

Deterioration and Maintenance of Pavements

Second edition

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A significant alternative to water as a binder arose as tar increasingly became available as a by-product of the growing production in the 19th century of ‘town gas’ from coal. Given the concurrent increase in the use of macadam construction, it was a natural, but still innovative, step to try to use the surplus tar as a replacement for the sand, stone, dust and soil rather than just as a binder for the surface. Tar was first used as a binder in this manner in 1832 in the English town of Gloucester for footpath construction. A subsequent major step was to precoat each particle of stone with a thin film of binder before placing it on the pavement. Such products are called precoated (or coated) macadams. Tarred heated gravel was first used in this manner in a trial in Nottingham in England in 1840 (Lay, 1986).

With the advent of a regular economical source of crushed rock, which became available in the early 1950s, hand pitching as in generic Telford construction became a thing of the past, and flexible pavements of a generic macadam form became the norm, especially in urban and suburban areas. In addition, most of the early motorways in the UK were built using flexible constructions with an asphalt surface. The major advantage of this method was that the construction process could be mechanised, and thus considerably less labour was required. Typically, a flexible construction consists of three layers, as shown in Table 2.1.

Flexible construction in rural areas generally comprises a macadam-type base surmounted by several layers of surface dressing to provide a dust-free impervious surface.

While many of the early flexible roads were ‘designed empirically’, based on incremental practical experience of what had performed successfully in the past, there has been a progressive desire to undertake some form of analytical design in an attempt to make more economical use of materials, especially the asphalt layer, which is the most expensive.

2.12. Flexible composite pavements

A flexible composite pavement is similar to a flexible one, except a cement or otherwise stabilised layer replaces the granular layer to provide a significantly enhanced bearing capacity platform to support the asphalt surfacing layers.

The early use of cement-bound granular base (CBGB) material was an attempt to construct a thinner and more economical pavement using stabilised gravel. With the more recent use of other binders,

Table 2.1 Typical layer structure of a flexible pavement

Asphalt (usually more than 1 layer)

Crushed rock granular sub-base

Formation (existing ground)

which have lower early-age performance properties, this class of supporting layer is now generally referred to as a hydraulically bound material (HBM). The combination of stiffness and strength is crucial for the design of a hydraulically bound base.

This CBGB form of construction was used extensively in some of the early UK motorways, but was not entirely successful due to thermal movement of the cement-bound layer. This resulted in reflection cracks migrating to the surface, leading to progressive failure, initially of the surface course and subsequently the CBGB layer.

There has been a progressive movement away from the use solely of cement as a binder. Experience of the use of fly ash, slags and lime mixtures as a partial replacement for the cement has been reported, and substantial economies have been noted, without significant loss of strength. The general philosophy of the current UK design method allows both types of CBGB and a wide range of HBMs to be used in the base, provided that some empirical justification for the calibration of the design criteria is met (A detailed explanation is given in Chapter 4 and in Chapter 5). Current thinking regarding HBM is to pre-crack the layer such that the location of potential reflection cracking can be controlled.

The various types of environmental distress experienced by a flexible composite pavement during the early stages of its life are similar to those experienced by an asphalt surface course on a flexible construction.

2.13. Concrete slab pavements

Since the first strip of concrete pavement was completed in 1893, concrete has been used extensively for the paving of highways and airports as well as business and residential streets. Concrete slab pavements were originally thought to be the panacea for many problems, particularly as it was believed they would not need any maintenance. This aspiration proved to be incorrect, as there is a continuous need to maintain the joint filler and sealer between adjacent slabs. Individual slabs, typically 4–5 m long and up to 300 mm thick for a lane width of 3.65 m, have been used extensively, both with and without reinforcement and with and without load-transfer dowels between adjacent slabs.

2.14. Continuously reinforced concrete pavements

In the UK, as concrete is not acceptable as a running surface on the national road network, at the present time there are two options for continuously reinforced concrete pavements, as shown in Table 2.2.

The need for maintenance is usually related to degradation of the asphalt surface course, resulting from materials failure exacerbated by thermal stresses. The replacement of the asphalt layer is relatively straightforward thanks to the continuing development of large planing machines.

4.4. Design process

The structural design of pavement basically involves determining appropriate bound and unbound layer thicknesses to be laid on a suitable subgrade which is capable of withstanding traffic and environmental loading during the design life. The pavement design is typically a three-stage process: stages 1 and 2 are traffic and foundation design, respectively, which then feed into stage 3, the calculation of the bound layer thicknesses.

In pavement design, traffic loading is the most important design input, but it varies over the design life of the structures (heavy loading during construction, unexpected growth in traffic, etc.). Traffic load is a function of the types and number of vehicles, speed of travel, tyre and contact pressure, growth and, finally, the use of the pavement. Similarly, the foundation is designed to carry construction traffic and act as a construction platform. The long-term properties of the foundation (modulus, CBR, etc.) are used in the analytical model to design the pavement structure. The process of designing a pavement may be split into the following steps

- assess the design load based on life, traffic flow and vehicle type
- assess the bearing capacity of the foundation and any needed stabilisation
- assess the required thickness and specifications of the asphalt layers
- ensure the serviceability of the pavement for its design life
- define the maintenance profile to ensure the required serviceability level(s).

4.5. Failure of a pavement

Any design must be done against some assumed failure or serviceability criteria. In the case of a pavement, failure is usually considered to be a combination of surface deformation (rutting), generally taken as 20 mm, and cracking, when this affects 50% of the wheel path. In addition, failure to meet functional requirements such as skidding resistance will require immediate attention.

Even in this ‘failed’ condition the pavement will still be serviceable to some degree, in the context that its capability to carry traffic is still viable and the traffic may only have to reduce speed of travel by a small amount to maintain safe passage. In the case of a pavement, it must be understood that the term ‘failure’ is not used in the context that it will no longer be serviceable. In other words, failure of a pavement is a defined as a state of deterioration and not an inability to allow the passage of traffic.

4.6. Pavement analysis

The design philosophy of the mechanistic-empirical method is similar to that used in other civil engineering design problems, where some form of simplified layer structure is assumed to facilitate analysis. The design load is then determined, and the size of the

layer is estimated. The analysis for stresses, strain and deflections at critical points are conducted, and the values obtained are compared with the maximum allowable values to assess whether the design is satisfactory. The performance of the pavement, in terms of resistance against cracking and permanent deformation, is then predicted for specific types of material, and empirically determined from performance test under different traffic and environmental conditions. The following section explores the mechanistic analysis of pavements, which is the basis of mechanistic-empirical design (FHWA, 1995; Ullidtz, 1987, 1998).

4.6.1 Basic concepts

In mechanics there is a fundamental relationship between stress and strain when a load is applied to an engineering material. As both the foundation soil and the various components from which a pavement is built may be engineering materials, this relationship can also be applied to pavement design. This may be set out simply as

$$\text{Stress} = \frac{\text{Load}}{\text{Area}} \quad (4.1)$$

$$\text{Strain} = \frac{\text{Change in length}}{\text{Original length}} \quad (4.2)$$

The fundamental relationship between stress and strain is characterised by the elastic modulus, which has in the past generally been referred to as ‘Young’s modulus’ and is denoted by the symbol E . This may be set out in the form

$$\text{Stress} = E \times \text{Strain} \quad (4.3)$$

Stress and strain may be either

- tensile
- compressive
- shear.

Whatever the form, the basic principles and relationship set out above hold good.

4.6.2 Reasons for using the mechanistic-empirical approach

Mechanics is the science of motion and the action of forces on bodies. When engineers refer to a mechanistic approach in engineering, they are alluding to the application of elementary physics to determine the reaction of structures to loading. The primary concern in pavements is how the structure distributes vehicle loads to the underlying soil layers.

Weak pavements concentrate the load over a smaller area of the subgrade than strong pavements, resulting in higher stresses, as shown in Figure 4.1. In order to quantify how the load is being

6.8. Utility apparatus

Pavements are often a conduit for utility apparatus, and this needs to be considered when planning intrusive surveys such as coring, trial pits or dynamic cone penetrometer (DCP) testing (Figure 6.5).

Damage to underground services during surveying can cause fatal or severe injury, as well as significant disruption and environmental damage; it can also delay a project and incur considerable costs. The potential risks associated with service strikes are summarised in Table 6.3.

The risks to health from striking a live cable or high-pressure gas main are obvious. However, managing risk involves more than just a consideration of the risks that may be harmful to health; reputational and financial risks resulting from damage to non-hazardous services have the potential to cause disruption, reputational damage and require expensive repair. Engineers need to be mindful that a risk that may result in a low potential for harm to operatives (e.g. severing a fibre-optic cable) may have the potential to do harm to others who may be relying on that utility. Pavement designers should always employ the principles of prevention hierarchy when designing for utilities.

1. *Eliminate*. Can the identified risk be eliminated so far as is reasonably practicable?
2. *Reduce*. If the risk cannot be eliminated, can it be reduced?
3. *Inform*. Pass on details of significant risks to those who need to know.
4. *Control*. What actions does the designer consider are necessary to be taken to control the foreseeable risks that could not be eliminated or have had their impact reduced through the design?

Figure 6.5 Underground utilities identified on a pavement surface



Table 6.3 Potential risks associated with service strikes during pavement intrusive testing and/or construction activity

Service	Typical risk associated with service strike
Electric cables	Explosive effects of arcing current, which may cause fire or flames Damage to nearby services, including risk of explosion and fire
Gas pipeline	Immediate explosion and fire risk caused by damage Creation of a long-term leak that results in a safety and/or serviceability risk sometime later
Water pipeline	A water jet can have sufficient pressure to cause injury Leaks can cause damage to adjacent services and structures
Sewers	Possible flooding and risk of drowning and/or collapse of excavations Health of workers from exposure to raw sewage Ground collapse
Other pipelines	Environmental contamination and pollution Risk of fire and explosion from flammable gases and liquids Injury from sudden release of contents Poisoning from toxic liquids and gases Asphyxiation from inert gases
Telecommunication cables	Expensive repairs Considerable disruption

To minimise the potential risk, and design to the principles of prevention, it is essential to have utility survey data for all designs. Designing without this information can result in costly mistakes and the potential to harm, or even kill, site operatives.

6.9. Recent developments in pavement data (the 'big data' revolution)

Reliable and consistent data collection methods that have been in place over many decades have undoubtedly been beneficial in the development of pavement engineering as a specialist discipline. Data collection has traditionally been restricted to well used and

Figure 8.9 A pothole

The pothole shown in Figure 8.9 developed over a period of just a few days. At the time when the photograph was taken the location and depth of the pothole were sufficient for it to be considered a serious safety defect and an emergency repair was undertaken by the highway authority.

8.2.17 Patches and service reinstatements

A reinstated excavation (trench or patch) has the potential to result in a weakening of the pavement structure. Poorly reinstated trenches and patches are a common cause of defects. Poor consideration of ironwork during construction or maintenance is also a common cause of cracking. Failed trenches and patches can cause localised structural failures, and where these extend throughout the majority of a pavement surface they can become a serious issue that may require maintenance repairs or even full-scale reconstruction.

8.2.18 Ironwork defects

Ironwork located within a pavement has the potential to be a point of weakness. All ironwork should be recorded during a visual condition survey, together with any defects associated with the asset. A ‘rocking’ cover has the potential to be a safety concern and an annoyance to anybody living or working nearby.

The area of cracking shown in Figure 8.10 is significantly larger than the area of the ironwork that has caused the cracking defect to occur. These defects are often caused by inadequate attention being paid to ironwork during maintenance (i.e. ironwork is not properly realigned to maintenance treatments with the differential in levels resulting in cracking).

8.2.19 Edge deterioration

Edge deterioration is a measure of cracking and fretting at the edge of a pavement. It can only be recorded where there is no edge restraint present (i.e. no kerb or channel). Where defects extend beyond the carriageway edge they should also be recorded as

Figure 8.10 Pavement cracking around a small ironwork asset located within a carriageway

whole-carriageway defects. Edge deterioration should be measured in linear metres, and for measurement purposes the minimum defect length should be taken as 1 m. Recording edge defects is important because they can often relate to safety. In assessing severity, it may be prudent to consider whether a vehicle is likely to overrun the pavement edge. For example, significant safety hazards can occur on the inside of a bend, where vehicles are more likely to run close to the pavement edge.

The pavement shown in Figure 8.11 is a rural lane with poor lateral support and inadequate drainage. The photo also shows evidence of a previous patch repair, which indicates that this is likely to be an ongoing problem at this location. Recording the presence and condition of previous repairs can be useful in understanding the maintenance history of a pavement.

Figure 8.11 Serious edge deterioration at a rural location

Condition surveys may provide contributory information and reduce the scope of detailed inspections. The surveys may be undertaken either by a slow-moving vehicle, on foot or by utilising data such as video, depending on the circumstances. The frequency of the detailed inspection should be determined on a local basis.

17.2.3.3 Condition inspections

Condition inspections are primarily intended to identify deficiencies in the fabric of the highway network which, if untreated, are likely to adversely affect its long-term performance, serviceability and safety. Repeatable condition surveys allow trend analysis to be used, either to confirm the original decisions or to allow for changes as a result of the changing network condition, and to inform life-cycle planning.

17.2.4 Warning/intervention (investigatory) levels

The 2005 code was prescriptive regarding intervention if the defect was below a set investigatory level. An example in Table 17.3 sets out a typical recommendation for the standards of maintenance for whole-carriageway minor deterioration (Roads Liaison Group, 2005). The 2016 code, on the other hand, steps away from prescribing or encouraging a set level, and allows authorities to have a reference level. In the risk-based assessment, all defects observed during safety inspections that provide a risk should be recorded, and the response must be determined based on the risk assessment, meaning that, in some circumstances, inspection items with a lesser degree of deficiency may pose an equal or greater safety hazard to those with a greater degree of deficiency. For example, the degree of risk from a pothole depends not only on its depth but also on its surface area and location, and as such different potholes may warrant different response times. When distress is approaching, has reached or has exceeded the investigatory level, the safety inspector should conduct a risk assessment to determine the appropriate level of response.

Surface treatment covers all forms of surface sealing techniques, including patching, surface dressing using normal or special aggregates and binders, thin coatings using dense material and, in

extreme cases of traffic loading, relaying or overlaying the road surface layers. Surface treatment should be considered when the warning levels set out in Table 17.3 are reached (or close to being reached). Once a certain level of roughness has been reached, the rate of structural deterioration caused by commercial vehicle axles increases at an exponential rate due to dynamic effects rather than effects simply related to the flow of traffic.

Bituminous pavements and concrete pavements are considered separately, as the character of the work is fundamentally different. The character of work envisaged in this chapter covers a range, including

- patching
- surface dressing
- retreading
- resurfacing.

This area is one of considerable current innovation. However, many of the products are proprietary, and therefore it is difficult to obtain much information about them.

17.3. Damage and distress in asphalt surfaces

This section sets out the more common forms of damage and distress found in asphalt surfaces. It examines the causes and comments on appropriate maintenance responses. Brief consideration is also given to the materials that are considered most suitable in each case.

17.3.1 Potholes

Potholes are the result of local materials deterioration and appear in the form of small or large bowl-shaped holes on the pavement surface. In potholes, pieces of aggregate have become detached from the parent body, allowing the ingress of water, which may lead to stripping of the binder and enhanced deterioration – not to mention damage to passing traffic.

Table 17.3 Typical investigatory level in the 2005 code

Category to which applicable	Limitation or severity	Percentage of area	Treatment
2–4	Note 1	20%	Surface treatment (Notes 1–4)

Data taken from Roads Liaison Group, 2005.

Notes 1–4

1. Whole-carriageway minor deterioration covers: fine crazing, permeable surfaces, fretting, loss of chippings and fatting up of existing surface dressings.
2. With the commercial introduction of a range of improved binders and chipping application techniques, surface treatment should be seriously considered as an alternative to resurfacing all categories of the road when minor carriageway defects emerge.
3. Patching, either in isolation or before surface treatment, should always be carried out where required to ensure a uniform surface with the remainder of the road and to remove isolated weak areas.
4. Patching repairs should be considered when the repairs are those resulting primarily from ageing or thermal stresses and as such lead either to a poor ride or a permeable pavement. The objectives, therefore, are to maintain the impermeability of the surface course and at the same time provide a smooth ride.