Study Report

SR399 [2018]

The effects of humidity on gypsum plasterboard used as lateral load bracing for buildings

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The effects of humidity on gypsum plasterboard used as lateral load bracing for buildings

BRANZ Study Report SR399

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Abstract

Currently in New Zealand, a major portion of 1 and 2-storey buildings are constructed to NZS 3604:2011 *Timber-framed buildings* using light timber framing with gypsum plasterboard linings serving as the primary lateral load-resisting system. Due to the nature of the materials comprising plasterboard, environmental moisture levels have the potential to reduce the effectiveness of plasterboard as a structural component. This includes potentially lower earthquake and wind bracing ratings as determined using the P21 test method. This project investigated the relationships between and the performance of plasterboard linings as lateral load-resisting elements in buildings. Testing was conducted on plasterboard at different humidity levels to determine how fastener holding capacity was affected. Results were considered in the context of humidity levels that would likely be experienced in these low-rise buildings throughout New Zealand. The results indicated there was some degradation in plasterboard performance at higher humidity levels. However, the decreases were not considered to be significant enough to warrant changes in current test standards and building practices for buildings constructed according to NZS 3604:2011.

Keywords

Absolute humidity, relative humidity, gypsum plasterboard, bracing walls, bracing performance, P21.

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1. Introduction and background

Currently in New Zealand, a major portion of 1 and 2-storey buildings are constructed to NZS 3604:2011 *Timber-framed buildings* using light timber framing with gypsum plasterboard linings serving as the primary lateral load-resisting system. Due to the nature of the materials comprising plasterboard, environmental moisture levels have the potential to reduce the effectiveness of plasterboard as a structural component. This includes potentially lower earthquake and wind bracing ratings as determined using the P21 test method (Shelton, 2010). Proprietary research on products being frequently used in New Zealand has further supported the notion that increased moisture levels can result in lower than expected performance. This includes lower earthquake and wind bracing ratings as determined using the P21 test method. Based on these findings, it is important to determine if there is a predictable relationship between humidity and bracing performance of plasterboard linings. This will allow designers to have confidence that buildings will provide adequate resistance to applied loads across a range of expected environmental conditions.

There is an understanding that plasterboard lining materials contribute to the bracing performance of light timber-framed buildings (Cobeen, Russell & Dolan, 2004). Many parts of the world include some minimal contribution to bracing resistance from plasterboard. However, Australia and New Zealand allow for 50% and 100% of lateral bracing resistance to be contributed by plasterboard linings under AS 1684.2-2010 *Residential timber-framed construction* and NZS 3604:2011, respectively. There are limitations on the size and use of buildings to which these bracing methods can be applied according to NZS 3604:2011. In New Zealand, approximately 90% of recently constructed 1 and 2-storey houses are braced against earthquake and wind loads using plasterboard linings attached to timber framing (Rosevear & Curtis, 2017).

There is evidence that New Zealand buildings using plasterboard linings as bracing can effectively resist required lateral loads in both experimental and real earthquake scenarios. It was found following the February 2011 Canterbury earthquake sequence that plasterboard linings in houses were very effective at resisting seismic loads (Buchanan et al., 2011; Beattie, Shelton & Thomas, 2015). There were also no collapses of buildings using primarily plasterboard for bracing. Shake table testing of a three-dimensional specimen (Thurston, 2012) has also confirmed that plasterboard linings on timber framing can be used as an effective bracing system. This research also showed that, if anything, P21 tests provided a conservative estimate of bracing resistance for plasterboard-lined walls.

At present, there are no specific requirements in the P21 test method regarding humidity conditions, although Section 9 includes information on conditioning of specimens. It specifies that specimens shall be tested and built in conditions representative of anticipated construction and in-service conditions. Timber frame moisture content is required to be a maximum of 18%. It is required that temperature and humidity conditions during construction and testing be recorded but not reported in detail. It is also stated that materials may be conditioned to 20°C and 65% relative humidity prior to testing, but no further information is provided.

Most plasterboard is comprised of paper facings with primarily gypsum cores – both hygroscopic materials that can be affected by water. This raises the question of whether there is a need to evaluate moisture effects on plasterboard performance to inform future versions of the P21 test method. Such an evaluation will ensure that the

P21 test method remains a comprehensive and relevant method for evaluating bracing ratings of plasterboard-based lateral load-resisting wall systems in New Zealand.

As markets have grown in New Zealand over the past decade, there are now several suppliers of gypsum plasterboard, all of which may have products that are affected differently by moisture conditions. Therefore, it is important to determine how significant these effects can be on performance and whether there is a need to account for them either in P21 tests or in building designs using plasterboard for bracing. This will allow recommendations to be made for improving the accuracy of bracing ratings as determined using the P21 test method as required for designs according to NZS 3604:2011.

There are a number of parameters that can affect P21 test performance and the performance of walls in buildings using plasterboard as the primary bracing element. Because the testing equipment and data analysis methods in the P21 method are not highly prescriptive, test results can be variable. There are differences in testing rigs and equipment at different laboratories around New Zealand. While all equipment and methods are allowed by the P21 test method, different bracing ratings can result between laboratories and specimens.

Individual test specimens can also contain sources of variability that show up in P21 test results. The moisture content and density of timber, installation of the screws securing plasterboard to timber framing (possibly overdriven), variation in plastering and methods of load application can all contribute to the variability of P21 test results. In addition, building weathertightness, quality of plasterboard installation, final coatings and details for trim at floors and ceilings can affect bracing performance in buildings in different ways.

This project was undertaken to look at moisture as a potential source of variability that could result in incorrect bracing ratings as determined by the P21 test method. It was also considered valuable to determine typical humidity conditions occurring within buildings as a means of identifying potential moisture levels in the event that negative impacts on bracing performance were observed at higher humidity conditions.

2. Test materials and methods

This research project focused on conducting plasterboard connection tests at different humidity levels and determining from these tests the effects of different humidity levels on the fastening capacity of plasterboard as a measure of bracing performance. Six different types of plasterboard from three manufacturers were tested as a representation of the range of products from the primary suppliers of plasterboard in New Zealand.

To establish some context for the humidity test levels, information was gathered on commonly occurring environmental conditions in buildings in New Zealand. Using these data, preliminary bending tests were conducted on the plasterboard products to further establish appropriate humidity levels for the cyclic connection tests. Following the connection tests, analyses were conducted to determine whether:

- there were significant differences in the performance of plasterboard and its fixings at different humidity levels
- these differences would result in artificially reduced bracing ratings or possibly in-service performance.

A summary is provided in Section 4 on the findings, and conclusions are drawn regarding the effects of humidity on plasterboard performance.

2.1 Plasterboard materials tested

There are currently three main suppliers of plasterboard for the New Zealand building market – Winstone Wallboards, Elephant Plasterboard and USG Boral. Each of these suppliers has a range of products that are used for wall linings and have different properties for fire resistance, bracing, wet area use and other applications.

For this project, two plasterboard types were selected from each manufacturer – a standard plasterboard and a bracing plasterboard. All tested plasterboard was nominally 10 mm thick. Plasterboard products used for testing are shown in Table 1.

Table 1. Plasterboard manufacturers and tested plasterboard products.

Manufacturer	Plasterboard tested
Elephant Plasterboard	Standard-Plus
Winstone Wallboards	GIB® Standard
USG Boral	Sheetrock®
Elephant Plasterboard	Multiboard
Winstone Wallboards	GIB Braceline®
USG Boral	Fiberock®

At the time of product selection, these were considered the most applicable products for standard and bracing applications. The testing and analysis were blind, and no performance characteristics were matched to specific manufacturers or products. Plasterboard specimens were taken from typical 1.2 x 2.4 m sheets that were either purchased from retailers or provided directly from manufacturer inventory.

2.2 Building internal humidity evaluation

In order to determine the temperature and humidity levels to be used for testing, it was necessary to identify the environmental conditions plasterboard is exposed to in an average building. It is also important to consider what sort of laboratory environmental conditions are likely to be in cases where P21 specimens and materials are not typically conditioned but tested at ambient laboratory conditions. Data was obtained from different sources to establish a likely range of temperature and relative humidity (RH) conditions occurring in New Zealand buildings. These sources included data from BRANZ Study Report SR329 (Burrough, Saville-Smith & Pollard, 2015) as well as data from around the BRANZ campus in Judgeford.

Burrough et al. (2015) obtained data for a series of 168 randomly selected houses around New Zealand that were instrumented to gather temperature and RH data. From this original data, absolute humidity (AH) data throughout the course of an entire year was calculated for the houses. AH was identified as the crucial parameter for this study as it represents the mass of water present in the air per volume (Vaisala, 2013) and is a function of both temperature and RH. For privacy reasons, specific details on the houses other than the general area in which they are located were not included. Due to this lack of detail, it was not known what year the houses were constructed or to what building codes. Nevertheless, it was assumed that they represented a broad range of house styles and vintages. This removed bias based on the type of house or construction. It is also worth noting that all of these houses included a heat pump as part of their heating scheme. Recent research has indicated that unheated rooms in houses can have significantly higher moisture levels than those recorded for this report (Pollard, 2017).

Table 2 provides a summary of the AH data. All values shown are average values over the data obtained for each location.

Table 2. Summary of AH (g/m^3) for houses throughout New Zealand.

Location	No. of houses	Min.	10% quantile	Average	90% quantile	95% quantile	Max.
Auckland	32	5.4	8.2	10.5	13.0	13.9	18.1
Blenheim	4	3.9	5.8	8.2	10.7	11.4	15.2
Canterbury	45	4.2	6.5	8.5	10.6	11.2	15.5
West Coast	2	5.1	7.9	10.0	12.4	13.0	16.1
Gisborne	3	4.4	6.7	9.4	12.6	13.5	19.5
Hawke's Bay	7	4.6	6.9	9.1	11.6	12.3	16.2
Hamilton/Waikato	13	4.5	7.3	9.9	12.7	14.0	18.6
Nelson	3	3.8	6.1	8.7	11.7	12.4	15.6
Wanganui/Manawatu	6	4.8	7.4	9.8	12.4	13.4	17.7
Northland	3	5.6	8.2	10.8	13.8	15.0	19.8
Otago	15	3.4	5.8	7.7	9.8	10.4	14.3
Bay of Plenty	10	4.7	7.0	9.5	12.3	13.1	16.7
Taranaki	3	4.5	7.2	9.4	11.9	12.5	14.8
Southland	4	4.2	6.1	8.1	10.2	10.8	14.8
Tasman Bay	3	4.0	6.2	8.9	11.8	12.6	15.7
Wellington/Wairarapa	15	4.9	7.4	9.4	11.6	12.3	15.4

The temperature and humidity data obtained for the BRANZ site in Judgeford included interior building and two different laboratory environments and were recorded for a 1-year period. The data was very similar to the data in Table 2 for the Wellington/Wairarapa region, even considering that the laboratories would often have large roller doors open during the day, especially during the summer months.

This body of data was useful for this project because it provided an understanding of the expected AH conditions for buildings throughout New Zealand and provided some targets for the AH conditions to be used for the next phase of the project. It also provided a basis for comparing the performance of the plasterboard at different AH levels that are likely to be encountered in buildings throughout New Zealand.

2.3 Testing methods for plasterboard

Testing standards for plasterboard in general do not consider the material as a bracing element in buildings. It was therefore necessary to consider alternative methods for assessing the bracing performance of these materials at different levels of humidity. Methods exist for assessing properties of plasterboard in New Zealand according to AS/NZS 2588:1998 *Gypsum plasterboard*. This standard includes test methods for a variety of properties including bending strength, dimensions and effects of high humidity on bending strength. However, it does not specifically assess the in-plane bracing capacity of the plasterboard. It also does not consider the capacity of fixings working in shear between the plasterboard and timber framing, which is the primary load-resisting mechanism for bracing panels.

There has been some research on developing test methods that specifically consider the bearing capacity of connections between the plasterboard and timber framing as it relates to bracing (Liew, Gad & Duffield, 2008). While this work provided some good methods for testing plasterboard for bracing, it was limited in that it considered nailed connections and it was only applicable for monotonic loading. Plasterboard in New Zealand is most commonly attached using screws and must be evaluated for cyclic performance due to earthquake loading, thereby limiting the application of this testing method.

Traditionally at BRANZ and other testing laboratories around New Zealand, fastener and connection testing has been performed using slip tests done in accordance with BRANZ Evaluation and Test Method EM1 (BRANZ, 1999). This method has provisions for cyclic testing and was developed to be material neutral and general in nature so that it can be used for a wide range of base materials and connection types. Fastener slip testing was conducted in general accordance with methods described in EM1 using laminated veneer lumber as a substrate with plasterboard segments attached using two typical 32 mm long 6-gauge plasterboard screws. Slip testing is described in detail in Section 3.2.

While the most applicable test of plasterboard bracing performance is considered to be the P21 test method, this is a test of an entire wall system and is known to provide variable results, as previously discussed. It is also cumbersome to condition full-scale P21 test specimens to different environmental conditions due to the size and complexity of the wall segments. It was decided that fastener slip tests would be more appropriate and manageable for assessing the effects of different humidity levels on plasterboard. No P21 tests were conducted for this research project. None of the plasterboard tested was painted or finished as it would be in practice once installed in buildings.

2.3.1 Bending tests

The initial testing phase of the project included conditioning samples of the six types of plasterboard to different environmental conditions and conducting bending tests according to AS/NZS 2588:1998 Appendix C. This testing was conducted in order to get some understanding about how different humidity levels would affect the flexural strength of different plasterboard materials. This was not done to assess bracing performance but rather to get an idea of the impacts of humidity on the mechanical properties of the plasterboard. It was also important to determine how quickly plasterboard would achieve equilibrium under different environmental conditions to inform how quickly specimens would need to be tested once removed from the conditioned chamber.

Based on the collected data previously discussed, the AH levels provided in Table 3 were used for testing to see how quickly plasterboard specimens achieved equilibrium and at what point there were significant changes in strength or stiffness using flexural testing. These levels were determined using the data available and considering what levels of AH are likely to occur within New Zealand buildings. The levels selected were on the higher end of the range of what was identified. As previously noted, these were based on heated rooms and likely to be lower than actually occurring levels.

Table 3. Environmental conditions used for flexural testing of plasterboard.

Conditioning number	Temperature (°C)	RH (%)	AH (g/m^3)
1	20	50	8.7
2	20	65	11.3
3	25	50	11.6
4	24	65	14.3
5	24	85	16.0
6	24	77	16.9
7	31	77	21.0
8	24	97	21.2
9	31	76	24.5

Bending test specimens of 300 x 400 mm were cut from full plasterboard sheets. All specimens were configured with the long axis of the specimen parallel to the long axis of the original sheet and with all edges cut. Some of the first groups of specimens to be tested had tape placed along the cut edges to see if this would affect the rate of achieving equilibrium. The time for specimens to achieve equilibrium in the conditioning chambers varied between 9 and 14 days with differences observed between products and environmental conditions. Equilibrium was determined by weighing selected specimens and was reached when the weights stabilised between daily measurements. The taping of the edges did not affect the time required to achieve equilibrium and the following specimens were equilibrated and tested without taping the edges. Once specimens had equilibrated at the specified conditions (see Table 3) they were removed one at a time from the conditioning chambers and tested as quickly as possible.

Bending tests were conducted using three-point bending over a 356 mm span using supports and loading head as described in AS/NZS 2588:1998 Appendix C. Specimens were loaded at a rate of 25 mm per minute up the point of failure, with load and mid-span deflections recorded using a computer-controlled data acquisition system. For each type of plasterboard used for the different environmental conditions, four specimens were taken from different plasterboard sheets, with two tested face up and two tested face down as defined in the test standard. The maximum load for each test was considered to provide a suitable comparison to the bending strength of the specimen. These were compared across the different conditions as a means of determining the effects of the conditions on the plasterboard (see Section 3.1).

2.3.2 Fastener slip tests

The conditioning and flexural tests provided results that identified AH and RH levels where the bending strength of the plasterboard started to have a noticeable decrease from the less humid conditions. This provided information that informed the environmental condition levels selected for connection tests conducted to assess the effects of humidity on plasterboard bracing performance. It was found that RH tended to have a more direct relationship to decreasing performance than AH. Therefore, RH was included in the analysis of results and determination of environmental levels for connection testing. Temperature and environmental conditions used for the plasterboard connection testing are presented in Table 4.

Table 4. Environmental conditions used for plasterboard connection slip testing.

Test description	Temperature (°C)	RH (%)	AH (g/m^3)
Baseline	23	50	10.3
Test level A	20	80	13.8
Test level B	20	90	15.6
Test level C	25	50	11.5
Test level D	25	80	18.4

Slip test specimens consisted of a block of laminated veneer lumber (LVL) with a segment of plasterboard fixed to the LVL using two 6-gauge by 32 mm plasterboard screws as shown in Figure 1.

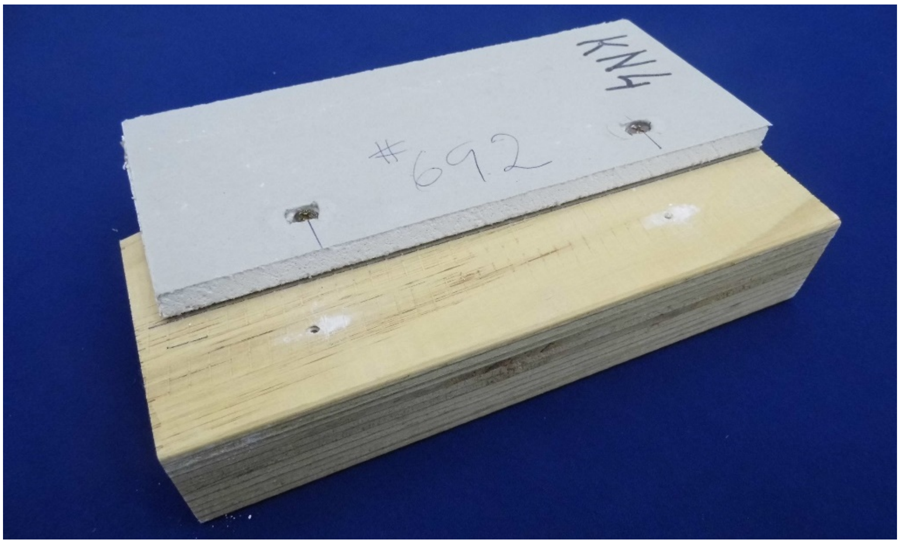

Figure 1. Plasterboard slip testing specimen

The LVL blocks were 240 mm long and cut from 45 x 90 mm material. The plasterboard segments were 100 x 230 mm and were all taken from the centre of sheets, no closer than 100 mm from a bound or factory-cut edge. All specimens were configured with the long axis of the specimen parallel to the long axis of the original sheet. Test configurations consisted of 10 replicate specimens taken from different plasterboard sheets. Screws were installed 50 mm in from each end using an edge distance of 18 mm to the centre of the screw. LVL was used for this testing as it is known to have less variability in mechanical properties than sawn timber. Screws were oriented so they were perpendicular the glue lines in order to avoid any splitting of the LVL and to avoid effects of individual veneer property differences.

The LVL blocks were conditioned in a constant climate chamber at 23°C and 50% RH for all test specimens to avoid variations in moisture content. Plasterboard segments were placed in conditioning chambers under conditions in Table 4 and allowed to achieve equilibrium using methods described for bending test specimens. Once the plasterboard specimens reached equilibrium, they were removed in small batches from the conditioning chamber, screwed to the LVL blocks and kept in a sealed plastic container until tested.

Times to equilibrium were less than those for the bending test specimens, ranging between 3 and 7 days, and this was attributed to the smaller size of the slip test specimens. Equilibrium was reached when regularly weighed specimens did not exhibit significant changes in weight from previous weight measurements. Assembled test specimens were clamped into the test fixture shown in Figure 2.

Figure 2. Assembled slip test specimen following testing.

The lower part of the two-part fixture held the plasterboard segment securely and was fixed rigidly to the bottom platen of the universal test frame. The LVL block was clamped to a separate upper fixture that was connected to the crosshead of the test frame, and loads were induced by moving the test frame crosshead.

Vertical load was applied to specimens with a 100 kN closed-loop electro-hydraulic ram and measured with a 10 kN load cell. The slip was measured using the displacement transducer integral to the test frame ram, which measured the differential movement between the LVL and the plasterboard. The test load and displacement measurements were recorded using a computer-controlled data acquisition system.

The loading protocol included three cycles at displacement levels of ±0.5 mm, ±1.0 mm, ± 2.0 mm, ±3.0 mm, ±4.0 mm, ±5.0 mm and ±6.0 mm. The rate of loading was 1.0 mm per minute for all displacement levels.

3. Test results and comparisons

Results for bending and slip tests were collated and compared to determine the effects of different environmental conditions on the plasterboard as well as the connections between plasterboard and the LVL substrate. The bending test results were used to inform humidity levels for the slip testing. Slip testing results were used to assess the effects of humidity on the connection performance between the plasterboard and a timber-based substrate. This was considered an indicator of bracing performance of systems using plasterboard linings screwed to timber framing. (Note that products are intentionally not identified due to the blind nature of testing.)

3.1 Bending tests

It was initially thought that AH would provide some clear trend in terms of a relationship between plasterboard performance, bending strength and humidity. Analysis of average maximum bending strength data as a function of AH for the six different products resulted in the graphs shown in Figure 3 and Figure 4. These results indicated that there was little degradation in bending capacity until the AH had reached a high level, but this was not a clear trend considering some higher AH levels resulted in greater strength. Overall, these results did not provide a clear relationship between AH and bending strength.

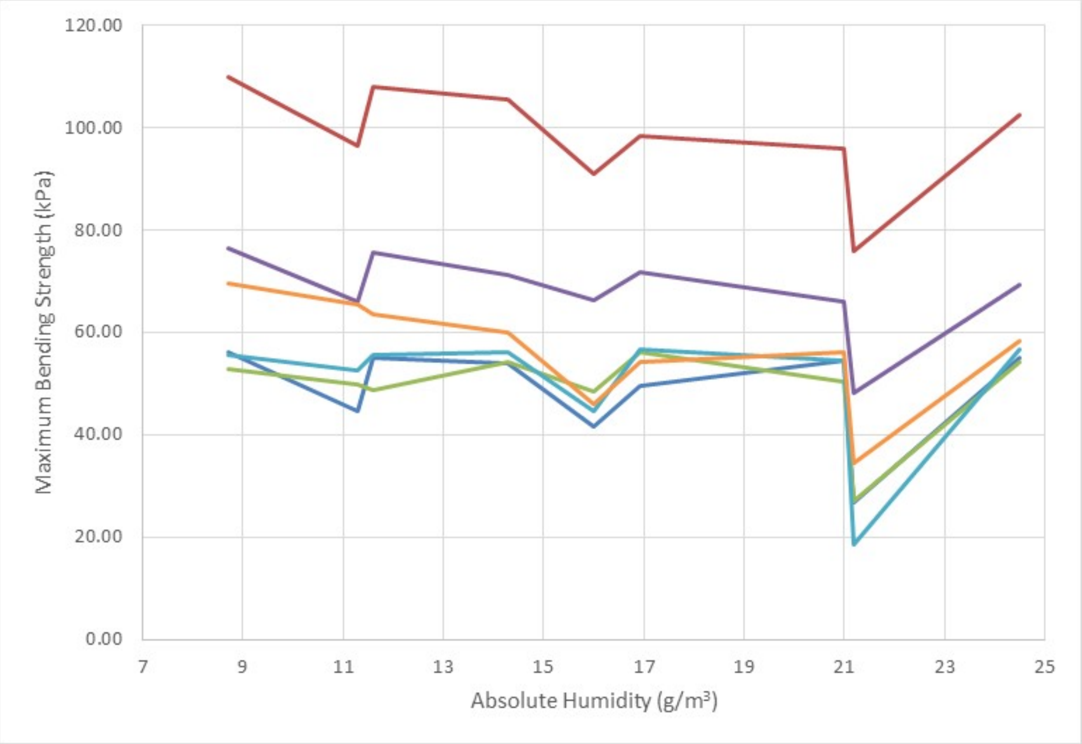

Figure 3. Plasterboard maximum bending strength (face up) plotted against AH for six plasterboard products.

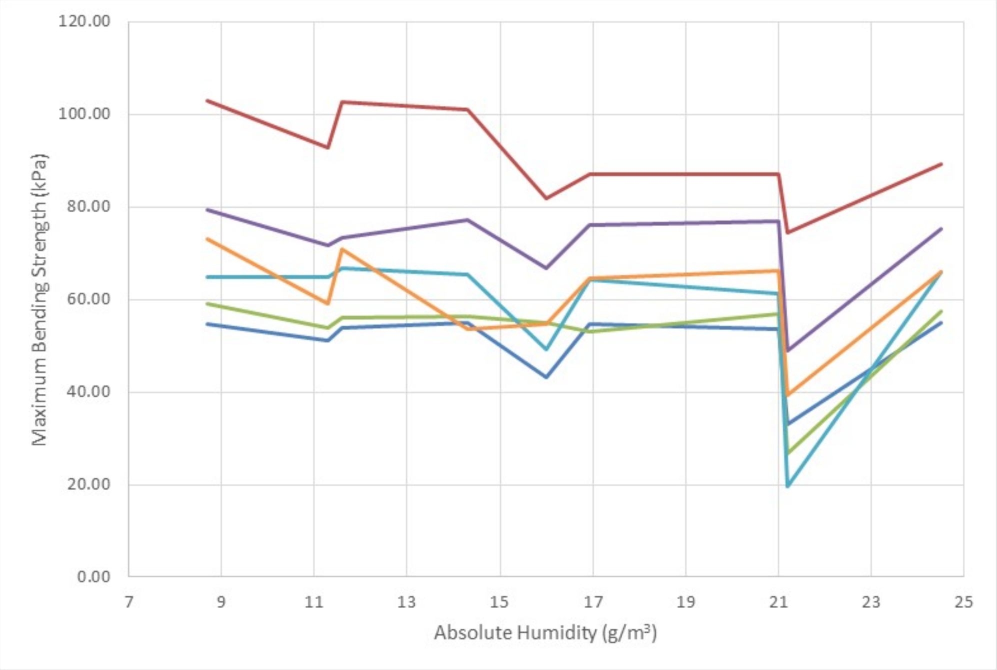

Figure 4. Plasterboard maximum bending strength (face down) plotted against AH for six plasterboard products.

The data was further analysed to consider the relationship between RH and bending strength (maximum applied load). The RH analysis results are shown in Figure 5 and Figure 6.

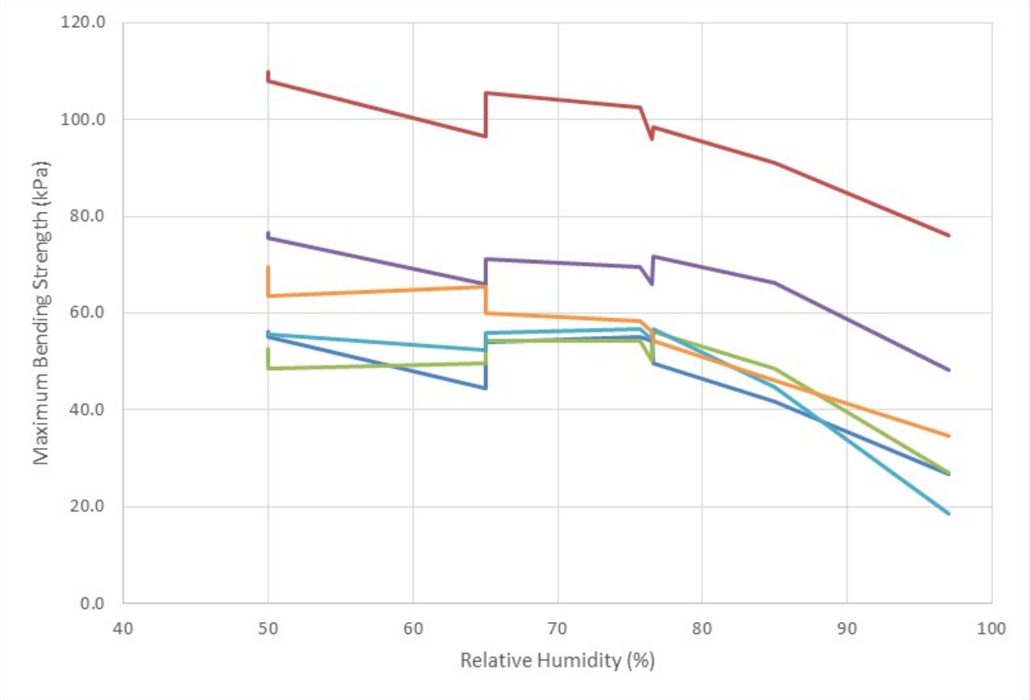

Figure 5. Plasterboard maximum bending strength (face up) plotted against RH for six plasterboard products.

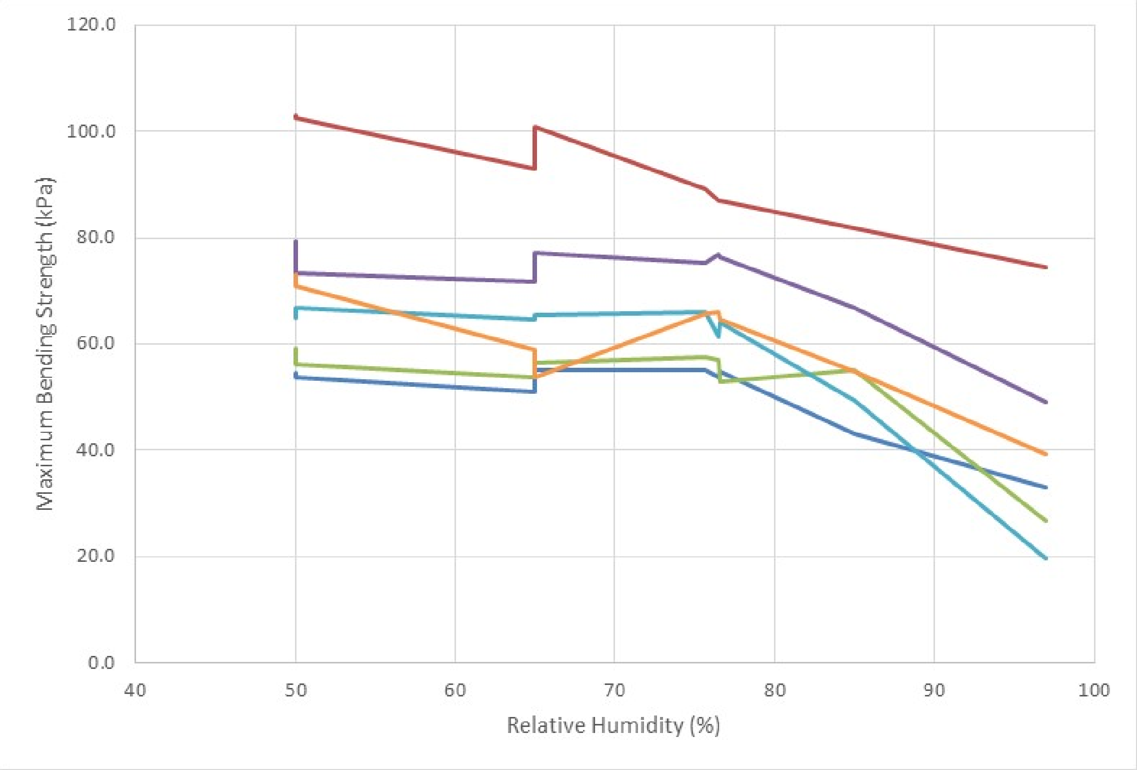

Figure 6. Plasterboard maximum bending strength (face down) plotted against RH for six plasterboard products.

Using RH rather than AH showed a more distinct trend on the effect humidity was having on the bending performance of plasterboard. These results suggest that, for the majority of products tested, for up to 75% RH, there is negligible loss in strength. However, beyond 75% RH, there are continued decreases in strength up to 97% RH, the maximum RH tested for this project. The bending test results were used to derive the environmental levels presented in Table 4 that were then used for the fastener slip testing.

3.2 Fastener slip tests

Slip testing was performed under different environmental conditions to assess the effects of humidity on the connection capacity of the plasterboard screwed to an LVL substrate. The resulting data from each test provided a series of hysteresis loops, and a typical example is shown in Figure 7. The + and ∆ symbols on the plot illustrate where the first and fourth cycle peak values were extracted. Although only three cycles were imposed at each deflection limit, the peak value was measured on reloading through this deflection to the next deflection level. Thus, the extracted peak is referred to as the fourth cycle peak. First and fourth cycle peak loads were extracted from test data for each displacement level and averaged across sets of replicate specimens. Average first and fourth cycle peak backbone curves were created for each set of replicates as shown in Figure 8. These were then compared across products for different humidity levels to assess the impact of the different environmental conditions on the slip test results as shown in Figure 9 for first cycle peak data on one of the products.

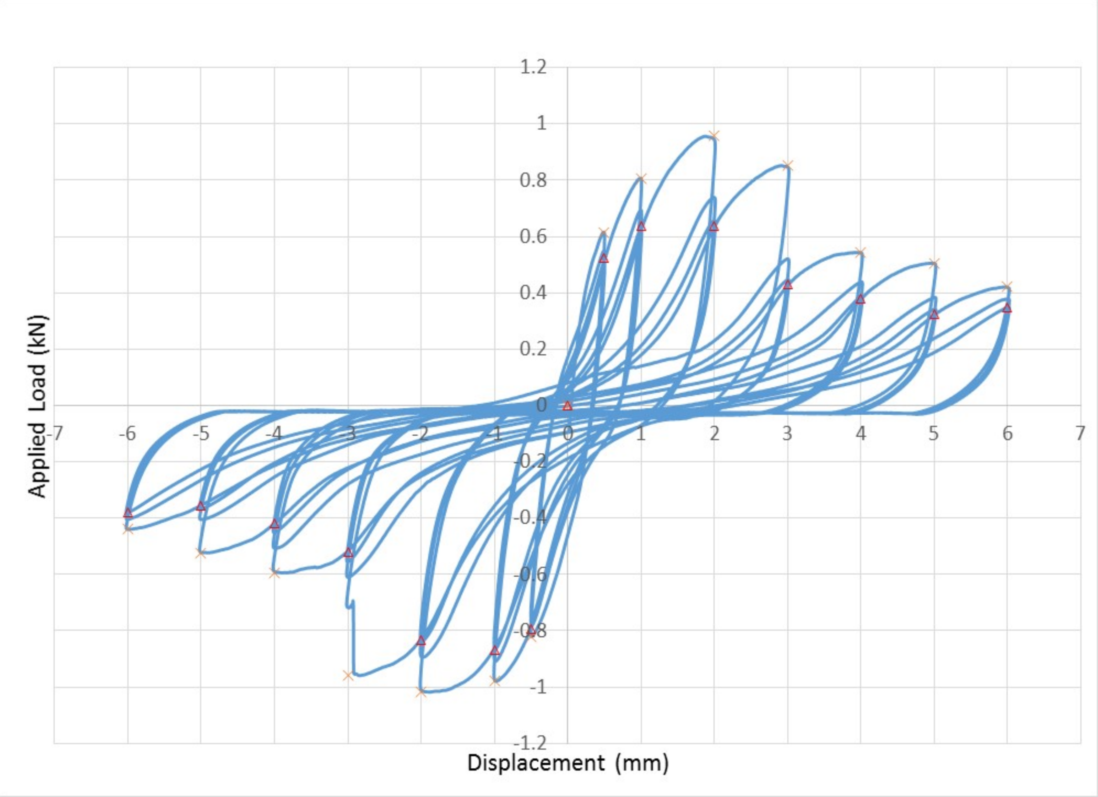

Figure 7. Typical hysteresis plot for cyclic slip test.

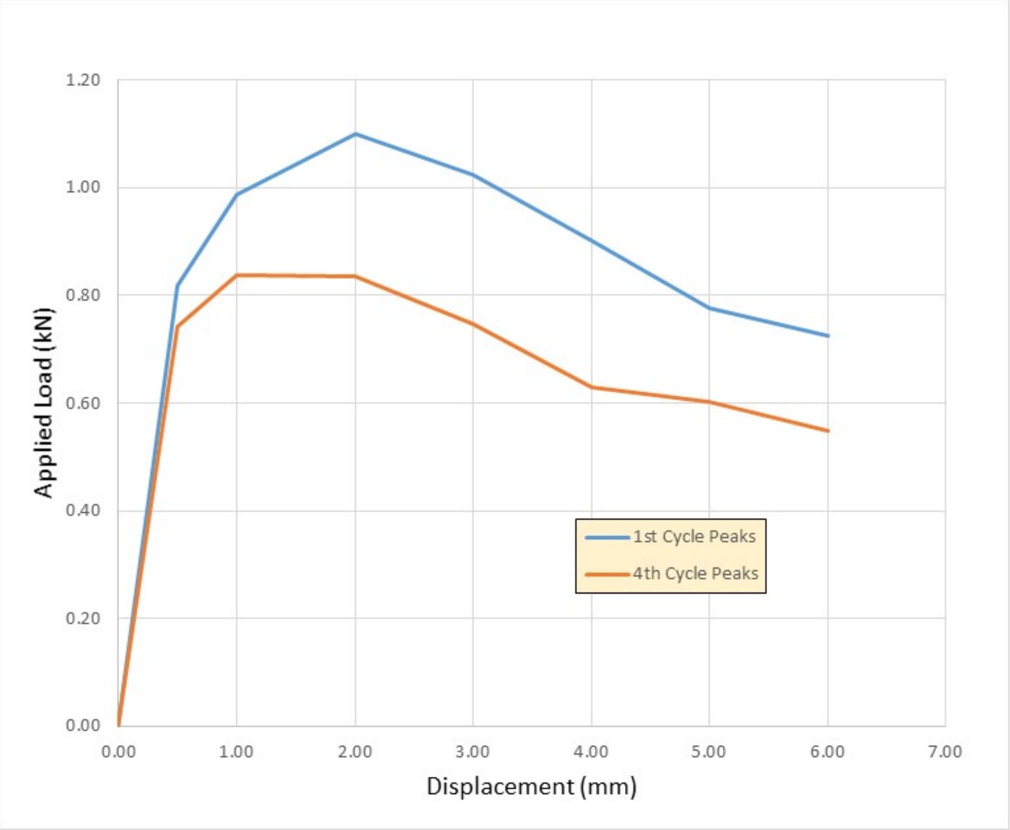

Figure 8. Typical slip testing backbone curves using averaged first and fourth cycle peaks.

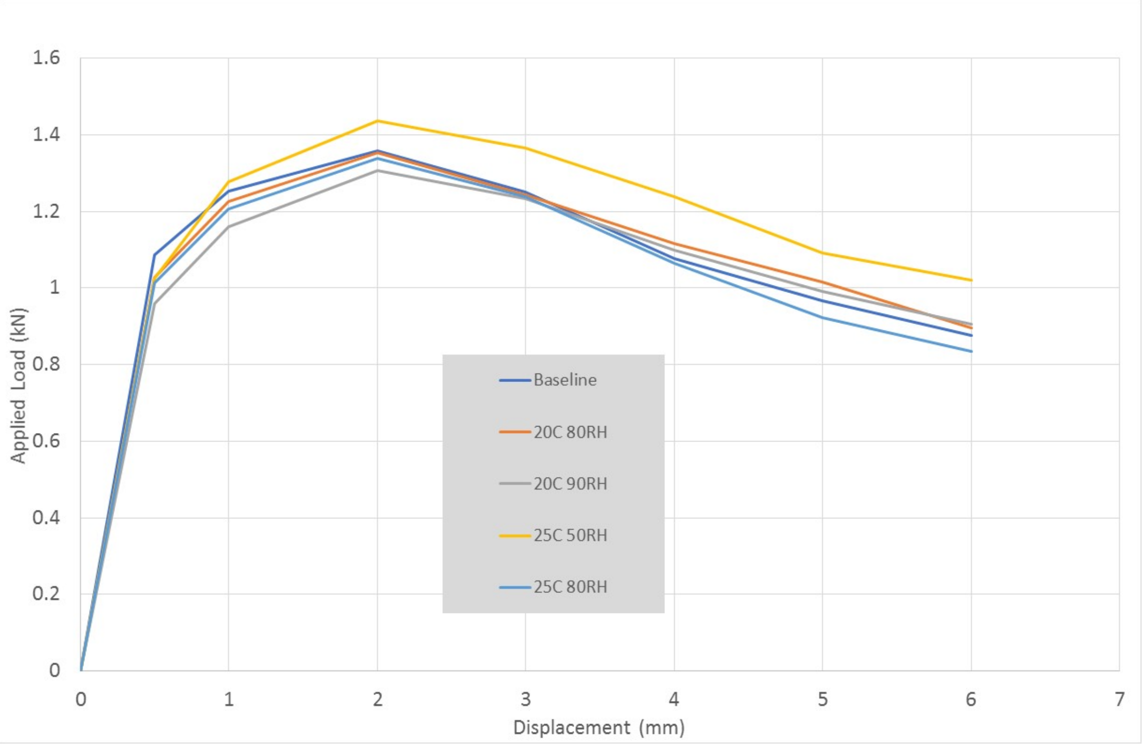

Figure 9. Typical first cycle backbone comparison of single plasterboard product across all environmental conditions.

There were some challenges to analysing the multiple sets of test data across the different displacement levels at different environmental conditions due to the lack of clear trends when results were evaluated at different humidity levels. As can be seen in Figure 9, there are points where the backbone curves for individual conditions cross each other and make it difficult to determine if in fact the conditioning has resulted in a difference in performance. This was typical across the different plasterboard products, suggesting that there may be differences in the effects of the humidity at different displacement levels.

Based on the backbone plots and the different behaviours observed, the data was analysed to determine the deviations in applied load across the test configurations and products. This data considered maximum (the most detrimental or negative) changes, minimum (the least detrimental and positive in some cases) changes and the average change for each conditional shift.

Table 5 and Table 6 provide the results of this analysis for the range of products tested. This analysis did not accommodate for the different displacement levels and only considered changes in values from average baseline conditions results to average results at the other conditions.

Table 5. Average changes in applied load for changes in conditions from the baseline for products A, B and C.

Product A				Product B				Product C			
Level A Change from Baseline				Level A Change from Baseline				Level A Change from Baseline			
1st Cycle		4th Cycle		1st Cycle		4th Cycle		1st Cycle		4th Cycle	
Max	-6.4%	Max	-9.2%	Max	-6.6%	Max	-10.6%	Max	-5.4%	Max	-5.6%
Min	2.8%	Min	2.9%	Min	0.2%	Min	0.7%	Min	5.0%	Min	11.4%
Average	-3.3%	Average	-3.5%	Average	-2.7%	Average	-2.9%	Average	0.3%	Average	2.2%
Level B Change from Baseline				Level B Change from Baseline				Level B Change from Baseline			
1st Cycle		4th Cycle		1st Cycle		4th Cycle		1st Cycle		4th Cycle	
Max	-13.5%	Max	-15.2%	Max	-24.8%	Max	-30.6%	Max	-11.7%	Max	-12.1%
Min	-5.4%	Min	-4.0%	Min	-5.7%	Min	-6.4%	Min	3.4%	Min	5.3%
Average	-9.9%	Average	-9.0%	Average	-11.0%	Average	-13.9%	Average	-2.4%	Average	-0.9%
Level C Change from Baseline				Level C Change from Baseline				Level C Change from Baseline			
1st Cycle		4th Cycle		1st Cycle		4th Cycle		1st Cycle		4th Cycle	
Max	-3.6%	Max	-2.6%	Max	2.5%	Max	5.4%	Max	-5.6%	Max	1.8%
Min	7.0%	Min	6.6%	Min	13.0%	Min	18.6%	Min	16.5%	Min	26.9%
Average	1.1%	Average	0.9%	Average	7.8%	Average	10.6%	Average	7.9%	Average	13.7%
Level D Change from Baseline				Level D Change from Baseline				Level D Change from Baseline			
1st Cycle		4th Cycle		1st Cycle		4th Cycle		1st Cycle		4th Cycle	
Max	-17.4%	Max	-25.4%	Max	-16.2%	Max	-17.3%	Max	-6.8%	Max	-6.7%
Min	-1.0%	Min	-5.9%	Min	-0.7%	Min	-0.2%	Min	-1.1%	Min	1.9%
Average	-10.7%	Average	-15.2%	Average	-5.8%	Average	-6.3%	Average	-3.4%	Average	-2.6%

Table 6. Average changes in applied load for changes in conditions from the baseline for products D, E and F.

Product D				Product E				Product F			
Level A Change from Baseline				Level A Change from Baseline				Level A Change from Baseline			
1st Cycle		4th Cycle		1st Cycle		4th Cycle		1st Cycle		4th Cycle	
Max	-5.0%	Max	-5.9%	Max	-6.0%	Max	-7.7%	Max	-1.9%	Max	-9.4%
Min	-1.2%	Min	0.9%	Min	1.0%	Min	2.2%	Min	5.2%	Min	2.7%
Average	-3.2%	Average	-3.8%	Average	-2.7%	Average	-2.9%	Average	1.6%	Average	-0.7%
Level B Change from Baseline				Level B Change from Baseline				Level B Change from Baseline			
1st Cycle		4th Cycle		1st Cycle		4th Cycle		1st Cycle		4th Cycle	
Max	-15.0%	Max	-17.4%	Max	-15.2%	Max	-17.0%	Max	-18.7%	Max	-27.0%
Min	-8.0%	Min	-8.1%	Min	-11.1%	Min	-12.2%	Min	3.8%	Min	-2.1%
Average	-12.4%	Average	-15.0%	Average	-12.9%	Average	-14.8%	Average	-7.5%	Average	-13.3%
Level C Change from Baseline				Level C Change from Baseline				Level C Change from Baseline			
1st Cycle		4th Cycle		1st Cycle		4th Cycle		1st Cycle		4th Cycle	
Max	-6.1%	Max	-5.1%	Max	3.6%	Max	3.4%	Max	-3.3%	Max	-5.2%
Min	4.4%	Min	4.1%	Min	9.2%	Min	10.9%	Min	18.3%	Min	12.0%
Average	-0.3%	Average	0.5%	Average	6.1%	Average	7.1%	Average	4.2%	Average	0.8%
Level D Change from Baseline				Level D Change from Baseline				Level D Change from Baseline			
1st Cycle		4th Cycle		1st Cycle		4th Cycle		1st Cycle		4th Cycle	
Max	-5.4%	Max	-6.5%	Max	-18.1%	Max	-20.9%	Max	-22.9%	Max	-30.8%
Min	-3.3%	Min	-2.0%	Min	-0.8%	Min	-0.2%	Min	10.5%	Min	5.2%
Average	-4.4%	Average	-4.7%	Average	-7.7%	Average	-10.8%	Average	-6.3%	Average	-12.9%

The data provided in Table 5 and Table 6 show the variability in results across products and amongst conditions. Even with this variability, there are some trends that were identified. The changes in applied load resistance from the baseline (23°C and 50%

RH; AH = 10.3 g/m^3) to Level A (20°C and 80% RH; AH = 13.8 g/m^3) and from the Baseline to Level C (25°C and 50% RH; AH = 11.5 g/m^3) show both gains and losses in performance across the different plasterboard products. This suggests that, for smaller changes in AH and up to a 30% change in RH from the Baseline, there are only minimal changes in plasterboard load resistance performance, and these changes can be positive or negative.

Going from the Baseline to Level B (20°C and 90% RH; AH = 15.6 g/m^3) resulted in average performance changes that were negative for all plasterboard tested but ranged from -0.9% to -15.0%. These conditioning level changes were more significant, with the AH increasing by 5.3 g/m^3 and the RH increasing by 40%. While this suggests that higher AH and RH levels could result in decreased plasterboard connection resistance, it is clearly different across the different products. It would be difficult to determine a specific reduction level that could be applied to the range of tested materials.

The changes in applied load resistance from the Baseline to Level D (25°C and 80% RH; AH = 18.4 g/m^3) also resulted in decreased average performance for all products ranging from -2.6% to -15.2%. These results were similar to the reductions observed for the Level B condition changes. This suggests that, while the RH was only increased by 30%, the AH was increased by 8.1 g/m^3 and that there is likely some impact of the changing temperature. This is an indication that both RH and AH can have effects on the bracing performance of plasterboard systems, but predicting these effects can be difficult. It is also worth noting that these AH and RH levels are in general very high in comparison to what would be expected either in a typical residence or testing laboratory.

Additional analyses were conducted to see if more specific trends could be determined using the plasterboard connection slip test results. Linear and non-linear trends were established for the different plasterboard products to see if the performance of the slip tests could be predicted as a function of the RH and AH. These analyses showed very poor predictions of performance with linear and non-linear methods having very low r-squared values, most typically less than 0.15 and all less than 0.3. These analyses were also conducted to determine if AH or RH would have more predictive value, but results were not consistent across products, displacement levels or conditioning levels. Therefore, no conclusions could be drawn on this aspect.

4. Summary and conclusions

A significant number of 1 and 2-storey buildings in New Zealand utilise plasterboard panels screwed to light timber framing as the main lateral load-resisting system. This project included investigations, testing and analysis to determine if there were significant reductions in the bracing capacity of plasterboard bracing systems at higher humidity levels. Six different types of plasterboard from three manufacturers were investigated as a means of covering a range of products from the primary suppliers of plasterboard in New Zealand. The environmental conditions included humidity levels that would be expected in typical buildings but also in unconditioned laboratories where P21 testing would be conducted. Preliminary flexural tests of plasterboard indicated that reductions in plasterboard performance would not occur until higher levels of humidity exposure (RH greater than 80%) were present. This informed the fastener slip testing that was conducted as a more direct indication of bracing performance because bracing loads are transferred through the fasteners.

Following the cyclic connection tests, comparative analyses were conducted to determine if there were significant differences in the performance of plasterboard at different humidity levels and if these differences would result in artificially reduced bracing ratings or possibly in-service performance. The humidity levels used for connection testing were on the high end of what would be expected in average buildings, and it is worth noting these levels can be different throughout the country depending on location, altitude, weather patterns and other environmental factors. Both bending and fastener slip test results indicated there was some degradation in plasterboard performance at RH levels above 80%. The decreases were neither consistent enough nor of significant magnitude to necessitate specific recommendations on P21 testing requirements or current building practices where plasterboard is used as part of a lateral bracing system. Observable changes in performance were only observed at RH levels starting at 80% and AH levels starting at 15 g/m^3. These humidity levels are in general greater than what would be expected to occur in the interior of residential buildings and also for typical laboratory conditions, even for spaces that are regularly exposed to exterior conditions.

Based on the plasterboard testing and subsequent analyses, the following conclusions and recommendations have been formulated:

- Current requirements in the P21 test method are adequate with regards to environmental conditioning of plasterboard-lined test specimens.
- Based on the testing and analyses conducted, it was not possible to develop a predictive model for the cyclic bracing performance of screwed plasterboard connections as a function of RH or AH.
- At RH and AH levels greater than 80% and 15.0 g/m^3, respectively, there were indications that screwed plasterboard connections could decrease in cyclic load resistance. These decreases varied widely across different plasterboard products and at different displacement levels.
- It is recommended that P21 tests be conducted under ambient conditions that have less than 80% RH and less than 15.0 g/m^3 AH for results that could be broadly applied to timber-framed buildings in New Zealand.
- It is recommended that P21 test specimens be constructed and stored under ambient conditions prior to testing that have less than 80% RH and less than 15.0 g/m^3 AH for results that could be broadly applied to timber-framed buildings in New Zealand.

This project provided some insight into the behaviour of plasterboard connections to timber framing for use as bracing elements in buildings used to resist wind and earthquake loads. Further research should consider the effects of cycling humidity levels, as this could result in different mechanical property behaviour. Additional research should also be conducted where plasterboard is fully soaked with water to simulate the effects of flooding on the bracing resistance of plasterboard systems, including once the plasterboard has dried following the soaking. It is worth noting again that the effect of humidity on the performance of plasterboard screwed to timber framing is only one of a number of factors that can influence P21 test results and subsequent bracing for buildings designed according to NZS 3604:2011.

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