National Roads Authority
An tÚdarás um Bóithre Náisiúnta

NRA Interim Advice Note

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on

Low-Energy

Pavements

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Summary:

This Interim Advice Note sets out advice and specification on the use of low-energy materials for the maintenance of road pavements carrying less than 5 MSA for a 20 year design. The materials involved are hydraulically bound mixtures using cement and bitumen-bound materials using foamed bitumen or bitumen emulsion. These materials may be produced with both recycled and virgin aggregates.

This document will not be issued as an NRA DMRB standard and NRA MCDRW specification until greater experience of the techniques involved has been gained in this country.

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Low-Energy Pavements

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0 Background

Introduction

0.1 The intention of this Interim Advice Note is to allow the use of low-energy pavements to be offered as an option on suitable road schemes in Ireland. Initially, the option will be limited to roads carrying up to 5 million standard axles (msa) for a 20 year design life.

0.2 Schemes that are considered appropriate will then be offered with alternative design thicknesses, based on the subgrade CBR values found, for the structural layers in:

- Traditional hot mix asphalt to the NRA Specification for Road Works;
- Hydraulic bound cold mix; and
- Bitumen bound (emulsion or foam) cold mix.

0.3 In order to allow use of these materials on relatively small jobs, the requirements are drafted based on the assumption that the aggregate will be reclaimed asphalt (taken from the site and/or other sites and stockpiled) and/or virgin aggregate. However, the reuse of asphalt reclaimed directly from the site is permitted provided there sufficient time between reclaiming the asphalt and using it as a component material to check the validity of the mix design with it as a component material.

0.4 The advice in this Interim Advice Note is primarily taken from TRL Report TRL611 (Merrill *et al*., 2004), from which further advice can be obtained.

Sustainable construction practices

0.5 The need and desire for change to the methods and materials used for construction and maintenance has accelerated in the last two decades. The major instigator was the Rio Earth Summit in 1992 (Keaton, 1993) that elevated sustainable development to the forefront of government policy.

0.6 The Irish Government objective for our transport system is that it should provide the choice, or freedom, to travel but to minimise any damage to the environment. In designing for construction projects, the way in which materials are specified is changing to allow for innovation and alternatives to the use of primary aggregates newly extracted from a quarry. For instance, specifications can be based upon performance rather than on the use of standard materials made to strict recipes and design procedures can be introduced to permit many options to be considered rather than demanding combinations of strengths and layer thicknesses that limits the choice to new materials. A comprehensive sustainability strategy requires considering the use of all resources (including aggregates, binders and fuel) alongside engineering requirements in the selection of construction techniques.

0.7 The use of low-energy pavements should now be a major construction activity. Variants of hot and cold techniques are now all feasible and many large and specialist contracting organisations can offer these services. Cold mixtures can contribute to a reduction in energy, fuel and material consumption. The lower mixing temperatures reduce the energy required to produce these materials compared to conventional hot bituminous materials. Significant savings can also be made in reduced transport and demand for virgin aggregate.

Potential uses of low-energy pavements

0.8 Provided that the low-energy pavement can achieve the desired performance, the potential use of low-energy materials is not limited. However, there are general details that need consideration at each site.

0.9 Each site needs to be evaluated for the most appropriate maintenance in terms of:

- Location;
- Proximity of suitable location for setting up ex situ plant;
- Proximity of source(s) of alternative materials, if required;
- Type(s) and severity of deterioration;
- Extent of deterioration;
- Location of services within the pavement construction;
- Condition of drainage; and
- Edge detail and verge condition.

Families of low-energy material

0.10 There is a wide range of low-energy materials that can be allocated into material families. The principal binders for these materials are Portland cement; other hydraulic binders; foamed bitumen; and bitumen emulsion.

0.11 A versatile design methodology will permit a wide range of aggregate types to be used in low-energy pavements; however, the stabilising agents are likely to be the dominant component in terms of the overall performance characteristics of a given mixture. Materials bound with Portland cement are expected to cure more quickly than materials with other types of hydraulic binder, and visco-elastic materials (foamed bitumen or bitumen emulsion) are likely to be less prone to shrinkage cracking than hydraulically bound materials. It is, therefore, practical to define material families based upon the characteristics of the stabilising agents.

0.12 A ternary diagram, based on three distinct material types, can be used to classify materials into families, as shown in Figure **Error! Reference source not found.**.1. The apexes of this diagram correspond to fully hydraulic bound, fully visco-elastic bound and unbound material. Low-energy materials using combinations of binder and curing behaviour can be characterised by areas within this chart. Four material types that fall into three material families are illustrated on this chart. These are classified according to the primary binder type and their rate of curing. The four materials are defined as:

- Quick Hydraulic (QH) with hydraulic only binder(s) including cement;
- Slow Hydraulic (SH) with hydraulic only binder(s) excluding cement;
- Quick Visco-Elastic (QVE) with bituminous and hydraulic binder(s) including cement; and
- Slow Visco-Elastic (SVE) with bituminous only or bituminous and hydraulic binder(s) excluding cement.

QH and SH are hydraulic bound mixture families and QVE and SVE are bitumen bound families. The SH family is excluded from the designs given in this Interim Advice Note.

Aggregate sources

0.13 Reclaimed asphalt is often stockpiled prior to use. The extent to which the material is separated into aggregate type and size before stockpiling will affect the extent of subsequent processing that may be needed for particular uses. In such allocation, reclaimed asphalts from different layers are likely to have different aggregate types and sizes. If the material allocated to stockpiles are not selected and the material taken from stockpiles are not processed before use, the material in the stockpile will need to be thoroughly mixed before a representative grading or other properties can be determined.

0.14 Aggregate freshly dug from a quarry (virgin aggregate) can be used. The grading and other properties for use in the design will be as given on the CE Mark for the aggregate.

0.15 Reclaimed asphalt from site can be used, but there needs to be sufficient time between extraction and undertaking the main works to allow the relevant properties for the mix design to be confirmed. If the existing materials on the site were not laid at the same time and from the same source, the reclaimed asphalt is likely to have different aggregate types and sizes. However, if a long section of road is known to have consistent asphalt layers, it becomes practicable to design a mixture with that reclaimed asphalt.

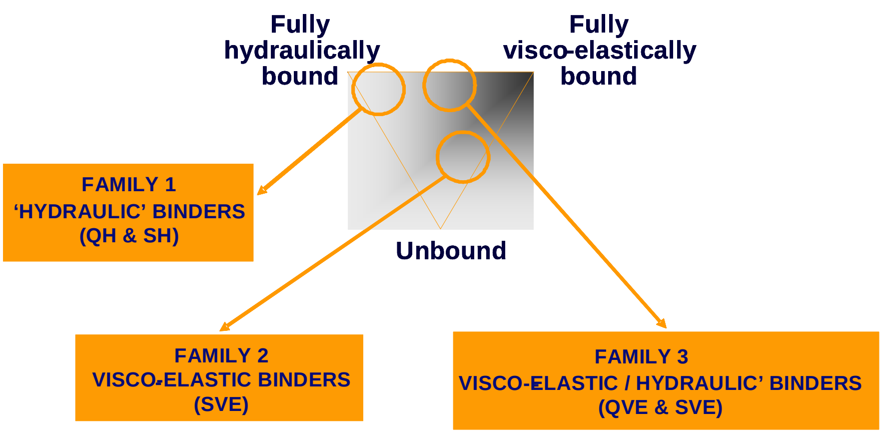

Figure Error! Reference source not found.**.1: Identification of material families**

1 SITE EVALUATION

Assessment of pavement deterioration

1.1 A site may be identified for maintenance following an assessment of the pavement condition. The maintenance needs of the pavement can range from a remedy for substandard functional characteristics of the pavement such as ride quality to structural maintenance. The cause of the deterioration of the pavement must be identified through an appropriate combination of visual survey, local knowledge, and structural evaluation in order to address the cause as part of the solution. Particular attention should be given to the destructive effect of inadequate drainage.

1.2 Where pavement deterioration is identified as being a failure in the road haunch, the site assessment should be carried out in accordance with the advice contained in the following documents.

- Road Haunches: A Guide to Maintenance Practice (TRL, 1994).
- Practical Guide to Haunching (County Surveyors Society, 1991)
- Road Haunches: A Guide to Re-useable Materials (Potter, 1996)

1.3 If the deterioration in the pavement can be remedied by the replacement of the surfacing, a rehabilitation treatment of the pavement using low-energy pavement materials is not appropriate.

1.4 Where structural maintenance is required, or replacement of the binder course layer, a rehabilitation treatment of the pavement using low-energy pavement materials should be considered as an alternative to traditional re-construction using hot mixed materials.

Traffic assessment

1.5 A pavement must be designed so that it can carry the traffic over the whole of the design period, whatever the form of construction. Traffic can be described in terms of a cumulative number of equivalent 80 kN standard axles. A method of calculating design traffic for maintenance purposes is described in the NRA Design Manual for Roads and Bridges (DMRB 7.2.1).

1.6 For the purposes of designing low-energy materials, six road categories are used. These road categories are defined in terms of million standard axles (msa) in Table 1.1 and will be maintained to describe the pavement design options for pavements comprising low-energy materials.

1.7 The pavement designs using low-energy materials are currently restricted to Types 2b, 3 and 4 roads. For these categories, the increased risk of failure with more economic pavements incorporating low-energy materials is balanced by the more limited consequences of such failures.

Table 1.1: Road type categories

Road type category	Design traffic (msa) for a 20 year design life
0	Roads carrying over 30 to 80 msa
1	Roads carrying over 10 to 30 msa
2a	Roads carrying over 5 to 10 msa
2b	Roads carrying over 2.5 to 5 msa
3	Roads carrying over 0.5 to 2.5 msa
4	Roads carrying up to 0.5 msa

1.8 The road type category initially directs the designer to use the appropriate design methodology and later to select the appropriate design thicknesses.

Evaluating the suitability of low-energy treatments

1.9 The suitability of low-energy treatments depends on a large number of factors. The chief criterion for the selection of rehabilitation treatments will be an economic one. However, if low-energy treatments are uneconomic compared to treatments using conventional hot mix materials, the case for low-energy pavements may still be viable provided that there is an appropriate policy for low-energy and recycling treatments as part of a wider sustainability campaign.

1.10 The economic analysis of treatments comprising low-energy material should be based on a whole life cost approach. This whole life cost approach should include the present cost of performing the treatment as well as all other discounted future maintenance costs associated with this treatment within a specified analysis period. In order to compare with conventional treatments, a default analysis period should be 20 years although longer periods could be selected dependent on the local policy or the nature of the treatment. For example, a full-depth reconstruction may need to be assessed over 40 years to be compared with long-life fully-flexible pavements.

1.11 As part of the economic assessment, the determination of initial costs of the treatments is required. For a maintenance scheme where low-energy treatment is a consideration, the initial costs are likely to be highly scheme specific. The method of estimating initial costs will include:

- The size of the maintenance scheme and the amount of low-energy material that is expected to be required. It is likely that the economic use of low-energy treatment of a road pavement will be highly influenced by economies of scale. Some low-energy methods will involve the mobilisation of a substantial amount of plant. As a rough guide, a minimum programme of work in the order of 3,000 m^2 is estimated to be an economic threshold.
- The availability of raw recycled aggregates, both from within the maintenance scheme and also from other locally won materials. The cost of low-energy recycling can increase if there is insufficient raw materials from within the scheme or if raw aggregates are required to be transported over long distances.
- Where a treatment comprising low-energy materials cannot be accommodated within the existing pavement thickness, adjustment of the drainage and other street furniture will need to be considered. If the finished level cannot be raised to accommodate the new pavement design, it may be possible to process some of the existing foundation material into the low-energy material; such a procedure could introduce cohesive material that will require modification prior to stabilisation.

1.12 The suitability of low-energy processes for maintenance is closely tied in with the likely performance of the resulting material and the consequential pavement design. Thus the economic assessment of a low-energy scheme must be allied to a robust pavement and material design.

1.13 Long detour routes may require that the road is reopened immediately after construction to prevent excessive user delays. As a result, a high demand may be required of the performance of low-energy materials at an early stage. For these reasons, special care should be taken in order to ensure that the mix design has adequate mechanical stability in early life. One test that could be used to show the mechanical stability of low-energy material is the Immediate Bearing Index as described in IS EN 13286-47.

1.14 The location, condition and construction of the existing pavement will have a significant bearing on the methods of assessment as well as the contract details such as job size and job risk. An assessment of the pavement support as well as the suitability of materials from the existing pavement may be required.

Assessment of the suitability of materials

1.15 For any assessment related to the design of recycling works, it is particularly important that any sample of aggregate obtained is fully representative of the aggregate to be used in the low-energy pavement. The sample can be obtained as a mixed sample or in separate components, for recombining later in appropriate proportions. Furthermore, test specimens should ideally be representative of the aggregate obtained by pulverisation or planing, for both grading and particle shape.

1.16 However, the design process may rely on test specimens derived from samples crushed in the laboratory because actual pulverised aggregate may not generally available during the pre-contract investigation. A variety of laboratory crushing methods are currently available, although none are believed to be specifically designed to recreate the pulverised aggregate produced by a recycler or planer. Guidance should be sought from the plant manufacturer on the most appropriate method of crushing material in the laboratory to simulate the performance of their plant.

1.17 The method of sampling material from the existing pavement should consider the condition of that pavement. Three basic conditions of existing pavements have been defined (Milton and Earland, 1999) with each condition associated with a level of uncertainty. As uncertainty increases, the operations proposed for sampling material increase; the proposals are reproduced in Table 1.2.

Table 1.2: Site investigation requirements for low-energy projects including requirements where material in the existing pavement is to be re-used

Pavement Type	Fieldwork proposals	Sampling and testing
Designed pavement structure comprising standard materials of known thickness and consistency	Excavate trial pits at a target frequency of 1 per 200 m in each of the lanes to be recycled, with a minimum of three pits for any scheme. Record details of each construction layer, including any unbound foundation. Obtain separate representative samples of each distinct material. Determine the nature and condition of the subgrade and obtain a measure of bearing strength.	Collect sufficient representative material from each construction layer to produce a 100 kg bulk sample comprising proportionally recombined mixture of materials from all trial pits. Use bulk sample for design and trial mix tests.
Designed pavement structure comprising standard materials of known thickness and consistency - but with reinstatement of openings or pavement repairs that could locally affect the consistency of the pulverised aggregate.	As above. Plus one trial pit or full-depth 200 mm diameter core from each distinct reinstatement/repair that has an area greater than 25 m^2 or extends full width for more than 5 m in any lane. Plus minimum of one full-depth 200 mm diameter core from smaller, closely spaced and recurrent areas of reinstatements, where their combined area locally, accounts for more than 20 % of the paved area in any lane.	As above, with additional representative bulk samples from each distinct area of reinstatement/repair, used to produce additional recombined bulk samples to assess any mixture design changes that may be needed in these areas.
Undesigned pavement structure comprising a variety of standard and/or non-standard materials built over time by maintenance processes, in layers/zones of unknown thickness or continuity.	Carry out an initial evaluation by extracting full-depth 200 mm diameter cores at target frequency of 1 per 100 m in each lane to be recycled. If materials are consistent proceed with design using the material from the cores as the test samples. If pavement structure is inconsistent, carry out further investigations to try to determine the extent and/or thickness changes of the different materials. As an alternative to widespread coverage of further cores, traverses of ground penetrating radar may be found useful to reveal thickness and profile changes, to help divide the site into reasonably consistent sections and target the position of trial pits and/or further cores. Investigate each section using a minimum of three trial pits or three sets of three full-depth 200 mm diameter cores, dispersing evenly throughout the section, with at least one trial pit or core in each lane to be recycled. Obtain representative samples from each layer from each section.	Visually assess the material retrieved from the initial cores to decide on the consistency of materials. For a consistent material profile use the materials from the cores to produce a proportionally representative 100 kg bulk sample for overall design and trial mix tests. For inconsistent material profiles, collect sufficient representative material from each construction layer in each of the defined sections to produce 100 kg bulk samples comprising proportionally recombined mixtures of materials from each section. Use bulk sample from each section for separate design and trial mix tests.

Assessment of the suitability of materials from an existing pavement

1.18 The assessment of the suitability of materials in existing pavement structures will only be required if it is anticipated that the low-energy materials will contain aggregate from the existing structures. Where required, the assessment is likely to be carried out at the same time as the assessment of pavement support using invasive procedures. If this is not possible, an alternative method of obtaining material for the assessment should be investigated such as a limited coring survey.

1.19 In all other respects, the assessment of the suitability of materials from an existing pavement should be the same as the assessment of the suitability of materials from existing stockpiles.

Risk assessment

General

1.20 The use of low-energy techniques for pavement maintenance involves particular risks that may not be encountered with other types of maintenance. Site specific and material specific risks will be encountered which will need to be considered prior to commencement of the works. These risks are often difficult to quantify in terms of any standard measure, but their consideration and equitable allocation will be vital if the low-energy operations are to be completed to the satisfaction of both contractor and client. Ignorance of these risks could lead to economic losses and/or a poor product and it is recommended that both the Client as well as the Contractor should be aware of the risks associated with low-energy processes at a particular site to prevent unnecessary negative outcomes on maintenance schemes.

1.21 In all types of construction work, even where comprehensive site evaluation has been carried out, there will always remain those sites where unsuspected situations arise. However, for certain types of recycling works, such situations are more likely to play a part in the final outcome.

1.22 To offset this risk, greater understanding through a shared risk approach should be accepted for low-energy operations. For sites where ex situ materials are to be laid, the Contractor will usually supply the main aggregate and, therefore, the risk is similar to other conventional material supplies. When existing pavement materials are being used, both parties in the contract are given the opportunity to satisfy themselves and agree that these materials in the sections of the works defined by the contract are capable of being recycled to form the main aggregate component of the low-energy mixture. In general, the Client is responsible for ensuring that the contracting partner has sufficient capability to obtain the main aggregate and material components of sufficient quantity and quality so that the recycled mixture is capable of being designed and produced to meet the specified end-product performance requirements.

1.23 For sites where the existing pavement materials are to be used in the low-energy material, the Client is normally expected to organise and implement the site investigation works separately, as part of the general design process for the purposes of competitive tender arrangements. In these circumstances, if risk is to be shared, the investigation must be comprehensive, and offer all potential contractors suitable data for designing and programming their individual method of working, appropriate to the particular site conditions.

1.24 The risks associated with any particular pavement recycling scheme will need to be included in any whole-life cost analysis.

1.25 Risks can be broadly classified into design risks and construction risks. The design risks are associated with the pavement design in terms of the expected performance on the structure and mix design risks in terms of the expected performance on the recycled material. Construction risks are encountered during the preparation of the site for laying recycled materials as well as the production, transporting and laying of recycled material.

Pavement design risks

1.26 Pavement design is the process of selecting materials and construction thicknesses in order to ensure that the pavement structure will carry the expected traffic for a given period of time. It relies upon the assumption that the construction process will provide expected long-term properties of the material in layers that are of sufficient thickness.

1.27 A comprehensive site investigation needs to be carried out to minimise the risks in the calculation of the design of the pavement structure, including a detailed subgrade study looking at such aspects as moisture, density and strength of the subgrade where these properties need to be taken into account in the design process. The properties of subgrade may be variable and, therefore, the investigation should be detailed enough to detect significant changes; a pavement design based upon an insufficient site investigation that did not detect weak areas in the subgrade could adversely affect the performance of the low-energy pavement structure.

1.28 The fatigue life of strongly cemented pavements is highly sensitive to thickness and stiffness. It is imperative that the expected long-term properties of the material and the pavement thickness design are monitored at construction in a reliable fashion otherwise substantial reductions in performance may occur. Also, the type of binders used in the low-energy mixture will affect the workability and setting time. Such considerations are important in being able to achieve the specified layer density; density is the key factor in ensuring that the long-term performance assumed in the design is achieved.

1.29 The binder content will also influence the stiffness and strength of the low-energy mixture. An inadequate quantity of binder may lead to the material being susceptible to moisture. Increasing the quantity of bituminous binders could lead to premature deformation problems while increasing the quantity of quick setting cementitious binders increases likelihood of thermal cracking.

Mix design risks

1.30 The mix design is principally performed as an essential input to the pavement design process. As such, the risks for mix design will have a significant impact on the risks associated with pavement design.

1.31 The principle feedstock of aggregate for the mix design process should be the same feedstock of aggregate for the permanent works. If sufficient aggregate from the same source as for the permanent works is not available, the mix design should be performed on an aggregate as close as is reasonably possible to the aggregate in the permanent works. A degree of caution should be applied to the results of this mix design process because these can be highly influenced by the nature of the aggregate involved.

1.32 Recycled aggregates from existing roads containing multiple layers may be more variable in quality and type than those from a single layer because there is effectively more than one source. Where possible, the mix design stage should take into account this variability by varying the proportions of recycled aggregate from each layer.

Construction risks

1.33 Construction of a pavement comprising low-energy materials is dependent on a large number of linked processes.

1.34 The compaction of low-energy material is one of the most critical parts of the construction procedure; it can be influenced by the duration between mixing and laying of the material, moisture content and the selection and use of compaction plant. The Contractor should be aware of the workability of the material and manage the construction processes so that delays are minimised; some slow curing low-energy materials are more workable and tolerant of delays than quick curing materials. Delay after mixing the material or poor selection or use of compaction equipment may lead to a substantial loss of serviceability of the finished pavement due to reduced levels of compaction and consequential loss of durability in the material.

1.35 The risk of causing nuisance and possible risk to health by dust must be assessed when a pulverisation process forms part of the maintenance scheme, particularly in urban areas. In addition, the effects from the use of pulverisation plant and large compaction plant need to be considered and monitored if works are adjacent to underground services and buildings or other structures likely to be damaged by high amplitude vibrations.

Underground services and other hazards

1.36 It is vital to accurately locate and record the depth of all underground services because of their disruptive potential within recycling works, particularly if disturbed or damaged. If a pipe or cable lies within 150 mm of formation level, it should be deemed at risk, particularly if the services are old. It is prudent, therefore, to consult with the Statutory Undertakers at an early stage of the design process. Additional enquiries and investigation will probably be needed to establish the location and depth of service connections to adjacent properties, because these connections are often unrecorded and are at a shallow depth in relation to the depth of the mains supply. If premature deterioration of the existing road has been caused by damaged or defective services, any such problem should be remedied before or as part of the pavement renovation contract.

1.37 Care must be taken to locate and avoid existing road furniture, such as man-hole covers, because collision with these items during pulverisation may cause serious damage to the plant and delay the works.

2 MIX DESIGN

General requirements for aggregate

2.1 The aggregate for low-energy material can come from the pulverised material from existing roads that have been stockpiled or from freshly-won aggregate; alternatively, other approved aggregate types may be used from other sources.

2.2 The source and stock of the aggregate for recycling is a key factor in the decision about material composition and the construction process. A fine grained aggregate may be more suitable to hydraulic binders whilst certain types of aggregate may prove incompatible with certain bituminous binders.

Aggregate grading

2.3 Three grading envelopes are shown in Figure 2.1:

- Zone A Suitable for all low-energy materials;
- Zone B Finely graded aggregate only suitable in certain circumstances; and
- Zone C Coarse grading that is only suitable for in situ stabilisation.

The details of the grading requirements for these zones are given in Table 4.1.

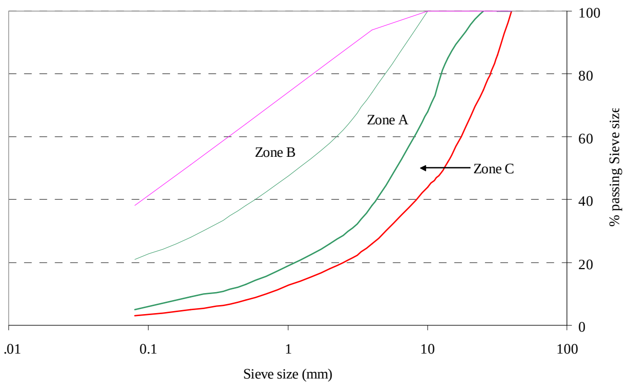

Figure 2.1: Grading curves for low-energy mixtures

2.4 Materials that are in Zone C have a greater risk of segregation and their use is excluded.

2.5 Bitumen bound material is highly sensitive to the fines component of the material. For low-energy materials, bitumen has a tendency to be attracted to the fine aggregate particles before coating the coarser fractions of aggregate so that the amount of fine material passing the 63 µm sieve is restricted to between 5 and 20 %. Coarse material that cannot be modified to meet the desired grading can be augmented with suitable filler materials such as pit sand or PFA. Zone B should not be used with bitumen bound mixtures.

Moisture content

2.6 The moisture content of a low-energy material has a large influence on the workability of the material; in particular, it can control the degree of compaction that may be achieved. The optimum moisture content is the natural selection as target moisture content.

2.7 For recently reclaimed asphalt, the target moisture content will depend, to a certain extent, on the moisture content reached in the road. Due to the effect of variable moisture content in the road, the target moisture content of the mix can be slightly dry of optimum.

Portland cement

2.8 Portland cement is used to a lesser or greater degree in Quick Hydraulic (QH) materials and Quick Visco-Elastic (QVE) materials; it is the key component that ensures the materials are classified as quick curing.

2.9 The primary reason for the use of Portland cement is to provide a material that gains strength quickly at reasonable cost. Portland cement is a widely used road construction binding agent that can be used with a wide range of aggregate types (including pulverised aggregates). It is relatively tolerant of poor weather conditions because it cures quickly. It is also tolerant of some plastic or organic material in the mixture.

2.10 Care should be taken in the design of materials comprising Portland cement. Whilst its use has clear advantageous effects, mixtures with a high proportion of cement will have a risk of thermal cracking.

Other hydraulic binders

2.11 Granulated blast furnace slag (GBS) and Ground granulated blast furnace slag (GGBS) are by-products of the steel industry. These materials are formed by rapid cooling of molten slag in water. GGBS is a fine material that can be used to substitute for a proportion of Portland cement. GBS is a coarse material that could be used to form more of the aggregate skeleton of the mix; GBS can also be used as a binder if crushed in the presence of lime or sulphate.

2.12 Pulverised fuel ash (PFA) is a by-product from the burning of fuels in power stations and has been used in road construction for many years. It is a very fine grained material and can be used to modify the amount of fine materials in the mix. The use of PFA in preference to Portland cement creates a slower curing material in which diffuse cracking rather than large cracks develop. The long-term properties of a mixture containing PFA are likely to be similar to the equivalent mixture containing Portland cement.

Foamed bitumen

2.13 Foamed bitumen can be used with a variety of combinations of other binders to produce fully-flexible pavement structures. When used with other hydraulic binders, it could be viewed as a hybrid material: neither bituminous nor hydraulic. Foamed bitumen binders are used to produce both QVE and SVE material families; QVE materials also include a proportion of Portland cement.

2.14 Foamed bitumen is produced by the injection of 1 to 2 % cold water with air into hot penetration grade bitumen. This process produces a high-volume, low viscosity fluid with low surface tension; these properties enable the foamed bitumen to coat a wide range of moist, cold and recycled aggregates.

2.15 The foaming temperature or water content has an influence on expansion ratio (volumetric fluid expansion after foaming) and bubble life; high temperatures and water content increases the expansion ratio but reduces bubble life. The choice of bitumen grade is a compromise between foaming ability and stiffness; higher penetration bitumen foams easily but has lower stiffness.

2.16 Materials bound with foamed bitumen, on its own or with lime and PFA, are highly workable; they can be stock-piled or reworked if necessary up to 48 h after production. This feature indicates that the material is slow curing; indeed, the long-term performance of these materials is reliant on the slow curing properties. Provided that the material is sufficiently compacted, it can normally be opened to a moderate degree of traffic after one day.

2.17 For an increased rate of curing, foamed bitumen can be combined with Portland cement or other hydraulic binder. Increased curing may be required when the chosen binder/aggregate combination does not generate early-life stiffness or when more demanding traffic conditions are encountered. The balance between foamed bitumen and some hydraulic binders can be a compromise between early life performance and the risk of thermal cracking.

Bitumen emulsions

2.18 Bitumen emulsions are widely used in road construction in a range of applications from tack coats to surface dressings. They are also used as a bituminous binder for cold mixed materials including those in cold-mix recycling.

2.19 An emulsion is a system comprised of two immiscible liquids, the one dispersed in the other, in the form of fine globules or droplets. Bitumen emulsion is generally an oil-in-water type of emulsion in which the bitumen (the oil) is dispersed in water and held in suspension by means of one or more emulsifying agents. This process produces a low viscosity fluid at low temperatures that is suitable for coating cold and recycled aggregates. Compaction of the mixture accelerates the rate of development of cohesion by laminating the bitumen globules and squeezing out the water. Bitumen emulsion is readily combined with hydraulic binders but care should be taken to prevent stripping problems by the selection of an emulsion that it is compatible with the aggregate.

2.20 The early life and long term properties of mixtures with bitumen emulsion are similar to those with foamed bitumen.

Other components

2.21 Other components that are covered are principally lime, although particular material components are not excluded provided that their value in road construction can be demonstrated.

2.22 Lime (quick lime or hydrated lime) is used as both a modifier and an activator of certain hydraulic components. Lime can create weak bonds between recycled aggregate particles and can be used to reduce the plasticity of aggregate containing plastic or organic elements. Lime can improve the adhesion properties of the aggregate with bituminous binder.

Guidance on the selection of material family

2.23 Quick curing materials achieve their optimal properties fairly early in their life. Such materials are suited to locations where there are demands to open the pavement quickly and/or the traffic intensity will be high.

2.24 Slow curing materials offer increased workability and a reduced risk of material performance being adversely affected by delays during construction. Slow curing materials can be suitable for locations where there is a traffic demand in early life provided that the material has adequate mechanical stability.

2.25 Low-energy materials can perform well under early-life trafficking provided that the materials are not damaged through permanent deformation or cracking. Permanent deformation occurs where the traffic stresses exceed the internal friction or strength of the material, when the material is said to be unstable. For some materials, cracks that have occurred in early-life can be healed if significant curing occurs after the cracks were initially formed. Quick curing materials are at risk of damage during early-life trafficking due to cracking; deformation should be prevented by adequate stability. Slow curing materials are at risk of damage during early-life trafficking due to deformation; cracks that occur in early-life are likely to be healed during the slow curing process.

2.26 The selection of either hydraulic or visco-elastic materials remains largely an economic decision. However, aggregates whose grading contains a high proportion of fine material may be unsuitable for the production of low-energy materials.

Mix appraisal and design

General

2.27 The mix design stage should be fully documented and used as part of the compliance procedure in the permanent works.

2.28 Advice is given on the mix design process on the treatment of the different families in the Notes for Guidance section of the specification. Therefore, it does not form part of the contract requirements but the end product requirements (which state that the work carried out in the mix design stage must be followed) will form part of the contract. The Contractor has some freedom to choose the method and detail of the mix design stage as agreed with the Client. The method of acquiring the results of the mix design needs to be recorded for insertion into the Material Quality Plan.

2.29 The mix design stage should be as detailed as is economically feasible. The greater investment in the mix design stage, the less the risk will be at construction stage.

Material conditioning in the laboratory

2.30 The design and specification of low-energy material is based upon the one year or long-term performance of the materials. In order to obtain these estimates of performance in the laboratory, some form of sample conditioning is required. When a material is described as quick-curing, it can develop stiffness or strength rapidly and assurance of its long-term characteristics can be obtained in a relatively short time. Such behaviour has been traditionally exploited for specification of Portland cement bound materials.

2.31 Many materials cure at a slower rate and it is not possible to provide assurance of the long-term properties of the materials in the traditional manner. In order to obtain a reliable estimate of the long-term properties, there should either be a defined progression of performance from short to long-term or an accelerated curing regime implemented that reliably predicts the long terms properties of the material. The wide spectrum of materials that are covered in this guide does not allow for a defined progression of performance to be assumed; there is, therefore, a requirement to cure the material in some accelerated manner to provide a more reliable assurance of its long-term properties.

2.32 Accelerated curing is achieved by raising the temperature of the environment surrounding the material to increase the rate of chemical reaction in the sample. Curing at elevated temperatures can affect the type of chemical reaction in the sample and it is, therefore, preferable to use a temperature for curing that is as close as possible to the temperature that would be encountered in the pavement.

2.33 The specification does not prescribe the method to use but simply advises on the most applicable regime in the Notes for Guidance. A summary of the advised conditioning regimes is shown in Table 2.1. A curing regime for SVE material is provided only when it contains a pozzolanic component; otherwise a high curing temperature is required to generate some form of curing in early life. Curing at such temperatures is not encouraged for prediction of long-term performance, but may be suitable only for establishing a provisional mix design.

Table 2.1: Laboratory conditioning regimes and factors to relate to long-term performance

Family	Temperature (°C)	Duration (days)	Long-term Factor
QH	20	28	1.2
QVE	20	28	1.2
QVE*	40	28	1.0
SVE	–	–	–
SVE*	40	28	1.0

* for materials containing a pozzolanic binder

2.34 The long-term factors shown in Table 2.1 are used to provide an estimate of the performance of low-energy materials after approximately one year. The pavement designs given in Section 3 are based upon the properties of low-energy material at one year. Therefore, the conditioning regimes described in Table 2.1 can be used with an appropriate laboratory test procedure to give confidence, at an early stage, that the properties assumed to design the pavement are likely to be achieved. The long-term factors are conservative but other factors may be used with appropriate supporting evidence.

3 PAVEMENT DESIGN

Full depth or partial depth pavement design

3.1 Low-energy materials can be utilised in a pavement structure in two ways:

- The low-energy materials can form the layer immediately above the foundation and is covered by a bituminous surfacing.
- Low-energy materials can be used as a substitute for conventional hot mix material for inlay treatments where a significant proportion of the existing pavement remains to form part of the rehabilitated pavement.

3.2 This Section includes mutually exclusive methods to perform pavement design for both situations. Current NRA policy is to proceed with trial projects following the first of these methods, as described in paragraphs 3.3-3.21. Once experience is gained using this method consideration may be given to extending the use of low energy materials to the second category using the method described in paragraphs 3.22-3.25.

Pavement design for full depth low-energy pavements

Background

3.3 The design of pavements comprising low-energy material follows the Versatile Pavement Design methodology. This method uses a single pool of input data from which separate design criteria are applied depending on whether the base comprises a hydraulically bound or bituminous bound material. Figure 3.1 gives an illustrative view of the pavement design process for low-energy materials.

Definitions

3.4 In the context of structural maintenance of road pavements using low-energy materials, whilst carrying out the same function, a standard pavement layer may be constructed significantly differently to that of the same layer in a new pavement. Therefore, the broader definitions applicable to this design guide are:

Subgrade: Underlying natural soil or rock. However, in the situations where the subgrade is weak or there is insufficient depth to the existing pavement, the upper layer of the subgrade may be stabilised using the in situ recycling technique and incorporated as part the foundation platform.

Formation level: Immediately below the sub-base layer and at the top of the subgrade or capping layer.

Foundation: The support to the overlying pavement layers that serves as a platform to construct the structural course. It includes the sub-base, subgrade and the capping layer if required. For maintenance purposes, this layer will normally comprise the undisturbed lower sections of the existing pavement. In situations where there is insufficient depth of existing pavement to satisfy the current design or where other circumstances dictate, this platform may be constructed, in part or whole, using low-energy material.

Structural course: The main stress distribution layer within the pavement whose thickness is dependent on stiffness of the material itself, stiffness of the underlying structure and the anticipated traffic loading. This layer will normally comprise low-energy material, but where there is insufficient depth of existing pavement and the in situ recycled material is used to form the foundation platform, it may comprise in part or whole, new plant mixed material. This layer is often called the base.

Surfacing: The upper layer or layers of the road, designed to provide an even surface with a high resistance to deformation and an adequate resistance to skidding.

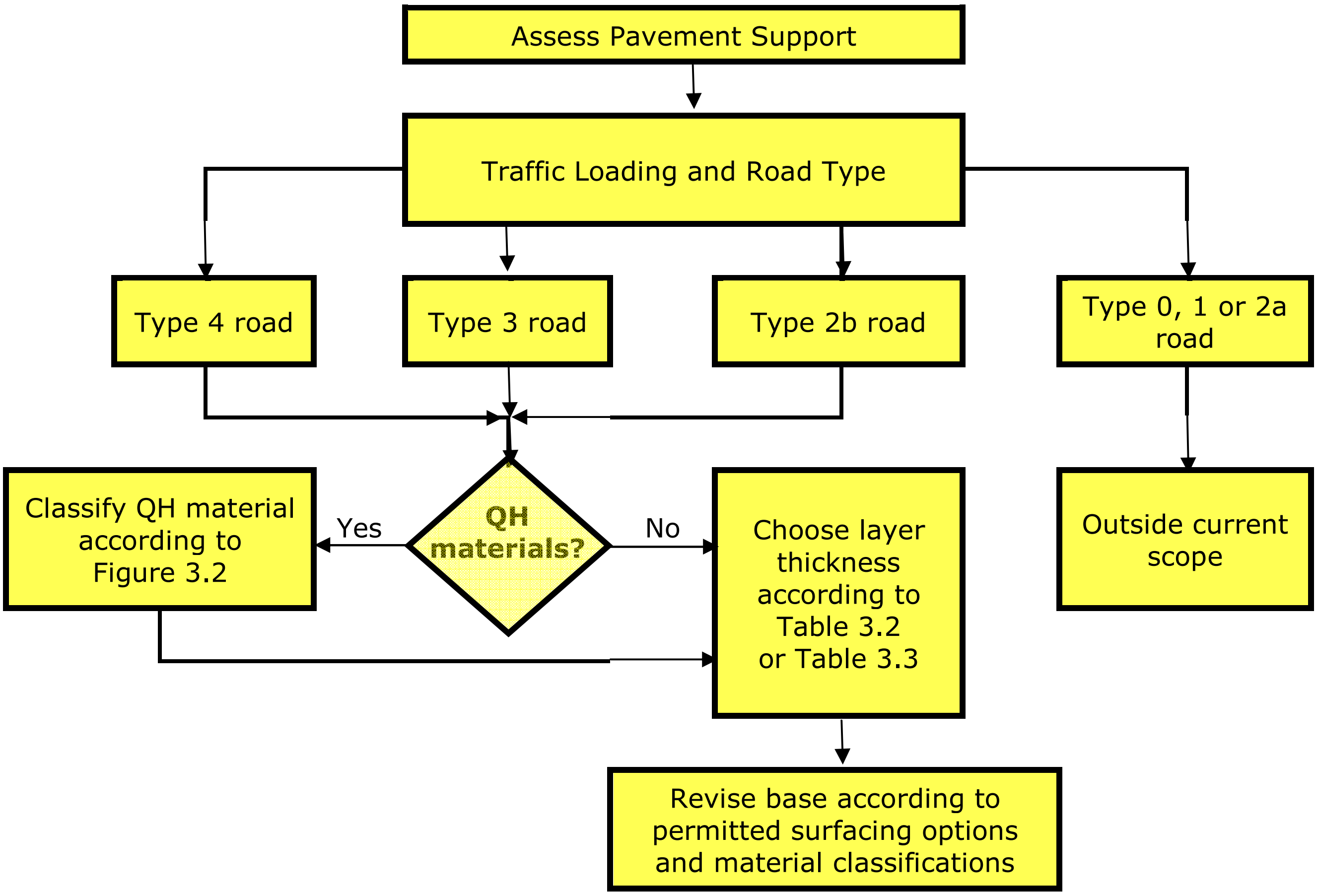

Figure 3.1: Full depth pavement design process for low-energy materials

Pavement support

3.5 The foundation layer of a pavement performs two main functions: to allow the construction of the overlying pavement and to provide support to the pavement throughout the life of the pavement. The scope of this design guide is not to design the foundation but to characterise the foundation in order to design the overlying pavement. As such, it is assumed that the foundation design is sufficient to carry the construction traffic to build the pavement layers.

Hydraulically bound low-energy structural course

3.6 The design method for pavements comprising hydraulically bound structural courses has two stages: material classification and thickness design. Hydraulically bound materials are classified into one of nine zones labelled H1 to H9.

3.7 The combination of stiffness and strength is imperative for the design of a hydraulically bound structural course. Two different hydraulically bound materials can have the same base thicknesses for a given level of traffic, provided their flexural strengths compensate for any differences in their levels of stiffness. If stiffness is increased, the traffic induced tensile stresses in the structural course, which influence performance, also increase. Therefore, the strength would need to be higher to achieve the same performance. Relationships between elastic stiffness modulus and flexural strength have been developed for equivalent performance and grouped into nine zones. These are shown for materials of stiffness between 5 GPa and 60 GPa in Figure 3.2.

3.8 The star illustrates that a material with elastic modulus of 20 GPa and a flexural strength of 0.9 MPa falls into material Zone H3. Classification of materials according to Figure 3.2 requires that the elastic modulus and tensile strength are known. Generally, these values are not directly measurable and need to derived as follows:

i) Using compressive strength tests in accordance with IS EN 13286-41 (CEN,

2003) and using relationships from Croney *et al*. (1997):

$$E_{dyn} = \frac{\log R_f + 0.773}{0.0301} \quad [3.1]$$

$$R_f = 0.11 R_c \quad [3.2]$$

ii) Using the indirect tensile strength and static stiffness in accordance with IS EN 13286-42 (CEN, 2003).

$$E_{dyn} = 8.4 + 0.93 E_S \quad [3.3]$$

$$R_f = 1.33 R_{it} \quad [3.4]$$

where E_{dyn} is elastic dynamic stiffness in GPa,

E_S is the static stiffness in GPa,

R_f is the flexural strength in MPa,

R_c is the compressive strength in MPa,

R_{it} is the indirect tensile strength in MPa.

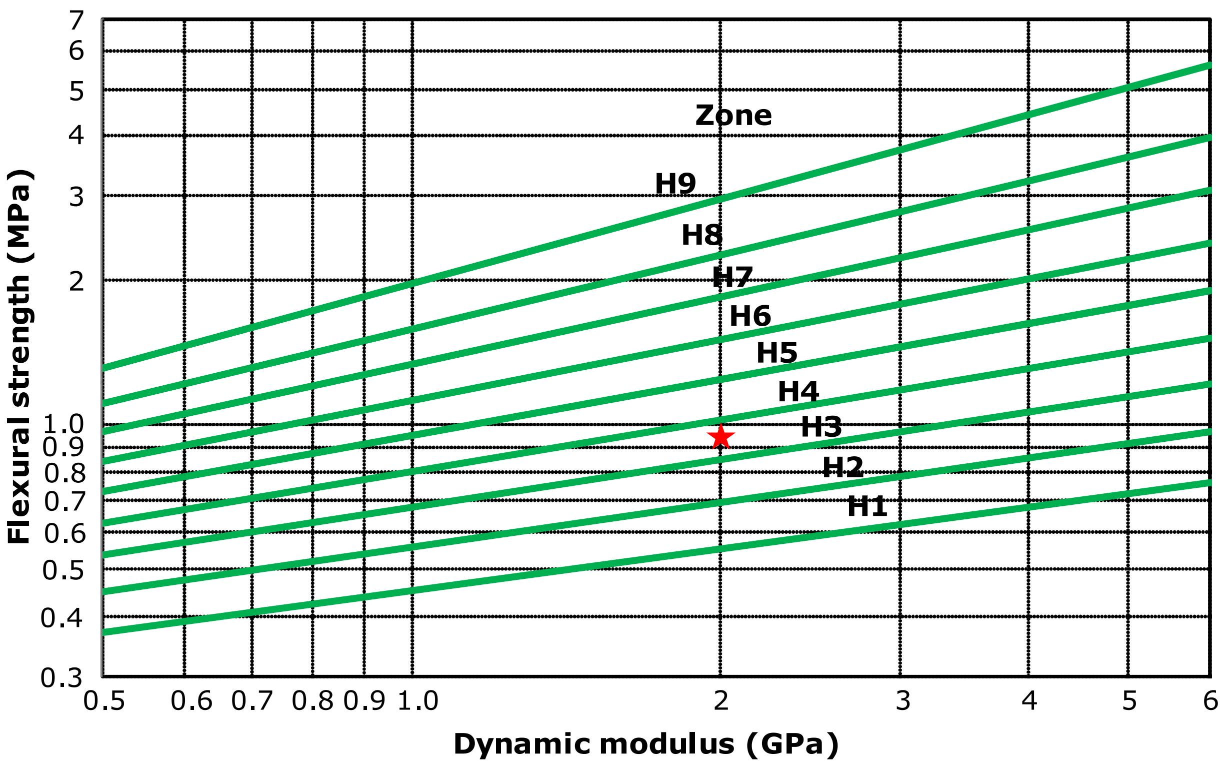

Figure 3.2: Performance classifications for hydraulically bound low-energy materials

3.9 For roads carrying up to 5 MSA with hydraulically bound material, the target is to achieve a material in zone H5.

Bitumen bound low-energy structural courses

3.10 The design method for pavements comprising bitumen bound structural courses has two stages: material classification and thickness design. Bitumen bound materials are classified into one of three zones labelled B1, B2 and B3. Once classified, the designer selects the appropriate thickness design chart for the foundation class; the thickness for the design traffic can be determined for the curve associated with the material zone.

3.11 Bituminous bound low-energy structural courses cover a wide range of material compositions. They may contain cement in the case of QVE type materials or other binders. Ex situ foam mix material has been found to be not unduly susceptible to fatigue (Nunn and Thom, 2002) and, therefore, can be expected to perform in a similar fashion to conventional hot mixed bituminous material. In the absence of any evidence to suggest otherwise, the entire family of bituminous bound structural courses, when used as described elsewhere in this document, are expected to perform in a similar fashion to conventional bituminous materials.

3.12 Care should be taken not to have too high a cement content because that may change the material from a flexible material to a flexible semi-rigid material.

3.13 Table 3.1 specifies a minimum long-term (one year) stiffness for each class which should be demonstrated in the specification using the laboratory conditioning regimes defined in Table 2.1.

Table 3.1: Bitumen bound low-energy material classification

Bitumen bound low energy zone	Minimum long-term stiffness
B1	1900 MPa
B2	2500 MPa
B3	3100 MPa

Pavement designs

3.14 Low volume roads (Type 2b, 3 and 4) can be designed from the formation level with the structural contribution of the sub-base layer incorporated into an increased thickness of low-energy structural course from the traditional design (Merrill *et al*., 2004). There is no evidence to suggest that these designs have not performed well and, therefore, they have been maintained for all low-energy materials covered within this IAN. These designs cover a range of surfacing options from surface dressing up to a cover of 100 mm of hot-mixed bituminous material.

3.15 Tables 3.2 and 3.3 show the thickness design of low-energy structural courses (incorporating the foundation platform). Alternative surfacing options allow for a reduction in the thickness of the low-energy layer for a compensating increase in surfacing thickness.

3.16 These designs incorporating structural and foundation layers were proposed assuming minimum performance requirements for strength and stiffness; the equivalent minimum requirements are:

- hydraulically bound material should be Type H5 or superior (Figure 3.2)
- bitumen bound material should be Type B1 or superior (Table 3.1)

3.17 For hydraulically bound materials classed as H1, H2, H3 or H4, the following adjustments in Table 3.4 can be applied to the thickness of the materials in Tables 3.2 and 3.3. For example, for a Type 3 road with subgrade CBR of between 5 % and 7 %, a hydraulically bound material of Class H4 with a layer thickness of 250 mm (220 x 1.13) with a 40 mm surfacing can be used. Some combinations of material quality and subgrade strength will require layers that are too thick for use with this approach.

Table 3.2: Thickness of pavements using hydraulically bound low-energy materials (QH) as the combined structural course

Subgrade CBR (%)	Thickness of low-energy material (mm)								
	Type 2b road			Type 3 road			Type 4 road		
<2	n/r	n/r	n/r	n/r	n/r	n/r	n/r	n/r	n/r
2*-4*	n/r	300	240	280	240	180	240	200	150
5*-7	n/r	280	220	260	220	160	220	180	150
8-14	n/r	270	200	240	200	150	200	160	150
>15	n/r	250	200	220	180	150	190	150	150
Surfacing thickness (mm)	**Surface dressing**	**40**	**100**	**Surface dressing**	**40**	**100**	**Surface dressing**	**40**	**100**

n/r: not recommended

* Weak sub-grades may be susceptible to damage during construction, particularly in poor weather, and will require measures to ensure that they do not become degraded.

Table 3.3: Thickness of pavements using bitumen bound low-energy materials (QVE and SVE) as the combined structural course

Subgrade CBR (%)	Thickness of low-energy material (mm)								
	Type 2b road			Type 3 road			Type 4 road		
<2	n/r	n/r	n/r	n/r	n/r	n/r	n/r	n/r	n/r
2*-4*	n/r	n/r	n/r	n/r	310 (n/r)	250	320 (n/r)	280	195
5*-7	n/r	n/r	n/r	330	290	230	300	260	185
8-14	n/r	n/r	300	315	275	215	285	245	160
>15	n/r	n/r	270	285	245	185	255	215	150
Surfacing thickness (mm)	**Surface dressing**	**40**	**100**	**Surface dressing**	**40**	**100**	**Surface dressing**	**40**	**100**

n/r: not recommended (including where a recommended value is given that is greater than 300 mm and is, therefore, unsuitable for use in situ)

* Weak sub-grades may be susceptible to damage during construction, particularly in poor weather, and will require measures to ensure that they do not become degraded.

Table 3.4: Adjustments for Hydraulically Bound Materials H1 to H4

Material	Thickness Adjustment
H1	1.66
H2	1.45
H3	1.28
H4	1.13
H5 or superior	1.0

3.18 The asphalt thicknesses shown in Tables 3.2 and 3.3 have been defined so that there is a minimal risk of reflection cracking. It is possible to reduce the thickness of asphalt cover with a corresponding increasing in the thickness of hydraulically bound layer without compromising the bearing capacity of the structure; however, such action could increase the risk of reflection cracking occurring in the asphalt layer.

3.19 Many slow-curing materials are thought to give a low risk of reflection cracking due to the diffuse nature in which naturally forming shrinkage cracks occur; however, such materials are currently excluded from the scope of this document. Hydraulically bound materials that cure quickly are most likely to produce wide, naturally formed shrinkage cracks; for such materials, the substitution of asphalt for hydraulically bound material should be avoided.

3.20 All permitted alternatives are subject to a 150 mm minimum layer thickness of cold recycled material and a maximum thickness of 300 mm is recommended.

3.21 Designs are not provided for weak subgrade conditions that may give inadequate resistance to damage by construction traffic or may not provide the necessary support for adequate compaction of the cold recycled layer. Methods for dealing with weak subgrade conditions can be found in the NRA Design Manual for Roads and Bridges (DMRB 7.2.2).

Treatment design for partial depth inlay using low-energy materials

Design methodology

3.22 Paragraphs 3.3 to 3.21 cover pavement designs comprising low-energy materials for the pavements layers from the foundation upwards. Such designs are applicable to new construction and full-depth reconstruction. Some maintenance treatments for fully-flexible roads do not require the complete replacement of the pavement layers, particularly for thick bituminous roads. Therefore, an alternative treatment design procedure is proposed that still utilises significant amounts of low-energy materials.

3.23 The design methodology described is based upon long-term design stiffness for ex situ cold recycled materials. The method of equivalent thickness (Ullidtz, 1987) can be used to compare the adequacy of a rehabilitated layer using low-energy material compared with that of a conventional hot mix material, such as a dense asphalt concrete, using a structural equivalence number (SEN). The structural equivalence number is calculated using Equation 3.6 using the parameters given in Table 3.4.

$$SEN = \sum_i h_i E_i^{1/3} \qquad [3.6]$$

where I = layer identifier

h = thickness of the layer (m)

E = Design stiffness of the layer (MPa)

Table 3.4: Long-term design stiffness for bitumen bound material

Material Description	Design Stiffness (MPa)
Surfacing	2000
Low-energy material Class B1	1900
Low-energy material Class B2	2500
Low-energy material Class B3	3100
New hot-mixed asphalt	3100
Existing asphalt base material*	3100

* The design stiffness may be augmented by values obtained from laboratory testing on in situ material.

3.24 Using standard designs for full depth constructions using conventional hot mix material, the criterion for the minimum SEN for designing a partial depth treatment comprising low-energy materials is given in Table 3.5. A minimum thickness of asphalt surfacing is required to concur with the requirements for full depth reconstruction option in Tables 3.2 and 3.3. For cases where a hydraulically bound mixture (HBM) base layer exists, alternative SEN are given; for these cases, the structural contribution of the HBM layer is not accounted for in the SEN calculations.

3.25 The minimum requirements for the SEN shown in Table 3.5 have been deduced using an 85 % probability of survival. For less important roads, a lower probability appropriate to the performance of the road should be used. Table 3.6 gives factors that can be applied to the SEN for different probabilities of survival. For a 70 % probability of survival, the minimum SEN requirement for a Road Type Category 2 will be 4.0 x 0.9 = 3.6.

Table 3.5: Minimum required SEN for partial depth inlay

Road Type Category	Minimum SEN	Minimum SEN (HBM Base)	Minimum surfacing thickness (mm)
0	5.7	2.6	100
1	4.8	2.4	100
2a, 2b	4.0	1.9	50
3	3.2	1.2	Surface dressing
4	2.5	0.2	Surface dressing

Table 3.6: Factors to be applied to SEN requirements

Probability of survival (%)	Factor
85	1.0
70	0.9
60	0.8

4 SPECIFICATION OF LOW-ENERGY BOUND MATERIAL

General

4.1 Low-Energy Bound Material (LEBM) comprises base and binder courses produced in a fixed or mobile mixing plant from graded aggregate processed from quarried sources or arisings from the excavation of roads and similar sources, blended if necessary with other aggregate and bound with hydraulic or bituminous binders, separately or in combination. The pavement shall comply with the NRA Specification for Road Works as further extended by the following requirements which cover three generic material families: Quick Hydraulic (QH), Quick Visco-Elastic (QVE) and Slow Visco-Elastic (SVE). The Slow Hydraulic (SH) family is deliberately excluded. The primary binder of these families of materials shall be as follows:

QH: CEM I (Portland cement) as the main hydraulic component and excluding bituminous binders.

QVE: Bituminous binder as the main component but also including CEM I (Portland cement).

SVE: Bituminous binder as main component but excluding CEM I (Portland cement).

4.2 LEBM shall be designed to achieve the specified level of the appropriate end performance property

Construction options

4.3 Where options for hot mix asphalt, QH cold mix material and QVE/SVE cold mix materials are offered, the option to be undertaken shall be declared before construction of the road pavement starts.

Ground conditions

4.4 The CBR of the subgrade onto which the LEBM is to be placed shall be measured at regular intervals of not less than 200 m but not less than two measurements per site. The spacing measurements shall be reduced when the results are variable, with a minimum spacing of one every 60 m when the values are very variable. When the values obtained are less than those assumed in the pavement design, the required thickness of bound material shall be re-calculated and the thicknesses increased as appropriate.

Quality plan

4.5 Ex situ LEBM shall be produced in plants that have an independently accredited IS EN ISO 9001 Quality Management System. The ISO 9001 Certificate scope shall include this activity.

Sourcing of aggregate

4.6 The Contractor shall submit a quality plan which shall contain details of all aggregates to be used in the LEBM. Aggregate may include:

i) asphalt, concrete or granular material planed or excavated from roads or other paved areas and stockpiled;

ii) primary or secondary aggregate from other sources;

iii) fillers from primary or secondary sources (e.g. PFA);

iv) asphalt, concrete or granular material planed or excavated from the road or other paved area being resurfaced/reconstructed.

4.7 The processed aggregate, including added filler, shall not contain deleterious material that adversely affects the performance of the mixture.

Processing of aggregate

4.8 For ex situ LEBM, the submitted quality plan shall describe how, in particular, arisings, whether stockpiled or extracted, are to be processed, crushed, screened and stocked to enable consistent production of the LEBM in line with the Job Standard mixture.

Binders and other constituents

4.9 The bitumen and other constituents shall conform to the following standards:

i) Bitumen emulsion shall comply with IS EN 13808.

ii) Cement shall be CEM I conforming to IS EN 197-1.

iii) Bitumen used for foaming shall comply with IS EN 12591 and shall be grade 160/220 or harder.

iv) Granulated blast furnace slag (GBS) and ground granulated blast furnace slag (GGBS) shall comply with IS EN 14227-2.

v) Lime shall comply with IS EN 14227-11.

vi) Fly ash (PFA) shall comply with IS EN 14227-4.

CEM II, CEM III and CEM IV conforming to IS EN 197-1 that are pre-blended combinations of the above are also permitted, subject to the total proportions of the individual components of the binder complying with clause 4.15 below.

4.10 Subject to the agreement of the National Roads Authority, other constituents, including setting and hardening agents, may be used to enhance the performance of the mixture.

4.11 Water shall not contain material that adversely affects the performance of the mixture.

Job standard mixture

4.12 The Contractor shall submit details of the composition of the job standard mixture as follows:

i) Source, origin and proportion of all aggregate constituents.

ii) Combined target grading, including mineral binders and tolerances.

iii) Source, origin and proportion of all binders.

iv) Target moisture content.

4.13 The grading of the job standard mixture (the aggregate together with the other constituents including binders) shall comply with one of the zones in Table 4.1.

Table 4.1: Particle size distribution of mixture for low-energy materials

Sieve (mm)	Percentage by mass passing		
	Zone A	Zone B	Zone C
40	100	100	100
31,5	100	100	86 – 100
20	100	100	75 – 100
14	85 – 100	85 – 100	52 – 100
10	68 – 100	68 – 100	44 – 100
4	38 – 74	38 – 94	26 – 74
2	26 – 58	26 – 84	18 – 58
0,5	13 – 38	13 – 64	8 – 38
0,250	9 – 28	9 – 51	5 – 28
0,063	5 – 21	5 – 38	3 – 21

4.14 Use of Zone B or C graded material shall be permitted only when the results of a full mixture design showing compliance with the required 28 day performance properties are available or when evidence can be provided of satisfactory achievement of the performance requirements on an earlier contract with a similar composition.

4.15 The binder addition shall comply with Table 4.2 for ex situ LEBM and Table 4.3 for in situ LEBM.

Table 4.2: Minimum binder addition (%) for ex situ construction by family and binder type

Family	QH				QVE	SVE
CEM I	3	2	2	2	1	–
Lime	–	–	–	–	–	1.5[3]
PFA	–	4	–	–	–[2]	–[2]
GBS	–	–	4	–	–	–
GGBS	–	–	–	2	–	–
Bitumen[1]	–	–	–	–	3	3

Table 4.3: Minimum binder addition (%) for in situ construction by family and binder type

Family	QH				QVE	SVE
CEM I	4	3	3	3	1	–
Lime	–	–	–	–	–	2.5[3]
PFA	–	5	–	–	–[2]	–[2]
GBS	–	–	5	–	–	–
GGBS	–	–	–	3	–	–
Bitumen[1]	–	–	–	–	4	4

Notes (Table 4.2 and Table 4.3)
1 – foamed or emulsion (residual)
2 – PFA may be added as filler
3 – lime may be added for 'breaking' and adhesion purposes, and, if PFA included as filler, will contribute to strength

Mixture design validation

4.16 A mixture trial validation shall be undertaken on any mixture for which there is no past history of successful use and for which there has not been a mixture trial validation with the component materials to be used.

4.17 Mixture design validations shall be carried out on aggregates and binders representative of those to be used on the Works. The validation shall be carried out on LEBM mixed either in the laboratory or, for ex situ LEBM, on a pilot basis on a full scale plant.

4.18 The target mixture shall comply with sub-clauses 4.9 to 4.14.

4.19 A preliminary exercise shall be undertaken to establish a target grading and suitable moisture content.

4.20 Representative samples of the mixture shall be taken; from which 150 mm diameter cylindrical specimens shall be produced in accordance with sub-clauses 4.36 and 4.37. The height of these specimens shall be 150 mm high for hydraulic bound mixtures and 70 – 75 mm high for visco-elastic bound mixtures. The time between mixing and specimen production shall be kept to a minimum but within the setting times given in Table 4.6.

4.21 The density of each specimen shall be measured and, using the respective moisture content values, the dry density values shall be determined. The cylindrical specimens shall be conditioned and tested. The conditioning and testing regime shall be agreed with the Employer [Specialist responsible for the design] and the measured characteristics shall be classified in accordance with Figure 4.1 for QH LEBM materials and shall demonstrate a mean stiffness modulus classification of not less than 1900 MPa for QVE and SVE LEBM materials.

4.22 The performance properties of the conditioned specimens shall be declared. The results shall be considered as indicative only because the compliance criteria only apply to the specimens prepared during the execution of the Works.

4.23 Additional sets of specimens shall be made which, after the 28 day conditioning period, shall be soaked in water at (20 ± 2) °C for 7 days and the soaked specimen tested. After the test, the specimens shall not show any signs of cracking or swelling and the modulus or strength values shall be at least 80 % of the un-soaked values determined at the same age.

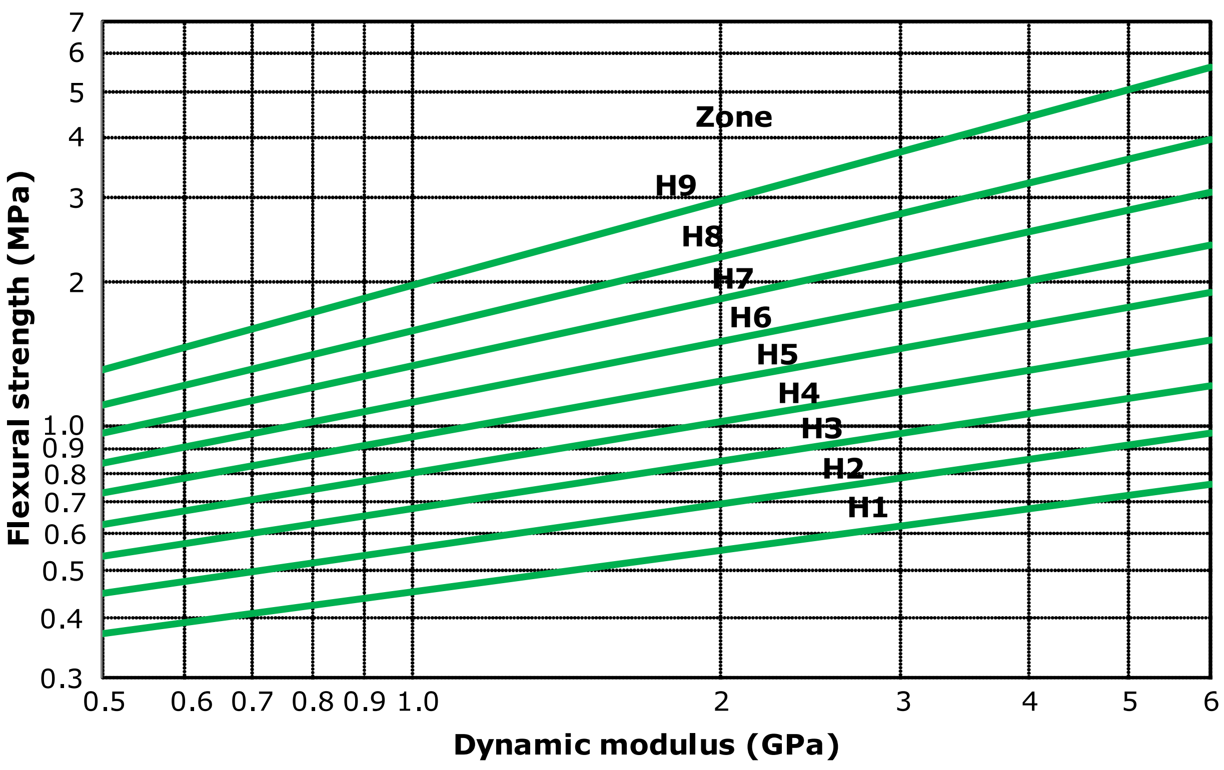

Figure 4.1 – Mix design and end product requirements at 360 days* for QH LEBM

Trafficking trial

4.24 Unless agreed with the Employer [Specialist responsible for the design], a trafficking trial shall be undertaken to demonstrate that the LEBM is not prone to excessive rutting in its early life, as follows:

i) A trial area shall be laid using the materials and plant to be used for the permanent Works and on a foundation typical of that in the permanent Works. The trial area shall be left to cure for 24 h or other declared time and shall then be subjected to controlled trafficking. The trafficking shall be performed by a heavy goods vehicle with an axle configuration and loading typical of that to be encountered in the construction phase.The number of passes shall equate to the total expected amount of traffic to be carried during construction, with a default value equivalent to 100 standard axles.

ii) The measured rutting in the trafficking trial shall be less than 10 mm or that stated in Appendix 7/1.

Process control

4.25 Production of the ex situ LEBM shall be subject to process control detailed in the quality plan and meeting the following requirements:

i) There shall be a description of the plant and the production process, preferably including a flow diagram, detailing how material is to be produced in accordance with this specification.

ii) Calibration schedules for all parts of the plant involved in determining mixture consistency shall be provided. These shall be accompanied by calibration records.

iii) Details of transportation shall be provided. These shall include the location of the mixing plant and the expected average time between mixing and laying. The Contractor shall record the duration between mixing and the completion of compaction at the site during the execution of the Works.

iv) The measures to maintain quality of construction at joints shall be described; in addition, measures to deal with hard edges and obstructions shall be included.

v) Measures to avoid problems caused by extreme weather. In particular, production shall not proceed if the feedstock is frozen or excessively wet.

4.26 Production of in situ recycled LEBM shall be subject to process control detailed in the submitted quality plan and meeting the following requirements:

i) There shall be a description of the plant and the production process, preferably including a flow diagram, detailing how material is to be produced in accordance with this specification. A description of the systematic pattern of the pulverisation and stabilisation process shall be included.

ii) Measures to deal with hard edges and obstructions shall be included.

iii) Calibration schedules for all parts of the plant involved in determining mix consistency shall be provided. Calibration records shall accompany these schedules.

iv) Measures to avoid problems caused by extreme weather. In particular, construction shall not proceed if road and or other materials are frozen or excessively wet.

Inspection and test

4.27 There shall be a schedule of inspection and test frequencies to be made during production of LEBM. This schedule shall comply with the minimum frequencies in Table 4.5.

Table 4.5: Minimum frequencies for inspection and test

Item	Inspection	Test
Aggregate stockpiles*	Daily	Grading and moisture content Before production and weekly
Binders	On receipt	Supplier data
Combined grading of mixture	Continual	Daily
Moisture content of mixture	Continual	Daily

* If applicable for in situ LEBM

Laying

4.28 A written procedure for the laying of the LEBM shall be provided before laying commences.

4.29 The plant used for placing ex situ processed material shall be capable of laying the material without significant segregation, evenly and to the required thickness across at least one lane width.

4.30 The plant used for levelling in situ processed material shall be capable of levelling the material without significant segregation, evenly and to the required thickness across at least one lane width.

4.31 A method for the making of longitudinal and transverse joints, appropriate to the type of LEBM being laid shall be provided.

Compaction

4.32 The compaction of each layer shall be carried out to a defined rolling pattern until both the required in situ density is achieved and the low-energy layer provides a stable and dense tight surface. The stability of the layer after compaction shall be deemed adequate if the finished surface does not shove, rut or exhibit transverse cracking under the load of subsequent traffic. Open edges shall be protected from traffic.

4.33 After trimming and final compaction of the low-energy layer, the in situ bulk density shall be measured using a nuclear density gauge in direct transmission mode, to a depth within 25 mm of the layer thickness. The meter readings shall be verified periodically in accordance with IS EN 13286-2.

4.34 The in situ bulk density values obtained shall be compared with the refusal density value of the Job Standard Mix or of the refusal density of a specimen representative of the day's production. The average in situ bulk density of each set of five values shall be at least 95 % of the refusal density, with no individual in situ density value being less than 93 % of the respective refusal density.

Sealing

4.35 When specified in Appendix 7/1, the surface shall be sealed using a sprayed membrane of cationic bitumen emulsion with a nominal 40 % bitumen content. The bitumen emulsion shall be sprayed at a rate of 1.0 to 1.5 l/m^2 to achieve a uniform and continuous seal to the surface of the layer. Where the surface is opened to traffic, the bitumen emulsion shall be blinded with fine aggregate or sand applied at a rate of 5.5 to 7.0 kg/m^2.

End product testing

4.36 The end-product testing of the LEBM shall be assessed on the basis of representative specimens made up in accordance with the schedule in Appendix 7/1.

4.37 Representative samples of the LEBM shall be taken either at the mixing plant or from site prior to compaction. 150 mm diameter cylindrical test specimens shall be manufactured in sets of six by compacting to refusal in accordance with IS EN 12697-9. The height of the test specimens and the time period after mixing during which compaction must be completed shall be in accordance with Table 4.6.

Table 4.6: Setting times of families of low-energy materials

Family	Setting time under normal temperature conditions
QH	2 h
QVE	2 h
SVE	24 h*

* can be longer depending on material composition

Conditioning and testing of samples

4.38 Prior to testing, specimens shall be conditioned in a controlled environment, sealed to keep the moisture in, as described in sub-clause 4.39. The purpose of this conditioning is to simulate the likely curing over the first year in the road.

4.39 Immediately after compaction, the cylindrical specimens in their moulds shall be double wrapped in cling-film plastic using two separate sheets; each of which shall be sufficient to cover the entire circumference of the cylinder and the two ends of the specimen. Once wrapped in cling-film, the sample shall be placed in a sealed plastic bag. Care shall be taken when handling the specimens not to damage the plastic bag or the underlying cling-film layer. The specimens shall be stored in air or water at a temperature within 2 °C of the nominal conditioning temperature.

4.40 Conditioning shall be in accordance with Table 4.7.

Table 4.7: Laboratory conditioning regimes and factors to relate to long-term performance

Family	Temperature (°C)	Duration (days)	Long-term Factor
QH	20	28	1.2
QVE	20	28	1.2
QVE*	40	28	1.0
SVE	–	–	–
SVE*	40	28	1.0

* for materials containing a pozzolanic binder

Note: SVE with bitumen only requires mix specific conditioning proposals to be calibrated against established long term performance of the same materials. The proposed conditioning values and their substantiation shall be included in the Contractor's Quality Plan.

End product criteria

4.41 The minimum specification compliance criteria for the process control tests shall be as described in Table 4.8.

Table 4.8: End product criteria

Material property or characteristic	Individual results	Mean from test set of six measurements
Particle size distribution	Zone	–
Moisture content	±2 %	–
Relative in situ density	93 % minimum	95 % minimum
Layer thickness	±25 mm of specified	±15 mm of specified
Mechanical performance	N/A	In accordance with clause 4.21, less 5 %

4.42 In the event of test specimens failing to achieve the required mechanical performance, compliance shall be determined by the testing of cores extracted by dry coring after one year. The results shall be compared with the criteria in clause 4.21.

5 NOTES FOR GUIDANCE ON LOW-ENERGY BOUND MATERIAL

General

5.1 Materials to this clause should be specified in Appendix 7/1. Either a specific material or materials should be stated or the Contractor permitted to choose a suitable material to meet the design thickness required.

5.2 Examples of the types of materials that satisfy the material classifications QH, QVE and SVE are provided below. It is realised that the combinations listed in Table 5.1 for each family are not exhaustive and alternatives to those shown can be considered (as indicated by 'other' in the table).

Sourcing of aggregate

5.3 The aggregate component should be of a quality generally suitable for use in cement bound material or asphalt. However, given the nature of the operation, which involves processing arisings from existing road pavements, some discretion should be applied. The emphasis should be on ensuring that deleterious materials, such as clay lumps and badly weathered aggregate, are excluded from the recycled material.

Job standard mixture

5.4 When determining the grading of materials containing asphalt planings, samples should be dried to constant mass at 40 °C and care should be taken not to break down the aggregated particles of asphalt unnecessarily.

5.5 Care should be taken not to have too high a cement content because that may change the material from a flexible material to a flexible semi-rigid material.

Mixture design validation

5.6 It is good practice to undertake mix design evaluation in advance of works on site, but it must be recognised that this is not always practicable, particularly for small projects. Additionally, there will not always be time for the full design procedure and, in particular, the curing stage to be carried out in advance of the works. Where this is the case, information from earlier works with similar material and the same process or accelerated curing regimes should be taken into consideration.

5.7 The components used in the mix design stage should represent the materials available in the permanent Works. Where a representative component is unavailable, the Contractor should use a replacement component of similar properties in the mix design stage.

5.8 The laboratory prepared aggregate should be thoroughly mixed with the measured proportions of the bitumen binder, cementing binder, adhesion agent(s) and other constituents. The constituents, including the type and grade of bitumen and adhesion agent(s), should be the same as those used in the finished Works.

5.9 For QVE materials, as well as SVE materials that contain pozzolanic binders, the Contractor should declare the stiffness modulus by indirect tension to cylindrical specimens (IT-CY) in accordance with IS EN 12697-26, Annex C, after conditioning.

Table 5.1: Examples of material families

Quick Hydraulic (QH)	Quick Visco-elastic/hydraulic (QVE)	Slow Visco-elastic/hydraulic (SVE)
PC/PFA	Foam/PC	Foam/Lime/PFA
PC/GGBS	Foam/PC/PFA	Foam/Lime/GGBS
PC/PFA/GGBS	Foam/PC/GGBS	Foam/Lime
PC/'other'	Foam/PC/'other'	Foam/GBS
	Emulsion/PC	Foam/'other'
	Emulsion/PC/PFA	Emulsion/GBS
	Emulsion/PC/GGBS	Emulsion/Lime/PFA
	Emulsion/PC/GBS	Emulsion/Lime/'other'
	Emulsion/PC/'other'	Emulsion/'other'

5.10 For QH materials, the Contractor should declare the minimum performance class achieved according to the direct measurement of Dynamic Modulus and Flexural Strength after conditioning. Generally, these values are not directly measurable and need to derived as described below.

5.11 Declaration using alternative test methods for hydraulic mixtures should be dealt with as follows:

iii) Using compressive strength tests in accordance with IS EN 13286-41 and using relationships from Croney *et al*. (1997):

$$E_{dyn} = \frac{\log R_f + 0.773}{0.0301} \quad [5.1]$$

$$R_f = 0.11 R_c \quad [5.2]$$

iv) Using the indirect tensile strength and static stiffness in accordance with IS EN 13286-42.

$$E_{dyn} = 8.4 + 0.93 E_S \quad [5.3]$$

$$R_f = 1.33 R_{it} \quad [5.4]$$

where E_{dyn} is elastic dynamic stiffness in GPa,

E_S is the static stiffness in GPa,

R_f is the flexural strength in MPa,

R_c is the compressive strength in MPa,

R_{it} is the indirect tensile strength in MPa.

5.12 This declaration shall include the direct values from laboratory tests, the converted values using the above transfer functions and also predicted 360 day values. Based on current knowledge, the factors in Table 5.2 are suggested; other factors may be used supporting evidence. These factors should be applied to the test results prior to any transfer functions.

5.13 The Contractor should also justify the construction with appropriate references to design charts or, if requested by the Employer, by carrying out analytical pavement design.

Table 5.2: Factors to link 28 day laboratory test values and 360 day values

Material Type	Factor
QH	1.2
QVE	1.0
SVE	N/A

Trafficking trial

5.14 It is recommended that a trafficking trial be performed as part of the mixture approval trial and is a best-practice approach to ensure that excessive deformation will not occur in the permanent Works. It should be noted that a trafficking trial cannot guarantee deformation resistance in the permanent Works and it can be a time-consuming method of approving a foundation.

5.15 As a general rule, the 'Quick' mixtures, which include cement, are less likely to be susceptible to rutting, as are other materials with a stable, angular, granular aggregate content. Particular care should be taken if there is a high proportion of rounded gravel in the mixture.

5.16 A trafficking trial may not be necessary if:

- evidence is available to show that the proposed construction (materials, construction and thicknesses) has performed well at other sites under the same moisture conditions, or
- the type of construction is of a type that is unlikely to be susceptible to deformation, or
- where a PTR is used to compact the low-energy layer, after 8 passes of a PTR with a minimum wheel load of 3 tonnes there is no measurable deformation.

The experience of the Contractor with this type of work and evidence of satisfactory application of the same techniques on similar sites in the past should be taken into consideration.

5.17 Deformation may also result from weak underlying foundations which may be exposed during construction operations. This potential movement should be taken into account by those responsible for the design of the Works. Whether a trafficking trial is performed or not, it is important to ensure that the foundation meets the specified requirements in the permanent Works.

5.18 If the construction is to be trafficked by special, very heavy vehicles, additional consideration should be given to the proven performance of the material approval trial under trafficking in relation to these vehicles.

Process control ex situ stabilisation

5.19 The plant used should be capable of achieving controlled batching by weight or volume. The plant should have hoppers and tanks appropriate for the component materials to be mixed. The mixing plant should be located close enough to the site to enable placing of the material within the appropriate setting time.

Process Control for in situ stabilisation

5.20 Pulverisation of the existing road structure should be carried out in a systematic pattern, to the required depth, to ensure that it covers all parts of the existing road; a description of the pattern should be given in the Quality Plan. An overlap of at least 150 mm should be made between adjacent passes of the machine. Any material missed along hard edges or around obstructions should be excavated and placed in the path of subsequent passes of the machine until a uniform fully pulverised aggregate is obtained. The surface of the pulverised layer should be graded to the required level profile and nominally compacted.

5.21 Where work continues adjacent to previously placed low-energy material, transverse joints should be reformed a minimum 0.5 m into the previously treated construction. Where a layer of material for recycling is placed over a layer previously recycled, the depth of pulverisation/stabilisation of the upper layer should be set to cut into the underlying recycled layer by at least 20 mm.

5.22 Excess pulverised material should be removed by grader and/or excavator for use elsewhere on site or transported to stockpile at locations given in the Quality Plan. The surface of the layer should be graded to the required level profile and nominally compacted.

5.23 The moisture content of the pulverised aggregate immediately prior to stabilisation should be measured in accordance with BS 812-109 using a method suitable for subsequent process control testing. The moisture content should be uniform throughout the layer within the range ±2 % of optimum moisture content for the pulverised aggregate including any designed proportion of filler, determined in accordance with BS 1924-2.

5.24 If the moisture content of the pulverised aggregate fails to meet the specified moisture content range, corrective action should be taken either by aeration to reduce the moisture content or controlled addition of water to increase the moisture content.

5.25 Prior to stabilisation, pulverised materials within 100 mm of restricted hard edges such as kerbs and channels, or around obstructions such as gullies, should be removed and spread uniformly over the remaining full width of the pulverised material.

5.26 The stabilisation should be carried out to the required depth in a systematic pattern similar to that used for the pulverisation process, with an overlap of at least 150 mm between adjacent passes of the machine using a method approved by the Employer [Specialist responsible for the design].

5.27 The layer of recycled material should be graded to level and compacted within two hours of the final pass of the stabilising plant, unless a curing or 'maturing' period of aeration is required. Any furrow formed by prior excavation of edge material should be re-filled by grading the adjacent recycled material into the space using a minimum amount of re-working.

5.28 For in situ mixtures, there should be a procedure and suitable equipment to produce a final material that is as homogeneous as practicable.

Sealing

5.29 A tack coat or bond coat may be required by the Employer [Specialist responsible for the design] to improve the bond between layers and the overall durability of the structure.

End product testing

5.30 It is important to establish a testing regime for end performance properties (stiffness, tensile strength) appropriate to the nature of the works. It is recommended, given the precision of the testing, that the results are assessed for conformity in sets of six. This recommendation does not, however, mean that a full set of six specimens needs to be made up at one time.

5.31 For works of a reasonable size, it is recommended that specimens are prepared at an overall frequency of three per 1000 tonnes with a minimum of three per working day. Conformity should be assessed on a rolling basis.

5.32 It may be possible to relax this requirement for small and intermittent jobs.

5.33 40 kg of material is required for each sample to have sufficient material for the three test samples (PRD, cylindrical and moisture content) to be produced. PRD samples require a minimum of 5 kg of material; cylindrical samples, 4 kg; moisture content samples, 3 kg; as well as three particle size distribution tests from a bulk sample of six individual samples.

Conditioning and testing of samples

5.34 A PRD or other suitable mould may be used. Where long-term storage of materials is required, the use of an inexpensive mould such as plastic soil pipe is advised.

End product criteria

5.35 The criteria in this Sub-clause represent the minimum permitted end-product compliance criteria; however, they can be supplemented by other laboratory and non-destructive in situ test methods as agreed with the Employer [Specialist responsible for the design]. For QVE and SVE materials, particularly those containing asphalt planings, analysing for bitumen content is unlikely to be of value. This aspect of process control is better controlled through tank reconciliation. A description of the supplementary test methods and expected outcomes of the testing can be including in the Material Quality Plan declaration. Supplementary testing can be of value to both the Contractor and the Employer [Specialist responsible for the design] and should be viewed as good practice. For example, a non-destructive falling weight test device can, in certain circumstances, be used to show the in situ performance of the layer and also show that curing is occurring. It is advised that any agreed supplementary testing is used as a tool for 'acceptance' (as opposed to 'rejection') so that, along with practical evidence at other sites, these may be used to resolve non-compliance issues should they occur.

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7 ENQUIRIES

7.1 All technical enquiries or comments on this Interim Advice Note should be sent in writing to:

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Tim Ahern
Head of Standards