DESIGN RECOMMENDATIONS FOR
UNREINFORCED CONCRETE PAVEMENTS

Road Research Laboratory
Crowthorne, Berkshire.
1968
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DESIGN RECOMMENDATIONS FOR
UNREINFORCED CONCRETE PAVEMENTS

ABSTRACT

A re-examination of the performance data relating to unreinforced concrete roads has enabled a revision to be made of the design recommendations for this type of pavement given in Road Note No. 29. Slab and base thicknesses are recommended for all intensities of traffic and revision has also been made of the recommended joint spacings. Expansion joints may be omitted in roads constructed in the summer months. Tied warping joints may be substituted for some contraction joints and a description is given of the form of warping joint recommended.

1. INTRODUCTION

The 1960 edition of Road Note No. 29(1) did not include recommendations for reinforced concrete roads. The scope of the 1965 edition(2) was widened to include housing estate and other lightly trafficked roads and consideration was given to the inclusion of recommendations for plain concrete pavements. On the review then made of the available evidence it was decided to include recommendations for plain concrete pavements to carry up to 1,500 commercial vehicles per day, and these recommendations entailed increasing the slab thickness by 2 inches over the requirement for equivalent reinforced concrete pavements.

The available evidence relating to plain concrete roads both in Britain and in the United States of America has again been re-examined by the Laboratory in conjunction with a Panel of its Research Committee on Concrete. The following recommendations now supersede those referring to plain concrete in the 1965 edition of Road Note No. 29.

The other sections of Road Note No. 29, i.e. those dealing with flexible and reinforced concrete pavements will also be reviewed in the near future; in the meantime the recommendations in Road Note No. 29 still stand.

2. USE OF DESIGN CHART FOR UNREINFORCED CONCRETE PAVEMENTS

The recommended design of unreinforced concrete pavements embracing the thickness of slab and base is given in Table 1, and is based on the traffic and on the subgrade and drainage conditions. The recommendations for joint spacing are given in Table 4.
<table>
<thead>
<tr>
<th>(1) Traffic (Commercial vehicles per day 20 years after construction, see Section 2.1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design thickness (in) / (see Sections 2.3, 2.4)</td>
<td>More than 3000 *</td>
<td>1500–3000</td>
<td>150–1500</td>
<td>45–150</td>
<td>Less than 45**</td>
</tr>
<tr>
<td>(i) Very stable subgrades</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slab thickness</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Base thickness</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>(ii) Normal subgrades</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slab thickness</td>
<td>10</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Base thickness</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>(iii) Subgrade very susceptible to non-uniform movement (also normal subgrades with a water-table rising to within 2 feet of the formation)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slab thickness</td>
<td>11</td>
<td>10</td>
<td>9</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Base thickness</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

* For traffic in excess of about 6000 commercial vehicles per day it will generally be desirable to increase the thickness of slab by 1 inch.

** When construction traffic (see para. 2.1.2) is likely to be heavy the slab thicknesses should be increased by 1 inch.

/ No base is needed where the top 2 feet of fill consists of sandy gravel as defined in Table 2 of Road Note No. 29. An extra depth of base will be needed on subgrades susceptible to frost heave or where the base is to be used for heavy construction traffic – see Section 2.3.
2.1 Traffic

The designs recommended in this Note are based on an estimate of the traffic that will be carried by the road 20 years after construction. Traffic is considered in terms of the number of commercial vehicles (unladen weight exceeding 30 cwt) per day summed in both directions, or on both carriageways if dual.

2.1.1 Estimation of commercial vehicle traffic

In making the estimate of traffic, consideration should be given to the existing traffic data, including a consideration of the roads to be replaced or supplemented, the area served and the probable growth of traffic during the expected life of the road. For major through roads the following formula may be used, in the absence of other information, to estimate the traffic figure for design purposes

\[ A = P (1 + r)x + 20 \]

where \( A \) = number of commercial vehicles per day for design;
\( P \) = number of commercial vehicles per day at last census,
\( r \) = annual rate of increase in the number of commercial vehicles – this may be taken as 0.04 (an average figure based on recent census data);
\( x \) = number of years between last census and year of construction.

The census figure should be a seven-day average based on 24 hour counts, or where this is not available, on 16-hour counts plus 6 per cent. In the absence of a special census, the latest appropriate census figure available should be used. When it is suspected that night traffic is abnormally heavy a 24 hour count should be used.

The designs provide for the normal small number of notifiable heavy loads (as defined by the Road Traffic Act) but where the number of such loads is likely to be high such as on approach roads to docks and similar places it will be advisable to select a design corresponding to a higher traffic intensity than that estimated.

2.1.2 Traffic on housing estate roads

On housing estate and other very lightly trafficked roads it is often difficult to obtain any accurate information on the commercial traffic likely to use the roads or its potential growth. Where such roads are constructed prior to the development they are likely to be subjected to their heaviest loads during the development period.

For such roads it is more appropriate to design the roads on their type and, where the roads are constructed prior to development, to take into account the construction traffic likely to use them. The intensity of this traffic will be influenced by the layout of roads adopted for the development and also by the type of development i.e. low-rise or high blocks. A classification of traffic for
housing estates roads is given in Table 2.

**TABLE 2**

Classification of traffic for housing estate roads

<table>
<thead>
<tr>
<th>Type of housing estate road</th>
<th>Traffic intensity to be assumed for design purposes (commercial vehicles per day 20 years after construction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Streets in main shopping centres of large developments carrying goods deliveries to shops and more than 100 public service vehicles per day.</td>
<td>450 - 1500</td>
</tr>
<tr>
<td>Main roads carrying several regular bus routes involving 50 - 100 public service vehicles per day.</td>
<td>150 - 450</td>
</tr>
<tr>
<td>Through roads carrying up to 50 public service vehicles per day.</td>
<td>45 - 150</td>
</tr>
<tr>
<td>Cul-de-sac and minor through roads carrying no public service vehicles.</td>
<td>up to 45</td>
</tr>
</tbody>
</table>

2.2 Subgrade

Subgrades are classified as very stable, normal, and very susceptible to non-uniform movement. These three categories are defined in Table 3. Wherever practicable, the water-table should be prevented from rising within 2 ft of the formation level. This should be done by subsoil drainage or by raising the formation level by means of an embankment.
TABLE 3
Classification of subgrades for concrete roads

<table>
<thead>
<tr>
<th>Type of subgrade</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very susceptible to non-uniform</td>
<td>Organic soils, and heavy clays or subgrades containing pockets of peat within a depth of 15 ft below the surface.</td>
</tr>
<tr>
<td>movement</td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>Subgrades other than those defined in the other two groups.</td>
</tr>
<tr>
<td>Very stable</td>
<td>Well compacted and undisturbed foundations of old roads and well-graded sandy gravels.</td>
</tr>
</tbody>
</table>

2.2.1 Drainage and weather protection

It is important to provide efficient permanent drainage to remove water from the subgrade and base, both during construction and during the life of the road. Waterproofing of the subgrade and base, e.g. by sealing may also be desirable.

2.3 Base*

The thickness of base recommended to give satisfactory structural performance for the three subgrade conditions considered is given in Table 1.

2.3.1 Materials for bases

Base materials should be hard, durable, chemically inert and suitably graded. They should be capable of being compacted to a high density, and, when in this condition, they should not be susceptible to frost heave, as defined in the Road Research Laboratory test procedure, or to shrinkage, swelling or loss of stability resulting from changes in moisture content.

Subject to the above, the base material may consist of granular materials (Clause 804, Ministry of Transport Specification for Road and Bridge Works, 1963 edition), stabilised soil (Clause 818) or lean concrete (Clause 806). The range of granular materials includes suitably graded or self-binding gravel, crushed stone or crushed slag. Where local experience has shown them to be suitable, hard clinker, and selected well-burnt colliery shale may be used.

2.3.2 Use of base by construction traffic

Where, for roads carrying more than 1500 commercial vehicles per day, constructional traffic is to use the base it is recommended that this base should be Type 1 aggregate, lean concrete or cement stabilized material (Clause 818), and the base thickness should be increased by 3 in above that recommended in Table 1. It may be economic for dual carriageway roads to confine construction traffic to one carriageway.

* B.S. 892 A Glossary of Highway Engineering Terms now defines this as sub-base.
Where Type 1 materials are difficult to obtain Type 2 materials (Clause 804) may be used by traffic without stabilisation between April and September inclusive. It is then recommended that the thickness of the base be increased by 6 in above that recommended in the chart.

Where the base is used as a haul road the surface may need to be regulated before the concrete slabs are constructed.

### 2.3.3 Thickness of base when subgrade is frost susceptible

Where the subgrade is a material likely to be frost-susceptible, e.g. chalk, soft limestone or silty soils, the thickness of base for roads carrying more than 1,500 commercial vehicles per day should be such as to give a total thickness of pavement of at least 18 in.

For roads carrying up to 1,500 commercial vehicles per day, the total thickness of 18 in of frost-resistant construction may be reduced where local experience during very severe winters has shown that this is permissible.

### 2.4 Thickness of slab

Table 1 gives the recommended thickness of unreinforced slab for each type of subgrade and traffic intensity.

Where local conditions make it impracticable to lower the water-table to the recommendation of section 2.2, the thickness of slab on a normal subgrade should be made equal to that for a subgrade very susceptible to non-uniform movement as shown in Table 1.

### 2.5 Joints

#### 2.5.1 Spacing of joints

The recommended spacings of expansion and contraction joints for unreinforced concrete are given in Table 4.

The spacing of expansion joints should be decreased, as indicated, in cold weather, and when the road is to be constructed in two lanes at different times of the year, the spacing appropriate to the colder weather should be adopted.

If, for high speed road, it is considered desirable for psychological and other reasons to vary the spacings of contraction joints in a random manner, the variations should be within the range of 4 ft below the spacings given in Table 4, which should be considered as maxima.

Expansion joints may, at the discretion of the Engineer, be omitted from concrete pavements constructed during the summer months (between April 21st and October 21st) provided fixed structures are isolated by the provision of a short length of flexible construction, or by other means.

Tied warping joints can be substituted for some of the sliding contraction joints, but not more than three such warping joints should be used in succession. The specification for a suitable form of warping joint is given in Appendix 1.
Longitudinal joints should be provided so that the slabs are not more than 15 ft wide.

2.5.2 Joint filler and sealing grooves

Where expansion joints are spaced at the intervals given in Table 4 they should be provided with a joint filler 1 in thick. If they are spaced more closely than indicated in Table 4 the thickness of the joint filler may be reduced below 1 in in proportion to the expansion-joint spacing, but not to a thickness of less than ¼ in.

TABLE 4
Spacing of joints in unreinforced concrete

<table>
<thead>
<tr>
<th>Aggregate type</th>
<th>Joint spacing (ft)</th>
<th>Joint spacing (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 - 8 in.</td>
<td>9 - 11 in.</td>
</tr>
<tr>
<td>a) Expansion joints</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravel or igneous rock</td>
<td>90</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>(60)*</td>
<td>(100)</td>
</tr>
<tr>
<td>Limestone</td>
<td>180</td>
<td>230</td>
</tr>
<tr>
<td></td>
<td>(120)</td>
<td>(160)</td>
</tr>
<tr>
<td>b) Contraction joints</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravel or igneous rock</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Limestone</td>
<td>18</td>
<td>23</td>
</tr>
</tbody>
</table>

* Figures in brackets are to be used in cold weather only.

Where limestone aggregates are used in the bottom course of two layer construction with a gravel or igneous rock aggregate in the top course, it will be advisable to use the spacings recommended for gravel or igneous rock aggregates.

All joints, however made, should be provided with a groove to accommodate a sealing material and where the latter is of a type complying with Clause 2924 of the Ministry of Transport Specification (1963 edition) the dimensions of the sealing groove should be as given in Table 5, the groove being filled with sealing compound to between ¼ and ½ in below the surface of the concrete. If the grooves are made deeper than required for the sealing material they should be caulked to an appropriate depth with a soft, compressible filling material.

To ensure complete formation of contraction and longitudinal joints the combined depth of groove and fillet should be ¼ - ½ the thickness of the slab.
TABLE 5
Dimensions of sealing grooves for joints in unreinforced concrete roads

<table>
<thead>
<tr>
<th></th>
<th>Spacings (ft)</th>
<th>Minimum width (in)</th>
<th>Depth of groove (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Contraction</strong></td>
<td><strong>joints</strong></td>
<td><strong>All spacings</strong></td>
<td><strong>$\frac{3}{4}$</strong></td>
</tr>
<tr>
<td><strong>Expansion</strong></td>
<td><strong>joints</strong></td>
<td><strong>All spacings</strong></td>
<td><strong>$\frac{1}{4}$ greater than thickness of the filler</strong></td>
</tr>
<tr>
<td><strong>Longitudinal</strong></td>
<td><strong>joints</strong></td>
<td><strong>-</strong></td>
<td><strong>$\frac{1}{4}$</strong></td>
</tr>
</tbody>
</table>

2.5.3 Joints in edge beams

When edge beams are used expansion joints should be provided in them at the positions where expansion and contraction joints will be formed in the road. These joints should incorporate both a filler 1 in wide and dowel-bars similar to those used in the slab.

2.5.4 Load transference in joints

All transverse joints should be provided with adequate means of load transference except for roads designed to carry less than 150 commercial vehicles per day, when they may be omitted if desired.

All joints should have sliding dowel-bars, the diameter and length of these bars are shown in Table 6. The dowel-bars should be placed at 12 in centres and half the length of the bars should be coated with a thin film of bond breaking compound. The bars in expansion joints only should be provided with a cap at the end containing a thickness of 1 in of compressible material to allow the joint to open and close.

TABLE 6
Dimensions of dowel bars for expansion and contraction joints

<table>
<thead>
<tr>
<th>Slab thickness in in</th>
<th>Expansion Joints</th>
<th>Contraction Joints</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Diameter (in)</td>
<td>Length (in)</td>
</tr>
<tr>
<td>5 - 7</td>
<td>$\frac{7}{8}$</td>
<td>20</td>
</tr>
<tr>
<td>8 - 9</td>
<td>1</td>
<td>24</td>
</tr>
<tr>
<td>10 - 12</td>
<td>$1\frac{1}{4}$</td>
<td>28</td>
</tr>
</tbody>
</table>
Longitudinal joints should have ½ in diameter by 42 in long tie-bars at 24 in centres, except in the case of roads designed to carry less than 150 commercial vehicles per day when the spacing may be increased to 30 in. Where edge beams are used tie-bars should be provided at 24 in centres consisting of ½ in diameter bars 42 in long extending 21 in into the slab and hooked in the edge beam or ¼ in diameter wires 21 in long at 6 in centres, or wires giving an equivalent sectional area.

2.6 Concrete mix design

All concrete used in the slab should be designed on the basis of a minimum crushing strength of 4000 lb/in² at 28 days using ordinary Portland cement. Air-entrained concrete should be used either for the full depth of the slab or for at least the top 2 inches.

3. REFERENCES


4. APPENDIX I

WARPING JOINTS

4.1 Introduction

Transverse joints are needed in plain concrete slabs to relieve stresses of restraint due to both warping moments and longitudinal contraction in order to prevent cracking. Vertical temperature gradients in the slab produce warping moments, and theory suggests that the stresses caused by these moments are appreciably greater than those due to contractions in the longitudinal direction for normal slab lengths. Thus most of the contraction joints in unreinforced concrete roads could be replaced with hinged or ‘warping’ joints.

The requirements for a warping joint, in accordance with general requirements for joints are:

(a) a discontinuity in the slab to provide release of warping moments
(b) a load-transfer device
(c) a seal against water and grit.

The discontinuity in the slab is obtained by inducing a crack by a combination of top sealing groove and middle or bottom fillet. The load-transfer effect in unreinforced concrete is obtained from aggregate interlock, and tie-bars are necessary to prevent the crack from opening to such an extent as to render this ineffective, i.e. to perform a function similar to that of the steel in reinforced concrete slabs. The seal is obtained by a conventional sealing groove filled with sealing material.

4.2 Specification

Reinforcement for warping joints shall consist of a fabricated welded mesh with 7/0 gauge longitudinal bars at least 4 ft long at the spacing given in Table 1; a minimum of 3 wires of 3 gauge shall be used transversely at 2 ft centres. The number of transverse wires may be increased for handling purposes, if required. At least every third longitudinal bar shall be longer than 4 ft and shall be bent in order that a 4 ft effective length of longitudinal reinforcement shall lie at half depth of the slab with the assembly resting upon feet consisting of lengths of longitudinal bar upon the base, Fig. 1. The effective lengths of the bars shall be parallel to the finished surface of the slab and the carriageway centre line within the limits of ± 1 in in 4 ft. The centre 8 in of each 4 ft effective length of bar shall be painted with bond breaking compound as specified in the M.O.T. Standard Specification.

Appendix TABLE I

<table>
<thead>
<tr>
<th>Slab thickness in</th>
<th>Spacing in</th>
</tr>
</thead>
<tbody>
<tr>
<td>11 and 12</td>
<td>8</td>
</tr>
<tr>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>7</td>
<td>14</td>
</tr>
</tbody>
</table>

When several reinforcement assemblies are used in one joint they may be independent of each other but all the assemblies in one joint shall be truly aligned to an accuracy of ± ¼ in.

The reinforcement assemblies shall be fixed to the base, one method being to use 6 in lengths of each longitudinal bar held on the base by means of mortar pads. The mortar shall consist of 1 part by weight of Portland cement to 3 parts by weight of sand and shall be placed within one hour of mixing.

A crack inducer shall be provided at the base and a sealing groove at the top of the slab so that the combined depth of discontinuity is at least ½ of the depth of the slab and so that the difference in the depth of discontinuity at the top and bottom is not greater than ½ in. The crack inducer shall be fixed to the base along the centre line of the joint to ± ¼ in by nailing or other
approved method. The sealing groove located with its centre line vertically above the crack inducer within a tolerance of ± 1⁄8 in, shall be formed with a minimum width of 1⁄4 in. The depth of sealant within the groove should not exceed 1⁄2 in, the remainder of the groove being caulked with a soft compressible filling material.
Fig. 1 WARPING JOINT
Design recommendations for unreinforced concrete pavements:
(Road Research Laboratory). A re-examination of the performance data relating to unreinforced concrete roads has enabled a revision to be made of the design recommendations for this type of pavement given in Road Note No. 29. Slab and base thicknesses are recommended for all intensities of traffic and revision has also been made of the recommended joint spacings. Expansion joints may be omitted in roads constructed in the summer months. Tied warping joints may be substituted for some contraction joints and a description is given of the form of warping joint recommended.