Department of the Environment Road Research Laboratory

ROAD NOTE 29

Third Edition

a guide to the structural design of pavements for new roads

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Road Research Laboratory
Department of the Environment

Road Note 29

A guide to the structural design of pavements for new roads

Contents

Foreword

Road Note No.29 was first published in 1960 to provide a guide to the structural design of roads carrying medium and heavy traffic. The 1965 revision widened the scope to include lightly trafficked roads, such as those used in housing estates. Otherwise only relatively minor changes were made to the earlier edition.

Since 1960 the annual expenditure on the construction of new roads has increased fourfold. This alone provides sufficient reason for a detailed re-examination of all the recommendations given in the last edition. The growth rate of commercial traffic on many of the roads recently built has proved to be more than the 4 per cent per annum allowed for 10 years ago; this means that there are on some roads daily flows of commercial traffic already exceeding the 6000–8000 vehicles that the original drafting committee had in mind as a maximum after 20 years. The size of the commercial vehicles in use has also tended to increase, and this has resulted in a greater proportion of heavier axle loads.

This revision was drawn up by a Panel drawn principally from the Laboratory's Committee on Design and Construction. The Panel also included members of the County Surveyors' Society, consulting engineers, members of certain of the trade associations concerned with road pavings, and members of the staff of the Laboratory, of the Highways Directorate of the Ministry of Transport, and of the Ministry of Housing and Local Government. I am particularly grateful to Mr J.V. Leigh, the County Surveyor of Hertfordshire, for his able chairmanship of the Panel.

A major task of the revision Panel has been to define traffic more realistically in terms of its damaging power and to extend the design recommendations to cater for the very heavy traffic conditions that must be expected on many of the country's major roads before the end of the present century.

The revised document gives the engineer freedom of choice in selecting the design life, and it enables him to estimate the probable effect on pavement life of any modifications in design he may wish to consider.

The other principal changes made are reviewed in the introduction to the revised document. They include a new section dealing with the design of factory roads intended to carry specialized traffic.

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ROAD RESEARCH LABORATORY
1970

A guide to the structural design of pavements for new roads

1 Introduction

1 Road Note No. 29 was published originally in 1960, and the first major revision was issued in 1965. As recently as 1968 the recommendations for unreinforced concrete pavements were reviewed by a Panel of the Road Research Laboratory's Research Committee on Concrete and, as an interim measure, prior to a further complete revision of the Road Note, these were issued as RRL Report LR 192.[1]

The need to metricate has provided an opportunity to bring the Road Note up to date and to reconsider the basic layout originally adopted.

2 The present revision was drawn up within the Ministry of Transport in close consultation with a Panel set up by the Laboratory's Research Committee on Design and Construction. The Panel included county surveyors and consulting engineers.

3 **This note deals solely with the construction of new roads and not with the resurfacing and maintenance of existing roads.**

4 In the earlier editions, the designs catered for a limited selection of traffic categories defined in terms of the number of commercial vehicles per day to be carried by the road 20 years after construction. The use of a growth rate for commercial traffic of 4 per cent per annum was recommended.

To render the document more versatile, traffic is now defined in terms of the cumulative equivalent number of 8200 kg (18 000 lb) axles (to be called standard axles) to be carried during the design life of the road. Simple means of estimating traffic on this basis from normal census data are provided. Using this approach the changes in minimum design thickness are continuous throughout the traffic range from residential roads to motorways. From the initial traffic intensity and estimated growth rate, the engineer can prepare designs suitable for any 'life' up to 40 years.

The approach is also particularly applicable to the design of industrial access roads, or similar roads intended to carry specialized traffic. The accuracy of the designs will depend very largely on the accuracy of the traffic prediction over the chosen life.

5 The results of the latest research, and particularly those from full-scale experiments, have been incorporated. As a result, although for equivalent traffic the designs given are not markedly different from those in the previous edition, some economies result for certain traffic intensities.

6 The principal changes that have been made, apart from the metrication and the introduction of the new method of traffic assessment, are:

(a) The additional thickness of sub-base previously recommended under dense coated macadam and asphalt bases in flexible pavements is no longer required.

(b) Dense coated materials with tar binder and gravel aggregates for roadbases are included in the recommendations for flexible pavements regardless of the traffic to be carried. Gravel is also now included in the aggregates that may be used for rolled asphalt basecourses regardless of the traffic to be carried.

(c) The recommendations for unreinforced concrete pavements have been brought into line with RRL Report No. LR 192[1]

(d) Provision is made for varying the thickness of pavements across the width of carriageways carrying uni-directional traffic, so that the engineer can, if he wishes, take into account the reduced commercial traffic flow on middle and fast lanes.

(e) A design procedure is included for private roads intended to carry specialized traffic.

7 For the benefit of engineers designing roads to the Ministry of Transport *Specification for road and bridge works*,[2] reference is made in the text to the relevant clause numbers of the 1969 edition of the Specification. These clauses are subject to amendment from time to time by Technical Memoranda issued by the Department of the Environment.

2 Selection of the type of pavement

8 The recommendations allow the appropriate designs for flexible and concrete pavements to be deduced for any subgrade and traffic conditions. The type of pavement selected will then depend largely on economic considerations.

3 Estimation of traffic for design purposes

9 The loads imposed by private cars do not contribute significantly to the structural damage caused to road pavements by traffic. For the purpose of structural design, therefore, only the numbers of commercial vehicles and their axle-loadings are considered. (The commercial vehicle is defined here as a goods or public service vehicle of unladen weight exceeding 1500 kg.)

10 For two-lane single carriageway roads the procedure described in this Road Note will be appropriate to each lane. On dual carriageway roads with up to three lanes per carriageway or on single carriageways with more than two traffic lanes, the procedure will provide designs applicable to the slow traffic lanes. These designs will normally be used over the whole carriageway width but, if the engineer wishes, some reduction in thickness may be made on the other lanes of dual carriageway roads in accordance with Section 9 of this Note.

11 The traffic information that will normally be available from census data will enable an estimate to be made of the traffic at the time of construction expressed in commercial vehicles per day (either in each direction or the sum in both directions) and of a growth rate. Where no estimate of growth rate can be made, an average value of 4 per cent per year should be taken. In this Note traffic intensities are expressed in terms of commercial vehicles per day *in each direction* unless otherwise stated. (The traffic in each direction may be assumed to be half the sum in both directions when the latter only is known.)

12 For various initial intensities of commercial traffic, and a growth rate of 3 per cent, Fig.1 gives the cumulative number of commercial vehicles carried by each slow lane for design lives of up to 40 years. These curves take into account the transfer of commercial vehicles between the slow lanes and adjacent lanes as the traffic intensity increases. Figures 2, 3, and 4 give similar relations for growth rates of 4, 5, and 6 per cent respectively.

There will be rare cases in which roads need to be designed for initial traffic greater than 2500 commercial vehicles per day in each direction, the maximum shown in Figs.1–4. Such roads are also likely to have an initial growth rate greater than the national average. The cumulative number of commercial vehicles carried by each slow lane on such roads can be estimated by extrapolation from the curves given, but very high values (in excess of the 90 million maximum shown in Figs.1–4) may result for lives of more than 20 years. In practice it is most unlikely that a high growth rate would be maintained throughout the design life of the pavement without the road becoming saturated. For this reason estimates made on this basis will be unrealistic. It is suggested that where available traffic data lead to a cumulative total of more than 90 million commercial vehicles to be carried by each slow lane during the design life, a design based on the 90 million figure should be adopted.

13 Traffic census data are not generally available for residential roads. Table 1 shows the initial traffic intensities that should be assumed for the design of various categories of road in residential or associated development areas where more accurate assessments are not available. On the basis of these initial intensities and an assumed growth rate of 4 per cent, Fig.5 relates the cumulative number of commercial vehicles carried by each slow lane to the design life.

14 The average number of axles per commercial vehicle varies with the type of road. For motorways and trunk roads it is currently 2·7; for roads designed to carry between 250 and 1000 commercial vehicles per day, 2·4; and for residential and all other public roads, 2·25 (see Table 2). Using this factor, the cumulative number of commercial vehicles carried by each slow lane of a road during the design life can be converted to a number of axles.

15 The loads associated with individual axles constituting the commercial traffic will not normally be known. Observations of axle loads have been made on typical roads and these, considered in conjunction with the axle-load equivalence factors derived from the AASHO Road Test,[3] enable numbers of commercial axles to be expressed as equivalent numbers of 8200 kg (18 000 lb) axles,* referred to throughout this Note as standard axles.

Table 2 gives for three classes of road the number of standard axles per commercial axle and the multiplier that must be applied to the cumulative number of commercial vehicles on each slow lane to derive the cumulative number of standard axles to be catered for in the design.

16 The procedure to be used for deducing the cumulative number of standard axles for specialized traffic consisting of repetitions of particular types of loaded vehicle (e.g. roads in a refinery) is given in Section 10 of this Note.

4 Design life of pavements

17 The design engineer must first decide the structural life in years that he requires from the pavement. The life chosen will be influenced by the type of road, by its probable use after the end of the design period, and by whether a flexible or a concrete form of pavement is to be used.

18 The designs given in this Note cater for a terminal pavement condition at which partial reconstruction or a major overlay would be necessary to extend the life of the pavement. In view of the problems involved in achieving a major extension of life of a concrete road and the comparatively modest increase in initial slab thickness necessary to ensure a long life, it is suggested that such pavements should normally be designed for a life of 40 years.

The same argument does not apply to flexible pavements where it is more economical to design for a shorter life and to overlay rather earlier to increase the life and improve the riding quality. More knowledge is emerging on the relative performance of the different forms of flexible roadbase, but for the time being it is suggested that a flexible pavement should normally be designed for a life of 20 years.

19 For roads in residential and associated developments, the use beyond 20 years, without any significant change in layout, can be regarded as certain. On multiple access roads of this type, where levels are fixed by access points and drainage considerations, it is recommended that a 40-year design life should be adopted for all roads in the first two categories of Table 1. For a road in the third and fourth categories of Table 1, the engineer should choose a life in accordance with the recommendations given in paras. 17 and 18.

5 Design of flexible pavements

20 In formulating the design, the traffic, the design life, the subgrade, the sub-base, the roadbase and the surfacing are each considered in turn. From a consideration of initial commercial traffic, growth rate and design life, the cumulative number of standard axles to be carried by each slow lane of the pavement is estimated using the method given in Section 3. The recommended minimum thickness for the various layers of the pavement is obtained from Figs.6–10. The thicknesses of each individual layer are intended to be rounded upwards to the next 10 mm intercept.

5.1 Subgrade

21 It is essential that the subgrade, whether in cut or fill, is compacted and shaped as in the requirements of the Ministry of Transport Specification[2] (Clauses 609, 610).

22 The strength of the subgrade is a principal factor in determining the thickness of the pavement, but deterioration due to frost action must also be taken into account. The strength of the subgrade is assessed on the California Bearing Ratio (CBR) scale.

23 The CBR test is described in BS 1377 (*Methods of testing soils for civil engineering purposes*).[4] Experience has shown that on wet cohesive soils commonly found in Britain, reliable test results are difficult to obtain because of the influence on them of the method of sample preparation and compaction. Table 3 shows a correlation between CBR value and soil type based on British experience with a wide variety of subgrades in their equilibrium moisture condition for high and low levels of water-table. For most purposes this information will be sufficient to give the appropriate CBR values.

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*The 8200 kg (18 000 lb) axle has been chosen for the standard as, in terms of numbers and damaging power combined, it represents the most damaging class of axle load in Great Britain. The equivalent number of standard axles is that number that has the same damaging power as the actual traffic on the road.

Table 1 **Commercial traffic flows recommended for use in the design of roads in residential and associated developments when more accurate assessments are not available**

Type of road	*Estimated traffic flow of commercial vehicles per day* **(in each direction)** *at the time of construction*
1 Cul-de-sacs and minor residential roads	10
2 Through roads and roads carrying regular bus routes involving up to 25 public service vehicles per day **in each direction**	75
3 Major through roads carrying regular bus routes involving 25–50 public service vehicles per day **in each direction**	175
4 Main shopping centre of a large development carrying goods deliveries and main through roads carrying more than 50 public service vehicles per day **in each direction**	350

Table 2 **Conversion factors to be used to obtain the equivalent number of standard axles from the number of commercial vehicles**

Type of road	*Number of axles per commercial vehicle (see paragraph* 14) *(a)*	*Number of standard axles per commercial axle* *(b)*	*Number of standard axles per commercial vehicle* *(a) × (b)*
Motorways and trunk roads designed to carry over 1000 commercial vehicles per day **in each direction** at the time of construction	2·7	0·4	1·08
Roads designed to carry between 250 and 1000 commercial vehicles per day **in each direction** at the time of construction	2·4	0·3	0·72
All other public roads	2·25	0·2	0·45

Table 3 **Estimated laboratory CBR values for British soils compacted at the natural moisture content**

Type of soil	*Plasticity index (per cent)*	*CBR (per cent)*	
		Depth of water-table below formation level	
		More than 600 mm	*600 mm or less*
Heavy clay	70	2	1*
	60	2	1·5*
	50	2·5	2
	40	3	2
Silty clay	30	5	3
Sandy clay	20	6	4
	10	7	5
Silt	—	2	1*
Sand (poorly graded)	non-plastic	20	10
Sand (well graded)	non-plastic	40	15
Well-graded sandy gravel	non-plastic	60	20

* See para. 27

24 Where the specialist equipment and experience is available the CBR test may be carried out on recompacted samples in accordance with BS 1377: 1967. The method of compaction used should preferably be that referred to as Method 2 under paragraph 5.1.3.1 of the British Standard. The moisture content and density conditions used in the test should reproduce as closely as possible the conditions likely to apply under the road after construction. To estimate the appropriate density condition, it is suggested that a preliminary test should be carried out using the method specified in Test 13 of this Standard but with the soil at the expected average moisture content after construction. The CBR test specimen should then be compacted to a density corresponding to 95 per cent of the value obtained in the preliminary test.

For cohesive soils (in which the restraint effect of the CBR mould and the influence of surcharge is small), *in-situ* CBR measurements may be used if desired as a guide for design purposes. However, it is important that the moisture content and dry density conditions prevailing at the time of test should approximate to those expected under the completed road. (Where possible the test should be made on a freshly exposed soil surface at a depth below the zone likely to be affected by drying or wetting from the surface. A depth of not less than 1 metre is recommended.)

25 Whether or not the subgrade is likely to be frost susceptible must be considered. The guidance given in RRL Report LR 90 (*The frost susceptibility of soils and road materials*)[5] will generally be sufficient to decide whether a soil is likely to be frost susceptible. A summary of the conclusions reached in that Report is given in Appendix 1 of this Note. In cases of doubt the soil should be tested in accordance with the procedure given in that Report.

5.2 Drainage and weather protection

26 Wherever practicable the water-table should be prevented from rising to within 600mm of the formation level. This may be done by sub-soil drainage, or by raising the formation level by means of an embankment. Where neither of these measures is practicable, the high water-table condition, referred to in Table 3, should be used for design.

It is important to provide efficient permanent drainage to remove water from the subgrade and any other permeable layer of the road both during construction and during the life of the road. Waterproofing of the various layers during construction, e.g. by sealing, may also be desirable (Clauses 610, 611). This is dealt with more fully in Road Note No. 17.[6]

5.3 Sub-base

27 The required thickness of sub-base is determined from the cumulative number of standard axles to be carried and the CBR of the subgrade using Fig. 6. Where the CBR of the subgrade as indicated in Table 3 is less than 2 per cent (the lowest value considered on Fig.6), an additional 150mm of sub-base, above the requirement for CBR 2 per cent, should be used. (This will not necessarily cater for local soft spots located during construction. These may need individual treatment at the discretion of the engineer.)

28 No material within 450mm of the road surface should be susceptible to frost action (see Appendix 1) except as allowed below for roads designed to carry less than 2·0 million standard axles.

When the subgrade is frost susceptible (see para. 25), the thickness of the sub-base must be sufficient to give a total thickness of construction over the soil of not less than 450mm. After the design of the pavement has been prepared this must be checked and, if necessary, the thickness of the sub-base increased to give a total pavement thickness of not less than 450mm.

On roads designed to carry less than 2·0 million standard axles, the requirement of a total thickness of 450mm over frost-susceptible soils may be relaxed where local experience during severe winters has shown this to be permissible.

29 For cumulative traffic of less than 0·5 million standard axles, the minimum CBR of the sub-base should be 20 per cent. For cumulative traffic in excess of this figure, the minimum CBR of the sub-base should be 30 per cent. For natural gravels and other sub-base materials with less than 10 per cent coarser than the 20·0mm BS test sieve size, the CBR test should be carried out in accordance with BS 1377:1967 Test 15.[4] The method of compaction used should be similar to that described in paragraph 5.1.3.2, Method 3, of the British Standard, using the 10 lb (4.5 kg) rammer. The material should be tested at its natural moisture content, and the dry density used should conform to that likely to be achieved in the field (Road Research Technical Papers 17, 33, 45, and 53[7] [8] [9] [10] give guidance on this matter.) (The number of blows of the rammer necessary on each of the five layers of material to give the target density in the CBR mould must be determined by preliminary trials.) The CBR test is not applicable to materials conforming to the requirements of Type 1 sub-base (Clause 803) or to Type 2 sub-base materials (Clause 804) containing more than 10 per cent retained on the 20·0mm BS test sieve. Neither is it applicable to stabilized sub-bases (Clauses 805, 806). All such materials can be assumed to fulfil the CBR requirements of 30 per cent without test. Type 1 or stabilized materials should be used for the top 150mm where the sub-base is required to carry construction traffic under winter conditions.

30 If the CBR of the subgrade is in excess of the minimum requirement for the sub-base, no sub-base is required. Where sub-base is required the minimum thicknesses that should be laid are 80mm where the cumulative traffic is less than 0·5 million standard axles and 150mm where the traffic is in excess of that value (see Fig.6).

5.4 Roadbase

31 Roadbase materials comprise lean concrete (Clause 807), dense tarmacadam* (Clause 810), dense bitumen macadam (Clause 811), rolled asphalt (Clause 812), wet-mix macadam (Clause 808), dry-bound macadam (Clause 809), soil-cement (Clause 805) and cement-bound granular material (Clause 806).

32 For roads designed to carry less than 2·5 million standard axles, roadbase materials other than those listed in para.31 may be used where experience has proved their suitability under corresponding traffic conditions. Such materials must not be susceptible to the action of frost.

33 Figures 7–10 give the thicknesses required for each of the roadbase materials referred to in para.31, in terms of the cumulative number of standard axles to be carried.

34 Soil-cement roadbases should only be used when the cumulative number of standard axles is less than 1·5 millions. The required thickness is shown on Fig.9. Cement-bound granular roadbases may be used for cumulative numbers of standard axles less than 5 millions;

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* Where gravel aggregate is used in dense roadbases with tar binder for roads designed to carry more than 2·5 million standard axles, a tar of not less than 58° e.v.t. should be used for flint gravels or gravels containing flint, and not less than 54° e.v.t. for all other gravels.

Table 4 **Recommended bituminous surfacings for newly constructed flexible pavements** (see Note 1)

Traffic (cumulative number of standard axles)			
Over 11 millions (1)	*2·5–11 millions* (2)	*0·5–2·5 millions* (3)	*Less than 0·5 million* (4)
Wearing course (crushed rock or slag coarse aggregate only) **Minimum thickness 40 mm** Rolled asphalt to BS 594 (pitch-bitumen binder may be used) (Clause 907)		**Wearing course** **Minimum thickness 20 mm** Rolled asphalt to BS 594 (pitch-bitumen binder may be used) (Clause 907) Dense tar surfacing to BTIA Specification (Clause 909) Cold asphalt to BS 1690 (Clause 910) (see note 4) Medium-textured tarmacadam to BS 802 (Clause 913) (to be surface-dressed immediately or as soon as possible—see Note 4) Dense bitumen macadam to BS 1621 (Clause 908) (see Note 4) Open-textured bitumen macadam to BS 1621 (Clause 912) (see Note 4)	**Two-course** (a) **Wearing course—** **Minimum thickness 20 mm** Cold asphalt to BS 1690 (Clause 910) Coated macadam to BS 802 BS 1621, BS 1241 or BS 2040 (Clause 913, 912 or 908) (see Notes 2 and 4) (b) **Basecourse** Coated macadam to BS 802, BS 1621, BS 1241 or BS 2040 (Clause 906 or 905) (see Note 2) **Single course** Rolled asphalt to BS 594 (pitch-bitumen binder may be used) Dense tar surfacing to BTIA Specification (Clause 909) Medium-textured tarmacadam to BS 802 (Clause 913) (to be surface-dressed immediately or as soon as possible—see Note 4) Dense bitumen macadam to BS 1621 (Clause 908) (see Note 4) 60 mm of single-coarse tarmacadam to BS 802 (Clause 906) or BS 1241 (to be surface-dressed immediately or as soon as possible—see Note 4) 60 mm of single-course bitumen macadam to BS 1621 (Clause 905) or BS 2040 (see Note 4)
Basecourse **Minimum thickness 60 mm** Rolled asphalt to BS 594 (Clause 902) (see Note 2) Dense bitumen macadam or dense tarmacadam (crushed rock or slag only) (Clause 903 or 904)	**Basecourse** Rolled asphalt to BS 594 (Clause 902) (see Note 2) Dense bitumen macadam or dense tarmacadam (Clause 903 or 904) (see Note 3)	**Basecourse** Rolled asphalt to BS 594 (Clause 902) (see Note 2) Dense bitumen macadam or dense tarmacadam (Clause 903 or 904) Single-course tarmacadam to BS 802 (Clause 906) or BS 1241 (see Notes 2 and 5) Single-course bitumen macadam to BS 1621 (Clause 905) or BS 2040 (see Notes 2 and 5)	

Notes:

1 The thicknesses of all layers of bituminous surfacings should be consistent with the appropriate British Standard Specification

2 When gravel, other than limestone, is used, 2 per cent of Portland cement should be added to the mix and the percentage of fine aggregate reduced accordingly

3 Gravel tarmacadam is not recommended as a basecourse for roads designed to carry more than 2·5 million standard axles

4 When the wearing course is neither rolled asphalt nor dense tar surfacing and where it is not intended to apply a surface-dressing immediately to the wearing course, it is essential to seal the construction against the ingress of water by applying a surface dressing either to the roadbase or to the basecourse

5 Under a wearing course of rolled asphalt or dense tar surfacing the basecourse should consist of rolled asphalt to BS 594 (Clause 902) or of dense coated macadam (Clause 903 or 904)

the required thickness of this roadbase material is also shown on Fig.9.

35 When lean-concrete, wet-mix or dry-bound macadam is used for the roadbase, the minimum thickness shown on Figs.9 or 10 will be required. For cumulative traffic of over 11 million standard axles the minimum thickness of wearing course plus basecourse is 100 mm (see Table 4). For the additional surfacing thickness over 100 mm shown in Figs.9 or 10, any approved bituminous roadbase or basecourse material included in para.31 and in Table 4, Column 1, may be used to form a composite roadbase with the wet-mix, dry-bound macadam or lean concrete roadbase material.

5.5 Surfacing courses

36 The recommended thickness of surfacing in terms of the cumulative number of standard axles to be carried is given in Figs.7–10 depending on the type of roadbase material used. The materials recommended for the surfacing vary with the cumulative traffic to be carried, and details are given in Table 4.

37 The surfacing is intended to be laid in two courses, except where the cumulative traffic is less than 0·5 million standard axles. The recommended thicknesses of wearing course are indicated on Table 4.

38 On major roads delay in laying the wearing course is likely to cause inconvenience to traffic and may create surface water drainage problems. On such works close control of materials and methods of construction should ensure that the roadbase and basecourse are well compacted so that little further compaction occurs under traffic.

39 Where inconvenience to traffic is not a major factor it may be convenient to delay the laying of the wearing course until compaction under traffic has occurred. The delay should be limited to 6–12 months.

Except in residential areas, delay in laying the wearing course is not recommended on roads with cemented roadbases.

40 It it is intended to delay the final wearing course, any temporary surfacing should be impervious or be rendered impervious by surface dressing. The engineer should consider the limits of surface irregularity and resistance to skidding acceptable for the temporary surfacing, bearing in mind its life as a surfacing and the local conditions.

41 On lightly trafficked residential roads, heavy loads may need to be carried during the development stage. Where unbound or coated macadam roadbases are used, it is advisable to delay laying the surfacing until such loads have been carried. The roadbase should then be regulated as necessary before the surfacing is laid. Unbound roadbases trafficked in this manner should be blinded with granular fines material and surface-dressed prior to carrying traffic.

5.6 Example illustrating the design procedure for flexible pavements

42 A flexible design is required for a road intended to carry 1100 commercial vehicles per day (sum in both directions) at the time of construction with a growth rate of 3 per cent. The soil is a silty clay, with a liquid limit of 50 per cent, a plastic limit of 20 per cent, and the water-table is more than 1·5 m below final road level. The design life is to be 25 years.

Traffic: Figure 1 shows that for present traffic of 550 commercial vehicles per day (in each direction) and a growth rate of 3 per cent each slow lane will carry 7·0 million commercial vehicles during the design life of 25 years.

Table 2 gives for this type of road a conversion factor of 0·72 to obtain the cumulative number of standard axles from the number of commercial vehicles carried by each slow lane. The number of standard axles carried during the design life will therefore be 7·0 ×0·72 millions =5·04 millions.

Subgrade: The soil has a plasticity index (liquid limit minus plastic limit) of 50–20 =30 per cent, and the water-table will be more than 600 mm below final road level. Table 3 indicates a design CBR value of 5 per cent.

Sub-base: For a CBR value of 5 per cent and traffic of 5 million standard axles, Fig. 6 indicates a sub-base of thickness 240 mm, the minimum CBR value of the sub-base being 30 per cent.

Roadbase and surfacing: For the traffic to be carried, Figs. 7–10 indicate the following thicknesses of roadbase and surfacing (rounded upwards to the next 10 mm intercept):

(a)

Rolled asphalt roadbase

Figure 7 shows a roadbase thickness of 110 mm, with a surfacing 90 mm thick using any combination of surfacing materials given in Table 4, Column 2. (On frost-susceptible soils the sub-base would therefore need to be increased to 250 mm.)

(b)

Dense macadam roadbase

Figure 8 shows a roadbase thickness of 130 mm, with a surfacing 90 mm thick using any combination of surfacing materials given in Table 4, Column 2.

(c)

Lean concrete roadbase

Figure 9 shows a roadbase thickness of 180 mm, with a surfacing 100 mm thick using any combination of surfacing materials given in Table 4, Column 2. As the cumulative traffic is greater than 5 million standard axles, soil-cement and cement-bound granular material will not be permitted.

(d)

Wet-mix or dry-bound macadam roadbase

Figure 10 shows a roadbase thickness of 200 mm, with a surfacing 100 mm thick using any combination of surfacing materials given in Table 4. Column 2.

6 Design of concrete pavements

43 The following Section deals with both reinforced and unreinforced concrete pavements. The design of continuously reinforced concrete slabs with bituminous surfacings is dealt with in Section 7.

In formulating the design for concrete pavements the traffic, the design life, the subgrade, the sub-base and the concrete slab are each considered in turn. From a consideration of initial commercial traffic, growth rate and design life, the cumulative number of standard axles to be carried by each slow lane of the pavement is estimated using the method given in Section 3.

6.1 Subgrade

44 It is essential that the subgrade, whether in cut or fill, is compacted and shaped as in the requirements of the Ministry of Transport Specification[2] (Clauses 609 and 610).

45 In the design of concrete roads, three qualities of subgrade are considered as defined in Table 5.

6.2 Drainage and weather protection

46 Wherever practicable the water-table should be prevented from rising to within 600 mm of the formation level. This may be done by sub-soil drainage, or by raising the formation level by means of an embankment.

It is important to provide efficient permanent drainage to remove water from the subgrade and sub-base, both during construction and during the life of the road. Waterproofing the subgrade or sub-base during construction, e.g. by sealing may also be desirable (Clauses 610, 611). This is dealt with more fully in Road Note No.17.[6]

6.3 Sub-base

47 The minimum thickness of sub-base recommended for the three types of subgrade is given in Table 5. These thicknesses are suitable for roads where no construction traffic is required to use the sub-base.

Where heavy construction vehicles (e.g. loaded trucks) have to be operated over the prepared sub-base laid on 'weak' or 'normal' subgrades, and the designer considers that this will entail a risk of damage, the sub-base should be strengthened. On subgrades with a CBR of 4 per cent or less an additional 150 mm of sub-base is considered sufficient. On other 'normal' subgrades an additional 80 mm should suffice. Type 1 sub-base material (Clause 803), lean concrete (Clause 807) or cement-stabilized material (Clauses 805, 806) will be required for the top 150 mm, unless construction is limited to the summer months when Type 2 sub-base material (Clause 804) may also be used.

Some regulation of the sub-base may be required before the concrete slabs are laid where the sub-base has been used by heavy construction traffic. It may be economical on dual-carriageway roads to confine construction traffic to one carriageway only.

48 No material within 450 mm of the road surface should be susceptible to frost action (see Appendix 1) except as allowed below. When the subgrade is frost susceptible (see para.25), the thickness of the sub-base must be sufficient to give a total thickness of construction over the soil of not less than 450 mm. After the design of the pavement has been prepared this must be checked and, if necessary, the thickness of sub-base increased to give a total pavement thickness of not less than 450 mm.

On roads designed to carry less than 2·0 million standard axles the requirement of a total thickness of 450 mm over frost-susceptible soils may be relaxed where local experience during severe winters has shown this to be permissible.

6.4 Concrete slabs

49 Figure 11 gives the thicknesses required for reinforced and unreinforced concrete slabs in terms of the cumulative number of standard axles to be carried for the three types of subgrade considered in Table 5. The thicknesses are intended to be rounded upwards to the next 10 mm intercept.

50 The designs given in this Note are based on a minimum crushing strength for concrete of 28 MN/m^2 at 28 days using ordinary Portland cement or Portland blast-furnace cement. If the indirect tensile test is used, an equivalent value should be taken. Air-entrained concrete should be used either for the full depth of the slab or for at least the top 50 mm (Clauses 1001–1004).

51 On residential roads and on similar roads built for light traffic, the pavement may be required to carry comparatively heavy loads associated with the construction of the surrounding development. The possibility of this must be considered at the design stage. With unreinforced concrete, if the road will be required to carry the construction traffic for 100 or more houses or buildings of equivalent accommodation, the alternative design thicknesses shown in Fig.11 should be used. These alternative designs should also be used for factory roads required to carry the construction traffic for large factory development schemes.

6.5 Reinforcement

52 For reinforced concrete the minimum weight of reinforcement required in relation to the cumulative number of standard axles to be carried is given in Fig.12 in terms of weight of long mesh reinforcement and area of steel per unit width of pavement. Reinforcement fabric should be in accordance with BS 4483. Deformed bar reinforcement should be in accordance with BS 4449 or BS 4461. The reinforcement should have 60 mm cover from the surface except for slabs less than 150 mm thick where 50 mm cover should be provided. The reinforcement should terminate at least 40 mm and not more than 80 mm from the edge of the slab and from all joints except longitudinal joints covered by para.53.

At the transverse overlap of reinforcing mats the first transverse wire of one mat should lie within the last complete mesh of the previous mat and the overlap should be not less than 450 mm. No overlap will be needed longitudinally between mats. When deformed bar reinforcement is used the overlap of the bars should not be less than 40 bar diameters.

53 Where a two- or three-lane carriageway width is constructed in one operation, reinforcing mats having transverse wires of 8 mm diameter at 200 mm centres may be used to span the longitudinal joints in place of tie bars (para.65). The longitudinal reinforcement in all mats should be as required by para.52. The 8 mm wires must be long enough to span at least 500 mm either side of the longitudinal joints (para.56).

54 Where a three-lane carriageway is constructed in two widths, transverse reinforcement, consisting of 8 mm diameter wires at 200 mm centres, which may be incorporated in special mats, should be used in slabs wider than 4·5 m. The length of this transverse reinforcement should be 600 mm longer than a third of the slab width and should be placed centrally.

Table 5 **Classification of subgrades for concrete roads and minimum thicknesses of sub-base required**

Type of subgrade	*Definition*	*Minimum thickness of sub-base required*
Weak	All subgrades of CBR value 2 per cent or less as defined in Table 3	150 mm
Normal	Subgrades other than those defined by the other categories	80 mm
Very stable	All subgrades of CBR value 15 per cent or more as defined in Table 3 This category includes undisturbed foundations of old roads	0

6.6 Spacing of joints in reinforced concrete slabs

55 The recommended maximum spacing of joints in relation to the weight of reinforcement is shown in Fig.13. The maximum joint spacings used in design should correspond to the actual weight of reinforcement used (see para.52) and not necessarily to the minimum weight required from Fig.12. Every third joint should be an expansion joint, the remainder being contraction joints, with the proviso that expansion joints may, at the discretion of the engineer, be replaced by contraction joints in concrete roads constructed during the summer months (between 21 April and 21 October) provided fixed structures are isolated by a short length of flexible construction or by other means.

When any lane or lanes of a multi-lane carriageway are to be constructed during the winter, expansion joints should not be replaced by contraction joints on any of the lanes as permitted for summer construction.

Where limestone aggregate is used throughout the depth of the slab, the maximum joint spacing may be increased by 20 per cent.

Reinforcement must be discontinuous at both contraction and expansion joints.

56 Longitudinal joints should be provided so that the slabs are not more than 4·5 m wide, except where special reinforcement is used as given in para. 54.

6.7 Spacing of joints in unreinforced concrete slabs

57 The maximum spacing of expansion joints recommended is 60 m for slabs of 200 mm or greater thickness and 40 m for slabs of lesser thickness, with intermediate contraction joints at 5 m intervals where aggregates other than limestone are used; where limestone is used throughout the depth of the slab, the maximum expansion joint spacing may be increased to 72 m and 48 m respectively with intermediate contraction joints at 6 m intervals.

Expansion joints may, at the discretion of the engineer, be replaced by contraction joints in concrete roads constructed in the summer months (between 21 April and 21 October), provided fixed structures are isolated with a short length of flexible construction or by other means.

When any lane or lanes of a multi-lane carriageway are to be constructed during winter, expansion joints should not be replaced by contraction joints on any of the lanes as permitted for summer construction.

58 Tied warping joints may be substituted for some of the sliding contraction joints, but not more than three such warping joints should be used in succession. (Details of warping joints are given in Appendix 2.) Distribution of contraction and expansion joints may be amended to take advantage of this.

59 Longitudinal joints should be provided so that the slabs are not more than 4·5 m wide.

6.8 Details of joints in concrete slabs

60 Expansion joints, spaced in accordance with the requirements of paras.55 or 57 should be provided with a joint filler 25 mm thick.

61 All joints, however made, should be provided with a groove to accommodate a sealing material the most important function of which is to keep out grit. Where the compound is of a type complying with Clause 2619 of the Ministry of Transport Specification,[2] the dimensions of the sealing material should conform to Table 6, the groove being filled with sealing compound to 5 mm below the surface of the concrete. If the grooves are made deeper than is required for the sealing material, they should be caulked to an appropriate depth with a compressible filling material considered suitable by the joint-sealing compound supplier. Where tied warping joints are substituted for some of the contraction joints, the size of groove for the contraction joints will depend on the spacing between sliding joints.

As an alternative to poured sealing compound, a preformed Neoprene compression sealing strip may be used. The width of groove for this method of sealing should be chosen in relation to the length of slab and the recommendations of the manufacturers of the sealing strip to be used; special care is required in forming the groove.

For residential and other lightly trafficked roads, soft wood may be used as a joint filler.

62 To ensure complete formation of contraction, warping and longitudinal joints, the combined depth of groove and fillet should be one-quarter to one-third of the thickness of the slab.

63 Adequate means of load transference should be provided at all joints in concrete pavements of 150 mm or greater thickness except for roads designed to carry

Table 6 **Dimensions for sealing materials and grooves for joints in concrete roads**

Type of joint	*Spacing (m)*	*Width of groove (mm)*	*Depth of seal (mm)* ‡
Contraction joint	Under 8 *	10	20–25
	8–15 *	15	20–25
	15–20 *	20	25–30
	Over 20 *	see note †	25–30
Warping joint	All spacings	5	15–20
Expansion joint	All spacings	5 mm greater than thickness of filler	25–30
Longitudinal joint	—	5	20–25 §

* When warping joints are used the spacing applicable is the distance between adjacent sliding joints

† For contraction joint spacings in excess of 20 m the width of groove should be increased by 5 mm for each 5 m in excess of 20 m

‡ See paras. 61 and 62

§ If the joint is formed and sealed simultaneously by the insertion of an 8 mm wide bituminous preformed filler strip, the depth of strip should comply with the requirements of para. 62

less than 0·15 million standard axles during the design life, when they may be omitted if desired.

64 All expansion and contraction joints, except those excluded by para. 63, should have sliding dowel bars conforming to the requirements of Table 7. The dowels should be placed at 300mm centres and half the length of the bars should be coated with a bond-breaking compound. The bars in expansion joints only should be provided with a cap at the debonded end, containing a thickness of 25mm of compressible material to allow the joint to open and close.

65 Longitudinal joints should have tie bars 12mm in diameter by 1 m long at 600mm centres except in the case of roads designed to carry less than 0·15 million standard axles, when the spacing may be increased to 700mm.

6.9 Edge beams

66 Where edge beams are used they should be reinforced with a weight of steel equivalent to that in the main slab (no reinforcement will be required if the slabs are unreinforced).

67 Joints in accordance with paras. 60 and 61 should be provided in the edge beams at the positions where joints occur in the adjacent slabs.

68 Dowel bars should be provided to give adequate means of load transference at joints in accordance with the recommendations of para. 64. At the longitudinal joint with the slab, tie bars consisting of 12mm diameter bars at 600mm centres or 6mm diameter wires at 150 centres (or wires giving equivalent sectional area) should be used.

6.10 Example illustrating the design procedure for reinforced concrete pavements

69 A reinforced concrete design is required for a road to carry 2200 commercial vehicles per day (sum in both directions) at the time of construction with a growth rate of 5 per cent. The soil is a clay with a liquid limit of 65 per cent, a plastic limit of 25 per cent, and the water-table 500mm below the finished road level. Construction traffic will require to use the base. The design life is to be 20 years.

Traffic: Figure 3 shows that for present traffic of 1100 commercial vehicles per day in each direction and a growth rate of 5 per cent, each slow lane will carry 12·5 million commercial vehicles during the design life of 20 years.

Table 2 gives for this type of road a conversion factor of 1·08 to obtain the number of standard axles from the number of commercial vehicles carried by each slow lane. The number of standard axles carried during the design life will therefore be 12·5 ×1·08 millions =13·5 millions.

Subgrade: The soil has a plasticity index (liquid limit minus plastic limit) of 40 per cent with a water-table less than 600mm below formation level. Table 3 indicates an estimated CBR value of 2 per cent and, in accordance with Table 5, the subgrade will be classified as 'weak'.

Sub-base: The minimum requirement for sub-base thickness is given in Table 5 as 150mm, but, in accordance with para. 47, this thickness may need to be increased by 150mm to allow the passage of heavy construction vehicles. This additional material would need to conform to the requirements of Type 1 sub-base or be stabilized with cement. The lower 150mm could be of Type 2 sub-base material.

Slab thickness: Figure 11 shows that on a weak subgrade a slab thickness of 250mm would be required for traffic corresponding to 13·5 million standard axles (i.e. 222 + 25=247, rounded upwards to 250 mm).

Reinforcement: Figure 12 gives the minimum weight of reinforcement required for the traffic to be carried as 3·8kg/m^2.

Joint spacing: The next standard weight of reinforcement fabric above the minimum of 3·8kg/m^2 is 4·34kg/m^2 and the joint spacing appropriate to this weight, from Fig.13, is 27·5m. From para. 55, expansion joints will be used at 82·5m spacing with two contraction joints in between at 27·5m spacing. In accordance with para. 55, expansion joints may be omitted and contraction joints spaced every 27·5m if the road is constructed during the summer.

The total thickness of construction would be 300 + 250mm, i.e. 550mm. Since this exceeds the value of 450mm specified in para. 48, the frost susceptibility of the subgrade need not be considered.

6.11 Example illustrating the design procedure for unreinforced concrete pavements

70 A design is required for an unreinforced concrete pavement to be constructed with gravel aggregate, suitable for a minor through road in a residential area. The road width is 7m and it is to carry no public service vehicles. The soil is sandy clay with a liquid limit of 35 per cent, a plastic limit of 20 per cent, and the water-table 3m below final road level. The pavement is intended to be used by traffic bringing in materials for the construction of an estate of several hundred houses. The design should cater for a life of 40 years.

Traffic: Reference to Table 1 and Fig.5, which relate to residential and associated development roads, shows that the number of commercial vehicles on each lane will be 0·4 million during the design life of 40 years.

Table 2 gives for this type of road a conversion factor of 0·45 to obtain the numbers of standard axles from the cumulative number of vehicles carried by each lane. The corresponding number of standard axles will therefore be 0·4 ×0·45 million =0·18 million.

Subgrade: The soil has a plasticity index (liquid limit minus plastic limit) of 15 per cent, with a water-table more

Table 7 **Dimensions of dowel bars for expansion and contraction joints**

Slab thickness (mm)	*Expansion joints*		*Contraction joints*	
	Diameter (mm)	*Length (mm)*	*Diameter (mm)*	*Length (mm)*
150–180*	20	550	12	400
190–230	25	650	20	500
240 and over	32	750	25	600

* Dowel bars are not recommended for slabs thinner than 150mm

than 600 mm below formation level. Table 3 indicates a probable CBR value of 6–7 per cent and, in accordance with Table 5, the subgrade would be classified as 'normal'.

Sub-base: The minimum requirement for sub-base thickness is given in Table 5 as 80 mm and, on a road of this type where heavy construction plant would not require to use the sub-base, this thickness would be structurally satisfactory. Type 2 sub-base material would satisfy the requirements of para. 47.

Slab thickness: Figure 11 shows that on a normal subgrade a slab thickness of 160 mm would normally be required, but because of the initial use of the pavement by heavy traffic concerned with the surrounding development, it would be desirable to increase the thickness to 180 mm.

Joint spacing: In accordance with para. 57 for gravel aggregates the spacing of contraction joints would be 5 m and the spacing of expansion joints for winter construction would be 40 m.

(The omission of expansion joints would probably not be practicable unless the road butted against flexible construction.)

Since the total thickness of construction would be 80 + 180 = 260 mm, i.e. considerably less than the thickness required by para. 48 over frost-susceptible soils, the frost susceptibility of the subgrade would need to be considered in the light of local experience.

7 Design of pavements with a continuously reinforced concrete base and bituminous surfacing

71 In some cases, notably in city streets, a combination of continuously reinforced concrete and bituminous surfacing may be justified in view of its trouble-free performance, especially on subgrades of doubtful quality or those extensively disturbed by excavations or where there are shallow service trenches. This form of construction also minimizes the risk of uneven settlement in areas formerly occupied by buildings. Because of its initial cost it is not anticipated that this form of construction would be used for pavements designed to carry less than 2·5 million standard axles during the design life.

72 The recommended thicknesses for the concrete slab and the surfacing are obtained from Fig.14. The thickness of slab is intended to be rounded upwards to the next 10 mm intercept. The thickness of the sub-base is obtained from Table 5.

7.1 Traffic, subgrade, drainage, and sub-base

73 The design of continuously reinforced concrete pavements follows closely that of normal reinforced and unreinforced concrete pavements, and paras. 43–48 inclusive, dealing with traffic, subgrade, drainage, and sub-base, apply equally to this form of construction.

7.2 Reinforced concrete roadbase

74 Figure 14 gives the thickness of continuously reinforced concrete roadbase required in terms of the cumulative number of standard axles to be carried, for the three types of subgrade considered in Table 5.

75 The designs given in this Note are based on a minimum crushing strength for concrete of 28 MN/m^2 at 28 days using ordinary Portland cement or Portland blastfurnace cement. If the indirect tensile test is used an equivalent value should be taken. The mix need not be air-entrained.

7.3 Reinforcement

76 The reinforcement should be of long mesh not lighter than 5·5 kg/m^2 or longitudinal deformed bar reinforcement of cross-sectional area not less than 650 mm^2 per metre width of road. The relatively heavy reinforcement is recommended in view of the absence of transverse joints. Reinforcement fabric should conform to BS 4483 and deformed bar to BS 4449 or BS 4461. The reinforcement should have 60 mm cover from the surface, and terminate at least 40 mm and not more than 80 mm from the edges of the slab and longitudinal joints, except for those covered by para. 77.

At transverse joints between reinforcing mats, the first transverse wire of one mat should lie within the last complete mesh of the previous mat and the overlap should not be less than 450 mm. No overlap will be needed at the longitudinal joint between mats. When deformed bar reinforcement is used, the overlap of the bars should not be less than 40 bar diameters.

77 Where a two- or three-lane carriageway is constructed in one operation, reinforcing mats having transverse wires of 8 mm diameter at 200 mm centres may be used to span the joints in place of tie bars (para. 80). The longitudinal reinforcement in all mats should be as required by para. 76. The 8 mm wires must be long enough to span at least 500 mm either side of the longitudinal joints (para. 80).

78 When a three-lane carriageway is constructed in two widths, transverse reinforcement consisting of 8 mm diameter wires at 200 mm centres, which may be incorporated in special mats, should be used in slabs wider than 4·5 m. The length of this transverse reinforcement should be 600 mm longer than one-third of the slab width and should be placed centrally.

7.4 Joints

79 It is recommended that no transverse joints should be introduced except for unavoidable construction joints. At a transverse construction joint the reinforcement should be allowed to project at least 700 mm beyond the end of the day's work, and when work is resumed the reinforcement should be overlapped by at least 700 mm in order to minimize the possibility of movement occurring at the joint.

80 Longitudinal joints should be provided so that the slabs are not more than 4·5 m wide except where extra transverse reinforcement is used as mentioned in para. 77. Tie bars as described in para. 65 should be used in all longitudinal joints except where additional transverse steel is used as described in para. 77.

7.5 Surfacing

81 The surfacing should be of two courses with total thickness not less than 90 mm. Materials conforming to the requirements given in Column 1 or 2 of Table 4 as appropriate, should be used for the wearing course and basecourse.

8 Hard shoulders

82 The design of hard shoulders is not considered in detail in this Note. Each length of shoulder, under normal conditions, is used by less than one disabled commercial vehicle per day, and for such traffic the design methods described in the preceding sections would indicate a very light form of construction. However, conditions of abnormal use must also be taken into account. Maintenance work on the carriageway is likely to require the temporary use of the full-width shoulder as the slow traffic lane. The probable periods of such use could be estimated and the design methods used to revise the thickness requirements. For this traffic the construction needed for structural reasons will still be comparatively light.

Consideration must also be given in any particular case to whether the shoulder may at some time be incorporated into the carriageway as part of a widening scheme. In such a case it would eventually need to fulfil the functions of the slow lane and the economics of a strong initial design will need to be evaluated.

Further, as part of the construction process, it is advantageous, particularly from the point of view of drainage, to carry the sub-base material and some roadbase materials across the full-width of the carriageway and shoulder. This imposes a design thickness for the shoulder similar to that used in the carriageway, although less expensive materials can often be used for the upper part of the roadbase and for the surfacing of the shoulder.

All these factors need to be considered in formulating the shoulder design.

9 Designs incorporating variations of thickness across the width of the carriageway

83 The designs considered in the previous Sections of this Note, when used for dual-carriageway roads, are based on the commercial traffic using the slow lanes. In general, these designs will be carried over the full width of the carriageways resulting in some measure of over-design for lanes other than the slow lanes. Some economy may be effected for a two- or three-lane carriageway by graduating the thickness of construction across the width to take some account of the different loading conditions on the lanes. The method which could be adopted for designing such a pavement is outlined in this Section.

84 When such a design is contemplated, preliminary consideration must be given to ensure that there is an overall economic advantage and that a practical design results. In certain cases, for example on a right-hand bend, the change in formation and sub-base levels across the carriageway owing to the tapered construction may, in combination with the superelevation, aggravate drainage difficulties during construction.

85 As traffic intensities increase there is a progressive transfer of commercial vehicles from the slow lane. The economic advantage in using tapered construction is therefore likely to be greatest on two-lane dual carriageways carrying the lightest commercial traffic for which each such road is likely to be designed. Where traffic is very heavy the economic advantage will probably be small.

86 Figure 15 shows the cumulative number of commercial vehicles to be carried on each carriageway by lanes adjacent to the slow lane for various intensities of commercial traffic. The growth rate assumed is 4 per cent, and Fig.15 is therefore complementary to Fig.2 which gives this information for each slow lane. For growth rates other than 4 per cent, the cumulative number of commercial vehicles given by Fig.15 should be multiplied by the following factors:

3 per cent—multiply by 0·7
5 per cent—multiply by 1·35
6 per cent—multiply by 1·75.

87 Under present regulations relating to the use of traffic lanes by commercial vehicles, Fig.15 will apply to the middle lanes of three-lane motorways and the fast lanes of two-lane dual carriageways. It will not apply to urban dual carriageway roads with four or more lanes per carriageway or three-lane dual carriageway roads not covered by current regulations.

88 Using the procedure given in Section 3 of this Note, Fig.15 can be used to estimate the cumulative number of standard axles to be carried by the middle lane or fast lane (in the case of two-lane duals). The design of these lanes can then be formulated in the same manner as for the slow lane.

89 Discontinuities across the width of a carriageway are not recommended and it is suggested that tapered thicknesses should be adopted, the calculated design thickness for each lane being used for the centre of that lane. (The design of the fast lane on a three-lane dual carriageway, which should carry no commercial traffic, will thus be determined by the commercial traffic flow on the other two lanes.) Typical cross-section for two- and three-lane dual carriageways are given in Fig.16.

90 It is not recommended that the thickness of the surfacing of flexible pavements should be tapered across the width of the carriageway. Any reduction in thickness should be confined to the sub-base and roadbase. In the case of lean concrete and wet-mix roadbases, however, the surfacing thickness obtained from Fig.9 or Fig.10 includes the additional bituminous material needed to form a composite roadbase (see para. 35). In these cases it would be permissible to taper the surfacing provided that the surfacing thickness at the edge adjacent to the central reserve is not less than 100 mm. Any such tapering should be done only in the lower course of the surfacing. The reduction of thickness of sub-base must be within the limits permitted by the use of the sub-base for construction traffic, if this is envisaged. In addition, the total thickness of the pavement must not be reduced at any point to a level where frost would be permitted to enter a frost-susceptible subgrade (see para. 28).

91 Any reduction of thickness of a concrete pavement should be confined to the concrete slab, and the thickness of the sub-base should be maintained constant over the carriageway width. The only practicable alteration in slab design across the carriageway is the thickness; all other aspects of design, such as weight of reinforcement, joint spacing, etc., should be the same as that used for the slow lane. For ease of construction, dowel bar assemblies should be positioned so that the line of the dowel bars across the carriageway is parallel to the bottom of the slab. Reinforcement should be positioned at a constant depth from the top of the slab in accordance with para. 52.

9.1 Examples illustrating the method of design for tapered cross-sections

92 The following examples illustrate the method of design for tapered cross-sections and indicate the order of economies in materials likely to accrue from its use:

Example 1

A three-lane dual carriageway road is required to carry 2500 commercial vehicles per day (in each direction) at the time of construction with a growth rate of 4 per cent. The soil has a CBR value of 3 per cent and the design life is to be 30 years. Suitable tapered cross-sections are required.

Figure 2 shows that during the design life the slow lanes will carry 39 million commercial vehicles, and Fig.15 shows that the lanes adjacent to the slow lanes will carry 21 million commercial vehicles.

Using the conversion factor of 1·08 from Table 2 for this class of road, the number of standard axles carried will be 42 millions on each slow lane and 22 millions on each adjacent lane.

Flexible construction. Figures 6, 7, and 9 indicate the following thicknesses of sub-base and roadbase:

	Sub-base	*Roadbase*	
		Rolled asphalt	*Lean concrete*
Slow lane	450 mm	180 mm	210mm+70mm *
Adjacent lane	430 mm	150 mm	210mm+50mm *

* dense bituminous roadbase to form composite construction

Figure 16(a) gives a cross-section for the rolled asphalt roadbase.

For a three-lane dual carriageway road this would reduce the sub-base requirement by 4 per cent. The corresponding reductions in roadbase requirements would be 17 per cent (rolled asphalt) or 7 per cent (lean concrete with a minimum surfacing thickness of 100 mm at the central reserve).

Concrete construction. Figure 11 gives the following thicknesses of concrete slab required on a normal subgrade:

Slow lane	260 mm
Adjacent lane	240 mm

For a three-lane dual carriageway this would reduce the quantity of concrete required by 7 per cent. On frost-susceptible soils, however, the thickness of sub-base required would be 240 mm (i.e. 450 mm total pavement thickness at the central reserve), instead of 190 mm for slow-lane design with uniform cross-section.

Example 2

A two-lane dual carriageway road is required to carry 1500 commercial vehicles per day (in each direction) at the time of construction with a growth rate of 4 per cent. The soil has a CBR value of 3 per cent and the design life is to be 30 years. Suitable tapered cross-sections are required.

Figure 2 shows that during the design life the slow lanes will carry 26·4 million commercial vehicles, and Fig. 15 shows that the fast lanes will carry 8·2 million commercial vehicles.

Using the conversion factor of 1·08 from Table 2, the number of standard axles carried will be 28 millions on each slow lane and 9 millions on each fast lane.

Flexible construction. Figures 6, 8, and 10 indicate the following thicknesses of sub-base and roadbase:

	Sub-base	*Roadbase*	
		Dense macadam	*Wet-mix*
Slow lane	440mm	200mm	250mm+60mm *
Fast lane	390mm	140mm	220mm+20mm *

* dense bituminous roadbase to form composite construction

Figure 16(b) gives a cross section for the wet-mix roadbase.

For a two-lane dual carriageway this would reduce the sub-base requirement by 6 per cent. The corresponding reductions in roadbase requirements would be 15 per cent (dense macadam) or 11 per cent (wet-mix).

Concrete construction. Figure 11 gives the following thicknesses of concrete slab required on a normal subgrade:

Slow lane	250 mm
Fast lane	220 mm

For a two-lane dual carriageway this would reduce the quantity of concrete required by 6 per cent. On frost-susceptible soils, however, the thickness of sub-base required would be 250 mm, instead of 200 mm for slow lane design with uniform cross-section.

10 Design of pavements to carry specialized traffic of known axle loading

93 Most private industrial roads are required to carry repeated passages of a limited number of types of loaded commercial vehicle. Because of this, the axle loads constituting the traffic will generally follow a very different pattern to the mixed traffic using public roads, but the magnitude of the various axle loads and their frequency will be known with comparative accuracy.

Under these circumstances it is possible to use the equivalence factors developed from the AASHO Road Test[3] to convert each axle load to an equivalent number of passages of a standard (8200 kg) axle, and then to use the design curves discussed in the earlier Sections of this Note.

94 Equivalence factors suitable for use for flexible and concrete pavements are given in Table 8. (The factors deduced from the AASHO Road Test showed variations related to the type of pavement and its thickness. The variations were, however, very small and for simplicity average values are quoted in the Table.)

Table 8 **Equivalence factors and damaging power of different axle loads**

Axle load		*Equivalence factor*
kg	*(lbs)*	
910	(2000)	0·0002
1810	(4000)	0·0025
2720	(6000)	0·01
3630	(8000)	0·03
4540	(10000)	0·09
5440	(12000)	0·19
6350	(14000)	0·35
7260	(16000)	0·61
8160	(18000)	1·0
9070	(20000)	1·5
9980	(22000)	2·3
10890	(24000)	3·2
11790	(26000)	4·4
12700	(28000)	5·8
13610	(30000)	7·6
14520	(32000)	9·7
15420	(34000)	12·1
16320	(36000)	15·0
17230	(38000)	18·6
18140	(40000)	22·8

95 If the loads on the various axles using the road are known, together with an estimate of the numbers of each to be carried during the design life of the pavement, the equivalence factors given in Table 8 are used as multipliers to obtain the equivalent number of standard axles to be catered for in the design. The procedure is illustrated in detail by the two examples given below.

96 If it is required to take into account a growth rate for any or all of the axle loads, the following formula may be used:

$$A = P\,(1+r)^{x}$$

where A = number of axles/day for a particular year
P = number of axles/day at the time of construction
r = annual growth rate; this is generally taken as 0·04 (i.e. 4 per cent) in the absence of information to the contrary
x = number of years from the year of construction to the year for which the number of axles per day is required.

To obtain the cumulative number of axles of any one category during the design life, the number of axles per day for each year, from the time of construction to the last year of life must be computed using the above formula. The number of axles per day (multiplied by 365) for each year of life is summed to give the cumulative number of axles over the design life. To simplify this calculation for growth rates between 3 and 6 per cent, the number of axles per day may be multiplied by the factor given in Table 9 for the appropriate life and growth rate, and by 365 to give the cumulative number of axles over the design life (see Example 2 below).

Table 9 **Factors for obtaining cumulative axles during the design life at a constant growth rate**

Life (x) (years)	*Growth rate (r)—per cent*			
	3	4	5	6
10	11·8	12·5	13·2	14·0
15	19·2	20·8	22·7	24·7
20	27·7	31·0	34·7	39·0
25	37·6	43·3	50·1	58·1
30	49·0	58·3	69·8	83·8
35	69·3	76·6	94·9	118
40	77·7	98·8	127	164

10.1 Examples illustrating the design of pavements to carry specialized traffic

97 *Example 1*

The daily traffic on a refinery road is to consist of 100 passages (in each direction) of four-axle vehicles with loads of 9000 kg on the two rear axles, 7300 kg on the second axle and 2700 kg on the front axle. In addition, there will be 200 passages in each direction of three-axle vehicles with loads of 9000 kg on the rear axles and 1800 kg on the front axle, and 100 passages (in each direction) of two-axle vehicles with 8200 kg on the rear axle and 2700 kg on the front axle. A flexible design is required for a soil with a CBR value of 4 per cent and a design life of 20 years.

In each direction, the traffic consists of: six hundred 9000 kg axles; one hundred 8200 kg axles; one hundred 7300 kg axles; two hundred 2700 kg axles and two hundred 1800 kg axles. The numbers of axles to be carried in each direction during the design life are therefore as follows:

Axle load (kg)	*Number during design life*	*Equivalence factor*	*Number of standard axles (millions)*
9000	600×365×20	1·5	6·57
8200	100×365×20	1·0	0·73
7300	100×365×20	0·61	0·45
2700	200×365×20	0·01	0·015
1800	200×365×20	0·0025	0·004
		Total	7·77

For this traffic, reference to Figs.6, 7, 8, 9, and 10 gives the following flexible design:

Sub-base	310mm
Roadbase:	
Rolled asphalt	120mm
Dense coated macadam	140mm
Lean concrete	190mm
Wet-mix	210mm
Surfacing: (Two-course bituminous material as Table 4) with rolled asphalt or dense macadam roadbase	100mm
with lean concrete or wet-mix roadbase	110mm

In such a case as this the width of the road would also need to be considered. If the carriageway was so narrow that vehicles moving in the two directions followed essentially the same tracks, the design would need to cater for double the above traffic, assuming that the vehicles were equally loaded in the two directions.

98 *Example 2*

A side-loading stacking truck is required to operate on loading lanes in a transit/storage area. The machine has two axles carrying the following loads:

	Axle 1 (kg)	*Axle 2 (kg)*
Loaded	17 000	15 000
Unloaded	13 000	11 000

It is estimated that the vehicle will make 400 movements per day along the lanes, 200 loaded and 200 unloaded. It is anticipated that the number of movements will increase at the rate of 3 per cent per year. A reinforced concrete design is required to give a design life of 15 years on a clay soil with a CBR value of 3 per cent.

Since only one machine is operating, it can be assumed that the lanes will be narrow and the movements in the two directions will follow the same wheel-tracks. The daily traffic will thus consist of:

200 17 000 kg axles;
200 15 000 kg axles;
200 13 000 kg axles;
and
200 11 000 kg axles.

The number of axles to be carried during the design life will be 17 000 kg:

1st year $200(1+0{\cdot}03)\times 365 = 206\times 365$
2nd year $200(1+0{\cdot}03)^{2}\times 365 = 212\times 365$
....
15th year $200(1+0{\cdot}03)^{15}\times 365 = \underline{312\times 365}$
Cumulative axles (15 years) $= 3840\times 365$
$= 1{\cdot}4\times 10^{6}$

Alternatively, the factor for 15 years at 3 per cent per year growth is 19·2 from Table 9. The cumulative number of axles is therefore $200 \times 19{\cdot}2 \times 365 = 1{\cdot}4 \times 10^6$.

The number of axle loads for the other categories will be the same.

Axle load (kg)	*Number during design life*	*Equivalence factor*	*Number of standard axles (millions)*
17 000	$1{\cdot}4\times10^6$	17·7	24·8
15 000	$1{\cdot}4\times10^6$	11·0	15·4
13 000	$1{\cdot}4\times10^6$	6·4	9·0
11 000	$1{\cdot}4\times10^6$	3·3	4·6
		Total	53·8

A soil with a CBR value of 3 per cent represents a normal subgrade, and Figs.11, 12, 13, and Table 5 show that a concrete slab 270 mm thick would be required on an 80 mm sub-base. Reinforcement would be of not less than 5 kg/m². The next standard long-mesh reinforcement is 5·55 kg/m² and the contraction joint spacing should therefore be not more than 35 m. The frost susceptibility of the subgrade would need to be considered (see para.48).

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12 Appendix 1. The frost susceptibility of soils and road materials

12.1 Introduction

Tests for frost susceptibility have been carried out by the Road Research Laboratory on a variety of materials used as subgrades, sub-bases, and roadbases both in research and during routine testing for motorway and trunk road projects. Details of these tests and other aspects of frost susceptibility are contained in RRL Report LR 90,[5] together with a description of the Road Research Laboratory Frost Test. The conclusions reached relating to the frost susceptibility of soils and granular sub-base and roadbase materials are summarized below. These conclusions will generally remove the need for testing, but in cases of doubt the test procedure given in LR 90 should be followed.

12.2 Cohesive soils

Cohesive soils can be regarded as non-frost-susceptible when the plasticity index is greater than 15 per cent for well-drained soils, or 20 per cent for poorly drained soils (i.e. water-table within 600 mm of the formation level).

12.3 Non-cohesive soils

(a) Non-cohesive soils (other than limestone gravels) can be regarded as non-frost-susceptible if the percentage of material passing the 75 µm BS test sieve is 10 per cent or less.

(b) The state of compaction of non-cohesive soils does not significantly affect their liability to frost heave.

(c) Limestone gravels are likely to be frost susceptible if the average saturation moisture content of the limestone aggregate exceeds 2 per cent.

12.4 Chalks

All crushed chalks are frost susceptible. The magnitude of frost heave increases linearly with the saturation moisture content of the chalk aggregate.

12.5 Limestones

(a) All oolitic and magnesian limestones with an average saturation moisture content within the aggregate greater than 3 per cent must be regarded as frost susceptible. The percentage passing the 75 µm BS test sieve has little influence on the heave likely to occur in these materials.

(b) All hard limestones with less than 2 per cent of average saturation moisture content within the aggregate and with 10 per cent or less of particles passing the 75 µm BS test sieve can be regarded as non-frost-susceptible.

12.6 Granites

Crushed granites with 10 per cent or less of particles passing the 75 µm BS test sieve can be regarded as non-frost-susceptible.

12.7 *Burnt colliery shales*

Burnt colliery shales are very liable to frost heave. The degree of heaving, which seems to be associated with the extent of burning, cannot be related either to the particle-size distribution or to the saturation moisture content of the aggregate. Tests on representative samples are regarded as essential before the material is used in the top 450 mm of the road structure.

12.8 Slags

Crushed, graded slags are not liable to frost heave if the percentage of material passing the 75 µm BS test sieve is 10 per cent or less.

12.9 Pulverized fuel ashes

(a) Coarse fuel ashes with less than 40 per cent of particles passing the 75 µm BS test sieve are unlikely to be frost susceptible.

(b) Fine ashes may be frost susceptible and frost-susceptibility tests should be carried out before such materials are used in the top 450 mm of road construction.

13 Appendix 2. Design of a warping joint

13.1 Introduction

Transverse joints are needed in unreinforced 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 the warping moments, and theory suggests that the stresses caused by these moments are greater than those due to contraction in the longitudinal direction for normal slab lengths. Thus some of the contraction joints in unreinforced concrete can be replaced by 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 a sealing material.

13.2 Specification

Reinforcement for warping joints shall consist of a fabricated welded mesh with 12 mm diameter longitudinal bars at least 1·4 m long at the spacing given in Table 10, a minimum of three wires of 6 mm diameter shall be used transversely at 700 mm centres. The number of transverse wires may be increased for handling purposes, if required. At least every third longitudinal bar shall be longer than 1·4 m and shall be bent in order that a 1·4 m effective length of longitudinal reinforcement shall lie at half depth of the slab with the assembly resting on feet supported on the base, the feet being formed from the extension of the longitudinal bars in the manner shown in Fig.17. 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 ±20 mm in 1 m. The centre 200 mm of each 1·4 m effective length of bar shall be painted with bond-breaking compound (Clause 2605).

Table 10 **Spacing of longitudinal bars**

Slab thickness (mm)	*Spacing (mm)*
300	180
280	200
260	220
240	240
220	270
200	300
180	360

Where several reinforcement assemblies are used in one joint (to facilitate handling) they may be independent of each other, but all the assemblies in one joint shall be truly aligned to an accuracy of ±5 mm.

The reinforcement assemblies shall be fixed to the base, one method being to use mortar pads round the horizontal portion of the feet. The mortar shall consist of one part by weight of Portland cement to three 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 one-third of the depth of the slab and so that the difference in the depth of the discontinuity at the top and bottom is not greater than 12 mm. The crack inducer shall be fixed to the base along the centre line of the joint to within 5 mm by nailing or other approved method. The sealing groove located with its centre line vertically above the crack inducer within a tolerance of ±12 mm, shall conform with the requirements of para. 61 and Table 6.

Figure 1 **Relation between cumulative number of commercial vehicles carried by each slow lane and design life – growth rate 3 per cent**

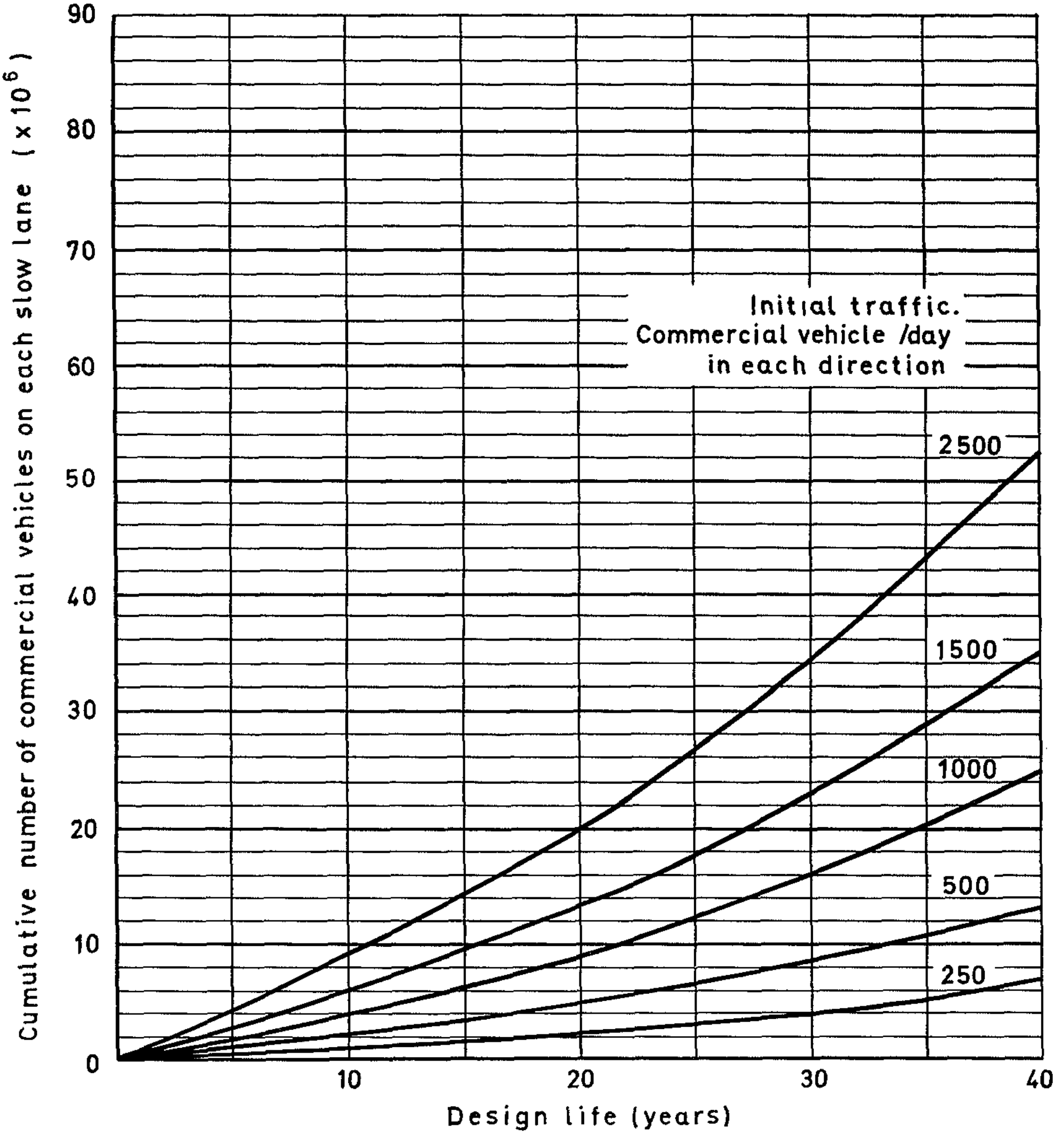


Figure 2 **Relation between cumulative number of commercial vehicles carried by each slow lane and design life – growth rate 4 per cent**

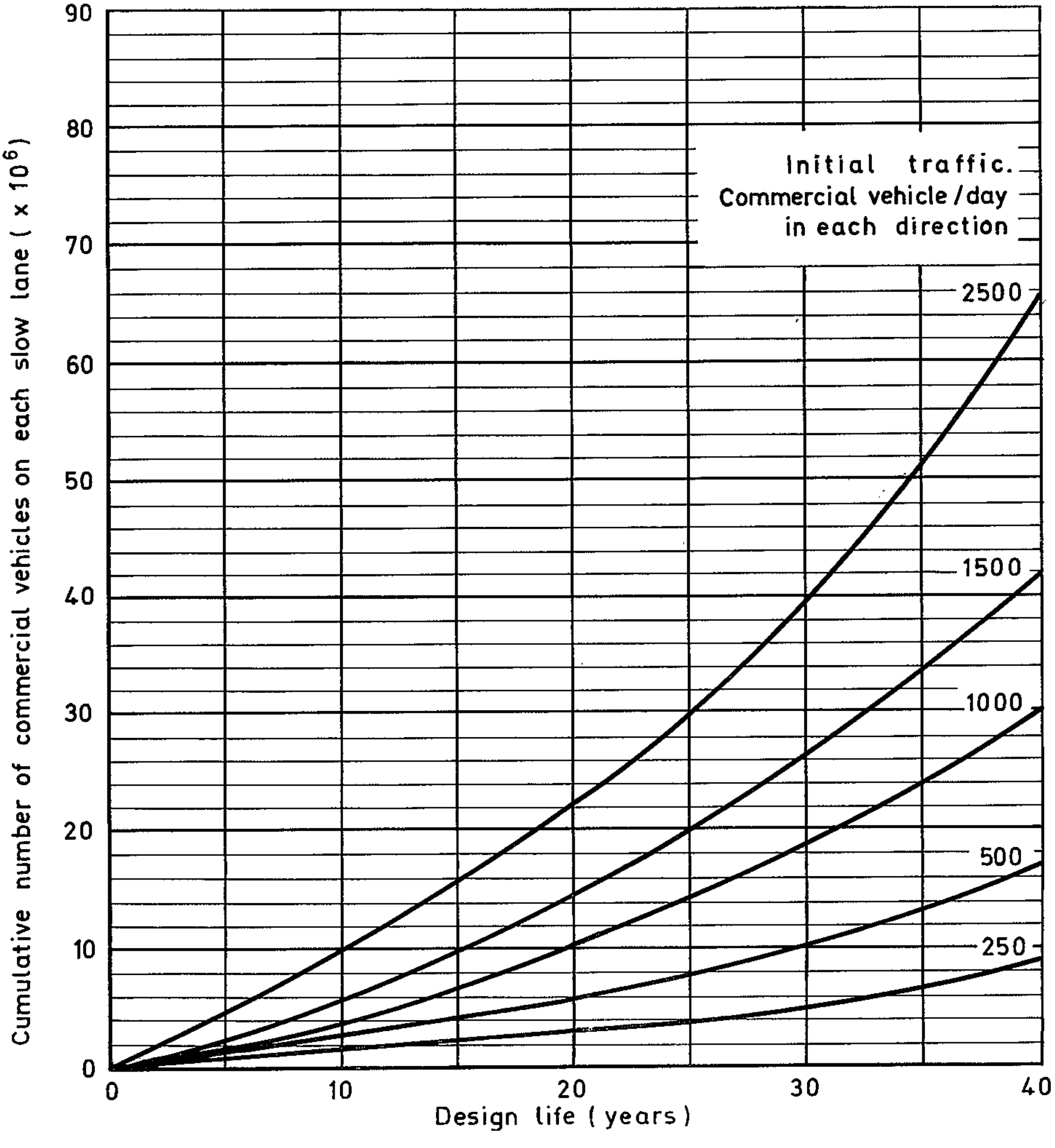


Figure 3 **Relation between cumulative number of commercial vehicles carried by each slow lane and design life – growth rate 5 per cent**

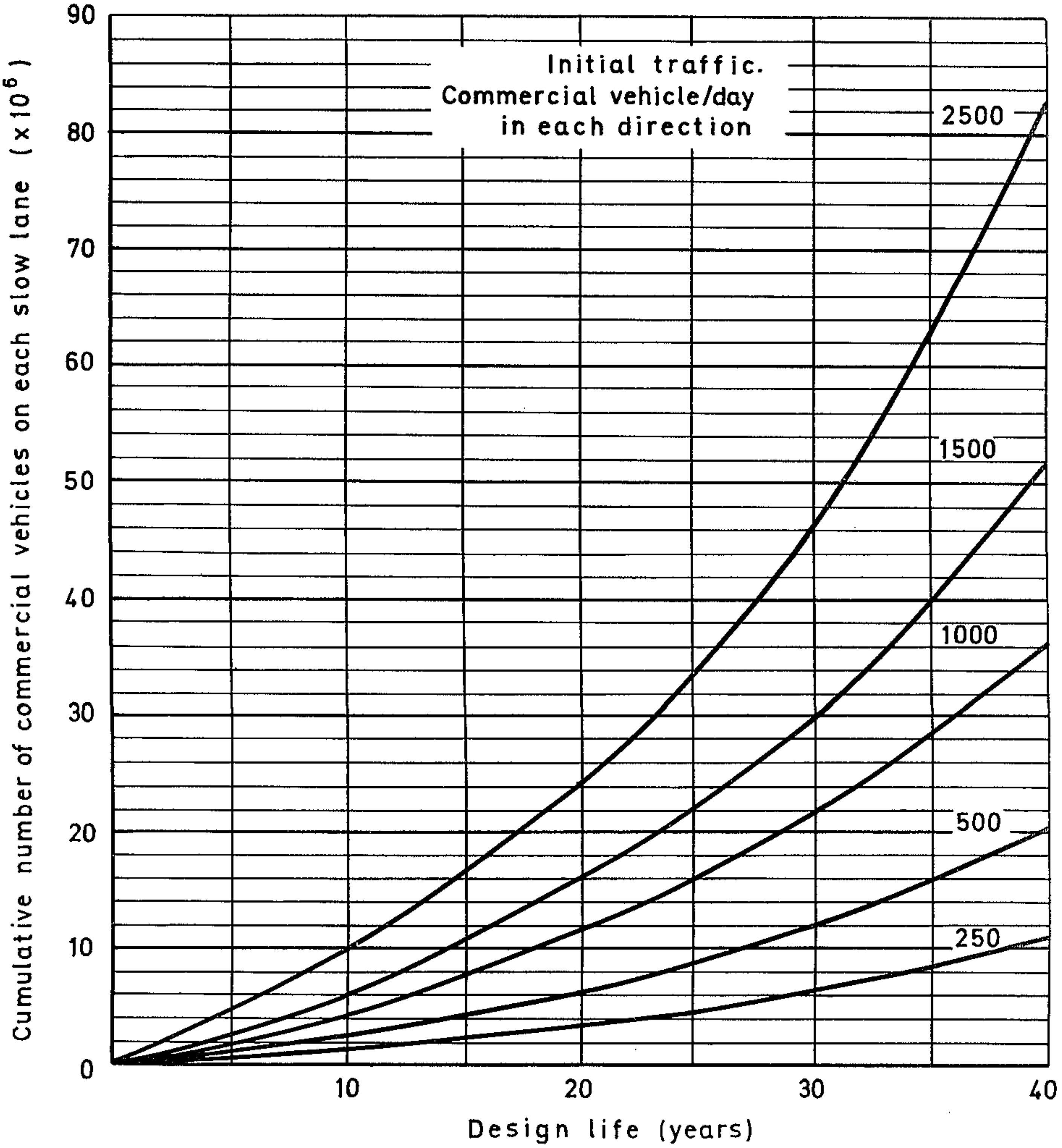


Figure 4 **Relation between cumulative number of commercial vehicles carried by each slow lane and design life – growth rate 6 per cent**

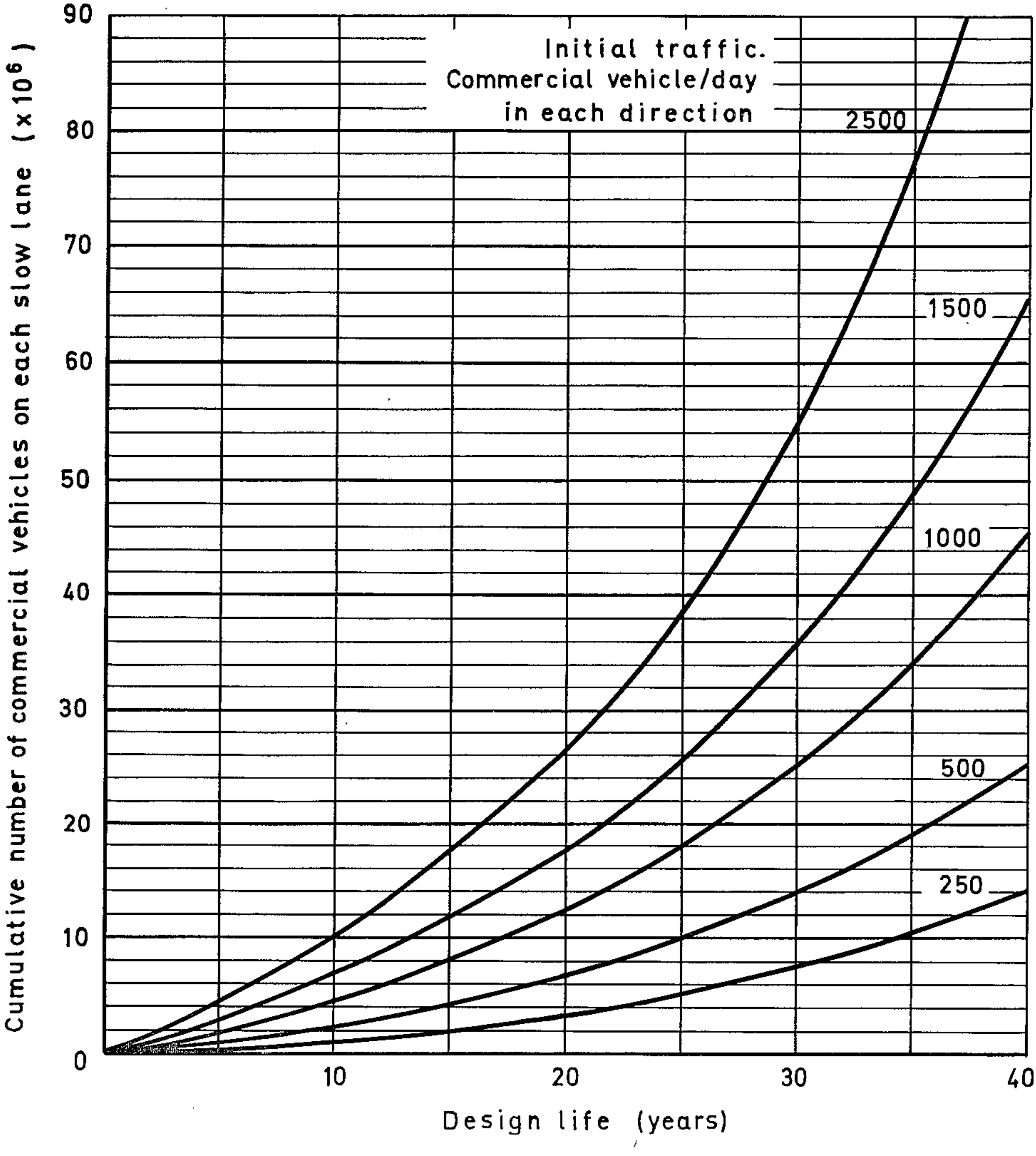


Figure 5 **Roads in residential and associated developments: relation between cumulative number of commercial vehicles carried by each slow lane and design life**

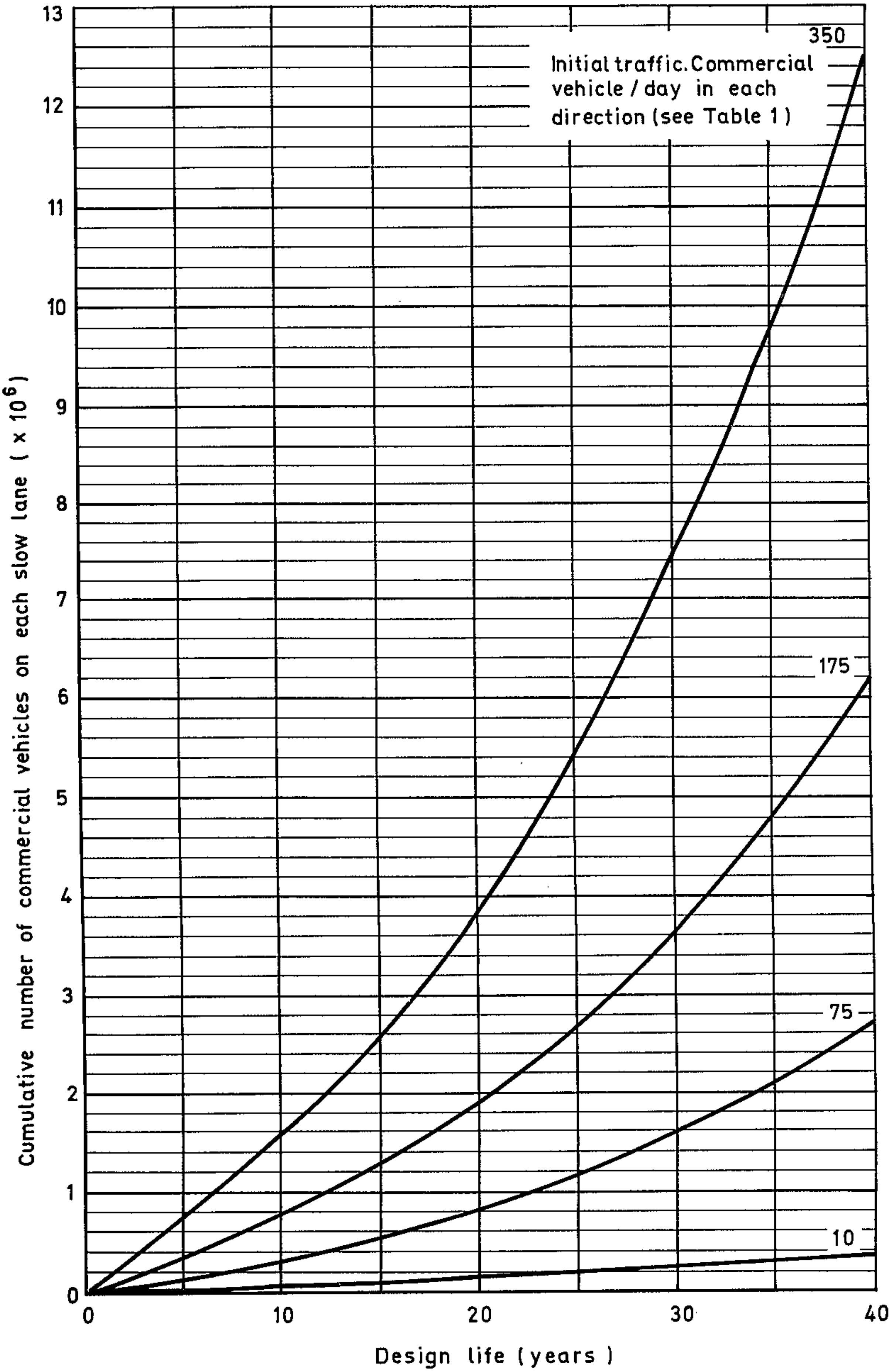


Figure 6 **Thickness of sub-base**

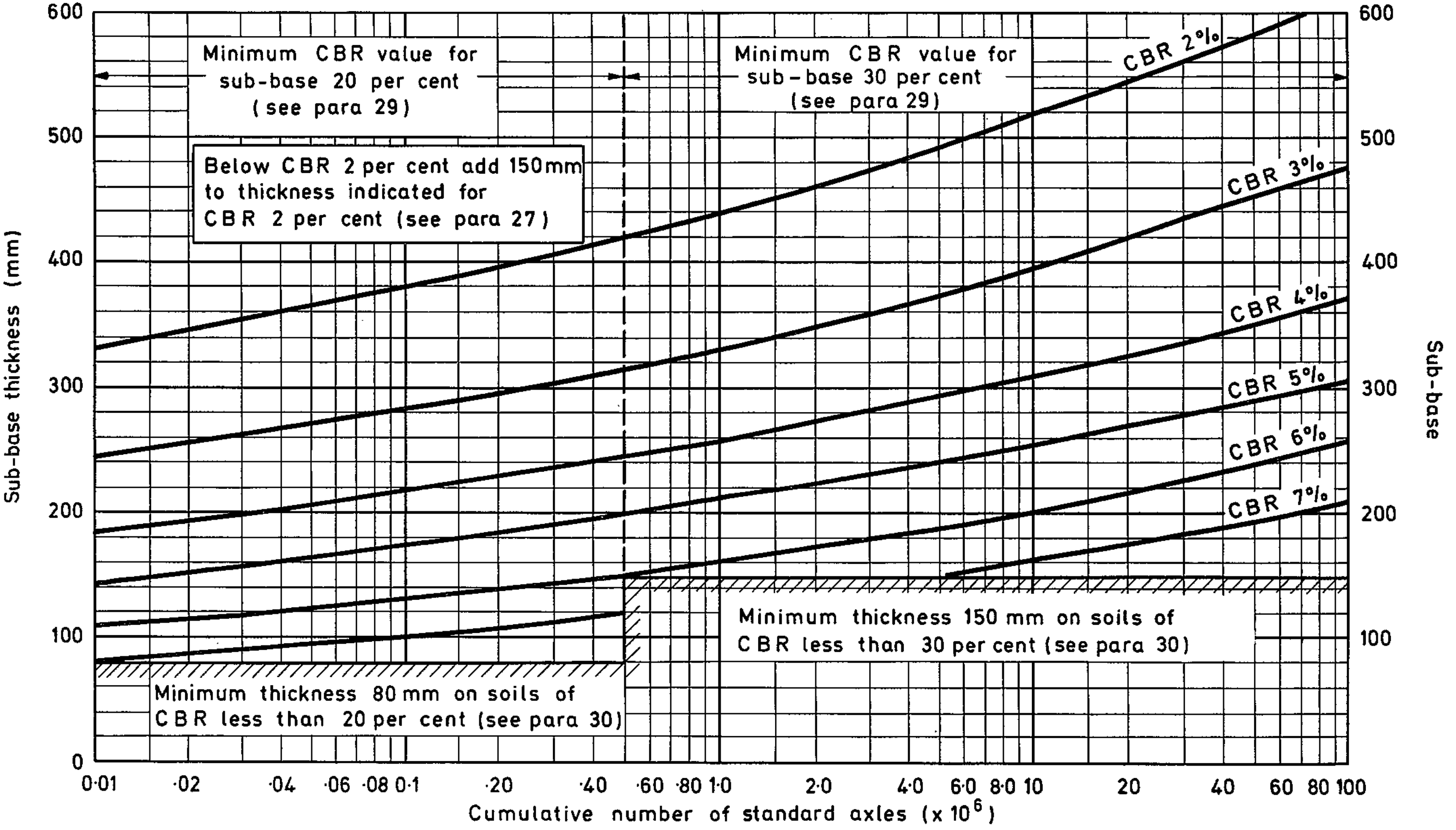


Figure 7 **Rolled asphalt roadbase: minimum thickness of surfacing and roadbase**

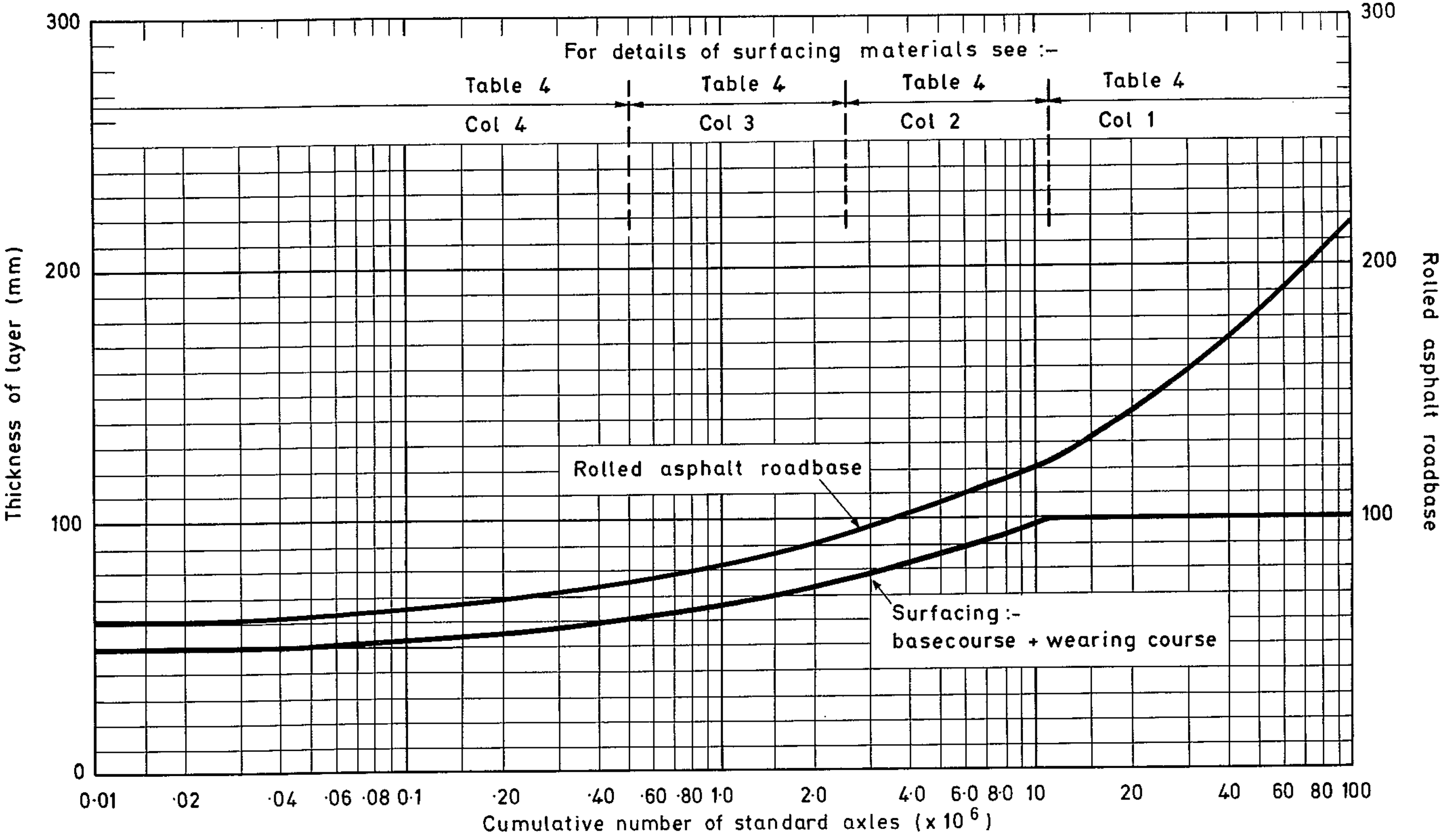
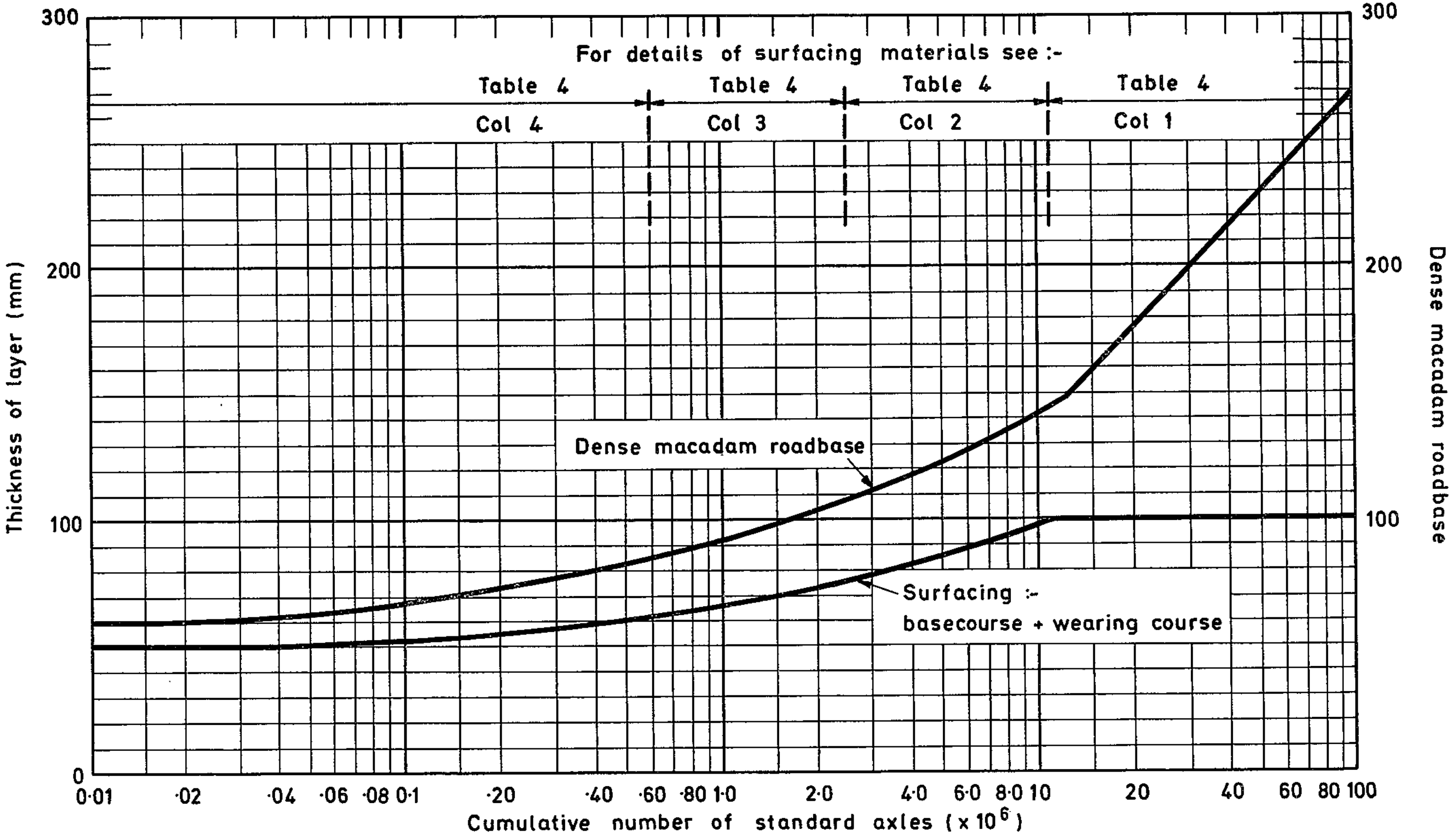


Figure 8 **Dense macadam roadbase: minimum thickness of surfacing and roadbase**



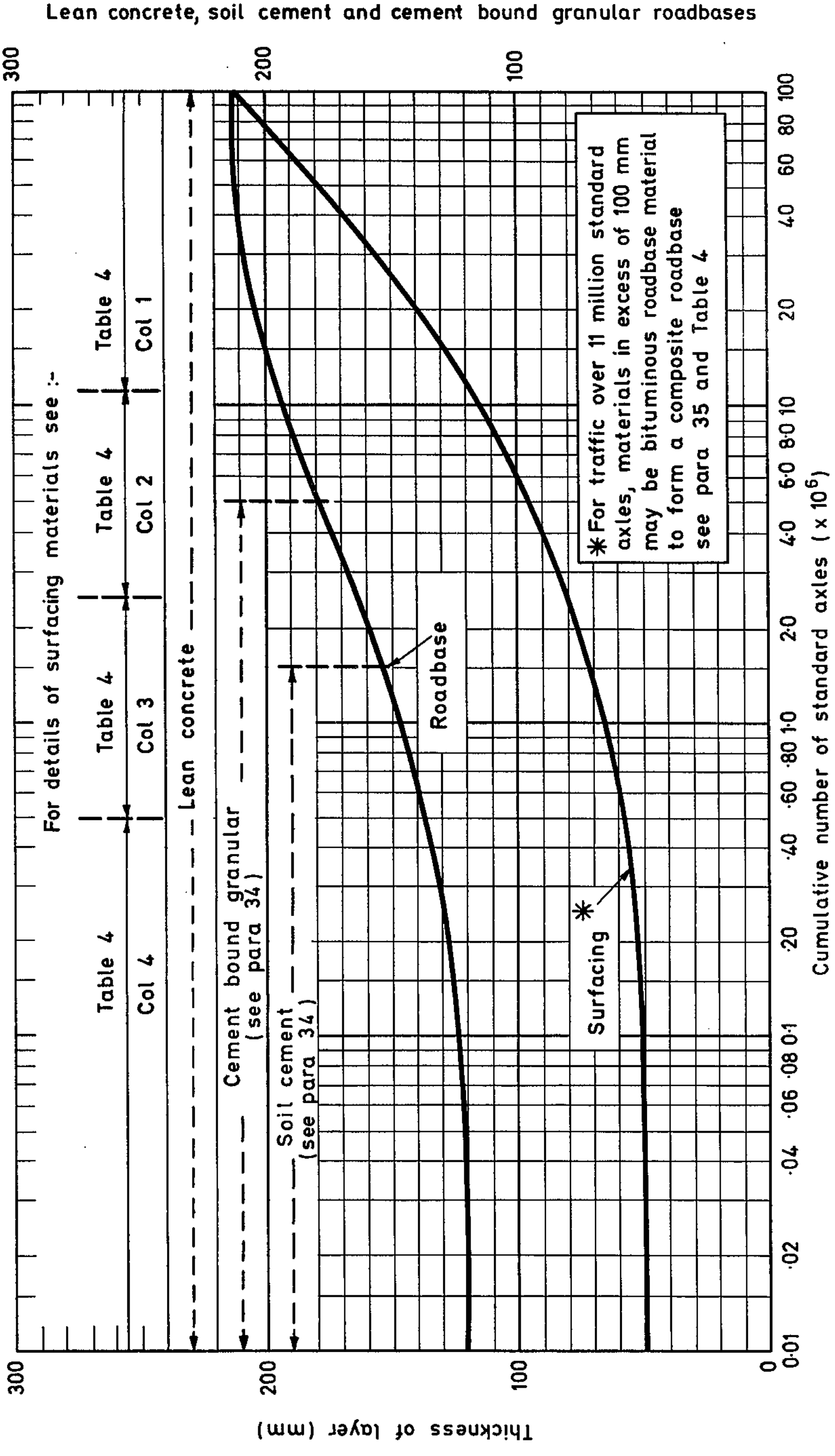


Figure 9 **Lean concrete, soil cement and cement-bound granular roadbases: minimum thickness of surfacing and roadbase**

Figure 10 **Wet-mix and dry-bound macadam roadbases: minimum thickness of surfacing and roadbase**

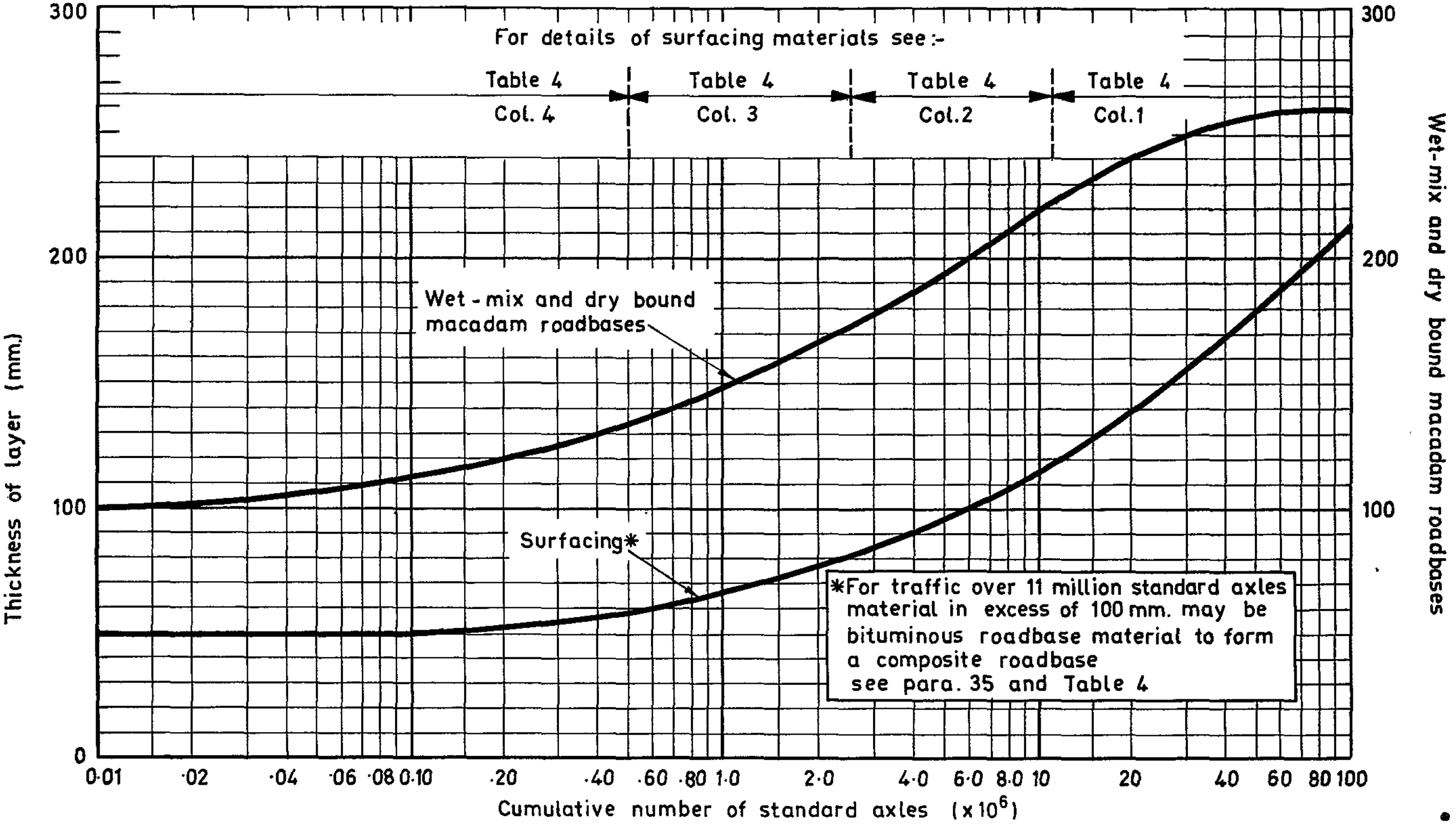
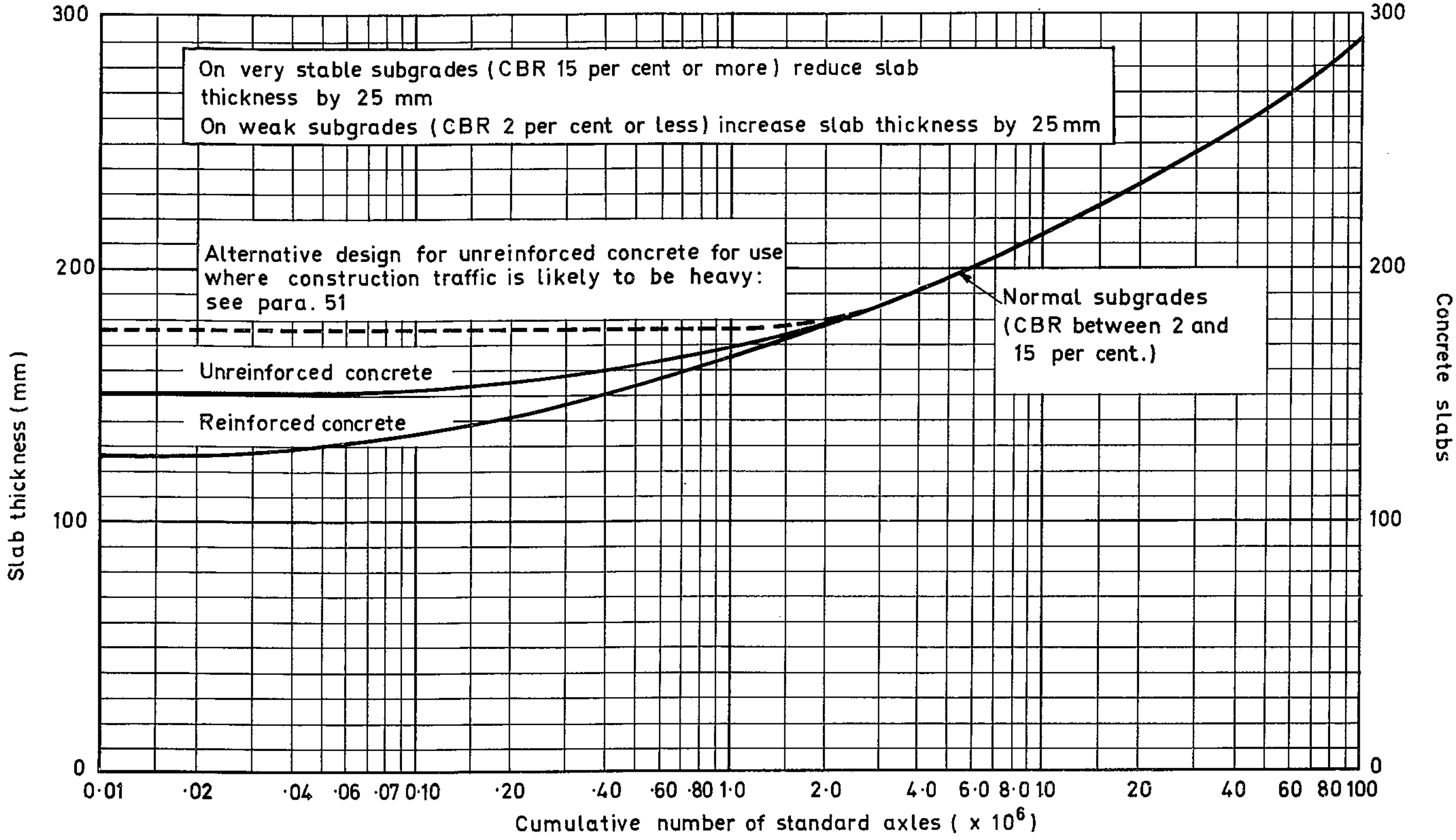


Figure 11 **Concrete: minimum thickness of slabs**



On very stable subgrades (CBR 15 per cent or more) reduce slab thickness by 25 mm
On weak subgrades (CBR 2 per cent or less) increase slab thickness by 25mm

Alternative design for unreinforced concrete for use where construction traffic is likely to be heavy: see para. 51

Normal subgrades (CBR between 2 and 15 per cent.)

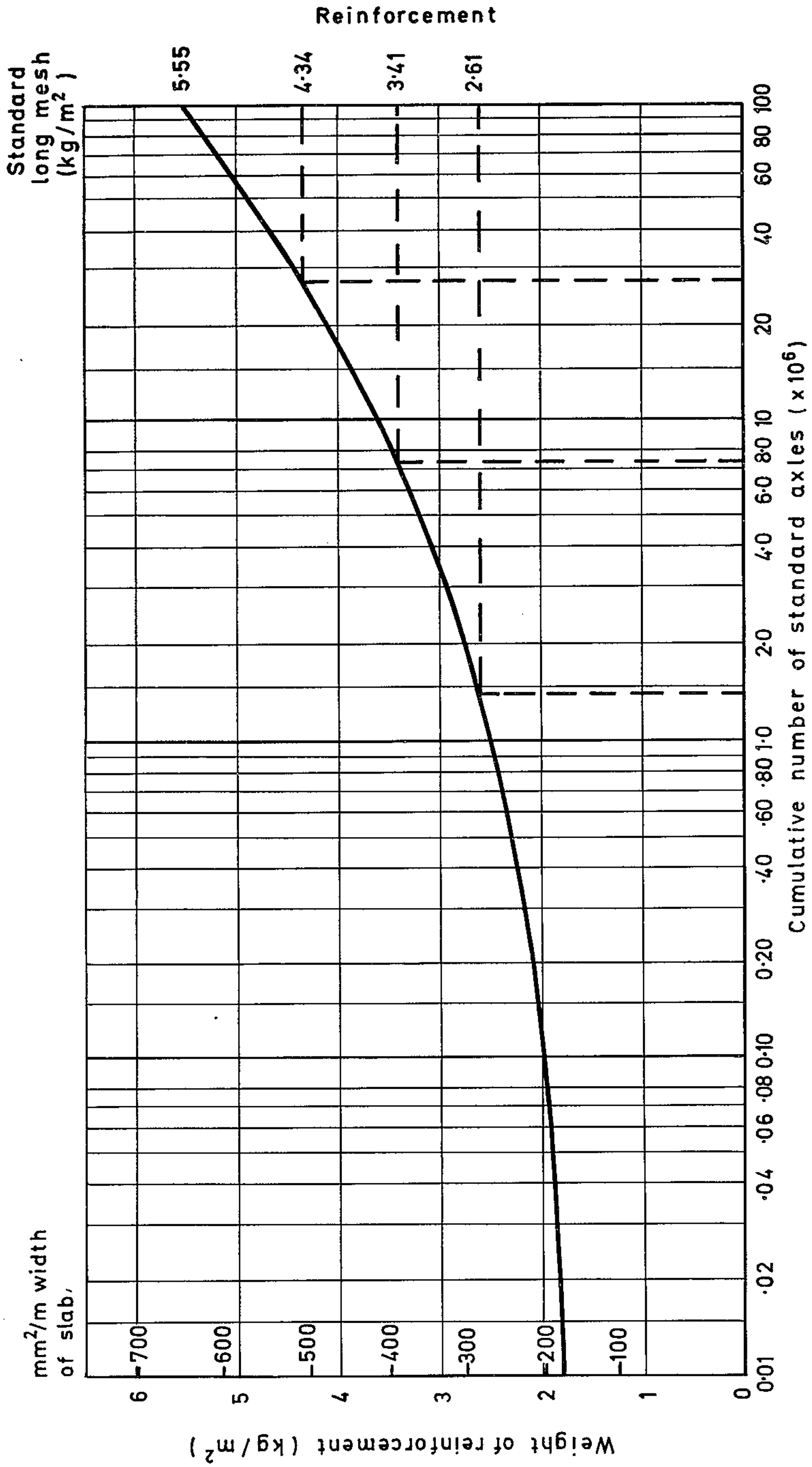


Figure 12 **Reinforcement: minimum weight for concrete slabs**

Figure 13 **Maximum spacing of joints for reinforced concrete slabs**

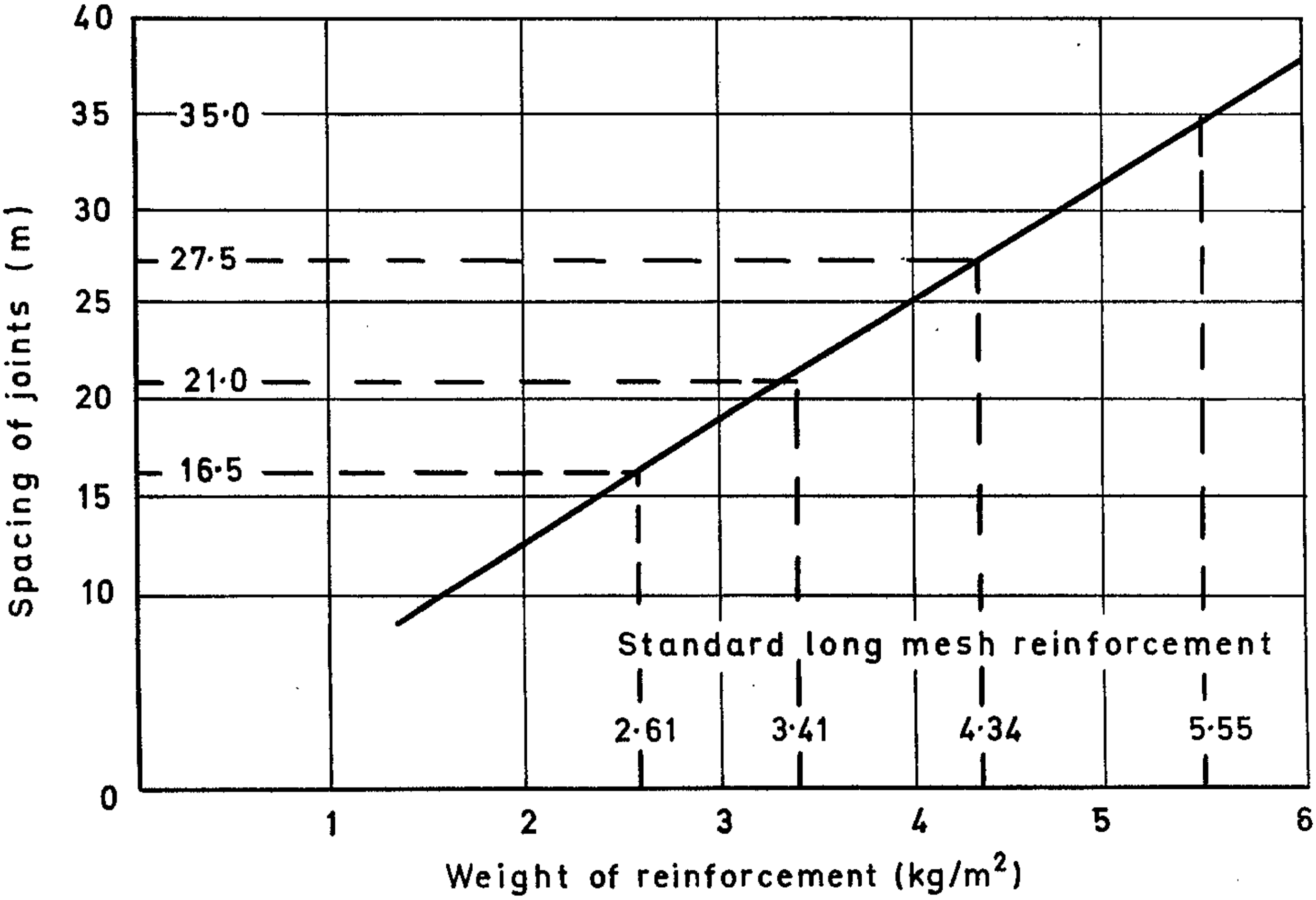


Figure 14 **Continuously reinforced concrete pavements with bituminous surfacings: details of design**

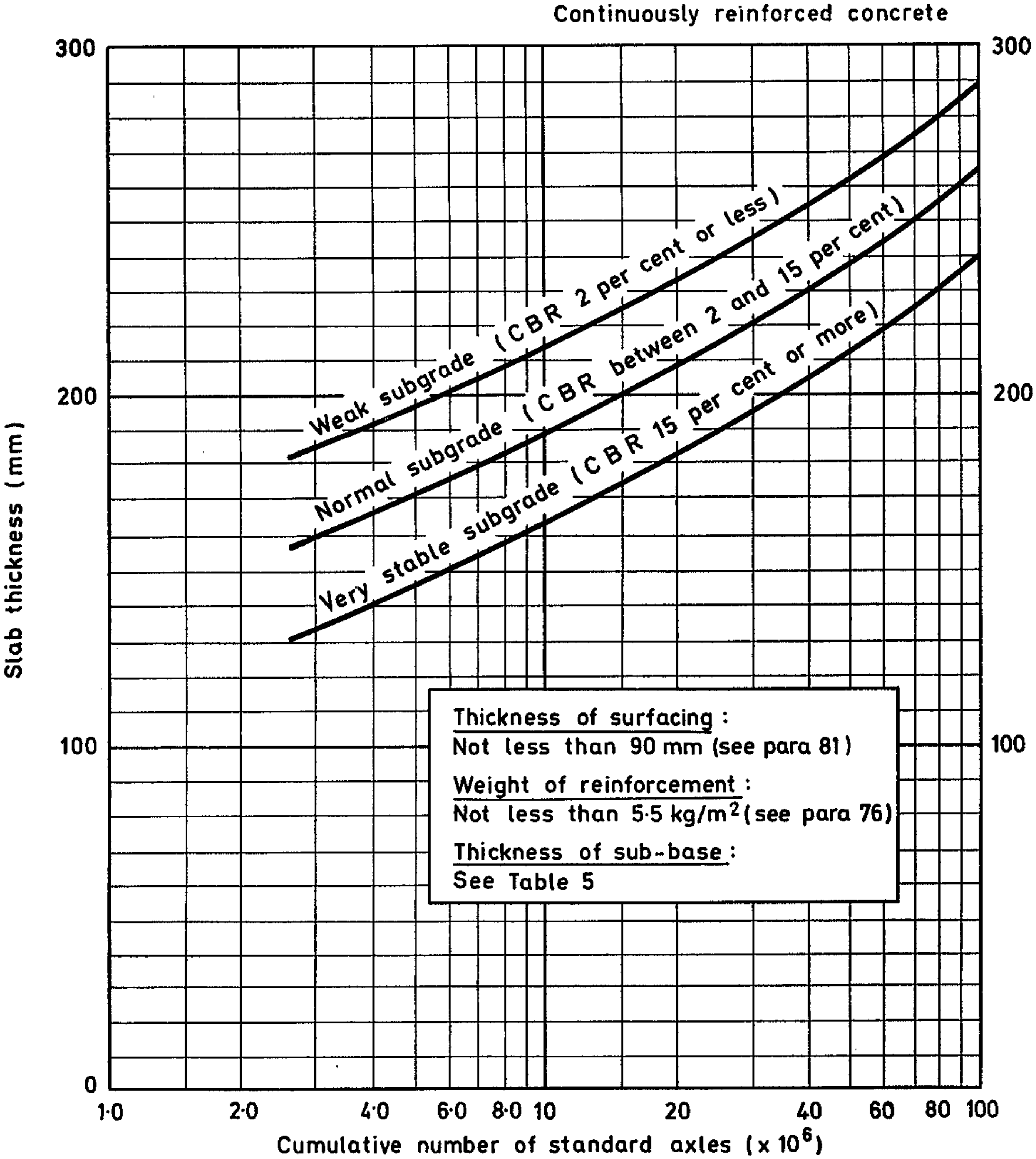


Figure 15 **Relation between cumulative number of commercial vehicles carried by lanes adjacent to the slow lane of each carriageway and design life – growth rate 4 per cent**

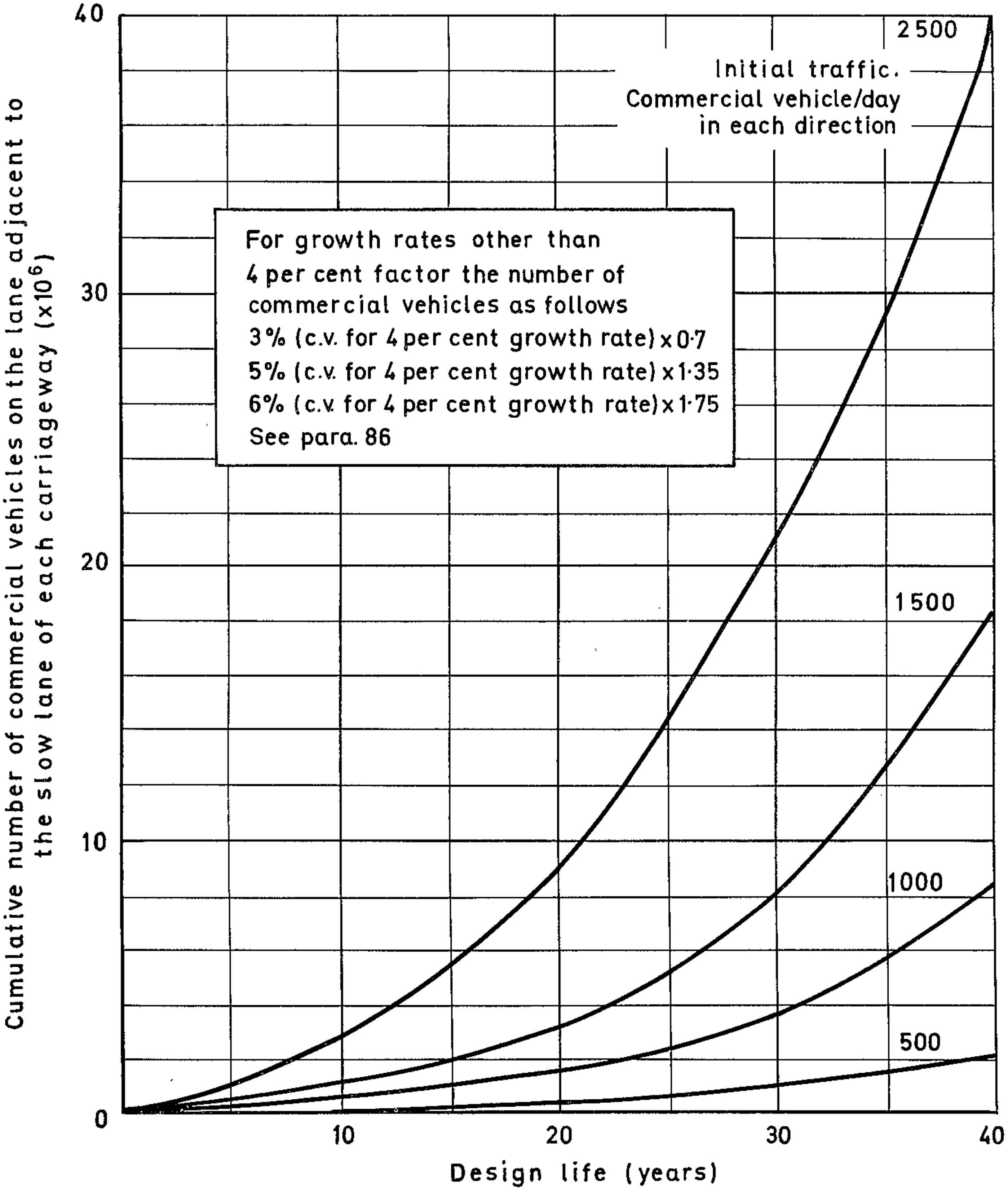
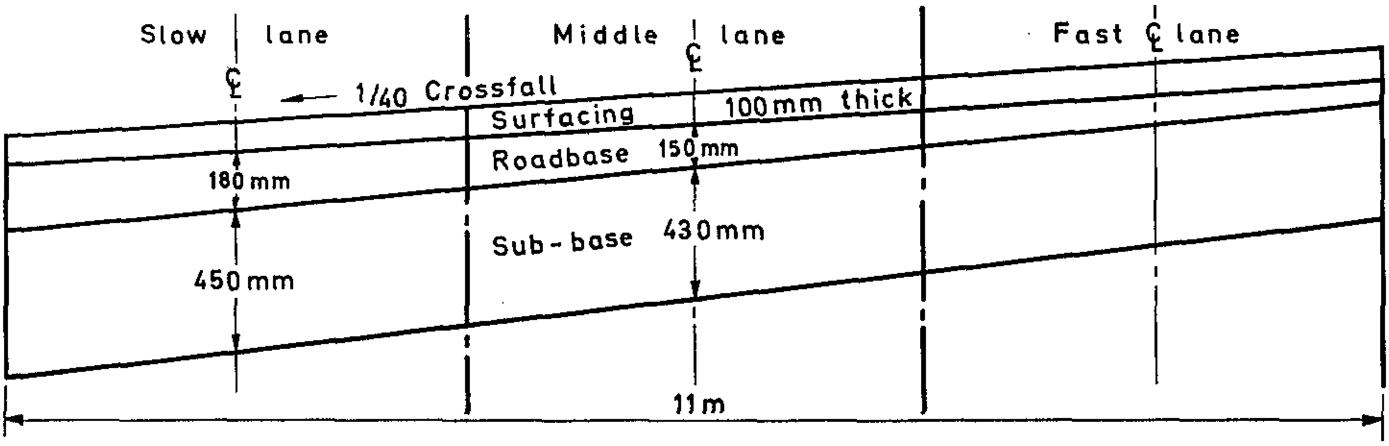
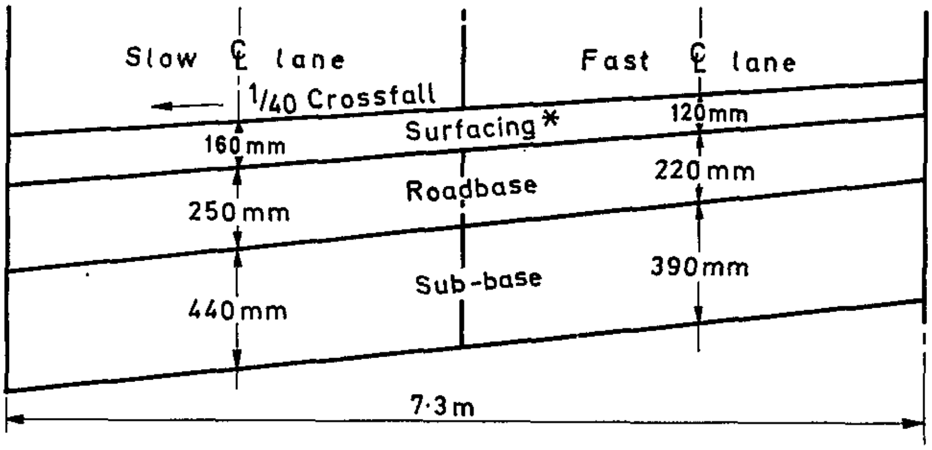


Figure 16 **Cross-sections for tapered construction – two-lane and three-lane dual carriageways**



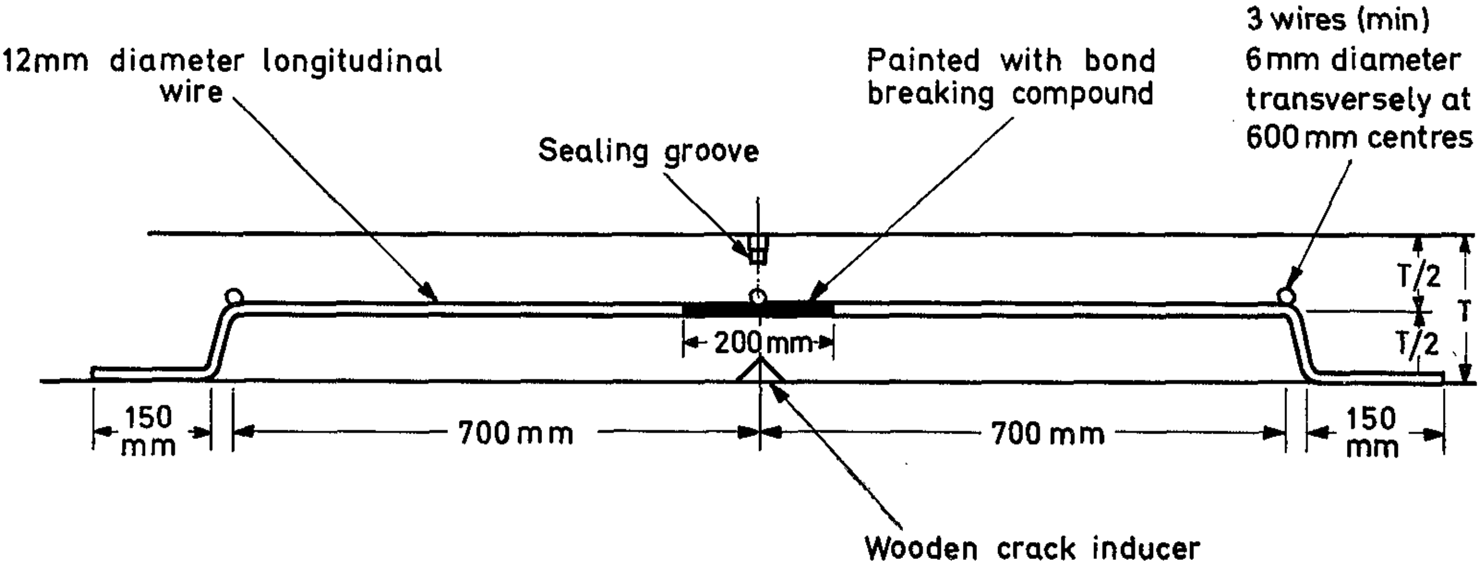
(a) Three-lane dual carriageway – rolled asphalt roadbase



* Surfacing includes dense bituminous roadbase material from composite roadbase

(b) Two-lane dual carriageway – wet-mix roadbase

Figure 17 **Details of a warping joint**



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