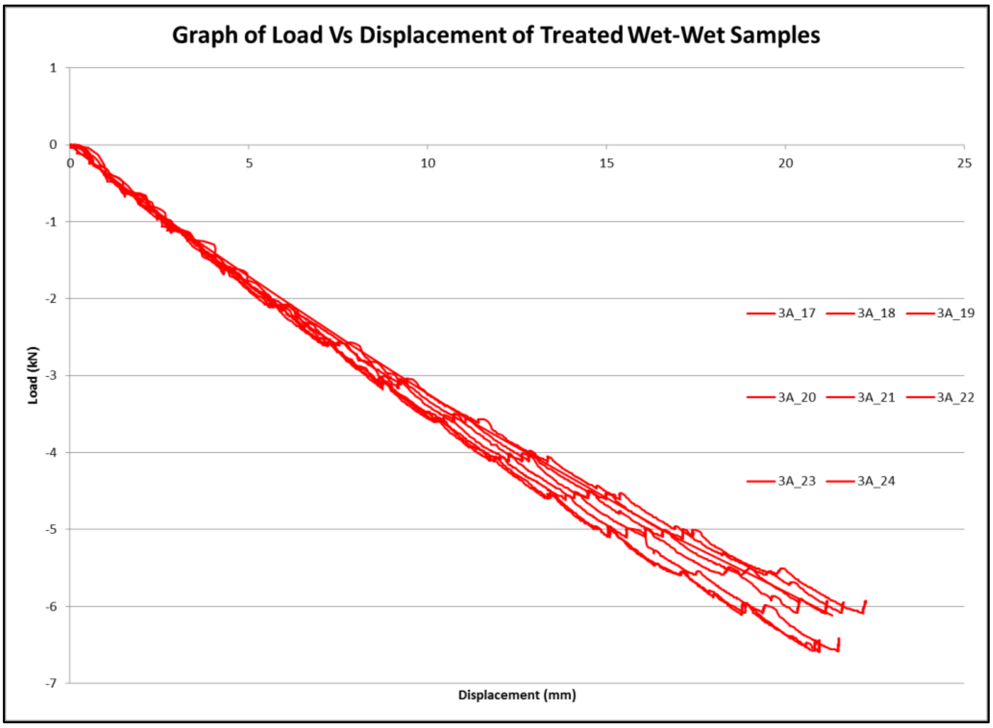


FIGURE C4: LOAD VS DISPLACEMENT GRAPHS OF H2 TREATED JOISTS (WET-WET SAMPLES)

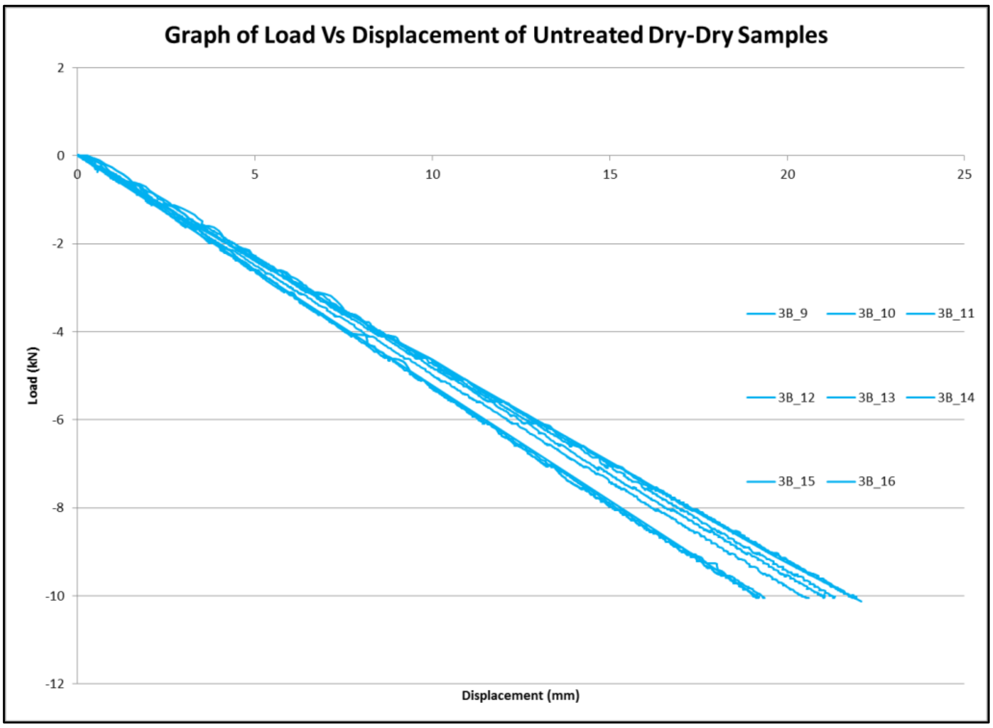


FIGURE C5: LOAD VS DISPLACEMENT GRAPHS OF UNTREATED JOISTS (DRY-DRY SAMPLES)

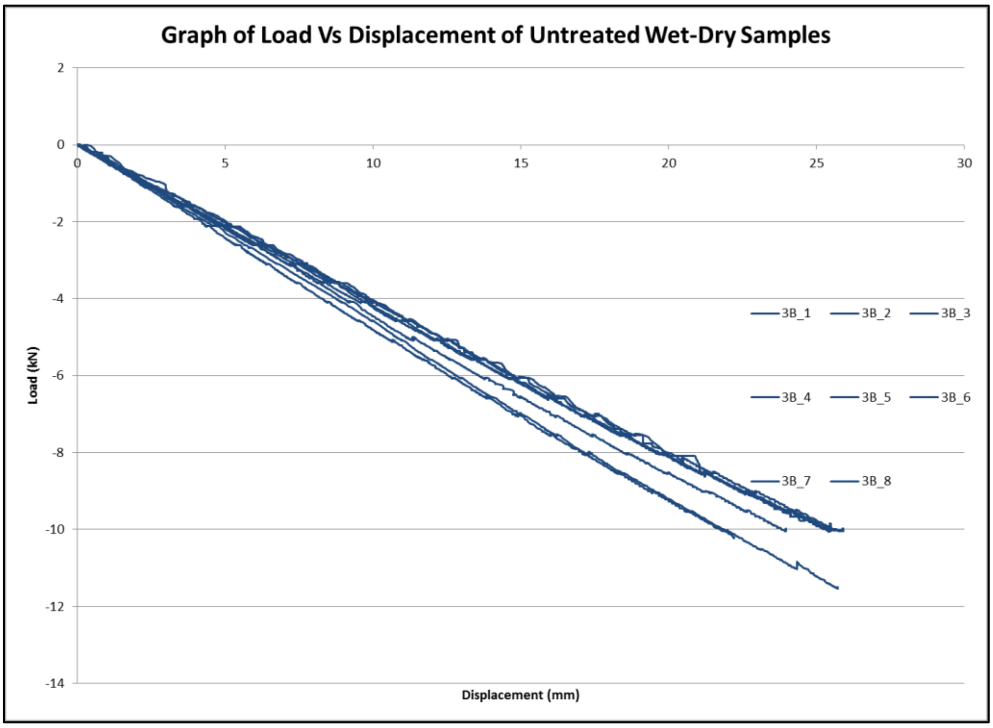


FIGURE C6: LOAD VS DISPLACEMENT GRAPHS OF UNREATED JOISTS (WET-DRY SAMPLES)

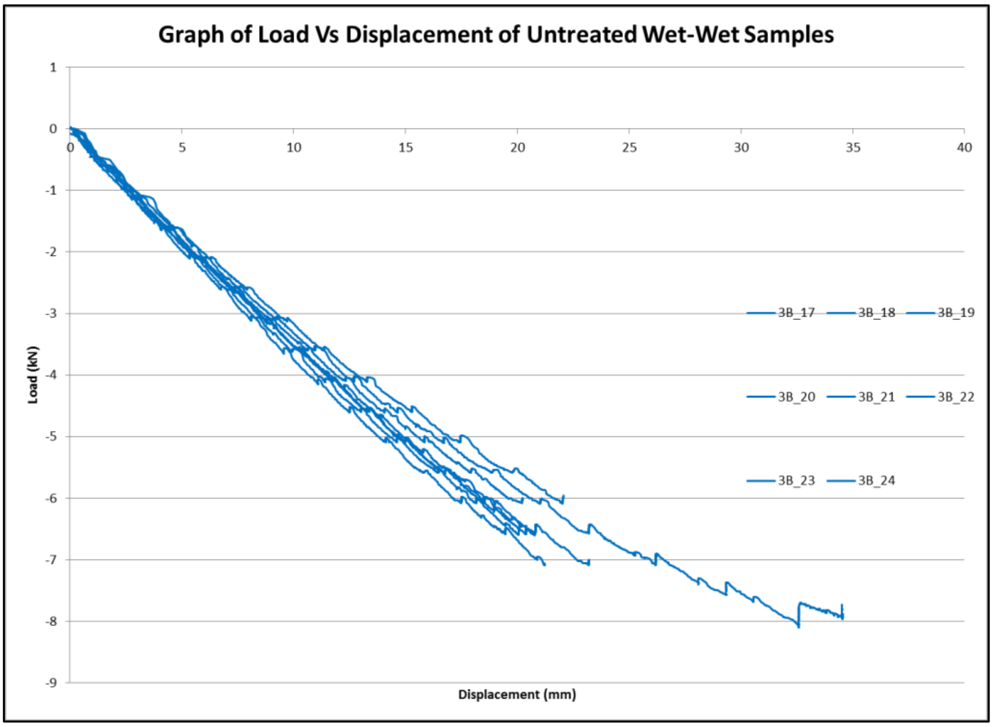


FIGURE C7: LOAD VS DISPLACEMENT GRAPHS OF UNTREATED JOISTS (WET-WET SAMPLES)

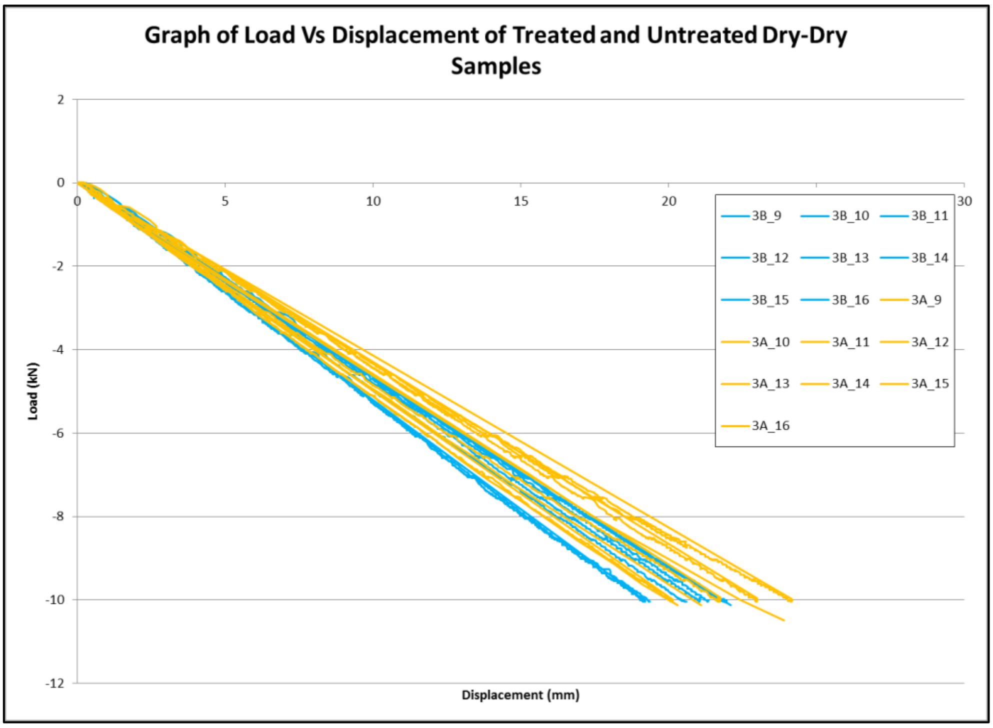


FIGURE C8: LOAD VS DISPLACEMENT GRAPHS OF H2 TREATED AND UNREATED JOISTS (DRY-DRY SAMPLES)

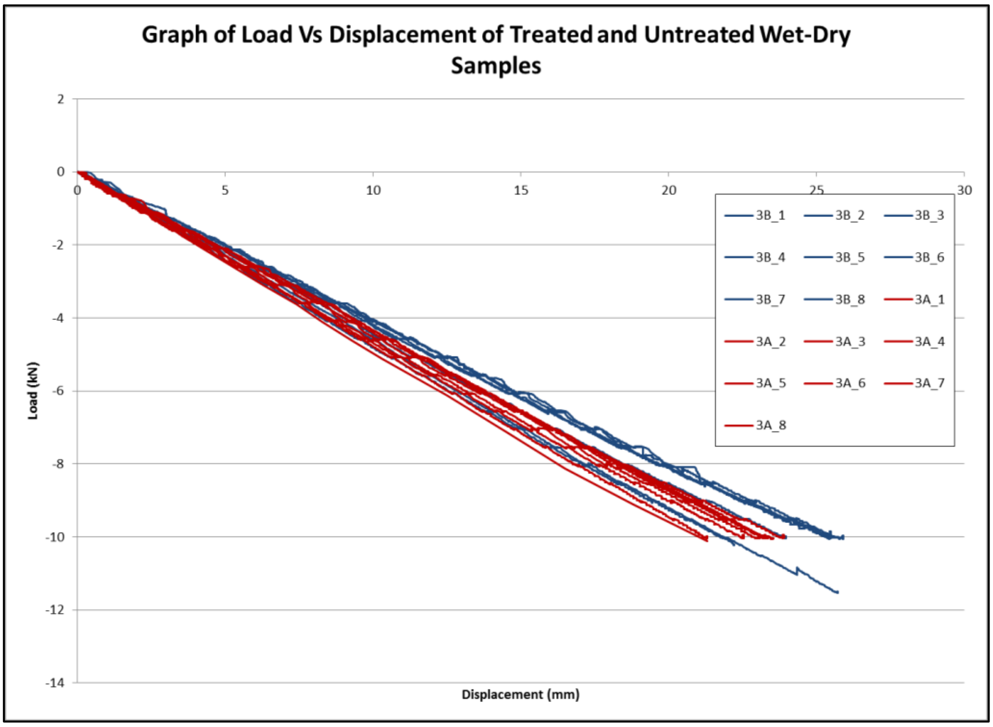


FIGURE C9: LOAD VS DISPLACEMENT GRAPHS OF H2 TREATED AND UNREATED JOISTS (WET-DRY SAMPLES)

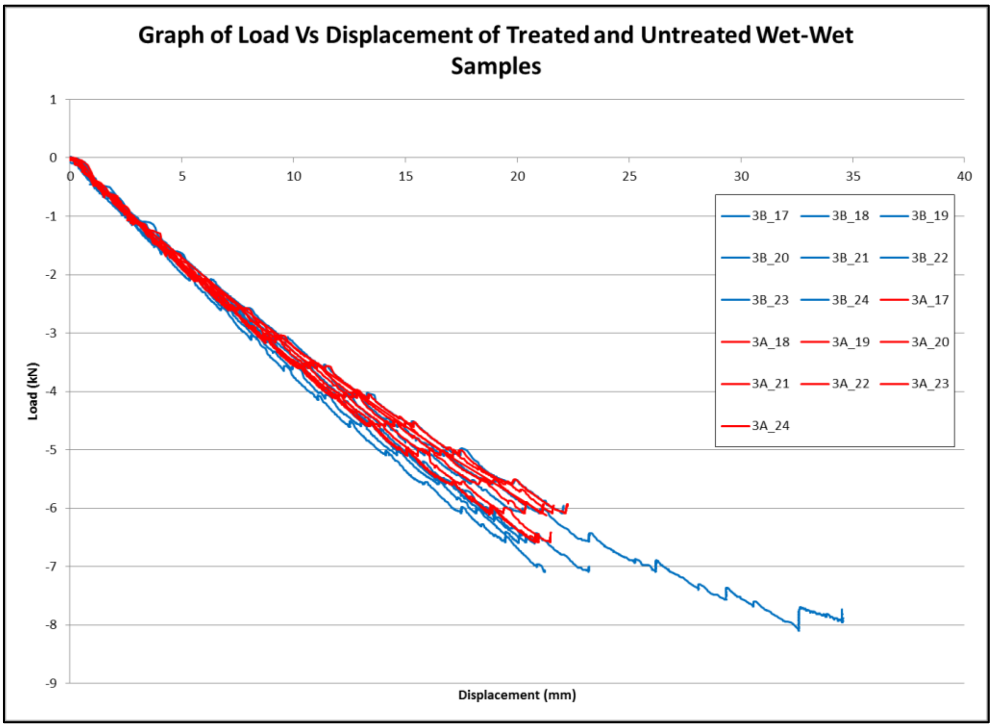


FIGURE C10: LOAD VS DISPLACEMENT GRAPHS OF H2 TREATED AND UNREATED JOISTS (WET-WET SAMPLES)

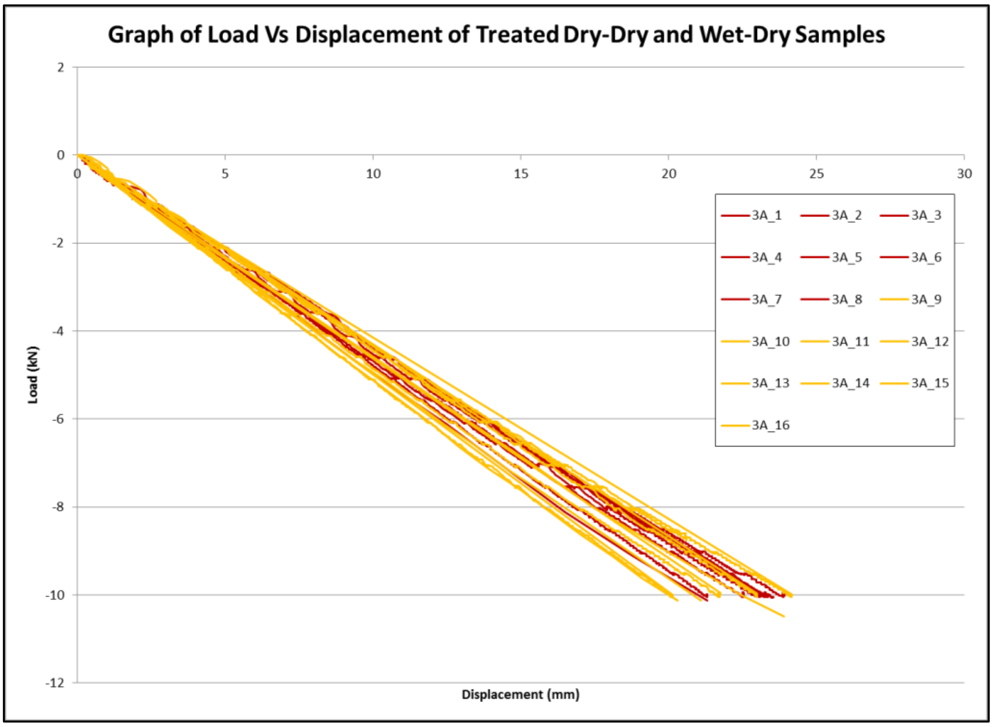


FIGURE C11: LOAD VS DISPLACEMENT GRAPHS OF H2 TREATED JOISTS (DRY-DRY AND WET-DRY SAMPLES)

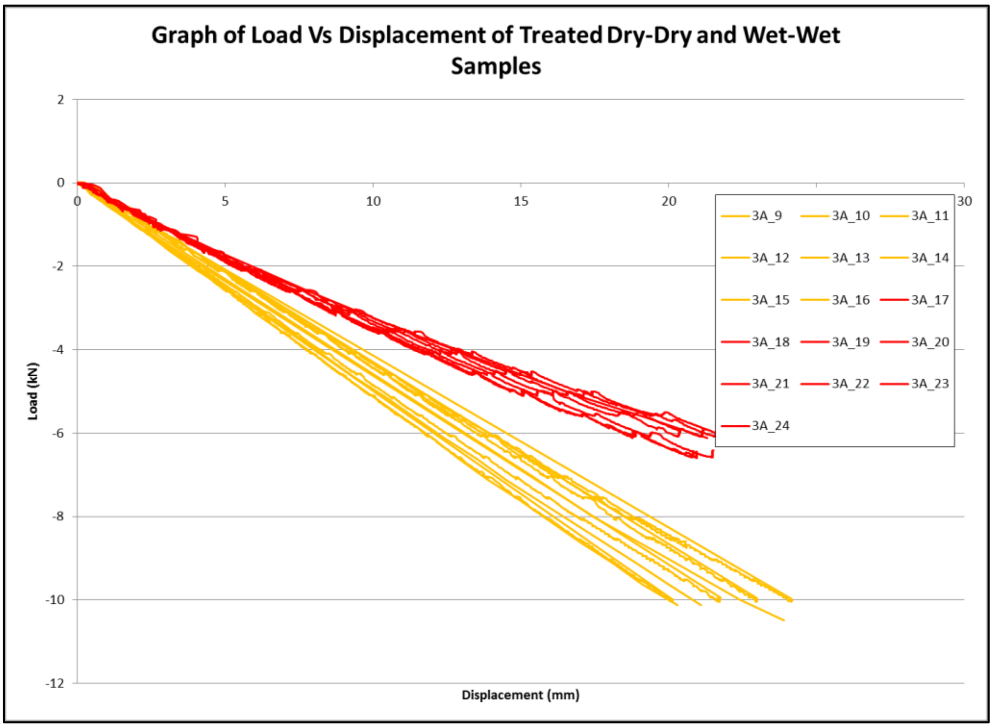


FIGURE C12: LOAD VS DISPLACEMENT GRAPHS OF H2 TREATED JOISTS (DRY-DRY AND WET-WET SAMPLES)

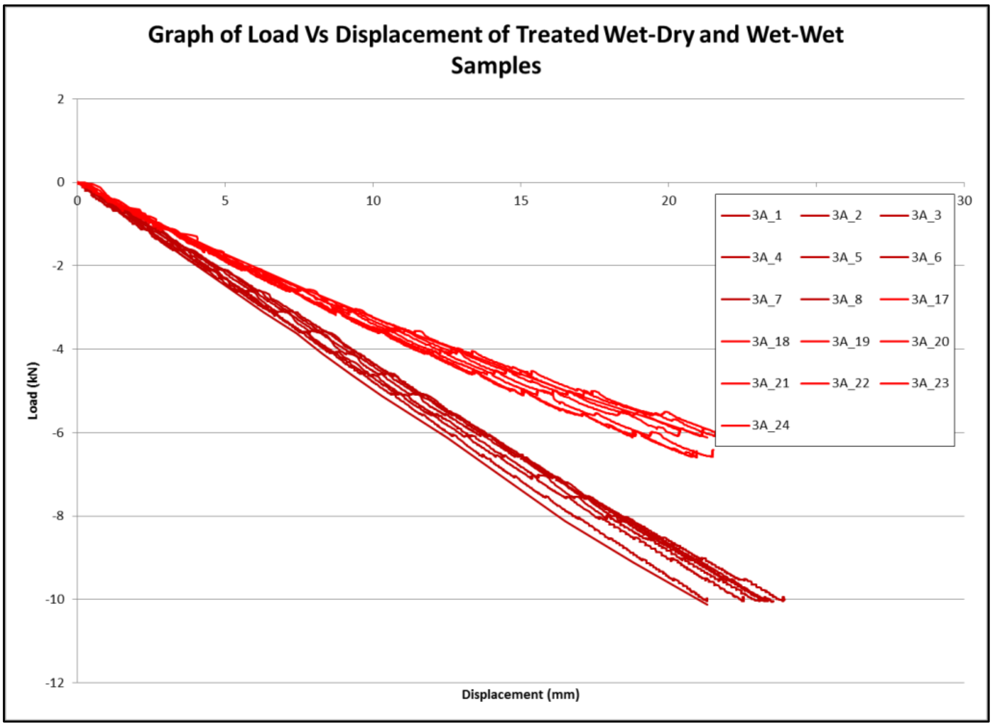


FIGURE C13: LOAD VS DISPLACEMENT GRAPHS OF H2 TREATED JOISTS (WET-DRY AND WET-WET SAMPLES)

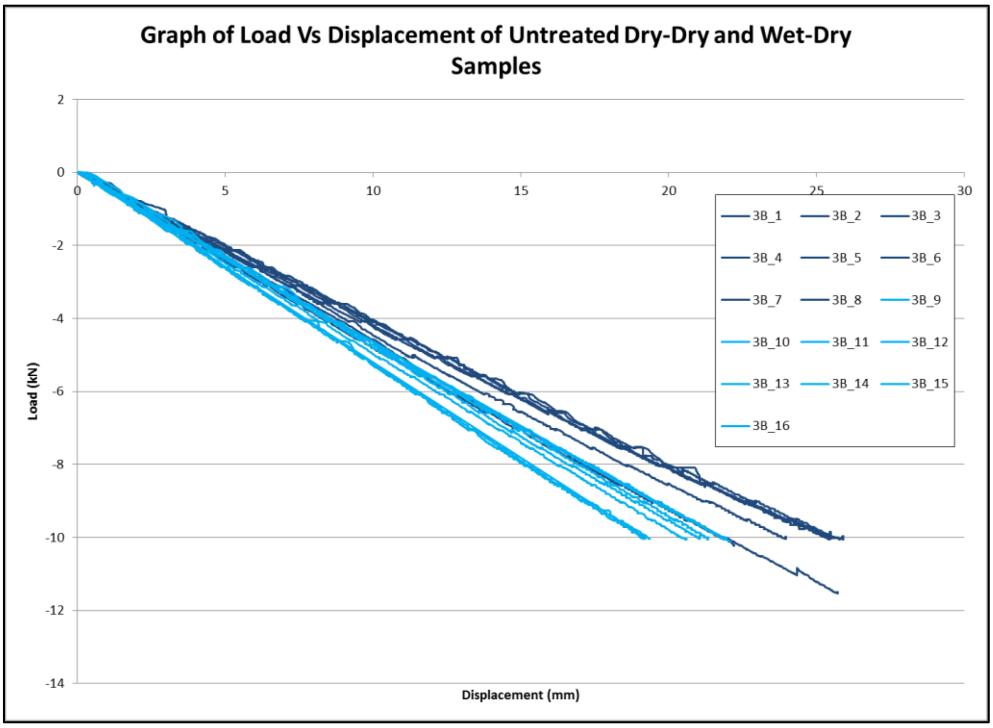


FIGURE C14: LOAD VS DISPLACEMENT GRAPHS OF UNTREATED JOISTS (DRY-DRY AND WET-DRY SAMPLES)

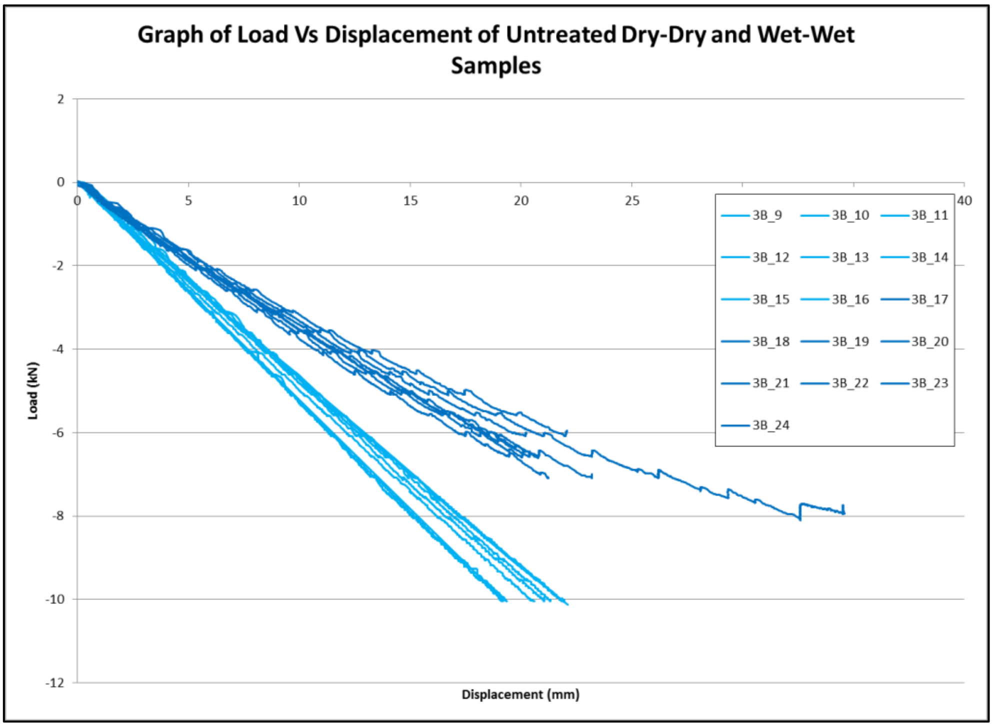


FIGURE C15: LOAD VS DISPLACEMENT GRAPHS OF UNTREATED JOISTS (DRY-DRY AND WET-WET SAMPLES)

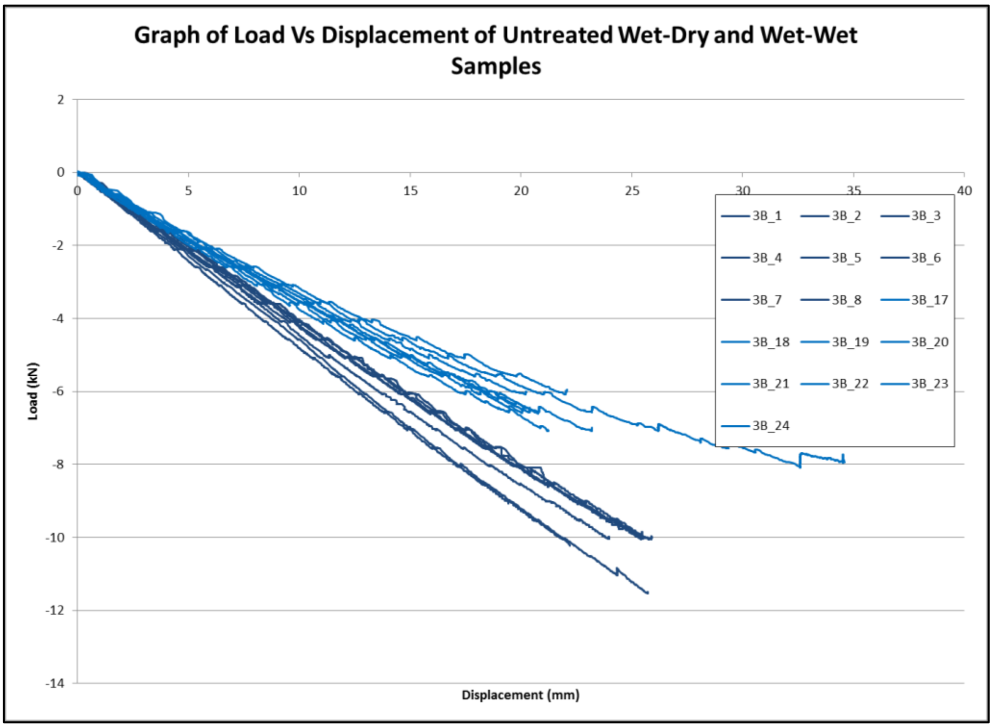


FIGURE C16: LOAD VS DISPLACEMENT GRAPHS OF UNTREATED JOISTS (WET-DRY AND WET-WET SAMPLES)

Figure C17 to Figure C28 show the typical failure in all the samples for Test Type 3.

FIGURE C17: FAILURE OF H2 TREATED TIMBER 'I' SECTIONS DRY-DRY SAMPLES: TOP AND BOTTOM RUPTURE AND CRACKED WEB

FIGURE C18: FAILURE OF H2 TREATED TIMBER 'I' SECTIONS DRY-DRY SAMPLES: BOTTOM FLANGE RUPTURE AND WEB DISLODGED FROM FLANGES

FIGURE C19: FAILURE OF H2 TREATED TIMBER 'I' SECTIONS WET-DRY SAMPLES: TOP FLANGE COLLAPSE (LOCALISED BUCKLING) AT LOADING POINTS

FIGURE C20: FAILURE OF H2 TREATED TIMBER 'I' SECTIONS WET-DRY SAMPLES: BOTTOM FLANGE RUPTURE AND WEB DISLODGED FROM FLANGES

FIGURE C21: FAILURE OF H2 TREATED TIMBER 'I' SECTIONS WET-WET SAMPLES: TOP FLANGE COLLAPSE (LOCALISED BUCKLING) AT LOADING POINTS

FIGURE C22: FAILURE OF H2 TREATED TIMBER 'I' SECTIONS WET-WET SAMPLES: WEB DISLODGED FROM FLANGES

FIGURE C23: FAILURE OF UNTREATED TIMBER 'I' SECTIONS DRY-DRY SAMPLES: TOP AND BOTTOM RUPTURE AND CRACKED WEB

FIGURE C24: FAILURE OF UNTREATED TIMBER 'I' SECTIONS DRY-DRY SAMPLES: TOP AND BOTTOM FLANGES CRACKED AT WEB JOINT

FIGURE C25: FAILURE OF UNTREATED TIMBER 'I' SECTIONS WET-DRY SAMPLES: TOP FLANGE COLLAPSE (LOCALISED BUCKLING) AT LOADING POINTS

FIGURE C26: FAILURE OF UNTREATED TIMBER 'I' SECTIONS WET-DRY SAMPLES: TOP FLANGE SPLIT LONGITUDINALLY AND BUCKLED

FIGURE C27: FAILURE OF UNTREATED TIMBER 'I' SECTIONS WET-WET SAMPLES: TOP FLANGE COLLAPSE (LOCALISED BUCKLING) AT LOADING POINTS

FIGURE C28: FAILURE OF UNTREATED TIMBER 'I' SECTIONS WET-WET SAMPLES: TOP FLANG AND WEB COLLAPSE