

3 ROAD PAVEMENTS

3.1 Introduction

Pavements are composite materials that bear the weight of pedestrian and vehicular loads. They require characteristics such as strength, durability, safety, skidding resistance, smoothness for traffic or reduction of noise.

Romans roads were constructed generally above ground level on embankments. The first operation being to cut deep ditches and three classes of road were used: levelled earth, gravel surface and paved. The paved road conforms roughly with present road structures whereby the quality of the material used improved nearer the surface.

The first significant development to reverse the gradual decline in the road infrastructure following the withdrawal of the Romans was the Act of 1663 providing for the first turnpike to be constructed and these developed eventually to extend to 22,000 miles of road controlled by Trusts.

During the eighteenth century, Britain's modern road builders developed expertise but the development of the railway led to a reduction in the use of their roads and this reduction caused a loss of revenue to the Turnpike Trust which became insolvent and the duties of the repair fell upon the parish. A series of Highway Acts culminated in the creation of the Ministry of Transport in 1919.

Road construction consists of two distinct phases: the earthworks and construction of the pavement. The earthworks are concerned with the preparation of the soil, to bring it to the correct level and profiles, up to formation level. It is known as the subgrade. Any unsatisfactory subsoil may need to be removed or stabilised. Soil stabilisation techniques may be used just below formation level. Cement stabilisation, for example, is achieved by mixing cement with pulverised soil to form material which when compacted and allowed to harden possesses appreciable strength. Bituminous materials and lime may also be used.

3.2 Standards for highways

There is a list of essential documents used on the design, construction and maintenance of highways. They make a complete review of all considerations for road pavements. In this course, we will refer to these documents in many occasions. They are the following:

Design Manual for Roads and Bridges (DMRB)

The DMRB was introduced in 1992 in England and Wales, and later in Scotland and Northern Ireland. It includes all current standards, advice notes and other documents relating to the design, assessment and operation of trunk roads, including motorways.

The DMRB has been developed from many separate series of documents previously published by the overseeing organisations of England, Scotland, Wales and Northern Ireland. These documents, together with later additions, have been gathered together in 15 volumes to help road transport professionals meet the requirements of quality assurance procedures.

Manual of Contract Documents for Highway Works (MCHW)

The MCHW, first published in 1992, consists of six volumes including the administrative procedures for its use, the *Specification for Highway Works* and its corresponding *Method of Measurement*. The

MCHW incorporates the requirements of EU legislation, which are mandatory for all public procurement bodies.

Interim Advice Notes (IANs)

IANs are issued by Highways England from time to time. They contain specific guidance, which shall be used only in connection with works on motorways and trunk roads in England, subject to any specific implementation instructions contained within an IAN.

While IANs must be read together with the DMRB and MCHW for works on motorways and trunk roads, and may incorporate amendments or additions to documents in these publications, they are not part of the DMRB or the MCHW.

Routine and Winter Service Code (RWSC)

This publication describes the requirements for the routine maintenance work that is carried out on trunk roads every winter.

The RWSC replaces Volume 2 of the *Trunk Road Maintenance Manual*. It covers the performance requirements for highways and structures and operational winter service on the motorway and trunk road network. The RWSC does not absolve service providers of any of their obligations to comply with legal and legislative requirements: this publication is designed to ensure compliance with all relevant standards and codes of practice. Much of the work is covered by many different types of contracts, including those between managing agents, contractors, maintenance and term maintenance contractors. Where routine and winter service activities are not covered by a lump sum payment, the RWSC should be read together with the *Network Maintenance Manual*.

Network Maintenance Manual (NMM)

The NMM replaces Volumes 1 and 3 of the *Trunk Road Maintenance Manual*. It provides advice, mandatory instructions and guidance on good practice for the management and provision of the routine and winter service on the trunk road network. It describes the processes for the management of the maintenance service including the interface between Highways England, its service providers and other stakeholders.

The performance requirements for routine and winter service activities on the trunk road network are included in the RWSC. The NMM, together with the RWSC, provides advice and guidance to enable service providers to achieve their performance requirements.

Technology Management and Maintenance Manual (TMMM)

The TMMM sets out Highways England's requirements for the management and maintenance of traffic technology systems.

3.3 Types of pavements

All pavements fall into these two main categories: flexible and rigid.

Flexible pavement

These pavements reflect the deformation of subgrade and the subsequent layers to the surface. Made usually in asphalt, it is laid with no reinforcement or with a specialized fabric reinforcement that permits limited flow or repositioning of the roadbed under ground changes.

The distribution of loads is based on the characteristics of the component layers. The main function of the pavement surface is to distribute loads to the lower layer, which transfers stress through contact points of the granular structure. So, it is distributed to large areas in the shape of a truncated cone and it is progressively decreased.

Flexible pavements are constructed in a number of layers, and the top one has to be as strong as the highest compressive stress. The lower layer then takes lesser magnitude of stress and so on.

Rigid pavement

Rigid pavements are associated with the characteristic of rigidity, developed mainly by a slab, which can distribute loads over a wider area of subgrade soil. Therefore, the lower layer needs to support smaller stress. These pavements are not developed in so many layers, and stress transmitted is much more reduced.

Rigid pavements are usually developed in slabs made of plan, reinforced or prestressed concrete. The critical conditions of stress are the maximum flexural stress occurring in the slab due to wheel loads and the temperature changes, by which they are much more affected.

Comparing the characteristics between flexible and rigid pavements, we develop the following table:

Flexible Pavements	Rigid Pavements
• Deformation in the sub grade transferred to the upper layers	• Deformation in the subgrade not transferred to subsequent layers
• Design based on load distributing • Have low flexural strength • Load is transferred by grain to grain contact	• Design based on flexural strength or slab action • Have high flexural strength • No such phenomenon of grain to grain load transfer exists
• Have low completion cost but high repairing cost • Have low life span (High Maintenance Cost) • Surfacing cannot be laid directly on the sub grade but a sub base is needed • No thermal stresses are induced as the pavement have the ability to contract and expand freely • That's why expansion joints are not needed	• Have low repairing cost but high completion cost • Life span is more as compare to flexible (Low Maintenance Cost) • Surfacing can be directly laid on the sub grade • Thermal stresses are more vulnerable to be induced as the ability to contract and expand is very less in concrete • That's why expansion joints are needed
• Strength of the road highly dependent on the strength of the sub grade • Rolling of the surfacing needed • Road can be used for traffic within 24 hours • Force of friction is less • Damaged by Oils and Certain Chemicals	• Strength of the road less dependent on the strength of the sub grade • Rolling of the surfacing not needed • Road cannot be used until 14 days of curing • Force of friction is high • No Damage by Oils and Greases

3.4 Construction

3.4.1 Materials

It is important to understand basic properties of materials when studying road pavement construction. A short explanation of these characteristics is included in the following lines.

Graduation of aggregates

We can measure the graduation of aggregates according to the size of grains. Sieves are used to establish the different sizes and proportions of an aggregate.

Each size occupies a volume. The bigger grains leave gaps between them that are filled by the smaller ones, and so on. If we have all sizes, all gaps can be filled properly, but if there is lack of one size, then these gaps cannot be filled and pores are left inside.

- A well-graded aggregate is an aggregate that cover all sizes properly.
- A gap-graded aggregate is an aggregate that lacks one or more sizes.
- A uniformly-graded aggregate is an aggregate formed by the same size.

We can think that porosity is reduced in a well-graded aggregate, it is bigger in a gap-graded aggregate, and very big in a uniformly-graded aggregate.

Compaction

Soil compaction mainly consists of the reduction of porosity in one soil. It depends on the following:

- As long as we reduce porosity, we get a better compaction and, therefore, better resistance. With compaction, we are relocating sizes to occupy less space.
- Water can help to compaction. Water sweeps smaller sizes to the bottom and fills these gaps. Besides, helps aggregates sliding between one another and relocates.
- On the other hand, a soil with clay retains water and makes compaction more difficult. The compaction of soils with clay needs to be developed along the time.

Vibration is a dynamic compaction method that helps to relocate aggregates, so it is good for compaction. On the other hand, this method is not good for clay soils as it does not eliminate water.

Static compaction methods are developed with heavy loads that compress the soil and reduce porosity. These loads can be instant (a short period of time) or permanent (along the time). For clay soils, permanent static compaction methods are required, as they get compacted as long as the water content is reduced.

Binders

Binders stick aggregates together. We can use cement or bitumen.

Cement is obtained mainly from calcareous rock mixed with some low proportions of clay and ferrous material. The heating process gives a product called clinker, which is then mixed with some proportions of gypsum and other additions. The different types of cement depend on these additions and proportions, some of them can be over 30% of the total clinker. This binder confers resistance and rigidity to the resulting product.

Bitumen is a naturally occurring material and is found in large quantities in the solid or semi solid forms of petroleum. It is also manufactured artificially in vast amounts globally. Almost 90% of its

consumption is for road pavement. The best characteristics attributed are that it is adhesive, water-proof, strong enough, durable, versatile and economical for this use.

Asphalt is a mixture of aggregates and a bituminous binder. It typically contains approximately 4-7% of bitumen, although it depends on the aggregate used and the type of road to build.

3.4.2 Machinery used

The most common machinery used is the following:

- Grader. It is a machine with a long blade used to extend soil and create a flat surface.
- Water truck. It spreads water to control dust and compaction.
- Rollers or compactors. We can use rollers to compact layers of soil as well as asphalt.
 - Padfoot. It is used for soil layer compaction. It breaks the natural bonds of cohesive soil and has better results with compaction.
 - Steel drum. They are vibratory compactors. They are used commonly for soil compaction. In the static mode, it is also used for rolling asphalt finishing.
 - Combination. It is used for the compaction of base and sub-base layers. It can combine the roller, pneumatics and vibration. The most important with pneumatics is that they can introduce less water in the layer.
- Oil distributor. It is used to apply prime or tack coats on a surface in preparation of paving.
- Road reclaimers, mixers
- Asphalt plant. To produce asphalt, macadam or other forms of coated road stone.
- Concrete mixing plant. To produce concrete.
- Ready-mix truck. To transport concrete.
- Paver. It is used to lay pavement on the roadway. It can be used both for flexible or rigid pavement, although they are different machinery.
- Chip spreader. It lays down the aggregate on top of a bituminous binder to be then rolled.
- Cold planer, pavement recycler or milling machine. It removes bituminous pavement and prepares it to be used as new aggregates. It is usually used to replace the previous asphalt.

3.4.3 Characteristics of layers

We need to differentiate between flexible and rigid pavement.

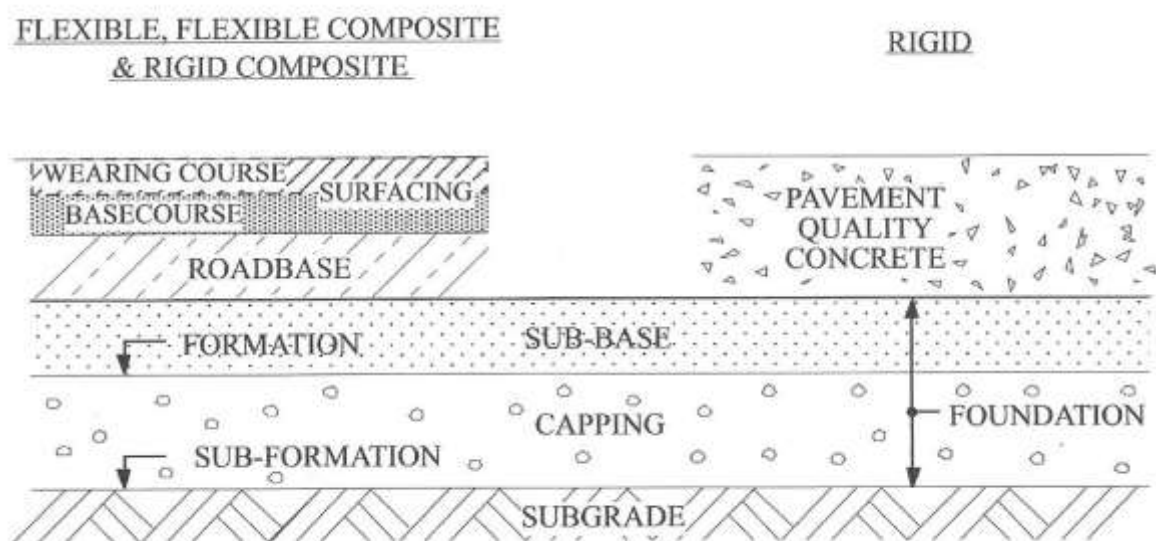


Figure 1. Typical pavement section.

Flexible pavement

A flexible pavement is composed of several layers. The characteristics of each layer are variable according to the stress they must support. The following section can be used as a guide for the composition of a flexible pavement.

Capping layer: It is developed to strengthen resistance of the subgrade whenever it is necessary. If the subgrade is strong enough, there is no need of this layer. Geotextiles may be laid below or above to inhibit penetration of material into lower layers, confine lateral movement and allow percolation of any excess water. It is selected granular material up to 125 mm. Thickness is variable.

Sub-base: Provides protection for subgrade/capping layer against damage from construction plant and effects of weather. The material most commonly used is granular and is usually naturally occurring material which can be mixed to satisfy grading. Thickness is variable. It must be compacted in sublayers of small thickness depending the compaction system (not more than 250 mm).

Road base: This is the main load distributing layer. It must be well compacted. It is composed by well-graded aggregates; we can also use a lean mix with a binder. Thickness depends on the loads to distribute.

Permitted hydraulically bound materials (HBM) for use in the base layers, according to HD 26/06:

- CBGM, cement bound granular material;
- FABM, fly ash bound material;
- SBM, slag bound material.

Basecourse: It forms part of the road pavement and contributes to the distribution of loads.

Flexible pavement types permitted by HD 26/06:

- Dense Bitumen Macadam (DBM50 or DBM125) or Heavy Duty Macadam (HDM50);
- Stone Mastic Asphalt (SMA), for use as a binder course only, not as a base;
- Hot Rolled Asphalt (HRA50) (it must comply with Clause 943)
- High modulus (stiff) dense bitumen macadam (EME2 - Enrobé à Module Élevé), but only on a Class 3 or 4 Foundation (see pavement design), subject to a "Departure from Standard" being granted by the Overseeing Organisation.

Thickness depends on the type of material.

Wearing course: It enables rapid drainage of surface water from the road reducing spray and general type noise. It can be porous asphalt (PA) (gap graded material with less quantity of binder) if we need to make a draining layer to evacuate water quickly, but resistance is reduced and it is not waterproof. Thickness depends on the type of materials. Sometimes, the pavement consists of one unique layer (much thicker), and the wearing course is developed by surface dressing and chipping.

Rigid pavement

It mainly consists of a concrete slab surface, which thickness is variable depending on the loads to be supported. The preferred rigid pavement construction according to HD 25/06 is either:

- Continuously reinforced concrete pavement (CRCP) (normally with an asphalt overlay of minimum thickness 30 mm); or
- Continuously reinforced concrete base (CRCB) with an asphalt overlay of 100 mm.

Other forms of rigid construction, permitted for limited use and in special circumstances but only with approval from the Overseeing Organisation, include:

- Unreinforced jointed concrete (URC);
- Jointed Reinforced Concrete (JRC).

3.5 Construction

Construction of flexible pavement

The granular materials for capping and sub-base are graded and dozed with the grader. Then they are constructed using compaction techniques. Thickness must be 150 mm or less to allow a good compaction. When the layer is bigger, then several sub-layers are created. The use of rollers is crucial for this work.

In general, bitumen-bound materials are laid using a paving machine, although small areas may be laid by hand. The function of the paving machine is to lay even thickness of material in strips usually in widths of 2.5 to 3 m. It lays the material at the right temperature and tamps it ready for compaction by the roller. Bitumen and tarmac-based materials requires a work temperature of between 95 to 190°C.

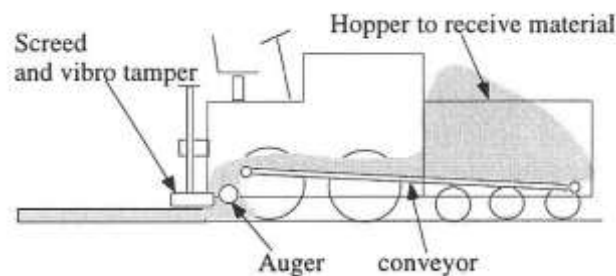


Figure 2. Paving machine. (Warren, 1996).

The principal of operation is that insulated trucks deliver the material into the hopper and it is taken by conveyor to the spreading augers. The augers spread the material across the width required and it is then tamped to an even surface by the screedboard and vibrotamper. The thickness of the material can be controlled manually or automatically by the use of sensor attached to averaging bar mounted along the side of the machine.

The contractor must ensure an uninterrupted supply of material at the correct temperature, and never start laying with less than two supply trucks on site.

Correct rolling is very important to the quality of the finished surface. Rolling is carried out with a 8 to 10 tonne dead-weight roller or a tandem vibratory roller. The dead-weight roller allows rolling to take place at higher temperatures and gently pushes the material into its compacted position, but it does not compact edges very well. The tandem vibratory roller can compact the edges well, but can be too violent with uncompacted material. The combination of both is the best solution.

Construction of rigid pavement

The concrete is poured and moulded by the paver. Fixed pavers required side formwork to be placed at the pavement edges and not to be removed for several hours after concrete placing. These have now been replaced by slip-form pavers whereby a carpet of concrete is placed without the need for side-forms. However, much stiffer mixes are required for the concrete to maintain shape without side supports.

If the finishing of the road is with concrete, the concrete surface must be textured to improve skid resistance, usually by mechanical wire brushing. The finished surface should be sprayed with a curing compound. Although paving machines are capable of travelling at 20 m/min, the logistical problem of supplying large quantities of concrete usually limits production to about 1000m per day.

Contraction and expansion joints must be developed:

Contraction joints: They allow the slab to shorten as its temperature drops. At the contraction joint there is a crack inducer that helps to break at this point in case cracking occurs. This joint is in the area of reinforcement (whenever we have a reinforced slab), and reinforcement is continued.

The spacing of these joints depends on the reinforcement.

- For unreinforced slabs, if they are thicker than 230 mm, contraction joints should be every 5 m. For slabs under 230 mm thick, it should be every 4 m.
- For reinforced slabs, there is a standard distance of every 25 m.

Expansion joints: They allow the slab to expand as its temperature increases above that at which it was cast. These joints are very effective for day-and-night temperature difference. This joint is complete, cutting the whole section of the slab. Reinforcement can be also cut or cased in this zone to allow free movement.

They replace every third contraction joint. With unreinforced concrete, it is at a spacing of 12-15 m. With reinforced concrete, the spacing is increased to 75 m.

3.6 Skidding resistance

The skidding resistance of a road is influenced by the micro and macro texture of the surface. The macro-texture facilitates the rapid removal of water. Then, the micro-texture has its effect influencing greatly the coefficient of friction.

The lubricating action of water reduces the adhesion between the tyre and the road, and a good surface drainage is essential as well as the avoidance of polished surfaces.

The maintenance of safe standards of skidding resistance is essential and techniques for restoring resistance includes the removal or addition of material. An interesting technique for the removal of concrete road surface is the use of hydrochloric acid spread and allowed to attack for 15 minutes. The road is then swilled. Safety precautions must be stringently followed for this method.

Other possibility to improve skidding resistance is, when developing surface dressing, thin wearing courses of 10 to 20 mm may be added to improve rugosity.

3.7 Drainage

In roadworks, the drainage requirements fall into two categories:

3.7.1 Sub-soil drainage

Essential for new roads and may also become necessary for existing roads and where the water table should be kept below the formation level. Before commencing work on the road structure, it is good practice to lay French drains along the limits of the roadworks. All these drains are laid to falls and linked to a natural watercourse by an outfall drain which should be clear of the highest normal water level in the watercourse.

Considerable use is now made of commercially available filter fabrics. In conventional drains, a geotextile may be used simply to line the sides of the trench prior to backfilling with a coarse aggregate. However, they can be used without granular material.

Good sub-soil drainage is necessary because in general the higher the moisture content the weaker the strength of the material, be it in the road structure or in the subgrade. However, good drainage can also avoid the effect of frost.

Frost action in soils

The two aspects of frost action that are of major interest to the road engineer are frost heaving and thawing.

By frost heaving is meant the process by which a portion of a frost-susceptible soil and the road pavement above it are raised as a result of ice formation in the soil. If the heaving occurs non-uniformly pavement cracking can occur.

Whilst the volume increase of soil water upon freezing being about 9% obviously contributes to heave, the major cause by far is the formation of ice lenses. For ice lenses to develop, three conditions must be met:

1. Sufficiently cold weather for freezing soil water
2. Supply of water available to freezing zone
3. Frost susceptible soil e.g. clays

The phenomenon can be described thus. When the freezing temperature penetrates into a fine-grained soil some of the water in the soil pores becomes frozen. The unfrozen moisture content decreases and the consequences of this is that large suction is created in the soil which causes moisture from the water source in the unfrozen soil to move to the freezing zone and form ice lenses as it freezes. The process continues until a suction valve is reached which inhibits further freezing at that temperature. If the temperature drops further the process can restart and can also commence at a deeper level.

When thawing begins the ice melts primarily from the top down and this additional water, which has been sucked up, causes weakness.

Whilst the cost of subsurface drainage systems is high in terms of material, etc., the extended pavement life invariably makes these systems economical. It is better to design a road to ensure that the water is kept out in the first instance, but if it does get in that sub-surface drainage is provided to ensure that it is removed as quickly as possible. Water can enter through joints, cracks and pores and even bituminous surfacing are often relatively permeable.

3.7.2 Road drainage

Water on a road results in longer braking distances and full aqua-planing can occur at water depths in excess of 4 mm. It can also reduce windscreen visibility and cause problems for pedestrians.

The objective is to provide drains/sewers with sufficient capacity to remove rainfall from the road surface. Falls must be sufficient to avoid solid gritty particles from settling in the invert of the pipes causing blockage. The gradients at which the various sizes of pipes are self-cleansing are approximately determined by dividing the pipe diameter by 2. Where there is little natural fall available on site the pipe size can be increased above that required to deal with the actual flow so that a slacker gradient may be used.

All sewer pipelines must be laid in straight lengths to a constant gradient over each length. Manholes should be built at every change in direction, gradient, pipe size and type. The access enables the sewer to be rodded in the event of blockage.

Gully connections to storm sewers are made by laying junction pipes at suitable points along the sewer line. The branch pipe to the gully should not be less than 100mm diameter. If it is not possible to predict the position of the gullies and thus include the junction, fittings connections can be made by means of a saddle. The position of and number of gullies depends on the area of carriageway to be drained and the gradient of the road.

Where the road is kerbed there are special kerbs which provide an outlet without gullies. In rural areas where minor roads are not kerbed, the drainage water is by means of grips which are shallow channels cut across the verge to conduct the water to a convenient roadside ditch.

The road camber or cross-fall should be designed to avoid danger of skidding or aquaplaning on the water, usually 1:40.

3.8 Pavement defects

Pavement damage and deterioration can be evident in many ways. The appearance of pavement deficiencies can occur due to different factors, for example an excess or very reduced thickness of asphalt, a poorly graduation, poor subgrade drainage, heavy traffic, accelerating and decelerating zones, weather conditions, spillages, thermal and moisture movements, etc. All these problems can bring to failures in the pavement and other supporting layers.

According to the WSDOT Maintenance Manual, the following deficiencies can be found:

Rutting

Rutting is a surface depression within the wheel path and is a result of permanent deformation of the pavement or subgrade. This condition is normally caused by heavy loads on roads lacking sufficient strength to support the loading. In some cases, rutting can also be caused by studded tire use. Wheel ruts, if not repaired, can trap water and cause hydroplaning.

Alligator Cracking

The condition known as alligator cracking is attained when discontinuous longitudinal cracks begin to interconnect to form a series of small polygons that resemble an alligator's skin. This distress is usually caused by poor drainage, poor mix design, or subgrade failure. Ideally the surface should be treated with a seal coat or overlaid with suitable material before water has an opportunity to penetrate the surface and lead to alligator cracking. If it is neglected and alligator cracks appear, heavy traffic can push the surfacing rock into the wet soil beneath it. This forces mud up through the asphalt surface (pumping) causing permanent damage that cannot be repaired by a seal or overlay. Spots where severe pumping has occurred will often need to be dug out, and the base rock, surfacing rock, and asphalt replaced.

Longitudinal Cracking

A longitudinal crack follows a course approximately parallel to the centre line. These is typically due to natural causes or traffic loading.

Transverse Cracking

Transverse cracks run roughly perpendicular to the roadway centre line. They may be due to surface shrinkage caused by low temperatures, hardening of the asphalt, or cracks in underlying pavement layers such as PCC slabs. They may extend partially or fully across the roadway.

Potholes

Potholes are voids in the roadway surface where pieces of the pavement have become dislodged. Areas in which many potholes occur become suspect for fundamental problems such as inadequate drainage, pavement strength, or base/subgrade problems. Single or infrequent potholes may be the only pavement distress to occur in an area, and beyond the treatment of the individual pothole no other pavement repair work may be required.

The location of potholes which receive a temporary fix should be documented so they are addressed as part of the Area's annual permanent fix program. The number of potholes that appear in the wet or winter seasons is often an indicator of the effectiveness of the permanent fix program.

Ravelling and Pitting

Ravelling and pitting distresses are characterized by the loss or dislodgment of surface aggregate particles. Oxidized asphalt binder is often the cause of ravelling and pitting. It could also be caused by poor compaction, letting the mix get cold when paving, dirty aggregate, not enough asphalt in the mix, overheating the mix during manufacture, or aging.

Routine maintenance repairs made to ravelled or pitted surfaces is made as soon as conditions permit and/or materials are available. The most important consideration in scheduling repair of ravelled or pitted areas is to perform the repairs before a more serious condition develops, and prior to the onset of inclement weather.

Open grade pavements that allow water to drain through and out the side don't need to be sealed if they are properly constructed. But, pavement that is ravelling must be sealed. Unsealed pavements will continue to ravel and will also age and harden at a much faster rate than normal. This condition may also encourage the loss or stripping of the asphalt within the pavement. Timely sealing can add significantly to the life of the pavement. Open grade pavements should be fog sealed on a schedule recommended by the Region Materials Engineer. Failure to do so can lead to premature failure of the open grade mat and lead to difficult maintenance problems.

Flushing

Flushing (or bleeding) is free asphalt on the surface of the pavement caused by, too many fines in the mix, too few voids, too much asphalt in patches, or a chip seal that has lost its rock. This type of distress often shows as a shiny, glass-like reflective surface. It is inherent to unstable mixes and often results in other roadway surface distresses if not corrected.

Removal and replacement of flushed or bleeding pavement areas is an expensive, but sometimes cost-effective method of repair. Thin overlays of flushed or bleeding areas will frequently have the "fat spot" show through in hot weather and exhibit the same characteristics as in the "before" condition. If repairs are not possible prior to a seasonally wet period, contact the regional traffic engineer to evaluate the need for posting "Slippery When Wet" signs.

Sags and Humps

Sags and humps are localized depressions or elevated areas of the pavement that result from settlement, pavement shoving, displacement due to subgrade swelling, or displacement due to tree roots. The deficiency usually occurs in isolated areas of the roadway surface.

Edge Ravelling

Edge ravelling occurs when the pavement edge breaks and is most commonly found on those roadways that were constructed without kerbs or paved shoulders.

3.9 Maintenance

It is the routine work performed to keep a pavement under normal conditions of traffic and environmental situations as nearly as possible to its as-built condition. The maintenance works should consider making repairs preferably during warm dry weather.

We can differentiate between cyclic and structural maintenance:

3.9.1 Cyclic maintenance

It helps to the movement of traffic. The actions involved are linked to keep in good conditions the road for its operation. The main actions are as follows:

- Grass cutting
- Gully maintenance
- Weed killing
- Signs repairing
- Renewal of markings

3.9.2 Structural maintenance

Apart from this cyclic maintenance, it is also needed to keep the road in good conditions for work. In addition to major maintenance due to surface deterioration (or other inner problems), a surface treatment may be expected to be required at about 10 and 20 year intervals, dependent on the nature of the traffic and the requirements for skidding resistance.

Crack sealing

It is applied to general cracking or even alligating. This is the cheapest solution. The objective is to fill this crack to prevent water from entering the subgrade layer and cause damage. Before the application, the supervisor should be aware of the nature, extent and severity of the cracking problem. If there is serious cracking and settlement, it may indicate that a more complex solution is needed to repair this pavement.

We must be careful when pouring. Over-poured cracks can be hazardous, causing loss of control for motorcycles for example. Areas that have excessive crack pouring material from past practices should be addressed to avoid accidents.

There are two types of crack pouring material: hot pour and cold pour. They use different techniques and equipment.

- Hot pour method. The pour material is heated in specialized crack pouring machines. The most common type are trailer mounted, oil jacketed units. This method is used for areas that are not going to be removed and repaired prior to an overlay. It is a common method of sealing the joint between the edge of a PCC road surface and the asphalt shoulder. It works properly for large volume work involving large cracks. This method requires a large crew and specialized equipment. Safety is a big concern as we are using extremely hot material. The cracks should be cleaned and dried with compressed air prior to pouring.
- Cold pour method. Cold applied liquid material is used and specialized equipment is not required. One person can apply it using directly the spout on the container it comes in. This method is also good for small asphalt patches and pothole repairs. It simplifies the problems

of tack storage, transporting and application. The performance is as well as hot pour material.

Patching

Flexible pavements require patching at some time during the service life. This method is used to repair different defects on the surface pavement that are located in specific areas. It should be performed according to resource availability and the objective to keep a smooth surface as much as possible.

There are two principal methods for patching:

- Overlay patching. It is generally applied when the pavement area is small enough to be repaired by hand with a small crew. The overlay patching has the advantage of setting quickly. The main drawback is that durability can be affected easily if it is not made properly. It only solves problems on surface. If we have ruts, depressions or humps, they need to be repaired or pre-levelled in advance. The steps are as follows:
 1. Remove all loose, broken asphalt
 2. Repairs and levelling works needed
 3. Apply a tack coat to the surface
 4. Pour and fill with asphalt
 5. Compaction works
- Patching with base repair or “dig-out patches”. They are permanent repairs to the pavement. At the same time that the surface material, it may be needed to remove some of the subgrade material to eliminate all the defective area. The edges are cut vertically in straight lines to provide a compaction line later. The steps are as follows:
 1. Vertically cutting of the patch edges with a pavement saw
 2. Removal of defective pavement and unstable surfacing materials
 3. Excavation of defective grade/subgrade material
 4. Level and compact the base material (compacted layers no more than 150 mm thick)
 5. Apply a tack coat of asphalt to the vertical edges
 6. Finally, replace the pavement

Surface dressing

Surface dressing has the purpose of sealing the road surface against water ingress and provides a non-skid surface. It consists of spraying the existing road surface with a film of binder which is then covered with a layer of stone chippings. The best period to be carried out is between April and September according to better weather conditions in the UK.

In order to obtain a good life for the dressing, the old surface must be clean and unbroken and should be expected to have about 5 years of life. Any required patching should be done preferably during the previous season. The procedure is as follows:

1. Sweep the old road surface
2. Spray binder to uniform thickness
3. Apply chippings by mechanical spreader fitted with a metering device. To ensure the binder is fully covered an excess quantity is needed.
4. Rolling should follow immediately. Rubber-tyred rollers are normally preferred as these press in the chippings as opposed to metal wheels which tend to crush them.
5. Excess chippings should be removed by sweeper prior to traffic which should not be allowed for 15-20 minutes.

Tar was the original binder but a range of cut-back bitumen is now used. Surface dressing may be applied to both flexible and rigid road structures.

Temporary road signs should be located to warn road users of the hazard and traffic management planned and ironwork masked.

Repaving

Where an irregular surface has developed on a carriageway the solution involves the removal of the wearing surface using hot or cold planning techniques.

Cold planning has largely replaced hot planning which was usually limited to about 40 mm depth. Cold planning can cut to 300 mm and produces no fumes. The planning action is achieved with a tungsten carbide cutting drum.

Resurfacing is either by new surface dressing or more commonly a new wearing course.

3.10 Pavement recycling

We can recycle pavement by different techniques to transform it in new pavement with enough characteristics to support the traffic requirements. Materials from the existing pavement are reused and it results in considerable savings of material, money and energy. These techniques cover from heavy trafficked highways to low volume roads. Airport pavements can also be constructed with recycled pavement materials.

Different recycling methods are now available. The four primary methodologies are:

Hot Mix Asphalt (HMA) and Warm Mix Asphalt (WMA) recycling

It is the process in which Reclaimed Asphalt Pavement (RAP) is combined with new materials to produce HMA/WMA mixtures. Hot mix recycling can have better performance than HAM/WMA and better capability to correct most surface defects, deformation and cracking.

Hot in-place recycling (HIR)

The existing pavement is heated and softened, and then scarified/milled to a specified depth. Then, new HMA/WMA may be added to the scarified RAP during the recycling process. There are three HIR processes:

1. Surface recycling – Existing asphalt surface is heated and scarified to a specified depth; scarified material is combined with aggregate and/or recycling agent; and re-compacted. A new overlay or treatment is placed in the recycled mix.
2. Repaving – A simultaneous combination of surface recycling with a HMA/WMA overlay placed and compacted at the same time.
3. Remixing – Scarified RAP is combined with virgin HMA and mixed in a pugmill then placed and compacted as a single mix/lift.

Cold Recycling

The manipulation of the existing pavement material occurs without the application of heat. There are two types:

- Cold In-place Recycling (CIR). The existing pavement is pulverized/manipulated in-place and re-compacted into a pavement layer.
- Cold Central Plant Recycling (CCPR). The material removed from an existing asphalt pavement is transported to a central location – either on the project site or an existing asphalt plant. The removed material can be crushed and screened to make a uniform product or and be simply screened prior to feeding the cold plant. Once the material and the binding agent are mixed, it can be discharged into a truck and taken to a project for paving.

Full Depth Reclamation (FDR)

All the asphalt pavement section and a predetermined amount of underlying materials are mixed/manipulated in-place and treated to produce a stabilized basecourse.

3.11 Assessment

The maintenance of roads must be kept permanently. For that, it is necessary to establish particular schemes with the Overseeing Organisation. The HD29/08 establishes the following procedures as the most common ones for road assessment:

- Deflectograph testing
- Falling weight deflectometer
- Ground-penetrating radar (GPR)
- Coring and test pits

3.11.1 Deflectograph testing

It works on the principle that as a loaded wheel passes over the pavement, it deflects and the size of deflection is related to the strength of the pavement layers and subgrade. The survey speed is slow (2.5 Km/h), so it causes considerable disruption, particularly on heavily trafficked roads.

The deflectograph is an automated deflection measuring system. It is a fully self-contained lorry-mounted system, whereby measurements of deflection are taken at approximately 4m intervals in both wheel-tracks while the machine is in motion. The transient deflection is measured as the deflectograph travels slowly along the line of twin measurement beams which are attached to a reference frame. The measurement is not an absolute value of surface deflection since the reference frame sits within the wheelbase of the lorry and is itself influenced by the load. It represents a repeatable measure but since the analysis method is empirical, it is important that the procedures for the use of the deflectograph are closely followed.

3.11.2 Falling weight deflectometer (FWD)

Another approach is to measure the pavement deflection by dropping a mass using a device. The deflection measured relates to the combined stiffness of the component layers in the pavement and its ability to distribute traffic loads. The FWD is normally a trailer mounted device, towed behind a vehicle.

In principle, the FWD generates a load pulse by dropping a mass onto a spring system. The mass and drop height can be adjusted to achieve the desired impact loading. Peak vertical deflections are

measured at the centre of the loading plate and at several radial positions by a series of geophones. These deflections and the peak impact load are stored electronically.

The FWD method must only be used for:

- To assess the stiffness of pavement layers of all pavement types;
- To determine the load transfer efficiency across joints and cracks in rigid pavements.

The impact method of load application used by the FWD is fundamentally different from the rolling wheel system employed by the deflectograph. As yet, no satisfactory relationship has been found to convert FWD deflections to equivalent deflectograph deflections so they cannot be input to the Overseeing Organisation's design method. Whereas the deflectograph system normally only uses the maximum deflection recorded at each measurement point, FWD measurements allow the deflected shape of the pavement surface to be derived. Estimates of layer stiffness can be made from knowledge of this deflected shape and the layer thicknesses.

3.11.3 Ground-penetrating radar (GPR)

Ground-penetrating radar (GPR) is a nondestructive tool that can be used to obtain information about the construction of a pavement and its internal features. This information can be used to enhance pavement condition information obtained from visual condition, deflection surveys, coring and trial pits.

GPR operates by transmitting a pulse of electromagnetic radiation from an antenna into a pavement. The electromagnetic radiation penetrates down into the pavement as an energy wave, with an envelope in the shape of a cone. As the wave travels through the various pavement layers, its velocity is changed and its strength is attenuated. Part of the signal will be reflected back at buried discontinuities or interfaces between different materials such as different pavement layers. These reflected signals and the two-way travel time contain the information about the interior of the pavement.

Figure 6A.1

Typically, GPR can provide information about changes in pavement construction, layer thicknesses and defects/features within the pavement. The quality of the information obtained from ground radar is largely a function of three factors:

- the electrical properties (dielectric constant and the conductivity) of the materials forming the pavement;
- the type of GPR equipment employed;
- the processing software and analysis methodology including calibration procedures employed.

GPR systems available at present are able to identify pavement features to differing degrees of robustness for assessment purposes depending on the feature and the survey speed. The ability of GPR surveys to identify pavement features are therefore classified into four classes A to D, depending on how accurately and reliably they can be identified:

- Surveys with the classification A are considered *Routine* and have sufficient accuracy and reliability to be used regularly for pavement assessment.
- Surveys with the classification B are considered to be suitable for *Confirmation* that this pavement condition exists with the assistance of evidence from other techniques.
- Surveys with the classification C should only be used with *Caution* as a guide and together with other data to indicate the possible construction or condition of the pavement.
- Surveys with the classification D are *Unproven* and have yet to be demonstrated as suitable for use on the network.

3.11.4 Coring and testing pits

When assessing pavements, coring of the bound layers is normally required for one or more of the following purposes:

- a) determination of layer and total pavement thicknesses (usually in conjunction with Ground-Penetrating Radar);
- b) determination of the material type and condition of the layers;
- c) determination of the depth of cracking;
- d) determination of the condition of rigid pavement joints;
- e) provision of samples for compositional or physical tests;
- f) provision of access for carrying out Dynamic Cone Penetration tests in granular foundation layers.

150mm diameter cores are preferable to 100mm diameter as they will normally provide sufficient material for any laboratory testing and, if sited on cracks, are more likely to be successfully extracted. However, if only layer thicknesses are required from sound pavement, 100mm diameter or smaller cores could be satisfactory.

For each core, a full record of the core details must be made in the form of a Core Log. It must include:

- A good quality colour photograph with a scale strip and the core reference
- The reference information (reference, traffic direction, lane and offset, coring date, pavement condition at core location)
- Other details (thickness, any missing layers, type of material present and condition, possible presence of tar bound layers, crack characteristics, etc.)

Excavating test pits is a much slower and more expensive method of obtaining pavement information compared to coring and must therefore be used only when necessary data cannot be obtained by other means. The test pit reinstatement is a significant task and may not be very durable unless hot-mix surfacing material is used. Test pitting is normally required for one or more of the following purposes:

- a) obtaining bulk samples of the bound or unbound layers for laboratory testing;
- b) detailed examination of the unbound layers or subgrade including density measurement;
- c) investigating the causes of rutting;
- d) examination of joints in concrete pavements;

- e) investigating drainage problems within or beneath the pavement.

Information on bound layer thicknesses and quality is normally best obtained from cores. In test pits, bound layer details can only be reliably observed on the sawn edges of the excavation, which may only extend to 50 to 100mm.

The pavement layer details revealed in the pits sides must be recorded on a test pit log.

3.12 Design

Pavement design involves the following steps:

1. Assessment of the strength of the subgrade
2. Assessment of the possible traffic loading
3. Matching these to the best type of materials and thickness for the road pavement and the different layers

3.12.1 Subgrade

The strength of the subgrade is determined by the CBR test (California Bearing Ratio) which can be determined in the laboratory, on site or by soil classification.

In the laboratory, a premeasured mass of material is re-compacted into a cylinder mould. A metal plunger 45 mm in diameter is pushed into the soil sample at a rate of 1.08 mm per minute. The moisture content must be equal to that which is expected in situ and the force required to push the plunger in is plotted against the penetration. This test is compared as a percentage of the standard curve (carried out on crushed rock) to give the CBR value.

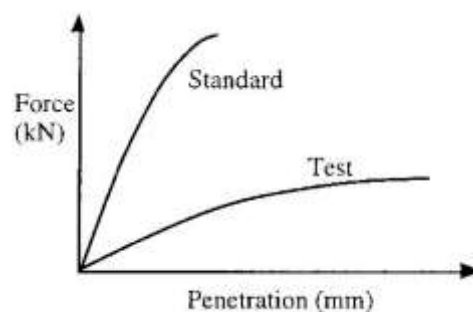


Figure 3. Comparison between the standard curve and the CBR test. (Warren, 1996).

The in situ plate bearing test can be carried out by hydraulic rams pushing a plate 300 mm² into the soil under the weight of a truck. The plate is at the bottom of a freshly dug 1 m deep hole in an attempt to reproduce the condition that can be expected at the formation level under a road.

A soil classification chart relates CBR to plasticity index for clay and particle size distribution for sand and gravel subgrades. The values also consider the position of the water table beneath the formation and the overall construction thickness of the road structure.

The strength of the subgrade depends on adequate drainage. The water table must be kept at least one metre below the formation level. If it is not possible, then the CBR must be adjusted. Other precautions to be taken against degradation are:

- It should not be exposed to weather during construction
- It must be covered by the sub-base as soon as possible
- Impermeable road constructions must also be used, at least one impermeable layer

3.12.2 Traffic loading

The traffic assessment is calculated according to HD 24/06, volume 7, section 2, part 1. The factors used to calculate the Design Traffic (T) are as follows:

- Commercial Vehicle Flow at opening (F)
- Design Period (Y)
- Growth Factor (G)
- Wear Factor (W)
- Percentage of vehicles in the heaviest loaded lane (P)

Commercial Vehicle Flow (F)

It is the number of commercial vehicles expected to use the road one way per day (cv/d) at the time of opening. It is called the Annual Average Daily Flow (AADF). Commercial vehicles are defined as those over 3.5 tonnes gross vehicle weight. The rest lighter traffic (i.e. bikes or cars) is considered to be negligible. The following table identifies the commercial vehicle classes and categories to be used, as defined in the COBA manual (DMRB 13.1).

Commercial vehicle (cv)	cv class*	cv category
	Buses and Coaches	PSV
	2-axle rigid	OGV1
	3-axle rigid	
	3-axle articulated	OGV2
	4-axle rigid	
	4-axle articulated	
	5-axle articulated	
	6 (or more) -axle articulated	

* Classed by axles in contact with the road
 PSV = Public Service Vehicle
 OGV = Other Goods Vehicle

Table 1. Commercial vehicle classes and categories (DMRB).

Road Type	Motorway or Trunk	Principal
Percentage of Commercial Vehicles (% cv) within AADF	11	4
% OGV2	65	38

Table 2. Typical commercial vehicle flow compositions (DMRB).

For new road designs, the percentage of OGV2 vehicles is obtained by calculation or modelling, but it won't be less than the percentage given in the following figure.

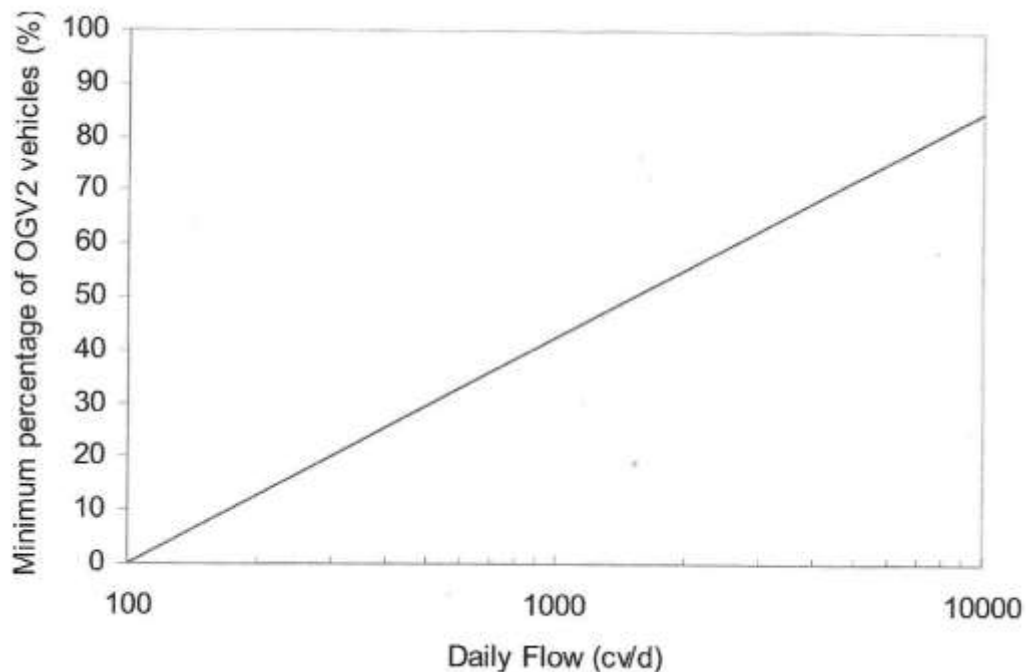


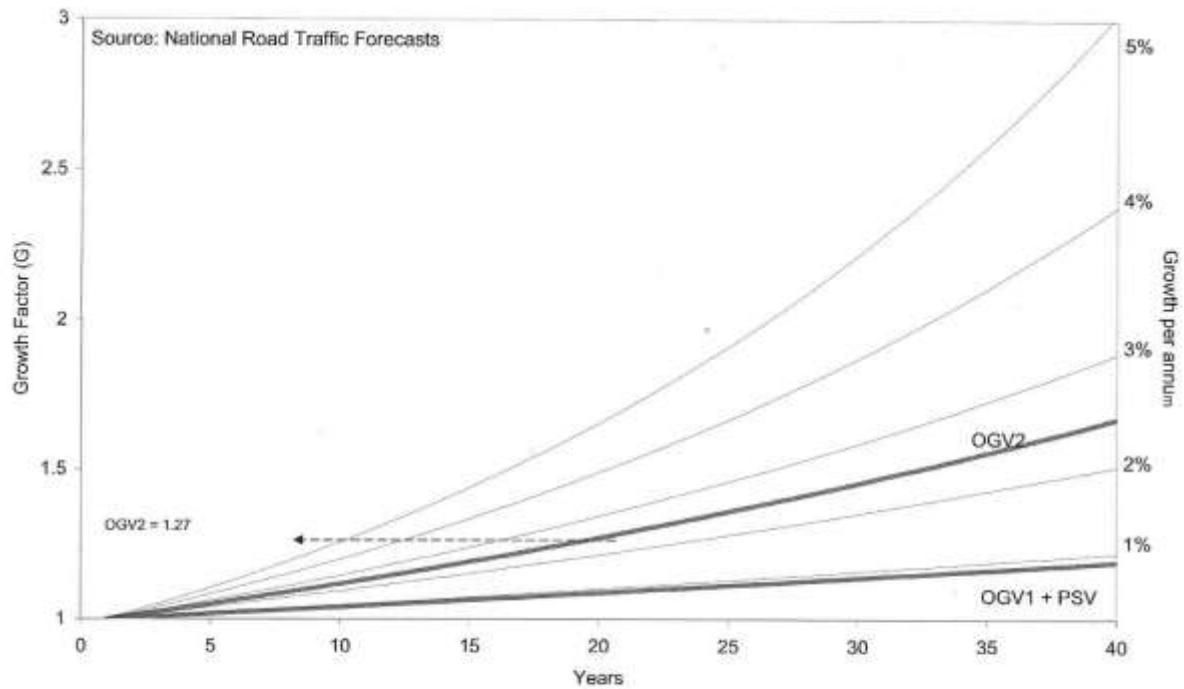
Figure 4. Minimum percentage of OGV2 class vehicles for new construction (DMRB).

Design Period (Y)

It is needed to select the number of years over which traffic is to be assessed. For future design traffic it is generally considered 40 years. Other design periods may be used if they are proven to be economic.

Growth Factor (G)

The National Road Traffic Forecast (NRTF) is published every 8 years and predicts future traffic trends. This factors are used according to the different classes and categories of vehicles considered. If there is not any better alternative, we can use the 1997 NRTF growth lines shown for OGV1+PSV and for OGV2.



Extracted Growth Factor (G) values assuming 1997 NRTF growth:

Design Period (Years)	5	10	15	20	25	30	35	40
OGV1 + PSV	1.02	1.04	1.06	1.09	1.11	1.14	1.17	1.19
OGV2	1.05	1.12	1.19	1.27	1.36	1.45	1.56	1.67

Figure 5. Derivation of Growth Factor (G) for Future Traffic from the NRTF (1997) (DMRB).

Example given

Considering OGV2

Design period – 20 years

Growth Factor – 1.27

Wear Factor (W)

The structural wear to a road associated with each vehicle that passes increases significantly with increasing axle load. Sets of wear factors have been produced for maintenance and new design cases. The derivation of these factors shown in the following table is given in TRL Report PPR 066 (2006).

Wear Factors	Maintenance W_M	New W_N
Buses and Coaches	2.6	3.9
2-axle rigid	0.4	0.6
3-axle rigid	2.3	3.4
4-axle rigid	3.0	4.6
3 and 4-axle articulated	1.7	2.5
5-axle articulated	2.9	4.4
6-axle articulated	3.7	5.6
OGV1 + PSV	0.6	1.0
OGV2	3.0	4.4

Table 3. Wear Factors for cv classes and categories (DMRB).

Percentage of Commercial Vehicles in Heaviest Loaded Lane (P)

All lanes are designed for the heaviest loaded lane. For new and existing carriageways with 2 or more lanes in one direction, the proportion of vehicles in the most heavily loaded lane shall be estimated using the following figure.

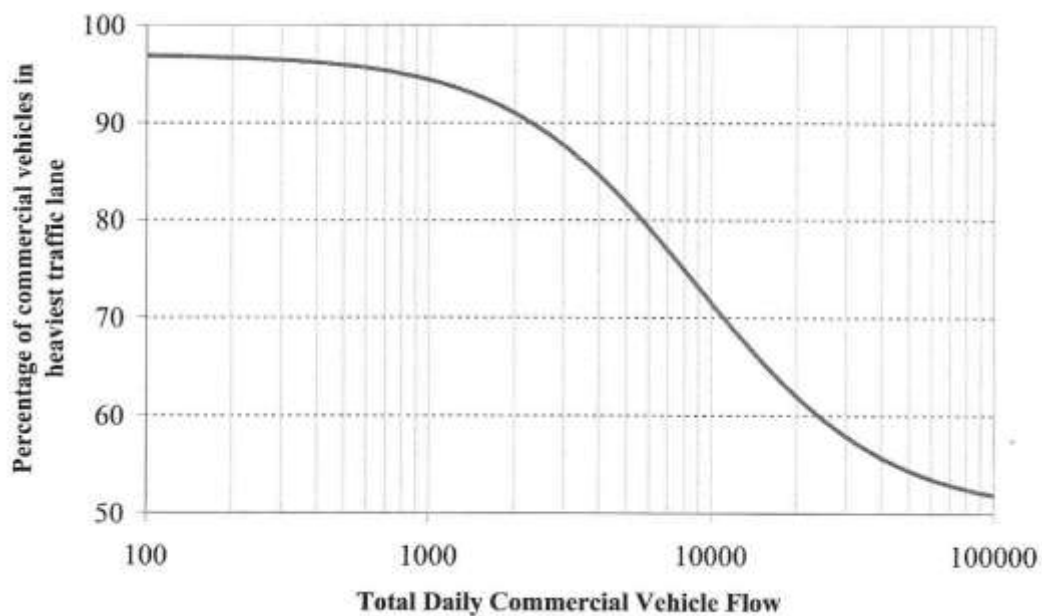


Figure 6. Percentage of commercial vehicles in heaviest load lane (P) (DMRB).

Estimation of Design Traffic (T)

The future cumulative flow, in terms of million standard axles (msa) for cv class, T_i can be determined according to the following equation:

$$T_i = 365 \times F \times Y \times G \times W \times P \times 10^{-6} \text{ msa}$$

Finally,

$$\text{Design Traffic } (T) = \sum T_i$$

For more detailed information, see HD 24/06, Volume 7, Section 2, Part 1.

3.12.3 Road pavement design

Pavement design is developed in HD 26/06, Volume 7, Section 2, Part 3.

Designed thicknesses are based on four foundation stiffness classes, defined as the equivalent half-space long-term stiffness of the composite foundation under the completed pavement, as follows:

- Foundation Class 1 ≥ 50 MPa;
- Foundation Class 2 ≥ 100 MPa;
- Foundation Class 3 ≥ 200 MPa;
- Foundation Class 4 ≥ 400 MPa.

Foundation Class 1 is a capping only design, without a subbase layer. This foundation must not be used for design traffic in excess of 20 msa without a “Departure from Standard” form the Overseeing Organisation.

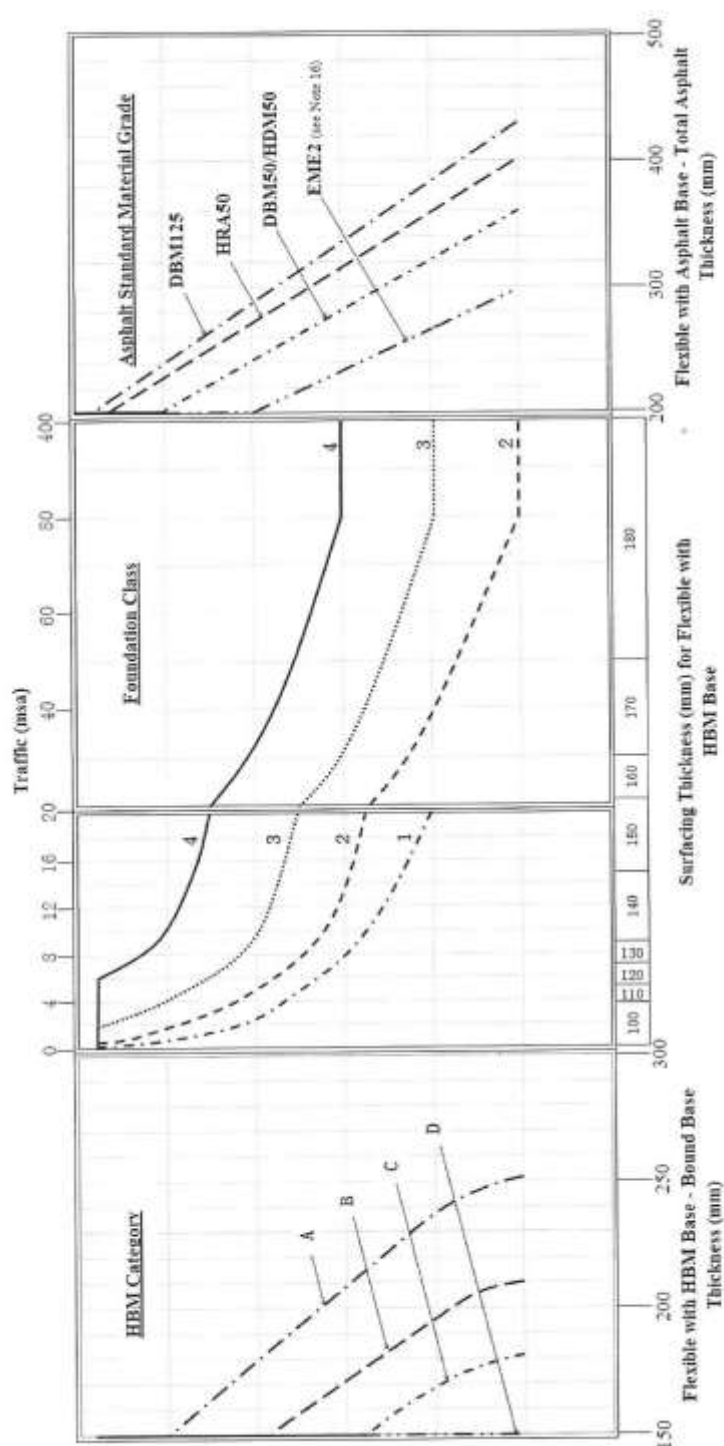
Foundation Class 2 is either a subbase and capping design, or a subbase only design. This foundation must not be used for design traffic in excess of 80 msa, unless 150mm or more of a bounda subbase is used, without a “Departure from Standard” from the Overseeing Organisation.

Foundation Classes 3 and 4 are designs typically incorporating cement or other hydraulically bound mixtures (HBM).

Flexible pavement design

The thickness calculation is obtained from the following figure. On an asphalt base, the total thickness of asphalt (comprising the wearing course, basecourse and road base) is obtained from the right hand portion of the nomograph and depends on the base material type. A DBM125 base is the least stiff material, and so requires the thickest construction. The stiffness of asphalt material then increases from HRA50, through DBM50/HDM50, to EME2. A reduced thickness of material will provide the same structural equivalence, provided the stiffness is adequately increased.

For a flexible composite pavement, the left hand portion of the nomograph gives the thickness of HBM for a given strength, with the thickness of overlying asphalt in the central portion of the nomograph. Better performance is expected for those mixtures made with a crushed rock coarse aggregate that has a coefficient of thermal expansion less than 10×10^{-6} per °C (typically limestone).



Examples of Hydraulic Bound Base Materials

HBM Category	A	B	C	D
Crushed Rock Coarse Aggregate; (with coefficient of thermal expansion $<10 \times 10^{-6}$ per °C)	-	CBGM B - C8/10 (or T3) SBM B1 - C9/12 (or T3) FABM1 - C9/12 (or T3)	CBGM B - C12/15 (or T4) SBM B1 - C12/16 (or T4) FABM1 - C12/16 (or T4)	CBGM B - C16/20 (or T5) SBM B1 - C15/20 (or T5) FABM1 - C15/20 (or T5)
Gravel Coarse Aggregate; (with coefficient of thermal expansion $\geq 10 \times 10^{-6}$ per °C)	CBGM B - C8/10 (or T3) SBM B1 - C9/12 (or T3) FABM1 - C9/12 (or T3)	CBGM B - C12/15 (or T4) SBM B1 - C12/16 (or T4) FABM1 - C12/16 (or T4)	CBGM B - C16/20 (or T5) SBM B1 - C15/20 (or T5) FABM1 - C15/20 (or T5)	-

Figure 7. Design thickness for flexible pavements (DMRB).

Some considerations about this nomograph:

- Thickness to be rounded up to the next 10 mm.
- Minimum allowable total asphalt material thickness is 200 mm. Minimum allowable HBM base thickness is 150 mm (in Scotland, 175 mm).

- This figure assumes that the basecourse is the same material as the base. However, any permitted material may be used as long as the overall pavement thickness is adjusted to give equivalent load spreading ability.
- If 50 mm of Porous Asphalt (PA) surfacing is to be used, it must be modified with a polymer or fibre additive. Its contribution to the material design thickness is only 20 mm. A 60 mm dense basecourse is required beneath PA surfacing, compacted so that the air voids are less than the maximum permitted (Series 900, MCHW1).
- A basecourse must be provided beneath a TSCS, but is optional beneath other materials such as HRA. If used, the basecourse can be of any permitted material and at least 50 mm thick (except for SMA, which should be at least 30 mm), and compacted.

Rigid pavement design

For a rigid pavement, the total thickness (excluding any asphalt surfacing) is obtained from the right hand portion of the nomograph for a CRCP, and the left hand portion for a CRCB. Thickness for a given design traffic depends on the flexural strength of concrete and the foundation class.

CRCP or CRCB options must be considered where the design traffic loading exceeds 30 msa, and the advantages of lower maintenance throughout the design life may be worthwhile.

It is very important to address the ends of the CRCP and CRCB to avoid any force transmittance to adjacent structures.

Some considerations about the nomograph in Figure 8:

- Thicknesses rounded up to next 10 mm.
- f_r (MPa) corresponds to concrete flexural strength at 28 days.
- Minimum allowable concrete material thickness is 200 mm for CRCP and 150 mm for CRCB. It does not include any asphalt surfacing.
- The concrete design thickness value assumes the presence of a minimum 1 m edge strip or tied shoulder, otherwise the concrete design thickness shall be increased by 30 mm.
- Foundations below rigid pavements must comprise at least 150 mm of bound subbase material, in order to ensure durability.
- Two options for CRCP are available:
 - o CRCP with minimum 30 mm of TSCS, for noise reduction; hence no binder course is required.
 - o CRCP with no surfacing (not a permitted option in England).
- Same conditions for PA as with flexible pavement. The PA will be 50 mm thick over a 90 mm basecourse or 50 mm thick over a 60 mm basecourse with the CRCB increased by 10 mm thickness.
- Longitudinal crack control steel in CRCP will be 0.6% of the concrete slab cross-sectional area, comprising 16 mm diameter deformed steel bars. Transverse steel must be 12 mm diameter deformed bars at 600 mm spacings.
- Longitudinal crack control steel in CRCB will be 0.4% of the concrete slab cross-sectional area, comprising 12 mm diameter deformed steel bars. Transverse steel must be 12 mm diameter deformed bars at 600 mm spacings.

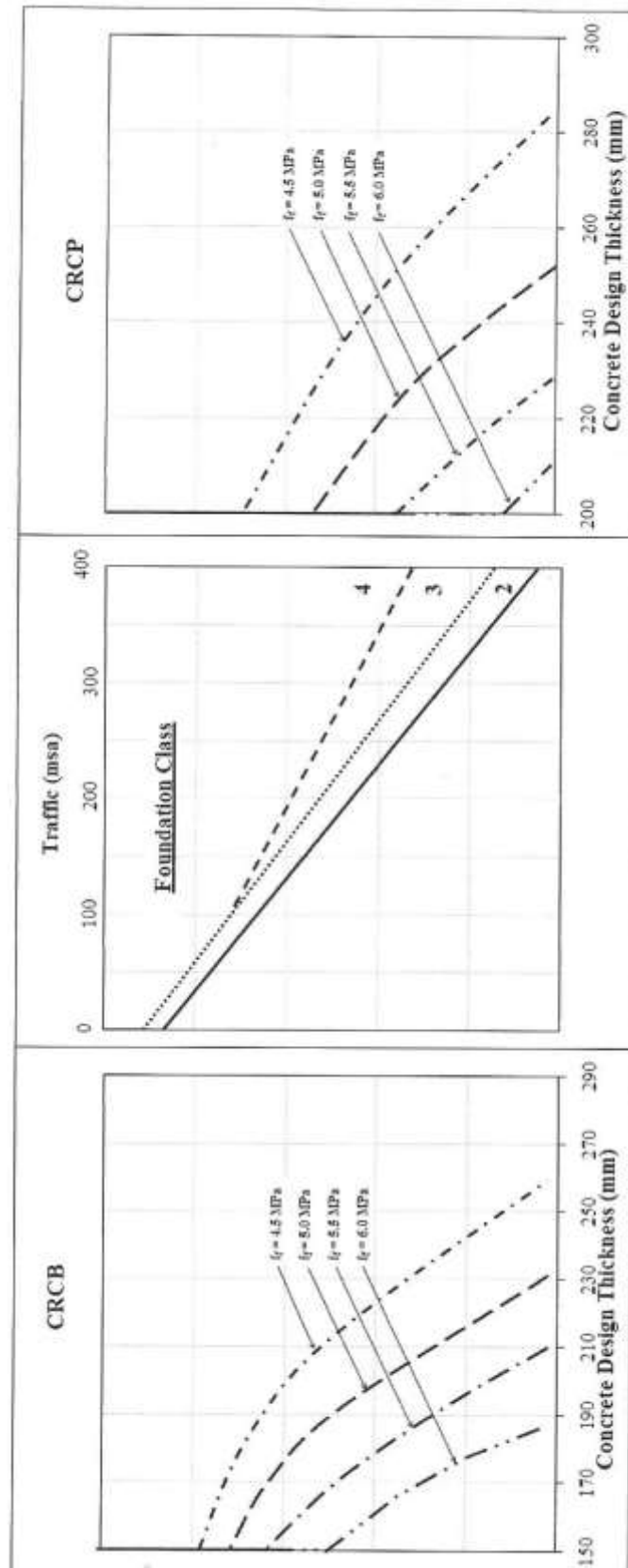


Figure 8. Design thickness for rigid pavements (DMRB).

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