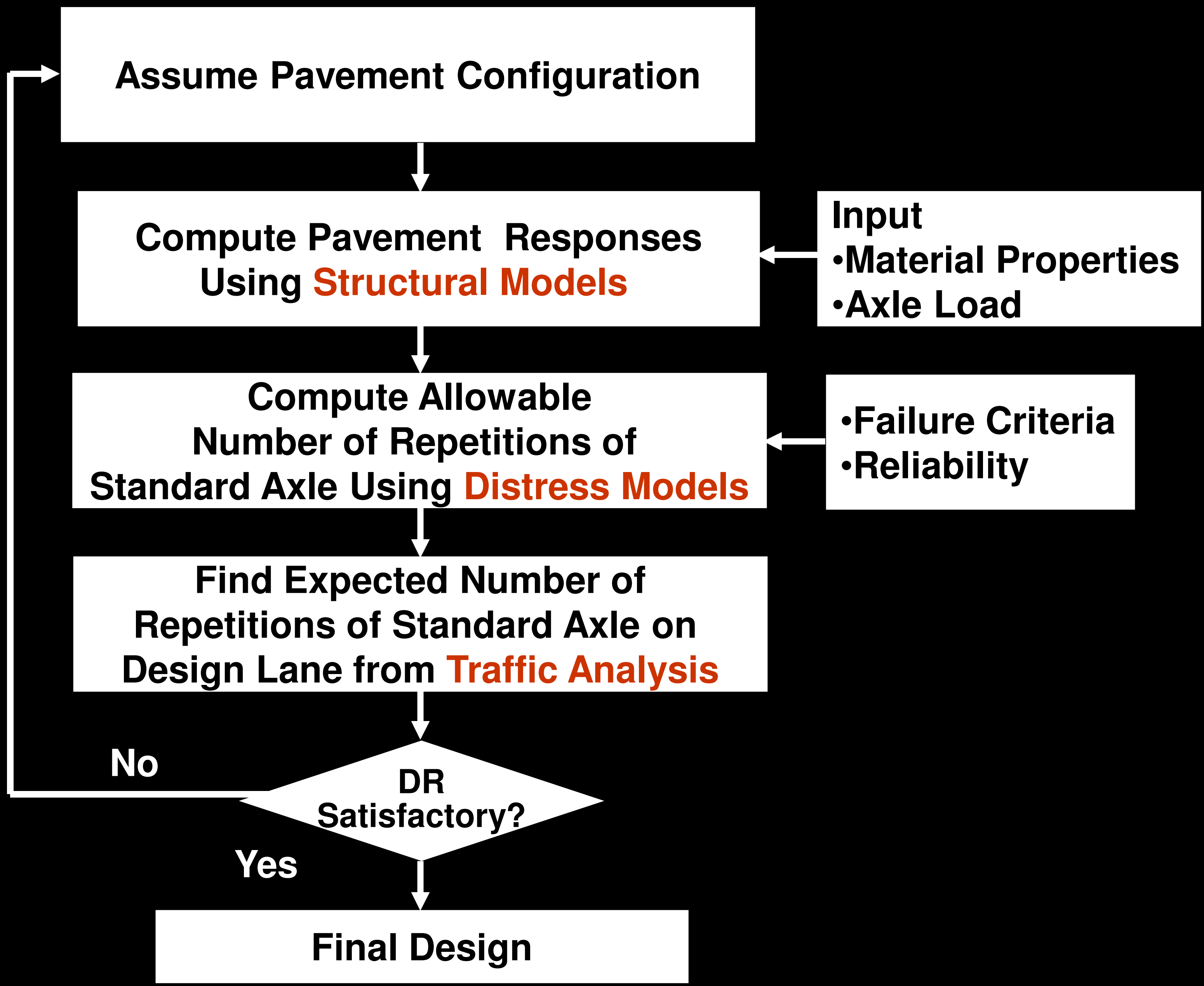
Flexible Pavement Design



Mechanistic Method of Pavement Design

Design Procedure of IRC

Design Approach and Criteria

- The following three types of pavement distress resulting from repeated application of traffic are considered:
  - (i) Horizontal tensile strain at the bottom of the bituminous layer
  - (ii) Vertical compressive strain at the top of the subgrade
  - (iii) Pavement deformation with in the bituminous layer
    - The deformation with in the bituminous layer is assumed to be controlled by meeting the mix design requirements

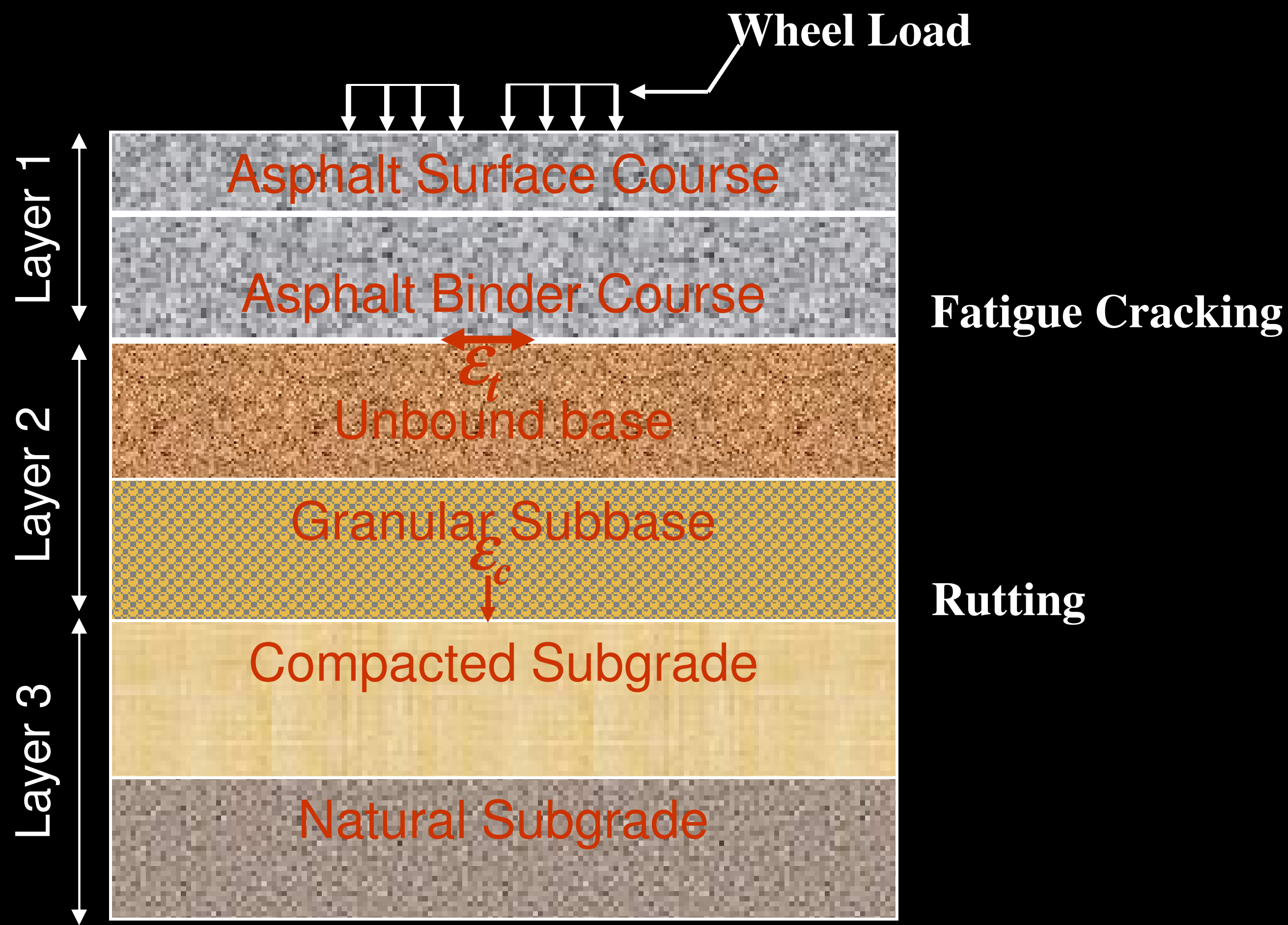
Failure Criteria

- Fatigue Cracking
  - Is due to the build up of tensile strain at the bottom of Asphaltic Concrete Layer
  - Pavement is considered failed if 20% of the surface has cracked
- Rutting Failure
  - Is due to the build up of excessive compressive strain at the top of subgrade layer
  - Pavement is considered failed if it exhibits a rut depth of 20 mm.

IRC Design Approach and Criteria

- The pavement has been modeled as a three layer structure and stresses and strains at critical locations have been computed using the linear elastic structural model FPAVE.

Fatigue Cracking and Rutting



Fatigue Cracking Model

$$N_f = k_3 \left[\frac{1}{\varepsilon_t}\right]^{k_1} \left[\frac{1}{E}\right]^{k_2}$$

N_f	=	No. of cumulative standard axles to produce 20% cracked surface area
ε_t	=	Tensile strain at the bottom of Bituminous Concrete layer
E	=	Elastic Modulus of Bituminous Surface (MPa)
k_1, k_2	=	Laboratory calibrated parameters
K_3	=	Transfer parameter

IRC Fatigue Cracking Model

Fatigue Cracking model

$$N_f = 2.21 \times 10^{-4} \left[\frac{1}{\varepsilon_t} \right]^{3.89} \left[\frac{1}{E} \right]^{0.854}$$

N_f	**=**	**No. of cumulative standard axles to produce 20% cracked surface area**
ε_t	**=**	**Tensile strain at the bottom of Bituminous Concrete layer**
E	**=**	**Elastic Modulus of Bituminous Surface (MPa)**

Rutting Failure Model

$$N_R = k_5 \left[\frac{1}{\varepsilon_c} \right]^{k_4}$$

N_R = No. of Repetitions to Rutting failure

ε_c = Vertical subgrade strain

k_4, k_5 = Calibrated parameters

IRC Rutting Failure Model

Rutting model

$$N_R = 4.156 \times 10^{-8} \left[\frac{1}{\varepsilon_c} \right]^{4.5337}$$

N_R	=	**No. of cumulative standard axles to produce 20mm rutting**
ε_c	=	**Vertical subgrade strain**

Traffic

- Traffic is considered in terms of the cumulative number of standard axles (8160 kg) to be carried by the pavement during the design life
- For estimating the design traffic, the following Information is needed:
  - Initial traffic after construction (CVPD)
  - Traffic growth rate during the design life
    - By studying the past trends of traffic growth
    - As per the econometric procedure outlined in IRC:108.

Relation Between CBR and E

Subgrade

E (MPa) = 10 * CBR if CBR<5% and

= 176 *(CBR)$^{0.64}$ for CBR > 5%

Granular subbase and base

$E_2 = E_3 * 0.2 * h^{0.45}$

E_2 = Composite modulus of sub-base and base (MPa)

E_3 = Modulus of subgrade (MPa)

h = Thickness of granular layers (mm)

Modulus Values for Bituminous Materials

Mix Type	**Temperature ^oC**				
	20	25	30	35	40
AC/DBM 80/100 bitumen	2300	1966	1455	975	797
AC/DBM 60/70 bitumen	3600	3126	2579	1695	1270
AC/DBM 30/40 bitumen	6000	4928	3809	2944	2276
BM 80/100 bitumen	-	-	-	500	-
BM 60/70 bitumen	-	-	-	700	-

Default Values of Poisson's Ratio (μ)
(as suggested in IRC:37-2001)

- Subgrade and unbound granular layers
  - Default value of $\mu = 0.4$
- Bituminous Layers
  - Default value of μ at 35/45 $^oC = 0.5$
  - Default value of μ at 20 - 30 $^oC = 0.35$

Traffic

- Design life in number of years
  - NH & SH – 15 years
  - Expressways & Urban Roads – 20 years
  - Other roads – 10 to 15 years
- Vehicle damage factor (VDF)
  - Need to be worked out from axle load survey
- Distribution of commercial traffic over the carriageway. (D & L Factors)

Computation of design traffic

$$N = \frac{365 * [(1 + r)^n - 1]}{r} * A * D * F$$

N = The cumulative number of standard axles to be catered for in the design in terms of msa.

A = Initial traffic in the year of completion of construction in terms of the number of the commercial vehicles per day.

D = Lane distribution factor

F = Vehicle damage factor

n = Design life in years

r = Annual growth rate of commercial vehicles

Traffic in the year of completion

$$A = P(1+r)^x$$

P = Number of commercial vehicles as per last count

x = Number of years between the last count and the year of the completion of construction

Subgrade

- The subgrade should be compacted to 97% of the dry density achieved with heavy compaction (modified proctor density) as per IS:2720 (Part 8).

- For Expressways, National Highways and State Highways, the material used for subgrade construction should have the dry density of not less than 1.75 gm/cc.

Subgrade

- For determining the CBR value, the standard test procedure described in IS:2720 (Part 16) should be strictly adhered to.
- The test must always be performed on remoulded samples of soils in the laboratory
- It is recommended that the samples be soaked in water for four days prior to testing
- In situ CBR test is not recommended

Pavement Composition

Sub-base course

- Granular Sub-base (GSB) materials conforming to clause 401 of MORT&H specifications for road and bridge works is recommended
- The sub-base material should have minimum CBR of 20% for cumulative traffic up to 2 msa and 30% for traffic exceeding 2 msa.
  - The material should be tested for CBR at the dry density and moisture content expected in the field.
- The thickness of sub-base should not be less than 150 mm for design traffic less than 10 msa and 200 mm for design traffic of 10 msa and above.

Sub-base Course

- Preferably the subgrade soil should have a CBR of 2%
- If the CBR<2%, the design should be based on a CBR of 2% and a capping layer of 150 mm thickness of material with a minimum CBR of 10% shall be provided in addition to the sub-base
- Where stage construction is adopted, the thickness of sub-base shall be provided for ultimate pavement section for the full design life

Base course

- The recommended minimum thickness of granular base is 225 mm for traffic upto 2 msa and 250 mm for traffic exceeding 2 msa.
- For heavily trafficked roads, use of WMM base laid by paver finisher or motor grader is recommended.
- Where WBM construction should be adopted in the base course for roads carrying traffic more than 10 msa, the thickness of WBM shall be increased from 250 mm to 300 mm.

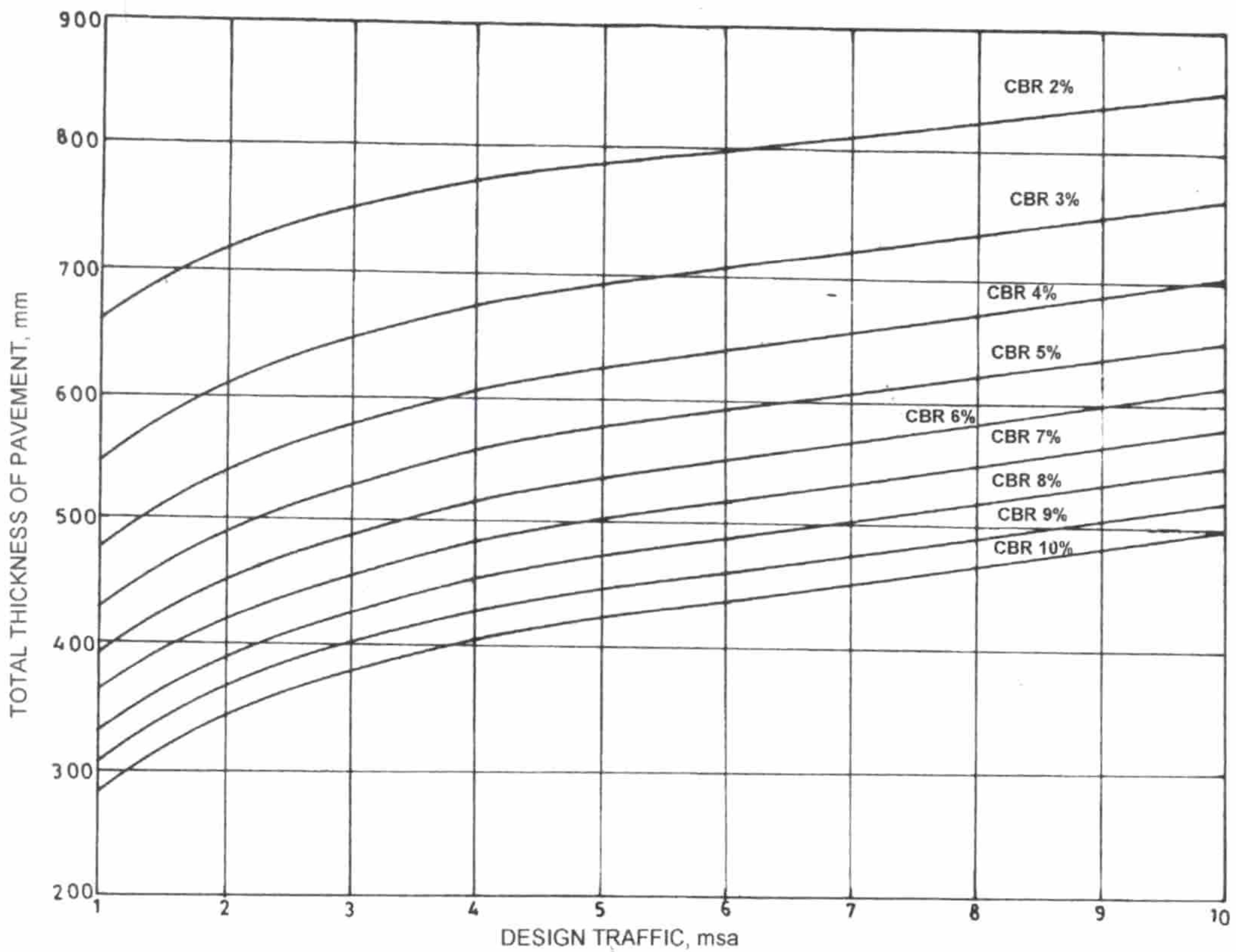
Bituminous Surfacing

- Shall consists of either a wearing course or a binder course with a wearing course depending upon the traffic to be carried.
- The selection criteria for the grade of bitumen to be used for bituminous courses are given in the table shown in the next slide.
- Where the wearing course adopted is premix carpet of thickness up to 25 mm, the thickness of surfacing should not be counted towards the total thickness of the pavement.

Table: Criteria for the selection of Grade of Bitumen for Bituminous courses

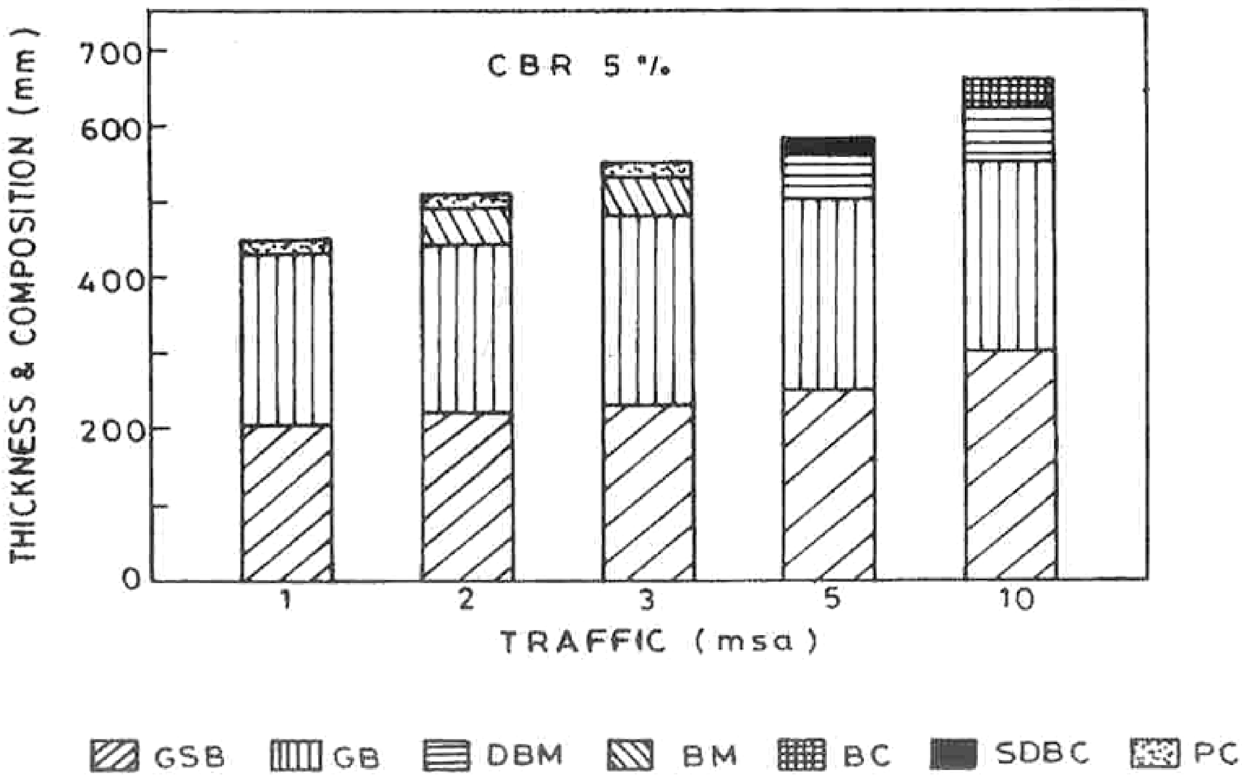
Climate	Traffic (CVD)	Bituminous course	Grade of Bitumen to be used
Hot	Any	BM, BPM, BUSG	60/70
Moderate/Cold	Any	BM, BPM, BUSG	80/100
Any	Heavy Loads, Expressways, Urban Roads	DBM, SDBC, BC	60/70
Hot/Moderate	Any	Premix Carpet	50/60 or 60/70
Cold	Any	Premix Carpet	80/100
Hot/Moderate	Any	Mastic Asphalt	15±5
Cold	Any	Mastic Asphalt	30/40

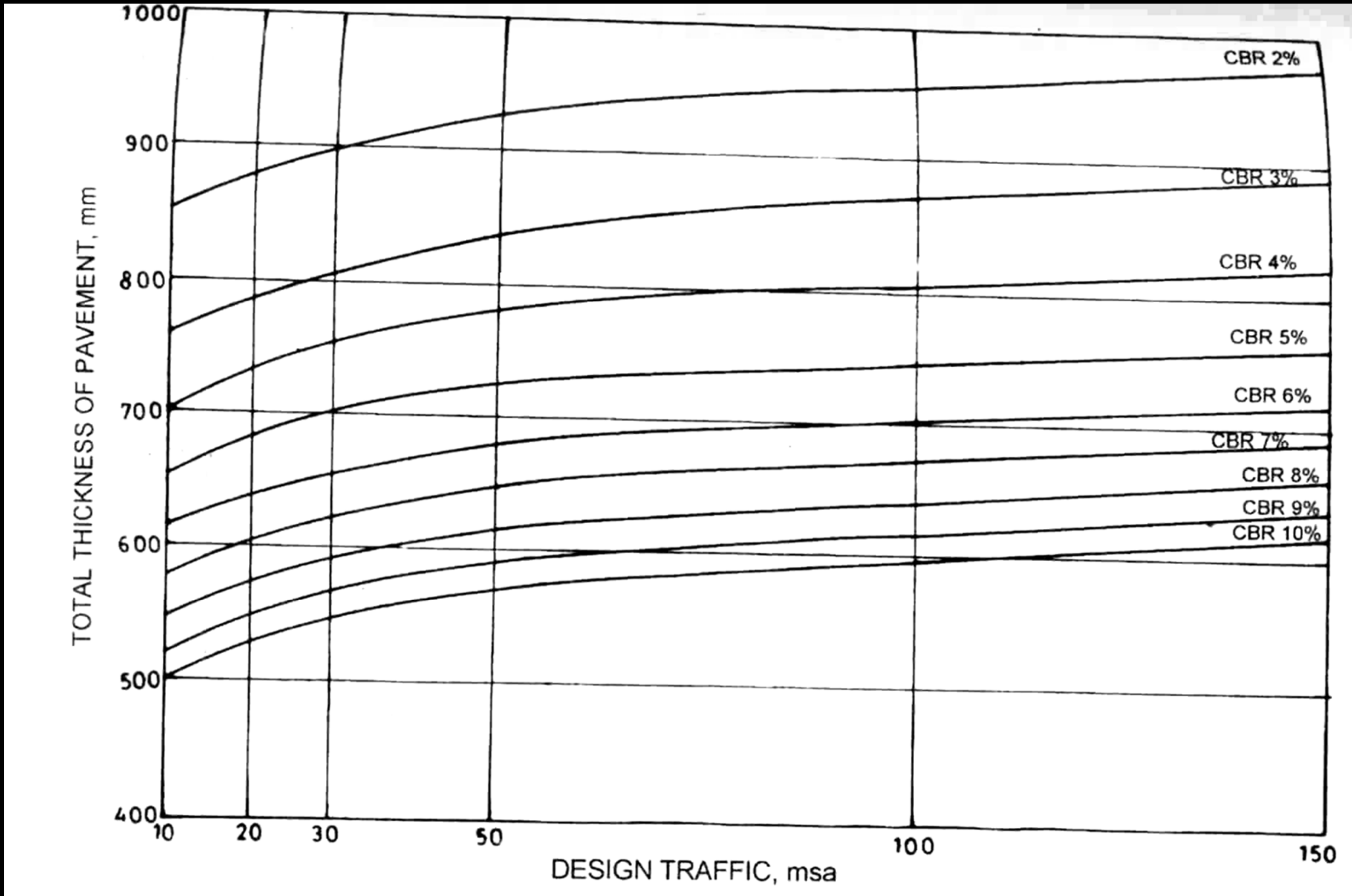
IRC Pavement Design Catalogue



Pavement Thickness Design Chart for Traffic 1-10 msa

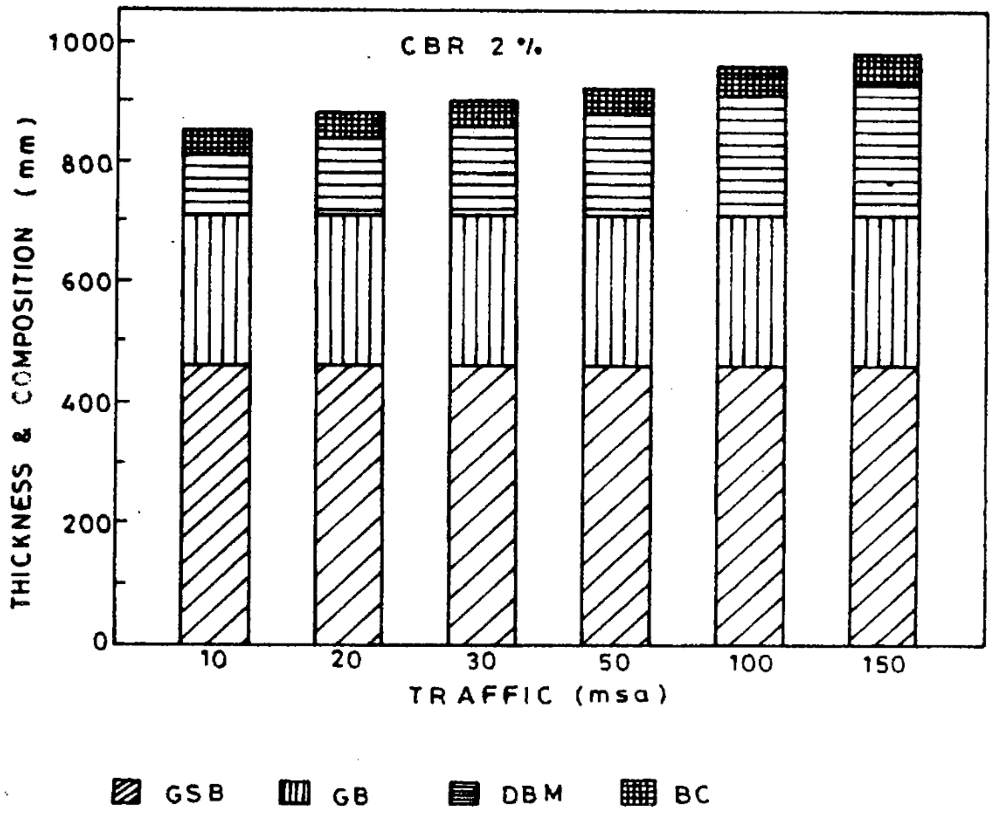
CBR 5%					
Cumulative Traffic (msa)	Total Pavement Thickness (mm)	PAVEMENT COMPOSITION			
		Bituminous Surfacing		Granular Base (mm)	Granular Sub-base (mm)
		Wearing Course (mm)	Binder Course (mm)		
1	430	20 PC		225	205
2	490	20 PC	50 BM	225	215
3	530	20 PC	50 BM	250	230
5	580	25 SDBC	55 DBM	250	250
10	660	40 BC	70 DBM	250	300





Pavement Thickness Design Chart for Traffic 10-150 msa

CBR 2%				
Cumulative Traffic (msa)	Total Pavement Thickness (mm)	PAVEMENT COMPOSITION		
		Bituminous Surfacing		Granular Base & Sub-base (mm)
		BC (mm)	DBM (mm)	
10	850	40	100	Base = 250 Sub-base = 460
20	880	40	130	
30	900	40	150	
50	925	40	175	
100	955	50	195	
150	975	50	215	



Example

- A new four lane divided highway is to be constructed on a subgrade of CBR 1.8 %. The ADT of truck traffic based on the last count was 8000. The directional split of traffic is 55:45. Vehicle damage factor based on axle load survey was 4.0. Design a suitable pavement section for a design life of 15 years. The last traffic count was taken 1 year back and the project would be completed in 2 years from now. Growth rate of traffic = 7%

DATA:

- 4-lane divided carriageway
- ADT of trucks in the last count = 8000
- Growth rate = 7%
- ADT of trucks in the year of completion of construction = 8000(1+0.07)1+2 = 9800
- Design life = 15 years
- Design CBR of subgrade soil = 1.8 percent
- VDF = 4.0

DESIGN CALCULATIONS

- Directional distribution factor, D = 0.55
- Lane distribution factor, L = 0.75
- Vehicle damage factor = 4.0
- Cumulative number of standard axles during design life of 15 years =

$$\frac{365*[(1+0.07)^{15}-1]}{0.07}*9800*0.55*0.75*4.0 \quad \text{msa}$$

=148 msa

Design Section

AC, 50 mm thick

DBM, 215 mm thick

WMM, 250 mm thick

GSB Layer, 460 mm thick

Capping Layer, 150 mm thick

Asphalt Institute Method

Asphalt Institute Method

- Empirical Mechanistic Method
- Distress Models
  - Fatigue cracking
  - Rutting
- Traffic Analysis
  - Determination of ESAL
- Material Properties
  - Resilient modulus for subgrade and granular layers
  - Dynamic modulus for Asphalt layers
- Environmental Effects
  - Monthly temperature changes, freezing and thawing

For any given material and environmental conditions, two thicknesses were obtained, one by each criteria and the larger of the two was used to prepare the design charts

AI Fatigue Cracking Model

Fatigue Cracking model

$$N_f = 0.0796 \left[\frac{1}{\varepsilon_t}\right]^{3.291} \left[\frac{1}{E}\right]^{0.854}$$

N_f	=	No. of cumulative standard axles to produce 20% cracked surface area
ε_t	=	Tensile strain at the bottom of Bituminous Concrete layer
E	=	Elastic Modulus of Bituminous Surface (psi)

AI Rutting Failure Model

Rutting model

$$N_R = 1.365 \times 10^{-9} \left[\frac{1}{\varepsilon_c} \right]^{4.477}$$

N_R	**=**	**No. of cumulative standard axles to produce 12.7 mm rutting**
ε_c	**=**	**Vertical subgrade strain**

Design of Full Depth HMA

Design Chart for Full Depth HMA

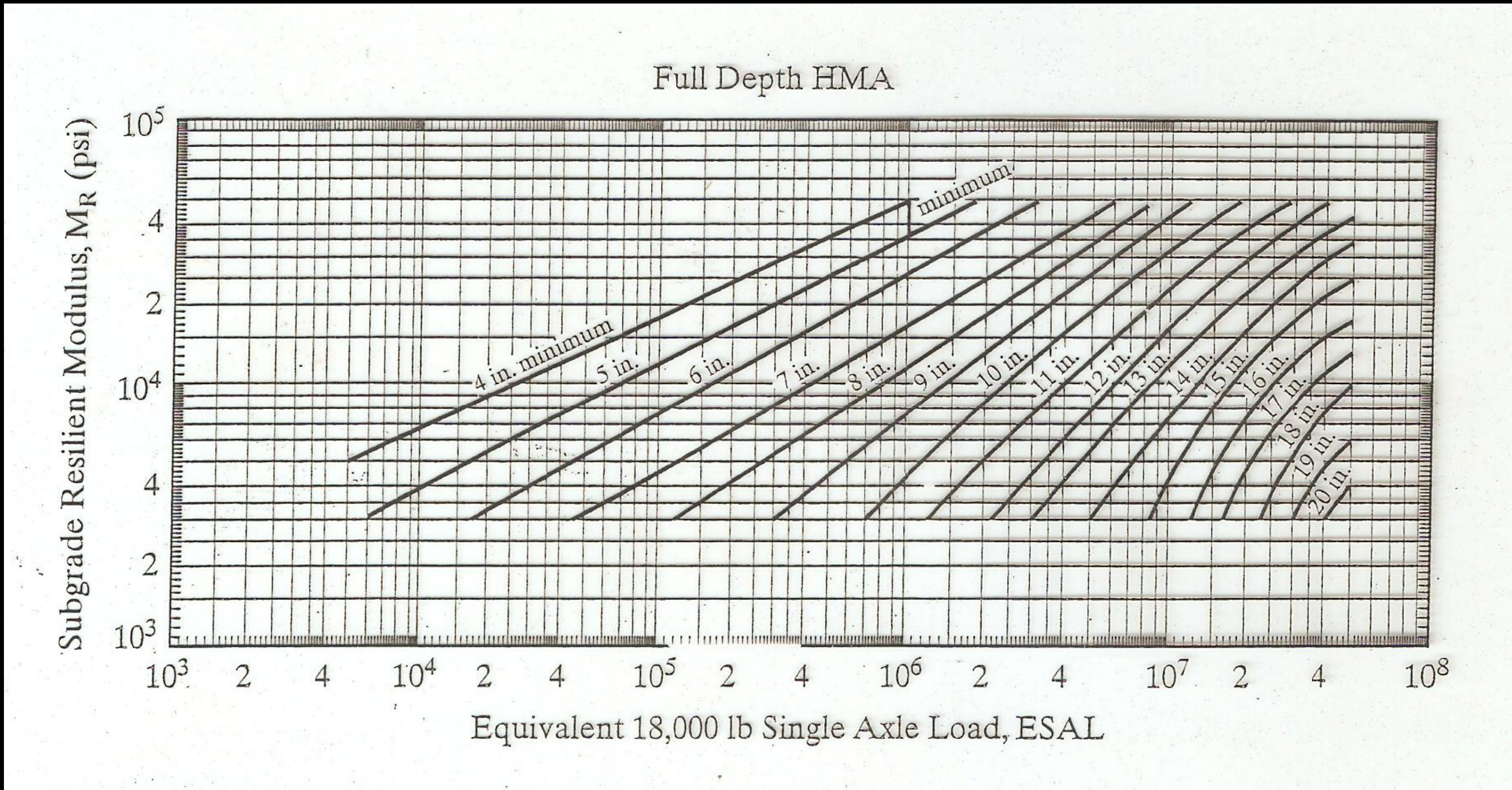


FIGURE 11.11

HMA over Emulsified Asphalt Bases

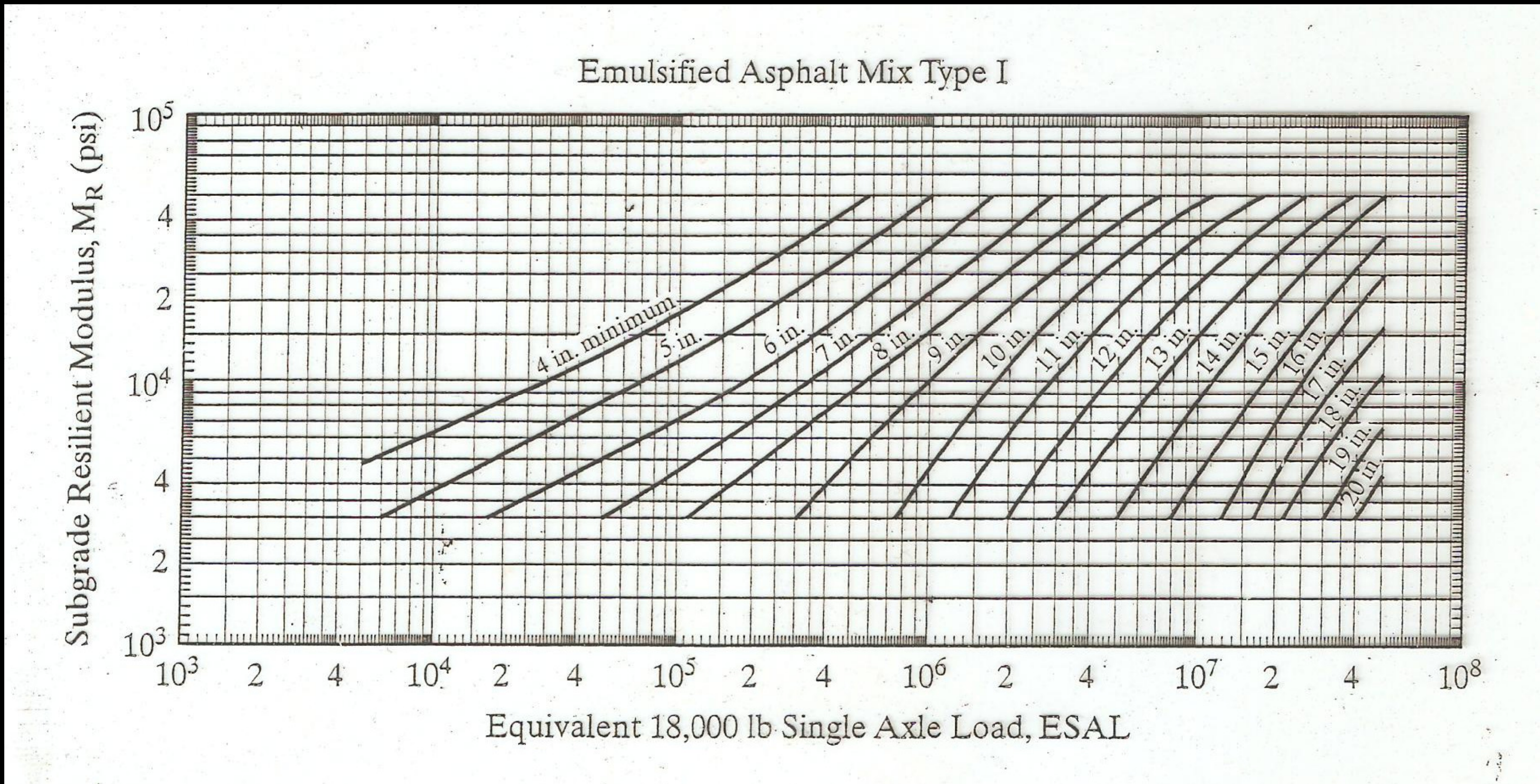
Emulsified Bases

Following Bases bound with bitumen emulsion are considered

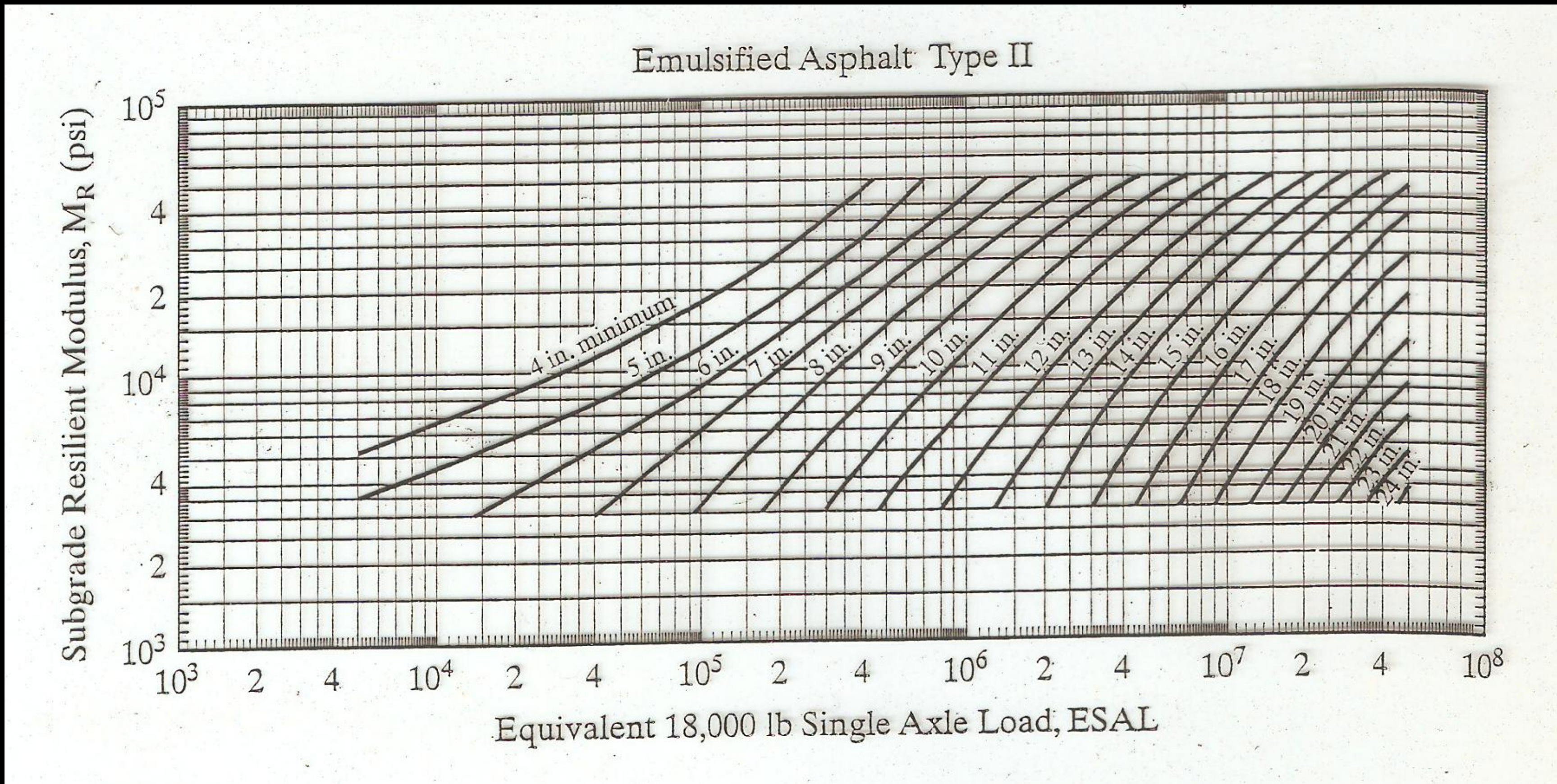
- Type-I : Graded Dense Aggregates
- Type-II: Semi processed Aggregates
- Type-III: Sand and Silty Sands

- Following charts give the total pavement thickness (i.e emulsified base + HMA) in inches.

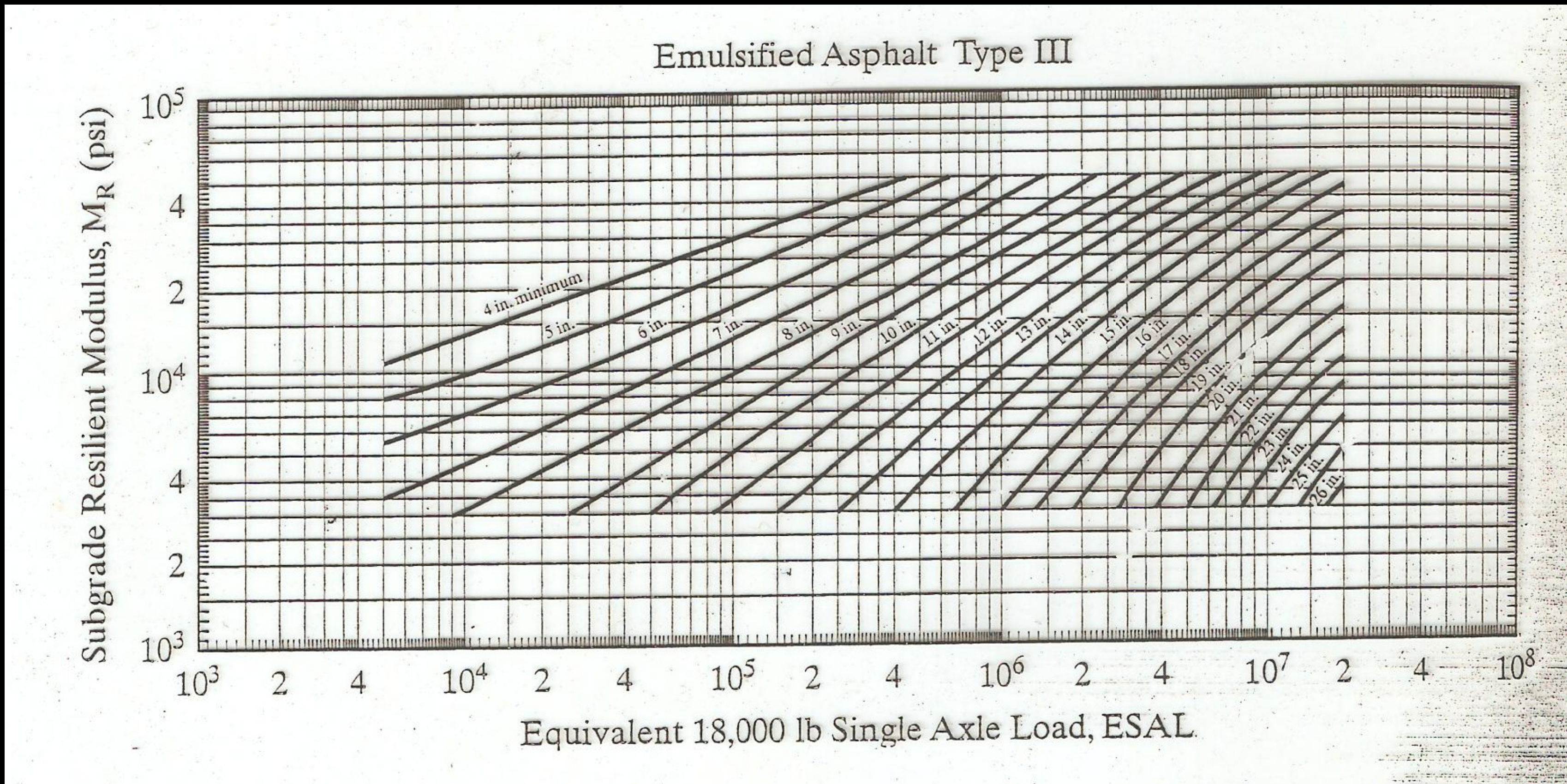
Design Chart for Type-I Emulsified Asphalt Mix



Design Chart for Type-II Emulsified Asphalt Mix



Design Chart for Type-III Emulsified Asphalt Mix

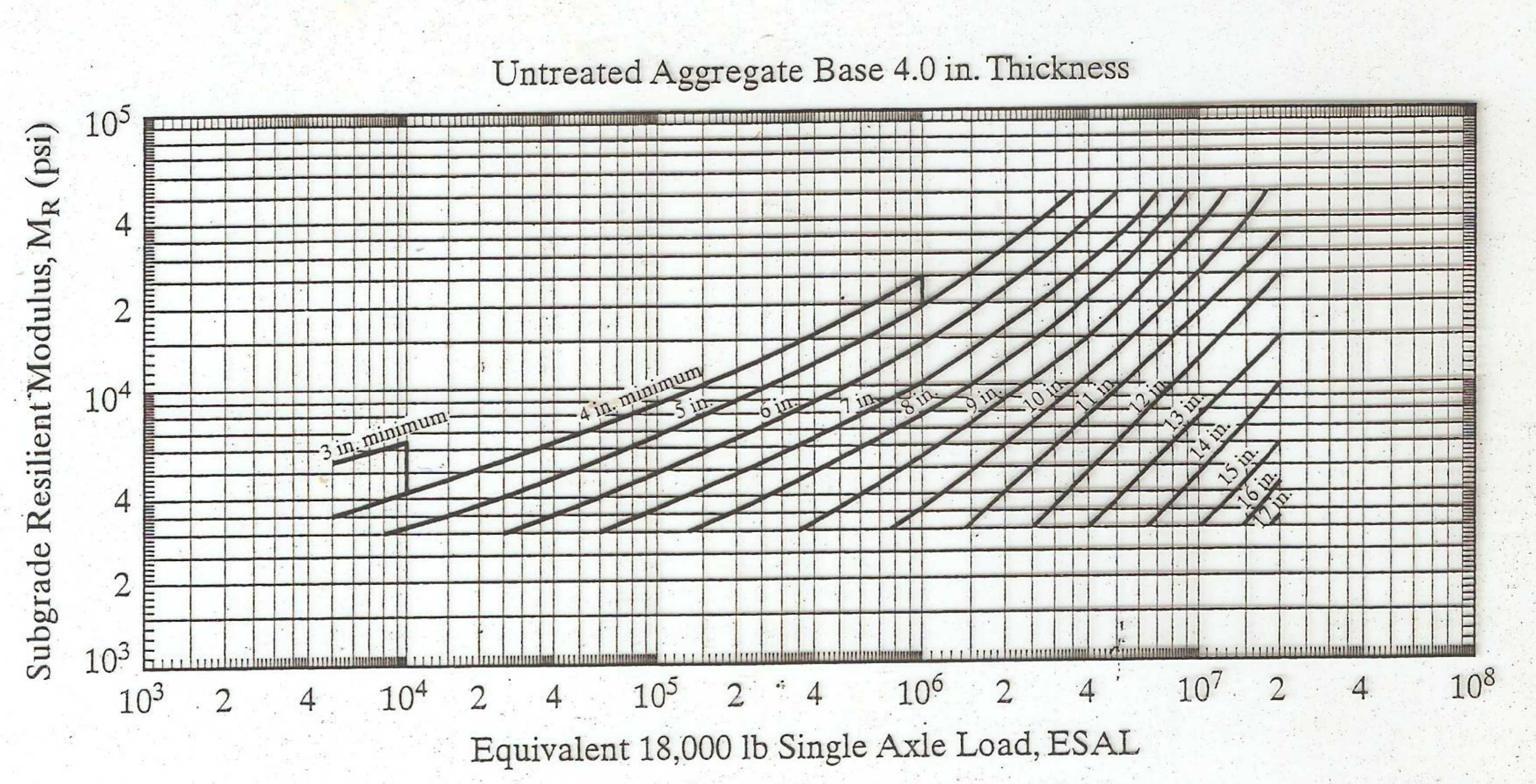


Minimum Thickness of HMA over Emulsified Asphalt Bases

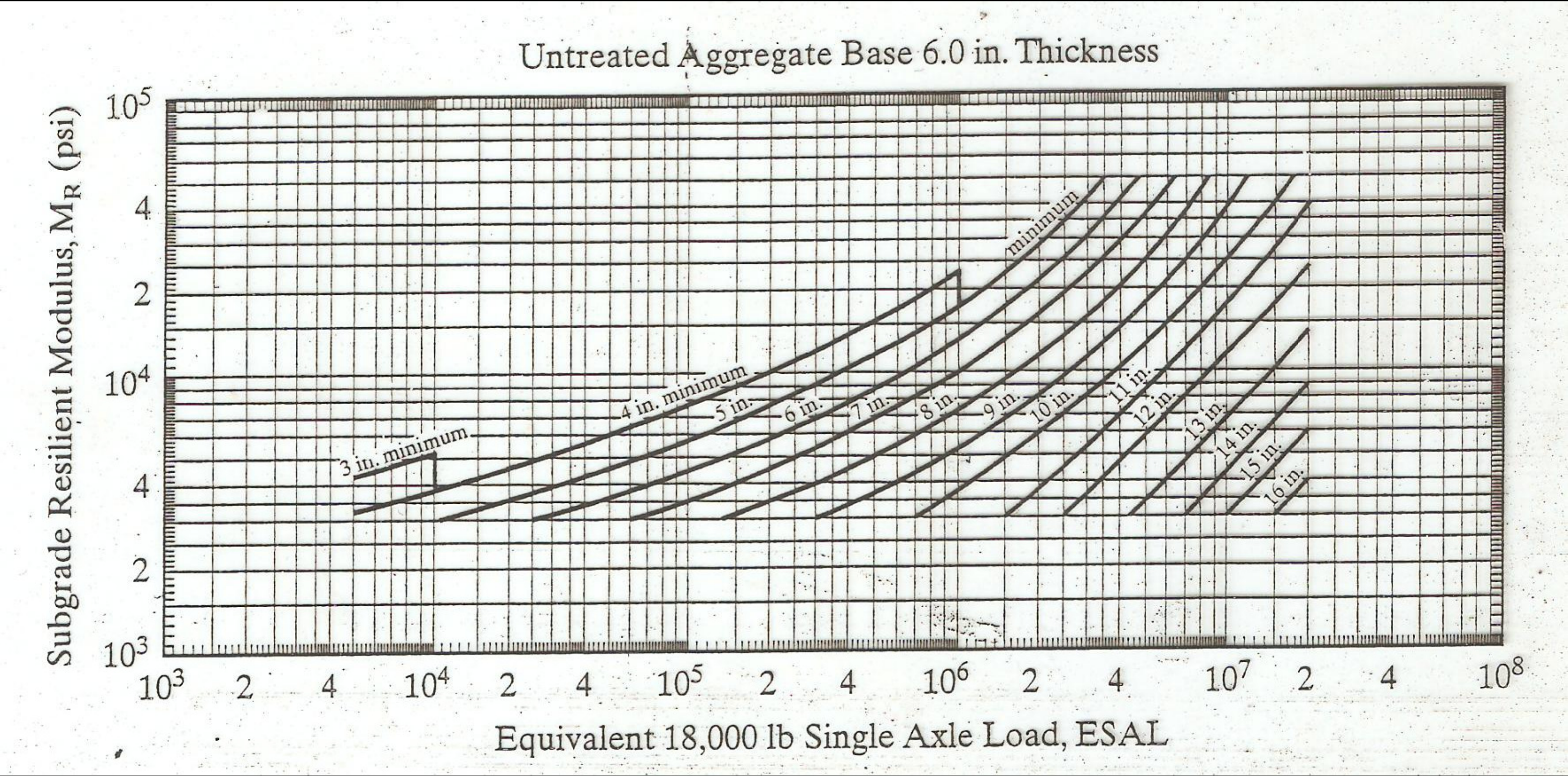
Traffic Level	HMA Thickness for Type-I Mix (in)	HMA Thickness for Type-II & III Mix (in)
10^4	1	2
10^5	1.5	2
10^6	2	3
10^7	2	4
$>10^7$	2	5

HMA over Untreated Aggregate Bases

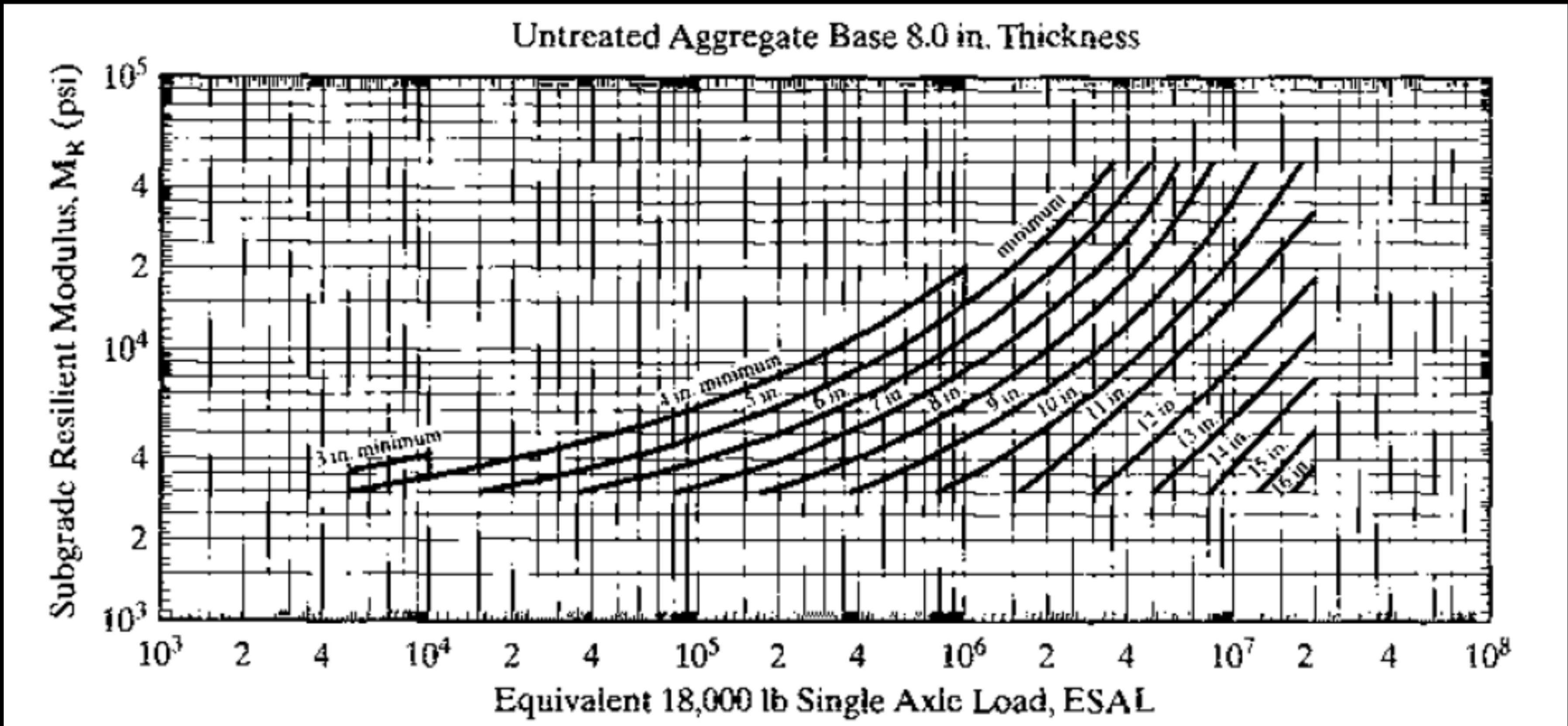
Design Chart for HMA with 4-in Untreated Aggregate Base



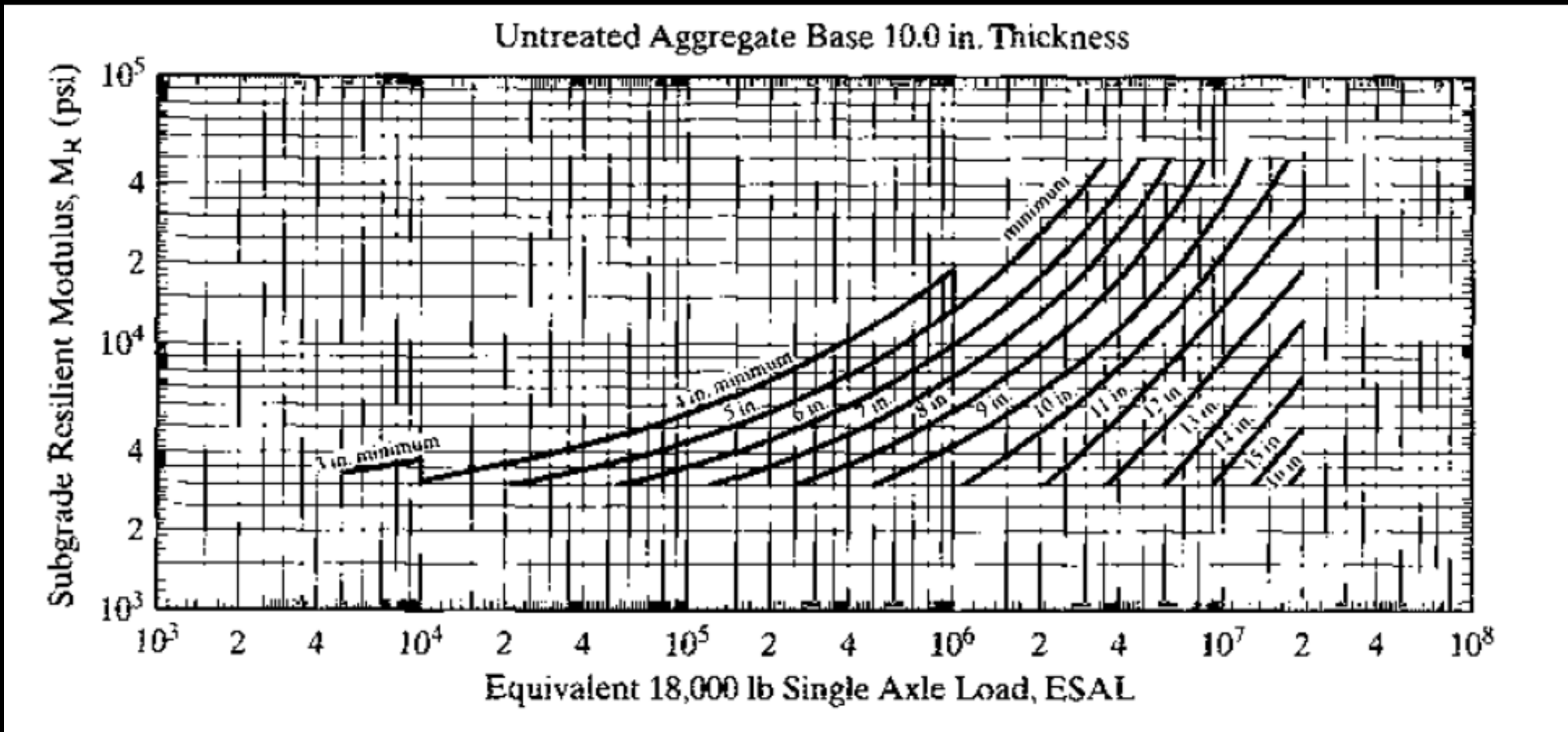
Design Chart for HMA with 6-in Untreated Aggregate Base



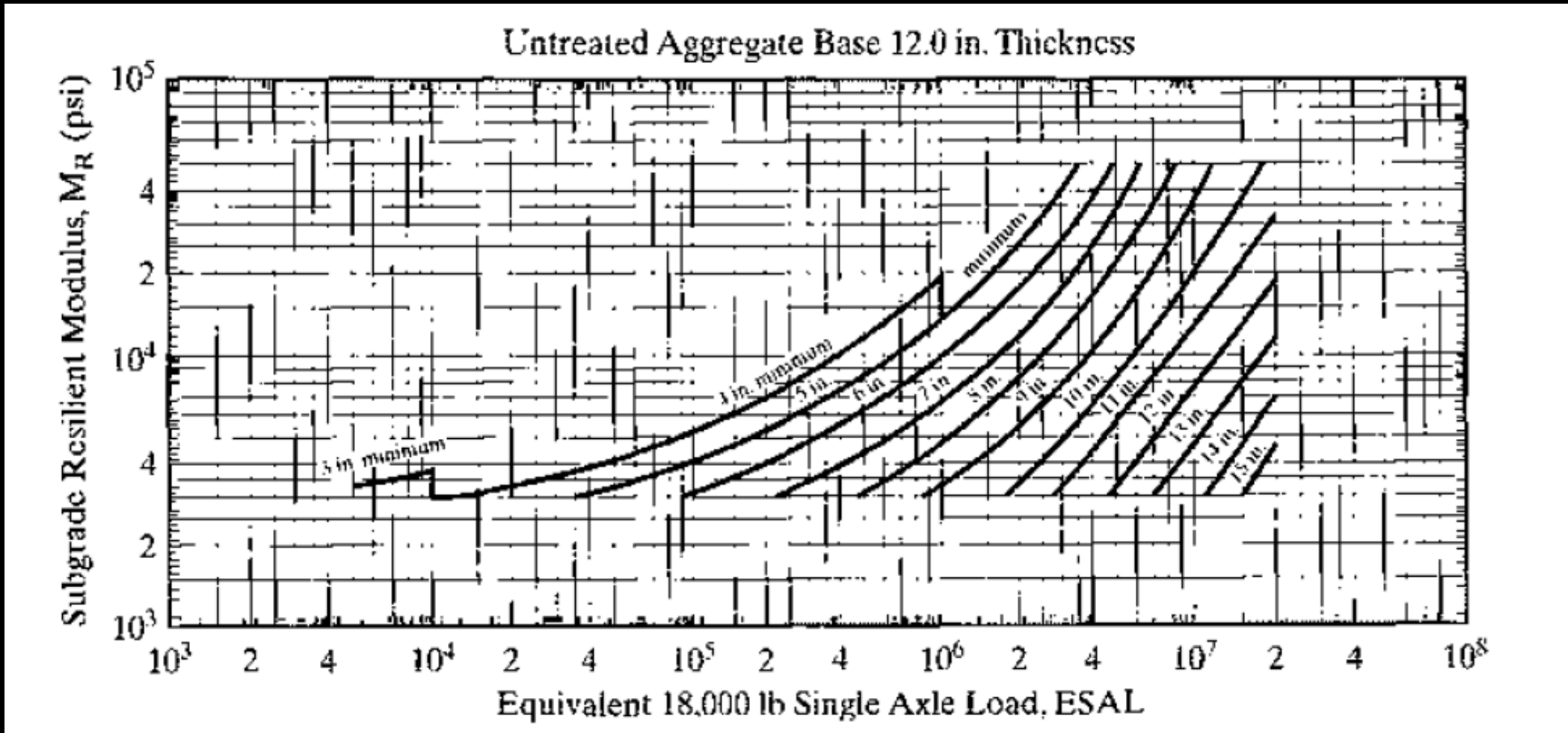
Design Chart for HMA with 8-in Untreated Aggregate Base



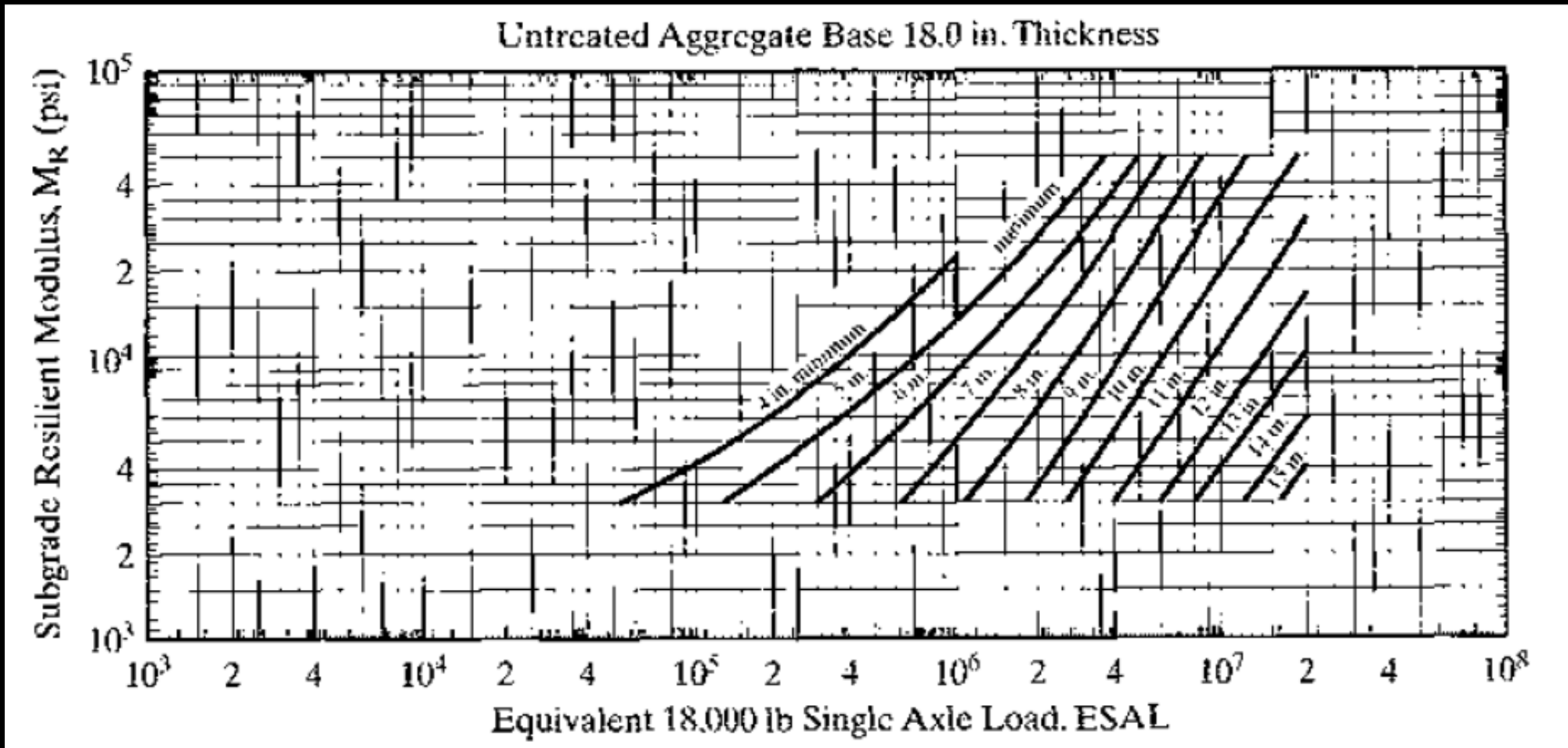
Design Chart for HMA with 10-in Untreated Aggregate Base



Design Chart for HMA with 12-in Untreated Aggregate Base



Design Chart for HMA with 18-in Untreated Aggregate Base



HMA and Emulsified Base over Untreated Aggregate Base

- Design full depth HMA for the traffic and subgrade condition. Out of this, consider 2-in as surface course and the remaining as base course.
- Design the pavement with the same traffic and subgrade condition using the selected emulsified base. Compute the thickness of emulsified base by taking the surface course thickness as 2-in.
- Find the substitution ratio between emulsified base and HMA base by dividing the emulsified base with the HMA base obtained in the first step.
- Design the pavement for the same traffic and subgrade condition using HMA and untreated base.
- Select a portion of the HMA thickness to be replaced by the emulsified asphalt mix, based on the minimum HMA surface course thickness specified as per the table
- Multiply the above thickness with the substitution ratio to get the thickness of emulsified asphalt base required.

Example

- Given *MR* = 10,000 psi (69 MPa), ESAL = 10^6 , and an 8-in . (203-mm) untreated aggregate base, design the thicknesses of HMA surface course and type II emulsified asphalt base course.

Planned Stage Construction

- What is the need?
  - Lack of funds
  - Uncertainty in estimating traffic
  - Detection of weak spots that develop in the first stage

Planned Stage Construction

- n_1 = Design (actual) ESAL for stage 1
- N_1= allowable ESAL for stage1
- Then, damage ratio, $D_r = n_1 / N_1$
- A damage ratio of much less than 1 (e.g., 0.6) is chosen for the first stage, so that the pavement has a remaining life of $(1-D_r)$ at the end of stage 1
- Determine the thickness h_1 for stage 1 based on N_1 $(= n_1 / D_r)$
- n_2 = Design ESAL for stage 2
- N_2= allowable or adjusted ESAL for stage2
- The damage incurred in Stage 2 should not exceed the remaining life, i.e.
- $n_2 / N_2 = (1-D_r)$ or $N_2 = n_2/(1-D_r)$
- Determine the thickness h_2 based on N_2
- *The difference between h_2 and h_1 is the additional thickness needed for stage 2*

Example

- A full-depth HMA pavement with a subgrade resilient modulus of 10,000 psi *(69* MPa) will be constructed in two stages. The first stage is *5* years with 150,000 ESAL repetitions, and the second stage is 15 years with *850,000* ESAL repetitions. Limiting the damage ratio to *0.6* at the end of stage 1, determine the thickness of HMA required for the first *5* years and the thickness of overlay required to accommodate the additional traffic expected during the next 15 years.

AASHTO Design Chart for flexible Pavements based on Mean Values for each Input