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BRE Test Report

Wind Uplift, Weathertightness and Snow Load Testing of Solar Limpets Solar Technology PV Mounting Bracket Clamps to MCS012

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1 Introduction

This report describes testing carried out on above-roof PV mounting systems to the MCS 012 test method for wind uplift resistance and weathertightness [1]. Additional testing included assessing “snow loads”, i.e. positive loads being applied to the system.

The MCS 012 standard specifies the test procedures which shall be used to demonstrate the performance of PV modules and solar thermal collectors and/or their installation kits under the action of wind loads.

These test methods apply to ‘in roof’ and ‘above roof’ systems fixed to pitched roofs. They do not apply to systems mounted inclined above flat roofs or mounted on vertical walls.

This report presents the results from wind uplift, weathertightness and positive load tests on individual PV mounting brackets.

Testing was completed based upon BRE proposal P120784 dated 11th June 2021.

Testing was completed at BRE between 20th July 2021 and 21st July 2021 witnessed by Carl Reynolds, Solar Limpets.

2 Details of the Test Specimen and Installation

A single bracket design was tested with both Rosemary plain tiles and slates.

The test specimens for the all testing were installed by Solar Limpet staff following the supplied instructions.

The Grade A PVC plastic bracket had baseplate dimensions of 265mm x 170mm x 10mm, and a removable vertical bracket fixed in place with a bolt. The bracket was fixed via two 115mm length x 6.5mm stainless steel Mage screws with a 22mm diameter stainless steel and EDPM washer, Figure 1.

Figure 1 Components of the bracket and fixings.

For the slate application, the underside design allowed for an EDPM seal and a capture for the CT1 liquid sealant applied to the slate surface during installation, Figure 2.

Figure 2 Underside of plastic PV bracket.

3 Details of the Tests Carried Out

3.1 Uplift Testing

Since there is no British Standard test specifically for assessing the wind uplift resistance of fixing brackets for solar modules, the testing was carried out using the principles of wind uplift testing described in MCS012 and BS EN 14437:2004. The brackets were fixed to the roofing elements and to a timber rafter using the screws provided by Solar Limpets Ltd. A chain was attached to the top of each bracket. A hydraulic ram and a calibrated load cell were attached to the loading chain. The ram was mounted on a cradle, which allowed movement in both horizontal axes, and, combined with the chain, allows the bracket to rotate as it would in practice when subjected to a wind uplift load. Calibrated displacement transducers were fixed to the bracket end and to the bracket base plate.

Load was applied to the bracket in increments of up to 1/20 of the estimated failure load. At each load increment the displacement of the bracket and base plate were measured. The bracket was then unloaded, and the residual displacement of the bracket edge and base plate were measured. The failure load was considered to be the load at which the residual displacement at the bracket end reached 5mm, as defined in BS EN 14437:2004 or when there was a mechanical failure of the bracket. The 5mm displacement is only relevant where a gap is formed in the roof elements that would affect the weathertightness of the roof. In this case, this can be ignored. Loading and unloading were both carried out at a rate of approximately 50 N/s. Figure 3 shows the test setup.

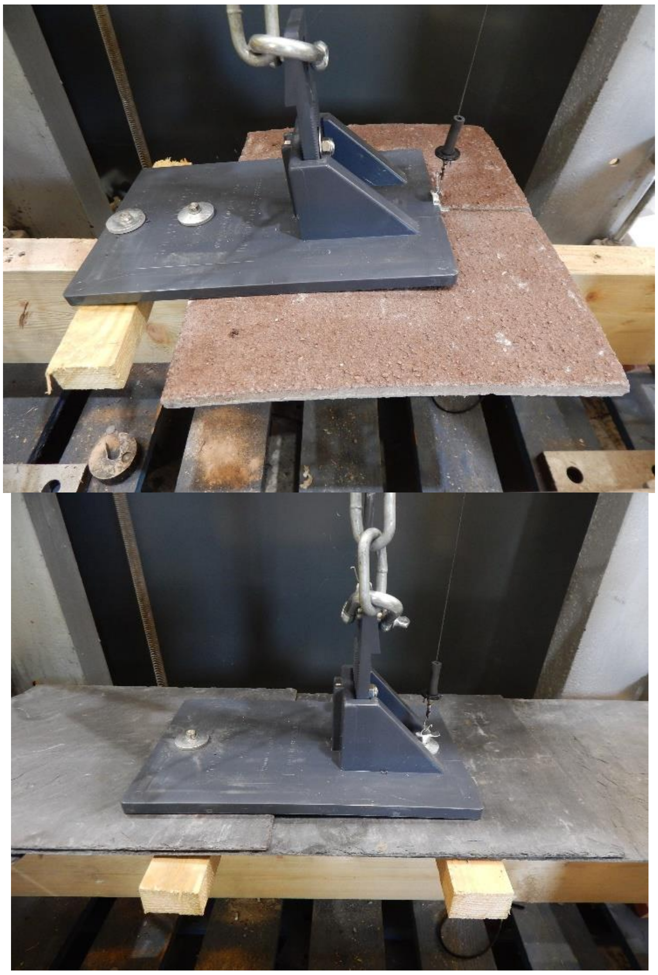

Figure 3 Example of the setup of the test rig with rafter, roofing element and bracket (plain tile top, slate bottom).

3.2 Weathertightness Testing

The specimens were installed on the BRE test rig positioned at the exit of the BRE's No. 3 Boundary Layer Wind Tunnel. Due to the need for only deluge testing to be completed, a simplified test was used, which did not have pressure chamber, suction device, or fan system as required in PD CEN/TR 15601:2012.

A spray nozzle was mounted above the roof, so that water could be sprayed down onto the roof to provide deluge rain at a rate equivalent to a rainfall of 225mm/hour over the whole roof. The wind tunnel was not running during deluge rain testing. To simulate a typical 7 metre rafter length, simulated rainfall of 225mm/hour over the rest of a typical 7m roof, a sparge bar was mounted across the top edge of the roof. The test conditions represent the worst-case wind and rain combination likely to occur in Northern Europe during any 50-year period.

The sample was sealed to a transparent box which allowed for the collection and measurement of water from leakage and also the ability to view the location of any leaks.

A schematic diagram of the test arrangement is shown in Figure 4.

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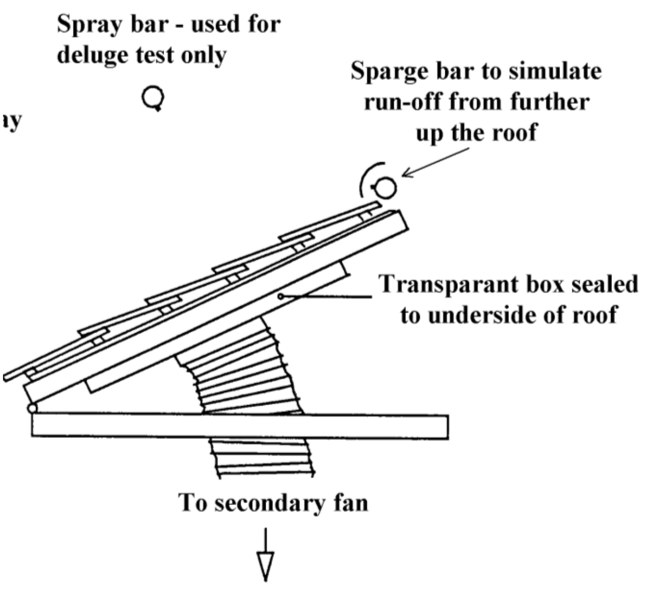

Figure 4 Diagram to show the simplified set up for deluge testing.

Two roofing element types were supplied to be tested: 500mm x 250mm natural slate (with predrilled fixing holes) and 265mm x 165mm plain rosemary tile (with predrilled fixing holes). The roof specimen was constructed in accordance with the roof element manufacturers specifications, Table 1.

Parameter		
Product	Slate, 500mm x 250mm	Plain Rosemary tile, 265mm x 165mm
Lap, mm	195mm	100mm
Lap type	Double lap	Double lap
Bond	Broken	Broken
Batten size, mm	38 x 25 x 2000	38 x 25 x 2000
Batten gauge, mm	210mm	110mm
Fixing	50mm x 4mm screws, x2 per tile	None
Pitch angle, °	22.5°	30°

Table 1 Roofing element details.

The fixing strategy was the same for each bracket, i.e. two screws into the rafters, but its location was dependent upon roofing element type. The bracket sits on top and is fixed to the slate roofing element but the bracket replaces a plain tile roofing element.

The brackets were attached to the roofing element according to the parts supplied by the client and according to the fitting instruction supplied by the client.

For the plain tiles, the installation guide was followed to install two brackets; one via fixing option 1 and one via fixing option 2. Figures 5 and 6 show the installation and final set up for fixing option 1.

Figure 5 Image to indicate the fixing of the brackets with the clay tiles.

Figure 6 Image to highlight the test set up for the brackets with clay tiles.

Figure 7 indicates the installation and final set up for fixing option 2. A 220mm wide section of damp proof membrane was laid on the roof and stapled to the roof batten prior to installing the bracket, as per the installation instructions, see Figure 8.

Figure 7 Inclusion of a standard damp proof course layer ensured weathertightness was maintained.

Figure 8 Fixing option 2 using blanking plates in the installation of the PV bracket.

For both fixing options, the addition of the PV bracket with the plain tiles created an unprotected gap that was larger than the baseline roofing elements. A strip of 15mm thick EDPM foam was added to fill the unprotected gap in accordance with the installation instructions, Figure 9.

Figure 9 Image to highlight the gap created by the installation of the PV bracket with plain tiles and the EDPM foam used to seal the gap.

The test set up may be seen in Figure 10.

Figure 10 Test set up for Rosemary plain tiles.

For the slate, again the installation instructions were followed. A collet pipe was not used in the installation since it is not required for this sized slate. Figure 11 shows the sealant used to seal the holes created by the drilling the fixing holes and Figure 12 highlights the set up of the PV bracket with slate.

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Figure 11 Image to indicate the fixing of the brackets with the slates.

Figure 12 Image to highlight the test set up for the brackets with slates.

Figure 13 highlights the test set up.

Figure 13 Test set up for PV brackets with slates.

3.3 Positive Load Testing

MSC 012 Issue 2.3 states that products which require the use of through bolts are only eligible for certification to MCS 44 012 subject to the bolt or flashing not transferring any load on the slates / tiles. This has been updated in Issue 3.0 to states that it can be demonstrated that the fixing does not transfer such load to the roof covering that could cause it damage in normal operating conditions.

Since there is no British Standard test specifically for assessing the positive loading of fixing brackets for solar modules, the testing was carried out using the principles of wind uplift testing described in MCS012 and BS EN 14437:2004. The brackets were fixed to the roofing elements and to a timber rafter using the fixing strategy described by Solar Limpets. A hydraulic ram and a calibrated load cell were rested on the bracket. Load was applied to the bracket slowly until the failure load was achieve. Failure was determined to be when the roof element was damaged. Figure 14 shows the test setup.

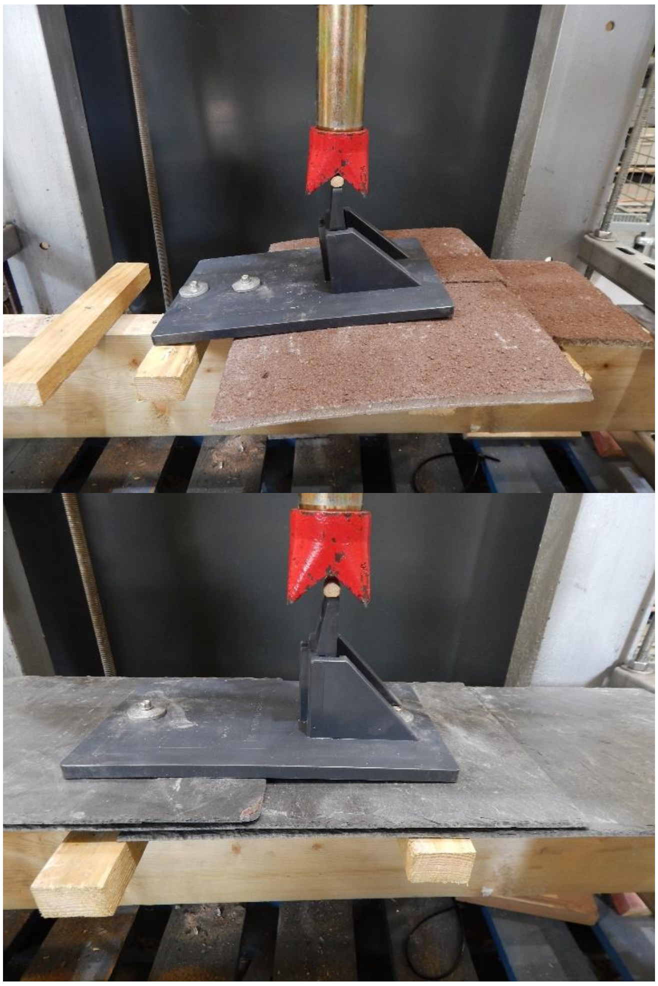

Figure 14 Test set up for positive load test (plain tiles top, slate bottom).

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4 Test Results

4.1 Uplift Test

4.1.1 Determination of the characteristic uplift resistance

EN 14437:2004 requires the characteristic uplift resistance R_k to be determined from equation 1:

$R_k = R_x – k_n s_x$ … (1)

Where R_x is the mean uplift resistance determined from $R_x = \frac{1}{n}\sum R_i$

s_x is the standard deviation of the resistance determined from $s_x = \sqrt{\frac{1}{n-1}\sum (R_i - R_x)^2}$

k_n is a statistical factor = 3.37 (for a sample size of 3 from Table D.1 in EN 14437)

R_i is the individual measured value from each test

EN14437 requires that the coefficient of variability given as s_x/ R_x be <0.1 after each batch of three tests. If this value exceeds 0.1 then at least two additional tests must be carried out.

The design wind uplift resistance is determined by dividing the characteristic uplift resistance by a safety factor. MCS012 specifies a range of partial factors to be used to calculate the design resistance of the system as follows:

- Failure of a metal component: 1.1
- Pull-out of a metal component: 1.25
- Failure in a timber component: 1.44
- Serviceability limit failure: 1.0

4.1.2 Results from tests on the bracket on Rosemary tile

Table 2 gives the calculated values of R_k, R_x, s_x and s_x/R_x and the individual failure loads from each of the three tests on the plastic bracket with clay tile at the limit state. The coefficient of variability (s_x/R_x) is <0.1 therefore this is a valid test result. Figure 15 shows the bracket under test.

Test configuration	Test number	Measured force (N)	Failure mode
Solar limpet on plain tile	1	1923	Screw head pulled through washer and bracket
Solar limpet on plain tile	2	1854	Screw head pulled through washer and bracket
Solar limpet on plain tile	3	1913	Screw head pulled through washer and bracket
Mean force (N)		**1896.6**	
Standard deviation (N)		**37.1**	
Coefficient of variability		**0.020**	
Characteristic wind uplift force (N)		**1771.4**	

Table 2 Ultimate failure load of bracket with plain tile.

Figure 15 The bracket on plain tile under test at failure.

Failure of the system occurred as a result of the screw head being pulled through the washer and bracket, Figure 15. The failure load in the ultimate limit state (ULS) testing was taken as 1771.4N. A partial safety factor of 1.1 is applied.

This gives a design wind uplift resistance at ULS of 1771.4/1.1 = **1610.4N**

4.1.3 Results from tests on the bracket on slate

Table 3 gives the calculated values of R_k, R_x, s_x and s_x/R_x and the individual failure loads from each of the three tests on the plastic bracket with slate at the limit state. The coefficient of variability (s_x/R_x) is <0.1 therefore this is a valid test result. Figure 16 shows the bracket under test.

Test configuration	Test number	Measured force (N)	Failure mode
Solar limpet on slate	1	4405	Adjuster bolt pulled through base bracket
Solar limpet on slate	2	4140	Adjuster bolt pulled through base bracket
Solar limpet on slate	3	3944	Adjuster bolt pulled through base bracket
Mean force (N)		**4162.7**	
Standard deviation (N)		**231.4**	
Coefficient of variability		**0.056**	
Characteristic wind uplift force (N)		**3382.9**	

Table 3 Ultimate failure load of bracket with slate.

Failure of the system occurred as a result of the adjuster bolt being pulled through the base bracket. The failure load in the ultimate limit state (ULS) testing was taken as 3382.9N, Figure 16. A partial safety factor of 1.1 is applied.

This gives a design wind uplift resistance at ULS of 3382.9.4/1.1 = **3075.4N**

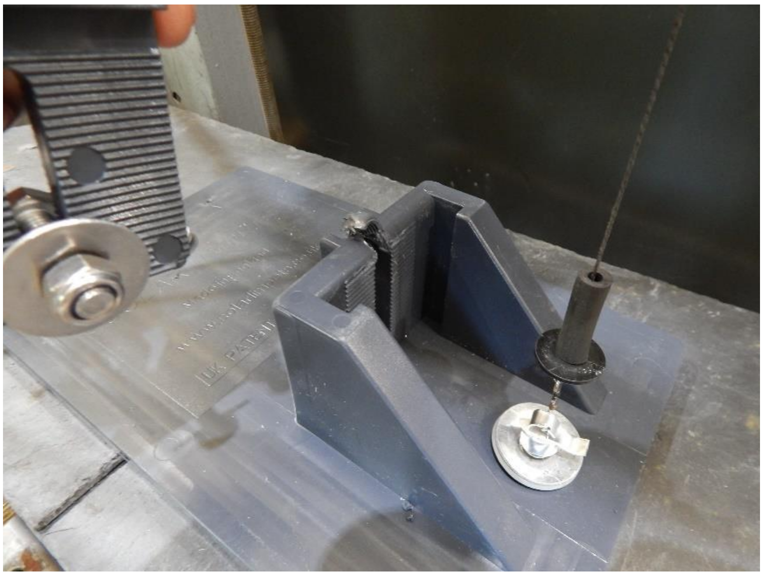

Figure 16 The bracket on slate under test at failure.

4.2 Weathertightness Test

The test is used to assess the water entry via the penetrations through the outer roof covering and to address the leakage mechanisms.

Essentially, the presence of the solar panel mounting system must not decrease the weather performance of the roof covering or the roof structure. The performance of the surrounding roof covering elements which are unaffected by the presence of the solar panels mounting brackets shall be taken as a benchmark against which to judge the performance of the solar panels. The comparison shall be made on the basis of any water entry during the test period. To be acceptable the solar panel mounting brackets system shall have a level of performance at least equal to that of the unaffected roofing elements.

4.2.1 Tests with Plain Rosemary Tiles

The amount of water collected during the deluge testing of each bracket installed on the plain clay tile and associated notes may be found in Table 4.

Configuration	Test Notes	
	Water collected, g	Notes
Standard installation	0	No leaks were visible during the test.
Installation with blanking plates	0	No leaks were visible during the test.

Table 4 Test results for the plain Rosemary tile at pitch angle of 22.5°.

Figure 17 highlights the PV bracket undergoing deluge testing. No leaks were visible as a result of the PV brackets being installed.

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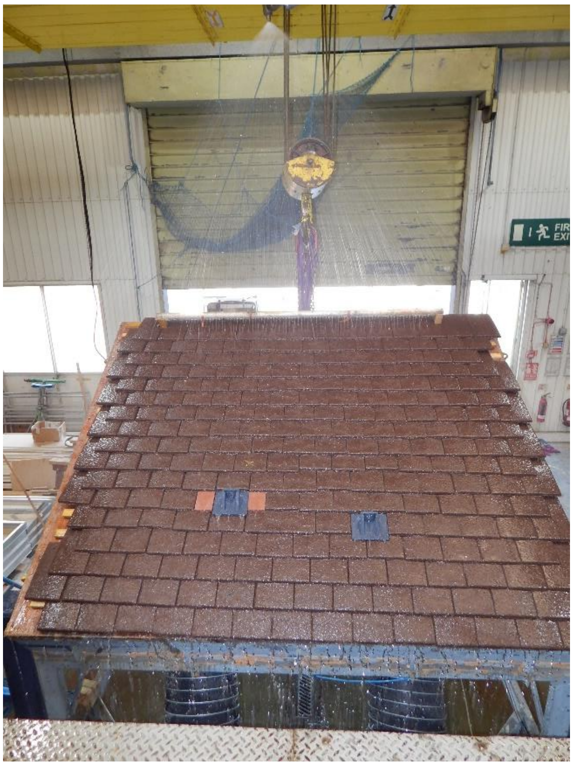

Figure 17 Bracket with plain tile under deluge test.

4.2.2 Tests with Natural Slates

The amount of water collected during the deluge testing of each bracket installed on the slate and associated notes may be found in Table 5.

Configuration	Test Notes	
	Water collected, g	Notes
Bracket, natural slate	0	No leaks were visible during the test.

Table 5 Test results for the plain Rosemary tile at pitch angle of 22.5°.

Figure 18 highlights the PV bracket undergoing deluge testing. No leaks were visible as a result of the PV brackets being installed.

Figure 18 Bracket with slate under deluge test.

Upon removal of the PV bracket, it was noted that the CT1 sealant had sealed the entire fixing hole, as evidenced by the fact that there was sealant present on the battens and rafters where the bracket had been fixed. The secondary inner housing is designed to allow the CT1 liquid sealant, under the subsequent hydraulic pressure created when fixing the baseplate to the slate surface, to also penetrate the predrilled screw hole shaft, further sealing the screw penetration down to the rafter, Figure 19.

Figure 19 Image to highlight the CT1 sealant on the rafters after testing.

4.3 Snow Load Test

4.3.1 Tests with Plain Rosemary Tiles

Table 6 gives the calculated values of R_k, R_x, s_x and s_x/R_x and the individual failure loads from each of the three tests on the plastic bracket with clay tile at the limit state. The coefficient of variability (s_x/R_x) is <0.1 therefore this is a valid test result. Figure 20 shows the bracket under test.

Test configuration	Test number	Measured force (N)	Failure mode
Plastic bracket on plain tile	1	1118.34	Failure of tile
Plastic bracket on plain tile	2	1275.3	Failure of tile
Plastic bracket on plain tile	3	1216.44	Failure of tile
Mean force (N)		**1203.4**	
Standard deviation (N)		**79.3**	
Coefficient of variability		**0.066**	
Characteristic wind positive force (N)		**936.1**	

Table 6 Ultimate failure load test of bracket with plain tile.

Figure 20 The bracket on plain tile under test.

Failure of the system occurred as a result of the tile cracking under load. The failure load in the ultimate limit state (ULS) testing was taken as **936.1N**. No partial safety factor have been applied.

4.3.2 Tests with Slates

Table 7 gives the calculated values of R_k, R_x, s_x and s_x/R_x and the individual failure loads from each of the three tests on the plastic bracket with clay tile at the limit state. The coefficient of variability (s_x/R_x) is <0.1 therefore this is a valid test result. Figure 21 shows the bracket under test.

Test configuration	Test number	Measured force (N)	Failure mode
Plastic bracket on slate	1	2491.74	Failure of slate
Plastic bracket on slate	2	2354.4	Failure of slate
Plastic bracket on slate	3	2550.6	Failure of slate
Mean force (N)		**2465.6**	
Standard deviation (N)		**100.7**	
Coefficient of variability		**0.041**	
Characteristic wind positive force (N)		**2126.3**	

Table 7 Ultimate faailure load test of bracket with slate.

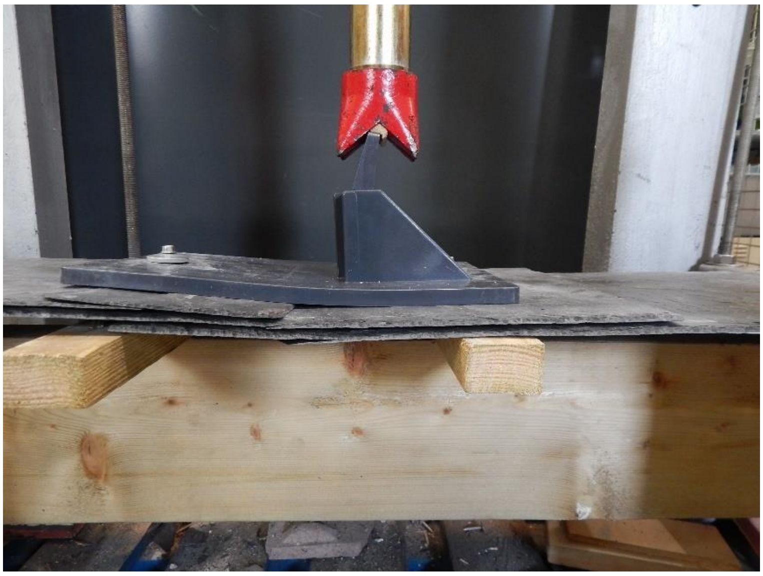

Figure 21 The bracket on slate under test.

Failure of the system occurred as a result of the slate cracking under load. The failure load in the ultimate limit state (ULS) testing was taken as **2126.3N**. No partial safety factor has been applied.

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5 Conclusions

This report describes tests carried out of the Solar Limpets PV brackets to determine the characteristic wind uplift resistance and weathertightness performance in accordance with MCS 012.

The following conclusions can be drawn from these tests:

Wind uplift tests

- The design uplift resistance of the bracket with Rosemary tile is **1610.4N** (based on failure at the ULS and a partial factor applied).
- The design uplift resistance of the bracket with slate is **3075.4N** (based on failure at the ULS and a partial factor applied).

Weathertightness tests

- Both installation options for the plain clay tile did not affect the weathertightness performance relative to the performance of the surrounding roof covering elements which are unaffected by the presence of the PV brackets at a pitch angle of 20°.
- Unprotected gaps created by the installation of the PV brackets were filled with EDPM foam to seal.
- Installation of the PV bracket with slate did not affect the weathertightness performance relative to the performance of the surrounding roof covering elements which are unaffected by the presence of the PV brackets at a pitch angle of 30°.

Positive (snow loading) tests

- The characteristic positive load of the bracket with plain tile is **936.1N** (based on failure at the ULS and no partial factor applied).
- The characteristic positive load of the bracket with slate is **2126.3N** (based on failure at the ULS and no partial factor applied).

6 References

1) MCS012; Microgeneration Certification Scheme, Roof performance tests for solar thermal collectors and PV modules.

Report Ends