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Sample preparation and testing of materials during and after treatment – Test method

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Introduction

Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international and European standards, comments will be reviewed by the relevant UK national committee before submitting the consensus UK vote and comments. If the draft standard is approved, it is usual for the resulting published standard to be adopted as a British Standard.

For national standards, comments will be reviewed by the relevant UK national committee and the resulting standards published as a British Standard.

UK Vote

Please indicate whether you consider the UK should submit a negative (with supporting technical reasons) or positive vote on this draft. Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.

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All comments should be submitted online at <http://standardsdevelopment.bsigroup.com>. You will need to register in order to comment.

BS 1924-2, Unbound, hydraulically bound and stabilized materials for civil engineering purposes – Part 2: Sample preparation and testing of materials during and after treatment – Test method

IMPORTANT INFORMATION

Please note that this is a draft and not a typeset document. Editorial comments are welcomed, but persons commenting on this draft are advised not to comment on detailed matters of typography and layout.

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Foreword

Publishing information

This part of BS 1924 is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on DD MONTH YYYY. It was prepared by Subcommittee B/510/4, *Cementitious bound materials, unbound granular materials, waste materials and marginal materials*, under the authority of Technical Committee B/510, *Road materials*. A list of organizations represented on these committees can be obtained on request to the committee manager.

Supersession

This part of BS 1924 supersedes BS 1924-2:2018, which is withdrawn.

Relationship with other publications

BS 1924 is published in the following parts:

- Unbound, hydraulically bound and stabilized materials for civil engineering purposes – Part 1: Sampling, sample preparation and testing of materials before treatment – Test method
- Unbound, hydraulically bound and stabilized materials for civil engineering purposes – Part 2: Sample preparation and testing of materials during and after treatment – Test method

Information about this document

BS 1924 provides tests for soil and/or aggregate treatment employing solely or in combination: cement, granulated blast furnace slag (GBS), ground granulated blast furnace slag (GGBS), (coal) fly ash and/or lime. Granulated blast furnace slag (GBS) and GGBS are hydraulic materials that require activation by the addition of lime and/or sulfate or products that contain these compounds. Coal fly ash exists in two forms: calcareous fly ash and siliceous fly ash. The former is hydraulic, i.e. cementitious, in its own right; the latter is pozzolanic and needs activation by lime or hydraulic binders.

BS 1924 contains the full range of tests required before and after treatment, whether improvement, modification or stabilization. This standard is also suitable for the testing of hydraulically bound materials and roller compacted concrete detailed in BS 9227 and BS 9228, granular mixtures detailed in BS EN 14227-1 to BS EN 14227-5, and hydraulically stabilized soils in BS EN 14227-15.

The tests for materials in the treated condition are given in BS 1924-2, either by reference to other British Standards or in full.

The tests for materials in the untreated condition are given in BS 1924-1, either by reference to other British Standards or in full.

This is a full revision of the standard, and introduces the following principal changes:

- general update to take into account new and revised standards published since 2018;
- introduction of new terminology, including consistency checks for LWD and PDP, and complex impedance density measurements;
- inclusion of additional test methods, including the PDP for determination of dynamic deformation modulus, and complex impedance measurements for determination of density;
- change of title to reflect the wider scope of this revision, which is intended to cover a greater range of materials within civil engineering applications; and
- a general revision of the initial consumption of lime test.

This revision includes all the tests, with minor exceptions, for materials treated with hydraulic binders and lime that were included in the 2018 edition.

This publication can be withdrawn, revised, partially superseded or superseded. Information regarding the status of this publication can be found in the Standards Catalogue on the BSI website at knowledge.bsigroup.com, or by contacting the Customer Services team.

Where websites and webpages have been cited, they are provided for ease of reference and are correct at the time of publication. The location of a webpage or website, or its contents, cannot be guaranteed.

Use of this document

It has been assumed in the drafting of this part of BS 1924 that the execution of its provisions will be entrusted to appropriately qualified and experienced people, for whose use it has been produced.

Presentational conventions

The provisions of this document are presented in roman (i.e. upright) type. Its methods are expressed as a set of instructions, a description, or in sentences in which the principal auxiliary verb is “shall”.

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Where words have alternative spellings, the preferred spelling of the *Shorter Oxford English Dictionary* is used (e.g. “organization” rather than “organisation”).

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1 Scope

This part of BS 1924 describes methods of testing unbound mixtures and materials treated solely or in combination with treating agents, including cement, granulated blast furnace slag (GBS), ground granulated blast furnace slag (GGBS), (coal) fly ash and lime.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes provisions, or limits the application, of this document¹⁾. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ASTM D6938-17, *Standard test methods for in-place density and water content of soil and soil-aggregate by nuclear methods (shallow depth)*

ASTM D7698-21, *Standard test method for in-place estimation of density and water content of soil and aggregate by correlation with complex impedance method*

BS 812-109, *Testing aggregates – Part 109: Methods for determination of moisture content*

BS 812-124, *Testing aggregates – Part 124: Method for determination of frost heave*

BS 1924-1, *Unbound, hydraulically bound and stabilized materials for civil engineering purposes – Part 1: Sampling, sample preparation and testing of materials before treatment – Test method*

BS 5930, *Code of practice for ground investigations*

BS EN 13286-1, *Unbound and hydraulically bound mixtures – Part 1: Test methods for laboratory reference density and water content – Introduction, general requirements and sampling*

BS EN 13286-2, *Unbound and hydraulically bound mixtures – Part 2: Test methods for the determination of the laboratory reference density and water content – Proctor compaction*

BS EN 13286-3, *Unbound and hydraulically bound mixtures – Part 3: Test methods for laboratory reference density and water content – Vibrocompression with controlled parameters*

BS EN 13286-4, *Unbound and hydraulically bound mixtures – Part 4: Test methods for laboratory reference density and water content – Vibrating hammer*

BS EN 13286-5, *Unbound and hydraulically bound mixtures – Part 5: Test methods for laboratory reference density and water content – Vibrating table*

BS EN 13286-40, *Unbound and hydraulically bound mixtures – Part 40: Test method for determination of the direct tensile strength of hydraulically bound mixtures*

BS EN 13286-41, *Unbound and hydraulically bound mixtures – Part 41: Test method for determination of the compressive strength of hydraulically bound mixtures*

BS EN 13286-42, *Unbound and hydraulically bound mixtures – Part 42: Test method for the determination of the indirect tensile strength of hydraulically bound mixtures*

BS EN 13286-43, *Unbound and hydraulically bound mixtures – Part 43: Test method for the determination of the modulus of elasticity of hydraulically bound mixtures*

BS EN 13286-45, *Unbound and hydraulically bound mixtures – Part 45: Test method for the determination of the workability period of hydraulically bound mixtures*

¹⁾ Documents that are referred to solely in an informative manner are listed in the Bibliography.

BS EN 13286-46, *Unbound and hydraulically bound mixtures – Part 46: Test method for the determination of the moisture condition value*

BS EN 13286-47, *Unbound and hydraulically bound mixtures – Part 47: Test method for the determination of California Bearing Ratio, immediate bearing index and linear swelling*

BS EN 13286-48, *Unbound and hydraulically bound mixtures – Part 48: Test method for the determination of the degree of pulverisation*

BS EN 13286-49, *Unbound and hydraulically bound mixtures – Part 49: Accelerated swelling test for soil treated by lime and/or hydraulic binder*

BS EN 13286-50, *Unbound and hydraulically bound mixtures – Part 50: Method for the manufacture of test specimens of hydraulically bound mixtures using Proctor equipment or vibrating table compaction*

BS EN 13286-51, *Unbound and hydraulically bound mixtures – Part 51: Method for the manufacture of test specimens of hydraulically bound mixtures using vibrating hammer compaction*

BS EN ISO 17892-1, *Geotechnical investigation and testing – Laboratory testing of soil – Part 1: Determination of water content*

BS EN ISO 17892-12, *Geotechnical investigation and testing – Laboratory testing of soil – Part 12: Determination of liquid and plastic limits*

BS ISO 5725-2, *Accuracy (trueness and precision) of measurement methods and results – Basic method for the determination of repeatability and reproducibility of a standard measurement method*

PD CEN/TS 13286-54, *Unbound and hydraulically bound mixtures – Part 54: Test method for the determination of frost susceptibility – Resistance to freezing and thawing of hydraulically bound mixtures*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this part of BS 1924, the following terms and definitions apply.

3.1.1 batch

definite quantity of material produced under conditions which are presumed uniform

3.1.2 bulk density

mass of material (including solid particles, any contained water and any fluid stabilizer) per unit volume, including voids

3.1.3 clay

fraction composed of particles smaller in size than 0.002 mm

3.1.4 cohesive material

material which by virtue of its clay content forms a coherent mass

3.1.5 compaction

process of packing treated particles more closely together by rolling or mechanical means, thus increasing the dry density of a treated material

3.1.6 dry density

mass of material after drying to constant mass at 105 °C, and after removal of any fluid stabilizers, contained in unit volume of undried material

3.1.7 hydraulic binder

material or a combination of materials that set and harden by chemical reaction with water and remain stable, even under water

NOTE 1 Within this part of BS 1924, the term “treating agent” is used to include hydraulic binder.

NOTE 2 Hydraulic binders include cements, (coal) fly ash, granulated blast furnace slag (GBS), ground granulated blast furnace slag (GGBS) and hydraulic road binder

3.1.8 hydraulically bound material

material that sets and hardens by hydraulic reaction

NOTE Hydraulically bound material includes stabilized soils and mixtures defined in BS EN 14227. The mixtures defined in BS EN 14227 are hydraulically bound granular mixtures and hydraulically stabilized soils. Within this part of BS 1924, the terms “treated material” and “untreated material” are used to differentiate materials with or without treating agent. Treating agents include cement, (coal) fly ash, granulated blast furnace slag (GBS), ground granulated blast furnace slag (GGBS), hydraulic road binder and/or lime.

3.1.9 laboratory sample

sample intended for laboratory inspection or testing

3.1.10 lime

quicklime (calcium oxide) which can be used in combination with other products in a hydraulic binder or on its own for improvement

NOTE Within this part of BS 1924, the term “treating agent” is used to include lime.

3.1.11 maximum dry density

dry density obtained using a specified amount of compaction at the optimum water content (3.1.24)

3.1.12 moisture density

mass of water per unit volume of the material

NOTE The term “moisture density” within this part of BS 1924 is specific to the nuclear gauge method.

3.1.13 optimum water content

water content at which a specified amount of compaction produces a maximum dry density (3.1.11)

3.1.14 particle size distribution

percentages of various grain sizes present in a material as determined by sieving and sedimentation

3.1.15 percentage air void

volume of air voids in a material expressed as a percentage of the total volume of the material

3.1.16 representative sample

sample taken to represent a body of material in order to study its average properties

3.1.17 sampling

selection of a representative portion of material

3.1.18 slenderness ratio

height to diameter ratio of a cylindrical specimen

3.1.19 stabilization

process that obtains an homogeneous mixture of soil or graded granular material with treating agent(s), and optionally with water, which, when properly compacted, significantly changes the characteristics of the material in a way that renders it stable, particularly with respect to the action of water and frost

3.1.20 test portion

material used as a whole in testing or inspection

3.1.21 treated material

material that incorporates a treating agent, including hydraulically bound material (3.1.8) and improved material

3.1.22 treating agent

material added to soil or graded granular material, which includes hydraulic binder (3.1.7) and/or lime (3.1.10), used to produce a treated material (3.1.21)

3.1.23 untreated material

material proposed for addition of a treatment agent, on which testing is undertaken prior to the addition of the treatment agent

3.1.24 water content

mass of free water that can be removed from a material, usually by heating at 105 °C, expressed as a percentage of the dry mass

3.2 Symbols

For the purposes of this part of BS 1924, the following symbols apply:

A	plate rigidity factor (use 2 as the default)
D_c	degree of compaction (%)
d	maximum deflection (mm)
E	stiffness modulus (MPa)
E_c	elastic modulus determined in compression (GPa)
E_{vd}	dynamic deformation modulus (MN/m ²)
m	mass of paraffin wax coating adhering to the specimen
m_a	mass of the soaked specimen immediately before weighing in water
m_b	mass of sand required to fill the hole
m_c	mass of core-cutter
m_d	mass of specimen after drying
m_f	mass of specimen after filling air voids with modelling clay or putty
m_g	apparent mass of specimen and paraffin wax coating when suspended in water
m_h	mass required to fill the calibrating container
m_i	mass of treated material together with the core-cutter
m_j	apparent mass of specimen when suspended in water
m_k	mass of specimen immediately before it is broken up for water content determination

m_m	mass of oven-dry material from the hole
m_n	mass of specimen before drying
m_s	mass of specimen
m_w	mass of specimen and paraffin wax coating
m_z	total mass of material excavated
m_1	mass of cylinder and sand before pouring into the calibrating container
m_2	mass of sand in the cone
m_3	mean mass of cylinder and sand after pouring into the calibrating container
m_4	mass of cylinder and sand after pouring into the hole
m_5	mass of container, together with any plasticine
m_6	mass of container plus water
m_7	mass of receiver
m_8	mass of receiver and water siphoned over into the receiver
N_o	average of four values of N_s taken prior to use
N_s	average value of the current standard count rate
P	maximum contact stress (kPa)
pH_T	pH at measured temperature T °C
pH_{25}	pH value of solution at 25 °C
R_c	compressive strength (MPa)
R_{it}	indirect tensile strength (MPa)
R_{RC}	retained compressive strength (%)
R_{Rit}	retained indirect tensile strength (%)
r	plate radius (m)
V_a	percentage air voids (%)
V_b	volume of specimen and paraffin wax coating
V_c	volume of core-cutter
V_s	volume of specimen
V_w	total volume of water siphoned over into the receiver
v	volume of calibrating container
W	moisture density (%)
w	water content (%)
ν	Poisson's ratio
ρ	bulk density (Mg/m ³)
ρ_c	amount of prescale applied to the detector counts prior to display
ρ_d	dry density (Mg/m ³)
ρ_p	density of paraffin wax
ρ_{mdd}	maximum dry density (Mg/m ³)

ρ_s bulk density of sand (Mg/m^3)
 ρ_w water density (Mg/m^3)

3.3 Abbreviated terms

For the purposes of this part of BS 1924, the following abbreviated terms apply:

CBR California bearing ratio
 IBI immediate bearing index
 FWD falling weight deflectometer
 LWD light weight deflectometer
 MCV moisture condition value
 PDP portable dynamic plate

4 Classification tests

4.1 General

Classification tests shall be carried out in accordance with the standards listed in Table 1.

NOTE 1 Where appropriate standards exist, then only supplementary procedures or notes are provided in BS 1924-2. Where a test method can be used without any amendment (for example, the determination of degree of pulverization) then the test method is only referenced in Table 1 for completeness.

NOTE 2 Sampling of materials, sample reduction and specimen preparation with treating agents is detailed in BS 1924-1.

Table 1 — Classification tests

Test method	Standard
Determination of water content by oven-drying method (definitive method)	BS EN 17892-1 ^{A)}
Determination of water content by microwave methods (subsidiary method for fine-grained materials)	BS 812-109 ^{B)}
Determination of water content by indirect density gauge method (for in-situ testing only)	BS 1924-2:2025, 6.1 ^{C)}
Determination of degree of pulverization	BS EN 13286-48
Determination of effect of the treating agent on plasticity properties	BS 1924-2:2025, 4.2

^{A)} The methods based on heating to remove water assume that all the “free” water in the treated material is removed in the heating process and that “chemically bound” water such as water of hydration is not removed by the test procedure. This is generally true for most materials likely to be encountered, but problems can occur with materials that contain hydrated salts such as gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) that lose water at temperatures below 105 °C. The definitive method of measuring water content is the oven-drying method and is based on drying at 105 °C to 110 °C to remove the water. If it is suspected that gypsum is present, the water content samples should be dried at not more than 80 °C and possibly for a longer time (until no weight change happens). The presence of gypsum can be identified by heating a small quantity of the material on a metal plate. Grains of gypsum turn white within a few minutes, whereas most other minerals remain unaltered. If the standard conditions are not used, the drying conditions used should be stated in the test record.

^{B)} Most aggregates can be dried in a microwave oven, but unsuitable materials include flints, slag and some calcareous aggregates which have a tendency to shatter. Materials such as pulverized fuel ash, colliery spoil (minestone) or aggregates derived from them are not suitable as any carbonaceous matter remaining in them ignites in the microwave oven. Materials with a high proportion of metallic iron compounds can also give rise to problems. For these reasons it is necessary to carry out preliminary trials to establish whether or not the material under test is adversely affected by microwave radiation.

^{C)} In-situ density testing is proven for bulk density measurements but not for water content measurement; in-situ density gauge figures should be used for guidance only. Dry density should be calculated or calibrated from the water content obtained in the laboratory from a material sample taken at the testing location.

4.2 Determination of effect of the treating agent on plasticity properties

COMMENTARY ON 4.2

The method for sample preparation for the determination of plastic limits, liquid limits and plasticity index in untreated fine-grained soils is amended in this part of BS 1924 to account for any impact of treating agent on these properties.

Some treating agents have a marked effect on the plasticity properties of materials containing clay minerals. This is brought about by two separate mechanisms: firstly, there is an immediate effect as a result of cation exchange at the surface of the clay particles, and secondly, there is a longer-term effect as a result of the pozzolanic reaction between the lime (or lime liberated by hydraulic binder) and the clay minerals. The cation exchange reactions have the most influence on the plasticity properties whilst the pozzolanic reaction is largely responsible for the increase in strength which occurs over a period of time. These mechanisms make the determination of plastic limits, liquid limits and plasticity index time-sensitive, and require the sample preparation procedures to be adjusted compared to materials which do not include treating agents.

4.2.1 Sample preparation

NOTE *The procedure given assumes that laboratory trials are being made to find the effect of the addition of treating agent on the plasticity properties of the material. If it is desired to find the plasticity properties of field-mixed material, the sample preparation procedure in this part of BS 1924 is not applicable.*

4.2.1.1 Preparation of samples for plastic limit determination

4.2.1.1.1 Two test samples shall be used for this determination. One sample shall be of the material in its natural condition and the other of the material following the addition of the treating agent.

4.2.1.1.2 Take two test samples each of mass (25 ± 0.25) g from the prepared material as described in BS EN ISO 17892-12. Weigh each sample to 0.1 g and calculate its dry mass from the mass of the wet sample and the value of its water content.

4.2.1.1.3 To one sample add the required amount of treating agent and mix thoroughly on the glass plate with the palette knife. If the immediate effect of the treating agent on the plastic limit is required, determine the plastic limit of both samples as described in BS EN ISO 17892-12. If the change of plastic limit with time is being investigated, roll each sample into a ball, wrap each in plastic sheeting and store in an airtight container until required.

4.2.1.2 Preparation of samples for liquid limit determination

4.2.1.2.1 Two test samples shall be used for this determination. One sample shall be of the material in its natural condition and the other of the material following the addition of the treating agent.

4.2.1.2.2 Take the material, prepared as described in BS EN ISO 17892-12, and set aside at least 50 g for the determination of the plastic limit, if this has not been done already. Split the remaining sample in half, weigh each test sample to 0.1 g, and calculate its dry mass from the mass of the wet sample and the value of its water content.

4.2.1.2.3 To one sample add the required amount of treating agent and mix thoroughly on the glass plate with the palette knife. Mix the paste for at least 10 min (see Note). If necessary, add more distilled or demineralized water so that the first cone penetration, when tested as described in BS EN ISO 17892-12 using the 80g/30° cone, is (15 ± 1) mm. If the immediate effect of the treating agent on the liquid limit is required, determine the liquid limit of both samples as described in BS EN ISO 17892-12. If the change of liquid limit with time is being investigated, roll each sample into a ball, wrap each in plastic sheeting and store in an airtight container until required.

NOTE *Some materials, e.g. clays of high plasticity, require up to 40 min of continuous mixing immediately before testing to obtain reliable results.*

4.2.2 Procedure

4.2.2.1 The liquid limit shall be determined using the four-point method in accordance with BS EN ISO 17892-12, with the 80g/30° cone.

4.2.2.2 The plastic limit and plasticity index shall be determined in accordance with BS EN ISO 17892-12.

4.2.3 Test report

The test report shall affirm that the effects of the treating agent on the plasticity properties of the material were determined in accordance with BS 1924-2 and whether or not a certificate of sampling is available. If available, a copy of the certificate of sampling shall be provided.

In addition to the requirements in BS EN ISO 17892-12, this test report shall contain the following:

- a) sample identification;
- b) the amount and type of treating agent used;
- c) the lapse in time (if more than 3 h) between the addition of the treating agent and carrying out the test;
- d) the plastic limit and/or the liquid limit of the material with and without the addition of treating agent;
- e) the proportion of material that was used, i.e. the amount that passes the 425 µm test sieve, and the method to be used to obtain the material to be tested, i.e. whether from a natural soil or a sieved specimen; and
- f) if both the liquid limit and the plastic limit have been determined, the plasticity index.

5 Compaction-related tests

5.1 General

Compaction-related tests shall be carried out in accordance with the standards listed in Table 2.

NOTE 1 Where appropriate standards exist, then only supplementary procedures or notes are provided in BS 1924-2.

NOTE 2 Sampling of materials, sample reduction and specimen preparation with treating agents is detailed in BS 1924-1.

Table 2 — Compaction-related tests

Test method	Standard	Supplementary procedures in BS 1924-2:2025
Determination of maximum dry density: General	BS EN 13286-1 ^{A)}	Specimen preparation (5.2.2)
Determination of maximum dry density: Proctor test	BS EN 13286-2 ^{A)}	Specimen preparation (5.2.2)
Determination of maximum dry density: Vibro-compression	BS EN 13286-3 ^{A)}	Specimen preparation (5.2.2)
Determination of maximum dry density: Vibratory hammer	BS EN 13286-4 ^{A)}	Specimen preparation (5.2.2)
Determination of maximum dry density: Vibrating table	BS EN 13286-5 ^{A)}	Specimen preparation (5.2.2)
MCV	BS EN 13286-46	—

^{A)} BS EN 13286-2 using the standard and modified proctor, and BS EN 13286-4 are most commonly used in the UK. Selection of the appropriate method is based on the material type and/or anticipated compacted effort on site.

The choice of the range of water contents to use is inevitably one of trial-and-error and an unfortunate choice could lead to a large number of test portions being required. Consequently, although five test portions might be sufficient, it is usually necessary to produce a larger number than this.

Table 2 — Compaction-related tests

Test method	Standard	Supplementary procedures in BS 1924-2:2025
If the amount of treating agent required has not been determined at this stage, the amount may be estimated, but the test should be repeated with the required amount of treating agent if this is found subsequently to be different from the estimated amount. The range of water contents obtained should include the optimum water content, and the amounts of water to be added to the test portions will therefore vary with the type of treated material under test. In general, with non-cohesive materials a minimum water content of 4% to 6% would be suitable, with additional increments of 1% to 2% for each successive test portion tested. With cohesive materials a minimum water content of 8% to 10% below the plastic limit of the material would usually be suitable, with additional increments of 2% to 4% for each successive sample tested. To increase the accuracy of the test it is often advisable to reduce the increments in the region of the optimum water content.		

5.2 Determination of the dry density/water content relation

5.2.1 Principle

Compaction of material is the process by which the solid particles are packed more closely together, usually by mechanical means, thereby increasing the dry density of the material. The dry density that can be achieved depends on the degree of compaction applied and the amount of water present in the material. For a given degree of compaction of a given material there is usually an optimum water content at which the dry density obtained reaches a maximum value.

5.2.2 Specimen preparation and testing

5.2.2.1 Where lime is the only treating agent used to treat a cohesive material, then the mixture shall be conserved for at least 1 h in sealed bags or an airtight container before compaction. Compaction shall be performed 90 min after mixing with lime. For other treating agents and/or use of lime in a graded granular material, the compaction shall be performed within 20 min after mixing of the material with the treating agent.

5.2.2.2 For two-stage treatment of a cohesive material, for example lime plus another treating agent, then the procedure in **5.2.2.1** shall be followed for the lime. After this, the second stage of treatment shall include addition of the treatment agent (for example GGBS, pfa or cement) and compaction shall be performed within 20 min after mixing.

5.2.3 Test report

5.2.3.1 In addition to the requirements in BS EN 13286, this test report shall contain the following:

- a) any deviation from the timings and/or process in **5.2.2.1** or **5.2.2.2**; and
- b) the amount and type of treating agent used.

NOTE 1 Justification for the deviation could include manufacturing materials for storage (for periods of time above the time limits detailed) prior to transportation and compaction.

NOTE 2 Two-stage treatment has a hiatus in the process. Adding two treating agents as part of a single mixing operation is not two-stage treatment.

6 Density tests

COMMENTARY ON CLAUSE 6

This clause describes the methods to be used for determining the in-situ density of a treated material. Several methods are included, the choice of which depends on the type of material, the circumstances in which the test is being made, and the equipment available. The applicability of the methods and their limitations are given under each test procedure.

The density methods in table 3 are included in this British Standard.

Table 3 — Density tests

Test method	Standard
In-situ measurement using nuclear moisture/density gauges	BS 1924-2:2025, 6.2
In-situ measurement using complex impedance method	BS 1924-2:2025, 6.3
In-situ measurement using sand replacement method	BS 1924-2:2025, 6.4
In-situ measurement using core-cutter method	BS 1924-2:2025, 6.5
Laboratory measurement by immersion in fluid method	BS 1924-2:2025, 6.6
Laboratory measurement by fluid displacement method	BS 1924-2:2025, 6.7

The determination of the in-situ density is carried out on small areas of compacted material so that the advice on sampling given in this British Standard is not generally applicable. It is impracticable to obtain a single sample that is representative of a given area of compacted material; selected locations of material therefore should be tested to find the variability of the in-situ density within the area of compacted treated material.

6.1 Indirect density gauges

Several models of indirect moisture/density gauges are available for the measurement of both density and water content, with indirect gauges measuring alternative properties which are proven to have a proportional correlation to density; where measurements are required for compliance, the material being tested shall have the same properties as that measured for the maximum dry density/water content relationship and the gauge correlation.

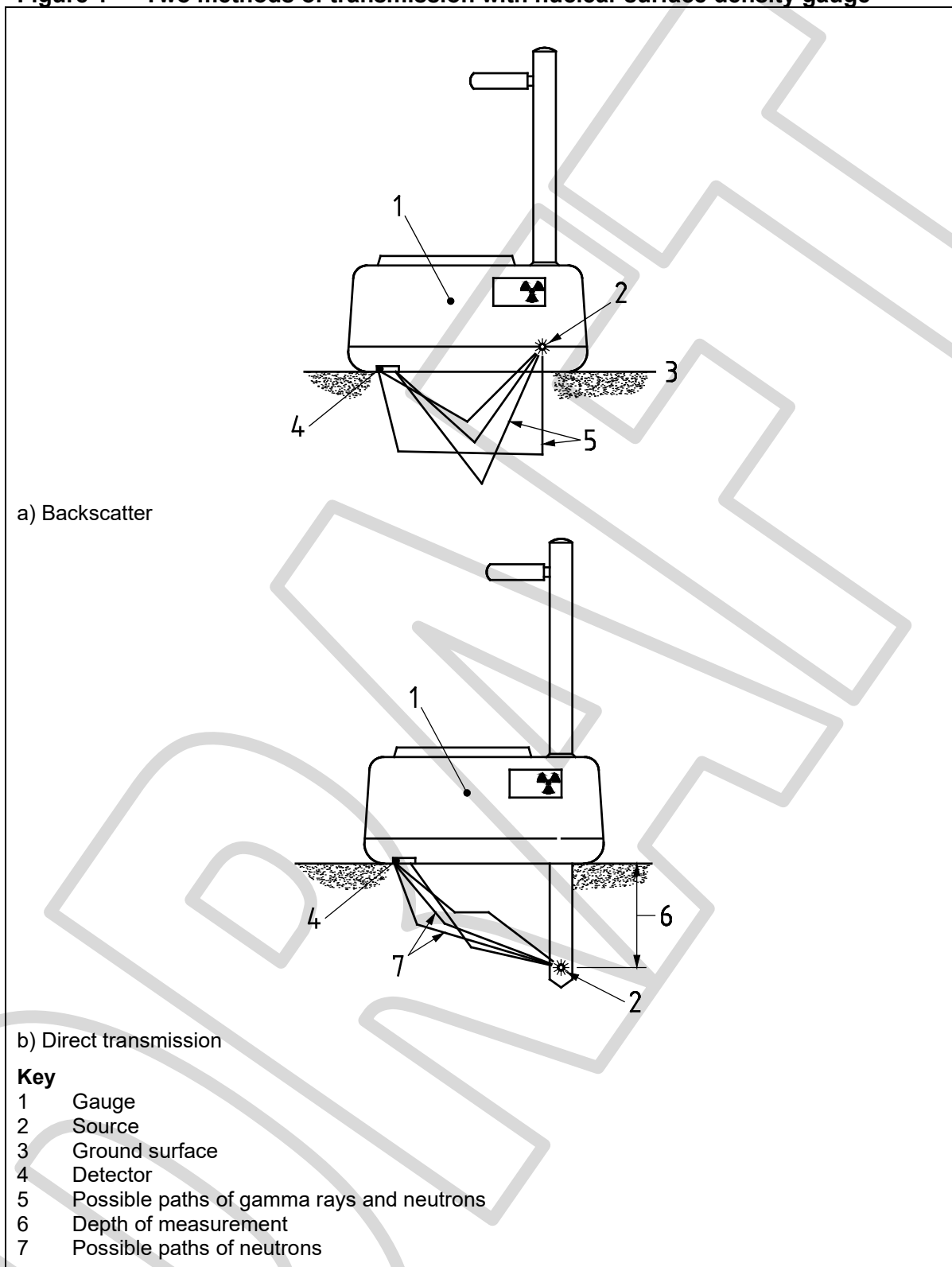
NOTE The principles on which the gauges work are described in **6.2** and **6.3**.

6.2 Nuclear gauge method

6.2.1 Principles

The nuclear gauge method measures density either by the back-scatter method or by the direct transmission method.

Figure 1 — Two methods of transmission with nuclear surface density gauge



6.2.1.1 Bulk density

The bulk density method uses the attenuation of gamma rays from a gamma source (usually in a movable probe) due to Compton scattering and photoelectric absorption. The intensity of radiation arriving at the detector, which is directly related to the electron density, provides an indication of the bulk density by comparison with an appropriate calibration. Direct transmission [shown in Figure 1b)] is the only mode that is used for bulk density testing.

NOTE Bulk density measurements can be affected by heterogeneity in the chemical composition of the material, e.g. the sporadic presence of metallic iron in slags and coal in colliery spoil.

6.2.1.2 Moisture density

The moisture density method uses the moderation (slowing down) of neutron radiation from a fast neutron source due to collisions, principally with hydrogen nuclei. The intensity of radiation reaching the detector is directly related to the state of arrival of modified neutrons and provides an indication, by comparison with an appropriate calibration, of the amount of water present within the volume of the zone of influence. It is assumed that water represents the only source of hydrogen present in the treated material.

NOTE 1 Moisture density measurements can be affected by unusual chemical composition of the materials, and materials containing significant content of organic matter or chemically bound water.

NOTE 2 The zone of influence, including the depth below the surface for measurement of moisture density, is not precise and depends on the design of the gauge. For guidance, about half of the measured count rate might refer to the uppermost 50 mm; the overall depth sampled varies with the moisture density.

NOTE 3 Nuclear density testing has been validated for measuring bulk density but is not as reliable for determining water content in soil and soil aggregate.

6.2.2 Apparatus

6.2.2.1 Calibrated nuclear gauge, suitable for bulk density and moisture density measurements. It shall contain sealed nuclear sources that are shielded to minimize exposure to radiation during storage, transportation and use, and suitable detectors and readout devices with electrical batteries, within a housing of rugged construction that is water- and dust-resistant. For the determination of bulk density by direct transmission, the housing shall also contain a moveable gauge probe for locating the bulk density measuring source in a preformed hole in the material to be tested. The probe aperture shall be fitted with an automatic shutter and shield mechanism which closes when the probe is withdrawn into the safe position. A manufacturer's handbook and certificates of calibrations, and an approved transport case, shall also be provided. The gauge shall be recalibrated after any repair or overhaul involving change of the sources, detectors or reference blocks.

6.2.2.2 Reference block, of suitable material, for checking the gauge operation and to establish conditions for reproducible standard count rates. The reference block shall have the same serial number as the gauge and shall not be interchangeable between gauges.

NOTE The reference block should be kept clean and free from adhering particles which could cause poor contact with the gauge and result in an erroneous standard count rate.

6.2.2.3 Gamma radiation monitor.

6.2.2.4 Test area preparation equipment, i.e. suitable tools for levelling the ground at the site of the test, such as a shovel, trowel and straightedge.

6.2.2.5 Steel drill pin and hammer, or auger, with a suitable template for positioning the hole for the direct transmission test. The drive pin shall produce a hole up to 3 mm larger than the external diameter of the gauge probe.

NOTE This equipment is specified for making holes for the insertion of the probe in untreated materials and is also suitable for freshly laid treated materials. It might not, however, be suitable for hardened materials in which it is necessary to bore a hole by means of a masonry drill.

6.2.2.6 Gauge log, containing standardization and stability test results.

6.2.2.7 Calibration results, which may be in the form of charts and may be stored in the memory bank of the readout system.

6.2.2.8 Dry fine quartz sand, for bedding gauge on uneven surfaces.

6.2.2.9 Electric vibrating hammer, in accordance with BS EN 13286-4, fitted with a square or rectangular foot having an area between 7 500 mm² and 14 000 mm².

6.2.2.10 *At least one cubical container*, of rigid construction and having minimum dimensions of 380 mm × 500 mm in plan, and a depth in excess of 50mm greater than the thickness to be tested.

6.2.3 Calibration for bulk density determinations

6.2.3.1 Manufacturer's bulk density calibration

This calibration shall be initially carried out in accordance with ASTM D6938-17. Every 24 months the manufacturer's calibration shall be checked using not fewer than three standard density blocks as described in ASTM D6938-17.

6.2.3.2 Initial site correlation for bulk density

Correlate the nuclear gauge depending upon the nature of the measurement application as follows.

- a) Ground investigation comparative tests. These tests require no initial site calibration, provided that the data obtained are used only for comparative purposes on the particular site. The test report shall clearly state that the comparative test method has been used.
- b) Compliance tests for compacted material. Where the nuclear gauge is to be used for compliance tests on compacted material, carry out the initial correlation twice by using the container as specified in **6.2.3.3.1**.

6.2.3.3 Material correlation for bulk density

6.2.3.3.1 Correlation using blocks of material of known density

6.2.3.3.1.1 Measure the internal dimensions of the containers described in **6.2.2.10** to the nearest 1 mm. Each parallel face shall have at least nine measurements evenly spaced, allowing any irregularities in the container construction to be accounted for. Calculate their internal volumes. Weigh the containers and record their masses (see Note).

NOTE The mass of the containers when filled with material is large. Therefore, it might be more convenient to weigh out suitable quantities of the mixed material beforehand into plastic bags. The total mass of the correlation block can then be calculated from the combined masses required for each of the separate layers of material. If the mass of material used in the construction of the block is known, there is no need to determine the mass of the empty container.

6.2.3.3.1.2 Using the containers, prepare at least two blocks of treated material using different masses of material in each (see Note 1). Prepare the blocks by compacting the treated material into the container(s) in four equal layers. Compact each layer with the vibrating hammer fitted with the foot. Scarify the surface of each layer before adding the next layer and finish the top layer flush with the top of the container by trowelling to a smooth surface. Form two holes up to 3mm in diameter larger than the gauge rod through the block to a depth equivalent to that which will be used for site measurements and normal to the surface. The holes shall be approximately 125 mm from each end and in the centre of the 380 mm dimension. Use treated material with mix proportions similar to that proposed for the main works (see Note 2).

NOTE 1 Suitable densities to compact the containers may be to the project specification limit of compaction $\pm 1\%$ and at the maximum dry density $\pm 1\%$ e.g. if the project specification is 95% compliance, compact to 94%-96%.

NOTE 2 Blocks of material other than the treated material to be tested should not be used because the chemical composition is unlikely to be similar; however, it is recognized that they are of value to the manufacturer for ascertaining the initial settings of the gauge and have advantages for traceability.

6.2.3.3.1.3 Calculate the bulk density of the blocks from the dimensions and mass of each block.

6.2.3.3.1.4 Within 1 h of the completion of compaction of each block, measure the bulk density with a nuclear gauge in the same manner as described for making site measurements of bulk density (see **6.2.7**) except three measurements will be taken at each

end of the cubical container. The source rod shall be lowered to the same depth as that which will be used for in situ measurements. Determine the variation between the calculated density and the average of the six measured density values of each block as a percentage of the calculated density.

6.2.3.3.2 Derivation of the bulk density correlation

6.2.3.3.2.5 If the difference between the variations for the two blocks is 1% or less, then readings taken by nuclear density gauges used to measure the field density of the treated material shall be corrected by the average amount of the variation between the two blocks. Make the correction either by using the gauge biasing device in accordance with the gauge manufacturer's instructions or by multiplying the derived in-situ bulk density by the appropriate factor.

6.2.3.3.2.2 If the difference between the variations for the two blocks is more than 1%, repeat the correlation. If this confirms the previous result, consult the gauge manufacturer as the gauge might require maintenance.

6.2.3.3.2.6 Repeat the correlation every 3 months when testing is to continue for longer than this period, or if there is a change in the source material.

6.2.4 Calibration for moisture density determinations

6.2.4.1 Manufacturer's moisture density calibration

This calibration shall be initially carried out in accordance with ASTM D6938-17. Every 24 months the manufacturer's calibration shall be serviced by an authorized agent for the nuclear gauge.

6.2.4.2 Initial site correlation for moisture density

Calibrate the nuclear gauge depending upon the nature of the measurement application as follows.

- a) Ground investigation comparative tests. These tests require no initial site calibration, provided that the data obtained are used only for comparative purposes on the particular site. The test report shall clearly state that the comparative test method has been used.
- b) Compliance tests for compacted material. Where the nuclear gauge is to be used for compliance tests on compacted material, carry out the initial correlation by using a container as specified in **6.2.4.3**.

6.2.4.3 Material correlation for moisture density

6.2.4.3.1 Correlation using blocks of material of known density

6.2.4.3.1.7 Measure the internal dimensions of the containers described in **6.2.2.10** to the nearest 1 mm. Each parallel face shall have at least nine measurements evenly spaced, allowing for any irregularities in the container construction to be accounted for. Calculate their internal volumes. Weigh the containers and record their masses (see Note).

NOTE The mass of the containers when filled with material is large. Therefore, it might be more convenient to weigh out suitable quantities of the mixed material beforehand into plastic bags. The total mass of the correlation block can then be calculated from the combined masses required for each of the separate layers of material. If the mass of material used in the construction of the block is known, there is no need to determine the mass of the empty container.

6.2.4.3.1.8 Using the containers, prepare at least two blocks of treated material using different water contents of material in each (see Note 1). Prepare the blocks by compacting the treated material into the container(s) in four equal layers. Compact each layer with the vibrating hammer fitted with the foot. Scarify the surface of each layer before adding the next layer and finish the top layer flush with the top of the container by trowelling to a smooth surface. Form two holes up to 3 mm in diameter larger than the gauge rod through the block to a depth equivalent to that which will be used for site measurements. The holes shall

be approximately 125 mm from each end and in the centre of the 380 mm dimension. Use treated material with mix proportions similar to that proposed for the main works (see Note 2).

NOTE 1 Suitable masses to compact the containers too may be the optimum water content at the project specification limit of compaction $\pm 1\%$ and at the maximum dry density $\pm 1\%$.

NOTE 2 Blocks of material other than the treated material to be tested should not be used because the chemical composition is unlikely to be similar. However, it is recognized that they are of value to the manufacturer for ascertaining the initial settings of the gauge and have advantages for traceability.

6.2.4.3.1.9 Calculate the moisture density of the blocks from the dimensions and mass of each block.

6.2.4.3.1.10 Within 1 h of the completion of compaction of each block, measure the bulk density with a nuclear gauge in the same manner as described for making site measurements of moisture density (see 6.2.7) except three measurements will be taken at each end of the cubical container. The source rod shall be lowered to the same depth as that which will be used for in situ measurements. Determine the variation between the calculated density and the average of the six measured density values of each block as a percentage of the calculated density.

6.2.4.3.2 Derivation of the moisture density correlation

6.2.4.3.2.11 If the difference between the variations for the two blocks is 1% or less, then readings taken by nuclear density gauges used to measure the field density of the treated material shall be corrected by the average amount of the variation between the two blocks. Make the correction either by using the gauge biasing device in accordance with the gauge manufacturer's instructions or by multiplying the derived in-situ moisture density by the appropriate factor.

6.2.4.3.2.12 If the difference between the variations for the two blocks is more than 1%, repeat the correlation. If this confirms the previous result, consult the gauge manufacturer as the gauge might require maintenance.

6.2.4.3.2.13 Repeat the correlation every 3 months when testing is to continue for longer than this period, or if there is a change in the source material.

6.2.5 Procedure: gauge standardization

COMMENTARY ON 6.2.5

All nuclear gauges are subject to long-term ageing of the sources, electronic components and detectors. Geographically affected background radiation can vary, which can change the gauge performance. Gauges are therefore calibrated in terms of a ratio of the measurement count rate for each nuclear source to a count rate made on a reference block.

6.2.5.1 Carry out the standardization of the gauge on the reference block for each type of measurement at the start and the end of each day's use. This procedure shall also be repeated after 8 h of continuous use, but may be carried out more frequently if appropriate. Retain a permanent record of these data. If the gauge is switched off, repeat the standardization procedure.

6.2.5.2 Switch on the gauge and allow for normalization, if required, in accordance with the gauge manufacturer's handbook. If the gauge is to be used either continuously or intermittently during the day, do not switch the gauge off. Perform the test with the gauge located at least 7 m away from other nuclear gauges and at least 1.5 m away from any large structure which could affect the gauge readings.

6.2.5.3 When it is necessary to use the gauge in a narrow trench or within 1.5 m of a building or other structure, take into account the effects of reflected radiation by determining the standard count rate with the reference block within 10 mm of each of the proposed test locations prior to each such test, and use the same orientation as for the test. Always keep the gauge at least 150 mm clear of any vertical projection.

6.2.5.4 Place the gauge on the reference block and correctly locate the source rod. For each type of measurement, i.e. bulk density and moisture density, take at least four consecutive readings over a measurement period of 1 min and calculate the mean value.

NOTE If available on the gauge, a single measurement taken over a period of 4 min or more is acceptable. This constitutes one standardization check.

6.2.5.5 Make a record of the results of each standardization check with the date of the measurements in the gauge log in order to retain a continuity of results.

6.2.5.6 Check whether the arithmetical mean value in each case is within the limits set by the following equation and record the value of N_s in the gauge log.

$$N_s = N_o \pm 2.0 \sqrt{\frac{N_o}{p_c}}$$

where:

N_s is the average value of the current standard count rate;

N_o is the average of four values of N_s taken prior to use;

p_c is the amount of prescale applied to the detector counts prior to display.

NOTE The value of p_c can be obtained from the manufacturer. If no prescale is built into the gauge, $p_c = 1$.

6.2.5.7 Provided that N_s is within the limits permitted by the equation, use the N_s value to determine the count rate ratios for the current day's use of the gauge.

6.2.5.8 If the value of N_s is outside the permitted limits, repeat at least twice more the procedure for determining the average standard count rate. If all three, or two of the three, determinations are outside the acceptable limits, withdraw the gauge from service until the fault is rectified.

6.2.5.9 If the standardization at the end of the working period gives values outside the permitted limits, all results with that working period shall be deemed to be invalid.

6.2.6 Procedure: gauge stability

6.2.6.1 Follow the gauge standardization procedure described in **6.2.5**, but carry out a series of at least 16 repetitive measurements of 1 min with the gauge on the reference block for each type of measurement. Do not move the gauge during this process.

6.2.6.2 Separately record each of the measurements for each nuclear source in the gauge log with the date of the measurements. Determine the standard deviation and determine the average value of each series of repetitive measurements. Check that each stability ratio, expressed as the standard deviation divided by the square root of the average value, lies within the gauge manufacturer's quoted range for the gauge. Take into account any prescale value used and record the results in the gauge log. Where either of the stability ratios fall outside the gauge manufacturer's specified range or the trend in successive checks is erratic, withdraw the gauge from service until the fault is rectified.

Carry out this check on the gauge stability for each type of measurement at least once a month when in general daily use and once every 3 months otherwise. If the trend in successive checks is erratic, the gauge shall be withdrawn.

6.2.7 Procedure: determination of bulk density by direct transmission

6.2.7.1 Standardize the gauge by the procedure described in **6.2.5**. Perform the test with the gauge located at least 7 m away from other nuclear gauges and at least 1.5 m away from any large structure (large structures can affect the gauge readings).