SPECIFICATION FOR THE TRRL FROST-HEAVE TEST

by

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The views expressed in this report are not necessarily those of the Department of Transport

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SPECIFICATION FOR THE TRRL FROST-HEAVE TEST

ABSTRACT

The TRRL frost-heave test is nominated in the Department of Transport's Specification for Road and Bridge Works to establish the degree of frost-susceptibility of unbound sub-base and base materials. The test as originally described in LR 90 contained insufficient detail for it to be carried out in a standardised manner with granular materials. This led to problems both in carrying out the test and in the interpretation of results; the Laboratory therefore undertook a research programme to improve the test. This work has now been completed and this report contains a specification for an improved test procedure that has been developed from the results of the research. This procedure supersedes that given in LR 90 and other publications of the Laboratory which give details of the test.

1. INTRODUCTION

If the surface of a road is permeable, winter damage can occur as a result of the expansion of water as it freezes in the voids of the pavement layers. This type of damage is a result of faulty construction or lack of maintenance and is most common when a bituminous surfacing is nearing the end of its useful life. The remedy is of course to ensure that the road is kept sealed.

More serious is the problem of frost damage resulting from the formation of ice-lenses in the lower pavement layers from water drawn up from the water-table; this causes heave of the whole road structure. The TRRL frost-heave test is used to determine the susceptibility of roadmaking materials to this type of frost damage and the specification for this test is the main subject of this Report. It supersedes the following Laboratory publications on this subject: LR 90 (Croney and Jacobs 1967), SR 318 (Anon 1977) and MM 64 (Anon 1981).

2. BACKGROUND OF THE TEST

Frost-heave damage on a nationwide scale is not common in Great Britain. Winters in which such damage is widespread occur infrequently and indeed there have been only two since 1960 (Sherwood and Roe 1984). However, this does not mean that the possibility of frost-heave can be ignored because, if frost-susceptible materials are used, roads exposed to prolonged severe freezing conditions may show serious foundation failures. When a thaw sets in, the affected materials retain a high moisture content, the bearing capacity of the road is considerably reduced and the road is liable to break-up under the action of traffic. This break-up can be severe, especially if differential heave has occurred, and reinstatement can be very expensive.

A quantitative measure of the frost-susceptibility of granular base and sub-base materials can be obtained from the laboratory test developed at the Laboratory and described in Laboratory Reports LR 90 and SR 318. The test was developed originally as a research tool for examining the frost-susceptibility of soils but it has been used since 1969 as a compliance requirement in the Specification for Road and Bridge Works (Department of Transport 1976). Its use in this role has led to difficulties because the procedure given in LR 90 was not sufficiently precise and many interpretations have been placed on the manner in which granular materials should be tested.
The differences in testing procedures exaggerated the poor reproducibility of the test and thus made apparent the urgent need for a standardised test procedure. The Laboratory therefore undertook work to improve the original test. As a result of this work, it has been possible to prepare the specification for carrying out the improved test contained in this report.

The test described in LR 90 involves the use of a cold-room which can be maintained at $-17^\circ\text{C}$. Because this is an expensive facility work was first centred on the substitution of a self-refrigerated unit (SRU) for a cold-room. Appendix 1 gives details of the main requirements for an SRU. As very few laboratories now use cold rooms for carrying out the LR 90 test no information is provided in the specification for carrying out the test in a cold-room.

The other major departure from the LR 90 test procedure is that the freezing period has been shortened from 10 days to 4 days. This means that the test criterion suggested by Croney and Jacobs has had to be modified. In addition a further modification has been made to allow the reproducibility of the test to be taken into account when interpreting the results. This is described in Section 7.

3. SCOPE OF THE FROST-HEAVE TEST

Because of the time and cost involved in carrying out the frost-heave test it is not suitable for routine on-site control checks. It is intended primarily as a method to establish whether or not an aggregate from a particular source is likely to be frost-susceptible when used in an unbound condition within that part of the road pavement subject to frost penetration.

The method of classification of a material in terms of its frost susceptibility described in Section 7 uses the test in this context. It assumes that a bulk-sample (at least 500 kg) that is representative of the source has been obtained and that several laboratory samples have been prepared (see 6.4).

3.1 Unbound granular base and sub-base materials

Because the purpose of the test is to ensure that materials susceptible to frost-heave are not used within 450 mm of the road surface, its principal use is to determine the frost-heave of unbound granular roadbase and sub-base materials. These are not only potentially susceptible to heave but will also be found at levels in the road pavement where frost penetration is likely to occur several times during the life of a road.

Since the introduction of the LR 90 test as a compliance requirement in the Specification for Road and Bridge Works, much more experience has been gained of the frost-heave properties of granular materials and it is now apparent that many materials which had been classified in LR 90 as being non-susceptible are, in fact, susceptible. This means that all granular materials used in an unbound condition within 450 mm of the road surface should be tested and the classifications given in LR 90 and Road Note 29 (Road Research Laboratory 1970) should be ignored.

3.2 Cement-bound and bituminous-bound materials

These materials, if they satisfy all the other requirements of their respective clauses in the Specification for Road and Bridge Works, will almost invariably have frost-heave values that are well within acceptable limits. It is therefore not necessary to use the test on such materials. However, relatively small proportions of cement and other additives are sometimes used to reduce frost-heave rather than to impart high strength. The test is applicable
in such cases, but, before freezing is carried out, the test specimens should be cured at constant moisture-content and temperature (paragraph 5.1.5 of Test 10 of BS 1924:1975 gives a suggested method of curing) for a sufficient time to elapse for the additive to have its desired effect.

3.3 Soils and subgrade materials

When the pavement is less than 450 mm thick it may be necessary to ascertain whether the subgrade is susceptible to frost-heave. For non-cohesive materials the guidance given for unbound granular materials will apply. For cohesive materials the main difference lies in the method of determining the moisture content and density to be used for the preparation of the specimens. The usual level of compaction adopted corresponds to 5 per cent of air voids at the natural moisture content or, if the latter is not known, at a moisture content of 2 per cent above the plastic limit.

Lime stabilisation of the surface of the subgrade to form a capping layer may increase its susceptibility to frost heave. This should be borne in mind if lime-stabilisation is used; at least 28 days should be allowed for the pozzolanic effect of the lime to occur before specimens are tested.

4. SELECTION OF SAMPLES FOR TEST

Both the user and the supplier of the aggregate need to give careful consideration as to the best means of obtaining a sample for test which will be truly representative of the source of supply. If the aggregate produced by any one source is likely to be particularly variable in quality this must be taken into account and it may be necessary to carry out checks to find the extent of this variability (see Section 5.2).

It is essential that both sides are satisfied at the outset that the sample being taken for test is one that can be relied upon to give a good indication of the quality of aggregate being supplied for the contract. Sampling of the material should use the procedures given in BS 812 Part 102:1984. A bulk sample containing at least 500 kg of material should be obtained and, by suitable sample-reduction techniques of the types described in BS 812:1984 and BS 1377:1975, it should be sub-divided to give the following laboratory samples:

(i) A minimum of 100 kg to be used for the advance tests, ie particle-size distribution, plasticity of the fines fraction and the '10 per cent fines' value.

(ii) A minimum of 100 kg for the determination of the moisture-content and dry density at which to prepare frost-test specimens.

(iii) A minimum of 100 kg for the main frost-heave test procedure.

The remainder of the bulk sample, which should weigh about 200 kg, should be set aside as a reserve from which further laboratory samples can be prepared for further testing should this prove necessary. It should be stored so that it does not become contaminated in any way.

Each laboratory sample should be oven-dried at a temperature not exceeding 110°C. If there is any reason to suspect that oven-drying changes the properties of the material it should be air-dried and its air-dry moisture content determined by Test 1 of BS 1377:1975. The amount of water in the material must then be allowed for when calculating the amounts of the material and water required in paragraphs 8.4.3, 8.5.2 and 8.7.1.
5. ADVANCE TESTING

5.1 General

The material for the Frost-heave Test must conform to all the requirements of the relevant clauses for unbound materials given in the Department of Transport Specification for Road and Bridge Works, or such other specification as may be relevant to a particular contract. It is therefore essential to carry out tests such as the particle-size distribution, ten per cent fines test and the plasticity index of the fines fraction before the Frost-heave Test is attempted. If the result of any of these tests is outside the specification the Frost-heave Test becomes superfluous and should be omitted.

5.2 Particle-size distribution test

With most granular materials the particle-size distribution (grading) will be the major variable factor and a knowledge of the variability of the grading from a particular source is a prerequisite of the Frost-heave Test. Many, but not all, sub-base materials show an increase in frost-heave with an increase in the fineness of the grading. If the sample being tested is on the fine side of the required grading envelope, the result obtained may give a pessimistic measure of the frost-heave of the bulk of the material and vice-versa.

6. INSTRUCTIONS TO TESTING LABORATORY

6.1 Particle-size distribution

In the instructions to the testing laboratory the client should include details of the particle-size distribution (grading) of the bulk sample determined in the advance testing (section 5). This will be used by the testing laboratory to cross-check the grading which it obtains for the actual laboratory sample supplied for the frost-heave test. If a marked discrepancy arises between the expected and actual grading this can be investigated (and, if necessary, new samples provided) before a frost-heave test is carried out.

6.2 Moisture-content and dry-density at which to prepare specimens

In order to prepare test specimens the laboratory needs to know the moisture-content and dry-density at which they are to be moulded. Sections 8.4.2 and 8.4.3 describe how these are to be determined. For granular materials the procedure involves carrying out a compaction test to find the optimum moisture-content and maximum dry-density while for cohesive soils the moisture-content is derived from the plastic limit and the density calculated to correspond to 5 per cent air voids. Using these figures for moisture-content and dry-density, trial specimens are prepared; adjustments are made to the moisture content if necessary to prepare a stable specimen. The values thus obtained are then used to prepare the actual specimens for testing.

The client may instruct the testing laboratory to determine the values following the full procedure given in Section 8. Alternatively, he may supply values for optimum moisture-content/maximum dry-density (or plastic limit and specific gravity as appropriate), provided these have been previously determined for material from the same bulk sample, and instruct the laboratory to proceed immediately to the second stage (8.4.3).

When a particular frost-heave test is to provide repeat measurements on material from the same bulk sample the client may specify the actual moisture-content and dry density to be used for the test specimens on the basis of a previous determination.
6.3 Number of specimens to be tested

The normal number of specimens to be prepared and tested is three. Where a wide spread of results arises, the test laboratory must perform a repeat test on a further six specimens before reporting any results. However, when the test to be performed is an extra test to confirm an earlier result from the same bulk sample, and it is known that in the earlier test a six-specimen repeat was necessary, the client may instruct the laboratory to test six specimens immediately (see Section 7.2).

6.4 Material to supply

Where the moisture-content and dry-density for specimen preparation are not known, two of the 100 kg laboratory samples prepared under Section 4 shall be forwarded to the test laboratory. When the moisture-content and dry-density are specified explicitly, one laboratory sample of not less than 100 kg (prepared, if necessary, from the reserve sample obtained under Section 4) should be forwarded for testing. A 100 kg sample provides sufficient material for a particle-size distribution test and all the necessary frost-heave specimens, leaving enough spare to repeat frost-heave tests in the event of equipment failure invalidating a test run.

7. METHOD OF CLASSIFICATION OF MATERIALS

This section describes how the results of the frost-heave test are used to classify a material as ‘frost-susceptible’ or ‘non frost-susceptible’ for the purposes of their use in road construction. The test is used in two stages.

7.1 Initial classification

In the first instance the client shall send a laboratory sample to one laboratory, and instruct them to carry out the test following the method given in Section 8. He may advise the laboratory of the optimum moisture content and maximum dry density to be used as the basis of sample preparation if the information is already available for the bulk sample, otherwise he shall provide a second laboratory sample and instruct the laboratory to determine the moisture-content and density to be used as described in the method.

When the first laboratory has reported its result the material shall be classified as follows.

(i) If the mean heave reported (see Section 8.9) is 9.0 mm or less, the material shall be classified as ‘non frost-susceptible’ and no further testing is necessary.

(ii) If the mean heave is 15.0 mm or greater the material shall be classified as ‘frost-susceptible’ and no further testing is necessary.

(iii) If the mean heave is in the range 9.1 to 14.9 mm, inclusive, the material shall be regarded as ‘not proven’ and shall be tested further. (Section 7.2).

7.2 Final classification of ‘not proven’ material

When a material has been placed in the ‘not proven’ category after the initial test the client shall forward a laboratory sample to two different laboratories and instruct them to test the material using the stable-specimen moisture-content and dry-density reported by the initial laboratory (Section 8.9.4). If the original laboratory reported results on two test runs due to excessive range on the first run the client should instruct the additional laboratories to include six specimens in the test run.
When the results are available from all three laboratories the overall mean heave shall be calculated to the nearest 0.1 mm. The material shall then be classified as follows:—

(i) If the mean heave is 12.0 mm or less, the material shall be classified ‘non frost-susceptible’.
(ii) If the mean heave is 12.1 mm or greater the material shall be classified ‘frost-susceptible’.

There will inevitably be occasions when discrepancies appear in the results reported by the three laboratories. It must be remembered that the range of single sets of heave results can be up to 6 mm (ie the reproducibility) on a mean of 12 mm, and more than this for higher mean heaves; on 1 in 20 occasions this figure may be exceeded. When this occurs it is a matter of the engineer’s judgement, using other available information (eg grading or density during test, nature of the material), to decide whether a suspect result is a genuine outlier which should properly be ignored or whether it is an inevitable random fluctuation which should still be included in calculating the mean heave for classification purposes.

8. SPECIFICATION FOR THE TRRL FROST-HEAVE TEST

8.1 General

This method covers the testing of a soil or granular material for frost-susceptibility by determining the frost-heave of the material under controlled conditions. To take account of the variability of the results of the frost-heave determination, materials are tested in sets of three specimens. Since the self-refrigerated unit used accommodates nine specimens, three sets are tested in a single test run. Normally three different materials are tested together but in certain circumstances two sets (ie six specimens) may be of the same material with one set of a different material making up the test run.

The method describes the procedure to be followed to carry out a complete test run on three sets of specimens, the methods to be used to assess the validity of the results and the manner in which they are to be reported.

8.2 Apparatus

The following items of equipment are required:—

(1) Apparatus required for carrying out the particle-size distribution by Test 7(A) of BS 1377:1975.
(2) Apparatus for determining the dry-density/moisture-content relation by BS 5835:Part 1:1980. (See Note 1)*
(3) A self-refrigerated unit (SRU) and ancillary equipment as specified in Appendix 1 and Figs 1, 2 and 3.
(4) At least four containers for holding 4 kg samples of dry aggregate. Metal trays approximately 200 mm square and 25 mm deep have been found suitable.

* Notes to this specification will be found in Appendix 4.
(5) At least one tared glass flask of each of the following capacities: 250 ml, 500 ml and 1000 ml.

(6) A suitable mechanical mixer with a capacity of at least 20 kg (see Note 2).

(7) At least nine containers which can be made airtight capable of holding 15 kg samples of mixed material.

(8) A steel mould and end-plugs as specified in Fig 4.

(9) A steel tamper weighing 1100–1200 g. A suitable design is shown in Fig 5.

(10) An electric vibrating hammer as specified in Test 14 of BS 1377:1975.

(11) A steel tamper for the vibrating hammer with a circular foot of 100 mm diameter. A suitable design is shown in Fig 6.

(12) A depth gauge capable of reading depths up to 250 mm, readable and accurate to 1 mm.

(13) A means of ejecting the compacted specimen from the mould, e.g., a jacking device as illustrated in Plate 1 or a compression testing machine with suitable extruders, as illustrated in Fig 7.

(14) Waxed paper sheets approximately 350 mm x 200 mm and suitable adhesive tape. The thickness of the tape should be between 0.1 mm and 0.25 mm and that of the waxed paper should be between 0.2 mm and 0.4 mm.

(15) At least nine Tufnol discs (Carp Brand) 95 mm diameter, 5 mm thick with a central recess 10 mm diameter and 2 mm deep in one side, of the type supplied by Tufnol Limited, PO Box 376, Perry Barr, Birmingham B42 2TB or 3 James Watt Place, College Milton North, East Kilbride, Scotland.

(16) At least nine porous ceramic discs 13 mm thick and 101.6 mm in diameter of maximum pore size 110 microns, grade P5, supplied by Doulton Industrial Products, Fillybrooks, Stone, Staffs.

(17) At least nine copper specimen carriers as specified in Fig 8.

8.3 Selection of samples and quantities required

All sampling and sample-reduction of the test material shall follow the procedures given in Part 102 of BS 812 (British Standards Institution, 1984). A laboratory sample of a minimum mass of 100 kg is required. This will contain sufficient material to provide test portions for the particle-size distribution test and the frost-heave test specimens needed for a single determination of the frost-heave of the material. This quantity allows enough spare material to cover a retest in the event of an equipment breakdown without obtaining a fresh laboratory sample.

If it is necessary to determine the moisture-content and dry-density at which to prepare specimens (see Section 8.4.2) a second laboratory sample of minimum mass of 100 kg will be required.

Advice on the size of bulk sample needed to provide the laboratory samples for the frost-test is given in Section 4.
8.4 Preliminary testing

8.4.1 Particle-size distribution of laboratory sample. A test portion of not less than 17 kg shall be obtained from the laboratory sample and its particle-size distribution determined by Test 7A of BS 1377:1975. Before proceeding with further testing the laboratory must confirm that this particle-size distribution does not differ markedly from that of the bulk sample from which the laboratory sample was prepared (see Note 3). If there is a discrepancy a proper representative sample must be obtained before continuing.

8.4.2 Selection of moisture-content and compacted density for the test specimens — Stage 1. The moisture-content and density at which test specimens are to be prepared may be nominated in advance by the client on the basis of earlier tests. Where this information is not available the testing laboratory will have to perform the preliminary tests to choose the values to be used as described below.

8.4.2.1 In the case of granular materials and non-cohesive soils the optimum moisture-content and maximum dry density shall be found (see Note 4) by the test described in BS 5835:Part 1:1980. (See Note 1).

8.4.2.2 In the case of cohesive soils the moisture-content shall be equivalent to the plastic limit plus two per cent (PL + 2) per cent and the compacted density shall correspond to an air-void content of 5 per cent at this moisture-content. It will therefore be necessary to determine the plastic limit of the soil by Test 3 of BS 1377:1975 and the specific gravity of the soil particles by Test 6 of BS 1377:1975 (see Note 5).

The dry-density to be used in Stage 2 shall be calculated from the equation:

\[ \rho_d = \frac{\rho_w}{\left(1 + \frac{V_a}{100}\right)} \left(\frac{1}{\frac{1}{G_s} + \frac{w}{100}}\right) \]

where

- \( \rho_d \) is the dry-density of the soil (Mgm\(^{-3}\))
- \( \rho_w \) is the density of water = 1 Mgm\(^{-3}\)
- \( V_a \) is the volume of air voids in the soil expressed as a percentage of the total volume of the soil, in this case equal to 5 per cent
- \( G_s \) is the specific gravity of the soil particles, as determined from test 6 of BS 1377
- \( w \) is the moisture content expressed as a percentage of the mass of the dry soil, in this case equal to PL + 2.

8.4.3 Selection of moisture-content and density for the test specimens — Stage 2

8.4.3.1 When the moisture-content (w, per cent) and dry density (\( \rho_d \) Mgm\(^{-3}\)) have been determined a trial frost-heave test specimen shall be prepared as follows:
8.4.3.1.1 A test portion (having been sieved to remove material coarser than 37.5 mm) of mass equal to 1360 Pdg shall be obtained from the laboratory sample and placed in the mixer.

8.4.3.1.2 A tared flask shall be placed on the balance and a mass of water equal to 13.6 w Pdg shall be weighed out (see Note 6).

8.4.3.1.3 The water shall then be added to the dry material already in the mixer and thoroughly mixed.

8.4.3.1.4 The mixed material shall be used to prepare and extrude a trial specimen using the procedure in paragraphs 8.7.1 and 8.7.2.

8.4.3.2 If immediately after extrusion the specimen is unstable, ie cannot stand on the extruder without collapsing, some adjustment to the dry-density and/or the moisture content may be necessary to achieve a specimen which is sufficiently stable but at the same time has not been subjected to such a degree of compaction that undue crushing of the individual particles has occurred (see Note 7). This adjustment has to be done systematically by trial and error until a stable specimen has been made.

8.4.3.3 When a stable specimen has been prepared the specimen shall be transferred to a suitable container, broken up and dried. The particle-size distribution of the material in the specimen shall then be determined using the test 7(A) of BS 1377:1975. The degree to which crushing of the particles has occurred during the preparation of the specimen may then be assessed (see Note 7). The moisture content value and dry density used to prepare the stable specimen will be the values to be substituted for w and Pdg in paragraphs 8.5.2.3 and 8.7.1 when mixing and preparing the actual test specimens.

8.5 Preparation of material for compaction into test specimens

8.5.1 Preparation of test portion

8.5.1.1 The laboratory sample of about 100 kg is sufficient to provide material for the particle-size distribution test (Section 8.4.1) and at least fifteen test specimens, including the trial specimen(s) prepared in Section 8.4.3. The frost-heave test itself normally is carried out on three specimens and because the SRU can accommodate nine, three different materials may be tested at a time. In some cases it may be necessary to prepare six specimens of one material, either to clarify variable results (see 8.9.3) or because the client has specified six on the basis of previous work. A small reserve of material is allowed for in the laboratory sample in case an equipment failure makes a repeat test necessary.

The remainder of the laboratory sample (initially about 75 kg) shall be sub-divided by riffling until a test portion of about 15 kg is obtained. The remainder of the laboratory sample shall be set aside in case it is needed for repeat tests and the 15 kg test portion used to prepare a set of three specimens for testing.

8.5.1.2 If two sets of specimens from one material (ie six specimens in all) are required a further 15 kg test portion shall be prepared at this stage. Before proceeding further any preliminary sample preparation and testing on other materials to be included in this test run must be done.
8.5.2 Mixing

8.5.2.1 A test portion from 8.5.1 to be used to prepare three test specimens shall be sieved to remove material coarser than 37.5 mm (see Note 8).

8.5.2.2 A representative mass equal to $4080 \rho_d g$ (where $\rho_d$ is the maximum dry-density in $\text{Mg/m}^3$ determined for this material in section 8.4.3) shall be selected from the sieved material and placed in the mixer. This weight includes excess material to allow for handling losses.

8.5.2.3 A tared flask shall be placed on the balance and a mass of water (see Note 6) equal to $40.8 w \rho_d g$ weighed out (where $w$ is the percentage moisture content determined for the stable trial specimen in Section 8.4.3).

8.5.2.4 The water shall then be added to the dry material already in the mixer and thoroughly mixed. The mixed material shall be stored in a sealed container for a minimum period of 16 hours before proceeding with the test (see Note 9).

8.5.2.5 The procedure in 8.5.2.1 to 8.5.2.4 shall be repeated until three batches of mixed material have been prepared.

8.6 Preparation of the SRU

Before the test specimens are prepared it is necessary to ensure that the SRU is ready to receive them. This shall be done as follows.

8.6.1 The SRU shall be level and the test chamber, including the water-bath and constant-level device, shall be clean, dry and at room temperature.

8.6.2 The coarse sand for filling the space around the specimens shall be clean and dry (see Note 10).

8.6.3 The operation of all the thermocouples shall be checked (see Note 11).

8.6.4 The wooden specimen cradle shall be located in its position within the test chamber (see Note 12).

8.6.5 The constant-level device (CLD) and water-bath shall be filled with fresh water (see Note 6) at $20\pm5$ degrees centigrade and the water-level setting checked. A step-by-step method for doing this is given below.

(1) Open taps F, V and O (Fig 3) of the CLD and close the drain-cock of the water-bath. Place a suitable receiver below the overflow-pipe outlet.

(2) Place a specimen carrier in one of the holes in the wooden cradle.

(3) Pour water into the water-bath until the bottom lip of the specimen carrier is just covered. Check that there is no airlock or blockage in the pipe connecting the CLD to the water-bath.
(4) Adjust the level of the capillary in the CLD if necessary so that it is about 5 mm above the present water level (see Note 13).

(5) Close tap O and fill the CLD through the filler tube. Air will be expelled through the vent pipe.

(6) Close taps F and V. Place a second specimen carrier with a porous disc in place in one of the other holes in the cradle.

(7) Open tap O. Air should bubble through the capillary tube as water flows into the water-bath. When the bubbling stops the water level in the bath must be checked (see Note 14). It should be about 1 mm from the top of the porous disc, i.e., the surface of the disc appears wet but is not covered. If the level is too low, close tap O and raise the level of the capillary slightly. Re-open tap O and allow the water to find its new level (see Note 14). This process should be repeated until the required setting has been achieved.

(8) When the level has been set, close tap O. Drain off water from the bath until the water again just covers the lip of the specimen carrier.

(9) Remove the specimen carriers and disc and dry them. Top up the CLD (taps V and F open, O closed) if necessary.

(10) Check that all the taps are closed.

8.6.6 The water circulating system shall be checked to ensure that it is operating satisfactorily.

8.6.7 The SRU controls shall be set to the positions which will give the correct operating temperature when the unit is eventually switched on (see Appendix 2).

8.7 Method for preparing a test specimen

This section describes the method to be used when preparing a single test specimen from a sample of mixed material.

8.7.1 Compaction into the mould.

8.7.1.1 Mixed material shall be transferred to the balance until the balance holds a mass, M, equal to one third of the exact mass required for one frost-heave specimen, to the nearest 2g. M is calculated from the formula

\[ M = 4.12 \rho_d (100 + w) \text{ grammes} \]

where \( \rho_d \) is the stable-specimen dry-density and \( w \) the stable-specimen moisture content determined in Section 8.4.3.

8.7.1.2 The weighed material shall be carefully transferred into the mould, which shall have been placed over its bottom (smaller) end-plug. The material shall be levelled in the mould with a suitable spatula. The tamper (Fig 5) shall be held inside the mould with the upper surface of its base level with the top of the mould. It shall then be allowed to drop freely under its own weight, taking care that the foot is level when it strikes the material. This process shall be repeated until 25 drops have been completed.
The material shall then be compacted using the vibrating hammer, fitted with the special 100 mm diameter foot, until a depth-gauge reading in the range 183–189 mm is obtained (see Note 15).

8.7.1.3 A second portion of material of mass M shall be weighed out and transferred to the mould, levelled and tamped 25 times as before. The vibrating hammer shall be used to compact the material in the mould until a depth-gauge reading in the range 133–139 mm is obtained.

8.7.1.4 A third portion of material of mass M shall be weighed out, transferred to the mould, levelled and tamped 25 times. The inside of the mould above the tamped material shall be carefully wiped clean and the top plug inserted. The 145 mm (standard) diameter tamping foot shall be fitted to the vibrating hammer and the vibrating hammer shall be applied to the top plug until the specimen is fully compacted (see Note 16). The specimen shall be regarded as fully compacted if the overall gap between the mould and the end-plugs does not exceed 4 mm.

8.7.2 Extrusion from the mould

8.7.2.1 Both plugs shall be removed. Normally one or two clockwise and anti-clockwise rotations loosen the top plug in the mould and allow it to be lifted off the mould directly. In a similar manner the mould itself can be lifted from the bottom plug (see Note 17).

8.7.2.2 The specimen shall then be extruded from the mould. Paragraph 8.7.2.3 describes an acceptable method using a compression machine. Other methods utilising compression machines or hydraulic-jack extruders (eg Plate 1) may be used if proved effective, provided that their operation is smooth and attention is paid to the rate of strain which should not be excessive. Plate 2 illustrates the use of a hydraulic jack extruder.

8.7.2.3 If a compression machine is used, the narrow end of the mould shall be placed over the short extruder. Both the mould and the extruder shall be placed on the platen of the compression machine and the extrusion process started on the machine. The mould and extruder shall be removed from the machine when extrusion can proceed no further. Final extrusion shall be effected by hand using the long extruder.

If hand-extrusion proves impossible the following procedure is recommended when the compression machine has a space of at least 720 mm between the platens. The sample is extruded using a specially designed cylinder (Fig 9) which shall be fitted over the top of the mould. The mould and cylinder are then placed on the long extruder on the compression machine and extrusion completed on the machine. Where the machine has a space of 780 mm between the platens the extrusion may be effected using the long extruder only. This extrusion process is illustrated in Fig 10.

8.7.3 Completion

8.7.3.1 Immediately after extrusion a waxed-paper sheet shall be wrapped round the curved face of the specimen and secured with adhesive tape so that the lower edge of the paper is in line with the bottom of the specimen (leaving an upstand of about 50 mm at the upper face). One of the Tufnol discs, with the recess uppermost, shall be placed on top of the specimen. The specimen shall be carefully placed on a porous disc and the specimen and porous disc positioned in a copper specimen carrier (see Note 18 and Plate 2). The completed specimen assembly is then ready to be placed into the test chamber (8.8.1.2).
8.7.3.2 The mould shall be removed from the extruder and before re-use the mould, both plugs and extruder(s) shall be cleaned and dried.

8.8 Determination of the frost heave

8.8.1 Loading test specimens into the SRU

8.8.1.1 Using mixed material from one of the batches prepared previously (Section 8.5), a frost test specimen shall be prepared using the method described in Section 8.7.

8.8.1.2 The prepared specimen shall then be placed in one of the holes in the wooden cradle in the test chamber. If the specimen is to be placed in any of positions 1, 3, 5, 7 or 9 (Fig 2) a thermocouple shall be located between the bottom of the porous disc and the copper specimen carrier before inserting the specimen into the cradle. If the specimen is to be located in position 5 (Fig 2) a thermocouple shall also be fixed to the underside of the Tufnol disc so that the junction is exposed at the centre of the disc and in contact with the upper surface of the test specimen.

8.8.1.3 The procedure in 8.8.1.1 and 8.8.1.2 shall be repeated until three specimens for each of three materials or six specimens for one material and three specimens of another material (see 8.9.3) have been prepared and located in the cradle. All nine positions must be filled (see Note 19).

8.8.1.4 When nine specimens have been positioned, four thermocouples shall be positioned so that there is one above each of the spots marked x on the floor of the cradle in Fig 2, at a level 250 mm above the plane containing the lower faces of the specimens. An acceptable method of achieving this is to attach each thermocouple to a 6 mm diameter wooden dowel about 300 mm long so that the junction is exposed 205+/−2 mm from the lower end of the dowel. The four dowels may then be positioned on the floor of the cradle (see Note 20). The coarse sand shall be placed carefully in the space around the specimens (and around the vertical dowels if these are used) until the sand is level with the tops of the specimens. This should leave the waxed-paper standing approximately 50 mm above the level of the sand. Care shall be taken to remove any sand particles accidentally spilt on the Tufnol discs, particularly in the recesses.

8.8.1.5 When the coarse sand has been placed the positions of the thermocouples and any control sensors shall be checked and the lid of the test chamber closed. The datum frame shall be located on the SRU. The push-rods shall then be passed through the holes in the frame and chamber lid and located in the central recesses of the corresponding Tufnol discs. The constant-level device shall be started by opening the outlet tap, O (Fig 3), to allow water to flow into the water-bath and restore the correct level. The water level is controlled automatically for the rest of the test.

8.8.1.6 The loading of the SRU must be completed within one working day. The loaded SRU shall be left undisturbed for 115+/−5 hours from the time that the last specimen was inserted in the cradle before proceeding. The chart recorder shall be used to monitor the temperatures in the test chamber during this period. The temperatures in both the water-bath and the air above the specimens should be close to room temperature by the end of the period.
8.8.2 Freezing the specimens

8.8.2.1 When 115+/-5 hours shall have elapsed from the time that the last specimen was inserted in the cradle, the push rods shall be checked that they are correctly located. Surgery wool or similar absorbent material shall be used to plug the gaps between each push-rod and the hole in the test-chamber lid through which it passes. This prevents condensation which may form on the rods when the SRU is cool from running into the test chamber. Care shall be taken to avoid dislocating any of the push-rods. The surgery wool should not be packed tightly into the holes.

8.8.2.2 The distance between the top of the rod and the top of the datum frame shall be recorded for each push-rod to the nearest 0.5 mm.

8.8.2.3 The temperature of each thermocouple shall be recorded.

8.8.2.4 The controls of the SRU shall be switched on to start the freezing process and the time noted. The operating temperatures defined in Appendix 2 should be reached between four and fourteen hours from switching on and maintained for the duration of test.

8.8.2.5 The frost-heave shall be measured after a period of 24+/-2 hours from the time of switching on the refrigeration, as follows.

8.8.2.5.1 The push-rods shall be rotated to ensure that they have not stuck. The surgery wool shall be checked and replaced if necessary.

8.8.2.5.2 The distance between the top of the rod and the top of the datum frame shall be recorded for each of the nine push-rods to the nearest 0.5 mm. Any heave that has occurred may be obtained by subtraction.

8.8.2.6 The frost-heave shall be further recorded as described in 8.8.2.5 at intervals of 24+/-2 hours until at least 96 hours have elapsed from the time of switching on the refrigeration.

8.8.3 Monitoring the temperature conditions. Although it is not necessary to carry out a detailed tuning check of the SRU before or during every test, it is important to ensure that the equipment continues to operate correctly. The procedure in 8.8.3.1 to 8.8.3.3 shall therefore be employed during every test.

8.8.3.1 The temperature at each thermocouple shall be recorded at least daily. The temperatures shall be recorded sequentially at intervals not exceeding five seconds. The Instantaneous Water Temperature (defined in 12.2.3 (1)) and Instantaneous Air Temperature (defined in 12.2.3 (4)) shall be calculated.

8.8.3.2 If the Instantaneous Water Temperature is outside the range 3.0 to 4.5°C, or if the Instantaneous Air Temperature is outside the range –18 to –16°C, then the Mean Temperatures in the air and the water shall be determined by the method given in Section 12.2.3 of Appendix 2 (see Note 21). If the Mean Water Temperature is outside the range 3.0 to 4.5°C, or the Mean Air Temperature is outside the range –18 to –16°C, the test shall be abandoned and the SRU retuned.
8.8.3.3 The chart recorder shall be inspected at least daily to check whether any sudden changes in temperature have occurred while the equipment has been unattended (eg resulting from a power cut). If this indicates that a sudden change of more than 0.5°C in the water or 1°C in the air of more than an hour's duration has occurred, the test shall be abandoned.

8.8.4 Unloading the SRU. When the freezing of the specimens has been completed, or it has been decided to abandon the test, the SRU shall be unloaded as follows.

8.8.4.1 The refrigeration system shall be switched off (see Note 22).

8.8.4.2 The surgery wool stopping the holes in the test-chamber lid shall be removed and discarded. The push-rods shall be removed and allowed to return to room temperature. The datum frame shall be removed and the test-chamber lid opened.

8.8.4.3 The thermocouples in the air above the specimens shall be carefully removed from above the cradle and put on one side.

8.8.4.4 The coarse sand shall be removed (a vacuum cleaner may be used), dried and any waste material removed to allow re-use of the sand (see Note 10). The sand must not be re-used until it has returned to room temperature.

8.8.4.5 The specimens shall be removed from the cradle, taking care not to damage any thermocouples as they are detached. The test specimens and waxed-paper shall be discarded. The Tufnol discs, porous discs and copper specimen carriers shall be cleaned and dried. It is important to check that the porous discs have not become blocked, particularly when fine-grained materials are being tested. If any are found to be inadequately permeable they shall be replaced for future tests.

8.8.4.6 The wooden cradle shall be removed, allowed to return to room temperature and then cleaned and dried.

8.8.4.7 The SRU shall be left with the lid open until the air in the test chamber has warmed to above freezing point (see Note 22). The water bath controls shall then be switched off and both the bath and the constant-level device shall be completely drained. The waste water shall be discarded. The SRU shall be defrosted and the test chamber (including the water-bath) thoroughly cleaned and dried. The SRU shall not be used for another test until it has returned to room temperature. Any signs of condensation on the walls of the chilled tank indicate that this condition has not yet been reached. (Normally leaving overnight after defrosting and cleaning is adequate).

8.9 Reporting of results

8.9.1 Calculation of individual frost-heaves. The frost-heave for each of the nine specimens on each of the four occasions the push-rod displacement was recorded during the 96-hour freezing period shall be calculated to the nearest 0.5 mm by subtracting the respective initial rod displacements.
8.9.2 **Validity of the test-run.** Section 8.8.3 gives details of when observed changes in temperature mean that the test becomes invalid and must be repeated. If during the freezing period the heaves of two or more specimens (of the nine in the SRU) fall by more than one millimetre, the test run shall be regarded as invalid. The results shall not be reported and all the materials involved shall be re-tested.

8.9.3 **Calculation of mean heave and precision of the mean**

8.9.3.1 For each material tested the maximum heave observed within 96 hours shall be determined for each specimen, and the mean of these maxima calculated to the nearest 0.1 mm. The level and range of the result shall be checked as follows and, if necessary, a further test must be made to improve the precision of the mean.

8.9.3.1.1 If the mean heave for a three-specimen test is less than 2.0 mm the result is suspiciously low and therefore a repeat test, using six specimens, shall be carried out before reporting any result.

8.9.3.1.2 If, for a three-specimen test, the mean heave is 2.0 mm or greater, but less than 18.0 mm the range (i.e., highest—lowest) of the three specimens shall be calculated. If the range exceeds 5.0 mm the test shall be repeated, using six specimens, before reporting any result.

8.9.3.1.3 If, for a three-specimen test, the mean heave is 18.0 mm or greater no further test is necessary.

8.9.3.1.4 When six specimens have been tested in a single run, either as a repeat test or as specified by the client on the basis of earlier work, no further testing is necessary.

8.9.3.2 When any repeat testing has been completed the mean heave shall be re-calculated using the results from all the specimens. A single outlier may be omitted from the calculation of a mean of nine specimens.

8.9.4 **Values to be reported.** The following results shall be reported:

1. The dry-density at which the specimens were prepared.

2. The moisture content used to prepare the specimens.

3. The particle-size distribution of the laboratory sample obtained in 8.4.1.

4. The particle-size distribution of the stable trial specimen obtained in 8.4.3.3.

5. The maximum heave observed in 96 hours for each specimen tested, including any re-test, to the nearest 0.5 mm.

6. The mean of the results reported under 5 above calculated to the nearest 0.1 mm. One outlier may be omitted from the calculation if nine specimens were tested, but if this is done the fact must be reported.

Guidance on interpreting the results of the test is given in Section 7.
9. ACKNOWLEDGEMENTS

The work described in this report was carried out in the Pavement Materials and Construction Division (Mr G F Salt, Division Head) of the Highways and Structures Department of TRRL.

10. REFERENCES


Fig. 1 Main features and dimensions of test chamber

Note: All dimensions shown must be maintained. Dimensions in millimetres.
Fig. 2 Specimen cradle showing specimen position numbers
Fig. 3 Principle of a constant level device to control water supply to frost-heave specimens
Fig. 4 Mould and end plugs for preparation of frost test specimens
Thread M10 and machine flush with end face on assembly
Finally, secure with loctite

Scale 1:2  Material: Mild steel
Dimensions in millimetres

Fig. 5 Hand-held tamper
Shank design to suit vibrating hammer

Scale 1:2  Material: Mild steel  Mass of tamper shall not exceed 3kg
Dimensions in millimetres
This design has been found satisfactory, but alternative designs may be employed provided that the essential requirements are fulfilled (Essential dimensions are indicated by an asterisk)

Fig. 6  100mm tamping foot for vibrating hammer
Fig. 7 Specimen extruder

Scale 1:2  Material: Mild steel  Dimensions in millimetres
* Denotes imperial units  Scale 1:2  Material: Copper  Dimensions in millimetres

Fig. 8 Specimen carrier
Scale 1:2 Dimensions in millimetres

Fig. 9 Extrusion cylinder
Fig. 10 Extrusion process

Scale 1:5  Dimensions in millimetres
Plate 1 Hydraulic extruder
Plate 2 Extruding a specimen using a jack extruder
11. APPENDIX 1
SPECIFICATION OF FROST-HEAVE TEST SELF-REFRIGERATED UNIT (SRU)

11.1 General description of SRU

The frost test SRU shall be a self-contained unit comprising a test chamber and associated refrigeration and control equipment. None of the major dimensions shall exceed two metres. The unit shall be fitted with castors. Adjustable legs shall be provided so that the equipment can be levelled.

11.2 Dimensions and main features of the test chamber

The principal features and dimensions of the test chamber are shown in Figs 1 and 2. It shall consist of a chilled tank with smooth stainless-steel sides, into the floor of which is let a stainless-steel water-bath. The sides of the water-bath shall be connected to the sides of the tank by a thermally insulating medium. A wooden cradle capable of holding nine test specimens shall locate centrally over the water-bath. The cooling system applied to the tank sides shall be above the specimen cradle.

The test chamber shall be provided with a hinged lid having a stainless-steel lower surface. The lid shall have nine holes at the same centres as the holes in the specimen cradle to allow push-rods (11.4.1) to be located. These holes shall be not less than 10 mm and not more than 15 mm in diameter. The water-bath shall be provided with an overflow tube as shown in Fig 3, and shall also be fitted with a separate drain-cock. An interior light shall be fitted to the underside of the lid.

11.3 Additional features of the SRU

The SRU shall also contain the following features:

11.3.1 A device to maintain the water in the water-bath at a constant level between 8 and 11 mm from the underside of the specimen cradle (ie as close as possible to the tops of the porous discs). The principle of this device is illustrated in Fig 3.

11.3.2 A means of gently agitating the water in the water-bath to maintain an even temperature distribution.

11.3.3 A means of cooling the sides of the tank above the specimen cradle such that the operating temperatures for the air defined in Appendix 2 can be achieved and maintained.

The system shall be capable of reducing the air temperature at the centre of the tank to -20°C with the normal arrangement of specimens (Fig 1) in place.

11.3.4 A means of cooling the water in the water-bath such that the operating temperatures for the water defined in Appendix 2 can be achieved and maintained.

It is not essential to have a separate cooling system for the water-bath. A system utilising heat-loss through the specimens and additional cooling from the system cooling the air above the specimen cradle, together with a
heater mat to limit the minimum temperature, is acceptable provided that the operating temperature requirements are met.

11.3.5 The cooling system(s) shall achieve the operating temperatures, defined in Appendix 2 in both the air and the water between four and fourteen hours from the time the system is switched on, and shall be capable of operating in ambient temperatures from 15 to 25°C.

11.3.6 At least five thermocouples in the water-bath and five in the air above the specimen cradle together with a compatible electronic thermometer with a resolution of at least 0.1°C. A selector switch shall be provided to allow thermocouples to be tested in quick succession.

11.3.7 A detachable metal datum frame to support the push-rods (Fig 1) which can be positively located above the lid of the test chamber having horizontal bars with holes 6.5 mm diameter at the same centres as the holes in the specimen cradle and the test-chamber lid. The upper surface of the datum frame shall be not less than 125 mm and not more than 175 mm above the top of the lid.

11.4 Additional apparatus

The following additional apparatus is required for use with the SRU.

11.4.1 Nine brass rods 750 mm long and 6 mm in diameter. These are illustrated in their positions during the test in Fig 1.

11.4.2 A supply of clean and dry single-sized silica sand from either the 5 mm – 2.36 mm or the 2.36 mm – 1.18 mm fractions. About 30 kg is sufficient for one SRU.

11.4.3 A means of measuring the displacement of the push-rods above the datum frame, readable and accurate to 0.5 mm (a steel rule is acceptable).

11.4.4 A two-pen chart recorder to record continuously the air and water temperatures during the test. It is recommended that the recorder be built into the SRU, although it is not essential that it should be, provided that access is provided for the sensors.

11.4.5 A supply of surgery wool or similar absorbent material.
12. APPENDIX 2
OPERATING TEMPERATURES AND SRU TUNING

12.1 Preamble
Because the temperature at a given point in the test chamber clearly depends on the location, the operating
temperatures within the test chamber cannot be specified in terms of a single point and temperature. Also the
temperature within the chamber will vary continuously as a result of cycling of the refrigeration system and,
possibly, changing ambient conditions. Section 12.2 gives details of how the temperatures are to be measured and
the SRU tuned to give the required values. Section 12.3 gives the actual values which must be achieved.

Once it has been established that the equipment is properly tuned to the requirements of the Specification,
it should not be necessary to carry out the full tuning procedure given in 12.2 before or during every test. Section
8.8.3 of the test specification gives details of the measurements normally made during a routine frost-heave test.

12.2 Tuning procedure

12.2.1 General. This section describes the procedure to be followed to check whether the test chamber is
correctly tuned. It should not be necessary to follow this procedure before every test, but the procedure should
be carried out periodically or after any major adjustments to the control system.

12.2.2 Setting up the Tuning Test. The SRU shall be prepared and loaded as described in Section 8.8.1
of the test specification. Any typical well-graded granular material may be used for the specimens. Cement-bound
specimens must not be used (see Note 23). Care shall be taken to ensure that all the thermocouples are properly
located and working correctly. When the SRU has been prepared and loaded it shall be left for at least 20 hours
to allow the initial temperature to reach an equilibrium.

After 20 hours have elapsed the SRU shall be switched on and left for a further 20 hours before any internal
temperature measurements are made. The length of the initial cooling period shall be determined (see Note 24).
The air and water should reach their operating temperatures between four and fourteen hours from starting the
SRU.

12.2.3 Determination of Mean Temperatures. The control system of the SRU shall be observed until
the thermostat controlling the air temperature causes the refrigeration to be switched OFF. At this point the
temperature indicated by each of the ten thermocouples shall be recorded in turn; all ten should be recorded in
not more than 50 seconds. The temperatures of the ten thermocouples shall be recorded again at equal intervals
until at least one hour has elapsed and three complete refrigeration cycles (ie OFF—ON—OFF—ON—OFF—ON—
OFF) have been observed (see Note 25). At least 20 sets of readings shall be taken.

When the measurements for a sampling period have been completed the following values shall be calculated.
An example of the calculations is given in Appendix 3.

(1) The Instantaneous Water Temperature (IWT), i.e. the mean of the five thermocouples below the porous
discs, shall be calculated for each set of readings.
(2) The Instantaneous Water Temperature Range (IWR) shall be noted for each set of readings.

(3) The Mean Water Temperature (MWT) shall be calculated. This is the mean of the IWTs from (1). The standard deviation shall also be calculated.

(4) The Instantaneous Air Temperature (IAT), i.e., the mean of the four thermocouples in the air above the specimens, shall be calculated for each set of readings.

(5) The Instantaneous Air Temperature Range (IAR) shall be noted for each set of readings.

(6) The Mean Air Temperature (MAT) shall be calculated. This is the mean of the IATs from (4). The standard deviation shall also be calculated.

(7) The Water temperature Mean Range (WMR) shall be calculated. This is the mean of the IWRs found in (2).

(8) The Air temperature Mean Range (AMR) shall be calculated. This is the mean of the IARs found in (5).

(9) The mean value of the temperature below the central Tufnol disc shall be calculated for the sampling period.

12.2.4 Measurement of variations in Mean Temperatures. If the first determination of Mean Temperatures shows that the equipment is set to operate within the temperature ranges given in 12.3, repeat measurements shall be made, the procedure given in 12.2.3 shall be repeated until six consecutive determinations of MAT and MWT have been made. At least three and not more than twenty hours shall be allowed to elapse between successive determinations. If any Mean Temperature is outside its specified range, the control system shall be adjusted accordingly and at least twenty hours allowed to elapse before starting again from 12.2.3 (see Note 26).

12.3 Required temperature values and tolerances

12.3.1 Mean Water Temperature: Any MWT must be in the range 3.0 to 4.5°C. The range of the six successive determinations with at least three and not more than twenty hours between each determination shall not exceed 0.5°C. The standard deviation of any individual determination of MWT shall not exceed 0.3°C.

12.3.2 Mean Air Temperature: Any MAT must be in the range −18.0 to −16.0°C. The range of the six successive determinations with at least three and not more than twenty hours between each determination shall not exceed 0.5°C. The standard deviation of any individual determination shall not exceed 0.8°C.

12.3.3 Temperature Mean Ranges:

(1) Any Water temperature Mean Range shall not exceed 0.5°C.

(2) Any Air temperature Mean Range shall not exceed 2.7°C.

12.3.4 Temperature below central Tufnol disc: the mean temperature below the central Tufnol disc in any sampling period must be in the range −2 to −8°C.
13. APPENDIX 3
EXAMPLE OF TEMPERATURE PARAMETER CALCULATIONS

Evaluation of the various parameters is facilitated by the use of special charts. Table 1 is a completed chart for the determination of Mean Water and Air Temperatures. In this example the temperatures were recorded in sets of ten at four-minute intervals. Columns are provided for recording Instantaneous Temperatures and ranges; the Mean Temperatures and Standard Deviation are recorded at the foot of each column.

Table 2 is a chart summarising all the determinations made during a complete tuning period. The data from Table 1 corresponds to sampling period 3 on this chart.
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| Mean | 3.87 | 0.22 |

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<th>Time Interval between each set of readings</th>
<th>Ambient Temperature</th>
<th>Recorded by</th>
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**TABLE 1**

SRU Tuning – Temperature Recording Chart
### TABLE 2
SRU Tuning – Temperature Parameter Summary Chart

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<th>TEST NUMBER</th>
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<td>by</td>
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<th>WMR</th>
<th>MAT</th>
<th>AMR</th>
<th>mean value</th>
<th>SAMPLING STARTED</th>
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14. APPENDIX 4
NOTES ON THE FROST-HEAVE TEST SPECIFICATION

NOTE 1: The method given in BS 5835 is the preferred method. In circumstances where it is not possible to determine optimum moisture content and maximum dry-density by this method, the method given in Test 14, BS 1377:1975 may be used.

NOTE 2: A mixer of lower capacity may be used provided it is capable of mixing the coarser particles (up to 37.5 mm) efficiently. In any case the mixer must have a capacity of at least 5 kg. The mixer must not cause any significant degradation of the particles.

NOTE 3: Confirmation of the grading will normally involve reference back to the client. It is sometimes the case that the laboratory doing the frost-test was also responsible for obtaining the bulk sample and preparing laboratory samples. In this situation a grading corresponding to that obtained for the bulk sample may be assumed for the laboratory sample without carrying out a duplicate grading test.

NOTE 4: If the moisture content/dry density relation has already been determined for the same BULK SAMPLE, the laboratory may use the figures for optimum moisture-content and maximum dry-density from the earlier test and proceed directly to stage two.

NOTE 5: If figures for plastic limit and/or specific gravity have already been determined for the same BULK SAMPLE, the laboratory may use these figures to calculate w and \( \rho_d' \), without repeating the tests, before proceeding to stage two.

NOTE 6: It is recommended that distilled or de-ionised water be used throughout, where this is available. The use of tap water is unlikely to affect the heave result, however, except in certain cases such as where a sodium-saturated material is mixed with hard water. Approximately 30 litres is a sufficient supply of water for a complete test.

NOTE 7: If as a result of the preparation of the specimen for test its grading changes to the extent that it falls outside the required limits, the frost-heave result given by such a specimen cannot be regarded as a valid indication of the frost-heave of the bulk sample. (See also clause 5.2).

NOTE 8: The procedure in 8.5.2 provides for mixing all the material for three test specimens at once and this is the preferred method. However, if a small mixer is being used it may be necessary to mix the material for each specimen separately. In this case a representative mass of \( 1360 \rho_d \) g of material shall be used with \( 13.6 w \rho_d \) g of water, and the procedure repeated three times for each batch of three specimens.

NOTE 9: Because inadequate mixing can give rise to variable test results it is important that the water is thoroughly and adequately mixed with the material. The procedure given ensures that this will be so but it is unnecessarily stringent for non-absorbent granular materials which need not be stored before proceeding with the test.

NOTE 10: Because the sand can become contaminated with use it should periodically be washed and re-sieved to maintain the correct grading.
NOTE 11: Any broken thermocouples shall be repaired or replaced. The electronic thermometer should be periodically checked and if necessary calibrated against a standard thermometer.

NOTE 12: It is useful at this stage to select the thermocouples from the water-bath which are to be used at the bottom of the porous discs (section 8.8.1.2), feed them through the respective holes in the cradle and temporarily secure them to the cradle. This is much easier to do at this stage than when the bath is full and specimens are in the cradle.

NOTE 13: It should not be necessary to adjust the level of the capillary once it has been set correctly. The actual method of adjustment will depend on the design of a particular vessel, but generally either means moving the capillary up or down within the vessel or, if it has a fixed capillary, moving the vessel itself.

NOTE 14: If the porous disc is covered or water overflows before the bubbling stops, the capillary is set too high. In this case tap O must be closed and water drained out of the bath to its original level covering the lip of the specimen carrier before adjusting the capillary.

NOTE 15: It is advisable to check the level before applying the vibrating hammer to gain an indication of the amount of compaction needed. Ear defenders should be worn at all times when the hammer is in use. The hammer must be held in an upright position when compacting material. The depth-gauge shall be used to measure the level at the centre of the material surface.

NOTE 16: The last layer may not be fully compacted after about one minute’s application of the hammer with some granular materials. In such cases it may help to invert the mould assembly and apply the hammer to the bottom plug. Do not apply the hammer to either end for more than one minute at any time. With very coarse materials it may be necessary to remove one of the plugs and apply the vibrating hammer directly onto the material surface during this stage.

NOTE 17: If the end-plugs cannot be removed by hand, the mould assembly should be left to stand for 5–10 minutes before a further attempt is made. This allows excess moisture which may form a seal around the plugs to drain away. It is important not to strike the mould or plugs with a heavy object since this is likely to damage them. If, however, after ten minutes standing the plugs still cannot be removed, gentle tapping with a suitable light (and preferably non-metallic) object may have to be employed. If plugs become persistently difficult to remove, the mould and plugs must be inspected for damage and their dimensions checked. A mould can become distorted, even during normal use.

NOTE 18: Positioning of the copper specimen carrier can be made easier if the carrier is placed over a cylinder slightly taller than the carrier and of slightly smaller diameter than the hole in the bottom of the carrier. The porous disc can then be placed on top of the cylinder and the carrier lifted gently into place. Thus the difficult operation of inverting the specimen is avoided.

NOTE 19: It is permissible to test only three specimens of one material in a single run, provided that the remaining positions are filled using dummy specimens. These may be of any typical well-graded granular material. Cement-bound materials must NOT be used since these can alter the heat transfer characteristics.

NOTE 20: It is not necessary to provide support for the dowels; they will be held in position by the coarse sand. Care should be taken to ensure that particles of sand do not get under the dowels thus raising the thermocouples.
NOTE 21: If this procedure has to be followed more than once during a test, even though the results are within the required range, this means that the SRU is operating close to the limits allowed and it should therefore be retuned before the next test. In any event the Mean Temperatures should be determined at least once during every test.

NOTE 22: It is advisable to keep the water-bath circulation/heating system running at this stage to prevent the water temperature falling too far while it is exposed to the very cold air in the test chamber.

NOTE 23: Although cement-bound specimens must not be used in tuning tests because they affect the heat transfer characteristics, they may be used for convenience in any preliminary trials to adjust thermostats.

NOTE 24: The initial cooling period can be estimated from the chart recorder, or a special timing device may be fitted to the SRU for the purpose.

NOTE 25: If the refrigeration system completes three cycles in less than one hour, measurements shall be continued until the first occasion that the refrigeration switches OFF after the hour has elapsed.

NOTE 26: Twenty hours must be allowed to elapse after any alteration to the controls before attempting a sequence of six determinations of Mean Temperatures. If several adjustments are needed it may be necessary to set up a new tuning test. In any case the tuning test must be completed within 250 hours of switching on the SRU.
ABSTRACT

Specification for the TRRL frost-heave test: P G ROE and D C WEBSTER: Department of Transport, TRRL Supplementary Report 829: Crowthorne, 1984 (Transport and Road Research Laboratory). The TRRL frost-heave test is nominated in the Department of Transport's Specification for Road and Bridge Works to establish the degree of frost-susceptibility of unbound sub-base and base materials. The test as originally described in LR 90 contained insufficient detail for it to be carried out in a standardised manner with granular materials. This led to problems both in carrying out the test and in the interpretation of results; the Laboratory therefore undertook a research programme to improve the test. This work has now been completed and this report contains a specification for an improved test procedure that has been developed from the results of the research. This procedure supersedes that given in LR 90 and other publications of the Laboratory which give details of the test.

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