Guidelines on the Depth of Overlay to be Used on Rural Non National Roads

May 1999

Printed on Recycled Paper

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DEPARTMENT OF THE ENVIRONMENT AND LOCAL GOVERNMENT

Contents

Acknowledgement

The Department of the Environment and Local Government wishes to acknowledge the role played by Mr Frank Clancy, National Roads Authority, in coordinating the preparation and drafting of these guidelines.

The Department also wishes to acknowledge the valued advice provided by Mr Michael Cahill, National Roads Authority and Mr John Tiernan, County Engineer, Cavan Co. Council representing the County and City Engineers Association.

1. Background to New Road Design

The evolution of road design based on the physical properties of the road materials began in earnest in the UK after the Second World War. The early design guides were based on surface deformation and cracking measurements carried out on full scale road experiments between 1950 and 1970. The performance of these pavements formed the basis of the first two editions of Road Note 29 in 1960 and 1965. The third edition of Road Note 29[(1)] published in 1970 included information on rolled asphalt and lean concrete road bases. The AASHO road test was carried out in the USA about this time also. This trial involved the construction of six purpose built test tracks in Illinois, USA. These tracks were then monitored while being trafficked by a wide range of axle configurations. This trial provided information for design guidelines based on Standard Axles.

With the rapid increase in axle load and volume of Heavy Commercial Vehicles, it became apparent that the empirical methods of Road Note 29 could not cope. A new approach was then taken to road design which was based primarily on the material properties of the road pavement and the load bearing capacity of the subgrade soil. This method is described in TRL's report LR1132 which was published in 1984[(2)].

2. *Design of New Granular Pavements*

Many non national roads in Ireland would be expected to carry from 0.5 to 2 Million Standard Axles(MSA) during a 20 year design life. These traffic volumes are in the range of Road Note 29 as opposed to LR1132. A study on thickness design for unbound gravel road pavements was carried out by J M Golden(3) in 1980. In this paper a thickness design method was formulated for granular pavements based on subgrade stiffness. The main design formula presented was:-

h(mm)		=	$635\ E2^{-0.468}\ N^{0.117}$	{1}
where	h	=	thickness of granular layer	
	E2	=	Stiffness Modulus of Subgrade(MN/m^2)	
	N	=	Design Number of Standard Axles	

Two formulae were also presented for estimating subgrade stiffness(E2 above) from California Bearing Ratio(CBR) test results. The following formulae were proposed:-

E2 (MN/m^2)	=	10 x CBR	{2}
E2 (MN/m^2))	=	17.9 (CBR)0.66	{3}

It was suggested that equation 3 may be more applicable in the case of boulder clays which are common in Ireland. However, this was not investigated at the time.

The design guidelines contained in this report relate to CBR values from 2 to 7 percent and traffic volumes up to 2.5 Million Standard Axles(MSA). Table 1 contains a summary of the design thickness values for these conditions. These values are compared with the corresponding design thickness from Road Note 29 in Table 2 for a design traffic loading of 1 MSA. The total design thickness in RC 218 are similar to those in Road Note 29 when a factor of 2:1 is used to convert from granular to bituminous bound material.

Table 1: Design Gravel mm Thickness Values based on RC218 (3)

	Design Number of Standard Axles			
Subgrade CBR	0.5 MSA	1 MSA	2 MSA	2.5 MSA
2	620	790	850	880
5	460	510	560	570
7	430	440	480	490

Table 2: Comparison of Design mm Thickness Values RC218 vs Road Note 29

	Design Thickness Values for 1 MSA			
Subgrade CBR	RC218	RN 29 Subbase	RN 29 Bituminous Layers*	Equivalent Granular Thickness***
2	787	440	158	756
5	512	210	158	526
7	438	150**	158	466

* Bituminous Layer = Dense Bitumen Macadam

** Minimum Road Note 29 Thickness

*** 2:1 Ratio for Bituminous to Granular Material

3. Overlay Design of Granular Pavements Using RC 218

An overlay design for granular pavements can be carried out using the methods described in RC 218. The thickness of granular material which must be used can be estimated using an adaptation of equation 1 taking the thickness of the existing layer into account. The formula then becomes:-

$$ho(mm) = 635\ E2^{-.468}\ (MN/m^2)\ N^{0.117} - he(mm) \qquad \{4\}$$

where; ho = Thickness of granular overlay

he = Existing thickness of granular material

N = Number of standard axles for overlay design life.

The only variable in the above which cannot readily be measured is the subgrade modulus E2. There are however several methods available to estimate this value.

The first is using either equation 2 or 3 above to estimate subgrade modulus from CBR. This is a quick method of estimating subgrade modulus. However, care must be taken with regard to sampling and moisture susceptibility of the soil. Road Note 29 contains a second method which predicts soil CBR based on liquid and plastic limit values. The advantage of this method is that it takes account of the moisture susceptibility of the soil. Estimated conversion factors for British soils are reproduced in Table 3[1] .

The main disadvantage of this type of overlay design is that it does not take into account the quality of the existing granular material in the road structure.

Table 3: Estimated Laboratory CBR Values for British Soils Compacted at the Natural Moisture Content

Type of Soil	Plasticity Index (percent)	CBR (Percent) Depth of water-table below formation	
		more than 600 mm	600 mm or less
Heavy Clay	70	2	1*
	60	2	1.5*
	50	2.5	2
	40	3	2
Silty Clay	30	5	3
Sandy Clay	20	6	4
	10	7	5
Silt	--	2	1*
Sand (poorly graded)	non plastic	20	10
Sand (well graded)	non plastic	40	15
Well graded sandy gravel	non plastic	60	20

Soils with plasticity indices of approximately 20% are most comparable with normal subgrade in Ireland

* Reference to Road Note 29 design of new roads with low soil CBR values

4. Overlay Design by Computer Analysis of FWD Data

4.1 General Description of FWD

During FWD testing, a load pulse is achieved by dropping a constant mass with rubber buffers attached through a particular height onto a loading platen. The load is usually transmitted to the pavement via a 300mm diameter loading plate. The loading plate has a rubber mat attached to the contact face and should preferably be segmented to ensure good contact with the road surface. The peak load is measured by a load cell placed between the platen and the loading plate. The resulting vertical deflection of the pavement is recorded by a number of geophones which are located on a radial axis from the loading plate. The FWD test set-up is shown diagrammatically in Figure 1(4).

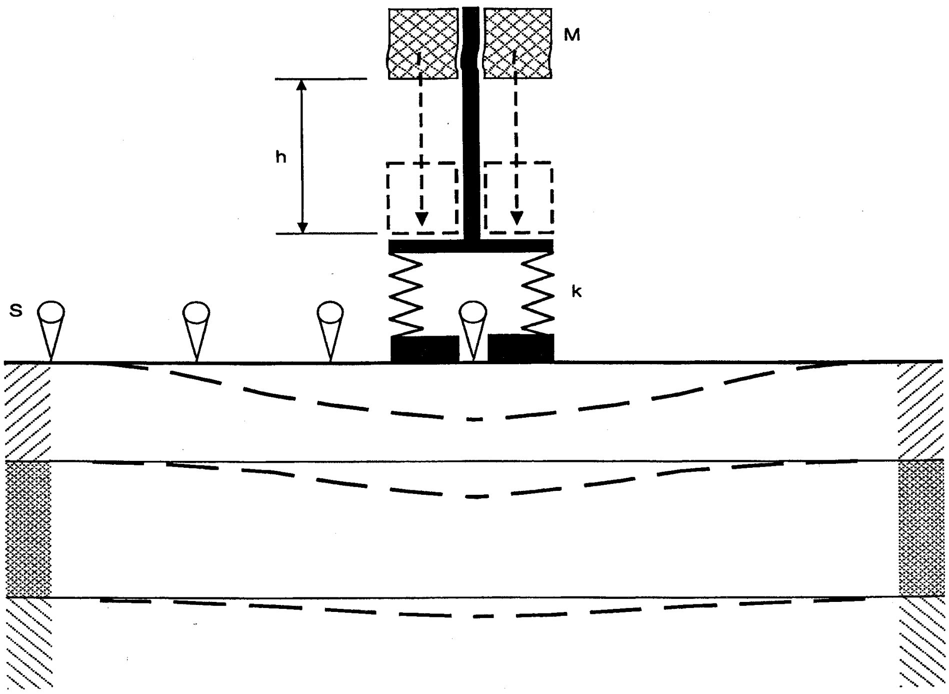

Fig. 1 Schematic diagram of an FWD

4.2 Overlay Design Using GWD

Overlay design using FWD deflections can be carried out using a number of methods. These methods calculate the in situ material properties which would be required to produce the same or similar deflection response to that recorded on site. One such package is the ELMOD(5) backcalculation process which is currently used by the NRA. This process uses either the "Method of Equivalent Thickness" or the "Deflection Basin Fit" method to calculate stiffness moduli. When the "Deflection Basin Fit" method is used, each measured deflection bowl is compared with deflection bowls which are contained in a database. An interpolation technique is then applied to obtain a set of layer moduli which minimises the squared error between measured and calculated deflections as shown in Equation 5:-

$$e^2 = \sum \left[1 - \frac{W_i^c}{W_i^m} \right]^2 * W_{ei} \qquad \{5\}$$

where e^2 is squared error

W_i^c computed deflection at sensor i

W_i^m measured deflection at sensor i

W_{ei} weighting factor for sensor i.

When using this procedure the pavement must first be modelled in the form of horizontal layers as shown in Figure 2. The thickness of these layers should be measured on site either from construction records or by digging trial pits. FWD deflection plots can be used as an effective method of choosing trial pit locations. FWD deflection criteria are described in Appendix A.

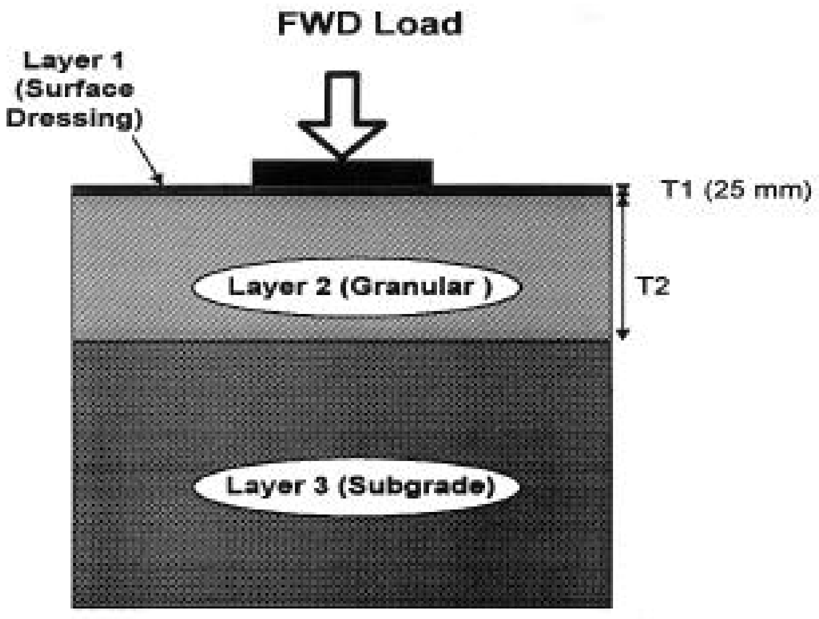

Figure 2: Typical Pavement Model for Non National Roads

The predicted traffic loading for the design period is also input into the pavement model. The program first calculates stiffness moduli for the various layers including subgrade. An overlay thickness is then calculated for each test point on the basis of the structural condition of the pavement at that point and the design traffic volume. A stiffness modulus of 4,000 MPa is often used for the overlay material. This stiffness value would be considered typical for dense basecourse macadam material.

The overlay thickness for a particular length of road can then be reported as an average or percentile value. The 85th Percentile value is often used for overlay design on National Roads. However, traffic volumes and speeds are generally lower on non national roads than on national roads. A lower probability of survival is therefore acceptable for these roads. For this reason, the average overlay value is usually used. In design philosophy terms, this implies that if all values chosen are truly accurate then 50 % of roads strengthened will exceed their 20 year design life to failure and 50 % will not. Failure in these circumstances is deemed to comprise a rut depth of 10 mm. Obviously 10 mm ruts on lower category non national roads would not be deemed inordinate in most circumstances where rut depths of the order of 50 mm often exist without giving rise to problems of pavement failure.

5. Integrated Approach to Overlay Design

Two separate design methods have been described so far. The method described in RC 218 is based on layer thickness and laboratory testing. The disadvantage of this approach is that it does not take into account the structural condition of the pavement unit. The FWD method is based on non-destructive site tests. An advantage of the FWD approach is that it takes account of the stiffness of the present structure.

FWD overlay calculations are usually based on the use of an overlay material with a high stiffness modulus such as dense bitumen macadam. Experience has shown that thin bituminous layers on weak pavements generally fail prematurely. Consequently, additional criteria are required to indicate where it is more practical to use a granular overlay or a combination of granular and bituminous overlays. The Surface Curvature Index(SCI) which is obtained from FWD deflection data is a measure of the load spreading properties of the upper layers and it is proposed that this parameter be used to identify when granular or bituminous material is most suitable. A range of SCI criteria are shown in Table A.1 (Appendix A) for non national roads. From this table, SCI values in excess of 250 microns (40 kN wheel load) indicate poor loadspreading ability. In such cases, a granular overlay should be the selected option so as to improve the overall bearing capacity of the road structure before consideration is given to the use of a composite Granular/ DBM overlay. DBM material alone should not be used in these cases.

The main choices for granular material are wet mix macadam (Cl. 810) and Cl. 804 subbase material. One of the differences between the two up to now is that there is a moisture content requirement for wet mix macadam but not for Cl. 804. This is significant in that the compaction and strength of these materials is affected by the insitu moisture content. There will be a moisture content requirement in the next specification for road works. In the new specification, Cl. 804 material "shall be laid and compacted at a moisture content within the range of optimum to 2 percent below the optimum ...." [(6)]. The relevant pages from the specification for Cl. 804 and Cl. 806 (new clause number for wet mix macadam) are included in Appendix C. The relevant specification should be used when Cl. 804 or wet mix material is to be used for overlay. Double surface dressing should be applied, on laying, to granular overlays(i.e. two surface dressing passes as soon as possible after laying). It is considered good practice to follow this double surface dressing with a further surface dressing when bedding in and initial settlement is deemed to have take place.

Table 4 contains a summary of some FWD test data. In this table the ELMOD method was used to calculate average bituminous overlay design thickness. A CBR value was then calculated from the ELMOD subgrade modulus using equation 3. This CBR value was then used to calculate a granular overlay thickness using RC 218.

Table 4: Summary of Deflection and Overlay Calculations

Review of Overlay Design Methods for Non National Roads Overlay Design for 1 MSA, Overlay in mm							
	Average Deflection (Microns)			Overlay Calculations			
Test Site	D1 (Under Load)	D1 - D2 (SCI)	D9 (2.1m)	Measured Granular Layer Thickness	Estimated Subgrade CBR (ELMOD)	Average Bituminous Overlay (ELMOD)	Average Granular Overlay (RC218)
A1	1030	385	43	300	4	102	269
A2	750	288	17	300	6	65	170
C1	511	183	24	250	10	38	120
C2	545	199	13	250	7	42	188
C3	444	189	11	250	13	23	78
D	804	348	16	250	6	77	221
E1	989	524	7	200	8	91	211
E2	704	291	10	200	6	73	271

Figure 3 contains a plot of ELMOD versus RC 218 overlay design values. The best fit line through this data set is shown on the plot. Based on this data set, the relationship between overlay based on RC 218 and ELMOD is as follows:-

RC 218 [Granular] = ELMOD [DBM] x 2.1 + 45 mm {6}

The coefficient of variation for this data set (R^2) is 0.675.

Comparison of ELMOD (DBM) and RC218 (Granular)
Overlay Thickness Values

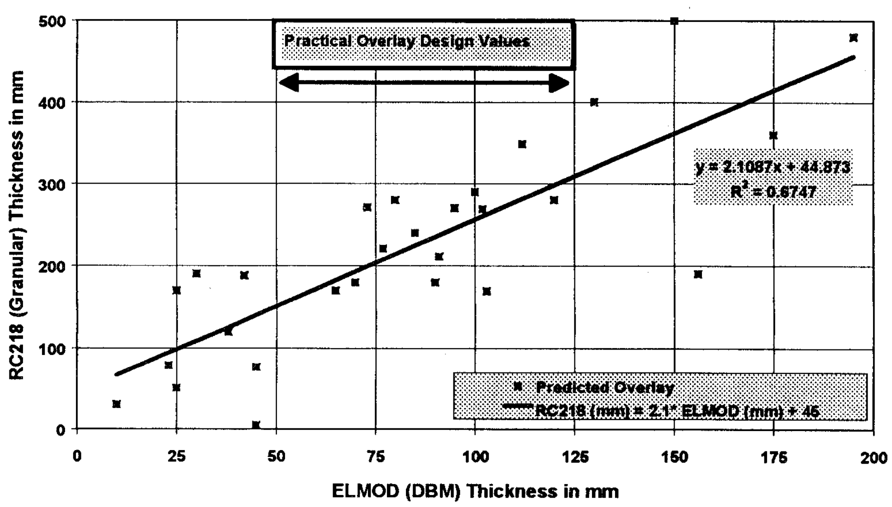

Figure 3: Overlay Design Results for Granular Pavements

6. *Practical Overlay Design Solutions*

The important physical parameters in this type of overlay design are traffic, existing granular thickness and subgrade CBR. The design number of standard axles for a given road can be predicted using the methods outlined in LR1132[2]. The AADT values quoted in Table 5 are the current AADT (in one direction) at the time of overlay. They have been used to calculate the design number of standard 80 kN axles in each direction. This design is based on a 20 year design life at a growth rate of 3 per cent and a heavy commercial vehicle content of 10 per cent. AADT is the total (in both directions) traffic count for a given road section and is usually divided in two for the purpose of pavement design as in Table 5. However, in the case of narrow roads (<= 4 m approximately), the driving lanes of the heavy commercial vehicles will overlap. In such cases, it would be more appropriate to use the measured (total) AADT value when using Table 5.

The existing thickness of granular material can be determined by digging trial pits. The condition of the granular material should also be noted i.e. whether it is gravel, crushed stone, graded or single size etc. Representative samples of the pavement materials should be taken and the grading and plasticity of the material determined for comparison with the unbound base and sub-base materials which meet current specifications. If the existing materials are shown to be of poor quality, the measured thickness of existing granular material should be reduced to a suitable equivalent depth for use in Table 5. The subgrade soil should be sampled in order to establish its CBR value. As stated earlier the subgrade CBR can be measured in a number of ways. Where compressive subgrades exist, specialist advice should be sought. A sample trial pit record sheet is shown in Appendix B.

Table 5 contains a range of sample overlay design thickness values. The design data used in Table 5 is intended to cover the range of conditions encountered in practice on non national roads. The overlay design values contained in Table 5 are typical of those estimated using backcalculation of FWD deflections. The design values using this method are often less than those calculated using the methods in RC 218. This is due in part to the current use of higher quality granular materials. The thickness values reported are based on the use of a good quality granular material such as wet mix macadam with a double surface dressing.

The minimum and maximum practical overlay design thickness values for granular material (Wet Mix Macadam, Cl. 804) are 150 and 300 mm respectively. Table 6 contains draft equivalent thickness factors for granular material, stabilised wet mix, composite construction(wet mix plus bituminous carpet) and bituminous bound only. The specifications contained in Appendix C should be used when specifying the use of wet mix macadam or Cl. 804 for this purpose.

Stabilised wet mix macadam is a cold mixed emulsion bound macadam which uses the wet mix macadam aggregate grading. Design mixes of this material are subject to laboratory tests which measure both the wet and dry compressive strength of the mix. The specimens are compacted in the laboratory using the Duriez compaction technique. There is a provisional specification available for this material[7]. This provisional specification is included in Appendix D.

Table 5: Typical Wet Mix Macadam Overlay Design Thickness Values for Rural Roads

Existing Granular Thickness 100 to 200 mm					
Subgrade CBR	Current AADT (total in one direction)**				
	0-200	201-1,000	1,001-2,000	2,001-3,250	3,251-4,500
1.5 - 3	150*	200	250	300	-
3 - 5	100*	150	200	250	300
> 5	100*	150	150	200	250
Existing Granular Thickness 201 to 300 mm					
Subgrade CBR	Current AADT (total in one direction)**				
	0-200	201-1,000	1,001-2,000	2,001-3,250	3,251-4,500
1.5 - 3	100*	150	200	250	300
3 - 5	-	150	150	200	250
> 5	-	-	150	150	200
Existing Granular Thickness 301 to 400 mm					
Subgrade CBR	Current AADT (total in one direction)**				
	0-200	201-1,000	1,001-2,000	2,001-3,250	3,251-4,500
1.5 - 3	-	150	150	200	250
3 - 5	-	-	150	150	200
> 5	-	-	-	150	150

* The use of a bituminous bound option is excluded for overlay in this case

** On roads narrower than 4m, use Current AADT (total of both directions)

Note 1: Where the existing granular layer thickness is less than 100 mm, the difference between the existing thickness and 100 mm should be added to the design overlay

Note 2: This table is not applicable when subgrade CBR is less than 1.5. When this is the case, consideration should be given to the use of increased thickness and/or the use of geotextiles

Note 3: This table is based on a 20 year design life, 3% per annum growth rate and 10% Heavy Commercial Vehicle content

Note 4: GOOD DRAINAGE IS ESSENTIAL in order to maintain road bearing capacity

Table 6: Approximate Equivalent mm Thickness Values

Wet Mix Macadam*	Stabilised Wet Mix	Wet Mix / DBM	Dense Bitumen Macadam (DBM)
150*	100	-	70**
200*	150	-	100**
250*	180	150 / 50	120**
300*	200	200 / 50	140**

* Cl. 804 may be substituted for Wet Mix Macadam for current AADT <= 500. For current AADT > 500, Cl. 804 thickness should be 50 mm greater than the indicated Wet Mix Macadam design thickness

** DBM alone should not be used for SCI > 250 microns (40 kN wheel load)

7. Drainage

Road drainage is essential if the bearing capacity of the pavement structure is to be maintained. The most suitable type of drainage to be used will generally depend on the particular circumstances of the road. The main options available are open, piped or filter drainage systems. Open drainage systems are preferred as they allow early (visual) detection of blockages etc. The problems associated with this type of drainage can be lack of installation space along the road width together with the risk that open drains may be closed in by agricultural machinery. Piped and filter drainage systems can be used to good effect where space is limited. These systems require regular maintenance of gullies etc. to ensure free drainage paths.

8. General Recommendations

8.1 Recommended Approach for Local Authorities

(a) Approach Using FWD

- Use soil maps and/ or local knowledge to divide the County into areas having assumed similar subgrades and depths of existing granular construction.
- Undertake a FWD survey and trial pits on a sample of roads representative of each subgrade type and construction depth.
- Utilise the FWD results and these guidelines to develop tables indicating the allowable overlay type (granular only, granular/ bituminous or bituminous only) and wet mix overlay thickness required on each sampled road under various levels of AADT/ percent HCV.
- Utilise these local thickness tables as guides when developing five year programs of overlay work on non national roads.

(b) Approach Using CBR Data

- Use soil maps and/ or local knowledge to divide the County into areas having assumed similar subgrades and depths of granular construction as in a) above.
- Use data from sample trial pits in these areas to estimate typical values for existing construction depth and subgrade CBR.
- Utilise the CBR results and these guidelines (Table 5) to develop tables indicating the allowable overlay type (granular only, granular/ bituminous or bituminous only) and wet mix overlay thickness required on each sampled road under various levels of AADT/ percent HCV.
- Utilise these local thickness tables as guides when developing five year programs of overlay work on non national roads as in a) above.

8.2 Requirement for FWD Providers

- The software system used should be capable of recommending overlay thickness values in terms of wet mix macadam.
- From the magnitude of the recorded SCI values (Table A.1 of Appendix A), the software should indicate whether the present pavement is strong enough to allow the use of a bituminous overlay only and, if strong enough, also recommend overlay thickness in terms of dense bituminous macadam.

8.3 Section overlay design value

The average overlay design value is often used for non national road test lengths. In effect, this means that some sections of the road under consideration will be under designed. It is usually more cost effective to use this average value and replace the most seriously disintegrated, cratered and badly cracked areas prior to full scale overlay. This will have the effect of improving the most critical sections and so reduce the risk of premature failure.

8.4 Wearing Course Macadam

Wearing course macadam should not be used in the rehabilitation of non national roads.

8.5 Design Thickness/ Nominal Size Values

The design thickness values used should be consistent with the nominal size of the material being used. This is important to ensure proper compaction of the layers. For example, the nominal and minimum thickness values given in Table 1, BS 4987: Part 2(8) should be referred to when specifying dense bituminous bound macadam. This table has been reproduced in Appendix E.

8.6 Drainage

Adequate road drainage which may be open, piped or filter should be provided in conjunction with overlays. This is to ensure that the bearing capacity of the road structure is maintained.

8.7 Quality Control of Site Operations

- Adequate sampling and testing of materials is essential to ensure that the works are carried out in accordance with the relevant specifications. A minimum sampling rate of one sample per material per site per day is desirable.
- The supervising engineer should visit each site each day of the works to ensure that quality control, level control etc. checks are being carried out.

8.8 Surface Dressing

- Surface dressing should be applied to dense bitumen macadam overlays as soon as is practicable for skid resistance purposes.
- Double surface dressing should be applied, on laying, to granular overlays(i.e. two surface dressing passes as soon as possible after laying Cl. 804/ Wet Mix). It is considered good practice to follow this double surface dressing with a further

surface dressing when bedding in and initial settlement is deemed to have taken place.

8.9 Standards for overlay works

An appendix such as that in Appendix F[9] should be included in all specifications for overlay of non national roads

9. Conclusions

This document deals with road structures where the main structural element is unbound granular material which is typically surface dressed. The most scientific approach to overlay design is to base the design on a measurement of the existing load bearing capacity of the pavement structure.

- This can be done using FWD in the following manner;
  - FWD survey at 50m intervals in one direction excepting where highly variable subgrades are suspected.
  - Examination of FWD plots to identify homogenous sub-sections.
  - Trial pits in strategic locations to provide most useful information.
  - Overlay design using backcalculation system (such as ELMOD) based on trial pit information and traffic data.
  - Examination of overlay design thickness in conjunction with SCI values to determine most appropriate overlay strategy, i.e. SCI values greater that 250 microns (40 kN) require granular or composite Granular/ DBM overlay.
- The alternative approach using RC 218 is as follows;
  - Excavation of trial pits based on visual inspection of road.
  - Laboratory analysis including CBR, Liquid and Plastic Limit tests to measure subgrade CBR.
  - Design thickness of granular overlay using above information and formulae in RC 218.
- In practice, Local Authorities should use either the FWD method or the CBR method outlined in Section 8.1.
- All seriously disintegrated, cratered and badly cracked areas should be replaced with good quality material prior to full scale overlay. Good drainage is also important in order to maintain the bearing capacity of the road structure.
- A named person should be indicated for the role of co-ordination of sampling and testing of materials to ensure that the works are carried out in accordance with the requirements of the relevant standards and contract specifications. This person must be given adequate access to a test facility in order that quality control can be carried out on a daily basis.

10. References

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8. British Standards Institution, *Coated macadam for roads and other paved areas*, BS 4987: Part 2: 1993.

9. Department of the Environment, *Appendix 3 of Circular RW 7/96 of guidelines on the preparation of the Regional and County Road Restoration Program*

Appendix A: Description of FWD Analysis

A.1 Test Method

The DYNATEST 8000 FWD TEST SYSTEM is one method available for carrying out FWD surveys. Using this system, the loading pulse is achieved by dropping a constant mass with rubber buffers through a particular height onto a loading platen. The load is then transmitted to the pavement via a 300mm diameter loading plate. The peak load is measured by a load cell placed between the platen and the loading plate. The resulting vertical deflection of the pavement is recorded by 9 geophones which are located on a radial axis from the loading plate. The location of these geophones is shown in Figure A.1.

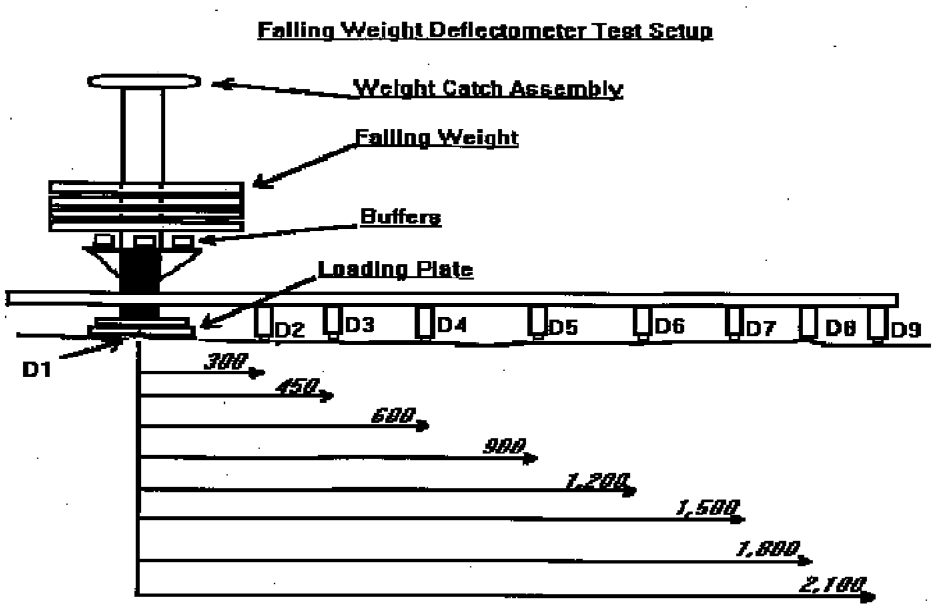

Figure A.1: Common Location of FWD Deflection Sensors

The testing sequence used on site is set up using a Field Program. This program allows a number of drops from various heights at each test location. The resulting load and deflection information is then stored for later calculation. The air and pavement temperatures are also recorded.

A series of four drops per test location is usually used. In the case of flexible roads the drop heights used produce loads varying in magnitude from 25 kN to 60 kN approximately. The deflections normalised to a load of 40 kN(Standard Wheel Load) are often used in the analysis of flexible pavements.

A.2 Explanation of Plots

A sample FWD deflection plot is shown in Figure A.2. The three main deflection parameters which are used in the initial assessment of pavements are Central Deflection (D1), Surface Curvature Index (D1 - D2) and one of the outer deflections (D9). The D1 plot gives an indication of the overall structural condition of the pavement.

The Surface Curvature Index plot (D1-D2) indicates the condition of the upper pavement layers. Low values of SCI suggest good load spreading ability of these layers. In cases where this plot takes the same shape as the D1 plot then the upper layers have a large influence on the pavement structural condition.

The third plot (D9) relates to the subgrade strength. Low values here indicate a stiff subgrade. In cases where this plot takes the same shape as the D1 plot then the subgrade layer has a large influence on the pavement structural condition. Tables A.1 and A.2 contain guideline deflection criteria for granular roads based on observation.

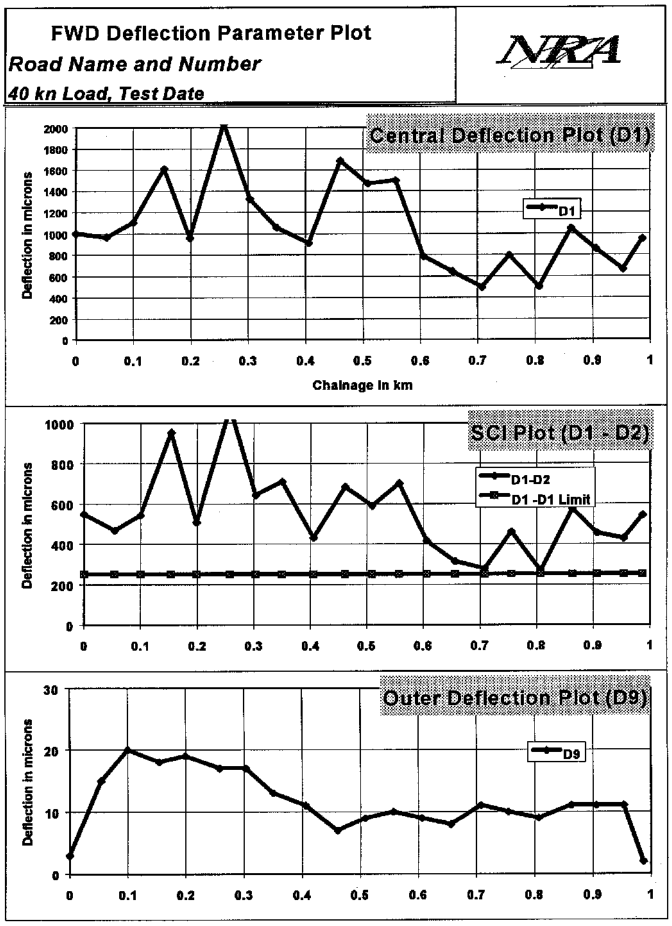

Figure A.2: Sample FWD Plot

Table A.1: Central and SCI Deflection Criteria for Non National Roads

Central and Surface Curvature Index (SCI) Criteria *Note: All deflections (microns) normalised to 40 kN Load*		
Central Deflection (D1)	SCI (D1 - D2)	Comment
< 300	< 150	Good Load Spreading Ability
300 - 500	150 - 250	Good to Poor Load Spreading Ability
501 - 800	251 - 400	Poor to Bad Load Spreading Ability
> 800	> 400	Bad Load Spreading Ability

Table A.2: Outer Deflection Criteria for Non National Roads

Outer Deflection (@ 2.1 m) Criteria *Note: All deflections (microns) normalised to 40 kN Load*	
Outer Deflection (D9 @ 2.1 m)	Comment
< 15	Stiff Subgrade
15 - 30	Stiff to Moderate Subgrade
31 - 45	Moderate to Weak Subgrade
>45	Weak Subgrade

A.3 Overlay Design

Overlay design using FWD deflections can be carried out using a number of methods. The design procedure contained in ELMOD 4 is one such system. In this system, the insitu stiffness moduli are calculated the from the FWD deflections using one of two methods available. The two methods available in this program are the "Method of Equivalent Thickness" and the "Deflection Basin Fit" method. These methods are also used by many other backcalculation programs.

When using this procedure the pavement must first be modelled in the form of horizontal layers. The thickness of these layers should be measured on site either by digging trial pits or cutting cores. The deflection plots can be used as a means of choosing trial pit or core locations.

The predicted traffic loading for the design period is also input into the pavement model. An overlay thickness is then calculated for each test point on the basis of the structural condition of the pavement at that point and the design traffic volume. In most cases a stiffness modulus of 4,000 MPa is used for the overlay material. This stiffness value would be considered typical for dense basecourse macadam material. In the case of many non national roads, a much lower design stiffness value of the order 200 - 300 MPa will be used.

The average and 85th Percentile overlay values are usually calculated. The 85th Percentile value is usually used for overlay on National Roads, while the average value is often used for non national roads. The calculated overlay values can be plotted to give a visual indication of the range of overlay requirement. In many cases remedial action will be required prior to the use of an overlay carpet.

Appendix B: Sample Trial Pit Log

Appendix B: Sample Trial Pit Log

Road Name, Number;	Trial Pit No.	Date	Time
Location on Road;			

Other Information (Chainage etc.);

Excavation Method;

Description of Material;	Layer Thickness (mm)	Total Depth (mm)	Sample Depth (mm)
1. Road Surface (Type, Cracking etc.)			
2. Bituminous Bound Layers			
3. Granular Layers (Type, grading, cleanliness etc.)			
4. Subgrade Soil (Type, moisture content etc.)			

Ground Water Conditions/ Road Drainage

Other Remarks (Surrounsing vegaitation etc)

Signed ______________ on behalf of ______________ Co. Council

Appendix C: Specification for Clause 804 and Clause 806 (Wet Mix Macadam)

Notes:

1. Appendix 7.1 of the Specification for Road Works deals with the permitted options for road construction
2. Sub-clauses 8 to 11 from Clause 806 (Wet Mix Macadam) have been included as sub-clauses 7 to 10 in the Clause 804 Specification below. These sub-clauses apply when Clause 804 is being used as an overlay material in place of Wet Mix Macadam (see footnote to Table 6 on page 16).

Specification for Road Works

Series 800

ROAD PAVEMENTS - UNBOUND MATERIALS

801 Unbound Materials for Sub-bases and Roadbases

1 Unbound sub-bases and roadbases shall be made and constructed using materials described in the following Clauses. The permitted alternatives for each part of the Works shall be as described in Appendix 7/1.

2 Materials when placed within 500 mm of cement-bound materials, concrete pavements, concrete structures or concrete products shall have a water soluble sulphate content not exceeding 1.9 g of sulphate (expressed as SO_3) per litre when tested in accordance with BS 1377 : Part 3.

3 Except where otherwise stated in Appendix 7/1, unbound material up to 225 mm compacted thickness shall be spread in one layer so that after compaction the total thickness is as specified. Unbound material of compacted thickness greater than 225mm shall be laid in two or more layers and the minimum compacted thickness of any such layer shall be 110 mm. Where the layers of unbound material are of unequal thickness the lowest layer shall be the thickest layer.

802 Compaction

1. Compaction shall be completed as soon as possible after the material has been spread and in accordance with the requirements for the individual materials.
2. Special care shall be taken to obtain full compaction in the vicinity of both longitudinal and transverse joints.
3. Compaction of unbound materials shall be carried out by a method specified in Table 8/1, unless the Contractor demonstrates at site trials that a state of compaction achieved by an alternative method is equivalent to or better than that using the specified method. The procedure for these trials shall be subject to approval by the Engineer.
4. Compaction of any layer of material shall continue until the material is free from movement under compaction plant. The surface of any layer of material shall on

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

5. For the purposes of Table 8/1 the following shall apply:

(i) The number of passes is the number of times that each point on the surface of the layer being compacted shall be traversed by the item of compaction plant in its operating mode (or struck, in the case of power rammers).

(ii) The compaction plant in Table 8/1 is categorised in terms of static mass. The mass per metre width of roll is the total mass on the roll divided by the total roll width. Where a smooth-wheeled roller has more than one axle, the category of the machine shall be determined on the basis of the axle giving the highest value of mass per metre width.

(iii) For pneumatic-tyred rollers the mass per wheel is the total mass of the roller divided by the number of wheels. In assessing the number of passes of pneumatic-tyred rollers the effective width shall be the sum of the widths of the individual wheel tracks together with the sum of the spacings between the wheel tracks provided that each spacing does not exceed 230 mm. Where the spacings exceed 230 mm the effective width shall be the sum of the widths of the individual wheel tracks only.

(iv) Vibratory rollers are self-propelled or towed smooth-wheeled rollers having means of applying mechanical vibration to one or more rolls:

(a) The requirements for vibratory rollers are based on the use of the lowest gear on a self-propelled machine with mechanical transmission and a speed of 1.5-2.5 km/h for a towed machine or a self-propelled machine with hydrostatic transmission. If higher gears or speeds are used an increased number of passes shall be provided in proportion to the increase in speed of travel.

(b) Where the mechanical vibration is applied to two rolls in tandem, the minimum number of passes shall be half the number given in Table 8/1 for the appropriate mass per metre width of one vibrating roll but if one roll differs in mass per metre width from the other, the number of passes shall be calculated as for the roll with the smaller value. Alternatively the minimum number of passes may be determined by treating the machine as having a single vibrating roll with a mass per metre width equal to that of the roll with the higher value.

(c) Vibratory rollers operating without vibration shall be classified as smooth- wheeled rollers.

(d) Vibratory rollers shall be operated with their vibratory mechanism operating at the frequency of vibration recommended by the manufacturer. All such rollers shall be equipped, or provided with devices indicating the frequency at which the mechanism is operating and the speed of travel. Both devices shall be capable of being read by an inspector alongside the machine.

(v) Vibrating-plate compactors are machines having a base-plate to which is attached a source of vibration consisting of one or two eccentrically-weighted shafts:

(a) The mass per square metre of base-plate of a vibrating-plate compactor is calculated by dividing the total mass of the machine in its working condition by its area in contact with compacted material.

(b) Vibrating-plate compactors shall be operated at the frequency of vibration recommended by the manufacturer. They shall normally be operated at travelling speeds of less than 1 km/h but if higher speeds are necessary, the number of passes shall be increased in proportion to the increase in speed of travel.

(vi) Vibro-tampers are machines in which an engine driven reciprocating mechanism acts on a spring system, through which oscillations are set up in a base-plate.

(vii) Power rammers are machines which are actuated by explosions in an internal combustion cylinder; each explosion being controlled manually by the operator. One pass of a power rammer shall be considered to have been made when the compacting shoe has made one strike on the area in question.

(viii) Combinations of different types of plant or different categories of the same plant will be permitted; in which case the number of passes for each shall be such proportion of the appropriate number in Table 8/1 as will together produce the same total compactive effort as any one operated singly, in accordance with Table 8/1.

TABLE 8/1: Compaction Requirements for Unbound Materials in Road Pavements

Type of Compaction plant	Category	Minimum number of passes for layers not exceeding the following compacted thickness:		
		110mm	150mm	225mm
Smooth-wheeled roller (or vibratory roller operating without vibration)	Mass per metre width of roll:			
	over 2700 kg up to 5400kg	16	unsuitable	unsuitable
	over 5400kg	8	16	unsuitable
Pneumatic-tyred roller	Mass per wheel:			
	over 4000kg up to 6000kg	12	unsuitable	unsuitable
	over 6000kg up to 8000kg	12	unsuitable	unsuitable
	over 8000kg up to 12000kg	10	16	unsuitable
	over 12000kg	8	12	unsuitable
Vibratory roller	Mass per metre width of vibrating roll:			
	over 700kg up to 1300kg	16	unsuitable	unsuitable
	over 1300kg up to 1800kg	6	16	unsuitable
	over 1800kg up to 2300kg	4	6	10
	over 2300kg up to 2900kg	3	5	9
	over 2900kg up to 3600kg	3	5	8
	over 3600kg up to 4300kg	2	4	7
	over 4300kg up to 5000kg	2	4	6
	over 5000kg	2	3	5
Vibrating-plate compactor	Mass per square metre of base plate:			
	over 1400kg/m^3 up to 1800kg/m^3	8	unsuitable	unsuitable
	over 1800kg/m^3 up to 2100kg/m^3	5	8	unsuitable
	over 2100kg/m^3	3	6	10
Vibro-tamper	Mass:			
	over 50kg up to 65kg	4	8	unsuitable
	over 65kg up to 75kg	3	6	10
	over 75kg	2	4	8
Power rammer	Mass:			
	100kg - 500kg	5	8	unsuitable
	over 500kg	5	8	12

804 Granular Material Type B

1. Type B granular material shall be crushed rock. The material shall be well-graded, and lie within the grading limits of Table 8/3.

2. The material passing the 425 µm BS sieve shall have a liquid limit, determined in accordance with the cone penetrometer method (definitive method) in BS 1377: Part 2, not greater than 20 for limestone and 21 for all other rock types.

3. The material shall be laid and compacted at a moisture content within the range of the optimum to 2 per cent below the optimum percentage determined in accordance with the vibrating hammer method test in BS 1377: Part 4, and without drying out or segregation.

4. The material shall have a ten per cent fines value of 130 kN or more when tested in compliance with BS 812 : Part 111. The test sample shall be in a soaked condition at the time of test.

5. The flakiness index shall be less than 45 when determined in accordance with BS 812: Section 105.1.

6. The aggregate source, when tested in accordance with BS 812 : Part 121, shall have a soundness value greater than 75, or such lower value as may be required in Appendix 7/1. Thereafter for routine testing of such aggregates, the water absorption value of the coarse aggregate shall be determined as in BS 812 : Part 2. If the absorption value of the coarse aggregate is greater than 2%, the soundness test shall be carried out on the material delivered to site.

Laying and Compaction (From Cl. 806)

7. The compacted thickness of each layer shall not be more than 150 mm.

8. Compaction of wet-mix macadam shall be carried out in accordance with the requirements of Clause 802, using vibrating rollers having a mass per metre width of vibrating roll of at least 1800 kg.

9. The material shall be protected from weather during transit to the site, whilst awaiting tipping and during laying.

10. On completion of compaction the surface of the material shall be sealed with cationic bitumen emulsion (70 per cent bitumen) sprayed at a rate between 1.1

and 1.4 litre/m^2, covered with 6 mm chippings at a rate of spread of 6 to 8 kg/m^2, and lightly rolled.

Table 8/3: Granular Material Type B

Range of Grading	
BS Sieve Size	Percentage by mass passing
75 mm	100
37.5 mm	85-100
10 mm	40-70
5 mm	25-45
600 µm	10-22
75 µm	0-8
The particle size shall be determined by the washing and sieving method of BS 812: Part 103	

806 Wet-Mix Macadam

1 Wet-mix macadam shall be made and constructed in the following manner.

Aggregate

2 The coarse and fine aggregate shall consist of crushed rock and the aggregate shall have the grading shown in Table 8/5.

3 The material shall have a 10% fines value of 130 kN or more when tested in compliance with BS 812: Part 111 except that the samples shall be tested in a saturated and surface dried condition. Prior to testing the selected test portions shall be soaked in water at room temperature for 24 hours without previously having been oven dried.

4 The flakiness index shall be less than 40 when determined in accordance with BS812: Section 105.1.

5 The material passing the 425 µm BS sieve shall have a liquid limit, determined in accordance with the cone penetrometer method (definitive method) in BS 1377: Part 2, not greater than 20 for limestone and 21 for all other rock types.

6 The aggregate source, when tested in accordance with BS 812: Part 121, shall have a soundness value greater than 75, or such lower value as may be required in Appendix 7/1. Thereafter for routine testing of such aggregates, the water absorption value of the coarse aggregate shall be determined as in BS 812: Part 2.

If the absorption value of the coarse aggregate is greater than 2%, the soundness test shall be carried out on the material delivered to site.

Moisture Content

7. The material shall be transported, laid and compacted at a moisture content within the range 0.5 to 1.5 percent below the optimum percentage determined in accordance with the vibrating hammer method test in BS 1377: Part 4 and without drying out or segregation.

Laying and Compaction

8. The compacted thickness of each layer shall not be more than 150 mm.

9. Compaction of wet-mix macadam shall be carried out in accordance with the requirements of Clause 802, using vibrating rollers having a mass per metre width of vibrating roll of at least 1800 kg.

10. The material shall be protected from weather during transit to the site, whilst awaiting tipping and during laying.

11. On completion of compaction the surface of the material shall be sealed with cationic bitumen emulsion (70 per cent bitumen) sprayed at a rate between 1.1 and 1.4 litre/m^2, covered with 6 mm chippings at a rate of spread of 6 to 8 kg/m^2, and lightly rolled.

Table 8/5: Mix Macadam

Range of Grading	
BS Sieve Size	Percentage by mass passing
50 mm	100
37.5 mm	95-100
20 mm	60-80
10 mm	40-60
5 mm	25-40
2.36 mm	15-30
600 µm	10-22
75 µm	0-8
The particle size shall be determined by the washing and sieving method of BS 812: Part 103	

Appendix D: Provisional Specification for stabilised wet-mix macadam

Stabilised Wet-Mix Macadam

1. Stabilised wet-mix macadam shall be designed, manufactured and laid in accordance with the recommendations in the French Ministry of Equipment Specification "Directive Pour la Realisation des assiser de chaussée en grave-émulsion" and comply with the following sub-clauses and with the appropriate requirements set down in series 700 of the Department of the Environment Specification for Road Works.

Aggregate

2. The coarse and fine aggregate shall consist of crushed rock complying with the requirements of Irish Standard Specification IS5, "Aggregates for concrete" as regards quality and cleanliness. In addition the fines passing the 425 micron sieve shall be non-plastic. The aggregate shall have a ten per cent fines value of 130 kN or more when tested in a soaked condition in accordance with BS.812: Part III: 1990.

Filler

3. If filler is required it shall consist of crushed rock portland cement or other material approved by the Engineer. The quality of filler shall comply with the requirements of BS.4987: Part I: 1993.

Binder

4. The binder shall be Cationic Bitumen Emulsion (63% Nominal Bitumen content) and shall comply with the requirements set out in Table 8/10. The bitumen used in the emulsion shall comply with the specification issued by the Department of the Environment for penetration grade petroleum bitumens and be within the grade range of 170-230 penetration. The Bitumen Content of the stabilised wet-mix macadam shall be within the range 3.3%±0.3% by mass of total mixture excluding moisture content.

Materials

5. Before coating the aggregate shall be clean, free of organic matter or contamination from clay. The aggregate shall be stockpiled on a hard clean base and in such a manner to enable the stockpile to drain quickly. The moisture content of the combined aggregate shall not be greater than 3.5%, before mixing with the emulsion. All aggregates used in the mix shall not be susceptible to frost.

Table 8/10: Specification for Cationic Bitumen Emulsion (63 per cent Bitumen Content) for use in Stabilised Wet-Mix Macadam

GRADE OF CATIONIC EMULSION (Binder content - nominal percent by Mass) 63%			
Property	Test Method	Specification	
		Minimum	Maximum
Particle Charge Test	ASTM D 244 Sections 19-20	Positive	
Viscosity °Engler 20°C	I.P.212	6	12
Storage Stability Test 1 day (% by mass)	ASTM D 244 Sections 56-62	-	1
Sieve Test (% by mass 850 micron sieve)	ASTM D 244 Sections 38-41	-	0.10
Distillation Oil distillate by volume of emulsion %	ASTM D 244 Section 8-10	-	1.0
Residue % by mass	ASTM D 244 Sections 8-10	61	-
Test on Residue from Distillation Test			
Penetration at 25°C (100 g 3 sec.)	I.P.49	100	250
Solubility in Trichloroethylene % by weight	I.P.47	99	-

General: The emulsifying agent should not exert any deleterious effects on the bitumen deposited and should be such that any drainage, washings or the like passing from the work into streams, ponds, rivers, etc. should not after dilution in water have any toxic effect upon plant, animals or fish life.

Test methods will be in accordance with "I.P. standards for petroleum and its products" current edition, published by the Institute of Petroleum, or, where stated, in accordance with the "Annual Book of A.S.T.M. Standards" current edition, published by the American Society for Testing and Materials.

Mixing

6. The materials including any added filler shall be accurately weighed or measured into a mechanical mixer of approved type and thoroughly mixed. The weighing or measuring mechanism shall at all times be maintained within the accuracies recommended by the manufacturer.

Composition of Mixed Material

7. The material, to the nominal size of aggregate described in the Contract, shall consist of an intimate mixture of coarse aggregates, fine aggregate, filler if necessary, and binder, combined in proportions to lie within the limits set out in Table 8/11.

The mixture shall satisfy the following criteria when compacted and tested in the manner laid down in BS.E4 of the French 'Laboratoire Central des Ponts et Chaussees' (LCPC) specification "Test for simple compression of hydrocarbon coated materials, using emulsions".

Immersion - Compression Test at 18°C	Not less than
Compactivity LCPC (geometric measurement)	> 85%
Resistance to compression - using 120 mm diameter moulds	> 30 kN
Immersion/Compression Ratio	> 0.55

Acceptance of Design Mix

8. At least four weeks before laying is to commence, the Contractor shall submit details of the mixture he intends to use to the Engineer for approval. These details shall include the following information:

(i) Grading curve (per cent by mass passing)

(ii) Bitumen content (per cent of total mass excluding moisture content)

(iii) Composition of mixture (percentages of constituents)

(iv) Emulsion type (Bitumen Content and specification)

(v) Mix design data showing compactivity, resistance to compression and immersion/compression ratio

The type of emulsion, the type of aggregate used in the mix and the moisture content of the mix are important factors in the break of the emulsion, the adhesion of the residual binder, the compactability and resistance to compression of the mix and its immersions/compression ratio. It is therefore necessary to examine the behaviour of different emulsions and aggregates formulations in order to obtain the optimum mix.

Table 8/11: Stabilised Wet-Mix Macadam

Nominal Maximum Size (mm)	37.5
Range of thickness of compacted course (mm)	60-120
Binder Grade 0 Cationic bitumen emulsion (63% bitumen content)	170-230 penetration bitumen
Bitumen Content (percentage by mass of total mixture excluding moisture content)	3.0-3.6
Moisture Content (before compaction percentage by mass of total mixture)	3-5
Aggregate Grading (*percentage by mass passing)	
BS Sieve Size	
50 mm	-100
37.5 mm	95-100
20 mm	60- 80
10 mm	40- 60
5 mm	25- 40
2.36 mm	15- 30
600 µm	8- 22
75 µm	0 - 8
*In addition to complying with the above grading envelopes at least 4 per cent by mass shall be retained between any consecutive sieves.	

Acceptance of Plant Mixes

9. Before full scale laying commences the Contractor shall prove to the Engineer by the laying of a preliminary trial length at a location approved by the Engineer that the stabilised wet-mix macadam he intends to supply complies with the specified requirements. For the trial the Contractor shall use the materials, mix proportions, mixing, laying, compaction plant and construction procedure that he proposes for the main work. The stabilised wet-mix macadam and its job-mix formula will be agreed after verification of the specified requirements, texture and appearance of coating at this trial.

Tolerance Limits

10. Agreement will be reached between the contractor and the Engineer on the job-mix material, its composition shall comply with the requirements of Table 8/11 and with the job tolerance specified in Table 8/12.

Table 8/12: Tolerance for stabilised wet-mix macadam Job-Mix Formula

BS Sieve Size	Job tolerance per cent by mass
37.5 mm	± 6
20 mm	± 6
10 mm	± 6
5 mm	± 6
2.36 mm	± 4
600 µm	± 4
75 µm	± 1.5
Binder Content	± 0.5

Acceptance of Compaction

11. The average compacted dry density shall be not less than 95% of the Duriez dry density obtained in the laboratory for the approved mix. Measurements of insitu dry density will be made daily and the results compared with the reference value. No individual result shall be less than 90% of the Duriez dry density.

Compaction should be carried out using a combination of a vibrating roller and a pneumatic tyred roller. The mass per metre width of roll of the vibrating roller should not be less than 2000 kg. The vibrating roller should operate at a speed at about 2 km/hr. The mass per wheel of the pneumatic tyred roller should not be less than 300 kg and the inflation pressure of the tyres should not be less than 7 bars. The pneumatic roller should be operated at a speed of about 6 km/hr.

Cold and wet weather

10. The laying of stabilised wet-mix macadam is prohibited during frost, heavy rain or in the period of the year when it may be subject to freezing before it matures (i.e. before the escape of added water and water contained in the emulsion). Unless permitted by the Engineer stabilised wet-mix macadam should not be laid in the period of the year between October and March.

The laying of stabilised wet-mix macadam shall cease when descending air temperature in the shade falls below 3°C and shall not be resumed until the ascending air temperature in the shade reaches 3°C. Matured stabilised wet-mix macadams should be overlaid by a bituminous carpet or by a surface dressing before the winter.

Appendix E: Table 1: BS 4987: Part 2: 1993, Specified nominal and minimum layer thickness for coated macadam

Material description	BS 4987: Part 1 references	Nominal size mm	Nominal layer thickness mm	Minimum thickness at any point mm
Fine graded wearing course	7.7	3	15 to 25	10
Medium graded wearing course*	7.6	6	20 to 25	15
Dense wearing course*	7.5	6	20 to 30	15
Porous asphalt wearing course	8.2	10	30 to 35	25
Open graded wearing course	7.2	10	30 to 35	25
Close graded wearing course*	7.4	10	30 to 35	25
Open graded wearing course	7.1	14	35 to 55	30
Close graded wearing course*	7.3	14	40 to 55	35
Porous asphalt wearing course	8.1	20	45 to 60	40
Open graded basecourse	6.1	20	45 to 75	40
Dense basecourse*	6.5	20	50 to 80	40
Dense basecourse	6.4	28	70 to 100	55
Dense roadbase*	5.2	28	70 to 100	55
Single course	6.2	40	75 to 105	65**
Dense basecourse	6.3	40	95 to 140	80
Dense roadbase	5.1	40	90 to 150	80

** 80 mm if used as a single course with no subsequent wearing course

* Preferred mixture

NOTE 1. Thicknesses less than the above should not be used except for regulating purposes, where the minimum thickness may be 1.5 times the nominal size.

NOTE 2. Thicknesses in excess of the above can provide better compaction if adequate equipment is used but may lead to problems with surface irregularity and level control.

Appendix F: Engineering Standards for Overlay Works on Non National Roads

1. Roads should be restored to their original width, and edges strengthened where necessary. The provision of additional width should only be countenanced where traffic considerations warrant it.

2. Particular attention should be paid to drainage and road crossfall (min. 3%) in the interests of maintaining the life of the pavement.

3. Superelevation should be provided where necessary.

4. Minor longitudinal irregularities should be eliminated by regulation with selected material prior to overlay.

5. A paving machine should be used where the lengths of road being treated are reasonably long and the machine can be accommodated within the available width.

6. The thickness of granular overlays should not be less than 150mm on non-national roads except on roads with less than 200 current AADT where 100mm can be used in the circumstances defined in Table 5 of this document.

7. All unbound materials shall be laid and compacted in accordance with the requirements of Appendix C.

8. Surface dressing should be carried out in accordance with the guidelines entitled "SURFACE DRESSING" issued by the Department of the Environment in 1981; the use of polymer-modified binders should be considered, where appropriate.

9. Road markings should be provided, replaced or renewed as soon as practicable. Reference should be made to the document "THERMOPLASTIC ROAD MARKINGS" published by the County and City Engineers' Association in 1988.

10. Road signs, particularly those with safety implications such as junction warning signs and regulatory signs such as STOP or YIELD, must be renewed as necessary.