SERIES NG 800
ROAD PAVEMENTS - (11/04) UNBOUND, CEMENT AND OTHER HYDRAULICALLY BOUND MIXTURES

Contents

ROAD PAVEMENTS - (05/01) UNBOUND, CEMENT AND OTHER HYDRAULICALLY BOUND MIXTURES

NG 800 (05/01) General

1 (11/07) Advice on design and construction of subbases and bases (roadbases) is published in the Design Manual for Roads and Bridges (DMRB) Volume 7. The Clauses in Series 800 refer to BS EN 13285, 'Unbound mixtures – Specification' and Parts 1 to 5 and 10 to 14 of BS EN 14227, 'Hydraulically bound mixtures – Specifications' which cover other hydraulically bound mixtures and now form the sub-Series 800. The cement bound Clauses of Series 1000 have been moved to Series 800. These are now part of sub-Series 800 referred to above. BS EN 13285 applies to unbound mixtures of natural, manufactured aggregates such as slags and recycled aggregates. The different parts of BS EN 14227 require aggregates to conform to BS 13242 which apply to aggregates obtained by processing natural or manufactured or recycled materials. DMRB also includes advice on the use of recycled materials, see HD 35 (DMRB 7.1.2).

(11/04) Unbound Mixtures for Subbase

NG 801 (11/04) General Requirements for Unbound Mixtures

1 (11/04) BS EN 13285 specifies the requirements for unbound mixtures used for the construction and maintenance of roads and other trafficked areas. All unbound mixtures used should comply with BS EN 13285. The requirements for the properties of aggregates used in unbound mixtures are defined by appropriate cross-reference to BS EN 13242.

2 (11/04) Because BS EN 13285 aims to satisfy differing custom and practice across many Member States (MS) of the European Economic Area (EEA), the standard contains many choices, which are set out in tables. The structure of the tables allows the user to choose an appropriate category for each mixture property. None of the combinations of categories from BS EN 13285 give a mixture that is directly equivalent to the established types of granular subbase material specified in previous editions of Specification for Highway Works (SHW).

3 (11/04) After detailed review of established practice and the capability of UK suppliers, the unbound mixtures in Table 8/1 have been chosen. The Table defines each mixture using a combination of categories for:

i) designation - in terms of lower sieve size (*d*) and the upper sieve size (*D*). The lower size sieve (*d*) = 0 for all unbound mixtures defined by BS EN 13285.

ii) maximum fines - as measured by the percentage by mass passing the 0.063 mm size sieve.

iii) oversize - in terms of the percentage by mass of particles passing a sieve size two times the upper sieve size (2*D*) and retained on the upper sieve size (*D*).

iv) overall grading - the combination of overall grading category and designation define the grading envelope.

For some mixtures, the overall grading category defines additional requirements to control the grading of individual batches, as detailed in Tables 8/5, 8/6, 8/7 and 8/8.

4 (11/04) It is unlikely that a single source of supply will routinely comply with the requirements for all four of the mixtures. Compliance depends upon the type of aggregate and the capability of the production process. Other BS EN 13285 mixtures not detailed in Table 8/1 should only be used after consultation with the Overseeing Organisation.

5 (11/05) The limiting values for sulfate characteristics in sub-Clauses 801.2 and 801.3 have been chosen to ensure that problems do not occur due to oxidation of reduced sulfur compounds such as pyrite. Further guidance is given in sub-Clause NG 601.8 and Clause NG 644.

6 The scope of BS EN 13285 is limited to the properties of unbound mixtures at the point of delivery; it does not include water content or the properties of the finished layer. To assist in the selection of an appropriate source and to help control compaction, the system of factory production control required for the unbound mixture includes an annual declaration of a typical value of laboratory dry density and optimum water content for each unbound mixture.

Frost susceptibility, plasticity, CBR and trafficking trials are outside the scope of BS EN 13285. The requirements of Series 800 apply to these mixture properties.

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Aggregates Used in Unbound Mixtures

7 BS EN 13285 requires the aggregates used in unbound mixtures to comply with BS EN 13242, Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction. Because BS EN 13242 aims to satisfy differing custom and practice across many member states of the EEA, the standard contains many choices, which are set out in tables. The structure of the tables allows the user to choose an appropriate category for each required aggregate property. BS EN 13242 also permits the use of the category "No requirement" for properties that are not relevant to a particular end use or origin of the mixture, in the interest of efficiency and economy. Further guidance on the use of BS EN 13242 is given in the Published Document PD 6682-6 'Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction - Guidance on the use of BS EN 13242' published by BSI.

8 (11/04) The requirements for aggregates in Table 8/2 have been chosen after detailed review of established practice and the characteristics of UK aggregates. The Table defines each aggregate used in the mixture as a combination of categories for:

i) **Crushed or broken particles - to ensure adequate aggregate interlock.** Crushed rock aggregates should be assumed to be in Category C90/3 without further testing. Where permitted, the use of Category C50/10 for crushed gravels ensures that not more than 10% of the particles are fully rounded.

ii) **Los Angeles coefficient - to control resistance to fragmentation.** The Los Angeles test replaces the Ten Percent Fines (TPV) and the Aggregate Impact Value (AIV) tests. The Los Angeles test can only test aggregate in a dry condition. There is not a direct correlation between the Los Angeles test and the BS 812 tests it replaces.

iii) **Magnesium sulfate soundness - to ensure resistance to freezing and thawing.** Category MS_{35} provides a level of resistance that is directly equivalent to the BS 812-121 value of greater than 65.

9 The micro-Deval test is used in some countries, notably France, to measure the resistance of aggregate particles to the abrasion caused when interlocking particles are subjected to repeated loading in the presence of water; particularly in thinner pavements with greater strains in the lower layers. The property measured by the micro-Deval test is not normally specified so Category M_{DE}NR (no requirement) is used. The supplier of the mixture is required to monitor micro-Deval values as part of the system of factory production control required by BS EN 13242. The value for the aggregate used should be stated to aid comparison between sources and so that the potential for the future use of this property can be reviewed.

10 Water absorption is not normally specified so Category WA_{24}NR (no requirement) is used. The supplier of the mixture is required to monitor water absorption values as part of the system of factory production control required by BS EN 13242. The value for the aggregate used should be stated. If necessary, the value may be used to provide a baseline for routine water absorption tests on delivered material. If any result from the tests on routine deliveries exceeds the declared value (d) by more than 0.5% further investigation will be required. Routine water absorption tests are not generally required for aggregates with a declared value of 2.0% or less.

11 In previous editions, blast furnace and steel slags were identified separately from other materials. The requirements for these materials, including those in BS 1047, are now incorporated into BS EN 13242. Table 8/2 defines requirements using categories for:

i) Volume stability for blast furnace slags - in terms of disintegration tests based on established UK requirements from BS 1047.

ii) Volume stability of steel (BOF and AEF) slags - in terms of a steam expansion test for which there is limited UK experience. Where permitted, the specified category is the most onerous. Evidence of recent satisfactory use of steel slag aggregate from the same source should also be obtained.

Recycled Aggregates

12 BS EN 13285 includes manufactured (such as slags and ashes) and recycled aggregates within its scope without specific mention in the requirement clauses. The approach adopted is blind to the source of the aggregate used in the mixture. The suitability of mixtures containing manufactured and recycled aggregates for use in subbase should be assessed in accordance with the requirements of the Series 800 Clauses.

13 The test procedure adopted in Clause 710 for identifying and quantifying constituent materials in recycled coarse aggregate and recycled concrete aggregate is a qualitative method. Where constituents other than those deemed to comply with the particle density requirements by the qualitative classification can be shown to be of a higher particle density, they

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may be included within these higher density fractions provided that written agreement has been given by the Overseeing Organisation.

14 (11/04) Sub-Clauses 803.4, 804.4, 805.4 and 806.4 describe requirements for material passing the 0.425 mm sieve. Were the foreign materials component of recycled coarse aggregate or recycled concrete aggregate to be ‘clay lumps’, the material may fail these tests and hence fail to meet the Specification.

Unbound Mixtures Produced as Part of The Works

15 BS EN 13242 (see Annex C) and BS EN 13285 (see Annex D) specify the operation of a factory production control system to confirm conformance with the relevant requirements of the standards. Although unbound mixtures produced on site as part of the Permanent Works are not placed on the market, a factory production control system (or a quality plan with equivalent requirements) is still required to provide the necessary level of assurance.

Frost Heave

16 (11/04) The frost heave test described in BS 812-124 is costly and time consuming and is not suitable for routine control checks on Site. The test has been developed from earlier test methods to overcome problems of repeatability and reproducibility. The test is primarily intended 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. Material for the frost heave test should be representative of the source and comply with all other requirements of the Specification otherwise the test is superfluous. Once a material has been established as non-frost-susceptible the test need only be repeated if the material varies from the original sample, or where the source is changed.

17 Clause 6 of BS 812-124 sets down the procedure for adjusting the water level in the self-refrigerated unit (SRU). A possible problem has been identified that with the tolerances given to the dimensions for the cradle and specimen carriers it is possible for the porous discs in the specimen carriers to be located incorrectly in relation to the water level. In order to guard against this it is recommended that before testing commences the cradle and specimen carriers be put into the SRU without samples. A check is then made to ensure that discs are set at the level specified in the above-mentioned standard.

18 (11/07) The requirement for material to be non-frost susceptible within 450 mm of the surface of a road or paved central reserve may be reduced to 350 mm if the Mean Annual Frost Index (MAFI) of the site is less than 50. The Frost Index is a measure of the severity of a period of cold weather and provides a means of assessing likely penetration of frost into a road. Frost index is measured in ‘degree days Celsius below zero’ and is calculated by taking the mean air temperature for each twenty four hour period and adding those values together. Frost penetration into a modern road in the British Isles may be estimated using the formula $x = 40\sqrt{I}$ where x is the approximate penetration in mm and I is the frost index for the freezing spell. The Annual Frost Index is the frost index accumulated over a year commencing September 1st. Mean Annual Frost Index (MAFI) is the average of all the frost index values computed for each year since September 1959. The MAFI for a site is determined using records from one or more meteorological stations close to the site, taking account of local geographical variation, such as high ground or frost hollows. Different requirements for different parts of a contract length may be used.

Further information on the MAFI can be found in HD 25.

Advice relating to any site, including the MAFI calculated for that site, may be purchased from:

Met. Office Customer Centre
FitzRoy Road
Exeter
Devon
EX1 3PB
United Kingdom

Tel No: 0870 900 0100
Fax No: 0870 900 5050
E-mail: claimate@metoffice.gov.uk

NG 803 (11/04) Type 1 Unbound Mixtures

1 The inclusion of up to 10% natural sand passing the 4 mm test sieve is permitted at the discretion of the supplier to adjust the material grading. Maximum limits of material content are included for asphalt and foreign material in recycled coarse aggregate and recycled concrete aggregate.

2 (11/04) BS EN 13285 details additional requirements to control individual batches of unbound mixtures with an overall grading Category G_P, within a system of factory production control. Table 8/5 in Clause 803 illustrates this. The supplier should nominate a supplier declared value for the intermediate sieves in the grading envelope as part of the system of factory production control for the mixture. The nominated value should lie within the supplier declared value grading range in Table 8/5. Individual batches are then assessed using the tolerances in Table 8/5, applied to the supplier declared values. As explained in Annex

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B (informative) of BS EN 13285, the use of tolerances does not change the overall grading range.

3 Table 8/5 also includes requirements for the calculated difference between the values of percentage by mass passing selected adjacent sieves. These requirements are taken from BS EN 13285 and ensure a 'well graded' mixture by controlling the continuity of the grading curve.

4 Because the requirements for aggregates used in the unbound mixtures now refer to the requirements of BS EN 13242, confirmation of conformity with the categories for Los Angeles coefficient and magnesium sulfate soundness can be obtained from the CE Mark Certificate for the aggregates used in the mixture. If a CE Mark Certificate is not available to confirm the suitability of the source, test certificates should be provided from a testing laboratory accredited by an appropriate organisation accredited in accordance with sub-Clauses 105.3 and 105.4 for the test, showing a value in excess of the minimum specified and dated not more than 6 months prior to the start of the contract.

5 Whilst there is no specified moisture content for laying and compacting unbound mixtures to Clause 803, in order to satisfy the requirements of sub-Clauses 802.8 and 803.7 it will be necessary to carry out these operations at optimum moisture content or thereabouts.

Mixtures Containing Crushed Gravel Aggregates

6 Previous editions of Clause 803 excludes all gravels from granular subbase material Type 1 but crushed gravel aggregate is permitted by BS EN 13285. Where local experience indicates that mixtures containing crushed gravel materials can be used successfully, the Overseeing Organisation may permit their use.

7 This edition of Clause 803 incorporates the requirements for crushed gravel subbase materials previously published as Clause 850SE. Trafficking trials of crushed gravel subbases used in Scotland have produced rut depths well within the upper limit (30 mm) recommended by the Transport Research Laboratory for the assessment of subbase materials if laid on Works contracts provided that:

(i) strict control over the grading is maintained; and

(ii) the crushed, broken and totally rounded particles requirements are met.

8 (11/04) No limiting value of design traffic has been imposed for Type 1 unbound mixtures containing crushed gravel. However their use on roads designed to carry more than 1500 commercial vehicles per lane per day should be clearly identified in the As-Built Records.

9 (11/04) For flexible roads with Type 1 unbound mixtures containing crushed gravel and carrying a traffic loading of more than 2 msa, the subbase strength should be at least an equivalent of CBR 30%. Further guidance about CBR is given in Clause NG 804. A trafficking trial should be considered for flexible roads carrying a traffic loading of more than 2 msa.

NG 804 (11/04) Type 2 Unbound Mixtures

1 (11/07) Current design requirements exclude Type 2 unbound mixtures from flexible roads carrying a traffic loading of more than 5 msa. Where local experience indicates that these materials can be used successfully at higher traffic levels, the Overseeing Organisation may require that a Substitute Clause should be written to permit their use. Mixtures containing a high proportion of asphalt arisings have been shown to perform well at design traffic levels higher than 5 msa, but performance should be assessed using a trafficking trial.

2 Table 8/6 in Clause 804 includes requirements for the calculated difference between the values of percentage by mass passing selected adjacent sieves. These requirements are taken from BS EN 13285 and ensure a 'well graded' mixture by controlling the continuity of the grading curve.

3 The value of CBR required for materials to Clause 804 will depend upon traffic loading. For flexible roads carrying a traffic loading of more than 2 msa the subbase strength should be at least an equivalent of CBR 30%. For traffic ranges below 2 msa the strength may be reduced to CBR 20%.

4 (11/04) If more than 15% of the material is retained on a 16 mm test sieve the whole material can be assumed without test to have a CBR value of 30% or more. CBR tests should be carried out (when necessary) on specimens which are compacted at a density and moisture content which represent equilibrium conditions under the completed pavement. In most cases the moisture content and density specified in sub-Clause 804.7 will apply but where this is not so it will be necessary to specify separately the required values of density and moisture content for the CBR test. The density relating to a particular air voids content can be calculated using the formula given in BS 1377-4. Compaction into the CBR mould should be carried out in such a way that the required density is obtained uniformly. The number of surcharge discs used in the CBR test should be equivalent to the weight of road construction above the subbase.

5 Although parameters related to the control of the construction of the pavement layer are outside the scope of BS EN 13285, it is appropriate to make information available to assist the purchaser's choice of unbound mixture. BS EN 13285 requires the laboratory dry density and optimum water content of an unbound mixture to be declared at least once each year, as part of the system of factory production control. BS EN 13285 permits choice from a list of four test methods for these properties, reflecting the range of mixtures and techniques used across Europe. In the UK, it is recommended that the vibrating hammer test (BS EN 13286-4) is used. This method is very similar to the established UK method defined in BS 1377-4. BS EN 13286-4 also includes a test method similar to that developed as BS 5835. That test procedure for the determination of optimum moisture content was developed specifically for graded aggregates and gives more reproducible results than the vibrating hammer test for these materials.

NG 805 (11/04) Type 3 (open graded) Unbound Mixtures

1 (11/04) Current design requirements permit the use of open graded mixtures in circumstances where a free draining layer is to be preferred. Type 3 (open graded) unbound mixtures is similar to the granular subbase materials previously known as Type 3 (Clause 850NI) and Type 1X, a grading derived by TRL.

2 (11/04) BS EN 13285 details additional requirements to control individual batches of unbound mixtures with an overall grading Category G_O, within a system of factory production control. Table 8/7 in Clause 805 illustrates this. The supplier should nominate a supplier declared value for the intermediate sieves in the grading envelope as part of the system of factory production control for the mixture. The nominated value should lie within the supplier declared value grading range in Table 8/7. Individual batches are then assessed using the tolerances in Table 8/7, applied to the supplier declared values. As explained in Annex B (informative) of BS EN 13285, the use of tolerances does not change the overall grading range.

3 Table 8/7 also includes requirements for the calculated difference between the values of percentage by mass passing selected adjacent sieves. These requirements are taken from BS EN 13285 and ensure a 'well graded' mixture by controlling the continuity of the grading curve.

4 Because the requirements for aggregates used in the unbound mixtures now refer to the requirements of BS EN 13242, confirmation of conformity with the categories for Los Angeles coefficient and magnesium sulfate soundness can be obtained from the CE Mark Certificate for the aggregates used in the mixture. If a CE Mark Certificate is not available to confirm the suitability of the source, test certificates should be provided from a testing laboratory accredited by an appropriate organisation accredited in accordance with sub-Clauses 105.3 and 105.3 for the test, showing a value in excess of the minimum specified and dated not more than 6 months prior to the start of the contract.

5 The chosen category for resistance to fragmentation in Table 8/2 is LA_{40}. A maximum Los Angeles coefficient of 35 is more appropriate for aggregates that have been used successfully in similar mixtures, but BS EN 13242 does not permit the choice of this value. Aggregate sources with a Los Angeles coefficient of 35 or more should be used with caution. Unless local experience indicates otherwise, aggregate sources with a Los Angeles coefficient in the range 30 to 35 should generally be considered as acceptable.

6 Whilst there is no specified moisture content for laying and compacting unbound mixtures to Clause 805, in order to satisfy the requirements of sub-Clauses 802.8 and 805.5 it will be necessary to carry out these operations at optimum moisture content or thereabouts.

NG 806 (11/04) Category B (close graded) Unbound Mixtures

1 For selected end uses where greater control of particle size distribution and consistency of performance is required than is available using the standard Type 1 unbound mixture, an unbound mixture with designation 0/31,5 and an overall grading category G_B can be used. This is known as a close graded granular mixture. The tighter tolerances of category G_B are unlikely to be achievable without special production regimes, probably involving batch blending of different aggregate sizes.

2 BS EN 13285 details additional requirements to control individual batches of unbound mixtures with an overall grading Category G_B, within a system of factory production control. Table 8/8 in Clause 806 illustrates this. The supplier should nominate a supplier declared value for the intermediate sieves in the grading envelope as part of the system of factory production control for the mixture. The nominated value should lie within the supplier declared value grading range in Table 8/8. Individual batches are then assessed using the tolerances in Table 8/8, applied to the supplier declared values. As explained in Annex B (informative) of BS EN 13285, the use of tolerances does not change the overall grading range.

3 Table 8/8 also includes requirements for the calculated difference between the values of percentage by mass passing selected adjacent sieves. These requirements are taken from BS EN 13285 and ensure a 'well graded' mixture by controlling the continuity of the grading curve.

4 Because the requirements for aggregates used in the unbound mixtures now refer to the requirements of BS EN 13242, confirmation of conformity with the categories for Los Angeles coefficient and magnesium sulfate soundness can be obtained from the CE Mark Certificate for the aggregates used in the mixture. If a CE Mark Certificate is not available to confirm the suitability of the source, test certificates should be provided from a testing laboratory accredited by an appropriate organisation accredited in accordance with sub-Clauses 105.3 and 105.3 for the test, showing a value in excess of the minimum specified and dated not more than 6 months prior to the start of the contract.

5 The chosen category for resistance to fragmentation in Table 8/2 is LA_{40}. A good resistance to fragmentation is required to ensure that a closely controlled product does not degrade excessively during handling and compaction. Aggregate sources with a Los Angeles coefficient of more than 30 should be used with caution. It may be appropriate to monitor changes in grading during laying and compaction if the Los Angeles coefficient is 35 or more.

6 Whilst there is no specified moisture content for laying and compacting materials to Clause 806, in order to satisfy the requirements of sub-Clauses 802.8 and 806.5 it will be necessary to carry out these operations at optimum moisture content or thereabouts.

NG 807 (11/07) Type 4 (asphalt arisings) Unbound Mixtures

1 (11/07) Trafficking trials of mixtures containing a high proportion of asphalt arisings carried out by TRL have produced rut-depths well within the upper recommended limit of 30 mm.

However the effects of this material on the surrounding environment should be fully assessed and approvals from statutory bodies obtained where necessary, before including this material as a permitted option in Appendix 7/1.

2 (11/07) When dry, asphalt arisings exhibit a considerable resistance to compaction due to the friction of the bitumen coating. The addition of water has a significant effect on the state of compaction by reducing the friction between the bitumen coated particles. Type 4 (asphalt arisings) unbound mixtures should, therefore, be compacted at moisture contents close to the declared value of optimum water content discussed in sub-clause NG 807.8.

3 (11/07) The particle size distribution of asphalt arisings is best described by the term 'lump size distribution' because of the binding effect of bitumen. The grading envelope obtained will be dependent on the duration of shaking, the temperature at which the determination is carried out and the grading of the mineral particles within the asphalt arisings.

Agglomeration of lumps can occur in stockpiled material especially in hot weather or when the material is stored for long periods. It is important that, at the time of placing, the asphalt arisings comply with the specified lump size distribution and care should be taken to ensure that, material taken from a stockpile is to the required grading. It may be necessary to demonstrate that the material actually placed meets the grading specification rather than to rely on tests at an earlier time.

Lumps, or individual particles of aggregate separated by the planing process, should be angular in appearance. Rounded particles that can be present when using arisings containing gravel aggregates can lead to difficulties in meeting the rutting criterion.

4 (11/07) Particle durability in terms of the magnesium sulfate soundness test need not be verified for mixtures containing a high proportion of asphalt arisings as the aggregates will have been tested prior to the introduction of bitumen.

5 (11/07) Particle hardness in terms of the Los Angeles test need not be verified for mixtures containing a high proportion of asphalt arisings as the test is unsuitable for materials containing bitumen and because the aggregate components will have been tested prior to the introduction of bitumen.

6 (11/07) The performance of unbound mixtures in subbase layers is dependent on the bearing strength of the compacted material. The measurement of bearing capacity in terms of CBR should not be specified for mixtures containing a high proportion of asphalt arisings. The measurement of CBR for mixtures containing bitumen is problematical because the results are dependent upon the temperatures at the time of compaction, the temperature at the time of testing and the duration of loading. However, as the grading envelope ensures that at least 19% of the mixture is retained on the 16 mm test sieve, it can be assumed without test that the material will have an adequate CBR value. Appendix 7/1 can be used to require a trafficking trial, if the additional assurance of performance is required.

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(11/07) **Cement and Other Hydraulically Bound Mixtures for Subbase and Base**

NG 810 (11/04) General Requirements for Cement and Other Hydraulically Bound Mixtures

Background for the Changes

1 Cement bound materials specifications have been moved from Series 1000 to Series 800. They are augmented by specifications for other hydraulically bound mixtures (HBM) and now form a collected sub-Series of the specifications under the general description of cement and other hydraulically bound mixtures for subbase and base. The term 'mixtures' is used in preference to 'materials' to conform to BS EN 14227 Parts 1 to 5 and 10 to 14, which provide specifications for mixture production as far as the point of mixture delivery.

2 Throughout BS EN 14227 there are options, from which the designer and compiler may choose.

3 Cement and other hydraulically bound mixtures are specified in BS EN 14227 with each part number applying to a unique binder type and separate part numbers for mixtures with granular aggregates and for mixtures with soil as the receptor material. The prime characteristic of hydraulically bound mixture (HBM) is the aggregate and mixtures are grouped within this specification by reference to their aggregate type and then to their binder type and as indicated in Table NG 8/1. Finally they are defined by their strength.

TABLE NG 8/1 (11/04) **Cement and Other Hydraulically Bound Mixtures - Classification**

Clause No	Desgination	Binder	Aggregate or mixture grading
821	CBGM A		Broad graded aggregate
822	CBGM B	Cement	Close grade aggregate
823	CBGM C		Graded mixture
	SBM B1-2	Slag	
830	FABM 1	Fly ash	0/31,5 mm graded mixture
	HRBBM 2	HRB	
	SBM B2	Slag	
831	FABM 2	Fly ash	Graded mixture with compacity requirement
	HRBBM 2	HRB	
	SBM B3	Slag	
832	FABM 3	Fly ash	0/6,3 mm graded mixture
	HRBBM 3	HRB	
834	FABM 3	Activator(s) only e.g. lime, cement etc.	Fly ash
	SC	Cement	
840	SS	Slag	Naturally occurring soils and secondary materials without controlled grading
	SHRB	HRB	
	SFA	Fly as	

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Application of HBM to the Chosen Pavement Designs

4 CBGM is relatively fast setting, by comparison with most of the other HBM formulations. It also generally has a lower binder demand for a given strength. Consequently the binder volume has less influence on the total grading than it does for other HBM types. Thus the CBGM grading is generally defined for the aggregate alone without regard to the total mixture proportions. The volume of fine material added to HBM, other than CBGM, as binder and/or activator can be large. Further, non-cement bound HBM is usually required to carry site traffic, and sometimes in service traffic, before it is fully set. Mechanical stability of the partially bound mixture is therefore important and the grading is specified for the complete mixture, including the binder and any activators. Where high grade cement bound mixtures (e.g., CBGM B or C) are required to take early trafficking, or where special considerations of shrinkage or density are appropriate, the mixture may be specified by mixture grading.

5 The secondary classification is by binder type. For cement bound granular mixtures three secondary classifications are provided, CBGM A which is approximately equivalent to CBM 2, and 2A and CBGM B and CBGM C which are approximately equivalent to CBM 3, 4 and 5. CBGM A, B and C cannot be directly substituted for the previous specifications without reference to the revised design method detailed in "Development of a More Versatile Approach to Flexible and Flexible Composite Pavement Design" TRL Report 615. Third classification is by strength by compressive or tensile strength, e.g., $C_{6/8}$ or T2.

6 All of the HBMs, other than CBGMs, have virtually identical specifications, other than that for the defining binder type. The mixtures are defined primarily by aggregate characteristics, secondly by binder type and thirdly by strength, in common with the GBGM approach. Mixtures with similar grading characteristics and strength classification but differing binder type cannot, necessarily, be substituted for each other due to differences in strength development with time.

7 BS EN 14227-10, -12, -13 and -14 for soil cement and treated soils are similar for each of the four principal binders and are covered by a single specification Clause. As with the granular mixtures, mixtures with similar grading characteristics and strength classification but differing binder type cannot, necessarily, be substituted for each other due to differences in strength development with time.

8 Allowable mixture specifications from the selection given in Table NG 8/2, together with their complementary layer depths should be included in Appendix 7/1, Schedules 3 and 5. The compiler may wish to include a number of options in Appendix 7/1, Schedules 3 and 5 to allow flexibility to ensure selection of the most appropriate mixture. Tenderers may be permitted to submit additional designs as alternative tenders.

9 Designs should be prepared using compressive strength class R_c, or when the R_tE design system is used the direct tensile class R_t of the mixtures. Mixtures may only be selected from those given in Table NG 8/2.

10 Frost resistance requirement was not considered previously, as the lowest design strength was sufficient to provide frost resistance. The new specifications allow the use of materials with compressive cube strength below 3 MPa, which is considered the lowest strength at which frost resistance is always likely to be achieved. Special consideration will be required where the design requirements are for mixtures, which will not have attained a compressive cube strength of 3 MPa before the 1st November. Such considerations will include:

(i) the frost penetration depth, see sub-Clause 801.7;

(ii) whether a sufficient depth of material to afford protection against temperatures less than 0ºC will cover the low strength material after the 1st November; and

(iii) The frost susceptibility of the aggregate or binder type e.g. mixtures with soft limestone aggregates will be more prone to frost degradation than mixtures with granite aggregate of a similar mixture strength. Thus in the case of a non-frost damage prone aggregate the 3 MPa limit could reasonably be reduced.

In cases of doubt reference should be made to Overseeing Organisation.

Table NG8/2 (11/04) **Laboratory Mechanical Performance Category Permitted Options**

HBM designation	**Compressive strength R_c**	**Direct tensile strength R_t**
CBGM A	C 3/4, C 5/6, C 8/10	T1, T2, T3
CBGM B	C 8/10, C 12/15, C 16/20, C 20/25	T3, T4, T5
CBGM C	C 8/10, C 12/15, C 16/20, C 20/25	T3, T4, T5
SBM B1-2	C 6/8, C 9/12, C 12/16, C 15/20, C 18/24	T2, T3, T4
FABM 1	C 6/8, C 9/12, C 12/16, C 15/20, C 18/24	T2, T3, T4
HRBBM 1	C 6/8, C9/12, C 12/16, C 15/20, C 18/24	T2, T3, T4
SBM B2	C 6/8, C 9/12, C 12/16, C 15/20, C 18/24	T2, T3, T4
FABM 2	C 6/8, C 9/12, C 12/16, C 15/20, C 18/24	T2, T3, T4
HRBBM 2	C 6/8, C 9/12, C 12/16, C 15/20, C 18/24	T2, T3, T4
SBM B3	C 3/4, C 6/8, C 9/12, C 12/16	T1, T2, T3
FABM 3	C 3/4, C 6/8, C 9/12, C 12/16	T1, T2, T3
HRBBM 3	C 3/4, C 6/8, C 9/12, C 12/16	T1, T2, T3
FABM 5	C 3/4, C 6/8	T1, T2
SC	C 0.8/1, C 1.5/2, C3/4, C6/8, C9/12	T1, T2, T3
SS	C 0.8/1, C 1.5/2, C3/4, C6/8, C9/12	T1, T2, T3
SHRB	C 0.8/1, C 1.5/2, C3/4, C6/8, C9/12	T1, T2, T3
SFA	C 0.8/1, C 1.5/2, C3/4, C6/8, C9/12	T1, T2, T3

NG 811 (11/04) Constituents of Cement and Other Hydraulically Bound Mixtures

1 Care will be necessary when mixing HBM when the amount of binder or activator is very low, due to the difficulty of obtaining a thorough dispersion of the binder or activator during mixing. When using blended cements in winter, or other slow hardening binders on the approach of winter, there is an increased risk of freeze/thaw damage if the early strength of the mixture is very low. Care should be taken to ensure that frost protection is provided when the ground and/or air temperature falls below 2ºC and until the in-situ equivalent cube strength of the in-situ layer has reached a value of 2 MPa.

2 Soil cement and GBGM A have been mixed successfully using volume batching or in-situ stabilisation at total cement contents at, or close to, the minimum in Table 8/10. Success at such low cement contents depends on:

(i) the cleanliness and grading of the soil to be stabilised;

(ii) the skill to maintain close control of the spread rates; and

(iii) the efficiency of the binder dispenser or spreader.

3 The additional cement requirements need not be applied if recent, well-documented and certified evidence can be produced of consistent mixing having been achieved with the same plant and operators on similar soils or aggregates. Unless such evidence is available a trial should be carried out over a period of not less than 5 full days work, covering a total area of not less than 3000 m^2. The success of the trial should be judged on the cubes made from samples taken at a minimum of 10 approximately evenly spaced locations per day and tested at not less than 7 days. A trial would normally be considered successful if the results for the mean strength were above the characteristic strength specified for the layer in question and no result fell below 85% of that strength, all results being adjusted to allow for the age of test on the basis of the results of job mix trials. A successful trial could be incorporated into the Permanent Works.

4 Any variation to the minimum binder content agreed by the Overseeing Organisation should be subject to reassessment if the source materials, method of working or operatives are significantly changed.

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NG 813 (11/04) General Requirements for Production of HBM and Construction of HBM Layers

1 Care will be necessary when using HBM when the amount of Portland cement CEM 1 to BS EN 197-1 or activator is very low, due to the difficulty of dispersion of the CEM 1 or activator during mixing. When using blended cements in winter, or other slow hardening binders on the approach of winter, there is an increased risk of freeze/thaw damage if the early strength of the mixture is very low. It is recommended that frost protection should be provided when the ground or air temperature falls below 2ºC, until the in-situ equivalent cube strength of the in-situ layer has reached a value of 2 MPa.

2 Where a mixture is to be mixed in-situ and then excavated and transported to the site of laying the construction requirements for mix-in-place construction should apply.

3 The construction period has formerly been defined by the number of hours from the addition of the binder to the mixture until the completion of compaction. This is thought to be too restrictive in some circumstances and inadequate in other circumstances. Table 8/11 provides greater flexibility and allows for the variation in the rate of hydration of HBM binder with temperature. No hydration is assumed at temperatures below 3ºC.

4 To calculate the elapsed construction period, the temperature (in ºC) should be the recorded at hourly intervals and 3ºC subtracted from the recorded value; to give the hourly maturity value. The sum of the hourly maturity values (positive only) will give the construction period in degree hours. For slow setting binders it is reasonable to measure temperature at greater regular time intervals, but not exceeding 6 hours, and to multiply each temperature difference by the number of hours between each measurement before summating the maturity values.

5 All plant-produced mixtures are required to be paver laid in order to assure consistent levels of compaction and level tolerance. The Overseeing Organisation may permit the use of other laying systems for subbase if the Contractor can demonstrate in a site trial that satisfactory performance is achieved. Subbase level consistency, while still required to be within the specified limits, is less important than the consistency of level and compaction of the base and the Overseeing Organisation should consider this when reviewing any contractor's proposals to construct subbase using machinery other than a paver.

NG 814 (11/04) Mix-in-Plant Method of Construction Using Weigh Batching for HBM

1 Types of mixers

(i) Forced action mixers are required to distribute and thoroughly mix the relatively small proportions of binder or activator with the often fine graded aggregates or soils, which are common in HBM layers. Forced action mixers mix the components of the mixture without reliance on gravity to produce mixing by the free-fall of the aggregates. This action is normally produced by either:

(a) a batch mix system using a vertical axis rotating pan mixer with fixed location vertical blades to force the flow to the center of the pan and prevent the agglomeration of fine material at the pan wall; or

(b) a continuous process where horizontal pairs of counter rotating intermeshing helical blades mix the aggregates and binders fed into the mixer, after blending.

2 The previous specification required that the mixed material should be protected from the weather during transport. Where haul distances are short and weather condition are unlikely to dry or cause excessive wetting at the surface of loads vehicles may not need sheeting. As a first approximation the omission of sheeting could be considered by the Overseeing Organisation when the construction period is less than half of the minimum period in Table 8/11.

3 Segregation may be observed as the occurrence of single zones of coarse aggregate greater than 0.04 m^2 without continuous medium or fine aggregate between the larger particles.

4 HBM binders do not hydrate once the mix temperature falls to close to zero. Further, if freezing occurs in a unhardened mixture it will disrupt the bonding of the matrix and coarse aggregates and could displace aggregates by the formation of ice lenses. It is therefore essential that a mixture should develop sufficient tensile strength to resist the internal freezing forces before being subject to temperatures below zero. With cement bound granular mixtures, soil cement and some HBMs with slag binder systems strength develops relatively quickly and if the construction is limited as described in the clause work may continue throughout the year. Where mixtures contain less than 3% of cement there is a danger of hardening taking place so slowly that the integrity of the mixture will be put at

risk. Construction of these mixtures is, therefore, not allowed in the winter.

5 In some circumstances, where rapid construction of the overlaying layers is proposed, the overlaying layers can provide adequate insulation to enable the winter working restrictions to be waived. In general it is unlikely that a cover of less than 300 mm would provide sufficient frost protection to non-cement bound mixtures. A risk assessment should be carried out taking into consideration:

(i) the likely strength gain of the mixture prior to overlay;

(ii) the site location, TRL Report RR 45 provides guidance on the influence of location; and

(iii) the likely construction date.

6 Drying out may be observed when the capillary suction forces of the mixing water no longer hold the fine material on the surface of a layer together. This can happen particularly as a result of high winds or low air humidity even in winter conditions.

7 Early, well controlled trafficking that will not cause damage to the pavement may be permitted. This is more likely to be achieved if:

(i) well graded mixtures made with 100% crushed hard aggregate should be suitable for immediate trafficking without demonstration;

(ii) subject to performance under a PTR, well graded mixtures made with 100% crushed weak aggregate should be suitable for immediate trafficking;

(iii) subject to performance under a PTR and provided the IBI > 50, well graded mixtures with not less than 50% crushed hard constituents should be suitable for immediate trafficking;

(iv) subject to performance under a PTR and provided IBI > 40, grity flakey sand mixtures should be suitable for immediate trafficking; and

(v) all other mixtures need 7 day non-trafficked curing periods.

NG815 (11/04) Mix-in-Plant Method of Construction Using Volume Batching for HBM

1 Generally most modern batching plants dispense their materials by mass. Some continuous mixers use belt weighers and integrate the belt speed with the load on the belt that give satisfactory control of the mixture proportions.

NG816 (11/04) Mix-in-Place Method of Construction for HBM

1 Advice on the mix-in-place construction can be found in TRL Report 611.

NG819 (11/04) Coefficient of Linear Thermal Expansion

1 (11/07) HD 26 (DMRB 7.2.3) for flexible composite pavement design makes assumptions for thermal warping stresses and a correlation tensile and compressive strength, which are both highly dependent upon the lithology of the coarse aggregate used in the mixture. The mixtures are designated as 'G' for gravel aggregate mixtures and 'R' for rock aggregate mixtures. As most of the gravel mixtures used in the UK use flint gravel and flint has a particularly high coefficient of linear thermal expansion, in excess of 10 x 10^{-6}/ºC, this limiting value parameter has been used to define G and R mixtures.

2 (11/07) The versatile design method (TRL Report 615), forms the basis of HD 26 does not consider thermal stresses to be critical but does differentiate between G and R mixtures for CBGM equivalent mixtures. The facility to define these mixtures by coefficient of linear thermal expansion has therefore been left in the current revision of the specification.

NG820 (11/04) Aggregates for HBM

1 The LA value indicates the resistance of an aggregate to size fragmentation during mixing and, to a lesser extent, the mechanical strength of the aggregate particles. It is thus of greater importance in bases than in sub-bases. For the mixtures, which have a LA requirement in Table 8/13, a LA_{60} requirement should be put Appendix 7/1 for sub-bases and LA_{50} for bases.

2 CBGM mixture designs have different layer thickness depth requirements for gravel and for rock aggregate mixtures. The designs should be designated as gravel or rock and alternative designs provided in Appendix 7/1, Schedule 5 for mixtures with each type of aggregate.

3 The limits stated in Table 8/13 for wood, glass and other impurities have been set to encourage the use of processed recycled aggregates and aggregates from secondary sources. However, there are opportunities on many schemes to use mixtures with much higher proportions of secondary materials. If a particular source is available on or adjacent to the site it should be investigated as part of the site investigation and identified to the tenderers. Where a possible source is known it can be tested to assess the construction and environmental risks associated with its use as part of the site investigation.

NG 821, NG822, NG 823, NG830, 831, 832 and 834 (11/04) Cement and Other Hydraulically Bound Mixtures

1 The mechanical performance level should be determined from the design requirements. Mixtures should only be selected from those shown in Table NG 8/2. Mixtures of C 5/6 or T2 designation or lower should not be used in bases.

2 Appendix 7/1, Schedules 3 and 5 should show the allowable alternatives of strength and the associated required layer thickness. The designation should be, e.g., CBGM A, followed by the appropriate strength class in BS EN 14227-1, e.g., for a $C_{5/6}$ class the designation should be 'CBGM A $C_{5/6}$' or, for a mixture defined using the R_tE system, 'CBGM A T_3', as appropriate for the chosen design. Where a gravel or rock aggregate is required, 'G' or 'R' should be inserted after the class designation letter to signify the requirement. Thus a gravel aggregate mixture with a minimum characteristic compressive cube strength requirement of 20 MPa would be designated as 'CBGM B G $C_{16/20}$'.

3 It should be noted that the strength requirements is for a characteristic strength at 28 days rather than a 7 days mean strength of 5 samples as in the previous specification. For first approximation purposes it has been found, for mixtures with CEM 1 (BS EN 197-1) cement, that the 28 days characteristic cube strength has been close to the mean strength of 5 samples tested using the protocol in the previous specification. However, if it is intended to use 7 days strength for production control purposes a job specific relationship should be determined.

4 The BS EN strength and elasticity requirements are based on the 28 day characteristic strength or characteristic tensile strength and characteristic elasticity determined throughout the project. To control the contractor's risk of non-compliance, if the values of the average and minimum individual 7 day results for each successive group of five tests at which the characteristic requirement are met, the material may be deemed to satisfy the requirements of this specification. Where sufficient results are available to allow the characteristic strength or the characteristic tensile strength and elasticity to be reliably determined new 7 day compliance levels may be set that to achieve the specified 28 day characteristic strength or the 28 day characteristic tensile strength and elasticity. Where the 7 day values are not achieved the values at 28 days should be used to determine compliance.

5 During the trial mixes the Contractor should take sufficient cubes or cylinders to establish a robust relationship between the 7 day mean strengths and the 28 day characteristic strength for the mixtures being proposed for the works. This relationship may be used to control the risk of non-compliance with the requirements of this specification.

6 It is envisaged that CBGM C mixtures will only be required where early trafficking is essential or highly advantageous. Thus it is not normally intended that tender designs should be prepared for both CBGM B and CBGM C mixtures. The designer should make a choice of which mixture to specify bearing in mind the strategic needs of the scheme.

NG 824 (05/05) Cold Recycled Cement Bound Material

1 General advice for the design and construction of cold recycled materials is published in Volume 7 of the Design Manual for Roads and Bridges (DMRB).

2 These Notes relate to the associated Specification for Cold Recycled Materials and offer the Design Consultant, Overseeing Organisation and Contractor the latest best practice advice on the design, supervision and execution of cold in-situ recycling works, used for structural maintenance of highway pavements.

3 Dependent on the type of pavement and specific site conditions, the cold recycling process may be used to form the structural course for a reconstructed pavement or the structural course and foundation platform as a combined layer. Alternatively, it may be used to provide a foundation course for a new overlying pavement construction.

Site Evaluation

Identification of Sites for Structural Maintenance by Cold Recycling

4 Structural maintenance of a road pavement may be required for a variety of reasons, when the running surface of the pavement becomes unserviceable and the cost of local repairs too expensive to sustain, due to the underlying pavement structure being incapable of offering the support required.

5 In the event of the deterioration being identified as a failure of the road haunch, any remedial measures should be investigated and implemented in accordance with TRL Report 216, Road Haunches: A Guide to Re-usable Materials (Potter, 1996).

6 If the deterioration is identified as being a general structural failure of the running lanes then any remedial measures should be investigated and implemented in accordance with TRL Report 386, Design Guide and Specification for Structural Maintenance of Highway Pavements by Cold In-situ Recycling (Milton and Earland, 1999).

7 In keeping with the objectives of sustainable development, each site should be investigated with the prime aim of determining the suitability of the existing materials for re-use. Irrespective of the remedial strategy ultimately implemented, the limits and condition of the site should be identified, including the following details for completion of Appendix 7/19.

(a) location, length and width of the site;

(b) construction of existing pavement;

(c) type and severity of deterioration;

(d) subgrade bearing capacity and condition;

(e) location and condition of drainage;

(f) location and condition of services;

(g) edge detail and verge condition, and

(h) future traffic loading.

8 To achieve the economies of scale and energy savings offered by the recycling process, a minimum programme of works of the order of 3,000 m^2 is suggested as a general guide, which could be a combination of a number of smaller schemes in close proximity. However, in particular circumstances, where conventional methods of reconstruction are onerous or precluded, smaller scale recycling works may still offer a cost effective solution.

9 The use of the cold recycling process may also depend on whether there is sufficient thickness of existing pavement available for recycling. Although, in certain circumstances, it may be possible to include subgrade material into the recycled structural course, provided that a non-plastic pulverised aggregate is produced naturally or by modification using lime or cement. Alternatively, it might be possible to import additional material suitable for recycling.

Investigation Framework

10 Any pre-contract site evaluation, forming the first stage of the design process, should be planned and implemented to ensure that sufficient information is obtained to demonstrate to the Overseeing Organisation whether or not, the recycling option is feasible. In addition, this evaluation should offer any prospective contractor all information necessary to plan their working practices and to tender on an equitable basis to achieve the targets set by an end-product performance specification.

11 The sampling and testing proposals for cold recycling projects on medium to heavily trafficked sites are summarised in Table 4 of TRL Report 386. However, the actual scope of the investigation carried out should reflect the nature and variation of the existing pavement materials.

12 Sites known to contain a variety of materials of uncertain origin should be evaluated more fully than those that are known to contain consistent layers of standard materials. The limits of each section of works should be identified and listed separately in Appendix 7/19. Also, sufficient representative information should be collected to enable the design process to be carried out for each of these sections.

Alternative Recycling Strategies

13 The situation may arise where it is impractical to divide the site into sections that contain consistent materials, capable of being designed as cold in-situ recycle material. However, as a mixed stockpile of materials from various parts of the site, it provides suitable feedstock for a processed recycled aggregate. In such cases, despite contributing less to sustainable development, in terms of transport movements and energy used, compared to the in-situ process, alternative recycling strategies could be considered using central or mobile crushing, screening and mixing plants.

14 To encourage and advance the cause of sustainable development, attention should be paid to the removal from site of surplus pulverised aggregate, which could be used to strengthen other roads in the area. Local co-operation between different highway authorities should be sought and programmes of maintenance works on different parts of the local road network co-ordinated. Locations for stockpiles of surplus materials should be included in Appendix 7/19.

Representative Test Specimens

15 For any assessment related to the design of recycling works, it is important that any sample of aggregate obtained for testing is typical of the pavement to be recycled, either as a mixed sample in representative proportions or as separate components for recombining later.

16 Ideally, the test specimens should also represent the grading and particle shape of the pulverised aggregate. Development and use of mini-planers designed for trenching works, used to excavate trial pits, may offer a means of obtaining such samples. However, to date, pulverised aggregate is not generally available during the pre-contract investigation and the design process relies on test specimens derived from samples crushed in the laboratory. A variety of laboratory crushing methods and devices are currently employed but none is specifically designed to produce the pulverised aggregate produced by a recycling machine.

17 Where it is recognised that the laboratory crushing process is not achieving sufficient fine material, which is often the case where the feedstock material contains a significant proportion of hot rolled asphalt, the finer grading should not be obtained by further excessive crushing because this would not reflect the pulverisation in the field, which tends not to break the existing aggregate component. Although not ideal, the grading of the test specimen should be modified to satisfy the specified grading envelope by the transfer of fine material from other sub-samples of the laboratory crushed material.

18 Alternatively, the grading of the test specimens could be made to meet the specified grading envelope by the addition of crushed rock fines, pit sand or PFA, particularly if their addition is considered beneficial to the performance of the recycled material in the field. Therefore, if the design using these test specimens is accepted, the proportion of fine material added to the material pulverised in the field should, ideally, be the same as the proportion of the same fine material used in the design process.

Underground Services, Ducts and Culverts

19 Because of their potential for disrupting the recycling works, all known services, ducts and culverts within 150 mm of the underside of the recycled layer should be accurately located and included with the site details given in Appendix 7/19.

Risk Assessment

20 Before drawing up a Contract involving the use of cold recycled materials, which are inherently more variable than plant produced new materials, the additional risks should be identified, apportioned and their management pre-planned to the satisfaction of all parties concerned. For this reason, the Overseeing Organisation and Contractor should be satisfied and agree that the existing pavement materials in all sections of the works, as defined in Appendix 7/19, are capable of being recycled by pulverisation, to form the primary aggregate component of a new cold recycled mixture. Also, that the mixture designed in accordance with sub-Clauses 824.43 to 824.49 for cement bound material is capable of being produced to meet the end-product performance requirements.

Component Materials

Pulverised Aggregate

21 The nature and grading of the aggregate produced by pulverisation will depend largely on the nature, thickness and proportions of the existing road materials. In situations where the depth of the existing pavement is insufficient to accommodate the new pavement design, it may be necessary to include subgrade material into the recycled structural layer or treat the subgrade as the foundation, compensated by an equivalent increase in thickness of the recycled layer provided that site level changes are acceptable.

22 Normally the cement bound recycling option is reasonably insensitive to the aggregate grading, nevertheless, an upper limit of 35 per cent by mass passing the 63 micron sieve is specified.

Moisture

23 The moisture content of the pulverised aggregate during stabilisation and compaction is as important as the grading because it is a prime feature controlling the consistence and, therefore, the degree of compaction that is achievable.

24 For compaction of granular material used in construction, the moisture content is usually targeted on the optimum moisture content determined in accordance with BS 5835. However, for recycled mixtures, the specified moisture content is dependent on the binder content, targeted slightly on the wet side of the optimum moisture content, determined in accordance with BS 1924: Part 2. Furthermore, the constituents of the mixture to determine the optimum moisture content are dependent on the proportion of filler added in the field.

25 For cement bound mixtures, experience has shown that the best compaction results are achieved using a specified moisture content range of optimum moisture content to +4% of the optimum moisture content. In those cases where a small amount of filler is added in the field, the optimum moisture content of the unmodified pulverised aggregate will normally suffice for control purpose because the moisture absorbed by the filler is mostly balanced by the suppression of the optimum value. However, where the addition of filler in the field accounts for more than 4 per cent by mass, the moisture content control should be based on the

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optimum moisture content determined for the modified aggregate.

Binder Agents

Primary Binder Agents

26 The selection of the primary binder agent for a particular recycling contract will depend to a great extent on the site conditions, cost factors and the design requirements in terms of either a flexible or flexible composite pavement. For UK conditions the current recommended choice is restricted to cement, as described in sub-Clause 1046.6 or foamed bitumen, as described in Clause 948.

27 Cement is readily available and, apart from the potential for thermal cracking of stronger CBMs, it has the advantage of being adaptable to a wide range of site conditions. Methods for safe working are well established and it is currently an accepted binder for mix-in-place CBM1 and CBM 2, as described in Table 8/14.

Supplementary Binder Agents

28 Lime may be added as filler or as the modifier for plastic fines within the pulverised aggregate. Despite the practical advantages of using quicklime, related to water absorption and control of spreading, the stringent safety measures required lead to hydrated lime as the preferred option for inclusion in Appendix 7/19.

Pulverisation and Stabilisation

29 Road pulverisation and stabilisation involves the use of specialised stabiliser plant that operates to the specified depth plus construction tolerances. To ensure adequate pulverisation and mixing of materials to full depth, it is recommended that the drive performance of the recycling machine is at least 260kW.

30 Stabilisers are manufactured with a height adjustable mixing box situated close to road level, incorporating a special toothed rotor designed to pulverise and mix the material within the mixing hood. The use of smaller agricultural equipment is no substitute because they are usually designed to work on cohesive soils and, therefore, are not designed to produce pulverised granular aggregate of the required grading and shape for construction purposes.

31 However, the powerful stabiliser plant can damage services, so the Overseeing Organisation should identify any services or obstructions present and include their details in Appendix 7/19. The time required to lower any services should also be taken into account within the Works programme.

32 A specialist manufactured stabiliser plant will incorporate all the features and facilities necessary to complete the works in accordance with the current recycling specification. Some will be larger and more powerful than others, whereas others may incorporate more refined control systems.

33 The systems normally employed to control the depth of pulverisation relate the position of the rotor relative to the vertical position of the wheels. Therefore, to ensure that the appropriate depth of pulverisation or stabilisation is carried out consistently, it is particularly important that a working platform of known level profile is prepared prior to the operation of the stabiliser.

Process Control

34 This section provides guidance for the Overseeing Organisation to help supervise the Works but, in addition, describes the best practice for the Contractor to follow to control the pulverisation and stabilisation processes.

Cement-bound Material

35 Because of the similar nature of the cement bound recycled material to that of plant mixed CBM, significant sections of the Clauses for CBM apply equally well for the recycled option. The Specification refers directly to the option of using a mix-in-place method of construction for CBM 1, 2 and CBM 3. In consequence, most of the Clauses given in the Notes for Guidance are also applicable to recycling.

36 One exception to the above guidance, relates to the curing period and use by traffic. In a structural maintenance situation there is usually a requirement to maintain access through and within the site for residents and services traffic. However, for most recycling contracts, any access restriction will inevitably delay the works programme. Therefore, early life or same day trafficking is sometimes unavoidable.

37 However, any damage to the recycled layer by early trafficking may be minimised by the use of higher cement content for early strength gain or by ensuring that adequate compactive effort has been applied and high density achieved. Provided that the as-installed elastic modulus, measured by dynamic plate loading or penetrometer techniques meets the targets set by the Specification, there should be no problem in proceeding with construction of the overlying pavement.

38 Conversely, without additional cement to enhance strength development, it is possible to argue that early life trafficking could be beneficial to the longer term performance of the pavement by establishing a closer spaced pattern of crack in the structural course, thus making the surfacing less prone to reflection cracking.

Added Water and Moisture Control

39 Although the control of moisture content is of prime importance for optimum compaction, there is currently no automated process available that can ensure the provision of moisture at a uniform and optimum level during the recycling process. It is vital, therefore, that the process is controlled by an experienced operator who has access to controls for adding water, particularly when the water is sprayed directly in the mixing box at the time of stabilisation.

40 The stabiliser should, ideally, be fitted with a separate pump and spraybar system for metering the added water, which is regulated to the ground speed of the machine. An experienced operator will normally assess the moisture content of the CBM relative to the target optimum by squeezing samples of the material regularly by hand and be guided by test results at the commencement and during any job so as to "calibrate" personal judgement. The operator must assess the moisture content immediately behind the stabiliser and be prepared to make quick adjustments as the machine may be progressing forward at a rate of 4-6 metres per minute.

Application of Cement or Hydrated Lime

41 Cement may be required either as the primary binder or as a supplementary binder to act as an adhesion agent or to help improve the short term properties of the compacted material. In comparison, hydrated lime is generally used as a plasticity modifier for cohesive fines within the pulverised aggregate.

42 Specialist spreaders are necessary for the application of these materials, which should incorporate control systems to ensure that the rate of spread is achievable to a target accuracy of ±0.5 per cent of the specified spread rate. The particle size of cement and lime as supplied may vary and such behaviour should be noted as it may affect the accuracy of application. The use of consistent sources and standard routines for storage and loading of the spreader is recommended to minimise any variation.

Compaction

43 Compaction is a critical part of the stabilisation process and demands particular care. This is especially the case for thicker layers of construction, where there is the possibility of a density profile developing during compaction, such that the lower part of the layer does not achieve the same density as the upper part.

44 This effect may be minimised when applying compaction at the earliest possible time using either heavy vibratory compaction or by a compactor capable of "kneading" the material at depth, as is the case with a tamping roller. To date in the UK, heavy compaction for cold recycling works has been carried out mostly using the heavy vibratory roller option although, more recently, a heavy combined pneumatic tyre roller (PTR) and vibratory drum roller has been trialed but their field performance has yet to be verified.

45 From monitored works, it is evident that vibratory compaction did not always achieve full depth compaction of thicker layers. Therefore, where the stabilised material is assessed as having poor consistence, it is recommended that consideration be given to the use of heavy tamping rollers for the initial deep-seated compaction, particularly for layers having a compacted thickness in excess of 225 mm. This should be followed by grading of the surface and final compaction using the conventional heavy vibratory compaction. This is similar to the compaction methodology commonly used in Australia for thick-lift construction.

46 When using heavy vibratory compactors, caution should be exercised where there is any danger of damage to shallow culverts, underground services or adjacent buildings.

47 The use of a pneumatic tyre roller (PTR) as a finishing roller is often advocated, particularly for the cement bound material. However, whereas the PTR may tend to assist in the compaction of the lower level material, care is required to ensure that the near surface material does not dry out or stiffen too quickly, which may result in disruption and shear displacement of the near surface material caused by the load applied under the individual tyres, which results in an unstable surface finish and the necessity for removing loosened unacceptable material.

Surface Sealant

48 The type and rate of spread of the bitumen sealant, as stated in Appendix 7/19 should comply with the recommendations given in BS 434.

End-Product Performance Specification

49 The process of cold recycling for the structural maintenance of highway pavements has been developed and used in a variety of countries, each with their own local requirements, often related to climate and geology. Consequently, the types of road available for recycling have been wide ranging. As a result, previous recycling specifications have been derived from a variety of component material designs and construction methods that were generally aimed at producing materials of conventional form with anticipated performance similar to the plant mixed option.

50 Whilst the recipe and methods specification has served the industry well for the lower trafficked roads, end-product performance specification is seen as a means of specifying recycled materials in their own right, using performance properties, allowing the recycled material to be considered for more heavily trafficked sites on an equitable basis to standard plant produced materials.

51 The end-product performance assessment is designed to follow a three stage procedure, to allow the construction to proceed at the same time as giving the Overseeing Organisation the opportunity to verify the acceptability of the product at the earliest possible time.

As-Installed Stiffness Using a Dynamic Plate or Penetrometer Tests

52 The as-installed performance of the stabilised layer, within 24 hours of completion of compaction, is evaluated using a dynamic plate loading or penetrometer techniques to determine the elastic modulus at points on a closely spaced grid pattern. Furthermore, before proceeding with the surfacing, repeated values are expected to demonstrate that the elastic modulus values have increased, as an indication that the curing/stengthening process has started. The first repeat measurements should normally be made after 24 hours and thereafter at intervals, dependent on the measured rate of increase of elastic modulus. In the trial and first section of main paving, tests should be carried out in a 2 m grid pattern. During main paving, should consistent elastic moduli be achieved, the longitudinal grid spacing can be relaxed to 5 m and 10 m should the latter spacing also produce consistent results. The single point and mean value of elastic modulus for the assessment areas, and their respective percentage increase, must comply with the minimum standards stated in Appendix 7/19.

53 Experience to date, using a dynamic (light) plate loading technique has determined that fresh, well compacted cold recycled material typically achieves a single point elastic modulus value (Evd) in the range 40 to 70 MPa. Therefore, the as-installed performance of an acceptable constructed layer, based on at least 100 point evaluations, is expected to display an initial minimum mean value of elastic modulus in excess of 50 MPa, with no single point value less than 30 MPa. Prior to surfacing, an increase of 20 per cent for single point values and 30 per cent for the mean value, would be indicative that the curing process is underway. These values should be applied to the as-installed condition and initial stage of curing. For other plate loading or penetrometer test methods, an equivalent correlation should be provided to the satisfaction of the Overseeing Organisation.

Pavement Stiffness from Falling Weight Deflectometer (FWD) Survey

54 The current status of the FWD and associated elastic stiffness evaluation does not allow the procedure to be used as a rejection method. However, if acceptably high stiffness modulus values are determined consistently, as described in Appendix 7/19 the method should provide the Overseeing Organisation with sufficient confidence and a means of acceptance for the cement bound material.

55 Experience to date using the FWD, as described in the Specification, suggests that a pavement stiffness value for the combined bound layers of the pavement (i.e. recycled layer plus surfacing) of the order of 5000 Mpa for the cement bound option below which not more than 15 per cent of the derived values should fall, offers an acceptable performance standard.

Compressive Strength/Stiffness Measurements of Core Specimens

56 The development of the end-product performance specification for the cold recycled materials has passed through various stages, in which the initial intention was to determine the performance of cored specimens in terms of the compressive strength of cement bound material.

57 The above option was set aside, however, when it was decided that coring should only be performed as a last resort. This decision was reinforced by the experience gained on some monitored sites, where the core extraction itself was difficult, such that a suitable number of test specimens could not be obtained.

58 The rate of success for extraction of cores from cold recycled material is generally enhanced by using air flush coring in place of the more usual water flush method. Also, removal of the cored asphalt surfacing layers, before proceeding with the coring into the recycled material, was found to improve the success rate of core extraction.

59 In the event that acceptance is not achieved using the FWD survey and analysis, the current specification uses the core testing option as the last resort performance assessment. If carried out after the FWD survey, as late as possible within the Contract maintenance period, it should maximise the success rate for the extraction of cores and offers the best opportunity of obtaining specimens that are suitable for testing.

Mixture Design and Characterisation

60 The design procedures adopted to date, have been developed by various organisations for their local needs

although, in general, most mixture design procedures for cold recycled materials are based on the determination of compressive strength for cement bound material related to a recycled layer of specified thickness, to carry a required traffic loading over a stated period of time.

61 In practice, the feedstock material to be stabilised does not usually exist until after pulverisation, so the initial mix appraisal or design process is often a matter of experience by the specialist contractors using their particular recycling plant, in order to obtain the optimum component design.

62 Also, the results of stiffness and other tests performed on laboratory prepared specimens are dependent on the curing regime of the specimens, which is unlikely to be representative of the site conditions, so these tests are only valid for comparison and assessment of the optimum mixture condition. Therefore, the values obtained do not necessarily relate to the in-situ condition of the material.

63 The detail of the procedure given in sub-Clauses 824.43 to 824.49 is based on the current industry practices, which will be developed when more representative specimens and test results can be verified.

Cement-bound Mixtures

64 For lower traffic situations, cold in-situ cement bound recycling is often used to provide a new foundation and/or structural course, designed to have an average 7-day cube compressive strength of 4.5 N/mm^2 or 7 N/mm^2 (i.e. either CBM 1 or CBM 2 equivalent strength).

65 For higher traffic loading, the recycled layer is used as the main structural course, designed to have an average 7-day cube compressive strength of 10 N/mm^2 (i.e. CBM 3 equivalent). In ideal circumstances, this material might be considered structurally equivalent to plant mixed CBM of equal compressive strength. In practice, inherent variability of the feedstock materials, short mixing period and practical difficulties associated with thick-lift construction, will require a factor of safety to be applied to the design thickness. Further guidance is given in TRL Report 386.

66 For the stronger recycled mixtures, the potential for thermal cracking and reflection cracking of the bituminous surfacing is similar to that for conventional plant mixed CBM. Therefore, the thickness of surfacing layers should normally be the same as that specified for a conventional flexible composite pavement carrying the same traffic loading. The cement contents used in the design process for recycled mixtures are similar to those required for the plant mixed equivalent, except that an absolute minimum cement content of 3 per cent by weight is recommended to ensure there is adequate cement available for distribution throughout the mixture during the short period of in-situ mixing.

NG 840 (11/04) Soil cement (SC), Soil Treated by Slag (SS), Soil Treated by HRB (SHRB), and Soil Treated by Fly Ash (SFA)

1 It is suggested that foundation designs will be required for two binder groups, i.e., for soil cement and for the slower acting binder treated soils. The curing of test specimens for treated soils, other than soil cement, is designed to model the strength at the assumed design time of one year whereas the soil cement test results require adjustment to one-year strength as part of the thickness design process. Designs may be included for Class $C_{1.5/2.0,}$ or T2, and above.

2 (11/07) Previous specifications have included requirements for soil cement subbases under the classification of CBM 1. To follow the form of the new standards, soil cement is now provided for as part of a suite of standards for soils treated with a range of hydraulic binders. The range of properties of the soil mixtures has also been expanded to allow the pavement designer sufficient options to achieve the optimum design solution for each site.

3 Research carried out at Transport Research Laboratory (TRL) and in full-scale trials has indicated that satisfactory subbases can be constructed and trafficked at lower strengths than provided in the previous specification. Also it has been shown that aggregates and soils not commonly used, including cohesive soils, can be satisfactorily stabilised with binder combinations to produce subbase material. These techniques give environmental benefits in avoiding the use of primary aggregates and often using secondary materials such as fly ash or slag as the major part of the binder. On many schemes they can reduce the need to dispose of surplus cut soil or allow a slight lowering of grade lines.

4 Where cohesive soils are to be stabilised to form subbase they will normally require amelioration with lime to allow the efficient mixing with the second binder, which is required to develop the specified strength. Traditionally cement has been used as the second binder. However, recent experience in the use of fly ash and of ground granulated blast furnace slag has indicated that more durable subbases can be constructed than with cement and frequently at a lower cost.

5 The use of lime or hydraulic binder with some clays requires some caution and the procedures set out in HA 74 (DMRB 4.1.6) need to be followed particularly in regard to investigating the presence of

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sulfates. More recent work by British Research Establishment (BRE) has suggested a more thorough protocol for the investigation of sulfates. The volumetric expansion test is preferred to the CBR swell test but where the proposed receptor soil contains any sulfate and calcium carbonate reference should be made to the Overseeing Organisation before commencing the detailed investigation.

6 The presence of sulfate, or potential sulfate, need not mean that the soil is unable to be permanently stabilised but it could mean that special measures will need to be taken, which could include additional, mixing, mellowing, temperature limitations, restrictions on binder type etc.

7 Mixtures of SC or treated soil require specification details in Appendix 7/1 for the attributes listed below:

(i) Aggregates requirements:

(a) Impurities

There are no limitations on the impurities in treated soils as generally un acceptable levels of deleterious constituents will result in failure to pass the requirements of the immersion test. However, an excess of reactive glass will not be revealed by such tests and alkali aggregate susceptibility will need to be investigated as in the case for CBGM.

(ii) Laboratory mechanical performance requirements:

(a) The mechanical performance level should be determined from the design requirements. Mixtures should only be selected from those shown in Table NG 8/2 as appropriate for the design.

(b) The BS EN strength and elasticity requirements for soil cement are based on the characteristic strength or strength and elasticity determined throughout the Contract. To control the risk of non-compliance, limiting values on the minimum average and minimum individual result for each successive group of five tests at which the characteristic requirement are deemed to be satisfied are set in this specification.

(11/04) Testing, Control and Checking of Cement and Other Hydraulically Bound Mixtures

NG 870 (11/04) Testing, Control and Checking of Cement and Other Hydraulically Bound Mixtures

1 HBM produced to conform to BS EN 14227 requires testing using the complementary BS EN 13286 Parts 4, 41 to 43, 46 to 48 and 51. These standards are restricted to mixture tests and tests on specimens made from mixtures. The tests for quality in the completed pavement layer continue to be found in BS 1924 Parts 1 and 2.

2 HDM formulations without cement binder compacted to refusal to produce cylindrical specimens, cured at 40°C and tested at 28 days have been found to be at least equivalent to the 364 days strength/stiffness achieved using 20 °C curing. For mixtures using binders containing a minimum of 3% by dry mass of cement, refusal cylindrical or cube specimens cured at 20°C and tested at 28 days have been found to be equivalent to 80% of the 364 days strength at 20°C curing.

3 For mixtures using binders containing a minimum of 3% by dry mass of cement, refusal cylindrical or cube specimens cured at 20°C and tested at 28 days have been found to be equivalent to 80% of the 364 days strength at 20°C curing.

4 For mixtures using binders without cement, refusal cylindrical specimens cured at 40 °C and tested at 28 days have been found to be at least equivalent to the 360 day strength/stiffness using 20 °C curing.

NG880 (11/04) Laboratory Mixture Design Procedure for HBM

1 A schedule of testing similar to that shown in Table NG 8/3 should be employed for each combination of binder and water content.

TABLE NG 8/3: Suggested Schedule of Testing for Laboratory Mechanical Performance of One Combination of Binder and Water Content

HBM Type	**Curing Temperature**	**Age of Test of Sealed Specimen (X Denotes One Result)**					
		7 days	**14 days**	**28 days**	**56 days**	**91 days**	**1 year**
Without cement	40 degrees C	XXX	XXX	XXX	-	-	-
	20 degrees C	-	-	XXX	XXX	XXX	XXX
With cement	20 degree C	XXX	XXX	XXX	XXX	XXX	XXX

NOTE: Note that for mixtures using binders without cement, refusal cylindrical specimens cured at 40°C and tested at 28 days have been found to be at least equivalent to the 360 day strength/stiffness using 20°C curing. For mixtures using binders containing cement, refusal cylindrical or cube specimens cured at 20°C and tested at 28 days have been found to be equivalent to 80% of the 360 day strength at 20°C curing.

2 The Contractor should provide evidence of strength development over a minimum of 28 days. On the basis of this information, the Contractor should declare the age of testing for site control purposes.

3 HBM complying with performance category C3/4 or T1 and greater or containing at least 8% binder addition (10% in the case of FA+lime) can be considered satisfactory as far as frost resistance is concerned without further testing.