Appendix K of NS130

Testing Of Backfills: Thermal Resistivity

SEPTEMBER 2009

Appendix K
of NS130
Testing Of Backfills: Thermal Resistivity

CONTENTS

1 BACKGROUND

Ausgrid has a high capital investment in underground cables.

The ratings of these buried cables are greatly affected by the thermal properties of the surrounding soils and imported thermal bedding materials.

Thermal resistivity (TR) is a major input parameter into cable rating calculations and a thorough understanding of the resulting values during construction is vital to ensure the specified cable ratings are achievable over the lifetime of installed assets.

Ausgrid wishes to ensure that the TR testing services being offered by external service providers are accurate and consistent, providing test results that can be relied on for it's determination of cable ratings.

This document has been developed with the intent that the quality of TR testing being offered by external service providers is of a standard compatible with Ausgrid's requirements. Information is included to assist Testing Laboratories experienced in soil analysis but not thermal studies to understand the basis for the requirements and procedures specified.

2 THERMAL RESISTIVITY (TR)

Thermal resistivity (TR) is the reciprocal of thermal conductivity.

Thermal resistivity (TR) is a property of the material being tested.

Thermal resistance depends upon the TR of the material AND the geometry of the installation

TR is often measured in either Km/W or ^{o}C.m/W, the units depicting temperature rise across a given distance due to an amount of heat(power) passing through the medium.

Regardless of whether K or ^{o}C are used, the magnitude of the TR will be the same.

For a given geometry: the higher the TR the greater the resistance to the flow of heat and, for a given amount of heat the greater the temperature rise.

The formula used to calculate TR for a line heat source of infinite length within an infinite medium is:

$$\rho = \frac{4 * \pi * (T2 - T1)}{2.303 * q * \log(t2/t1)}$$

Where:

ρ	= TR in K.m/W (or ^{o}C.m/W)
T_1 and T_2	= Temperatures at the beginning and end of the test period respectively
q	= Heat dissipated by the line heat source in watts/m
t_1 and t_2	= Times at the beginning and end of the test period in minutes

The qualifying factors that apply to the above expression should be noted as:

Thermal probes are not line heat sources and have physical diameters and wall thickness. The resulting mass and specific volumetric heat of the probes causes non linear relationships between temperature and log (time differences) at the initialisation of tests.

3 SCOPE

The scope of this document covers information relating to the necessary processes for ensuring that testing of thermally stable materials or soil samples is conducted in a manner that provides accurate and consistent results regardless of the Testing Laboratory undertaking the tests. In particular, the document includes information on :

- Tests to be Undertaken on Samples
- Quality of Test Procedures
- Sample Preparation
- Storage of Samples
- The development of thermal bedding materials
- General equipment needed

4 TESTS TO BE UNDERTAKEN ON SAMPLES

Tests to determine the thermal characteristics and performance of bedding materials for use in Ausgrid projects shall be generally in accordance with:

ASTM D5334-08 Standard Test Method for Determining the Thermal Conductivity of Soil and Soft Rock by Thermal Needle Probe Procedure.

Note that results from this method are for thermal conductivity, and it will be necessary to take the reciprocal of this value to calculate the thermal resistivity, which is the value generally used in Australia for cable installations.

Ausgrid require the following tests to be undertaken and results provided for samples for which thermal resistivity is being determined.

For native soil samples**:-**

- Thermal resistivity – as found
- Moisture content – as found
- Thermal resistivity – in the fully dried out state
- Thermal dryout curves – Thermal resistivity vs Moisture content.
- Soil density – as found

The density of native soils may not always be required. When commencing work on projects the Testing Laboratory should confirm that Ausgrid requires native soil density results.

For compacted granular thermal bedding materials (including graded sands) submitted for approval or routine testing**:**

- Thermal resistivity at a specified compaction density
- Moisture content – when compacted
- Proctor density of the compacted sample
- Thermal resistivity in the fully dried out state
- Dry Density

For flowable thermal bedding materials submitted for approval or routine testing:

- Thermal resistivity at commencement of testing
- Moisture content at commencement of testing
- Thermal resistivity in the fully dried out state
- Dry Density

Where the material is being submitted for approval (type testing), a dry out curve may also be required, recording moisture content and thermal resistivity at; zero moisture content, initial moisture content and at least two points in between. The initial moisture content shall be not less than 8%.

For compacted granular materials, the minimum Proctor density of samples shall be specified by Ausgrid. If not specified, the value shall be 98% Standard Proctor density. For material submitted for approval (type testing) the fully dried out TR shall also be determined at 95% and 90% standard Proctor density.

Sieve analysis may also be required When instigating projects the Testing Laboratory should confirm that Ausgrid requires sieve analysis results.

5 PROVISION OF TEST REPORTS

Results are to be provided to Ausgrid in both hard copy and an uneditable electronic format (e.g. pdf file).for storage and access by Ausgrid staff in Ausgrid's management systems.

6 QUALITY OF TEST PROCEDURES

Notwithstanding any standard, process or equipment used the Testing Laboratory must at all times be able to demonstrate to the satisfaction of Ausgrid that the methodologies and equipment used for the determination of the thermal resistivity of soils will provide accurate and repeatable test results.

The following references shall be used in place of the comparable US standards where referenced in ASTM D5334-08:

- AS 1289 5.1.1-2003: Method of Testing Soils for Engineering Purposes – Soil compaction and dry density Tests.
- AS 1289 2.1.1-1992: Method of Testing Soils for Engineering Purposes – Soil moisture content tests
- AS 1289 1.1.1-2001: Method of Testing Soils for Engineering Purposes – Sampling and preparation of soils.
- AS 1012.3.1 – 1993: Methods of Testing Concrete. Determination of properties related to the consistency of concrete – Slump test
- AS 1379 – 1997 Specification and supply of concrete

7 FACTORS THAT INFLUENCE TEST RESULTS

Test samples are also not infinite mediums (often being as small as 50mm in diameter). Boundary effects occur during tests as the heat flux reaches the outer surface of the sample where it often interfaces with air.

There are many factors that can influence test results such as:

- Moisture migration within the sample under test due to the heat from thermal needles can affect the rates of temperature rise.
- Non stable sample temperatures affect the flow of heat generated by the probe.
- Poor probe surface contact resistance with the surrounding aggregates can influence results due to situations such as: aggregate size, compaction, cracked samples or incorrectly installed thermal needles
- Poorly prepared samples where in the case of compacted granular materials the density of the material is inconsistent with the expected density

For these reasons when assessing the resulting values (or more fundamentally, the time periods over which analysis is to occur) a visual representation of the temperature/log time output must be referred to, to ensure initial and transient boundary effects have been considered and their effect on the TR result minimized.

8 EQUIPMENT

Thermal Resistivity Test Instruments.

Refer to part 5 of IEEE 442-1981 *Guide for Soil Thermal Resistivity Measurements* for general information on test equipment for use on TR testing.

Whilst the determination and analysis of TR can be achieved using relatively simple equipment, modern instrumentation usually incorporates constant current power sources and data logging facilities together with computer assistance to output a TR quantum.

Due to the effects of initial transients and edge effects, only those instruments that can demonstrate to the satisfaction of Ausgrid that these effects have been considered and eliminated in the determination of TR shall be approved for carrying out TR measurements.

Thermal needle length to diameter ratio shall be no less than: 30:1

The contractor may be required to perform a practical demonstration of the instrumentation offered and shall be required to provide specifications for the equipment to be used for testing samples for Ausgrid.

A list of the key equipment expected to be required by Testing Laboratory in carrying out TR measurements for Ausgrid is provided in Appendix A.

9 SAMPLE PREPARATION

The preparation and handling of samples has a great influence on the resulting TR.

Due to the relatively small size of commonly prepared samples the scaling effects on mix tolerances can lead to inaccuracies when specifying delivered quantities.

The measuring tolerances of equipment and methodologies used to prepare samples shall be suitably controlled to minimize scaling errors.

- The measurement accuracy of Thermal Resistivity shall be: < +/- 5%

- Routine daily calibration checks of balances shall be carried out using known test weights.
- The measurement accuracy of balances shall be: < +/- 1%
- The minimum diameter of samples to be tested shall be: 50mm
- The minimum length of sample to be tested shall be: 150mm
- Larger samples are preferred

Routine daily calibration checks of balances shall be carried out using known test weights.

9.1 COMPACTED GRANULAR SAMPLES

For a given material type the TR of compacted granular materials is usually quite sensitive to both compaction density and moisture content.

For results to be accurate and repeatable the compaction of samples must be well controlled.

Testing Laboratories must have systems in place to ensure:

- The positioning of test probes within the samples being prepared is controlled to prevent movement of the probes during compaction
- The density of the compacted material within the sample is consistent throughout the sample volume.
- Sample compaction is carried out at known moisture contents(as a percentage of dry weight)

For these reasons samples must be prepared in controlled layers where the mass of the material being compacted within each successive layer volume is known. Quality balances must be used to accurately measure the mass of material used within the layered samples.

Samples shall be taken from site or prepared from ingredients in accordance with AS 1289.1.1.1. When placed in the test cylinder, compaction shall be tested in accordance with AS1289.5.1.1.

Compaction rates and the densities must be referenced to standards to ensure repeatability in the field i.e. Standard Proctor Test.

Where a dryout curve is being prepared, moisture content shall be tested at the beginning and end of tests, as well as at additional points in between. Testing for moisture content shall be in accordance with the requirements of AS1289.2.1.1.

9.2 FLOWABLE SAMPLES

The collection and treatment of fluidised samples before solidifying can have marked effect on the TR of the sample under test. The aggregates within these high slump materials (designed such that they should flow without mechanical vibration) can easily segregate under vibration. The consistency of the collected sample under test must be representative of the material installed within the cable trench and for this reason, further movement/vibration caused by influences such as but not limited to:

- Rodding
- Transport
- Tapping the sample tube

should be avoided until the material has solidified to prevent aggregate segregation. Collected samples are usually best left on site until solidified before transporting to a test laboratory for further testing.

9.3 PROBE INSTALLATION AND COLLECTION OF UNDISTURBED SOIL SAMPLES

The installation of thermal needles/probes must be done with a view to ensuring good contact between the needle and the surrounding material without disturbing the soil.

Poor contact between the thermal needle and surrounding material will greatly effect the TR measurement.

If the sample material is so hard as to require the drilling of a hole to permit installation of the needle without damage to the needle or disturbance to the sample, the hole shall be of slightly smaller diameter than the needle to ensure that the needle maintains a good contact with the sample through out its length.

The most common method used for collecting undisturbed samples is via driven tubes. These tubes must comply with the minimum dimensions specified above.

The tubes used must be thin walled (nominally 1.0mm) and driving operations undertaken with processes that prevent inadvertent compaction of the collected sample.

NOTE: Driving thermal needles and sample tubes into native soil within the field environment bring with it the risk of damaging other services. The Contractor's attention is brought to the necessity to locate services before driving probes, collection tubes or drilling holes for needles. The cost of rectification of any damage caused by the contractor in carrying out probe installation or the collection of samples shall be borne by the contractor.

10 STORAGE OF SAMPLES

The Test Laboratory shall have in place suitable storage facilities for the preservation and storage of test samples.

Following final tests, samples are usually discarded, however there may be a requirement for samples to be stored for a period of time for records and/ or retest either by the Test Laboratory or by others.

The maximum time samples are required to be stored is: 6 weeks.

For samples to be stored by the Test Laboratory, Ausgrid must issue notice to the Test Laboratory no less then 2 weeks prior the commencement of testing that samples are to be stored. At the completion of the storage time the Test Laboratory may discard the samples unless within the 6 week storage period notice has been given by Ausgrid that prolonged storage of samples would be required.

- The maximum prolonged period of storage (including the initial 6 weeks) shall be 12 weeks.
- The minimum volume to be allocated for the storage of samples shall be $24m^3$

The storage facility shall be in a cool dry place with security and appropriate filing to prevent the loss and ensure proper identification of samples for the storage period.

At the end of the storage period the Test Laboratory may discard the samples and/or hand them over to Ausgrid at Ausgrid's discretion.

11 DEVELOPMENT OF THERMAL BEDDING MATERIALS

Once a mix design for thermal bedding or backfill material has been determined within the laboratory, and constituent components specified to a level such that variation in the delivered material prevents the resulting TR from exceeding Ausgrid's specified maximum TR for the project in hand, before it can be used on Ausgrid's network it must be type tested in the following manner.

Samples for type testing shall be collected from a batched mix of no less than 1m^3 with no less than 3 samples for TR testing being taken from the beginning, middle and end of the batched product (a total of 9 samples for thermal testing plus additional samples for compressive strength tests).

Test reports for these materials shall include:

- Detail description of the constituent components
- Sieve analysis
- Identification of the source quarries and batching plants
- Mix design (in kg/m^3 – dry weight)
- Water content in liters/m^3 or % dry weight
- Compressive strength at 7, 14 and 28 days (with a maximum of 3MPa for encasing/bedding direct buried cables) at the minimum and maximum site acceptable slump (moisture content) values.
- Thermal Resistivity in the fully dried out state in Km/W (for materials mixed at the minimum and maximum site acceptable slump (moisture content) values.
- Methods used for the sample preparation and installation to ensure the type test results are representative of the "in field installed" materials.

For compacted granular mixes only:-

- Compaction density to be used on site as a % of the Standard Proctor Density (used to achieve the type test results for compacted granular materials)

For flowable type mixes only:-

- Nominated slump (in the case of fluid type product) to be used on site
- Forecast Compressive strength @ 6, 12 and 24 months at the minimum and maximum site acceptable slump (moisture content) values.

Six cylindrical samples nominally 100mmD * 150mm long shall also be provided for inspection by Ausgrid.

The type test results (including the 28 day compressive strength results) together with work method statements (WMS) for their installation for controlled thermal bedding together with samples, shall be provided no less than 6 weeks prior to first installation.

12 QUALITY MANAGEMENT PLANS

Testing Laboratories undertaking TR testing must have in place, accredited or approved quality systems documenting the:

- Work method statements for each of the individual processes being undertaken
- Test report formats
- Equipment list that positively identifies the equipment used and the accuracy of the instrumentation provided
- List of key personnel undertaking TR testing and sample preparation
- Methods used to calibrate instrumentation, including calibration frequency

13 OWNERSHIP AND TREATMENT OF SAMPLES

Samples provided by Ausgrid shall remain the property of Ausgrid until testing is completed and samples are discarded.

Samples collected by the Test Laboratory or contactor for testing shall remain the property of the Test Laboratory until full payment of the testing services is received.

From the time of receipt of samples the Test Laboratory shall ensure that the samples are maintained within a controlled environment and treated such that the variation in TR results due to storage are minimized. For this reason bulk samples shall be stored in sealed enclosures to prevent moisture loss and or migration of moisture within the sample itself.

14 RIGHT OF ACCESS

Ausgrid reserves the right to witness any testing being carried out on its behalf, whether this testing is on site or within laboratories.

Ausgrid reserves the right to audit any testing or equipment that may be used for testing samples on its behalf. The cost of auditing will be to Ausgrid who will provide reasonable notice to the Test Laboratory for the audit.

15 CONFIDENTIALITY

The Test Laboratory must have in place quality systems to guarantee the confidentiality of tests carried out on Ausgrid's behalf.

16 TYPICAL EQUIPMENT

ITEM	EQUIPMENT	DESCRIPTION / USE
1	TR test instrumentation	Suitable constant power sources (adjustable) with temperature/log time data logging facilities. Output results to be able to be confirmed by graphical output.
2	Thermal needles probes	Thermal probes/needles with a length to diameter ratio of > 30:1 capable of withstanding oven temperatures ≥ 105°C. Sized to suit field and laboratory situations.
3	Forced air oven	Used for drying out and stage drying samples (at up to 105°C ± 2.5%) as well as treating soil samples at elevated temperatures prior disposal in accordance with the NSW department of agriculture specifications.
4	Balance and calibration test weights	± 0.01% for accurately weighing component materials and mixtures.
5	Sieve / shaker -	Multistage vibrating sieve up to 25mm sieve sizes.
6	Standard proctor compaction hammer and test cell	These standardized items (to AS 1289 – Methods For Testing Soils For Engineering Purposes) are used for the laboratory compaction and density measurement of samples.
7	Field sample tubes with sealing caps	50mmd * 150mm long Stainless steel tubes for the collection of undisturbed field samples with "in-situ/natural" density or allowing uncontrolled drying out of test samples.
8	Laboratory sample tubes and compaction equipment	For accurately preparing compacted granular samples with consistent density throughout the sample.
9	Slump cone and tamping rod	Used for determining the standard slump of "fluid" materials.
10	Measuring cylinder	0-500ml ± 0.5ml measuring cylinder for accurately measuring the required moisture component of samples under manufacture.
11	Manuals and work instructions	Quality assurance for equipment calibration and work procedures.