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TECHNICAL NOTE No.5
Simulated Wind Load Strength Testing of Photo Voltaic Solar Panel Systems

1 INTRODUCTION

The Cyclone Testing Station (CTS) is an independent authority on the effects of severe wind and related damage to low-rise building systems in Australia and the surrounding region.

The CTS provides a service to the building industry for testing the effects of wind forces on buildings and building components.

CTS has the equipment and technical expertise to test photovoltaic (PV) solar systems in typical applications, when mounted parallel to roofs.

2 SCOPE

This document applies to the testing of the structural strength performance of photo voltaic solar systems to resist simulated wind loads when installed on residential roofs, where the panels are installed parallel to the roof surface with a small gap (typically 50 mm to 300 mm) between the roof and the underside of the arrays. The evaluation normally includes the performance of the panels themselves as well as any supporting rails or other framework, brackets and connections.

3 BACKGROUND

AS 5033 (*Installation and safety requirements for photovoltaic (PV) arrays*), details the many electrical and safety issues that must be considered in designing and installing a photo voltaic solar panel system. Clause 2.2.5 in the standard also considers the effects of wind loading on PV arrays including the mounting system.

This technical note further highlights the consideration that should be made to ensure that a photovoltaic (PV) solar system is designed, tested and installed to resist the wind pressures that may be imposed upon it during a severe wind event such as a thunderstorm or cyclone whilst not compromising the surrounding structure.

For wind events, the critical case on a solar system will usually be uplift loading. In a severe wind event, this could result in all or part of the panel system becoming detached from the roof with any dislodged components becoming wind-borne debris, thus resulting in a risk to life and other property.

Manufacturers of PV solar systems evaluate the capacity of components and their connections, including the panels, the clamp connections from the panels to the rails, the rail and bracket fixing to the roof. In addition, it is necessary to also consider the strength of the roof support members (typically battens) and in turn their connections to the roof structure completing the connection chain for the PV solar system.

For example; if the brackets connecting the solar system rails to the roof batten are too far apart, the uplift wind force transmitted by the brackets could exceed the strength of the connections (typically roof cladding screws) to resist the loads.

In 2011 the CTS completed a wind tunnel study on PV solar panels for Building Codes Queensland (BCQ), as documented in Report No. TS821 "*Investigation on Wind Loads Applied to Solar Panels Mounted on Roofs*", dated 22 December 2011. BCQ have allowed this report to be published on the CTS web page. The pressure coefficients derived from this study have been included in the latest amendments to *AS/NZS 1170.2 making* it easier for the designer, tester, certifier or regulatory authorities to be confident that these systems are fit for purpose.

To allow PV solar systems to be installed anywhere on the roof surface, it is proposed that a maximum nett pressure coefficient of -1.7 be used in panel system design. Whilst this will ensure the panel system will be structurally adequate, consideration should still be given to the strength and design implications for the rest of the building structure.

4 SIMULATED WIND LOAD TESTING OF PV SOLAR SYSTEMS

4.1 General

In the absence of standards or regulations that specifically cover the simulated wind load testing of PV solar panels mounted on roofs, the CTS adopted an approach of considering these solar panel systems as being similar to roof cladding.

The results from the CTS wind tunnel study detailed in Report No. TS821 and Appendix D6 of *AS/NZS 1170.2:2011* can be used to determine the peak wind loads on solar panels mounted parallel to the roof surface and with a small gap (50 mm to 300 mm) between the roof and the underside of the panel array.

As already noted in Section 3, it is recommended that the nett uplift wind pressure on panels be calculated using the largest peak negative (uplift) aerodynamic shape factor value (C_{fig} = -1.7). This value accounts for panels located anywhere on the roof.

The net design wind pressure acting on solar panel arrays is calculated using the following formula:

$$p_{design,n} = 0.5\rho_{air}V_h^2 C_{fig}\ C_{dyn}$$

Where:

$p_{design,n}$ is the net design wind pressure applied to the solar panels

ρ_{air} is the density of air, taken as 1.2 kg/m^3

V_h is the design wind speed for the building where the panels will be installed

C_{fig} is the net aerodynamic shape factor for the panels (taken as - 1.7 for the critical case)

C_{dyn} is the dynamic response factor, taken as 1.0 as there is no dynamic wind sensitivity

For the critical case (with C_{fig} = -1.7), this formula simplifies to:

$$p_{design,n} = -1.02V_h^2$$

Here the design wind speed is in m/s and the net design (uplift) pressure on the solar panel is in Pa.

In preparation for testing, target design pressures should be calculated for the PV solar system(s) so that equivalent test pressures can be calculated to ensure target design pressures are replicated during testing.

4.2 Static Strength Testing

It is recommended that an initial static strength test be conducted for both cyclonic and non-cyclonic areas. This is normally a test to failure, which will identify the (static) strength capacity of the system. Alternatively, the system can be tested to a target static strength test pressure, based on the maximum design pressure for the location where it will be used, multiplied by an appropriate factor for variability.

CTS performs static strength testing in accordance with *AS4040.2-1992, "Methods of Testing Sheet Roof and Wall Cladding, Method 2: Resistance to Wind Pressures for Non-Cyclone Regions*". This standard sets out a test method for determining the resistance of roof and wall cladding to wind pressure for non-cyclonic regions. Due to the absence of information on methods for static strength testing on PV solar systems, CTS considers it an appropriate method for conducting static strength testing on PV solar systems for use in both cyclonic and non-cyclonic areas.

Static strength test results can be used to determine strength design wind capacities and can also help to predict the maximum test pressure that may be achieved in cyclic testing if this criteria testing is required.

4.2.1 Static Strength Testing Methodology Adopted

The static strength test methodology adopted is specified in accordance with Clause 6.1.3 of *AS 4040.2-1992*, "*Methods of Testing Sheet Roof and Wall Cladding, Method 2: Resistance to Wind Pressures for Non Cyclone Regions*". This clause specifies that the test pressure shall be determined by multiplying the strength limit state design pressure by an appropriate factor to allow for variability of structural units (k_t). If a number of identical tests are carried out, then each sample is required to support this test pressure. The material variability factor adopted is based on the strength limit state values from Table 5.1 in the Australian standard, *AS 1562.1-1992*, "*Design and Installation of Sheet Roof and Wall Cladding, Part 1: Metal*".

Note that Clause 6.3 of *AS 4040.2* requires that the test pressure must be held for 1 minute. However, as the test method is for an ultimate limit state design strength criteria, the test specimen can show signs of distortion and permanent deformation and still be considered a successful outcome providing that it can resist the pressure.

Where a design pressure is to be determined from the static strength failure pressure, the CTS approach is similar. For this case, the static limit state strength design pressure is calculated by dividing the last pressure reading at which the test specimen was able to support the load for 1 minute by the value of (k_t) for the number of identical units tested. The number of identical units tested will be determined by the failure mode and test configuration.

4.3 Cyclic Strength Testing

CTS conducts cyclic testing on PV solar systems in accordance with the Low-High-Low fatigue loading sequence as specified for metal roof cladding for Class 2 to 9 buildings *Specification B1.2: Design of Buildings in Cyclonic Areas* of the National Construction Code (*NCC) Volume One* and for Class 1 & 10 buildings (Part 3.10.1.0 (f), NCC 2016 Volume Two). This specification sets out a loading regime for determining the resistance of roof cladding to wind pressures in cyclonic regions. It is the opinion of CTS that this method can be used to assess PV solar systems. It may be slightly conservative but until better information or further research becomes available, this fatigue loading regime is the best one available.

The Low-High-Low (LHL) test regime, as specified in the National Construction Code of Australia, is mandatory for metal roof cladding and its immediate supporting members. The LHL test sequence consists of 10360 cycles at various percentages of the test pressure (P_t) and one cycle to the full test pressure, which must be held for at least 10 seconds.

Details of the loading sequence are detailed in Table 1.

Table 1: *Low-High-Low Fatigue Loading Sequence*

Sequence	No. of Cycles	Load
A	4500	0 to 0.45 P_t
B	600	0 to 0.60 P_t
C	80	0 to 0.80 P_t
D	1	0 to 1.00 P_t
E	80	0 to 0.80 P_t
F	600	0 to 0.60 P_t
G	4500	0 to 0.45 P_t

The test pressure (P_t) for strength limit state must be equal to the design pressure for the wind load strength limit state multiplied by the appropriate factor for variability (k_t) as defined in *AS/NZS 1170.0*. This factor depends upon the number of repeat tests conducted and the test configuration.

4.3.1 Cyclic Strength Testing Methodology Adopted

The PV solar system to be tested, including its connections and immediate supporting members are subjected to the Low High Low fatigue loading sequence specified in Table 1. This test regime specifies that the test assembly must be capable of remaining in position notwithstanding any permanent distortion, fracture or damage that might occur in the test specimen or its support systems and fastenings, without loss of load carrying capacity.

The acceptance criteria adopted for the cyclic strength tests to be considered successful are detailed in Clause 7.2 of the *Draft Guide to LHL Cyclic Testing (Version 1)*, dated 9 April 2009 and issued by the CTS.

The cyclic strength limit design wind capacity can be calculated by dividing the test pressure (P_t) by a variability factor (k_t). The variability factor can be obtained from Table B1 of *AS/NZS 1170.0* and depends on the coefficient of structural characteristics (V_{sc}) and the number of identical units tested.

Where no reliable data for the coefficient of variation of structural characteristics (V_{sc}) is available, a value of 10% may be adopted for roof assembly testing and 15% for connection testing, as recommended in Clause 6.1 of the *Draft Guide to LHL Cyclic Testing (Version 1)*.

Successful LHL cyclic wind loading tests can be counted as replications for roof assembly testing provided the same set–up is used (panel size, model, rail spacing, mounting frame assembly and connection details) and have no deformation or exhibit the same potential mode of failure.

For PV solar panel systems, a test specimen can contain more than one "unit to be tested" (replication) provided the individual panels and components are identical and have the same boundary conditions and same potential mode of failure. However, as recommended in Clause 6.2 of the *Draft Guide to LHL Cyclic Testing (Version 1),* no more than four (4) "*units*" for any one test specimen can be counted, and where only one specimen is tested no more than two (2) "*units*" can be counted.

The same clause also recommends a maximum of ten (10) replications, the upper limit in Table B1 of *AS/NZS 1170.0,* for any test programme. For example, if two cyclic tests were successfully conducted on identical systems, each with three full panels, hence two end modules, then the number of replications can be taken as four (4), provided that both tests exhibited no deformation or the same potential mode of failure.

5 TESTTING EQUIPMENT AND TEST SET-UP

Static or cyclic testing of PV solar panel systems can be undertaken as:

1. An "*Assembly Test*" - using a test specimen that incorporates many system components (for example two or more panels, fixed to rails that are supported by brackets) or
2. A "*Joint Test*" - using a test specimen that models the connection or the component and its connections that is to be tested.

5.1 Assembly Testing

These tests are normally conducted using an airbag test rig.

5.1.1 Airbag Test Rig

In brief, airbags are used to apply a uniform positive pressure load to the underside of solar panels, to simulate the nett negative pressure (suction) that applies to the panels on the roof. The test assembly is installed in an "Upside Down" position and so uplift loads normally applied in practice are simulated as downwards loads when testing.

The airbag test rig consists of a structural steel frame fixed to a strong floor. One or more identical hydraulic loading rams (normally one for each panel) are attached to the underside of a strong beam mounted on the structural steel frame. Each hydraulic ram is used to drive a rectangular load platen that can apply load, to an airbag which then transmits this load, as a uniform pressure, to the underside of a solar panel. If more than one hydraulic ram is used, they are all driven by hydraulic oil from a manifold, thus ensuring that each ram applies equal loads to all of the panels in the test assembly. A load cell is installed in series with one of the rams to monitor the force applied. Note that the nett equivalent uniform pressure applied to the underside of the panel is calculated by dividing the net load applied to one panel by the face area of the panel.

For static testing the load applied by the hydraulic rams is gradually increased until the target test load is achieved or failure of the specimen. For cyclic testing, a computer controlled hydraulic pump operates the rams to apply the cyclic loading.

5.1.2 Specimen for Test Assembly

The test specimen is assembled, in an “Upside Down” orientation, to be representative of a typical PV solar panel system with panels, fixing clamps for the panels, supporting rails (or other supporting system) and if requested by the client, brackets that normally fix the rails to the roof. The test assembly normally consists of at least two PV solar panels, but for cyclic testing the CTS recommends using three panels, as this provides additional replications that will usually allow a smaller value for the coefficient of variation and thus a larger design pressure for any given test pressure.

5.2 Joint Testing

5.2.1 Joint Test Rig

Joint tests are conducted as “Uplift Tests” that normally use a tension testing machine that includes the capability to measure and record the tension load applied. An alternative test rig that can be used comprises a single hydraulic loading ram in series with a load cell to apply the tensile load.

5.2.2 Specimen for Joint Test

The test specimen is assembled in such a way so as to model the normal in use situation as closely as possible.

6 NATA ACCREDITED TEST REPORTS

After completion of testing, the CTS will issue a commercial in confidence test report describing the test methods, results and if requested, recommended design capacities for the configurations tested. CTS will also issue a test summary sheet referencing the corresponding report number. Test results are valid until the expiry date identified (typically about 4 years until June 30 or December 31 of the relevant year). CTS offers a reappraisal service at this time

Note that the CTS test procedures are conducted in accordance with its quality management system which is NATA accredited.

7 REFERENCES

- AS/NZS 1170.0:2002 – Structural Design Actions – General Principles
- AS/NZS 1170.1:2002 – Structural Design Actions – Permanent, Imposed and Other Actions
- AS/NZS 1170.2:2011 – Structural Design Actions – Wind Actions
- AS 1562.1:1992 - Design and Installation of Sheet Roof and Wall Cladding, Part 1: Metal
- AS 4040.0:1992 – Methods of Testing Sheet Roof and Wall Cladding – Introduction, List of Methods and General Requirements
- AS 4040.2:1992 – Methods of Testing Sheet Roof and Wall Cladding – Resistance to Wind Pressures for Non-Cyclone Regions
- AS 4040.3:2018 – Methods of Testing Sheet Roof and Wall Cladding – Resistance to Wind Pressures for Cyclone Regions
- AS/NZS 5033:2014 - Installation and safety requirements for photovoltaic (PV) arrays
- National Construction Code of Australia
- *Draft Guide to LHL Cyclic Testing (Version 1)* dated 9 April 2009. Published by Cyclone Testing Station (PDF copy available on CTS web page).
- Report No. TS821 (2011) “*Investigation on Wind Loads Applied to Solar Panels Mounted on Roofs*”. Prepared by Cyclone Testing Station (PDF copy available on CTS web page).