



**HIGHWAYS DEPARTMENT**

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**GUIDANCE NOTES**  
**ON**  
**PAVEMENT DESIGN FOR**  
**CARRIAGEWAY CONSTRUCTION**

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**Research & Development Division**

**RD/GN/042**  
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## **1. INTRODUCTION**

This set of guidance notes is intended to serve as a comprehensive reference for highway practitioners on the design of carriageway pavements in Hong Kong. It lays down the general principles and technical aspects to be considered while designing a pavement for new roads or widening/reconstruction of an existing road. The step-by-step design procedures and easy-to-use design charts provided in HyD Guidance Notes No. RD/GN/017 (which is hereby superseded) are updated to incorporate the latest research findings.

The recommendations given in this set of guidance notes are not intended to be exhaustive. As state-of-the-practice evolves and situation warrants, designers may wish to propose design modifications aiming at a more cost effective and durable pavement. Designs deviating from the provisions in this set of guidance notes shall be subject to prior agreement from the Highways Department (HyD) if the completed works will be handed over to the Department for maintenance.

This set of guidance notes should be read in conjunction with other relevant guidelines. Where reference documents are quoted in this set of guidance notes, practitioners should refer to their latest version for the relevant details.

## **2. BACKGROUND**

The pavement design guidance in Hong Kong has undergone certain stages of development over the past few decades. Back in the 1970s or earlier, 'Pavement Design' formed a chapter in the then Civil Engineering Manual, which was mostly based on the empirical approach laid down in the United Kingdom Road Note 29 of that time.

In view of the rapid progress of major road projects and the growing number of heavy goods vehicles in the territory, a revised version of road pavement design (known as Road Note 1) was promulgated in 1983. It was intended to design more robust and long lasting pavements to avoid any premature structural maintenance problems associated with under-design. A significant increase in the standard axle conversion factor for commercial vehicles and the design life were thus adopted in the traffic loading assessment. Some changes in the subbase and capping layers were also added to provide an improved foundation on weak subgrade.

In 1991, a consultancy study, called Road Testing Programme, was commissioned by HyD to develop a pavement design system using the mechanistic-empirical approach among other tasks. The mechanical properties of local asphaltic road base materials and pavement quality concrete were evaluated through laboratory tests. The “Guidance Notes on Pavement Design” (RD/GN/017) was subsequently issued in 1993 to incorporate those findings.

In the past few years, comprehensive assessments were carried out by HyD to study the overall conditions and maintenance needs of our road pavements. The results reflect that the general integrity of our pavement assets is in order. Regular maintenance and surface rehabilitation could be able to upkeep our pavement serviceability effectively without leading to the bottom-up structural deterioration as suggested by classical pavement fatigue theory. The Research and Development (R&D) Division of HyD has also completed a series of in-house pavement related research studies with the findings presented in the respective technical reports. Equipped with internal research findings, and with reference to overseas development on the concept of long-life pavements toward the end of the 20<sup>th</sup> century, the renewal strategy for the local pavement design guidance is formulated.

In tandem with the above, with a view to reaping the best benefit from academics, a collaboration research study with the Hong Kong Polytechnic University commenced in 2012 to review RD/GN/017. The major findings serve to reinforce the formulation of this updated pavement design guidance.

### **3. SELECTION OF PAVEMENT TYPE**

#### **3.1 General**

Many designers tend to adopt flexible pavement in new design, partly because of the perceived difficulty in repairs of rigid pavement in busy areas. However, this approach is not necessarily cost effective, in particular when the oil price is on a far steeper rising trend in comparison with cement. Depending on the category of roads, maintenance difficulty of rigid pavement may not be an insurmountable factor either, taking into account the state-of-the-art technology.

This section lays down the relative advantages and general selection criteria for

flexible and rigid pavements as well as some overriding factors to be noted. These recommendations are based on a recent in-house study of the selection between flexible and rigid pavements with particular focus on local conditions.

Application of blocked paving on carriageway shall only be considered under special circumstances, e.g. pedestrian areas or tourist attractions.

### **3.2 Relative Advantages of Rigid Pavement in comparison with Flexible Pavement**

Rigid pavement is relatively inert to chemical attack and far less susceptible to surface distresses in form of raveling and potholes than bituminous materials, thus can be considered in roads with frequent stationary usage by vehicles, including public transport interchanges, side streets with regular loading/unloading activities in industrial areas, lay-bys and car parks, to improve the overall durability and minimize the maintenance needs.

Elastic modulus and shear modulus of concrete are much greater than those of bituminous mixtures. Under heavy axle loading and braking forces, bituminous pavements are relatively vulnerable to certain defects, i.e. shoving, rutting, corrugation and slipping cracks. Rigid pavement would hence be far more durable over heavy braking zones, e.g. roads near/at container terminal, carriageway sections near road junctions, at the bottom of downhill ramps and at sharp bends.

Composite pavement, in the form of some 100mm thick bituminous layers on some 250mm thick continuously reinforced concrete pavement, has gradually received attention in developed countries in the domain of long life pavement design. The continuously reinforced concrete base can serve as a very strong structural layer to withstand vehicular loading without being prone to reflective cracking because of its jointless construction; whereas the uppermost bituminous surfacing can give better riding comfort and be easier to maintain. Though its applicability would be limited under typical city roads with various site constraints and unavoidable utility opening works over years, consideration on applying this particular pavement type may be worthwhile in planning for the sections of a new expressway or trunk road across vulnerable spots.

To reap the highest benefit from different pavement types under specific site conditions, an open and careful mind should be maintained to adopt the most suitable

pavement type for different sections and/or different lanes on the same road. As a general guide, factors elaborated in section 3.3 below may be considered as overriding, whereas section 3.4 prescribes general situations when rigid pavement may be preferred.

### **3.3 Overriding Factors**

Flexible pavement shall be adopted for road sections with designed vehicular speed at or exceeding 80km/h, or road sections subject to settlement; whereas rigid pavement is suitable for road sections on which frequent chemical attack, or frequent stop and go or sharp turning manoeuvring of heavy vehicles, is expected.

Other than the above specific situations, a road pavement may in general follow the type of the adjoining road subject to considerations described below.

### **3.4 Situations when Rigid Pavement may be Preferred**

For roads not predominated by the above overriding factors, construction of carriageway using rigid pavement should be considered by the pavement designers when all the following prerequisites are fulfilled:

- (a) The pavement is not anticipated to have traffic of vehicular speed exceeding 80km/h in normal circumstances;
- (b) Busy traffic for the road section is not expected. In case of necessity for lane closure for road maintenance or utility road opening works in future, the works will not be forced to be carried out outside normal working hours due to traffic considerations; and
- (c) There is no indication that frequency of utility road opening works along the carriageway section would be high.



## 4. FOUNDATION DESIGN

### 4.1 General

The condition of foundation support is a crucial factor to be considered while designing a pavement structure. Adequate investigation of the in-situ subgrade material should be conducted to assess its soil type, load bearing characteristics and moisture susceptibility.

### 4.2 In-situ Subgrade Properties

The design models for both flexible and rigid pavements, to be mentioned in Chapters 5 and 6, require the strength of each layer of the pavement to be expressed as the elastic modulus. For granular soils, California Bearing Ratio (CBR) test is the most common way for determining the elastic modulus of subgrade. Reference can be made to **HyD Guidance Notes No. RD/GN/012** or relevant testing standard. For cohesive soils or clays, plasticity index is always used for the determination of the elastic modulus of the subgrade. Some other non-destructive in-situ tests, for example Falling Weight Deflectometer and Dynamic Cone Penetrometer, can also be used to assess the elastic modulus of the subgrade.

#### (a) CBR Tests (Granular Soils)

There is no precise direct relationship between CBR values and the elastic modulus of the subgrade. However, for granular soils, the following relationship is found satisfactory:

$$E_s = 10 \times \text{CBR}$$

where  $E_s$  = elastic modulus of the subgrade [MPa]  
CBR = California Bearing Ratio [%]

#### (b) Plasticity Index (Cohesive Soils)

For cohesive soils, the CBR test is not very reliable. The following relationship allows the elastic modulus of the subgrade to be estimated from the plasticity index:

$$E_s = 70 - I_p$$

where  $E_s$  = elastic modulus of the subgrade [MPa]  
 $I_p$  = Plasticity Index [%]

In-situ testing on the subgrade should be carried out to assess the elastic modulus for pavement design as far as feasible. However, in cases when the soil parameters are not available, guidance on typical values of elastic modulus for a range of subgrades listed in **Table 1** can be referred to.

Table 1 – Typical Values of Elastic Modulus of Subgrades

Subgrade Type	Elastic Modulus, $E_s$ (MPa)
Cohesive soils (Clay)	$\leq 60$
Granular soils	50 – 300
Rock/weathered rock	$> 300$

When the condition of subgrade is very weak or abruptly varied, it would result in an engineering undesirable design option. The constructability is also questionable. Appropriate treatments as suggested in the following sub-section should be considered, whereas removal of weak in-situ material below the formation level may be the last resort.

### 4.3 Subgrade Treatment

For subgrade of elastic modulus below 50MPa, strengthening measures are required in order to provide a strong and uniform support for the pavement and to allow road construction vehicles to pass over the subgrade without damaging the layer. This can be achieved by providing a thick layer of sub-base on the subgrade but it may be more economical to provide a capping layer of selected materials. The provision of a capping layer over a weak subgrade avoids the necessity of an extraordinarily thick sub-base, and provides an adequate working platform for sub-base compaction as well as reduces the risk of damage to the subgrade during construction. The CBR value of the capping layer shall be of at least 15%.

The recommended thicknesses of the capping layer for various CBR values of subgrade for flexible and rigid pavements are shown in **Table 2**.

The capping layer can be specified as granular fill material in accordance with Section 6 of the General Specification for Civil Engineering Works.

#### 4.4 Sub-base

The sub-base forms the upper layer of the pavement foundation and provides a regulated working platform on which to transport, place and compact the bound layers of the pavement. Within a flexible pavement structure, the sub-base is also treated as a structural layer to spread the loading from the surface down to the subgrade.

Sub-base shall be specified as granular material in accordance with Section 9 of the General Specification for Civil Engineering Works. Lean concrete is generally not recommended for sub-base application. For flexible pavements, localised shrinkage cracks developed in the lean concrete sub-base would likely propagate upwards through the bituminous surfacing causing reflective cracking at the pavement surface, which reduces the service life of pavement. For rigid pavements, the high rigidity and flexural strength of concrete itself contribute to most of the load bearing function, resulting in very small deflections and pressures induced by vehicular loading on the sub-layers. The purpose of sub-base on rigid pavements is primarily for controlling pumping, which can be achieved by using granular materials.

The thickness of the sub-base layer is determined primarily from the strength of the subgrade, i.e. the CBR value. The recommended thicknesses and type of sub-base for flexible and rigid pavements are shown in **Table 2**.

Table 2 – Capping Layer and Sub-base Recommendations  
for Flexible and Rigid Pavements

Subgrade Modulus of Elasticity [MPa]	Subgrade CBR Value [%]	Subgrade Plasticity Index ( $I_p$ ) [%]	Minimum Thickness [mm]	
			Capping Layer	Granular Sub-base
< 20	-	> 50	600	150
20 – < 50	-	> 20 – 50	350	150
50 – < 150	5 – < 15	≤ 20	-	225
≥ 150	≥ 15	-	-	150

Note

1. For weak subgrades (< 50 MPa), an overlaying capping layer of min. CBR value of 15% is required.
2. For abnormally weak subgrade (< 20 MPa), geotextiles may be used to separate the soil and the capping layer in order to reduce deformations under construction traffic.

## 5. DESIGN OF FLEXIBLE PAVEMENT

### 5.1 Pavement Model

Flexible pavement structure is assumed to behave elastically under the dynamic loads exerted by vehicular traffic. Linear elastic theory for layered system is adopted to calculate the stress/strain distribution within a pavement structure in response to traffic load.

Although a flexible pavement structure is typically constructed in several layers, it is modelled as a three-layered system for design purposes as presented in **Figure 1**. All the bituminous layers, including wearing course, base course and roadbase, are combined into one layer. The materials are assumed as homogeneous and isotropic and are characterized by the modulus of elasticity ( $E$ ) and Poisson's Ratio ( $\nu$ ). A constant value of 0.35 is assumed for the Poisson's ratios of all the layers.

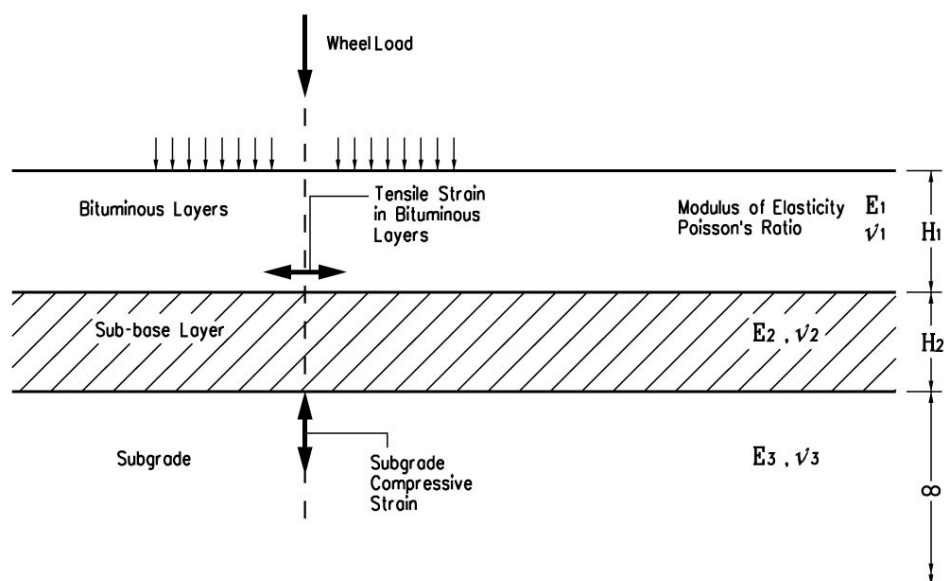


Figure 1 – Three-layered flexible pavement model

### 5.2 Design Criteria

Two classical failure modes are considered in designing flexible pavements, i.e. fatigue cracking and permanent deformation.

Fatigue cracking is defined as the phenomenon of fracture under repeated or

fluctuating stress having a maximum value generally less than the tensile strength of the materials. Under traffic loading, flexible pavement structure experiences continuous flexing. Provided that the bituminous layers are fully bonded, the initiation of fatigue cracks would be governed by the horizontal tensile strain at the bottom of the bituminous road base.

Permanent deformation refers to the pavement material under the wheel path continually consolidating and settling under repeated traffic loading to form a groove or rut. Bituminous materials with continuously graded aggregates or large proportion of coarse aggregate content and good volumetric composition are likely to be able to resist the permanent deformation. Strong foundation support also improves the resistance to rutting. Such deformations primarily depend on the vertical compressive strain at the surface of subgrade.

It should be noted that when the thickness of bituminous layers increases, the chance of occurrence of the above mentioned failure modes reduces. Up to certain thickness, a pavement structure would behave as 'long-life'. Overseas experiences and studies draw a threshold at the condition when the critical horizontal tensile strain at the bottom of bituminous road base is less than 70 microns. Under such condition, the pavement deterioration would mostly be initiated from the surface rather than following the classical bottom-up fatigue failure mechanism. The surface distresses can then be rectified by timely rehabilitation to stop them from propagating downwards in order to effectively preserve the overall integrity of the structure.

### **5.3 Design Life**

To achieve a design of low life-cycle cost and in respect of the high social cost for full depth reconstruction, a design life of 40 years is generally recommended for flexible pavements. Within this life span, it is expected that no structural maintenance is required under normal circumstances and the service life of the pavement structure can be sustained by minor repairs coupled with resurfacing at appropriate intervals. Due to the low tensile strain to be incurred at bottom of the road base, if sufficient thickness is designed, it is anticipated that the service life can be further extended by suitable surface rehabilitation measures upon 'expiry' of the original 'design life'.

### **5.4 Traffic Load**

The design traffic load shall be determined by considering the factors mentioned

below. The combined damaging effect of vehicular traffic is collectively expressed as a cumulative number of equivalent standard axles with a 80kN single axle dual-wheel configuration with tyre pressure of 0.577 MPa (**Figure 2** refers).

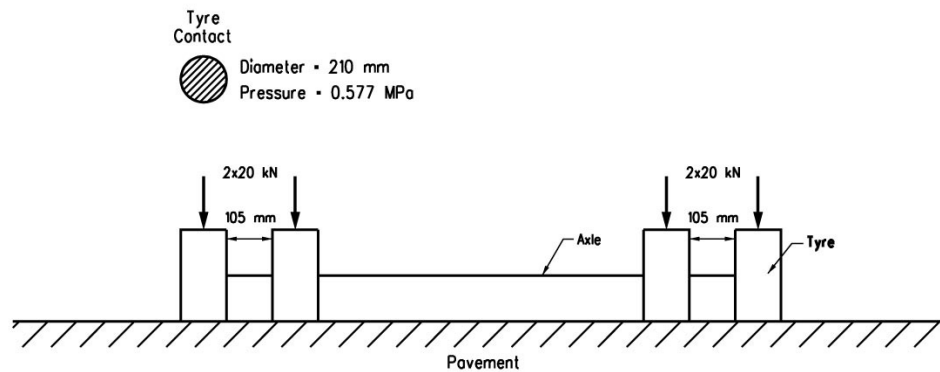


Figure 2 – Configuration of an Equivalent Standard Axle

(a) *Commercial Vehicle Forecast*

The definition of commercial vehicle follows the one given in the Annual Traffic Census published by Transport Department, which includes medium / heavy goods vehicle and bus. Other light vehicles, for examples, motor cycle, private car and public light bus, are normally ignored as their induced structural damage on pavements is minimal. The annual flow of commercial vehicles at the time of road opening is obtained by multiplying the daily flow by 365 days/year. The cumulative number of commercial vehicles using a road during its design life is obtained by summing up the annual traffic of each year taking into consideration the predicted growth rate. The forecast can be done with reference to on-site traffic count data, traffic census or other available traffic studies or planning data.

(b) *Commercial Vehicle Damage Factors*

Commercial vehicle damage factors (CVDF) are the numbers of equivalent standard axles per class of commercial vehicles, taking into account the cumulative damage effects arising from different axle loads of vehicles. It depends on the number and weight of all the axles per vehicle class. With reference to sampled axle load surveys in the nineties and a review of sampled load spectrum data collected in 2012 from the weigh-in-motion sensors at

Lantau Fixed Crossing, Ting Kau Bridge and Shenzhen Western Corridor, a set of CVDF are recommended in **Table 3**. For pavement design purpose, a weighted mean of these factors shall be determined in order to obtain an overall CVDF to represent the structural damaging effect resulted from the cumulative number of commercial vehicles during the design life.

Table 3 – Commercial Vehicle Damage Factors

Class of commercial vehicle	CVDF (No. of standard axles / vehicle)
Medium & heavy goods vehicle	3.3
Bus	2.9

For situations when the composition of commercial vehicle classes is not readily predictable, it is recommended an average of the two factors given in **Table 3** be adopted in the design.

(c) *Distribution of Commercial Vehicles among Lanes*

Following the general driving behavior and legal restrictions, it can be assumed that a higher percentage of commercial vehicles along a multi-lane carriageway would travel along the nearside slow lane. Depending on the actual traffic volume and the proportion of commercial vehicles, a different split among lanes will occur at different road sections.

For design purposes, it is generally recommended, based on statistical data collected from typical local highway sections, that 65% of the commercial vehicles be assumed travelling in the slow lane. However, in no case should the estimated number of commercial vehicles using the slow lane exceed the traffic capacity of that lane. The estimated number of vehicles should therefore be checked to ensure that it does not exceed the capacity of the lane. Guidance on this can be obtained from the **Transport Planning and Design Manual (TPDM), Volume 2**.

For new roads or full reconstruction projects, all traffic lanes, including the hard shoulders, shall be designed and constructed to cater for the most heavily trafficked scenario, normally along the slow lane. The same consideration shall be given to projects under which only partial reconstruction of existing carriageway pavement is involved.

(d) *Lateral Wander*

The cumulative number of commercial vehicles using a pavement during its design life shall be corrected for the positive effect of lateral wander of vehicles within or across the traffic lanes. The lateral wander correction factors ( $W_f$ ) for flexible pavements are shown in **Table 4**. For an intermediate lane width, an appropriate factor may be derived by interpolation.

Table 4 - Lateral Wander Correction Factors

Lane Width (m)	Lateral Wander Correction Factor ( $W_f$ )
3.00	1.00
3.37	0.96
3.50	0.95
3.65	0.92
3.75	0.90

(e) *Step-by-step Calculation of Design Traffic Load*

The anticipated number of equivalent standard axles for structural design is determined according to the following steps.

**Step 1** - Determine the design initial average daily traffic flow ( $AADT_d$ )

$$AADT_d = AADT_b \times (1 + r)^m \quad [vehicles/day]$$

where  $AADT_b$  = base annual average daily traffic flow [vehicle/day]  
 $r$  = annual traffic growth rate [in decimal], from past traffic figures or from Transport Department (typical values ranging from 0.01 to 0.04)  
 $m$  = length of period between timing in  $AADT_b$  and the time that the road is expected to open to traffic [years]

**Step 2** - Determine the initial daily number of commercial vehicles ( $C_e$ ) in the slow lane in one direction

$$C_e = P_s \times P_v \times D_s \times AADT_d \quad [no. of commercial veh./day]$$

where  $P_s$  = percentage of commercial vehicles using slow lane  
= 1 where there is only 1 traffic lane in the direction concerned; or  
0.65 for other cases  
 $P_v$  = percentage of commercial vehicles in  $AADT_b$ ,



$D_s$  = directional split factor  
 = 1 for 1-way roads; or  
 0.55 for 2-way roads (assuming 55%/45% split)

**Step 3** - Determine the cumulative number of commercial vehicles ( $C_v$ ) using the slow lane during the design life

$$C_v = 365 \times C_e \times \frac{(1+r)^n - 1}{r} \quad [\text{no. of commercial vehicles}]$$

where  $r$  = annual traffic growth rate [in decimal]  
 $n$  = design life [years]

**Step 4** - Check that  $C_v$  does not exceed the design flow capacity of the traffic lane ( $C_d$ )

$$C_v \leq C_d = 365 \times n \times \frac{D_f}{K_p} \quad [\text{no. of vehicles}]$$

where  $n$  = design life [years]  
 $D_f$  = maximum design flow [vehicles per hour per lane] recommended in the TPDM, Volume 2 Chapter 2  
 $K_p$  = peak hour factor recommended in **Table 5**

Table 5 – Peak Hour Factor

Road Type	Peak Hour Factor ( $K_p$ )
Expressways Urban Trunk Roads Primary Distributor	0.05
Rural Trunk Roads Rural Roads	0.065
District Distributors Local Distributors	0.08

**Step 5** - Determine the design traffic load ( $C_n$ ) for flexible pavements

$$C_n = C_v \times \overline{\text{CVDF}} \times W_f \quad [\text{million standard axles}]$$

where  $\overline{\text{CVDF}}$  = weighted mean of commercial vehicle damage factors [standard axle / commercial vehicle] recommended in **Table 3**  
 $W_f$  = lateral wander correction factor recommended in **Table 4**

## 5.5 Properties of Bituminous Materials

The mechanical properties of bituminous materials vary with temperature, loading time and mixture types. In the analytical design of flexible pavements, elastic modulus of bituminous materials is adopted as one of the input parameters.

The design charts provided in this guidance were developed based on the typical bituminous road base material, with their properties determined under the 'Road Testing Programme' consultancy study completed in early nineties.

## 5.6 Structural Design

Design charts 1 to 6 are for structural design of flexible pavements in Hong Kong. These charts were established taking into account the local environmental conditions, the properties of conventional pavement materials and the two critical failure modes. The required total thickness of the bituminous materials can be obtained by checking against the design traffic load estimated in section 5.4 and modulus of elasticity of subgrade ranging from 50 MPa to 300 MPa. Taking account of the concept of 'long-life pavement', a lower and upper bound for pavement thickness as given in **Table 6** should be observed.

Table 6 – Lower and Upper Bounds for Total Thickness of Bituminous Pavement

Road Type	Lower Bound (mm)	Upper Bound (mm)
Expressway Trunk Road Primary Distributor	350	500
Others	280 *	500

\* lower bound can be reduced to 205mm for roads with AADT <400 (section 5.9 refers)

The lower bound is set to indicate the bituminous pavement thickness below which a pavement structure would unlikely manifest long-life behavior due to the substantial tensile strain that would be incurred at the bottom of the road base under wheel load. For expressway, trunk road and primary distributor, a relatively conservative minimum thickness is specified to cater for the higher consequence of insufficient structural design.

On the other hand, when the total thickness of a bituminous pavement has reached a

certain substantial value, the tensile strain at the bottom of the road base that might be induced by the axle load of a commercial vehicle would be low enough to avoid the chance of fatigue failure no matter how large is the traffic volume. As such, an upper bound is set for the bituminous pavement thickness so that a pavement structure would not be over-designed.

When the modulus of elasticity of the subgrade is less than 50 MPa but where capping and sub-base layers are provided in accordance with **Table 2**, Design Chart No. 1 (50 MPa) can be used. For intermediate values of subgrade strength, the appropriate thickness can be obtained by interpolation.

Owing to the large amount of air voids in the porous friction course material, it is not classified as a structural layer and the thickness of the porous friction course would not contribute to the required thickness of the bituminous layers.

### **5.7 Composition and Thickness of Bituminous Layers**

The composition of bituminous layers within a flexible pavement structure and their recommended thicknesses shall be as indicated in **HyD Standard Drawing No. H1101**.

### **5.8 Selection of Surfacing Material**

The role of surfacing layer in a bituminous pavement structure is to resist repeated traffic load and environmental weathering. Moreover, it should provide necessary skid resistance and riding comfort to serve the vehicular traffic.

Three main types of bituminous surfacing are locally available, namely ordinary wearing course material, stone mastic asphalt material and porous friction course material. Their mechanical properties, and durability characteristics in terms of rutting and cracking, vary depending on the aggregate grading and bitumen type and content. These factors have to be carefully considered in the selection process to suit the anticipated usage.

Ordinary wearing course material is technically referred as dense graded or continuously graded bituminous mixture. It is suitable for general carriageway as an impermeable and smooth surfacing layer.

Stone mastic asphalt material (SMA), known as a gap graded material, consists of high coarse aggregate content, high binder and filler content with added fibre to stop bitumen drain down and give additional binder stability. The strong rut resistance provided by its stone-on-stone skeleton is particularly suitable for road sections with heavy axle loads and frequent stop-and-go traffic. Detailed guidelines on its application are given in **HyD Guidance Notes No. RD/GN/038**.

Porous friction course has a similar coarse aggregate skeleton as SMA but a smaller amount of sand/filler mortar. This sort of open-graded bituminous mixture, with a higher percentage of interconnecting void content, becomes permeable and can facilitate effective surface drainage. Its high porosity results in a lower tensile strength and fatigue resistance, making friction course being considered as a non-structural layer from a conservative design perspective. Detailed guidelines on its application are given in **HyD Guidance Notes No. RD/GN/032**.

For particular location with skidding concern but not practically feasible to be tackled by large-scale modification of the road geometry, provision of anti-skid surface dressing would be an alternative technical solution. Reference shall be made to **HyD Guidance Notes No. RD/GN/038** for the design consideration.

## **5.9 Design for Low-volume Roads**

For certain local, rural or feeder roads (AADT < 400), it can be envisaged that those carriageway sections are mostly trafficked by light vehicles with a rare number of heavy vehicles. They can be referred as low-volume roads.

The minimum thicknesses specified in the design charts may cause these low-volume roads to be resulted in a highly conservative structural design. Under such circumstances, the designer is suggested to determine the bituminous layer thickness directly from the design curves based on the design traffic load whereas the minimum road base thickness could be reduced to 100 mm. With this reduced thickness, tensile strain under incidental heavy axle loads could exceed the threshold, and may lead to random fatigue cracks upon expiry of the original 'design life' of the pavement. However, due to the low traffic volume, the service life could be extended by cold milling and resurfacing of the wearing course and base course only, albeit at relatively frequent yet tolerable intervals.

## 6. DESIGN OF RIGID PAVEMENT

### 6.1 Pavement Model

Rigid pavement consists of concrete slab and sub-base on top of the subgrade. Modulus of elasticity of concrete slab is normally much greater than that of granular sub-base and in-situ subgrade, resulting in most of the load bearing capacity of a pavement being attributed to the strength of the concrete slab. Stresses in rigid pavements are induced by traffic loads and cyclic temperature changes of concrete slab, with their magnitudes also depending on the in-situ subgrade support.

For design purposes, longitudinally and transversely jointed concrete slabs are modelled as a system of hinged connected slabs on an elastic foundation that comprises the subgrade and the overlying sub-base. The elastic foundation is simulated by a series of springs of constant stiffness, which are characterised by the modulus of subgrade reaction. Only one slab is considered in the structural design, and the adjacent slabs are modelled to allow a reduction of the imposed loads along the edge of this slab. The pavement model is shown in **Figure 3** for calculating the traffic-induced stresses across the slab.

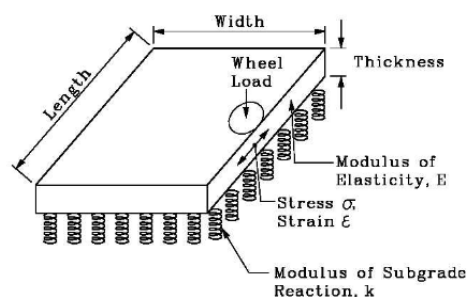


Figure 3 – Model of Concrete Pavement

### 6.2 Design Criteria

#### (a) *Traffic-induced Stresses*

Bending of a concrete slab due to traffic loading will generate both compressive and tensile stresses within the slab. In general, the thickness of the slab will be governed by maximum tensile stress within the slab.

The critical loading point is along the slab edges in both longitudinal and

transverse directions. The stresses can be reduced by providing an effective mechanism, such as dowels or tie bars, to transfer part of the loads to the adjacent slabs.

*(b) Thermal Stresses*

Thermal stresses consist of two components, i.e. uniform longitudinal stresses over the cross-section of the concrete due to seasonal temperature variations and warping stresses due to daily temperature gradient change.

Longitudinal tensile stresses develop when the concrete cools and its contraction is prevented by the friction between the concrete slab and sub-base. Stresses are greatest in the centre of the slab and increase with longer slabs.

Warping stresses are the result of an uneven temperature distribution over the cross-section of the slab. If the top surface of a slab is warmer than the bottom surface, the slab becomes convex but its own gravity opposes such stress-free distortion, resulting in compressive stresses at the top and tensile stresses at the bottom of the slab.

*(c) Fatigue Failure*

Concrete is subject to the effects of fatigue which are induced by repeated traffic loading and temperature variations. The fatigue behaviour of concrete depends on the stress ratio which is the quotient of tensile stress and modulus of rupture of concrete. Individual damage of axle loads is accumulated using Miner's rule to assess the pavement failure.

### **6.3 Design Life**

To achieve a design of low life cycle cost and in respect of the high social cost for full depth reconstruction, the design life for rigid pavement is generally recommended as 40 years. Within this life span, it is expected that no extensive rehabilitation is required under normal circumstances and the service life of the pavement structure can be sustained by minor repairs. It is anticipated that the service life can be further extended upon 'expiry' of the original 'design life' by timely maintenance and localized bay replacement.

## 6.4 Traffic Load

The non-linear load transfer mechanism and the non-linear fatigue damage occurring in rigid pavements hinder the practicality of expressing traffic load in term of equivalent standard axles. The damage induced by different loading conditions and magnitudes are separately analysed by referring to a standard axle load spectrum which was derived from sampled axle load data to represent the local traffic characteristic. Previous axle weighing studies also gave an average number of axles per commercial vehicle as the basis for rigid pavement design. Designers shall consider the following factors while determining the design traffic load.

### (a) *Commercial Vehicle Forecast*

The procedures and considerations in forecasting the number of commercial vehicles for rigid pavement design are identical to those described in section 5.4(a) for flexible pavements.

### (b) *Average Number of Axles per Commercial Vehicle*

The predicted number of commercial vehicles is converted to number of axles by multiplying the number of commercial vehicles by the average number of axles ( $A_a$ ) per commercial vehicle which is recommended to be 3.1.

### (c) *Distribution of Commercial Vehicles among Lanes*

The procedures and considerations in forecasting the distribution of commercial vehicles among traffic lanes for rigid pavement design are identical to those described in section 5.4(c) for flexible pavements.

### (d) *Step-by-step Calculation of Design Traffic Load*

The steps for determining the anticipated number of axles for structural design of rigid pavement is identical to those for flexible pavement, except step 5 below.

**Step 5** - Determine the design traffic load ( $C_a$ ) for rigid pavements

$$C_a = A_a \times C_v \quad [\text{axles}]$$

where  $A_a$  = average number of axles per commercial vehicle

$$= \frac{[axle/vehicle]}{3.1}$$

## 6.5 Modulus of Subgrade Reaction

In the design analysis, it is assumed that the reactive pressure provided by the sub-base/subgrade material under a concrete slab is proportional to the deformation below the point of loading. The ratio is known as the ‘modulus of subgrade reaction’ or ‘k-value’.

By using **Table 7**, the k-value can be estimated from the elastic modulus of the subgrade, the thickness and modulus of elasticity of the sub-base, in which the elastic modulus of subgrade should be assessed on-site wherever possible.

Table 7 – Modulus of Subgrade Reaction (k) [in N/mm<sup>3</sup> or MPa/mm]

E <sub>subgrade</sub> (MPa)	Thickness of Granular Sub-base		
	150 mm	225 mm	300 mm
50	0.045	0.050	0.060
100	0.060	0.075	0.090
150	0.075	0.090	0.110
200	0.085	0.105	0.125
250	0.095	0.115	0.140
300	0.100	0.125	0.150

## 6.6 Properties of Concrete

Grade 40/20 concrete is specified for the construction of rigid pavements in Hong Kong. The following material properties are adopted in the pavement analysis for developing Design Charts 7 to 9.

Modulus of rupture	= 5.25 MPa
Modulus of elasticity	= 33,000 MPa
Poisson’s ratio	= 0.15
Temperature differential	= 2.7°C within typical slab thickness

## 6.7 Structural Design

For structural design of rigid pavements, Design Charts 7 to 9 shall be followed for slab length of 4m, 5m, and greater than or equal to 6m respectively.



## 6.8 Types of Concrete Pavements

Descriptions and characteristics of two common types of concrete pavements, namely unreinforced concrete pavement (also known as jointed plain concrete pavement) and jointed reinforced concrete pavement, are mentioned below. Construction details will be elaborated in later paragraphs. Further guidance on slab length and reinforcement detail is given on **HyD Standard Drawing No. H1102**.

When a particular situation is considered necessary, special design by using continuously reinforced concrete pavement may be explored.

### *(a) Unreinforced concrete pavement*

For slab length not more than 5m, thermal and shrinkage effects within the concrete slabs can be released at saw-cut contraction joints timely provided in the construction, so that transverse cracking could be developed at the designed locations with no particular need of crack control using mesh reinforcement. To ensure proper load transfer across the contraction joints, dowel bars have to be installed between them.

The smaller size of unreinforced concrete slabs is, by nature, more suitable for areas with higher density of metal works since the provision of box-outs is by all means required. Plain slab design allows the possibility for continuous pouring and potential cost saving on steel reinforcements and joint sealants though some extra saw-cutting and dowel installation works are needed.

### *(b) Jointed reinforced concrete pavement*

For slab length longer than 5m, mesh reinforcement shall be provided in accordance with the requirements given in **Table 8** to assist the distribution of traffic and thermal stresses.

With fewer transverse joints, jointed reinforced concrete pavement behaves more robust and is less likely to have slab rocking/faulting or full panel cracked through kind of defects developed. In the nineties, there were concerns that wider sealing groove might be more vulnerable to joint defects, such as loss of sealant and joint spalling. With a well-established inspection and maintenance

system in place and the improvement of sealant's technology over decades, such problem is believed not prevailing. Over locations with rare chance of utility excavation, like roadside bus bays or public transport interchange, the use of reinforced concrete slabs may bring in longer term durability benefit.

Table 8 – Minimum Reinforcement Requirements

Concrete Slab Thickness (mm)	Mesh kg/m <sup>2</sup>	Cross Section	
		Main mm <sup>2</sup> /m	Cross mm <sup>2</sup> /m
< 170	2.61	283	49
170 – 210	3.41	385	49
210 – 235	4.34	503	49
235 – 300	5.55	636	70.8

## 6.9 Panelling Design and Joint Construction

Proper panelling design and construction of joints in concrete slabs are vital to the sustainability and serviceability of rigid pavements. Unlike the continuous nature of flexible pavement, sufficient discontinuities are purposely provided between the concrete slabs to allow thermal movements. The physical width of concrete slab is normally designed to match the traffic lane width, and separated by longitudinal joints to prevent longitudinal cracking. Along the traffic directions, suitable spacing and types of transverse joints shall be provided for thermal contraction and expansion and for isolation among the roads at their intersections. Guidance on the paneling design and joint construction details for concrete slabs is given in **HyD Guidance Notes No. RD/GN/020** and **HyD Standard Drawing Nos. H1105 to H1109**.

## 6.10 Anti-skid Treatment

For particular location with skidding concern but not practically feasible to be tackled by large-scale modification of the road geometry, provision of anti-skid treatment would be an alternative technical solution. Reference shall be made to **HyD Guidance Notes No. RD/GN/037**.

## **7. BLOCKED PAVING**

Run-in and carriageway pavements are directly exposed to vehicular traffic. When blocked paving is designed to be laid over such areas, special attention should be paid in both material selection and construction detailing to ensure its durability and serviceability. Designers shall refer to Section 11 of the General Specification for Civil Engineering Works for the technical requirements and relevant HyD standard drawings for the typical construction details.

Geogrid may be considered to be laid underneath block paved roads sustaining heavy traffic to improve the resistance to permanent settlement. Such provision may, however, impose certain practical difficulties in future road opening and associated reinstatement works. A balanced consideration shall be taken depending on individual site condition.

For any special design involving non-standard details of paving units to be handed over to HyD for maintenance, Regional Offices and Landscape Unit of the Department shall be consulted in advance.

## **8 PRINCIPLES FOR MISCELLANEOUS DETAILING**

This section highlights the principles and reference for certain detailing to be noted while performing a comprehensive pavement design.

### **8.1 Transition between Flexible and Rigid Pavements**

Different pavement structural layers will undergo certain extents of deformation under traffic loading. Although the deformation is mostly transient and recoverable, long-term permanent deformation still exists and largely depends on the material strength and stiffness. The differential settlement accumulated at the transition between flexible and rigid pavements would not only affect the riding comfort but also lead to rapid deterioration. Provision of transition slab is required to minimize such effect. Typical construction detail is given in **HyD Standard Drawing No. H1110**.

Notwithstanding the above, provision of transition slab between a flexible carriageway and the adjacent concrete bus bay may not be feasible. Regular monitoring and timely maintenance would be required to upkeep the serviceability and durability.

### **8.2 Transition between At-grade Pavement and Bridge Abutment**

To deal with the situation as mentioned in section 8.1 above, similar detailing should also be provided at the transition between at-grade pavement and bridge abutment to ensure the carriageway pavement functions properly and durably.

### **8.3 Details of Edge Abutting Drainage Facilities or other Utility Pit Covers**

For construction details to cope with roadside gullies, reference shall be made to **HyD Standard Drawing Nos. H3107 and H3108** for rigid and flexible pavements respectively.

For construction details of concrete road slab and joint arrangement around manhole or utility pit, reference shall be made to **HyD Standard Drawing Nos. H1111 and H1112**. When situation warrants, pit covers should be aligned orthogonally to the carriageway. Consideration should be given to place all kinds of frames and covers, except gully grating, near the lane centre as far as practicable.

## 8.4 Pavement Drainage

Proper drainage shall be provided to effectively discharge the surface runoff from carriageways to ensure the road safety during wet seasons and to minimize the pavement deterioration accelerated by ponding. The design shall follow the recommendations given in **HyD Guidance Notes No. RD/GN/035**.

While friction course is designed as the uppermost pavement layer, the installation details of gully grating shall be designed in accordance with **HyD Standard Drawing No. H3106**.

It is also of vital importance to provide efficient drainage to remove water from the subgrade, capping and sub-base layers both during construction and in-service stages. Where necessary, appropriate sub-soil drainage system should be provided to prevent the water table from rising to within 600 mm of the formation level. Guidance on the design of sub-soil drainage for pavement is given in **HyD Road Note 8**.

## 8.5 Edge Constraint and Kerb Necessity

Edge constraints, including kerbs, central dividers, railing, barrier fences, etc, are measures to properly delineate roadside features from the adjoining carriageway and to safeguard the road users. Typical cross sections and associated details vary among different road categories and roadside features. Reference shall be made to relevant sections of the **TPDM** and **HyD Standard Drawings**.

Concrete flat channel is an outdated provision between kerbs and flexible carriageway, which should be avoided in view of the consideration mentioned in **HyD Guidance Notes No. RD/GN/035**.

## 9. WORKED EXAMPLES

### Example 1 – New construction of Road A

#### Basic information

Road A is a local distributor of dual-two carriageways planned to serve as the main access to a dumping site with high percentage of medium to heavy commercial vehicles.

Proposed cross section: 2.5m f/p – 6.75m c/w – 2.2m c/r – 6.75m c/w – 2.5m f/p

$E_{\text{subgrade}} = 100 \text{ MPa}$

#### Selection of pavement type

Considering the heavy traffic loading due to frequent usage by medium to heavy commercial vehicles, rigid pavement is proposed to achieve a more wear-resistant and durable structure.

#### Calculation of design traffic load

##### Design parameters

Design initial average daily traffic flow,  $AADT_d = 20,000$  (sum of both bounds)

Annual growth rate,  $r = 2\%$

Design life,  $n = 40$

% of commercial vehicles,  $P_v = 70\%$

##### Initial daily number of commercial vehicles in the slow lane in one direction

$C_e = 0.65 \times 0.7 \times 0.55 \times 20,000 = 5,005$  commercial vehicles / day

##### Cumulative number of commercial vehicles using the slow lane during the design life

$C_v = 365 \times 5,005 \times [(1 + 0.02)^{40} - 1] / 0.02 = 110$  million commercial vehicles

##### Check against the design flow capacity of the traffic lane

$C_d = 365 \times 40 \times (2600 \times 0.9 / 2 / 0.08)$   
 $= 213$  million commercial vehicles  $> C_v$  (O.K.)

##### Design traffic load

$C_a = 3.1 \times 110 = 341$  million axles

## **Structural Design**

From Table 7,

k-value = 0.075 for  $E_{\text{subgrade}} = 100 \text{ MPa}$  & 225mm thick granular subbase

From Design Chart 8,

Concrete slab thickness = 260 mm (for slab length = 5 m)

Hence, the following pavement design is adopted.

Unreinforced concrete slab    260 mm (slab length of 5 m)

Granular subbase                    225 mm

## Example 2 – Reconstruction of Road B

### Basic information

Road B is a district distributor of single 2-lane 2-way carriageways with bus lay-bys to serve residential areas with around 10% of commercial vehicles

Proposed cross section for main carriageway: 4m f/p – 10.3m c/w – 4m f/p

$E_{\text{subgrade}} = 100 \text{ MPa}$

### Selection of pavement type

- (i) Main carriageway: flexible
- (ii) Bus lay-bys: rigid

### Calculation of design traffic load

- (i) Main carriageway

#### Design parameters

Design initial average daily traffic flow,  $AADT_d = 8,000$

Annual growth rate,  $r = 3\%$

Design life,  $n = 40$

% of commercial vehicles,  $P_v = 10\%$ ,

of which 30% medium/heavy goods vehicles and 70% buses

#### Initial daily number of commercial vehicles in the slow lane in one direction

$$C_e = 1 \times 0.1 \times 0.55 \times 8,000 = 440 \text{ commercial vehicles / day}$$

#### Cumulative number of commercial vehicles using the slow lane during the design life

$$C_v = 365 \times 440 \times [(1 + 0.03)^{40} - 1] / 0.03 = 12.1 \text{ million commercial vehicles}$$

#### Check against the design flow capacity of the traffic lane

$$\begin{aligned} C_d &= 365 \times 40 \times (2200 / 2 / 0.08) \\ &= 200 \text{ million commercial vehicles} > C_v \quad (\text{O.K.}) \end{aligned}$$

#### Design traffic load

$$CVDF = 0.3 \times 3.3 + 0.7 \times 2.9 = 3.02$$

$$Wf = 0.90 \quad (\text{Table 4 for lane width } \geq 3.75)$$

$$C_v = 12.1 \times 3.02 \times 0.90 = 33 \text{ million standard axles}$$



(ii) Bus lay-bys

Design traffic load

Assume a maximum of 8 bus routes using the same bus lay-by with an average frequency at 10 minutes during the period from 0600 to 2400, there will be  $8 \times 6 \times 18 \times 365 \times 40 = 12.6 \times 10^6$  buses passing the lay-by within the design period of 40 years.

$$C_a = 3.1 \times 12.6 \times 10^6 = 39 \text{ million axles}$$

**Structural Design**

(i) Main carriageway

From Design Chart 2,

Bituminous layer thickness = 330 mm for 225 mm thick subbase

From Table 6 (for district distributor),

Lower bound thickness = 280 mm (therefore, adopt 330 mm)

(ii) Bus lay-bys

From Table 7,

k-value = 0.075 for  $E_{\text{subgrade}} = 100 \text{ MPa}$  & 225mm thick granular subbase

Slab length = 10 m

From Design Chart 9,

Concrete slab thickness = 224 mm

Hence, the following designs are adopted.

(i) Main carriageway

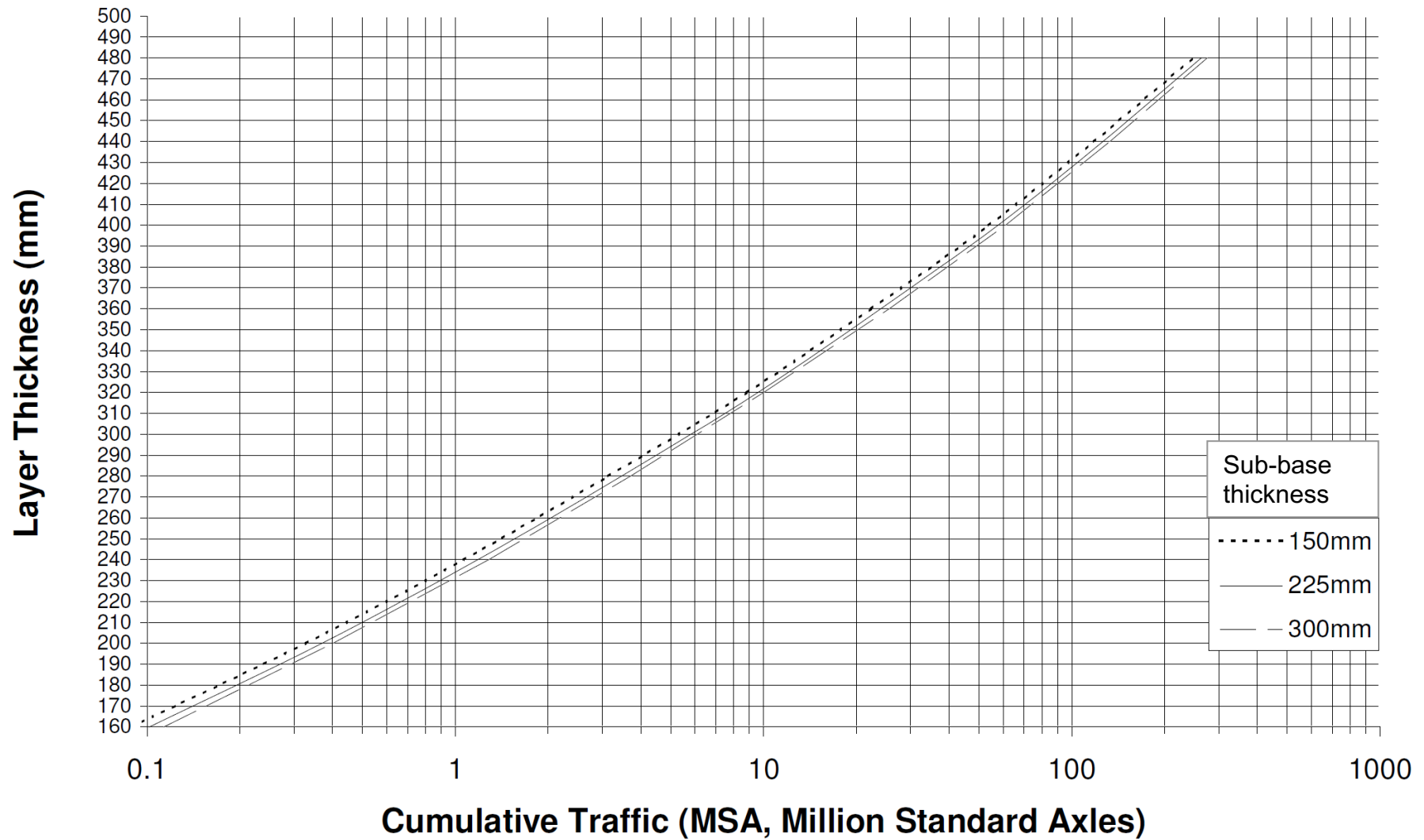
Wearing course material	40 mm
Base course material	65 mm
Road base material	225 mm
Granular subbase	225 mm

(ii) Bus lay-bys

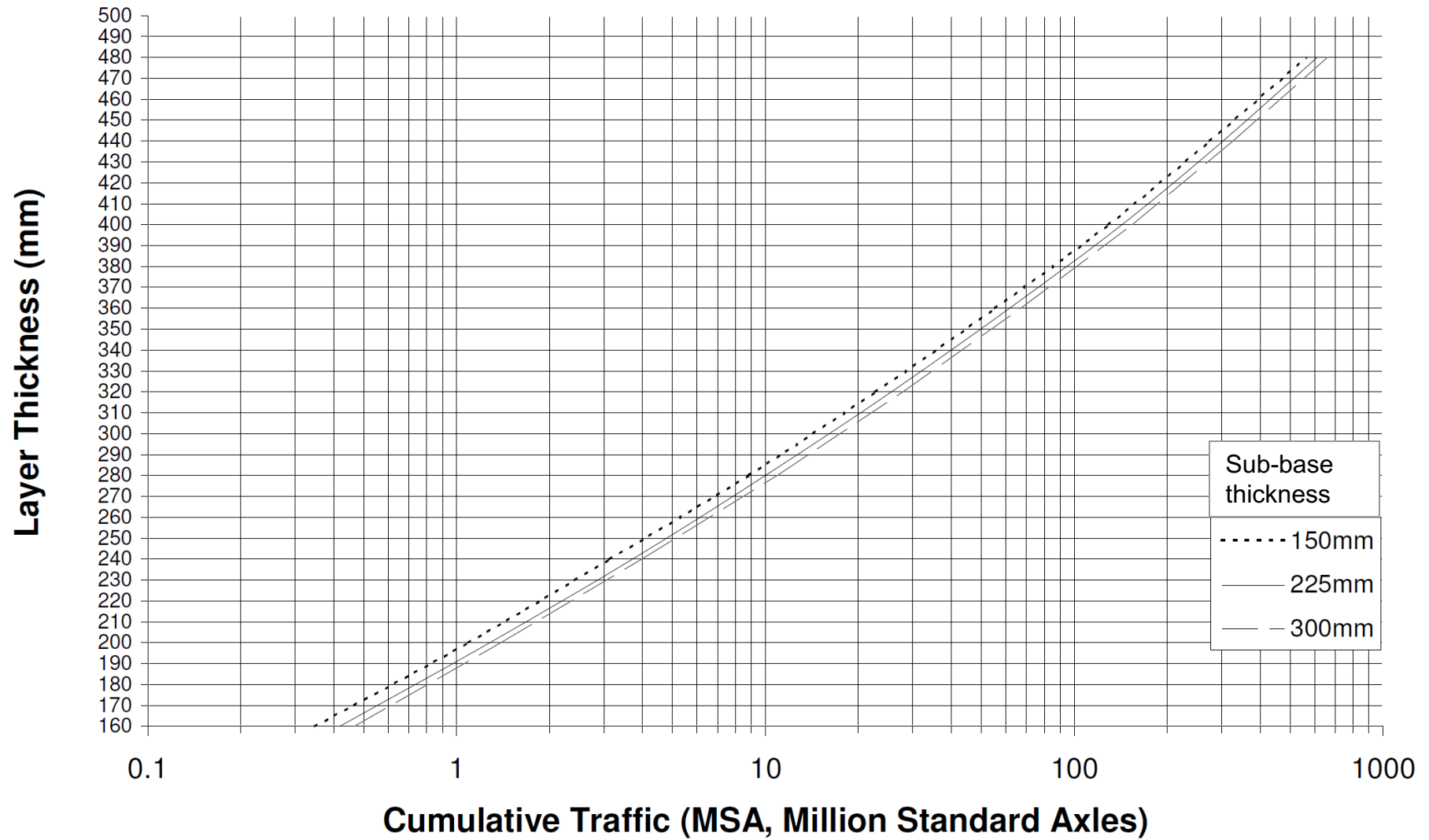
Reinforced concrete slab	230 mm (slab length of 10 m)
Minimum reinforcement	4.34 kg/m <sup>2</sup> (Table 8)
Granular subbase	225 mm

## **DESIGN CHARTS**

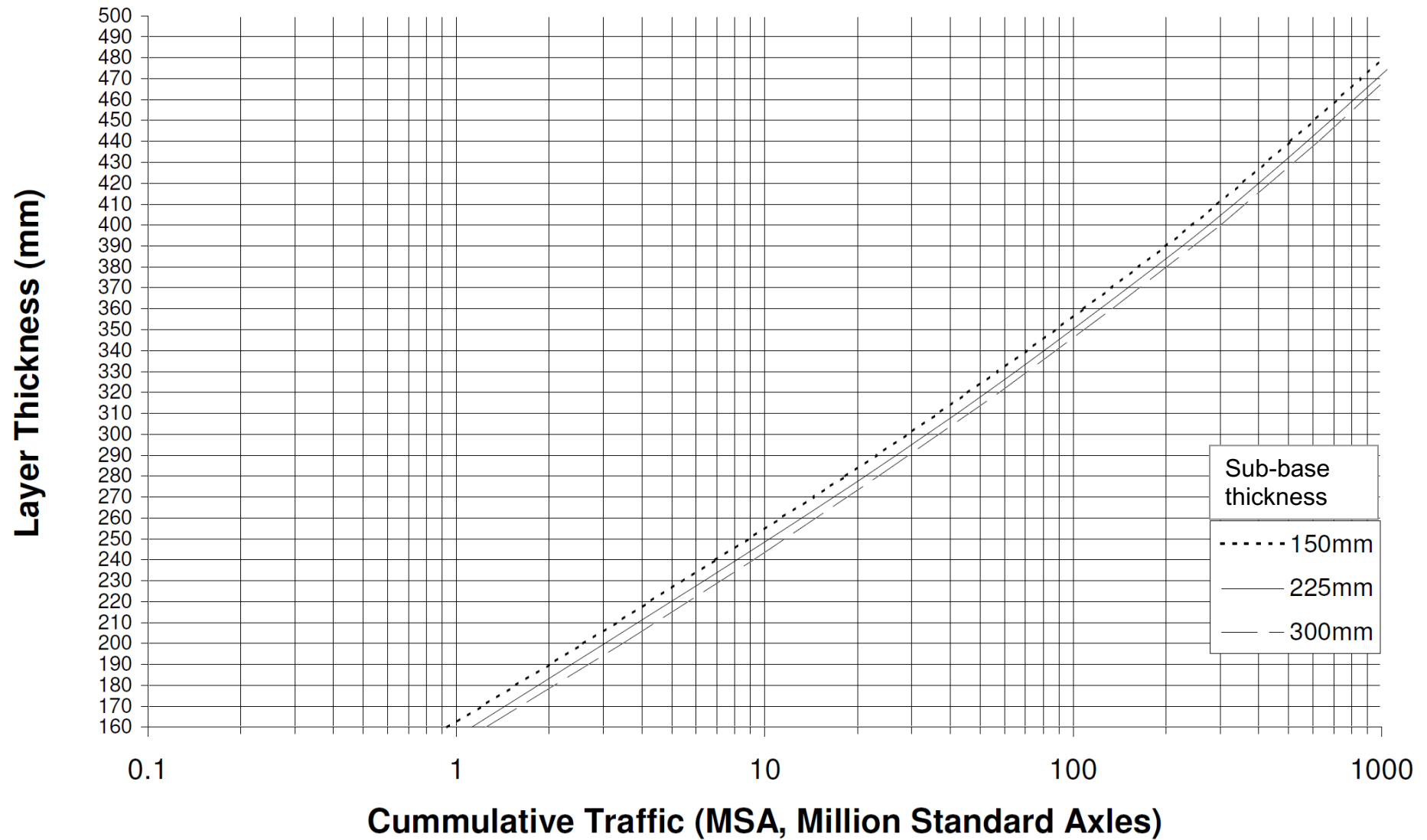
**Chart 1**  
**Bituminous Pavement ( $E_{\text{subgrade}} = 50\text{MPa}$ )**



**Chart 2**  
**Bituminous Pavement ( $E_{\text{subgrade}} = 100\text{MPa}$ )**

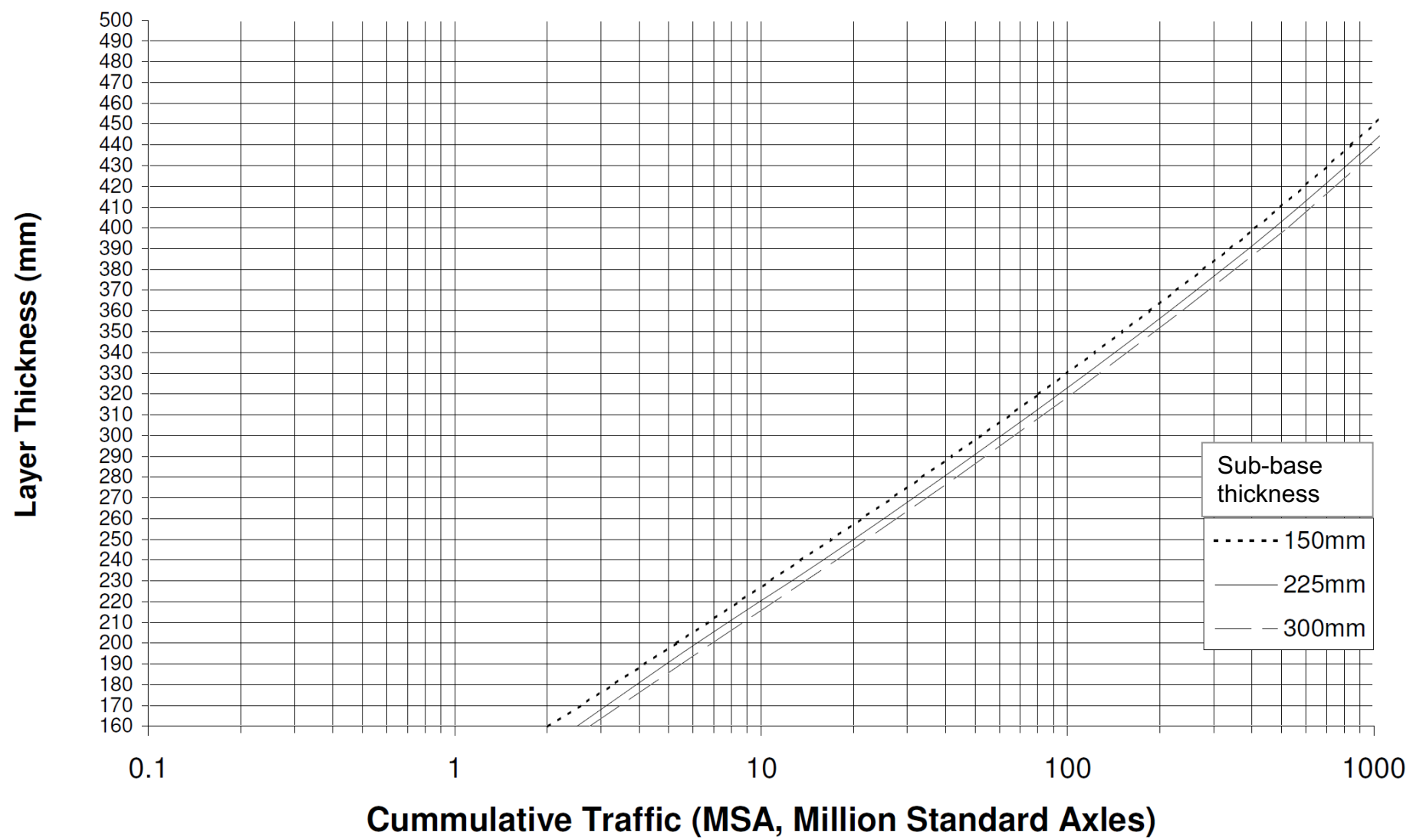


**Chart 3**  
**Bituminous Pavement ( $E_{\text{subgrade}} = 150\text{MPa}$ )**

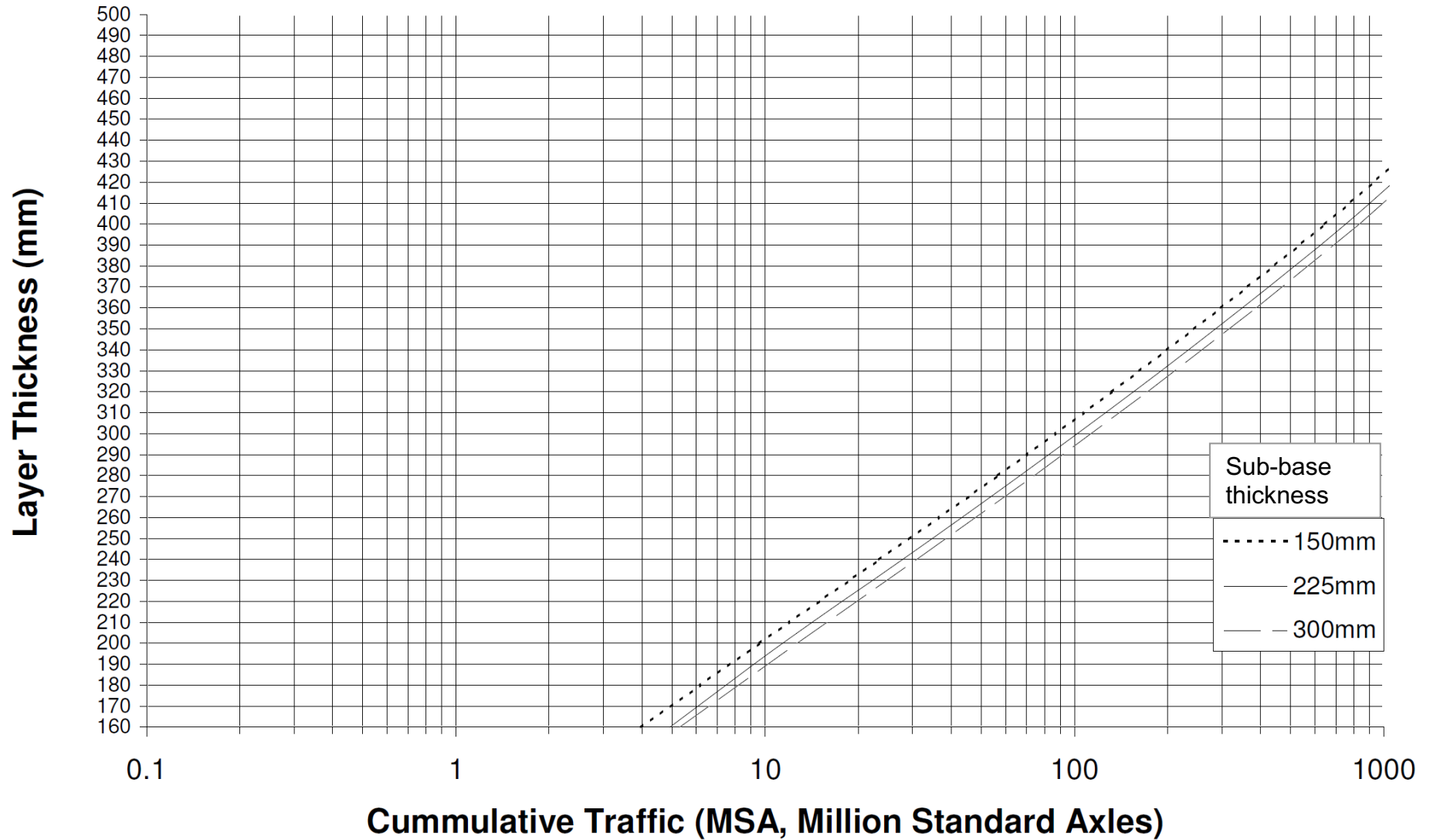


# Chart 4

## Bituminous Pavement ( $E_{\text{subgrade}} = 200\text{MPa}$ )



**Chart 5**  
**Bituminous Pavement ( $E_{\text{subgrade}} = 250\text{MPa}$ )**



**Chart 6**  
**Bituminous Pavement ( $E_{\text{subgrade}} = 300\text{MPa}$ )**

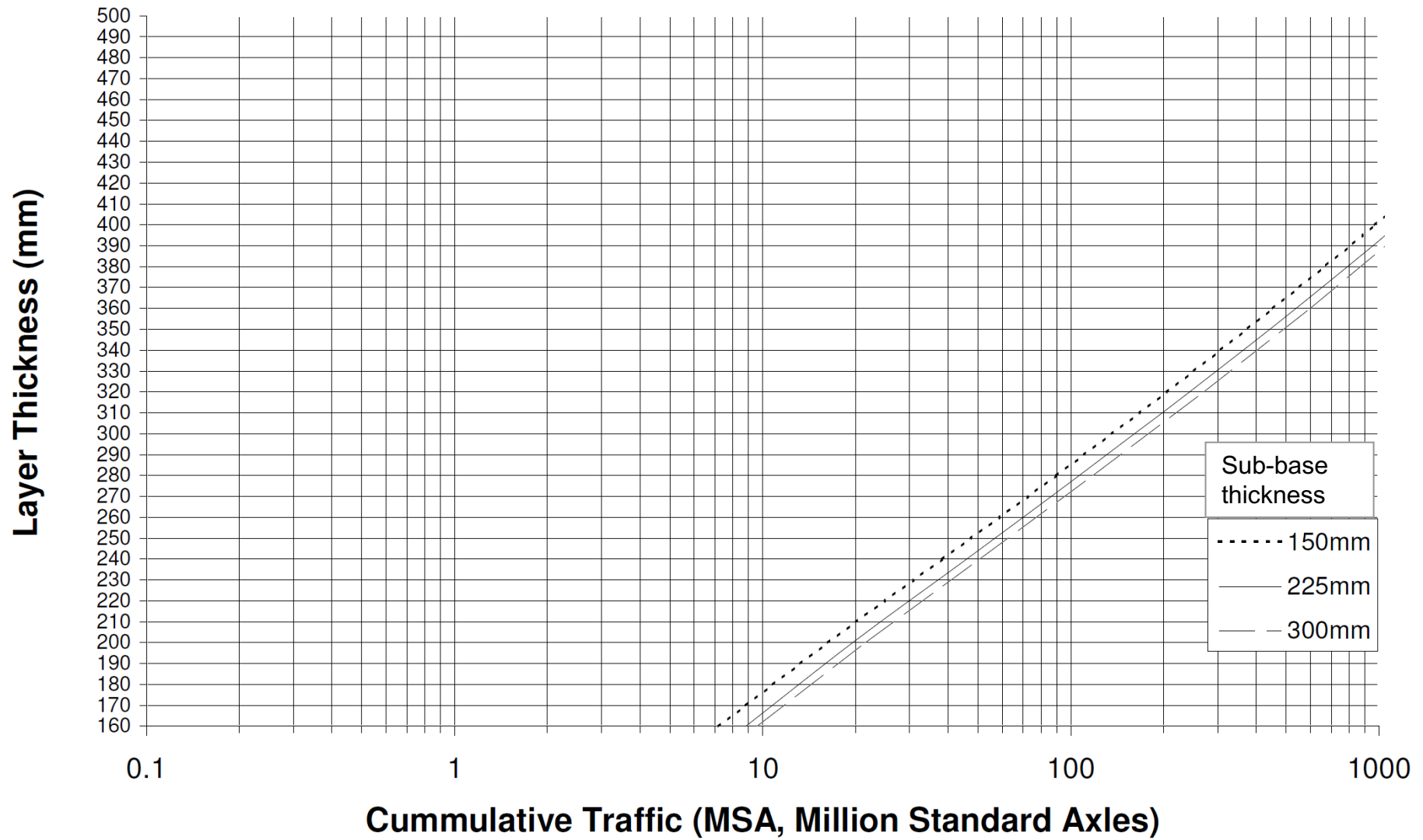




Chart 7  
Slab Length = 4m

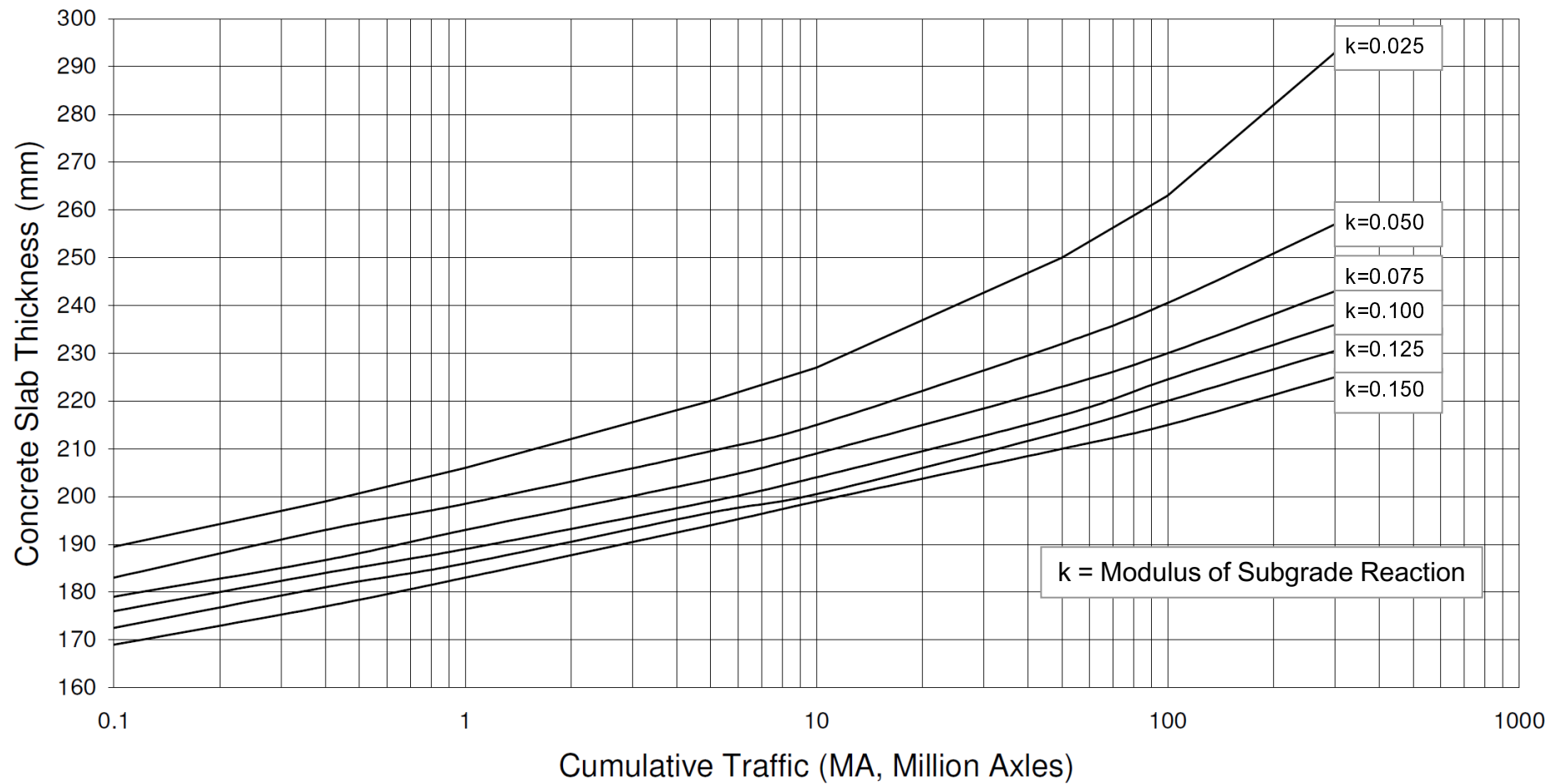


Chart 8  
Slab Length = 5m

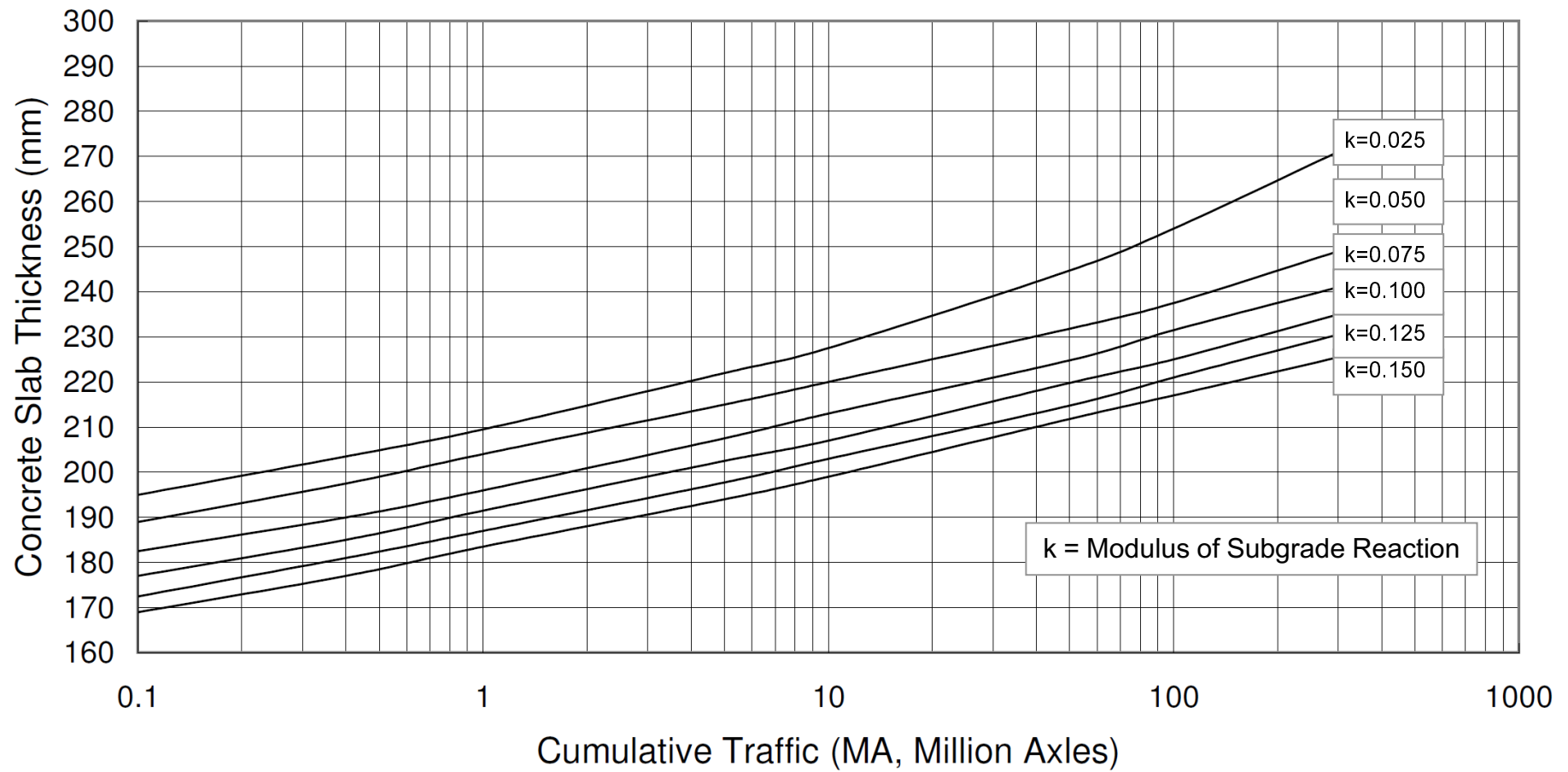


Chart 9  
Slab Length  $\geq 6\text{m}$

