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Road Pavements – Unbound and Hydraulically Bound Mixtures

CC-SPW-00800
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CC Construction & Commissioning

Standards

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TII Publications

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Contents

Updates to TII Publications resulting in changes to

Road Pavements – Unbound and Hydraulically Bound Mixtures CC-SPW-00800

Date:	August 2022
Page No:	
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Amendment Details:

The new CC-SPW-00800 covers the specification of unbound and hydraulically bound granular mixtures for use in pavements and foundations. The specification covers details related to the definition of mixture constituent properties, mixture properties and requirements for the works incorporating these mixtures. New material classifications are introduced using acronyms UGM – Unbound Granular Material and HBM – Hydraulically Bound Granular Material. Works requirements for mixtures now include works performance requirements, in addition to constituent and mixture requirements, creating an alignment with the new approach to pavement design detailed in the revised DN-APV-03021.

Date:	March 2023
Page No:	15
Section No:	3.3.5

Amendment Details:

Addendum March 2023: Table 3.8 updated with corrected Elastic Modulus and Indirect Tensile Strength performance limits.

Date:	October 2023
Page No:	3
Section No:	Table 2.1, Clause 2.2.1.1

Amendment Details:

Table 2.1 Requirements for Aggregates Used in UGMs

a) Liquid Limits requirements updated.

b) Methylene Blue testing requirements added.

c) Freeze thaw test method updated.

d) Notes 2, 3 and 4 updated.

Clause 2.2.1.1 Fines Quality

a) Updated requirements related the application of Liquid Limit determination and Methylene Blue testing.

Contents Table

1. General Requirements and Definitions

1.1 General

This document details the requirements for Unbound Granular and Hydraulically Bound Mixtures to be constructed as part of road pavement structure.

The requirements detailed in the document relate to the:

- Mixture Types
- Constituent Materials
- Mixture Composition
- The Works

1.2 Definitions, Symbols and Abbreviations

Item	Description
Base	Main structural element of a pavement. The base may be laid in one or more courses, described as “upper” base, “lower” base.
Coarse	Structural element of a pavement constructed with a single material. A course may be laid in one or more layers.
Contractor	Installer of the Works.
Employer	As defined in the Public Works Contract.
Employer’s Representative	As defined in the Public Works Contract.
Falling Weight Deflectometer (FWD)	The FWD is a trailer-mounted dynamic plate test device that measures the deflection response of road pavements under loading up to 120kN. The deflections are measured by sensors located at various positions relative to the load plate.
Hydraulically Bound Mixture (HBM)	A combination of aggregate, fine material particles and a hydraulic binder. When initially compacted layer strength is achieved through particle interlock and pore suction pressures. However, as the added binder hydration reaction begins in the presence of water, bonds develop between the mixture particles developing the materials characteristic strength.
Pavement	Structure, composed of one or more courses, to assist the passage of traffic over terrain
Producer	Defined as either ‘Manufacturer’ or ‘Contractor’ as appropriate.
Reclaimed Aggregates	Reclaimed aggregates are produced by the reuse or recycling of materials respectively defined by Article 27 (by product) and Article 28 (end of waste) as defined in European Union (Waste Management) Regulations, 2011- 2020 (transposing EU law)
Surface Modulus	Weighted average stiffness of a layered pavement structure calculated from surface deflections.
Unbound Granular Mixture (UGM)	A combination of aggregate and fine material particles which when compacted as a layer achieve stiffness through particle interlock and pore suction pressures.

Symbols and abbreviations not covered above shall be as per the applicable European Standard.

2. Unbound Granular Mixtures

The properties of aggregates used in Unbound Granular Mixtures (UGM) shall comply with the selected requirements of IS EN 13242 as set out in this document.

The Contractor shall ensure that the manufacturer of UGMs has in place a system of factory production control that complies with the requirements of Annex C of IS EN 13242.

The Contractor shall also ensure that the manufacturer of UGMs has in place an environmental management system which is in compliance with ISO 14001.

UGMs shall be manufactured and constructed to conform to the selected requirements of IS EN 13285 and additional requirements as set out in this document.

2.1 Mixture Types

The Unbound Granular Mixtures (UGMs) specified in this document are listed below.

2.1.1 UGM A – Unbound Granular Mixture A
2.1.2 UGM Ac – Unbound Granular Mixture A adjacent to cementitious materials
2.1.3 UGM Am – Unbound Granular Mixture A adjacent to metallic materials
2.1.4 UGM B – Unbound Granular Mixture B
2.1.5 UGM Bc – Unbound Granular Mixture B adjacent to cementitious materials
2.1.6 UGM Bm – Unbound Granular Mixture B adjacent to metallic materials

The constituent and mixture requirements for a UGM A (2.1.1 – 2.1.3) are such that improved long-term performance of the constructed layer is expected when compared to a UGM B (2.1.4 – 2.1.6) pavement layer of the same layer thickness.

Mixtures and their constituents which are required to meet additional requirements, related to their proximity to cementitious or metallic materials, are denoted by the additional notation “c” and “m” to the end of the mixture type.

UGM A / Ac / Am shall comprise of one or a combination of the following materials:

i. Crushed rock aggregate
ii. Limited content of reclaimed aggregates

UGM B / Bc / Bm shall comprise of one or a combination of the following materials:

i. Crushed rock aggregate
ii. Crushed natural gravels
iii. Reclaimed aggregates

Each mixture shall comply with the requirements regarding constituent materials, mixture composition and installation of the Works as laid out in this document. It is the responsibility of the Designer to ensure the particular mix chosen is suitable for the site location and the applicable design criteria.

2.2 Constituent Materials

2.2.1 Aggregates

All aggregates incorporated within a UGM shall be in accordance with the requirements of Table 2.1 and shall comply with the requirements of this Specification.

Table 2.1 Requirements for Aggregates Used in UGMs

Property			Mixture						Test Method
			2.1.1	2.1.2	2.1.3	2.1.4	2.1.5	2.1.6	
			UGM A	UGM Ac	UGM Am	UGM B	UGM Bc	UGM Bm	
Chemical	Water-soluble sulfate content in mg SO_4 per litre		NR[1]	≤1500	≤300	NR[1]	≤1500	≤300	I.S. EN 1744-1
	Oxidisable sulfides content as SO_4		NR[1]	≤0.30 %	≤0.06 %	NR[1]	≤0.30 %	≤0.06 %	
Geometric	Crushed or broken and totally rounded particles		$C_{90/3}$			C_{NR}			I.S. EN 933-5
	Shape of coarse aggregate - Flakiness Index		FI_{35}			FI_{50}			I.S. EN 933-3
	Fines Quality	Liquid Limit[2] (Virgin aggregate only)	≤ 20 (Limestone) ≤ 21 (Non-limestone)						BS 1377-2
		Methylene Blue test[3]	To be reported						I.S. EN 933-9
Physical	Resistance to fragmentation - Los Angeles test		LA_{30}			LA_{50}			I.S. EN 1097-2
Durability	Resistance to freezing and thawing	Water Absorption	$WA_{24}2$						I.S. EN 1097-6, Annex B
		Resistance to freezing and thawing[4]	F_4						I.S. EN 1367-1
Environment Considerations			Refer to 2.3.2						
All other IS EN 13242 aggregate requirements			NR[1]						

[1] *NR = No Requirement*

[2] *Where reclaimed aggregates are a constituent of the mixture, the liquid limit requirements apply to the virgin aggregate content only.*

[3] *Where reclaimed aggregates are a constituent of the mixture the Methylene Blue test shall be carried out on each of the virgin aggregate content, the reclaimed aggregate content, and the combined mixture.*

[4] *Resistance to freezing and thawing test is only required where water absorption requirements are not met.*

2.2.1.1 Fines Quality

The Liquid Limit shall be determined for virgin aggregate mixtures and the virgin aggregate content of mixtures with reclaimed aggregates as a constituent. The material passing the 0,425 mm BS sieve shall have a liquid limit, determined in accordance with the cone penetrometer method (definitive method) in BS 1377-2, not greater than 20 for limestone and 21 for all other rock types.

The Methylene Blue test shall be carried out on virgin aggregate mixtures and mixtures with reclaimed aggregates as a constituent. For mixtures with reclaimed aggregates as a constituent, the Methylene Blue test shall be carried out on the aggregate of the combined mixture, the virgin aggregate content and the reclaimed aggregate content of the mixture. All Methylene Blue test results and the reclaimed aggregate content shall be reported to TII Network Management.

2.2.1.2 Water-Soluble Sulfate (WS) and Oxidisable Sulfides (OS)

All UGMs deposited within 500 mm of cementitious (cement bound materials, concrete pavements, concrete structures or concrete products) or metallic structural elements shall meet the chemical requirements detailed in Table 2.1.

At least five samples of each material shall be tested for WS and OS. The mean of the highest two values shall be used for comparison with the limiting values. This also applies if six to nine results are available. If ten or more results are available, the mean of the highest 20% of the results shall be used for comparison with the limiting values.

The 2:1 water to soil extract prepared for the determination of water-soluble sulfate shall not have a pH value of less than 7.2, when tested using the electrometric method of pH determination in accordance with BS 1377-3.

Oxidisable Sulfides content shall be determined using the following relationships:

OS = TPS – AS

Where;
TPS = Total Potential Sulfate = 3 x TS
TS = Total Sulfur content
AS = Acid-soluble Sulfates
TS and AS shall be calculated in accordance with I.S. EN 1744-1.

2.2.1.3 Requirements Related to the use of Reclaimed Aggregates

Reclaimed aggregates may be incorporated within UGMs specified in this document. Reclaimed aggregates allowed for in this document shall only be derived from a combination of the following materials:

i. Concrete
ii. Bituminous Materials
iii. Unbound Granular and Hydraulically Bound Mixtures

Reclaimed aggregate content within the UGMs specified in this document shall meet the limits detailed in Table 2.2.

Table 2.2 Allowable reclaimed aggregate content within a UGM.

UGM A / Ac / Am	UGM B / Bc / Bm
% by mass	% by mass
≤ 30	No Limit

The quantity of specific types of material that may be incorporated within a UGM are detailed in Table 2.3, categorised as per I.S. EN 933-11.

Table 2.3 Allowable constituent contents of reclaimed aggregates portion of a UGM

Constituents	UGM A / Ac / Am	UGM B / Bc / Bm
	% by mass	% by mass
Rc - Concrete, concrete products, mortar Concrete masonry units	No limit	No limit
Ru - Unbound aggregate, natural stone Hydraulically bound aggregate	No limit	No limit
Ra - Bituminous materials	≤ 30	No limit
Rg - Glass	≤ 1	≤ 5
Rb - Clay masonry units (i.e. bricks and tiles) Calcium silicate masonry units Aerated non-floating concrete	≤ 1	≤ 2
X - Cohesive (i.e. clay and soil) Miscellaneous: metals (ferrous and nonferrous), non-floating wood, plastic and rubber Gypsum plaster	≤ 1	≤ 2
FL - Floating material	≤ 1	≤ 1

2.3 Mixture Composition

All UGMs shall be in accordance with the requirements of Table 2.4 and shall comply with the requirements of this Specification. The overall grading requirements for UGMs are provided in Table 2.5 and Table 2.6.

Table 2.4 UGM Requirements

Property	Mixture Type		Test Method
	UGM A / Ac / Am	UGM B / Bc / Bm	
Mixture Designation	0/31,5	0/31,5	-
Fines Content	UF_7	UF_9	IS EN 933-1
Oversize	OC_{80}	OC_{80}	IS EN 933-1
General Grading Curve	G_A	G_B	IS EN 933-1
Laboratory dry density and optimum water content	To be recorded		I.S. EN 13286-4 (Vibrating Hammer)
Frost Heave	Refer to 2.3.1		
Environmental Considerations	Refer to 2.3.2		

Table 2.5 UGM A / Ac / Am Overall Grading Requirement

Sieves for Grading / Fines Category	Sieve Size (mm)	Percentage by Mass Passing		
		Overall Grading Range	Supplier Declared Value Grading Range	Tolerance on the Supplier Declared Value
2D	63	100	No Requirement	No Requirement
D	31,5	80 – 99		
A	16	55 – 85	63 – 77	±8
B	8	35 – 65	43 – 57	±8
C	4	22 – 50	30 – 42	±8
E	2	15 – 40	22 – 33	±7
F	1	10 – 35	15 – 30	±5
G	0,5	0 – 20	5 – 15	±5
UF_7	0,063	0 – 7	No Requirement	No Requirement
Grading of individual batches – differences in values passing selected sieves				
Retained sieve size / Passing sieve size (mm)			Percentage by mass passing	
8/16			10 – 25	
4/8			10 – 25	
2/4			7 – 20	
1/2			4 – 15	

Table 2.6 UGM B / Bc / Bm Overall Grading Requirement

Sieves for Grading / Fines Category	Sieve Size (mm)	Percentage by Mass Passing		
		Overall Grading Range	Supplier Declared Value Grading Range	Tolerance on the Supplier Declared Value
2D	63	100	No Requirement	No Requirement
D	31,5	80 – 99		
A	16	55 – 85	63 – 77	±8
B	8	35 – 68	43 – 60	±8
C	4	22 – 60	30 – 52	±8
E	2	16 – 47	23 – 40	±7
F	1	9 – 40	14 – 35	±5
G	0,5	5 – 35	10 – 30	±5
UF_9	0,063	0 – 9	No Requirement	No Requirement
Grading of individual batches – differences in values passing selected sieves				
Retained sieve size / Passing sieve size (mm)			Percentage by mass passing	

Sieves for Grading / Fines Category	Sieve Size (mm)	Percentage by Mass Passing		
		Overall Grading Range	Supplier Declared Value Grading Range	Tolerance on the Supplier Declared Value
8/16			10 – 25	
4/8			10 – 25	
2/4			7 – 20	
1/2			4 – 15	

2.3.1 Frost Heave

UGMs shall not be frost susceptible if placed within 350 mm of the designed final surface of a road. Material shall be classified as non-frost susceptible if the mean heave is 15 mm or less, when tested in accordance with BS 812-124. Comparator specimens in accordance with Annex B of BS 812-124 shall be used.

2.3.2 Environmental Considerations

Where reclaimed aggregates are incorporated within a UGM, the UGM is required to meet the requirements related to the reuse or recycling of materials respectively defined by Article 27 (by product) and Article 28 (end of waste) as defined in European Union (Waste Management) Regulations, 2011 - 2020 (transposing EU law).

2.4 The Works

2.4.1 Construction

2.4.1.1 Transport

UGMs shall be protected from drying out and segregation both during transit to the point of delivery and tipping.

2.4.1.2 Laying

UGMs in a frozen condition shall not be incorporated in the Works but may be used, if acceptable, when thawed. UGMs shall not be laid on any surface which is frozen or covered with ice.

All UGMs shall be placed and spread evenly. Spreading shall be undertaken either concurrently with placing or without delay.

UGM layers up to a compacted thickness of 225mm shall be constructed through the spreading and compaction of the UGM in a single layer. UGM layers with a compacted thickness greater than 225mm shall be constructed through the spreading and compaction of the UGM layer in multiple layers. The minimum allowable compacted thickness of a UGM layer is 110mm.

2.4.1.3 Compaction

The UGM shall be laid and compacted at a moisture content within the range of the optimum to 2 percent below the optimum percentage determined in accordance with Table 2.4, and without drying out or segregation.

The material shall be maintained within the 2% moisture content range determined in accordance with Table 2.4 whilst awaiting overlaying.

Compaction shall be completed immediately after the mixture has been spread.

Full compaction shall be obtained over the full area including in the vicinity of both longitudinal and transverse joints.

The compaction equipment and the number of roller passes used in the construction of a UGM layer shall be such that the specified layer densities are achieved without damage to the pavement or the breakdown of the aggregate particles due to excessive compaction.

The procedure for the determination of the degree of compaction of a UGM layer and the assessment of its compliance with this specification is detailed in Section 2.4.2.1.

The surface of any layer of UGM material, on completion of compaction and immediately before overlaying, shall be well closed, free from movement under construction plant and free from ridges, cracks, loose material, pot holes, ruts or other defects. All loose, segregated or otherwise defective areas shall be removed to the full thickness of the layer, and new material laid and compacted.

2.4.1.4 Use of Surfaces by Construction Plant and Other Traffic

Construction plant and other traffic used on pavements under construction shall be suitable in relation to the UGM material used, the condition and thickness of the layers it traverses so that damage is not caused to the subgrade or the pavement layers already constructed. The wheels or tracks of plant moving over the various pavement layers shall be kept free from deleterious materials.

Where the Contractor proposes to traffic the UGM layers with construction plant, the layers shall be improved where necessary, to accommodate the method of construction and the type of plant and vehicles which he proposes to use, in order to avoid damage to the laid pavement layer(s), and the subgrade. Any permanent thickening shall be across the whole width of the pavement. An temporary improvement in pavement layers shall not impede drainage of any layer or the subgrade.

2.4.2 Works

The works performance requirements for a UGM layer are specified based on the layer design level used within the Irish Analytic Pavement Design Method (IAPDM). Design requirements using the IAPDM are provided in DN-PAV-03021 Pavement and Foundation Design.

The works requirements to be achieved by a UGM layer depending on the selected layer design level are summarised in Table 2.7.

Table 2.7 UGM Works Requirements per Design Level

IAPDM Material Design Level	Works Requirement	
	Compaction	Design Performance
1	Yes	No
2	Yes	Yes

2.4.2.1 Compaction

The compaction requirements for a UGM layer are detailed in Table 2.8. The relative compaction of the constructed UGM layer is the works performance characteristic specified.

The relative compaction of the layer shall be measured taking the field density and moisture content of the constructed layer using a Nuclear Density Gauge (NDG). Annex A details the procedure for the operation of the NDG device.

The UGM Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) shall be determined in the laboratory according to I.S. EN 13286-4 (Vibrating hammer) from samples of the placed material at least once per 1000m^2 or part thereof laid per day. This will be used to determine the relative compaction of the pavement layer.

Table 2.8 UGM Compaction Requirements

Parameter	Test Method	Test Frequency	Requirements	
Relative Compaction	Nuclear Density Gauge (See Annex A)	Minimum of 5 locations within each 1000 m^2 or part thereof laid each day	Average	≥ 97% MDD
			Single location	≥ 92% MDD

2.4.2.2 Design Performance

The design performance requirements for a UGM are specified through the selection of a works performance category within the IAPDM. Design requirements using the IAPDM are provided in DN-PAV-03021 Pavement and Foundation Design.

The stiffness of the constructed UGM layer is the works performance characteristic specified. The definitive method of determining in-situ surface modulus for a pavement foundation or part thereof is the Falling Weight Deflectometer (FWD). The performance categories for UGM layers are detailed in Table 2.9.

Table 2.9 UGM Works Performance Requirements - Design Level 2

Characteristic	Test Method	FWD Test Spacing	Requirements		
			IAPDM Performance Category	Surface Modulus (MPa)	
				Rolling Average*	Minimum
Layer Stiffness	Refer to Section 2.4.2.2.1	Seating drop + 3 drops at 25m station spacing in the left wheel path of each lane	S1	≥ 100	≥ 70
			S2	≥ 200	≥ 120
			S3	≥ 300	≥ 175

** Rolling average of 5 consecutive FWD stations*

2.4.2.2.1 FWD Testing

The FWD testing on UGM layers shall be carried out in accordance with CC-GSW-04009 Falling Weight Deflectometer Setup and Quality Assurance for Works Performance Assessment of Unbound Granular Mixtures, CC-GSW-04008 Guidelines for the Use of the Falling Weight Deflectometer in Ireland and AM-PAV-06050 Pavement Assessment, Repair and Renewal Principles.

The UGM layer constructed as part of the permanent Works shall be tested according to the procedures detailed in 2.4.2.1 in all instances and 2.4.2.2 for Design Level 2. The works requirements test results shall form part of the contractor's construction quality control records.

Where the permanent Works do not meet the requirements specified in Table 2.11, the non-compliant section of pavement layer shall be reconstructed.

2.4.2.3 Validation Trial Section

The Contractor shall undertake a validation trial of the pavement structure incorporating mixtures with design performance requirements to Design Level 2, proposed for use in the permanent Works. A trial area shall be constructed, tested and assessed in accordance with the procedures described in 2.4.2. Proposals for validation trial sections shall be submitted to the Employer's Representative five days in advance of construction.

The trial area shall be located on a formation prepared in accordance with the Specification. The trial area may be located so that it can be incorporated within the permanent Works.

The trial area shall be at least 100 m long and 4 m width. The pavement structure layers shall be compacted to the thicknesses specified in Appendix 7/1. The formation shall extend for a further 1 m either side of the pavement layers.

The mixtures used in the trial shall be transported, laid and compacted using the equipment proposed for use in the Works.

A report on the verification trial, stating how the use of the mixtures was validated shall be submitted to the Employer's Representative, who shall raise any objection within two working days of receiving the report.

Where the trial does not meet the works requirements specified, the design and construction process shall be reviewed and the trial area reconstructed until the works requirements are achieved or the pavement structure redesigned ensuring no impact on the overall scheme design or contractual evaluation.

2.4.2.4 Works Proposal

Prior to the commencement of the works, the Contractor shall submit a works proposal to the Employer's Representative which shall include:

i. Mixture proportions with supporting data from trial mix results and/or historic records to justify the proportions, the water content limits and (if applicable) spread rates for all stages of the Works.
ii. Laying and compaction procedures for each layer – including size, type and number of rollers and the method employed to ensure compaction;
iii. The joint formation procedures for each layer – including paving width, the location of longitudinal and transverse joint(s);
iv. Measures to address working in different climatic conditions.
v. How traceability of the material in the Works will be addressed.

The works proposal shall include a sample record sheet for the submission of the data required for reporting purposes as detailed in 2.4.2.5.

2.4.2.5 Reporting

Required information on the layers constructed shall be submitted to the Employer's Representative as soon as it becomes available. Information to be provided includes:

i. Compacted layer depth measurements;
ii. Field density measurements;
iii. Relative compaction determination;
iv. Works performance test results (when required);

v. Sampling and test locations;

vi. Construction period records showing the time(s) of water addition, mixing, completion of compaction.

3. Hydraulically Bound Mixtures

The properties of aggregates used in Hydraulically Bound Mixtures (HBM) shall comply with the selected requirements of IS EN 13242 as set out in this document.

The Contractor shall ensure that the manufacturer of HBMs has in place a system of factory production control that complies with the requirements of Annex C of I.S. EN 13242.

The Contractor shall also ensure that the manufacturer of HBMs has in place an environmental management system which is in compliance with ISO 14001.

HBMs shall be produced and constructed to conform to the selected requirements of I.S. EN 14227-1 and additional requirements as set out in this document.

3.1 Mixture Types

The HBMs considered within this specification are divided into the following categories:

3.1.1 HBM A - Hydraulically Bound Mixture A
3.1.2 HBM B - Hydraulically Bound Mixture B

HBM A shall comprise of one or a combination of the following materials:

i. Crushed rock aggregate
ii. Limited content of reclaimed aggregates

HBM B shall comprise of one or a combination of the following materials:

i. Crushed rock aggregate
ii. Crushed natural gravels
iii. Reclaimed aggregates

3.2 Constituent Materials

3.2.1 Aggregate

All aggregates incorporated within a HBM shall be in accordance with the requirements of Table 3.1 and shall comply with the requirements of this Specification.

Table 3.1 Requirements for Aggregates Used in HBMs

Property		Mixture		Test Method
		HBM A	HBM B	
		3.1.1	3.1.2	
Geometrical	Crushed or broken and totally rounded particles	$C_{90/3}$	C_{NR}	I.S. EN 933-5
	Shape of course aggregate - Flakiness Index	FI_{50}	FI_{NR}	I.S. EN 933-3
Physical	Resistance to fragmentation - Los Angeles test	LA_{50}	LA_{NR}	I.S. EN 1097-2

Property		Mixture		Test Method
		HBM A	HBM B	
		3.1.1	3.1.2	
Chemical	Acid-soluble sulfate content	$AS_{0.2}$		I.S. EN 1744-1
	Water-soluble sulfate (WS) content in mg SO_4 per litre	≤ 1500		
	Oxidisable sulfides (OS) content as SO_4	≤ 0.3%		Refer to 2.2.1.2

3.2.1.1 Requirements Related to the use of Reclaimed Aggregates

Reclaimed aggregates may be incorporated within HBMs specified in this document. HBMs incorporating reclaimed aggregates shall meet the requirements detailed in Table 3.2. Reclaimed aggregates allowed for in this document may be derived from a combination of the following materials:

i. Concrete
ii. Bituminous Materials
iii. Unbound Granular and Hydraulically Bound Mixtures

Table 3.2 Allowable reclaimed aggregate content within a HBM.

HBM A	HBM B
% by mass	% by mass
≤ 50	No Limit

The quantity of specific types of material that may be incorporated within a UGM are detailed in Table 3.3, and shall be categorised in accordance with I.S. EN 933-11.

Table 3.3 Allowable contents of constituents of reclaimed aggregates for HBMs

Constituents	HBM A	HBM B
	% by mass	% by mass
Rc - Concrete, concrete products, mortar Concrete masonry units	No limit	No limit
Ru - Unbound aggregate, natural stone Hydraulically bound aggregate	No limit	No limit
Ra - Bituminous materials	≤ 50	No limit
Rg - Glass	≤ 1	≤ 5
Rb - Clay masonry units (i.e. bricks and tiles) Calcium silicate masonry units Aerated non-floating concrete	≤ 1	≤ 2
X - Cohesive (i.e. clay and soil) Miscellaneous: metals (ferrous and nonferrous), non-floating wood, plastic and rubber Gypsum plaster	≤ 1	≤ 2
FL - Floating material	≤ 1	≤ 1

3.2.2 Binder

The binders used in HBMs specified in this document shall comply with the requirements set out in I.S. EN 197-1 for cement products.

3.2.3 Water

Mixing water must fulfil the requirements specified in I.S. EN 1008. Residual water may be used with hydraulic binder in accordance with the regulations in I.S. EN 206 and I.S. EN 1008.

3.3 Mixture Composition

3.3.1 Mixture Requirements

All HBMs shall be in accordance with the requirements of Table 3.4 and shall comply with the requirements of this Specification.

Table 3.4 HBM requirements

Property	Mixture Type		Test Method
	HBM A	HBM B	
Aggregate Size	0/20	0/20	I.S. EN 933-1
Grading Envelope	G1, Table 3.4	G2, Table 3.4	I.S. EN 933-1
Water Content	Refer to 3.3.2		
Binder Content	Refer to 3.3.3		
Laboratory Performance	Refer to 3.3.5		
Strength after Immersion	I_{80}		Refer to 0
Reclaimed Aggregate Constituents	Refer to 3.2.1.1		
Environmental Considerations	Refer to 3.3.4		
Laboratory Performance	Refer to 3.3.5		

Table 3.5 HBM aggregate grading envelopes (I.S. EN 14227-1)

Sieve (mm)	Percentage Passing by Mass		
	Minimum	Maximum Category G1 (HBM A)	Maximum Category G2 (HBM B)
31.5	100	-	-
20	81	100	100
10	55	83	88
6.3	42	70	77
4	31	61	69
2	21	48	58
0.5	11	28	36
0.25	8	21	29
0.063	3.5	11	18

3.3.2 Water Content

The optimal water content for the HBM to achieve the required laboratory performance shall be determined through the mixture design procedure detailed in Section 3.3.5.1.

3.3.3 Binder Content

The optimal binder content for the HBM to achieve the required laboratory performance shall be determined through the mixture design procedure detailed in Section 3.3.5.1.

Minimum binder contents are required to be met in addition to the laboratory performance requirements. The minimum binder content requirements are detailed in Table 3.6.

Table 3.6 Minimum Binder Contents per HBM Construction Method

Binder Constituents	Mix-in-plant method of construction using batching by mass (% by dry mass of mixture)	Mix-in-plant method of construction using volume batching and for mix-in-place construction (% by dry mass of mixture)
Cement	3%	4%

3.3.4 Environmental Considerations

Where reclaimed aggregates are incorporated within a UGM, the UGM is required to meet the requirements related to the reuse or recycling of materials respectively defined by Article 27 (by product) and Article 28 (end of waste) as defined in European Union (Waste Management) Regulations, 2011- 2020 (transposing EU law).

3.3.5 Design Performance

HBMs are required to meet laboratory design performance requirements as set out in this document. The performance requirements for a HBM are specified through the selection of a performance category for a HBM layer within the IAPDM. HBMs designed to either Design Level 1 or 2 are required to meet performance requirements. Design requirements using the IAPDM are provided in DN-PAV-03021 Pavement and Foundation Design.

The HBM performance category specifies the required laboratory performance characteristics of the HBM and the long term performance characteristics of the layer as modelled within the Irish Analytic Pavement Design Method (IAPDM).

The Design Level 1 and 2 IAPDM performance categories and related requirements are detailed in Table 3.7 and Table 3.8. HBM specimens for performance testing shall be prepared according to Table 3.9.

Table 3.7 HBM Laboratory Performance Requirements - Design Level 1

Characteristic	Test Method	Requirements	
		IAPDM Performance Category	Minimum
Compressive Strength (R_c)	IS EN 13286-41	C8/10	10 MPa
		C12/15	15 MPa
		C16/20	20 MPa

Table 3.8 HBM Laboratory Performance Requirements - Design Level 2

Characteristic	Test Method	Requirements	
		IAPDM Performance Category	Minimum
Modulus of Elasticity in Compression (E_c)	IS EN 13286-43	S1	20 GPa
		S2	28 GPa
		S3	33 GPa
Indirect Tensile Strength (R_{it})	IS EN 13286-42	F1	1.2 MPa
		F2	1.8 MPa
		F3	2.4 MPa

Table 3.9 HBM Specimen Laboratory Preparation

Design Level	Mechanical Performance Characteristic	Test Method	Specimens	Specimen Preparation	Curing Regime
1	Compressive Strength (R_C)	IS EN 13286-41	Cubes of 150mm dimension	IS EN 13286-51 Vibrating hammer compaction	20ºC for 28 days
2	Indirect Tensile Strength (R_{it}) Modulus of Elasticity in Compression (E_c)	IS EN 13286-42 IS EN 13286-43	Cylindrical diameter and height of 150mm		

3.3.5.1 Mixture Design

The proportions of the constituents within a HBM shall be determined through the mixture design procedure detailed here.

The relevant design level laboratory performance tests, detailed in Table 3.9, shall be carried out on a minimum of 6 different HBM mixtures comprising of 3 values of binder contents and 2 values of water content for each value of binder content. The optimum binder and water content is achieved where the minimum laboratory performance requirements (Section 3.3.5) and minimum binder content requirements (Table 3.6) are achieved.

In addition to meeting the performance requirements set out in Section 3.3.5, a HBM shall meet the strength after immersion requirement of 80%. The strength after immersion assessment shall be carried out using the relevant design level test methods listed in Table 3.7 or Table 3.8.

The strength after immersion in water shall be assessed by comparing the average strength and condition of:

i. 3 wet specimens initially cured in a sealed condition for 14 days at the test temperature; and then removed from their moulds and immersed in aerated water for 14 days at the same test temperature
ii. 3 dry specimens cured in sealed condition for 28 days at the same test temperature.

The immersed specimens shall be unconfined and have water in contact with all surfaces. On completion of the immersion stage of the test the specimens shall show no signs of cracking or swelling.

HBMs shall be tested at a temperature of (20 ± 2)ºC.

HBMs provided for within this specification are considered resistant to frost heave due to the minimum strengths required to be achieved.

3.4 The Works

3.4.1 Construction

HBM shall be produced and HBM layers constructed using one of the following methods:

i. mix-in-plant method of construction using batching by mass in accordance with 3.4.1.4;
ii. mix-in-plant method of construction using volume batching in accordance with 3.4.1.5;
iii. mix-in-place method of construction, in accordance with 3.4.1.6.

Mixtures used in base layers shall be batched by mass and paver laid in a single lift. Construction of bases by other methods shall only be permitted when alternative proposals are submitted to the Employer's Representative to address confined spaces where it is impracticable for a paver to operate.

Laying shall be carried out in a way that avoids segregation and drying of the surface. The temporary intermediate surfaces within a multiple lift layer shall be sprayed with water to prevent surface drying.

The minimum compacted lift thickness in a multiple lift layer shall be 150 mm. The maximum compacted lift thickness shall be 225 mm.

Making-up of level after initial compaction shall not be permitted for single lift working or the uppermost lift of multiple lift working.

The edge of previously compacted HBM or other material shall be vertical and straight before fresh HBM is laid against it.

Construction of layers, including multiple lift layers, and any reworking and reuse, shall be completed within a maximum construction period of 35 °C hours, initiated from the time of the addition of cement. The construction period in °C hours shall be calculated through the summation of the products of the period average air temperature above 3ºC and time for each period in hours.

The air temperature during the time interval shall not fluctuate by more than 4ºC.

Compaction of HBM layers, including the intermediate lifts of multiple lift working, shall be completed without drying out and before setting of any part of the layer and shall meet the compaction requirements detailed 3.4.2.1.

Compaction of HBMs shall be carried out by vibrating roller and/or pneumatic-tyred roller (PTR).

On completion of compaction the surface shall be closed, free from ridges, cracks, loose material, visible voids, ruts, shear planes and other defects. All defective areas shall be rectified within the construction period specified above. If rectification is not completed within the specified time period, the defective area shall be removed to the full thickness of the layer, and new mixture laid and compacted.

3.4.1.1 Cold and Wet Weather Working

During cold weather:

i. the temperature of HBM shall not be less than 5ºC at the time of laying;
ii. HBM shall not be laid on a frozen surface;
iii. laying of HBM shall cease when the air temperature falls below 3ºC, and laying shall not be resumed until the rising air temperature reaches 3ºC;

In the case of heavy or persistent rain, production shall cease and any laid material shall be compacted immediately.

3.4.1.2 Induced Cracking of HBM

The HBM layer shall have cracks induced during construction, as described in below, at a maximum longitudinal spacing of 3 m ± 5%.

Where HBM layers are constructed in widths exceeding 4.75m, longitudinal cracks must be induced, as described below, at not more than 4.75m centres. Longitudinal construction joints or induced cracks shall not be located more than 150mm from the lane line, or edge line marking. Longitudinal construction joints or induced cracks shall not be located within the left hand lane of dual carriageways. and where necessary may also be permitted within 150mm of the mid-point of the traffic lane.

Where the pavement is made up of two or more layers of HBM with induced cracks, the cracks in the overlying HBM layer shall align with the induced cracks in the layer below with a tolerance of ± 100 mm.

Cracks shall be induced in fresh material after initial compaction. The transverse cracks shall be induced by grooving the fresh material to form straight vertical grooves not more than 20 mm wide, to a depth of between one half and two thirds of the layer thickness over the full width of the pavement.

Bitumen emulsion shall be poured or sprayed into the grooves prior to final compaction, to form a crack inducing membrane. The bitumen emulsion shall comply with Class C40B4, as specified in Table 15, CC-SPW-00900. During final compaction of the mixture, the surface of the groove shall be fully closed throughout its full length. The bitumen in the groove shall be fully encased and remain continuous, with not less than 70% of the sides of the groove coated with bitumen, as determined by a trial procedure prior to commencement of operations.

3.4.1.3 Curing, Protection and Trafficking

On completion of compaction the layer shall be cured to prevent loss of moisture by:

i. application of a bitumen emulsion spray complying with Class C40B4, as specified in Table 15, CC-SPW-00900, to produce an even and complete coverage of at least 0.2 kg/m^2 of residual bitumen. Before spraying commences, the surface shall be free of all loose material and standing water. The curing membrane shall be protected from any damage until the construction of the overlaying layer;

ii. application of a mist/fog/light spray of water, sufficient to keep the surface continuously wet until the specified strength of the HBM has been developed or the layer is overlaid.

Trafficking of HBM layers shall comply with the requirements set out below. Should any HBM layer exhibit signs of damage, trafficking shall cease immediately and shall only be resumed once the layer has gained sufficient stability to resist damage.

HBM shall not be trafficked for 7 days unless test specimens made at the same time as the specimens required in 3.4.2.1.1 but cured under the same conditions as the in-situ HBM have achieved the specified performance requirements.

Surface contamination shall be avoided as far as is practicable and any unavoidable contamination shall be removed prior to overlaying. Reworking and re-compaction of the layer shall only be permitted within the construction period set out in Table 3.8. Reworking shall only be permitted when the water content requirements of the reworked material are maintained within the limits stated in the work proposal required under 3.4.2.5.

Before overlaying, any loose material shall be removed and replaced to the full depth of the layer or, if within the construction period set out in Table 3.8, reworked as specified above.

3.4.1.4 Mix-in-Plant Method of Construction Using Batching by Mass

The HBM shall be produced in a stationary mixing plant that batches by mass and mixes in a forced-action mixer, allowing sufficient time in the mixer to produce a homogenous mixture.

The mixing plant shall have an automated surveillance and data collection system.

HBM shall be transported directly to the point where it is to be laid in covered trucks and protected from the weather both during transit and whilst awaiting tipping.

3.4.1.5 Mix-in-Plant Method of Construction Using Volume Batching

The HBM shall be produced in a stationary mixing plant that batches by volume and mixes in a forced action mixer, allowing sufficient time in the mixer to produce a homogenous mixture.

HBM shall be transported directly to the point where it is to be laid and protected from the weather during transit and whilst awaiting tipping.

Dispensing accuracy shall be verified by reconciliation between constituent deliveries and the area and depth of completed layer for each 5000m^2 of work, or part thereof, during each day's operations.

3.4.1.6 Mix-in-Place Method of Construction

Mixed-in-place HBM shall be produced by an in-situ pulverizing-mixing process with the added mixing water injected directly into the mixture during the mixing process. The pulverizing-mixing process shall be repeated until a homogenous mixture is produced.

When binder constituents are dispensed onto the surface to be pulverized-mixed, the rate of spread shall be confirmed by site checks carried out in accordance with 3.4.2. For each group of 5 readings the mean rate of spread of material shall be within ±10% of the stated target rate and each individual value shall be within ±15% of the mean value of the group of 5 readings.

The accuracy of the system used to dispense binder constituents shall be verified by reconciliation between constituent deliveries and the area and depth of completed layer for each 5000m^2 of work, or part thereof, during each day's operations.

Mixing of fresh material shall ensure a minimum overlap of 200mm with previously mixed material.

3.4.1.6.1 Spread Checks for the Mix-in-Place Method of Construction

The rate of spread of added constituents shall be determined by weighing the amount of material retained on five trays (or mats) of known area laid in the path of the spreading machine. The trays (or mats) shall be positioned at points equally spaced along a diagonal line bisecting the area of coverage so as to assess the full width of discharge from the spreading machine.

3.4.1.6.2 Depth of Mixing for the Mix-in-Place Method of Construction

The depth of mixing shall be checked by excavation and inspection on completion of each stage of the pulverizing-mixing process. The depth of mixing shall be referenced to the design levels for the pavement by precise levelling of the HBM to ensure that the level at the underside of the stabilised layer is in accordance with the specified requirements.

3.4.1.7 Joints

Where HBM placed either side of a joint is within the maximum construction period, the material shall be compacted in a single operation providing continuity of the HBM across the joint.

Where HBM at a joint is outside of the maximum construction period, the material shall be cutback to a vertical face of fully compacted HBM and the required layer thickness. The vertical face shall be protected as detailed in 3.4.1.3. The existing layer shall not be compacted when material is laid against it.

Longitudinal joints in HBM base layers shall not be positioned beneath the wheel track zone of the finished pavement surface.

3.4.2 Works Requirements

The works performance requirements for a HBM layer are specified based on the layer design level used within the Irish Analytic Pavement Design Method (IAPDM). Guidance on the IAPDM is provided in DN-PAV-03021 Pavement and Foundation Design.

The works requirements to be achieved by a HBM layer depending on the selected layer design level are summarised in Table 2.7.

Table 3.10 HBM Works Requirements per Design Level

IAPDM Material Design Level	Works Requirement	
	Compaction	Design Performance
1	Yes	No
2	Yes	Yes

3.4.2.1 Compaction

The compaction requirements for a constructed HBM layer are detailed in Table 3.11. The relative compaction of the layer is the layer characteristic specified.

The field density and moisture content of the constructed layer shall be tested using a Nuclear Density Gauge (NDG). Annex A details the procedures for the operation of the NDG device.

The OMC and Maximum Wet Density (MWD) of the HBM shall be determined in the laboratory according to I.S. EN 13286-4 (Vibrating hammer) from samples of the placed material at least once per 1000m^2 or part thereof laid per day. This MWD shall be used to calculate the relative compaction of the HBM layer.

Table 3.11 HBM Compaction Requirements

Parameter	Test Method	Test Frequency	Requirement	
Relative Compaction	Nuclear Density Gauge (See Annex A)	Minimum of 5 locations within each 1000 m^2 or part thereof laid each day	Group Average	≥ 95% MWD
			Single Location	≥ 92% MWD

3.4.2.1.1 Test Locations and Sampling

Locations for in-situ tests or material sampling of the constructed layer shall be equally spaced along a diagonal line that bisects the area of work being assessed.

Bulk samples of HBM shall be taken from the full layer depth and shall not be mixed with other bulk samples.

3.4.2.2 Performance Design

HBM layers designed to either design levels 1 or 2 are required to meet performance specifications as set out in this document. The performance requirements for a HBM layer are specified through the selection of a works performance category within the IAPDM. Guidance on the IAPDM is provided in DN-PAV-03021 Pavement and Foundation Design.

The performance categories and related performance requirements for HBM layers are detailed in Table 3.12 and Table 3.13.

Bulk samples of the HBM from the laid material shall be used to prepare specimens for performance testing. Specimens for performance testing shall be prepared according to Table 3.9.

Table 3.12 HBM Works Performance Requirements - Design Level 1

Characteristic	Test Method	Test Frequency	Requirement		
			IAPDM Performance Category	Single Location	Group Average
Compressive Strength (R_c)	IS EN 13286-41	Minimum of 5 locations per 1000m² or part thereof laid each day	C8/10	≥ 6.7 MPa	≥ 10 MPa
			C12/15	≥ 10 MPa	≥ 15 MPa
			C16/20	≥ 13.4 MPa	≥ 20 MPa

Table 3.13 HBM Works Performance Requirements - Design Level 2

Characteristic	Test Method	Test Frequency	Requirements		
			IAPDM Performance Category	Single Location	Group Average
Indirect Tensile Strength (R_{it})	IS EN 13286-42	Minimum of 5 locations per 1000m² or part thereof laid each day	S1	≥ 13.4 MPa	≥ 20 MPa
			S2	≥ 18.7 MPa	≥ 28 MPa
			S3	≥ 22.1 MPa	≥ 33 MPa
Modulus of Elasticity in Compression (E_c)	IS EN 13286-43	Minimum of 5 locations per 1000m² or part thereof laid each day	F1	≥ 0.5 MPa	≥ 0.8 MPa
			F2	≥ 1.1 MPa	≥ 1.7 MPa
			F3	≥ 2.0 MPa	≥ 2.8 MPa

3.4.2.3 Non-Compliance

The HBM pavement layer constructed as part of the permanent Works shall be tested according to the procedures detailed in 3.4.2.1 and 3.4.2.1.1. The works requirements test results shall form part of the contractors construction quality control records.

Where the permanent works do not meet the requirements of the UGM specified, the non-compliant section of pavement layer shall be reconstructed.

3.4.2.4 Validation Trial Section

The Contractor shall undertake a validation trial of the pavement structure incorporating mixtures with design performance requirements to Design Level 2. A trial area shall be constructed, tested and assessed in accordance with the requirements described in 3.4.2. Proposals for validation trials shall be submitted to the Employer's Representative five days in advance of construction.

The trial area shall be located on a formation prepared in accordance with the Specification. The trial area may be located so that it can be incorporated within the permanent Works.

The trial area shall be at least 100m long and 4m width. The pavement structure layers shall be compacted to the thicknesses specified in Appendix 7/1. The formation shall extend for a further 1 m either side of the pavement layers.

The mixtures used in the trial shall be transported, laid and compacted using the equipment proposed for use in the Works.

A report on the verification trial, stating how the use of the mixtures was validated shall be submitted to the Employer's Representative, who shall raise any objection within two working days of receiving the report.

Where the trial does not meet the works requirements specified, the design and construction process shall be reviewed and the trial area reconstructed until the works requirements are achieved or the pavement structure redesigned if there is no impact on the contractual evaluation and site constraints such as limits related to the road geometric alignments.

3.4.2.5 Works Proposal

Prior to the commencement of the works, the Contractor shall submit a works proposal to the Employer's Representative which shall include:

i. Mixture proportions with supporting data from trial mix results and/or historic records to justify the proportions, the water content limits and (if applicable) spread rates for all stages of the Works.
ii. Laying and compaction procedures for each layer – including size, type and number of rollers; the number of roller passes or other method employed to ensure compaction e.g. by continuous monitoring of density with a non-destructive gauge.
iii. Procedures to ensure adequate bond between layers where multiple lifts are to be constructed.
iv. Induced crack formation procedure for each layer.
v. The joint formation procedures for each layer – including paving width, the location of longitudinal and transverse joint(s); and the method(s) of treating upstanding edges.
vi. Measures to address working in different climatic conditions.
vii. How traceability of the material in the Works will be addressed.

The works proposal shall include a sample record sheet for the submission of the data required by 3.4.2.6.

3.4.2.6 Reporting

Required information on the layers constructed shall be submitted to the Employer's Representative as soon as it becomes available. Information to be provided includes:

i. Binder spread rate/batching record results;
ii. Compacted layer depth measurements;
iii. Field density test measurements;
iv. Relative compaction determinations;
v. Works performance test results;
vi. Sample and test locations;

vii. Construction period records showing the time(s) of mixing, water addition, completion of compaction and application of curing membrane.

Annex A:

Determination of Field Density and Moisture Content using a Nuclear Density Gauge

Annex A (normative) – Determination of Field Density and Moisture Content using a Nuclear Density Gauge

A1 Apparatus

1. Calibrated nuclear gauge
2. Steel drill pin and hammer
3. Drill pin template
4. Calibration results
5. Dry fine sand

A2 Procedure

1. The direct transmission method of Nuclear Density Gauge (NDG) operation shall be used to determine the field density of the compacted layer.
2. The test shall take place at least 7m away from other nuclear gauges and 1.5m away from large structures.
3. The pavement layer surface on which the test shall take place and the NDG will sit shall be smooth, level and free from depressions.
4. Create a probe hole to the required depth in the pavement layer using the template as a guide. Mark the outline of the template on the pavement surface to allow for accurate positioning of the NDG on the layer surface and probe extension into the probe hole.
5. Place the gauge on the test site and ensure that there is good contact between the base of the gauge and the material being tested. Where small voids exist on the test area a small quantity of fine sand may be used to improve the NDG seating. The addition of fine material should not create a new, separate layer beneath the NDG.
6. Once the NDG is positioned correctly at the test location, the probe shall be extended into the probe hole.
7. A field density and moisture density measurement as per the manufacturer's handbook shall then be initiated.
8. Once the measurement is complete, the probe shall be fully retracted.
9. The field density and moisture density reading shall then be read from the gauge and recorded.
10. A test at a single location shall consist of at least three measurements at 120° to each other using the same NDG device.

A3 Calculation of the Test Results

Field Density

The field density measurements shall be adjusted using the calibration charts.

The field density test result shall be taken as the average of the two higher results.

Water Content

Calculate the water content, w, as a percentage (%), using the equation:

$w = 100W/(\rho - W)$

where:

W is the moisture density, i.e. the mass of water per unit volume of material determined with the nuclear gauge;

ρ is the bulk density of the material, in megagrams per cubic metre (Mg/m^3), determined with the nuclear gauge.

Test Report

The test report shall contain the following information:

1. the field density of the material, in megagrams per cubic metre (Mg/m^3), to the nearest 0.01 Mg/m^3;
2. the water content as a percentage to two significant figures;
3. the test location and test number;
4. the time-lapse between completion of compaction and the time at which the in-situ density was determined.

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