SERIES NG 1000
ROAD PAVEMENTS - CONCRETE AND CEMENT BOUND MATERIALS

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NG 1000 General

1 (05/01) Advice on the design, construction and maintenance of concrete roads and for concrete mix design is published in Standards and Advice Notes and

Design:	The Design Manual for Roads and Bridges (DMRB)
Construction:	Mechanical Construction of Concrete Pavements and Ancillary Works, Concrete Society, Technical Report No. 45.
Mix Design:	Design of Concrete Mixes, SO, 1988
Remedial Works:	Concrete Pavement Maintenance Manual published by the Concrete Society

2 (05/01) The pavement design requirements for concrete pavements should be based on the Design Manual for Roads and Bridges Volume 7 and shown in Appendices 7/1 and 10/1.

NG 1001 (05/01) Grades of Concrete and Constituent Materials for Pavement Layers

1 Clauses 1001 and 1002 give the requirements for materials and limits for mix proportions for designed concrete mixes in the form required in BS 5328.

2 Six grades of concrete are included to meet the needs of sub-bases, road bases with flexible surfacing, continuously reinforced concrete road bases with flexible surfacing and slabs in the pavement surface. Dry, roller compacted, concrete is specified in Clauses 1035 to 1041.

3 The grade for pavement surface concrete has been selected to provide greater durability for increasingly heavy traffic.

4 (05/02) In addition to Portland cement CEM I the term ‘cement’ includes other hydraulic binders such as combinations of CEM I and ground granulated blastfurnace slag (ggbs) and pozzolanic cements such as blends of CEM I and pulverised-fuel ash (pfa), whether they are blended on site or manufactured by blending or intergrinding. These include Portland blastfurnace cement, Portland-fly ash CEM II/A-V and CEM II/B-V cements and pozzolanic cement.

5 Portland filler cement should not be used in the top 50 mm of the road surface, as this would increase the fine calcium carbonate content and lead to slipperiness. Microsilica may be used with PC to obtain high early strength concrete.

6 (05/01) For durability it is necessary to have a water/cement ratio below 0.45 for pavement surface slabs. The water/cement ratio is defined as the ratio of free water to total cement content of the mix, which can include CEM I /ggbs or CEM I /pfa blends.

7 High early strength Portland cements should only be used where rapid construction is required. In such cases, insulation blankets will be required over the concrete to provide suitable curing conditions which will reduce the risk of thermal cracking of the concrete.

8 High early strength cements and high cement contents may be used when there is a need to open a section of concrete pavement to traffic early. Prescribed mixes of fixed proportions may be used in rapid construction for high early strength concrete. The proportions of ingredients to be used should be decided by trial mixes which when tested provide the quality, workability and strength development required for the particular application.

9 (05/01) Both CEM I /pfa and CEM I /ggbs concrete have a long term increase in strength greater than CEM I concretes for the same 28-day strength and provide greater durability and resistance to chemical attack. However, there is evidence that concretes in the top 50 mm of a road pavement which contain more than 25% pfa or 35% ggbs are more likely to suffer from damage under freeze/thaw conditions, and is the reason the amount of pfa and slag is limited to these values. If pfa is included in the mix it permits lower water/cement ratios for a required workability, so providing denser concrete of lower permeability and greater durability.

Admixtures

10 (05/02) Air entraining agents are essential in pavement surface slabs to reduce permeability and frost damage. They also have a plasticising effect. They are not necessary in concrete slabs covered with asphalt materials of 30 mm thickness or more - unless the concrete is to be exposed to frost before the surfacing is applied. A small loss in strength is to be expected with air entrained concrete compared with plain concrete with the same mix proportions.

11 Plasticisers can be used to reduce water in the mix, increase strength and maintain workability at the required level. They can be beneficial in mixes with

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blends of PC with ggbs or pfa, as the water reduction partially compensates for the loss of early strength.

12 Where low water/cement ratios are used to obtain C40 strength, retarders can be used in high summer temperatures, to ensure that the finishing processes can be completed in time.

Aggregates

13 The maximum size of aggregate allowed is 40 mm, but the Contractor's choice of size will depend on construction methods, and his ability to achieve surface regularity, properly constructed joints and correct alignment of dowels. Larger aggregate provides an advantage in producing a more stable concrete in the lower layer, while 20 mm aggregate is preferable in the top course for forming joints and achieving a good finish.

14 Popouts can occur in the surface of the concrete slab when frost-susceptible particles are included in the aggregate. If there is a sufficient proportion of such particles this can lead to 'D' cracking which is a form of cracking caused by expansion due to frost, close to transverse and longitudinal joints. The particles which can cause popouts with flint gravel aggregates are clay or chalk impurities or white flint particles.

15 The white flints consist of modules of cortex or harder flints covered in cortex which is weathered flint and is porous. Research has shown that all flint aggregates are porous but to varying degrees. Black flint is of very low porosity. Brown flints are three times more porous than black, and white flints are about four times more porous than brown flints. The overall porosity of an aggregate will depend on the proportion of white flints. Smaller particles tend to have higher absorption than larger aggregate sizes. In addition to frost damage due to absorption of water there is a higher risk of alkali silica reaction in the presence of moisture in the porous aggregates.

16 Porous flint aggregates have been found to be widely spread in the South of England, including certain marine sources. However, where local knowledge or experience of a particular source is satisfactory and the material properties are constant, the need for testing may be reduced.

17 When dissimilar aggregates are used in two layer construction the effect of different thermal coefficients should be assessed. More easily-sawn aggregates may be preferred so that joint grooves can be made, but if used in the top layer above flint gravel for example, the effects of different thermal coefficients should be considered. The time for sawing joints will be dictated by the thermal characteristics of the flint gravel aggregate in the lower layer and not by the other aggregates.

18 Although cracking due to alkali silica reaction (ASR) is rare in concrete pavements, identical requirements to those for structural concrete are specified. (See also NG 1704.)

19 Where the soundness test is used as a means of confirming source suitability, a certificate from a testing laboratory accredited in accordance with EN 45002 by the United Kingdom Accreditation Service (UKAS) for that test, showing a value in excess of the minimum specified and dated not more than 6 months previous to the start of the contract, should be provided.

For those sources seeking suitability based on historical evidence of satisfactory use, the following should be provided:

(i) Dated certification showing supply of materials conforming with all other aspects of Clause 1001.6.

(ii) Copies of dated delivery tickets showing materials, source and site supplied.

(iii) Documentary evidence of material source, site and tonnage supplied.

Evidence should be provided for at least two major sites.

Routine water absorption tests should be made on the delivered material. If any result from these tests exceeds the declared value (d) by more than 0.5 ie, > (d + 0.5) %, further investigation will be required.

20 (05/01) When recycled coarse aggregate or recycled concrete aggregate is used as an aggregate, grading variations and quality should be carefully monitored to ensure the requirements of BS 882 and Table 10/2 are achieved. Material quality should also be controlled by the 10% fines value in BS 882. When flint coarse aggregate containing white flints is present in the crushed concrete, the requirements of Clause 1001.9 should be taken into account.

21 (05/01) The test procedure for identifying and quantifying constituent materials in recycled aggregates is described in Clause 710.

22 (05/01) When recycled coarse aggregate or recycled concrete aggregate is used, the maximum allowable proportion as part of the coarse aggregate should be determined from trial mixes.

23 (05/01) The method of test for chloride ion content in recycled coarse aggregate and recycled concrete aggregate should differ from that for natural and artificial aggregates due to the potential chloride content within any adhering cement fractions which needs to be taken into account.

NG 1003 Density

1 Density is required to be measured at regular intervals during paving as well as the trial length. Until nuclear density meters are proven as acceptable for plastic concrete, cores will be required to be cut. To prevent undue damage to the slabs, cores should not be taken at points of high stress such as corners of slabs. The most desirable position for taking cores for routine density and inspection checks is as follows:

(i) Between quarter points along the slab.

(ii) Within 0.5 m of any longitudinal joint in a hard shoulder, hard strip or the least trafficked lane of the section being inspected.

2 Where cores contain tie bars or other reinforcement, allowance for the amount of steel should be made in any calculation of the density of the concrete.

3 As a rough rule for assessment of strength, 1% reduction in density equates to a 5% loss of strength of concrete.

4 Calculation of the theoretical maximum dry density (TMDD) of the concrete, for comparison with cores, should take into account the bound water due to the hydration of the cement. This will vary with the age of the concrete. In calculating the TMDD the mass of hydrated cement is found by multiplying the mass of cement in the fresh cement mix by a time factor (F) determined from the following Table NG 10/1:

TABLE NG 10/1: (05/01) **Time Factor (F) for Hydrated Cements and Cement Blends**

Age (Days)	CEM I	CEM I/pfa	CEM I/ggbs
1-3	1.13	1.11	1.07
>3-7	1.15	1.14	1.12
>7-91	1.19	1.17	1.17
>91-365	1.22	1.22	1.21

5 The theoretical maximum dry density (TMDD) of the concrete shall be calculated from the formula:

$$\text{TMDD} = \frac{\left[\left(F x W_1\right) + W_3 + W_4\right] x 1000}{\frac{W_1}{P_1} + \frac{W_4}{P_4} + \frac{W_3}{P_3} + W_2}$$

Where

F = time factor for hydration of cement from Table NG 10/1

W_1 = mass of cement (kg)

W_2 = mass of total water (in aggregate + added) (kg)

W_3 = mass of oven-dry sand (ie fine aggregate) (kg)

W_4 = mass of oven-dry coarse aggregate (kg)

P_1 = relative density of cement

P_3 = apparent relative density of sand (ie fine aggregate)

P_4 = apparent relative density of coarse aggregate

Note:

(i) The apparent relative density and moisture content shall be determined in accordance with the method described in BS 812 : Part 2.

(ii) Where more than one size of coarse aggregate is used then:

$$W_4 = W_a + W_b + W_c + \ldots\ldots\ldots W_n$$

and

$$\frac{W_4}{P_4} = \frac{W_a}{P_a} + \frac{W_b}{P_b} + \frac{W_c}{P_c} + \ldots\ldots\ldots\ldots \frac{W_n}{P_n}$$

Where W_n is the mass of oven-dry aggregate of a certain fraction and P_n is the apparent relative density of that certain fraction.

(iii) Where blends of PC and ggbs or PC and pfa are used then:

$$W_1 = W_o + W_g \text{ or } W_1 = W_o + W_p$$

and

$$\frac{W_1}{P_1} = \frac{W_o}{P_o} + \frac{W_g}{P_g} \text{ or } \frac{W_1}{P_1} = \frac{W_o}{P_o} + \frac{W_p}{P_p}$$

where suffix o = PC

g = ggbs

p = pfa

values of $P_o = 3.12$

$P_g = 2.90$

$P_p = 2.00$ are recommended

Table NG 10/2 gives a worked example of the determination of the theoretical maximum dry density (TMDD).

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NG 1004 Quality Control of Concrete Strength

1 BS 5328 : Part 4 is used as the basis for control testing of pavement concrete but the rate of sampling and testing has been modified.

2 The 7-day strengths are used to give early warning of the possibility of low results and any need for additional cement after 7 days can be verified by the test results at 28 days. The ratio between 7 and 28 days should be established on laboratory trial mixes, but once paving has started this ratio can be updated from the most recent test results of 7 and 28 days on the same batches.

3 When two radically different mixes are used in the slab in two-layer construction, the statistical check on strength results should be carried out on the mixes separately.

4 The average value of 4 results represents 300 m² of work at the minimum specified rate of testing. If the Contractor wishes to reduce the area of pavement at risk he may wish to arrange for a higher rate of testing.

5 Cores may be taken and tested in compression and assessed in accordance with BS 6089 in order to assess whether (and how much) concrete should be rejected in the event of compression strengths of representative batches not meeting the specified value.

TABLE NG 10/2: Density of Concrete

Constituent	Batch† Weight kg	Moisture Content %	Water in Aggregate kg	Oven Dry Weight kg	Relative Density	Absolute Volume m³	Mass Partially Hydrated Material kg
Cement	336			336	3.12	0.108	386.4**
Water	137					0.191††	
Sand (ie Fine aggregate)	689	4.7	30.9	658.1	2.63*	0.250	658.1
Coarse 40-20	657	1.2	7.8	649.2	2.60*	0.250	649.2
20-10	330	1.9	6.2	323.8	2.60*	0.125	323.8
10-5	221	4.1	8.7	212.3	2.62*	0.081	212.3
			53.6			1.005	2229.8

* Apparent Relative Density
†† Volume of total water (water in aggregate + water added at mixer)
** Time Factor (F) of 1.15 used

Theoretical Maximum Dry Density (TMDD) $= \frac{2229.8}{1.005} = 2219$ kg/m³

Minimum Dry Density Requirement of 97% (non-air entrained concrete) = 2219 x 0.97 = 2152 kg/m³

Minimum Dry Density Requirement of 93%# (non-air entrained concrete) = 2219 x 0.93 = 2064 kg/m³

Notes: †In practice, the batch weights for air entrained and non-air entrained concretes are unlikely to be the same
92% for 20 mm maximum size

NG 1005 Workability

1 The Compacting factor (CF) is a suitable workability test for most of the stiff mixes required for machine paving. The CF test or the Vebe test should be used on trial mixes of cohesive mixes, eg. when ggbs or pfa are used, to measure the effect of vibration for a range of CF values.

2 The optimum compacting factor at the paver will need to be reassessed at intervals depending on the climatic conditions.

3 Workability should be constant. A useful check on whether the workability is constant can be obtained by noting the power input to the mixer. If necessary, plasticising or retarding admixtures should be used to suit local or weather conditions.

4 The target values for CF will vary with the mixes and materials used and with the weather. Approximate values are:

(i)	single layer construction	0.80 - 0.85
(ii)	two layer construction	
	top layer	0.80 - 0.83
	bottom layer	0.75 - 0.78

Low workabilities are required in the concrete to ensure that inserted dowel bars are retained in position. Higher workabilities are necessary to allow the texturing and finishing to be completed satisfactorily within the time available. In practice a compromise is required depending on the method of construction.

5 As consistently correct workability is of prime importance for the slab to meet the requirements of the Specification, it is in the Contractor's interest to control it by frequent testing at the batcher so that adjustments can be made quickly before too much concrete is transported to the paver. Tests at the paver are also required to ensure that the concrete placed in the paver is within specified limits.

6 For small scale works where ready mixed concrete is used, no water other than any amount required to produce the specified workability, should be added to the truck mixer drum before discharge. No additional water should be permitted in concrete which has been in transit for more than two hours.

NG 1006 Trial Mixes

1 Unless suitable data is available, trial mixes are required for each source of material to be used. Cements from different sources used with the same mix may have varying effects on the strength and workability of the concrete.

2 The trial mix in the laboratory should be assessed, not only for strength but also for workability and the effects of vibration. It should be used to assess the rate of gain of strength between 7 and 28 days. It is important to know what the ratio will be during the trial length as 28 day results may not be available before normal working is likely to commence.

3 Trial mixes should be used to obtain the rate of gain of strength of normal and high strength concretes to assess the time when the pavement layer may be used by traffic. The tests should be completed in advance of the start of urgent work such as reconstruction or widening existing roads.

NG 1007 (05/01) Separation and Waterproof Membranes

1 (05/01) A separation membrane is required to prevent loss of water from the fresh concrete. For jointed pavements a degree of slip is desirable, so polythene sheet is normally used. For continuously reinforced concrete (CRC), a waterproof bituminous spray should be used on the sub-base because a degree of restraint is required.

NG 1008 Steel Reinforcement

1 Supports for reinforcement should be sufficiently numerous and rigid so that the reinforcement will withstand a man's weight with no greater vertical distortion at any point than half the allowable vertical tolerance for the position of the reinforcement.

2 (05/02) When fixed height supports are used, eg. rings of standard mesh reinforcement, it is necessary to ensure a good surface regularity to the sub-base or base on which the reinforcement is laid.

3 When prefabricated sheets are laid in two layer construction it is permissible to lay alternate sheets along the pavement with transverse steel uppermost. This allows the transverse lap to be made by placing one transverse bar of one sheet within the first mesh of the next sheet. This requirement will not apply if flying ends are provided in the prefabricated sheets at the position of the laps.

NG 1009 Transverse Joints

1 Transverse joints are normally contraction joints. Warping joints are retained in Clause 1009 for special cases, eg. for extra joints at manhole positions or when unreinforced slabs are alongside reinforced slabs, or in long narrow or tapered URC slabs between normal joint positions, to reduce the length/width ratio of the slabs to 2 or less, and in other similar situations. Alternatively, instead of extra joints, slabs with an aspect ratio greater than 2 may be reinforced. The spacing of transverse joints should be described in Appendix 7/1.

2 Structures within the pavement depth should be isolated by at least 5 m of hot rolled asphalt or dense bitumen macadam roadbase.

3 (05/02) At buried structures the concrete slabs and sub-base should be continued over the structure. The sub-base should be isolated from the structure by not less than 150 mm of granular fill. Composite road bases should not be permitted to abut the structure.

4 (05/01) At the ends of CRCP, jointed reinforced slabs with expansion joints should be constructed between the anchorages and any other form of pavement. At the ends of CRCR, a jointed unreinforced slab with an expansion joint should be constructed between the anchorages and any other form of pavement. Between anchorages the only joints will be construction joints.

5 Where an unreinforced carriageway is constructed in more than one width and transverse cracking occurs before concreting the adjacent width, repair of the cracks should be carried out before the laying of adjoining slabs to reduce the risk of sympathetic cracking. If extra joints are put in as part of the repair, they should be matched in adjacent subsequently laid slabs.

NG 1010 Longitudinal Joints

1 Longitudinal joints are required at such a spacing as will reduce the combination of thermal warping stresses and loading stresses to a minimum and reduce the risk of longitudinal random cracking. The maximum bay width is therefore set at 4.2 m, except when reinforced pavements are constructed in widths up to 6.0 m (or 5.0 m and 7.6 m respectively with limestone aggregate).

2 Joints may be situated at or near lane lines or in the centre of a lane, whichever is the most economical for the Contractor's method of construction, but they should not be near the wheel track especially in heavily trafficked lanes.

NG 1011, NG 1012, NG 1019 Placing and Inspection of Dowel Bars and Tie Bars

1 When dowel and tie bars are to be inserted vertically into fresh concrete the concrete should be fully compacted over them. Tie bars may be inserted into the side of a slab provided the method ensures a good bond to the concrete.

2 The fixings for dowel bar assemblies should be tested for strength in the trial lengths. Once the type of assembly has been approved, sample testing should be carried out in the main construction in the Permanent Works to ensure that standards are maintained.

3 To check the alignment of dowel bars it is necessary to remove the fresh concrete carefully to expose the top half of each end of each bar across the whole width of the slab under construction. The position of the ends of the bars can be measured relative to the side forms or wires by means of steel tapes stretched between the forms or wires, using a vertical spirit level placed alongside the bars.

The alignment for level can be measured from nylon lines pulled taut across the forms or measured using a gauge incorporating a spirit level with legs 300 mm apart with forks at the ends for placing over the bars. The legs can include rules to measure the position of the bar ends below the steel tapes.

4 (05/01) As the measurement of all the bars in any one joint is time consuming it will not be possible to complete the measurement, recompact and finish the concrete within the normal time allowed in Table 10/6. It will be necessary to reinstate with a l m long reinforced slab as a full depth repair. Alternatively the penultimate joint in a day's work could be selected for the dowel alignment check. The remaining concrete in the last slab is then discarded before work starts again.

5 (05/01) Dowel bars, tie bars and transverse reinforcement across a longitudinal joint need to be protected from corrosion. Suitable bituminous protective paint is allowed for reinforcement. Tie bars and dowel bars should be protected by bonded polymeric corrosion resistant coatings.

NG 1013 Joint Grooves

1 Sawn grooves are preferred for transverse contraction and warping joints in summer work as they avoid disturbance to the surface of the plastic concrete. Because of the risk of cracking starting from the bottom in winter and the fact that bottom crack inducers are not used with sawn joints, joint grooves may be formed in winter (21 October to 21 April). The timing of sawing the hardened concrete is critical. If sawn too soon the aggregate will be plucked out, if too late, the concrete will have cracked already. With flint gravel aggregates in normal strength concrete, cracking may occur before sawing can begin. With high early strength concrete there is a better opportunity for sawing flint gravel concrete. In two course construction, with flint gravel in the bottom layer, the time for sawing before cracking will be governed by the flint gravel, as it has the highest coefficient of expansion. If a crack forms before or during sawing, it should be left without sawing alongside it until the time comes to seal it. If the crack cannot be encompassed within a 40 mm wide joint, the slab should be repaired. In slabs constructed in more than one pass of the paver (one rip) cracks may occur earlier in the second pass under the influence of joint movement of the first pass unless sawing is carried out as soon as possible.

2 Narrow crack-inducing grooves should be sawn first and widened for sealing later. In order to meet the requirements for high paving speeds with an economical number of saws and still reduce the risk of random cracking, it is common practice for approximately every third joint to be sawn as early as possible; the intermediate joints being sawn within the next few hours.

3 Wet-formed joint grooves with bottom crack inducers will be allowed for winter work to ensure cracks appear at joint positions. In such cases it is important that the concrete is fully recompacted around the former or cork seal. As the joint groove former is placed just below the surface of the concrete, it is important to ensure that the surface of the concrete is a straight plane between the forms at wet-formed joints. Otherwise if the surface level is bowed by excess concrete the former will be tilted by the diagonal finisher when planing off the excess concrete. The depth of the top layers should be considerably greater than the depth of the joint former so that the positions of the formers are not influenced by the stiffness of the bottom layer.

4 It is not good practice to set the formers low and pull them up again after the diagonal finisher. It is likely to cause lack of compaction of the concrete adjacent to the former and may lead to separation of the removable part of the former and bridging by mortar under it, which may cause horizontal cracking. However, it may be necessary on occasions to adjust the depth of former in which case the whole former must be raised in a vertical plane only using suitable tools. If excess concrete is not cleaned off above the former, concrete or mortar will bridge over the joint and will cause spalling of the arrises before sealing.

5 The joint groove must form a complete discontinuity across the slab, so that the concrete will crack along the joint position. It is necessary to ensure that the groove is continued across the longitudinal joint and to the edge of the slab by sawing when forms have been removed.

6 In normal summer work in URC only about one joint in four will crack initially. These joints tend to have greater movement at first until the other joints crack later with seasonal temperature changes or under traffic. In pavements constructed in two or more slabs the movement of joints in one slab will influence the cracking of uncracked joints in the adjacent slab from the longitudinal construction joint to the outer edge. A lack of discontinuity along the joint or dowel restraint may result in a crack appearing off line. This can be avoided by cleaning the top of the joint formers, using bottom crack inducers, and ensuring dowel alignment is satisfactory.

NG 1015 Joint Filler Board

1 Expansion joint filler board should have a pointed ridge as shown in the HCD, drawing number C2. The top of the ridge should be below the surface of the concrete but just within the depth of the sealing groove. It acts as a crack inducer initially and the sealing groove is sawn out later. Any other method of forming the sealing groove should be demonstrated in a trial.

NG 1016, NG 1017 Preparation and Sealing of Joint Grooves

1 One of the main causes of compression failures and damage to joints is the ingress and build up of solids or water-borne silt in the joint over a long period preventing or limiting proper movement at the joint. The requirements of a pavement joint sealant are:

(i) It should prevent the ingress of any solid matter into the joint.

(ii) It should form a waterproof seal and prevent most of the surface water from entering the joint crack.

(iii) It should be robust, have high extensibility, be resilient, be resistant to tearing, have a good bond to concrete and be unaffected by ageing and weathering.

2 Preparation of the sealing groove is most important. In order to remove any laitance from the groove sides and to provide a good key for applied seals, the joint sides must be grit blasted. Grinding may be permitted to clean small lengths of groove where grit blasting is impracticable. Wire brushes may be used to remove filler board prior to grit blasting, and for preparing grooves for compression seals.

3 Cracks will appear at transverse joints sporadically in new unreinforced concrete construction. Those that crack the earliest tend to have greater movement than would be expected if all the joints cracked evenly. This means that the groove width in winter may be wider than originally constructed, and allowance for future compression of the sealant should be made when sealing in cooler periods and the joint grooves should not be overfilled. Because of the extra movement in new URC pavement joints, cork and compression seal widths need to be greater to maintain them in compression.

4 For compression seals the width of the seal required is governed by the calculated movement to ensure that the seal remains always in compression.

5 With all sealants except cork seals which should be flush with the surface it is important to keep the top of the sealant below the surface at transverse joints to prevent damage by traffic when the joints are compressed in summer. When sealing in colder periods the level of the seal should be lower than in summer to allow for the compression of the seal upwards in warm periods. When longitudinal joints are sealed, the seal should be just below the surface.

6 There are two grades of two part cold-applied sealing compounds to BS 4254, used in structures and kerbs, etc; one for horizontal joints and the other for vertical joints. The grade offered by the Contractor should be suitable for the particular joint.

7 Although the British Standards refer to two part sealants some types have three parts. These sealants may also be permitted as it is often advantageous to vary the quantity of retarder (within limits set by the manufacturer) according to the temperature conditions at the time of sealing, rather than include it in the hardener. In cooler weather cold applied sealants take longer to cure.

8 (05/01) In circumstances where longitudinal joints may not be on line with road markings, consideration should be given to the avoidance of contrasting colours of joint sealant and pavement. The requirements for joint sealant colour should be included in Appendix 7/2.

NG 1018 Joints at Manhole and Gully Slabs

1 Wherever possible, manholes and gullies should be sited outside the pavement, but if they occur in the pavement they should either straddle or be adjacent to a transverse joint in jointed concrete pavement. If the joint spacings are such that a manhole or gully position is in the middle of the slab, an extra joint is necessary which should be a tied warping joint.

2 Details of the reinforcement required in the main slab and in CRC slabs around manhole or gully slabs are given in the HCD.

3 Gully and manhole slabs should have square corners as in the HCD, on the sides that are not adjacent to a joint to avoid a proliferation of cracks induced from oblique corners.

NG 1020 Side Forms, Rails and Guide Wires

1 In order to avoid adverse effects on the riding quality it is most important to check that all the sensors on any wire-guided machine are functioning within the correct tolerances during all paving, especially if the machine has been standing overnight in wet conditions.

2 The sub-base or any bedding for forms should be of sufficient strength to carry the train or paver without vertical movement and where necessary to carry any construction traffic. Cement bound bedding should have sufficient time to reach the necessary strength before paving begins. Precautions should be taken to prevent any construction traffic from damaging the subgrade next to the rails or paver tracks and so altering the levels after they have been set. Bedding other than the sub-base itself should be broken out after any section of pavement has been constructed and before any adjacent concrete is laid alongside, so that drainage of the sub-base and pavement is not impaired.

NG 1021 Delivery, Storage and Batching of Concreting Materials

1 The requirement for 8 hours storage of materials containing sands is to ensure that moisture contents are stabilised so reducing batch variability in the mixed concrete.

2 Checks should be made on the method of delivery and forming stockpiles to prevent segregation and accumulation of moisture. Aggregates can be contaminated during stockpiling, by ‘dozing’ or digging into the soil at the base of the stockpile.

3 For storing Portland cement, ggbs and pfa, a silo having a dividing partition down the middle may be regarded as two separate silos, provided the materials either side of the partition are kept separate from each other at all points in the silo and provided individual filters are fitted for each compartment. The operation of the two compartments must be independent of each other.

NG 1022, NG 1023 Mixing, Transport and Delivery of Concrete

1 A constant supply of concrete with consistent workability is essential to maintain steady progress in paving. Disruption to this steady progress inevitably results in loss of workability making finishing difficult and leading to bad riding quality. To maintain an adequate supply to the paver, pavement quality concrete should preferably be mixed on or adjacent to the site in a batch type mixer with an output greater than the capacity of the paver when proceeding at the average planned speed.

2 Supplies from off-site mixing can be very dependent on local traffic conditions outside the Contractor’s control, but they may be permitted for smaller or ancillary works.

The variability of concrete mixed in truck mixers may be greater than that mixed in batch mixers so they are unlikely to be suitable for large quantities of pavement quality concrete. Truck mixers may be permitted to mix pavement quality concrete for small individual slabs and may be used as agitators, the concrete having been mixed at the central batching and mixing plant. To maintain constant workability and consistent concrete its temperature should be kept as constant as possible during the day. In high ambient temperatures there is a considerable advantage in cooling the mixing water. Similarly in cold weather heated water is often necessary, but in both cases the temperature of the mixing water should not be excessive.

NG 1024 Construction by Machine

1 Descriptions of two main types of pavers (fixed form and slip-form) are given in the Guide to Concrete Road Construction (SO 1978). With either type of machine the slab may be laid in one or two layers. However, there are more restrictions on single course paving.

2 With fixed form paving, the control of surface levels is mainly governed by the spreader being able to spread the concrete evenly to the correct surcharge. It is bad practice to rely on subsequent regulating beams and the diagonal finisher to achieve the correct levels by a major planing operation. If the first regulating beam in the compactor/finisher has too big a roll of concrete anywhere along the beam the setting of the spreader should be changed. The roll in front of the regulating beam or diagonal finisher should be between 100 mm and 150 mm evenly distributed along the beam. If the roll is too great then adjustment should be made at the spreader. If segregation occurs in the roll, adjustments to the workability of the mix may be necessary.

3 With slip-form pavers there is a tendency for edge slump in the concrete immediately after leaving the paver. If the slump is out of tolerance for level fixed side forms are required where concrete being placed has to be matched to another section of pavement, eg. at slip road tapers or when construction is in two or more strips. In other work it is advisable for transverse finishing operations to be made against the crossfall to reduce the effect of flow towards the low side. Similarly on steep longitudinal gradients construction should preferably be up the gradient.

4 Joint groove formers should be cleaned prior to and after texturing to prevent concrete or mortar bridging over them, which would later cause spalling of the joint arrises.

NG 1025 Construction by Small Paving Machines or Hand Guided Methods

1 If sufficient internal vibration is provided and truss type finishing screeds with multi-vibration points are used together with scraping straight edge and bull floats where necessary, a well compacted slab with a satisfactory level and finish can be achieved. There is no technical restriction on the lengths of pavement which can be constructed in this manner, which is suitable for short bypasses, urban areas, widening or slip roads. More even distribution of the concrete is obtained if auger spreaders are fitted to the screeds.

2 Slip road tapers adjacent to a concrete pavement should always be of a similar construction for the full length of the taper, which is adjoining the concrete slab, in order to keep the same depth of construction across the whole pavement width. If the remainder of the junction or roundabout is of flexible construction, a standard transverse transition slab should be included at the end of the taper after the slip road has diverged and is separate from the carriageway. The slip road taper slab should not be tied longitudinally to the main carriageway after the point where the traffic lanes of the slip road leave the main carriageway, as this is the point at which changes in level and direction of movement of the slabs can occur. Joints in that part of the slip road taper which is tied to the carriageway and constructed at the same time can be normal to the axis of the main carriageway and in the same line of the main carriageway joint.

NG 1026 Finished Surface Requirements

1 It is important that a uniform texture is achieved both along and across the slab. It is therefore necessary to take full account of the workability of the concrete at the time of brushing and the operator must have the ability to gauge the optimum time for brushing after compaction and finishing of the concrete. Care should be taken to minimise variations which may occur with differences in ambient conditions and the workability of the concrete.

Brushed Concrete Surface Finish

2 From experience a suitable texture can be obtained by using a wire brush made of 32 gauge tape wires grouped together in tufts and initially 100 mm long. The brush should have two rows of tufts. The rows should be 20 mm apart and the tufts in one row should be opposite the centre of the gap between tufts in the other row. The brush should be replaced when the shortest tuft wears down to 90 mm long.

3 If the texture depth is over 1.25 mm it will produce unacceptable tyre noise. Trial lengths should be closely monitored and if the texture depth is outside the limits, adjustments should be made to the workability of the concrete mix, or to the pressure on the brush, or to the time when brushing is carried out after compaction, or the type of brush changed. Thereafter spot checks should be made on the concrete surface as necessary.

4 Where the surface texture from the average of ten results has been found to be deficient or excessive the areas to be rectified can be assessed from the individual measurements. If necessary, additional measurements can be made in a particular lane to decide the limit of treatment. If four or more successive individual measurements are deficient or excessive, the area relating to those measurements should be treated across the full lane (or lanes) width.

5 Isolated areas less than 6 m in length need not be treated unless the texture has been omitted altogether or riding quality is impaired. If such areas are close or occur in a regular pattern or chain, they should not be left untreated.

6 Measurements should be carried out in sufficient time before opening to general traffic to allow the Contractor to complete remedial works, taking into account the effect of wear of heavy construction traffic.

7 The depth of grooved texture (hardened concrete) should be measured by means of a tyre tread gauge.

NG 1027 Curing

1 Curing is essential to provide adequate protection from evaporation and against heat loss or gain by radiation and so permit the concrete to achieve its designed strength. The retention of moisture is particularly important with cement or cement blends which have a slow rate of increase in strength. Without moisture the hydration process cannot be completed. Without adequate curing the concrete strength could be half the strength of the corresponding cubes cured in water in the laboratory.

2 (05/02) The best form of curing is to keep the concrete constantly damp. This can be achieved by covering the concrete with plastic sheeting, or by a sprayed plastic material which hardens into a plastic sheet, which can be removed by traffic, or by an aluminised curing compound. For small bays or patches, wet hessian covered by plastic sheeting is satisfactory. For concrete slabs a waterproof bituminous spray is normally sufficient.

3 Plastic sheeting or sprayed plastic film will avoid the risk of damage by rainfall and the consequent cost of rectification by surface grinding, retexturing or relaying. The use of tentage will also reduce the risk of rain damage but unless closed at sides and ends it could cause a wind-tunnel effect which would reduce the curing. Where tentage is used measures should be taken to prevent drips falling on to unhardened concrete. Tentage covers should overlap by a minimum of 500 mm. Remedial works leave a generally patchy, aesthetically unpleasant surface. The rate of progress of fixed form paving plant makes the provision of tentage feasible, but with the higher output of slip form pavers tentage is generally uneconomical, and without rails there could be damage to the sides of the pavement. Sprayed plastic film allows paving to continue in wet weather, except in heavy storms.

4 Thermal insulation blankets provide accelerated curing and an increased rate of strength development.

NG 1028 Trial Lengths

1 Trials to prove new or modified machinery should be carried out off Site or below pavement level. The Contractor is permitted to choose whether he lays the trial as part of the pavement or elsewhere, but if the former, he is not allowed to proceed with other trials or further paving at pavement surface level until any defective trial lengths have been removed, or rectified to comply with the Specification.

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NG 1029 Texturing of Hardened Concrete

1 Experience has shown that grooving, with the grooves at an irregular spacing and of average size 3 mm wide by 4 mm deep as required, produces less tyre noise than surface dressing. It is the only acceptable method of retexturing the surface of concrete pavements as it will provide a long life texture.

Grooving across joints should be avoided as this could lead to minor spalling and damage to the seal. In order to obtain the minimum depth of 3 mm the setting of the machine should take into account the transverse irregularity of the surface. Isolated areas of substandard texture less than 1 m in length along the carriageway would be unlikely to require treatment except in special circumstances.

NG 1030 Wet Lean Concrete

1 Wet lean concrete is the term describing lower strength concretes which, using present pavement design, are suitable only for sub-bases. Four grades of wet lean concrete have been selected to equate in terms of strength to CBM 1, 2, 3 and 4. These provide a range of strengths sufficient to enable the Contractor to choose a mix stronger than the minimum specified to permit early access onto a sub-base after laying.

The inclusion of wet lean concrete in the Specification allows the Contractor to choose alternative methods of laying the sub-base most suited to the size and location of the contract; as a workable concrete via paving plant or by hand guided methods.

NG 1035 General Requirements for Cement Bound Materials

General

1 Soil cement, cement bound granular material and lean concrete are all categories of the family known as cement bound material (CBM). They have therefore been renamed cement bound material Category 1, cement bound material Category 2 and cement bound material Category 3, shortened to CBM1, CBM2 and CBM3 respectively. Stronger categories, CBM4 and CBM5, have been added.

Mix Design for Cement Bound Materials

2 Cement bound materials are mixtures of raw material and cement that have a moisture content compatible with compaction by rolling. If the requirement for surface level, regularity and surface finish are to be achieved, compaction will need to be carried out at or close to optimum moisture content (omc). The compaction tests described in BS 1377 : Part 4 can be used to determine omc or alternatively Clause 2.1.5 of BS 1924 : Part 2 : 1990. For fine-grained soils Clause 2.1.4 of BS 1924 : Part 2 : 1990 should be used. Difficulty in determining the exact omc for clean gravel mixtures is sometimes experienced due to the lack of fines present which allows the cement/water paste to be pumped out under vibration. However, a sufficiently accurate estimate of omc can usually be made from the results obtained.

3 Using the value of omc, the cement content needed to achieve the required strength can be determined by establishing the compressive strength of the CBM over a range of cement contents.

4 With some aggregates the strength requirements of CBM3 and CBM4 can be met with very low quantities of cement. Ratios of aggregate to cement greater than 24:1 are unlikely to result in an acceptable homogeneous mix and if permitted should be closely monitored throughout the works.

5 Pfa and ggbs may be used in combination with PC as cementitious binder for CBM. The strength gain for such mixes after 7 days is likely to be higher than for mixes using PC alone. The Contractor may wish to take account of this when using pfa or ggbs blends, and this may be achieved by testing at 28 days rather than 7 days. It will be necessary for the Contractor to show from trial mixes that the 28 day strength of the blended cement mix compares with that of the PC mix which meets the Specification requirements at 7 days. The curing period before use by traffic and overlaying should be extended to ensure that the specified 7-day strength is reached. The pozzolanic reaction of pfa requires the products of hydration of PC before it can take effect. Care will be necessary in mixes where the amount of PC is very low, due to the difficulty of dispersion of the PC during mixing. This can lead to local variations in strength with the risk of very weak patches. When using blended cements in winter there is an increased risk of frost damage if the early strength of the CBM is very low.

Delivery and Storage of Materials

6 It is important to prevent contamination and degradation of materials. The deposition of stockpiles of materials and subsequent extraction from them should be carried out in such a way that segregation is minimised.

Mixing

7 (05/01) Cement bound materials can be mixed in one of two ways “mix-in-place” or “mix-in-plant”. The permitted method of mixing depends on the pavement layer being constructed and is given in Table 10/9.

Mix-in-place Method of Construction

8 In this method a previously prepared layer is stabilized in situ with cement. The prepared layer can consist of either imported or as-found material. The preparation is different in each case. Successful stabilization can only be carried out on properly prepared material and it is recommended that the following procedure is adopted.

(i) Imported Material

(a) The imported material should be spread and compacted to a uniform density such that after stabilization the requirements for surface level and regularity will be met.

(ii) As-found Material

(a) The as-found material should be shaped and compacted to a uniform density such that after stabilization the requirements for surface level and regularity will be met.

(b) If, during preparation, soft spots are disclosed these should be replaced in the normal manner with acceptable material complying with the Specification.

(c) Where hard non-plastic soil is encountered in situ, the use of a scarifier or other suitable plant may assist the mixing process.

9 If it is necessary to add water this can either be done as part of the mixing operation or after the material to be stabilized has been shaped and compacted prior to the addition of cement. To ensure a thorough distribution of the added water it is preferable to add water as part of the mixing operation. Water added during the mixing process should be through a spray system such that it is added in a uniform manner over the required area and mixed uniformly to the required depth. Where the mixing plant does not enable water to be added or where it is not possible to add sufficient water during mixing, water should be added to the prepared material using a spray system that enables the amount of water to be controlled over the whole area. The material to be stabilized should then be mixed prior to the addition of cement to ensure the distribution of the water throughout the layer.

10 Cement should be spread by means of a spreader fitted with a device to ensure a uniform rate of spread over the whole area.

11 The mixer should be equipped with a device for controlling the depth of processing and the mixing blades should be maintained or reset periodically so that the correct depth of mixing is obtained at all times. When checking the depth it is important to realise the difference and the relationship between bulked and compacted thicknesses.

12 To ensure that all the material forming a layer is properly processed the mixing machine should be set such that it cuts (150 mm should be sufficient) into the edge of any adjoining mixed material.

13 Mixing should be continued with successive passes until the required depth and uniformity of processing has been obtained.

Mix-in-plant Method of Construction

14 In this method the material, cement and water are mixed in a central plant with the resulting mixture being transported to the point of laying and spreading.

15 To ensure completed distribution of the relatively small quantities of cement, mixing should preferably be carried out in a forced action mixer of either the batch or continuous type, carefully selected such that the plant can process the material and produce a uniform CBM to the requirements of Table 10/9. If the Contractor proposes a mixer other than a forced action mixer he should ensure during the trials that a satisfactory mixing is achieved. The mixer should have an output to satisfactorily meet the demands of the spreading and compacting operations.

16 Vehicles transporting mixed CBM should be of sufficient number and capacity to meet both the output of the mixer and spreading and compacting operations.

Laying

17 The formation of satisfactory joints between adjacent areas of CBM or other material and of longitudinal joints is vital to the performance of the layer. When laying against compacted cement-bound or other material, cut back vertical joints prevent wedges of CBM which may crack or allow the riding up of one area on another.

Compaction

18 When CBM has begun to harden it is important that the matrix is not disturbed, hence the requirement that compaction must be completed within two hours of the addition of the cement. However, some cement-bound materials are more critical than others in this respect. Equally the weather conditions at the time of construction affect this particular aspect. In all circumstances the two hour requirement should be adhered to unless site trials indicate a tightening or relaxation of this limit. Great care must be exercised when compacting CBM at joints to ensure that compaction plant does not bear on previously compacted CBM after the two hour period until the specified 7-day cube strength has been reached.

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Use by Traffic

19 CBM is susceptible to overstressing if traffic is permitted to run on it before it has obtained its specified strength. Use by traffic earlier than the specified times may be permitted once the specified strength has been achieved, which may be obtained by high cement contents or special mixes. Alternatively, if high density CBMs using pfa or ggbs as a filler to reach densities above 97% of theoretical density are used, early use by traffic to lay subsequent layers may be permitted.

Preliminary Trial

20 The size of the preliminary trial relates to larger areas of CBM. Where small areas are to be laid the Contractor may propose trial areas of less than 400 m².

NG 1036, NG 1037, NG 1038, NG 1039 Cement Bound Materials

1 The aim is to achieve a uniform layer meeting the strength and density requirements of the Specification. This is particularly important with CBM where the cement content is relatively low, and mixing and quality control need to be adequate so as to produce a homogeneous mix. The correct application of the trial and test regime clauses is most important to ensure that this is being achieved in the field. The rate of testing, in cases of non-uniformity, should be increased.

2 The compaction of CBM1 made from some single-sized or poorly graded materials can be difficult. If, however, the grading of the CBM has a coefficient of uniformity greater than 5 it is likely that it can be compacted satisfactorily. The coefficient of uniformity is the ratio of the sieve size through which 60% of the CBM passes, to the sieve size through which 10% passes.

3 CBM1 with a significant proportion of material having a liquid limit exceeding 45% and a plastic limit exceeding 20%, determined in accordance with BS 1377 : Part 2, can be difficult to mix. If the Contractor proposes to use such materials he should ensure during the trials that a uniform mix is being produced.

4 Clause 4.3 of BS 1924 : Part 2 : 1990 is included for CBM1 and CBM2 to assess the effect of immersing the CBM in water and to detect the presence of sulfates, expansive clays and deleterious constituents present in the material to be stabilised. The test should be repeated during construction, particularly if the material being stabilised varies.

5 In order to preclude the use of weak materials for CBM2, a ten per cent fines test is included.

6 Crushed concrete including crushed lean concrete can provide suitable aggregate for producing CBM. However, the quality of crushed concrete can vary widely and therefore before using such a source the Contractor should demonstrate that the crushed concrete is of an equivalent standard to aggregate conforming to BS 882 where it is to be used for CBM3, CBM4 or CBM5.

NG 1040 Testing of Cement Bound Materials

1 Cubes for strength testing for all cement-bound materials are effectively compacted to refusal when made in the specified manner. The cube strengths are consequently higher than would be expected from cubes compacted at field density. Field density requirements are met by comparing in situ measurements with those of the strength cubes. When making cubes with some of the more cohesive materials used for CBM, refusal density may best be obtained by using the smaller 7500 mm² tamping foot.

2 Care is necessary to ensure each cube has been made and cured correctly and is a valid specimen.

3 Nuclear density gauges can be operated in either direct transmission or backscatter mode. As the backscatter mode only measures the density of the top 50 mm - 60 mm of the layer, the direct transmission mode is used for CBM.

NG 1041 Use of Nuclear Density Gauges With Cement Bound Materials

1 Nuclear density gauges utilise radioactive substances and unless used in accordance with the manufacturer's instructions may be hazardous to the health of users. Regulations cover the use, transportation and storage of gauges. Gauge suppliers and manufacturers will usually advise on these regulations. Supervisory staff need to be familiar with the appropriate regulations and the manufacturer's operating instructions. In exceptional circumstances, where nuclear gauges cannot be used for the measurement of in situ wet density, the sand replacement method given in BS 1924 may be used as an alternative. The tests should be made between 4 hours and 24 hours of completion of compaction of the layer.

2 A preliminary check is included because Transport and Road Research Laboratory Report No. LR 1109 indicates that certain materials can give biased results when tested with nuclear density gauges. This is due to the radiation absorption characteristics of the material and is allowed for by re-calibration of the gauge or adjustment of the displayed result. It may be necessary to repeat the preliminary check from time to time where the materials used for CBM are variable. The mass of each block may be determined by weighing the concrete in batches before it is placed into the mould, providing accuracy is maintained.

NG 1042 Special Requirements for Cement Bound Materials

1 Clause 1042 is invoked by including a reference in Appendix 7/1 for flexible composite construction for certain designs. The criteria are to be found in HD 26 on pavement design. Examples of joint layouts that comply with Clause 1042 are to be found in the HCD and if to be adopted must be referred to in Appendix 7/1 and listed in Appendix 0/4. Joint layouts at tapers and junctions should be indicated on the Drawings.

NG 1043 (05/01) Foamed Concrete

1 Foamed concrete is a lightweight material produced by incorporating a preformed foam into a base mix of cement paste or mortar, using standard or proprietary mixing plant.

2 Foamed concrete is normally prepared on site, either from basic constituents, or using ready-mixed base mortar delivered to site. However, subject to experience gained by prior development that the mix is suitable for transport by road, foamed concrete may be delivered to site entirely ready-mixed.

3 Foamed concrete should be prepared in accordance with a mix formulation proven, by prior development testing, to yield a compressive strength within the required range. The mix wet density corresponding to the specified strength should be determined in the development testing.

4 The wet density of the foamed concrete should be checked prior to and during placement or as agreed.

5 On any site presenting special drainage or groundwater problems, the foamed concrete should be formulated to have a permeability not less than that of the surrounding ground. Alternatively a backfill layer of pea gravel, of 100 mm minimum thickness and surrounded by a geotextile filter fabric where appropriate, may be considered to offer an equivalent drainage potential.

6 Foamed concrete flows very easily and may infiltrate, and block, any damaged drainage or ducting existing within, or immediately adjacent to, the excavation. Unguarded reinstatements can represent a drowning hazard for children.

NG 1044 Pavements with an Exposed Aggregate Concrete Surface

1 Guidance to the requirements specified in Clause 1044 is contained in Chapter 3 of HD 38.

2 Methods and construction requirements for this type of surface should be based on the general requirements of Series 1000.

3 (05/01) The PSV and AAV requirements of the coarse aggregate in the surface layer concrete are dependent on the traffic category and should be specified in Appendix 7/1. Guidance on the PSV and AAV requirements is given in Chapter 2 of HD 36.

4 Attention is drawn to the flakiness index requirement in Clause 1044 for the coarse aggregate in the top layer concrete. This is 20%, rather than the more common 25% or 35%.

5 Sub-Clause 1044.5.(iv) specifies that at least 60% of the concrete (total mass of the constituents excluding water) should consist of the coarse aggregate specified in Appendix 7/1. This is to ensure that sufficient coarse aggregate is presented at the surface after brushing the laitance to expose the aggregate.

6 Hardness and durability of the coarse aggregate should be as described in sub-Clause 901.2.

7 (05/01) The compiler should specify in Appendix 7/1, coarse aggregate size and appropriate texture depth requirements using Table NG 10/3. A high speed road has an 85 percentile speed of traffic exceeding 90 km/h (55 miles/hour). The compiler should assess if the in-use traffic speed of the road is anticipated to be above this level.

8 The Contractor should be required to submit at the time of tender a completed Appendix 10/1, containing details of his proposed plant and equipment to achieve the required surface.

9 The Contractor is required to submit to the Overseeing Organisation for their consent a detailed method statement one month prior to the commencement of site trials. In the UK trials have been successfully concluded using conventional rail mounted paving equipment, but in the rest of Europe and elsewhere contractors have normally chosen to use slipform paving equipment.

TABLE NG 10/3 Grading and Texture Depth Requirements

CATEGORY OF ROAD	COARSE AGGREGATE SIZE	TEXTURE DEPTH REQUIREMENTS		
		AVERAGE	MAXIMUM	MINIMUM
High Speed Roads (> 90 km/h)	10-6 mm	1.5 mm ± 0.25 mm	1.80 mm	1.20 mm
Low Speed Roads (≤ 90 km/h)	8-4 mm	1.0 mm ± 0.20 mm	1.30 mm	0.75 mm

NG 1045 (05/01) Weather Conditions for Laying of Cementitious Materials

1 Thermal insulation blankets laid on the finished concrete can enhance the rapidity of curing by the retention of heat. This is of benefit not only in cold weather, but also at other periods to accelerate the curing of the concrete slab.

NG 1046 (05/01) Cold Recycled Cement Bound Material

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

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

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

Site Evaluation

Identification of Sites for Structural Maintenance by Cold Recycling.

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

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

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

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

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

(b) construction of existing pavement;

(c) type and severity of deterioration;

(d) subgrade bearing capacity and condition;

(e) location and condition of drainage;

(f) location and condition of services;

(g) edge detail and verge condition, and

(h) future traffic loading.

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

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

Investigation Framework

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

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

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

Alternative Recycling Strategies

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

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

Representative Test Specimens

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

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

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

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

Underground Services, Ducts and Culverts

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

Risk Assessment

20 Before drawing up a Contract involving the use of cold recycled materials, which are inherently more variable than plant produced new materials, the additional risks should be identified, apportioned and their management pre-planned to the satisfaction of all parties concerned. For this reason, the Overseeing Organisation and Contractor should be satisfied and agree that the existing pavement materials in all sections of the works, as defined in Appendix 7/19, are capable of being recycled by pulverisation, to form the primary aggregate component of a new cold recycled mixture. Also, that the mixture designed in accordance with sub-Clauses 1046.43 to 1046.49 for cement bound material is capable of being produced to meet the end-product performance requirements.

Component Materials

Pulverised Aggregate

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

22 Normally the cement bound recycling option is reasonably insensitive to the aggregate grading, nevertheless, an upper limit of 35 per cent by mass passing the 75 micron BS sieve is specified.

Moisture

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

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

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

Binder Agents

Primary Binder Agents

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

27 Cement is readily available and, apart from the potential for thermal cracking of stronger mixes, it has the advantage of being adaptable to a wide range of site conditions. Methods for safe working are well established and it is currently an accepted binder for mix-in-place CBM1 and CBM2, as described in Table 10/9.

Supplementary Binder Agents

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

Pulverisation and Stabilisation

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

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

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

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

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

Process Control

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

Cement-bound Material

35 Because of the similar nature of the cement bound recycled material to that of plant mixed CBM, significant sections of the Clauses for CBM apply equally well for the recycled option. The Specification refers directly to the option of using a mix-in-place method of construction for CBM1, CBM2 and CBM3 mixtures. In consequence, most of the Clauses given in the Notes for Guidance are also applicable to recycling.

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

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

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

Added Water and Moisture Control

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

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

Application of Cement or Hydrated Lime

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

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

Compaction

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

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

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

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

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

Surface Sealant

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

End-Product Performance Specification

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

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

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

As-Installed Stiffness Using a Dynamic Plate or Penetrometer Tests

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

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

Pavement Stiffness from Falling Weight Deflectometer (FWD) Survey

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

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

Compressive Strength/Stiffness Measurements of Core Specimens

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

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

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

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

Mixture Design and Characterisation

60 The design procedures adopted to date, have been developed by various organisations for their local needs although, in general, most mixture design procedures for cold recycled materials are based on the determination of compressive strength for cement bound material related to a recycled layer of specified thickness, to carry a required traffic loading over a stated period of time.

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

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

63 The detail of the procedure given in sub-Clauses 1046.43 to 1046.49 is based on the current industry practices, which will be developed when more representative specimens and test results can be verified.

Cement-bound Mixtures

64 For lower traffic situations, cold in-situ cement bound recycling is often used to provide a new foundation and/or structural course, designed to have an average 7-day cube compressive strength of 4.5 N/mm^2 or 7 N/mm^2 (i.e. either CBM1 or CBM2 equivalent strength).

65 For higher traffic loading, the recycled layer is used as the main structural course, designed to have an average 7-day cube compressive strength of 10 N/mm^2 (i.e. CBM3 equivalent). In ideal circumstances, this material might be considered structurally equivalent to plant mixed CBM of equal compressive strength. In practice, inherent variability of the feedstock materials, short mixing period and practical difficulties associated with thick-lift construction, will require a factor of safety to be applied to the design thickness. Further guidance is given in TRL Report 386.

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

NG 1047 (05/01) Induced Cracking of Cement and Hydraulically Bound Material

General

1 This Clause describes the method of inducing cracks in cement and hydraulically bound materials.

The insertion of a crack inducing material transversly across the pavement places a weakness in the material that allows shrinkage cracks to occur much more regularly than without inducement during curing. Further cracks may occur at the inducement locations during loading. The numerous small cracks reduce the forces in the surfacing that lead to reflection cracking. A crack 'pattern' is not formed when inducing cracks in CBM materials. The line of the crack can be determined either by:

a) the line of the indentation/surface spall when guillotining at 6 days or

b) bitumen lines on the surface when inducing cracks with the vibrating plate or CRAFT machine.

No surface indication is available with the OLIVIA technique

2 A groove will be formed within the material following laying, usually by a blade being run through the material prior to rolling. Specialist plant may be used to conduct this operation and insert the crack inducing material in a single operation. Alternatively, the use of a vibrating compaction plate with a metal blade welded perpendicular to the plate may be used to traverse the material and leave a groove.

3 Where it is found that a groove collapses before it is possible to insert the crack inducing material, the material mixture should be adjusted to give a more stable mixture or stability can be gained by extra compaction applied by the paver or a light finishing roller. If rolled prior to grooving, care must be taken to ensure full closing and compaction of the grooves following insertion of the crack inducing material.

4 Where bituminous emulsion is used as the crack inducing material, care will need to be taken to ensure complete coverage of the walls of the groove in the layer, without excessive pooling of emulsion at the bottom of the groove.

5 Where bitumen emulsion is used and this causes material to stick to the roller, additional layer material may be applied to cover the grooves prior to compaction.

Trial lengths

6 The trial is to prove the plant, equipment and methods proposed are suitable for use with the material being used. If the trial forms part of the finished pavement, any defective areas must be removed and replaced in accordance with the Specification, before any further paving is undertaken.

The contractor should be aware that the whip hammer method of inducing cracks does not comply with this sub-Clause.

NG 1048 (05/01) Use of surfaces by Traffic and Construction Plant

1 (05/02) Where there is a need to open a section of concrete pavement or base to traffic early after placing the concrete, high strength mixes may be used. To estimate the time when the required strength may be achieved trial mixes should be tested at various early periods to establish a rate of strength development. These times can be confirmed by testing cubes which were placed alongside the pavement in moulds insulated around the sides. However, such results can only be used as an expedient for the purpose and not for compliance with the Specification.

NG SAMPLE APPENDIX 10/1: (05/01) PLANT AND EQUIPMENT FOR THE CONSTRUCTION OF EXPOSED AGGREGATE CONCRETE SURFACE

The Contractor shall insert details below of the methods, plant and equipment he intends to use in the Works to construct an exposed aggregate concrete road surface to Clause 1044 and **shall submit this Appendix with his Tender**.

No. of Layers *[1044.3]*	a) One b) Two		....
Paving Equipment *[1044.6]*	a) Fixed Form b) Slip Form	i) Two Separate pavers ii) Two layer paver i) Two Separate pavers ii) Two layer paver	....
Retarder Type *[1044.12]*	a) Manufacturer b) Type reference		....
Brushing Details *[1044.8]*	a) Wet b) Dry		....
Brushing Equipment *[1044.23]*	a) On Slab b) Spanning Slab		....

Retarder Protection Method *[1044.16]* ....