A GUIDE TO THE STRUCTURAL DESIGN OF BITUMEN-SURFACED ROADS IN TROPICAL AND SUB-TROPICAL COUNTRIES

1. INTRODUCTION

1.1 GENERAL

This Road Note gives recommendations for the structural design of bituminous surfaced roads in tropical and subtropical climates. It is aimed at highway engineers responsible for the design and construction of new road pavements and is appropriate for roads which are required to carry up to 30 million cumulative equivalent standard axles in one direction. The design of strengthening overlays is not covered nor is the design of earth, gravel or concrete roads. Although this Note is appropriate for the structural design of flexible roads in urban areas, some of the special requirements of urban roads, such as the consideration of kerbing, sub-soil drainage, skid resistance, etc., are not covered.

For the structural design of more heavily trafficked roads, the recommendations of this Note may be supplemented by those given in the guides for the design of bituminous pavements in the United Kingdom (Powell et al. (1984)) but these are likely to require some form of calibration or adaptation to take account of the conditions encountered in the tropics.

1.2 ROAD DETERIORATION

The purpose of structural design is to limit the stresses induced in the subgrade by traffic to a safe level at which subgrade deformation is insignificant whilst at the same time ensuring that the road pavement layers themselves do not deteriorate to any serious extent within a specified period of time.

By the nature of the materials used for construction, it is impossible to design a road pavement which does not deteriorate in some way with time and traffic, hence the aim of structural design is to limit the level of pavement distress, measured primarily in terms of riding quality, rut depth and cracking, to predetermined values. Generally these values are set so that a suitable remedial treatment at the end of the design period is a strengthening overlay of some kind but this is not necessarily so and roads can, in principle, be designed to reach a terminal condition at which major rehabilitation or even complete reconstruction is necessary. However, assessing appropriate remedial treatments for roads which have deteriorated beyond a certain level is a difficult task. In most design methods it is assumed that adequate routine and periodic maintenance is carried out during the design period of the road and that at the end of the design period a relatively low level of deterioration has occurred.

Acceptable levels of surface condition have usually been based on the expectations of road users. These expectations have been found to depend upon the class of road and the volume of traffic such that the higher the geometric standard, and therefore the higher the vehicle speeds, the lower the level of pavement distress which is acceptable. In defining these levels, economic considerations were not considered because there was insufficient knowledge of the cost trade-offs for an economic analysis to be carried out with sufficient accuracy.

1.3 ECONOMIC CONSIDERATIONS

In recent years a number of important empirical studies have shown how the costs of operating vehicles depend on the surface condition of the road. The studies have also improved our knowledge of how the deterioration of roads depends on the nature of the traffic, the properties of the road-making materials, the environment, and the maintenance strategy adopted (Parsley and Robinson (1982), Paterson (1987), Cheshertard Harrison (1987), Watanatada et al. (1987)). In some circumstances it is now possible to design a road in such a way that provided maintenance and strengthening can be carried out at the proper time, the total cost of the transport facility i.e. the sum of construction costs, maintenance costs and road user costs, can be minimised. These techniques are expected to become more widespread in the future. Also, with the introduction in many countries of pavement management systems in which road condition is monitored on a regular basis, additional information will be collected to allow road performance models to be refined. Pavement structural design could then become an integral part of the management system in which design could be modified according to the expected maintenance inputs in such a way that the most economic strategies could be adopted. Whilst these refinements lie in the future, the research has provided important guidance on structural designs suitable for tropical and sub-tropical environments and has been used, in part, in preparing this edition of Road Note 31.

For the structures recommended in this Note, the level of deterioration that is reached by the end of the design period has been restricted to levels that experience has shown give rise to acceptable economic designs under a wide range of conditions. It has been assumed that routine and periodic maintenance activities are carried out to a reasonable, though not excessive, level. In particular, it has been assumed that periodic maintenance is done whenever the area of road surface experiencing defects i.e. cracking, ravelling, etc., exceeds 15 per cent. For example, for a 10 year design period, one surface maintenance treatment is likely to be required for
the higher traffic levels whereas for a 15 year design period, one treatment is likely to be required for the lower traffic levels and two for the higher. These are broad guidelines only and the exact requirements will depend on local conditions.

1.4 EFFECTS OF CLIMATE

Research has shown how different types of road deteriorate and has demonstrated that some of the most common modes of failure in the tropics are often different from those encountered in temperate regions. In particular, climate-related deterioration sometimes dominates performance and the research has emphasised the overriding importance of the design of bituminous surfacing materials to minimise this type of deterioration (Paterson (1987), Smith et al (1990), Strauss et al (1984)). This topic is dealt with in Chapter 8.

Climate also affects the nature of the soils and rocks encountered in the tropics. Sod-forming processes are still very active and the surface rocks are often deeply weathered. The soils themselves often display extreme or unusual properties which can pose considerable problems for road designers. The recent publication 'Road building in the tropics: materials and methods' provides an introduction to these topics (Millard (1993)).

1.5 VARIABILITY IN MATERIAL PROPERTIES AND ROAD PERFORMANCE

Variability in material properties and construction control is generally much greater than desired by the design engineer and must be taken into account explicitly in the design process. Only a very small percentage of the area of the surface of a road needs to show distress for the road to be considered unacceptable by road users. It is therefore the weakest parts of the road or the extreme tail of the statistical distribution of 'strength' which is important in design. In well controlled full-scale experiments this variability is such that the ten per cent of the road which performs best will carry about six times more traffic before reaching a defined terminal condition than the ten per cent which performs least well. Under normal construction conditions, this spread of performance becomes even greater. Some of this variability can be explained through the measured variability of those factors known to affect performance. Therefore, if the likely variability is known beforehand, it is possible, in principle, for it to be taken into account in design. It is a false economy to minimise the extent of preliminary investigations to determine this variability.

In practice, it is usually only the variability of subgrade strength that is considered and all other factors are controlled by means of specifications. By setting minimum acceptable values for the key properties, but specifications need to be based on easily measurable attributes of the materials and these may not correlate well with the fundamental mechanical properties on which behaviour depends. As a result, even when the variability of subgrade strength and pavement material properties are taken into account, there often remains a considerable variation in performance between nominally identical pavements which cannot be fully explained. Optimum design therefore remains partly dependent on knowledge of the performance of in-service roads and quantification of the variability of the observed performance itself. Thus, there is always likely to be scope for improving designs based on local experience.

Nevertheless, it is the task of the designer to estimate likely variations in layer thicknesses and material strengths so that realistic target values and tolerances can be set in the specifications to ensure that satisfactory road performance can be guaranteed as far as is possible.

The thickness and strength values described in this Road Note are essentially minimum values but practical considerations require that they are interpreted as lower ten percentile values with 90 per cent of all test results exceeding the values quoted. The random nature of variations in thickness and strength which occur when each layer is constructed should ensure that minor deficiencies in thickness or strength do not occur on top of the other, or very rarely so. The importance of good practice in quarrying, material handling and stockpiling to ensure this randomness and also to minimise variations themselves cannot be over emphasised.

1.6 UNCERTAINTY IN TRAFFIC FORECASTS

Pavement design also depends on the expected level of traffic. Axle load studies and traffic counts are essential prerequisites for successful design, but traffic forecasting remains a difficult task and therefore, sensitivity and risk analysis are recommended. This topic is discussed in Chapter 2.

1.7 BASIS FOR THE DESIGN CATALOGUE

The pavement designs incorporated into the fourth edition of Road Note 31 are based primarily on:

(a) The results of full-scale experiments where all factors affecting performance have been accurately measured and their variability quantified.

(b) Studies of the performance of as-built existing road networks.


In view of the statistical nature of pavement design caused by the large uncertainties in traffic forecasting and the variability in material properties, climate and road behaviour, the design charts have been presented as a

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catalogue of structures, each structure being applicable over a small range of traffic and subgrade strength. Such a procedure makes the charts extremely easy to use but it is important that the reader is thoroughly conversant with the notes applicable to each chart.

Throughout the text the component layers of a flexible pavement are referred to in the following terms (see Figure 1).

**Surfacing.** This is the uppermost layer of the pavement and will normally consist of a bituminous surface dressing or a layer of premixed bituminous material. Where premixed materials are laid in two layers, these are known as the wearing course and the basecourse (or binder course) as shown in Figure 1.

**Roadbase.** This is the main load-spreading layer of the pavement. It will normally consist of crushed stone or gravel, or of gravelly soils, decomposed rock, sands and sand-clays stabilised with cement, lime or bitumen.

**Sub-base.** This is the secondary load-spreading layer underlying the roadbase. It will normally consist of a material of lower quality than that used in the roadbase such as unprocessed natural gravel, gravel-sand, or gravel-sand-clay. This layer also serves as a separating layer preventing contamination of the roadbase by the subgrade material and, under wet conditions, it has an important role to play in protecting the subgrade from damage by construction traffic.

**Capping layer (selected or improved subgrade).** Where very weak soils are encountered, a capping layer is sometimes necessary. This may consist of better quality subgrade material imported from elsewhere or existing subgrade material improved by mechanical or chemical stabilisation.

**Subgrade.** This is the upper layer of the natural soil which may be undisturbed local material or may be soil excavated elsewhere and placed as fill. In either case it is compacted during construction to give added strength.

### 1.8 THE DESIGN PROCESS

There are three main steps to be followed in designing a new road pavement. These are:

(i) estimating the amount of traffic and the cumulative number of equivalent standard axles that will use the road over the selected design life;

(ii) assessing the strength of the subgrade soil over which the road is to be built;

(iii) selecting the most economical combination of pavement materials and layer thicknesses that will provide satisfactory service over the design life of the pavement (it is usually necessary to assume that an appropriate level of maintenance is also carried out).

This Note considers each of these steps in turn and puts special emphasis on five aspects of design that are of major significance in designing roads in most tropical countries:

- The influence of tropical climates on moisture conditions in road subgrades
- The severe conditions imposed on exposed bituminous surfacing materials by tropical climates and the implications of this for the design of such surfacings.
- The interrelationship between design and maintenance. If an appropriate level of maintenance cannot be assumed, it is not possible to produce designs that will carry the anticipated traffic loading without high costs to vehicle operators through increased road deterioration.
- The high axle loads and tyre pressures which are common in most countries.
- The influence of tropical climates on the nature of the soils and rocks used in road building.

The overall process of designing a road is illustrated in Figure 2. Some of the information necessary to carry out the tasks may be available from elsewhere, e.g., a feasibility study or Ministry records, but all existing data will need to be checked carefully to ensure that it is both up-to-date and accurate. Likely problem areas are highlighted in the relevant chapters of this Note.

![Fig. 1 Definition of pavement layers](image-url)
Fig. 2 The pavement design process