B.Sc - Road & Railway Design I. *Lecture 10.*

PAVEMENT DESIGN

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PAVEMENT DESIGN 1

- Pavement design is the major component of road design
- Road pavement (being flexible or asphalt pavement, predominant worldwide) is one of the most expensive element of road construction, apart from the bridges, tunnels and viaducts
- During maintenance and operation period, road pavement is the element where more money is being spent, requiring that its design should be done with the most accurate methods considering traffic load, climatic conditions and materials' behaviour

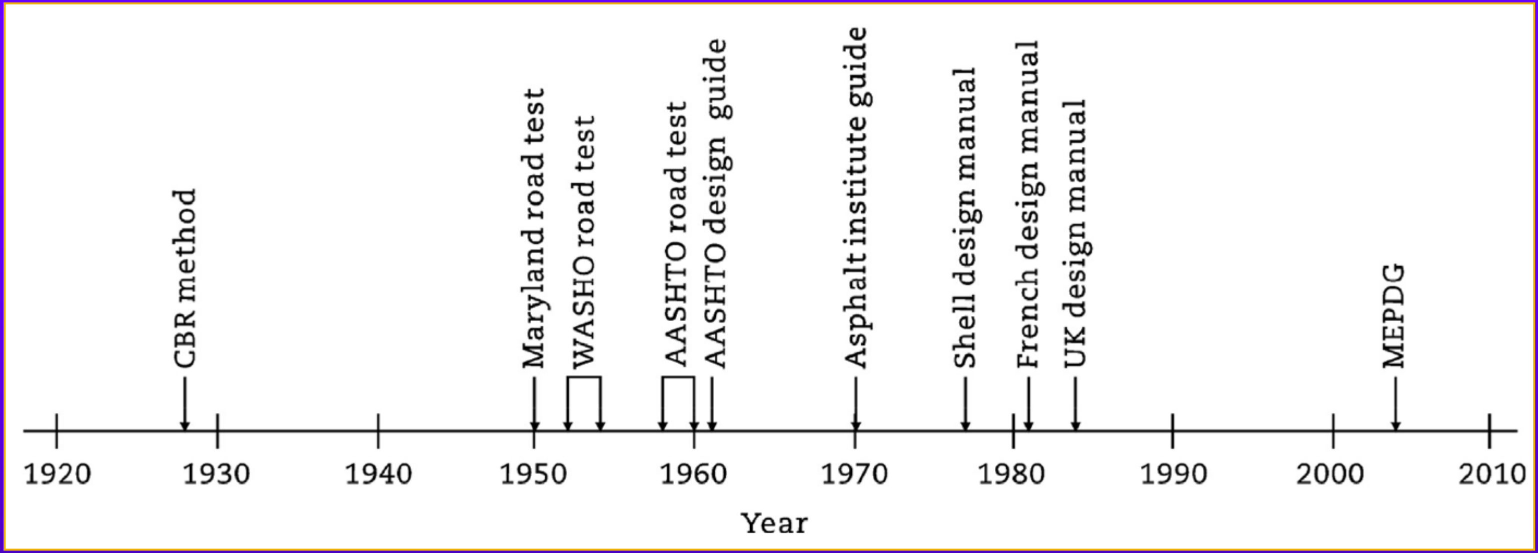
PAVEMENT DESIGN 2

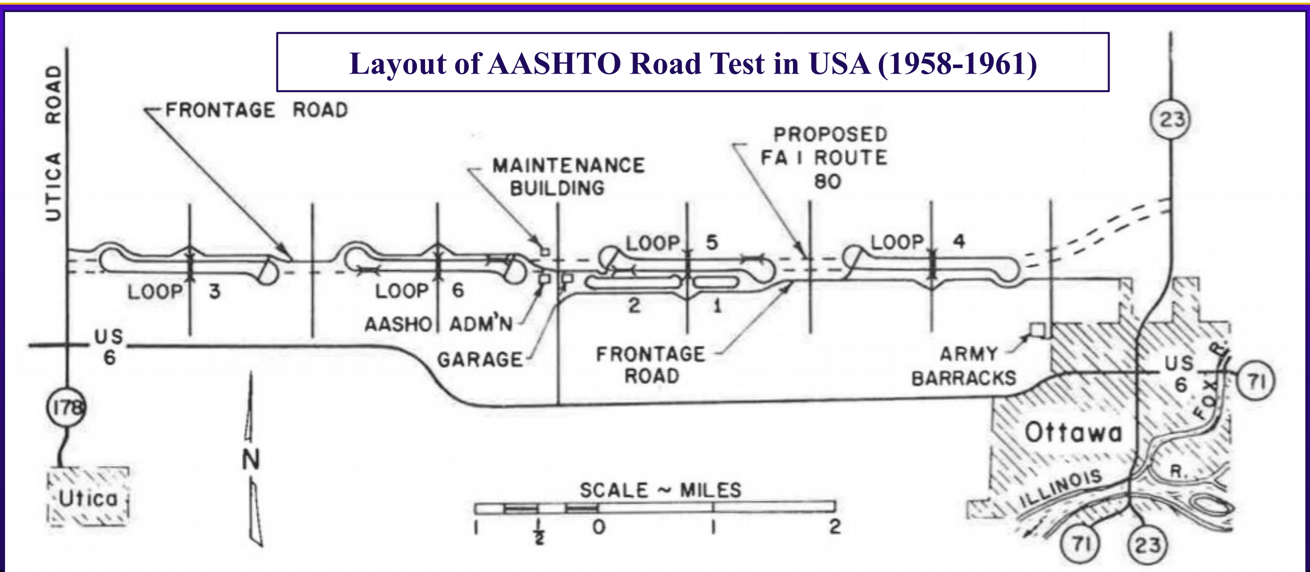
- Typically, pavement damage, defined as the ratio between the expected traffic and the number of loading cycles that the pavement can stand, is used as the design criteria in the design process
- Methods of pavement design:
    - *Empirical* or *traditional method* based on the results of the *AASHTO Road Test*, a series of experiments carried out by the *American Association of State Highway and Transportation Officials* to determine how traffic contributes to the deterioration of road pavements - design manuals published in 1962-1993
    - *Mechanistic-empirical method* identifies the physical causes of stresses in pavement structures and calibrate them with observed pavement performance - design manual (MEPDG) published in 2004)

PAVEMENT DESIGN 3

- Pavement design methodology has evolved over the last decades from an empirical to a mechanistic-empirical approach
- Empirical methods consider traffic input represented by a single wheel load as well as soil properties, with support from the observation of field pavement performance, in service roads or accelerated track test facilities with real pavement
- The main objective consists of the determination of the thickness of pavement layers to be constructed over the subgrade, with the major objective of allowing traffic circulation before reaching a predefined failure condition at the end of its designed lifespan

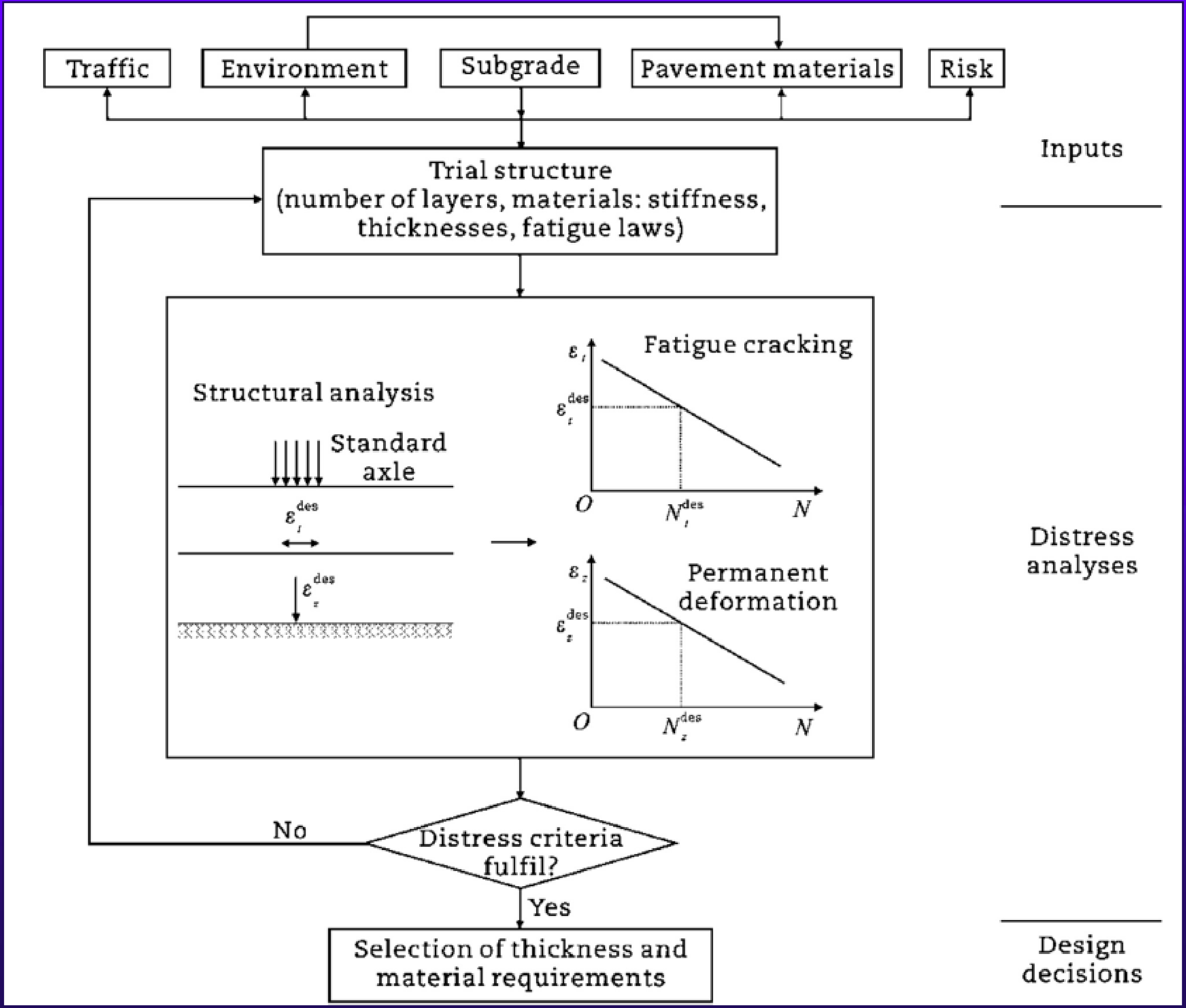
DEVELOPMENT OF PAVEMENT DESIGN METHODOLOGY



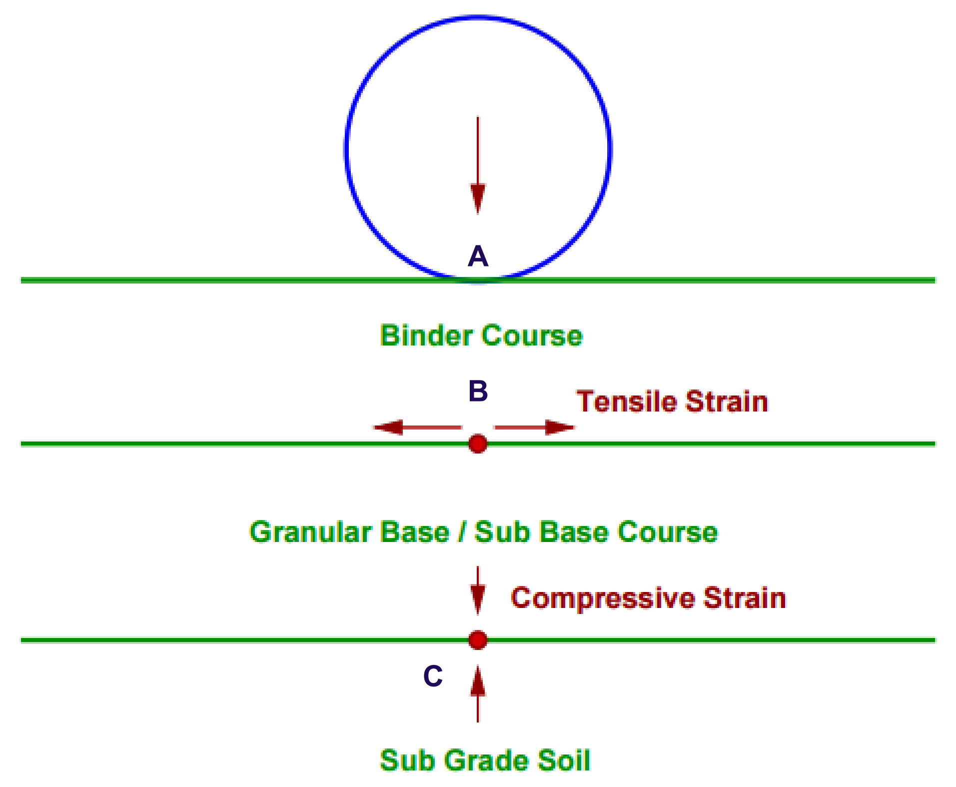


Layout of AASHTO Road Test in USA (1958-1961)

SIMPLIFIED DESIGN / ANALYSIS FRAMEWORK



MECHANISTIC-EMPIRICAL DESIGN METHOD 1



A and B are the critical locations for *tensile strains* (σ_t). Maximum value of the strain is adopted for design. C is the critical location for the *vertical subgrade strain* (σ_z) since the maximum value of (σ_z) occurs mostly at C

MECHANISTIC-EMPIRICAL DESIGN METHOD 2

- Bituminous surfacings of flexible pavements display flexural *fatigue cracking* if the tensile strain at the bottom of the bituminous layer is beyond certain limit
- The relation between the fatigue life of the pavement and the tensile strain in the bottom of the bituminous layer under certain conditions (e. g. in the method of the Indian Road Congress – *IRC*) was obtained as

$$N_f = 2.21 \times 10^{-4} \times \left(\frac{1}{\sigma_t}\right)^{3.89} \times \left(\frac{1}{E}\right)^{0.854}$$

- N_f is the allowable number of load repetitions to control fatigue cracking and *E* is the *elastic modulus* of bituminous layer; the use of this equation would result in fatigue cracking of 20% of the total area

EMPIRICAL-TRADITIONAL DESIGN METHOD

- In most countries of the World, the empirical method is standardized for the time being, using either *equivalency factors* or *design catalogue* to determine/select the structure of the pavement
- The AASHTO road test introduced many concepts in pavement engineering, including
  - the *Load Equivalency Factor* (LEF), expressing that the heavier vehicles reduce the serviceability (quality) of the pavement in a much shorter time than light vehicles and
  - the oft-quoted figure, called the *Generalized Fourth Power Law*, that damage caused by vehicles is *related to the 4th power of their axle weight* (t. e. doubling the axle load increases 16 times the damage)

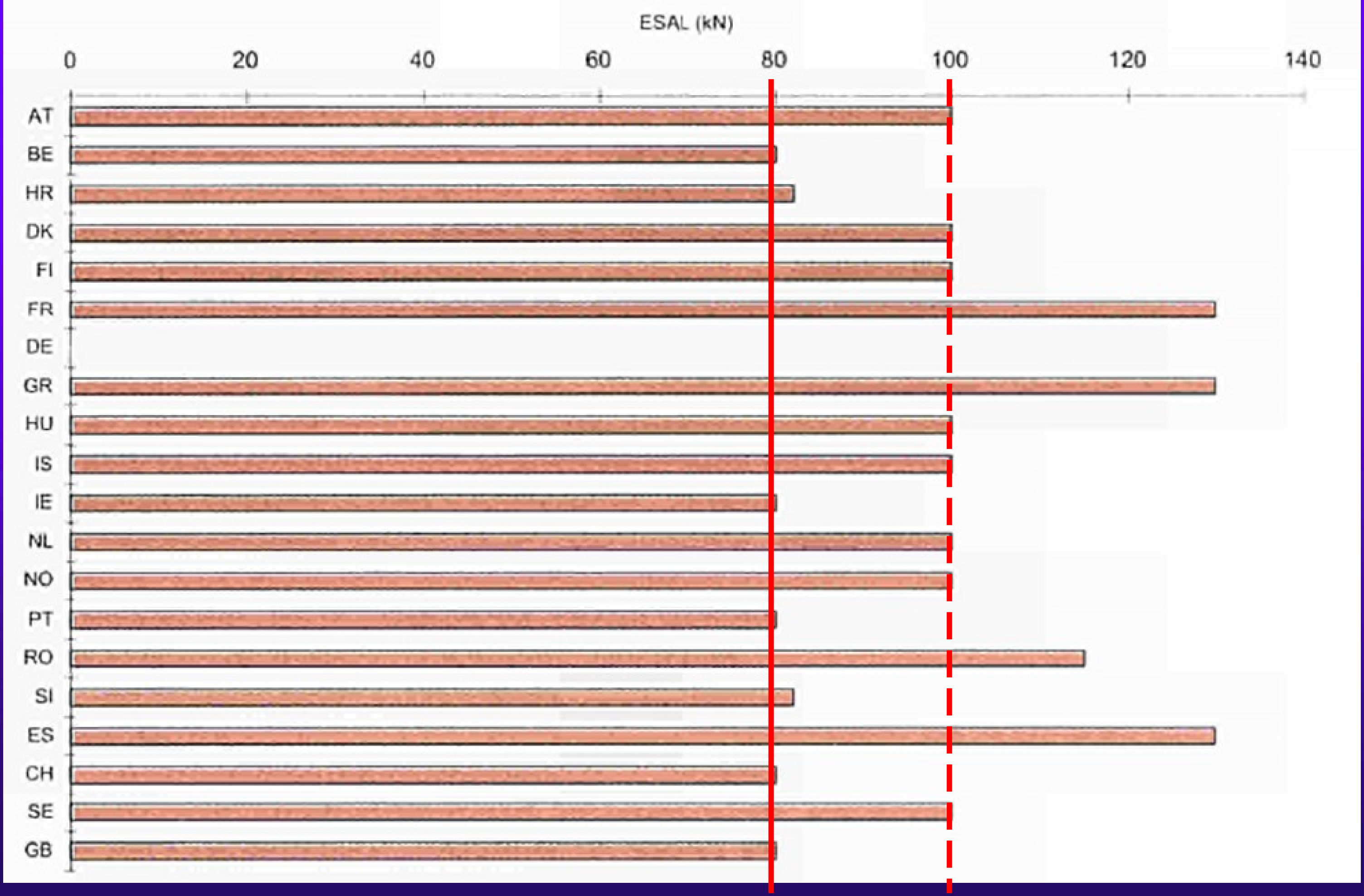
LOAD QUANTIFICATION

- *Equivalent Single Axle Load* (ESAL) is a concept to establish a damage relationship for comparing the effects of axles carrying different loads to that caused by a single (standard) axle load of 80kN (US) or 80-100kN (Europe)
- Using ESAL, wheel or axle loads of various magnitudes and repetitions (mixed traffic) are converted into an equivalent number of „standard" or „equivalent" loads
- *Load Equivalency Factor* (LEF) or generalized fourth power approximation:

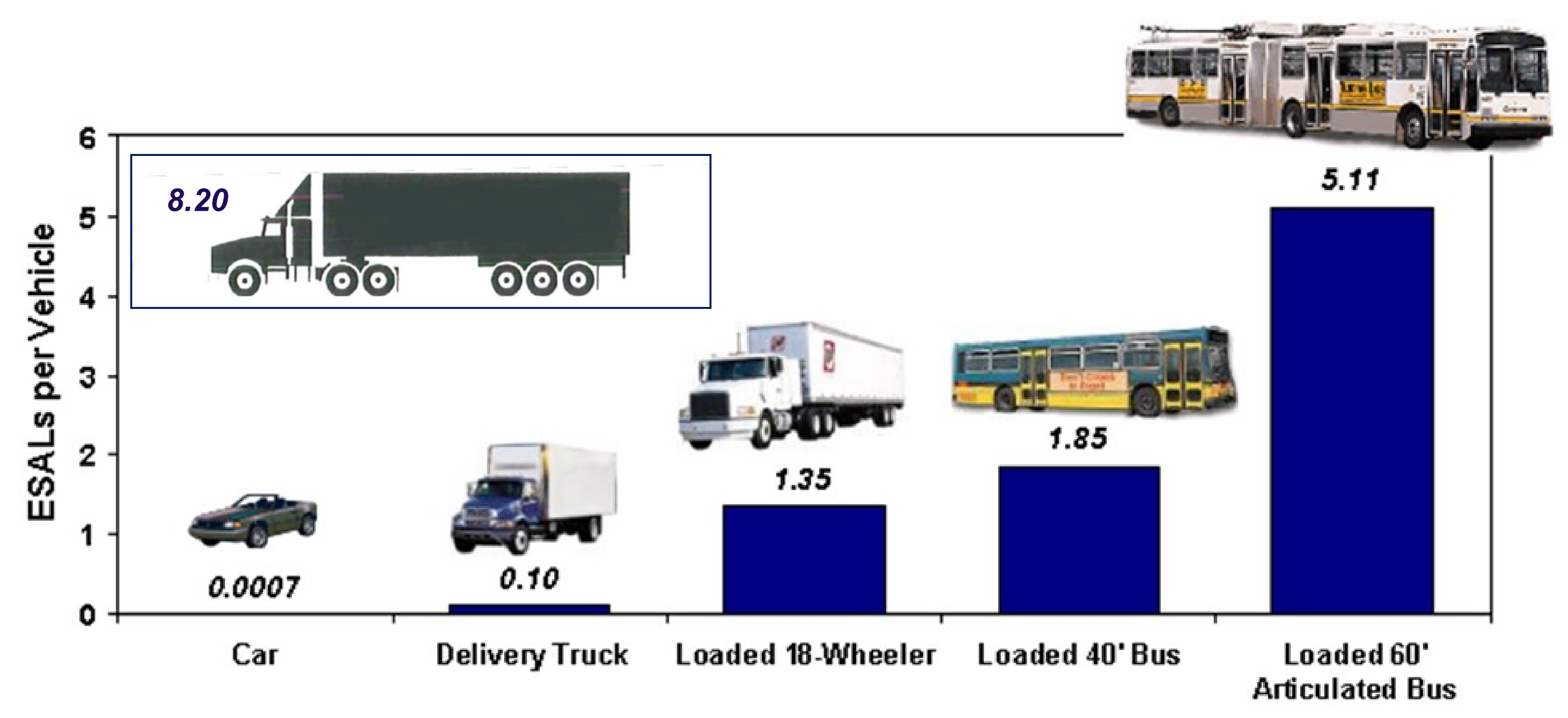
$$\boxed{\text{LEF} = (\text{axle load} / 100\text{kN})^4 = \text{relative damage factor}}$$

$$\boxed{\text{Number of standard axles for same damage} = (\text{Load on axle/Standard Axle Load})^4}$$

STANDARD AXLE LOAD VALUES IN EUROPE (2010)



TYPICAL ESALS

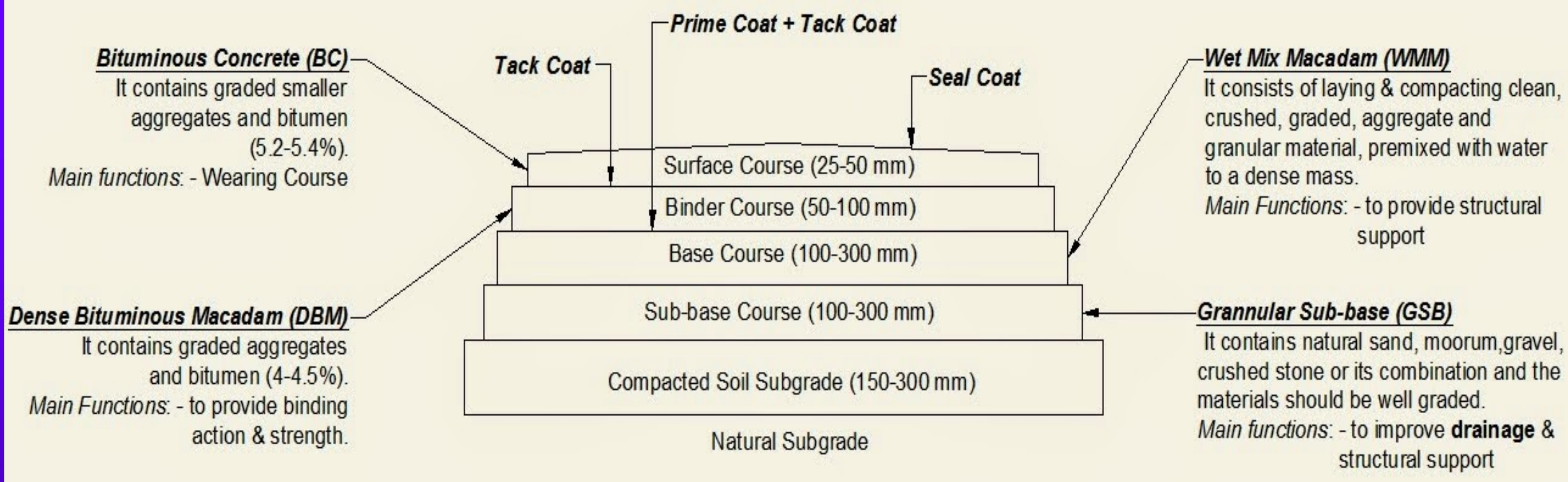


Damages caused by cars and light (<3.5 t mass) commercial vehicles are insignificant, thus ignored in pavement design

ESTIMATING ESALS

- **A basic element in pavement design is estimating the ESALs a pavement will encounter over its design life - this helps determine the pavement structural design (and the HMA mix design)**
- **This is done by forecasting the traffic the pavement will be subjected to over its design life then converting the traffic to a specific number of ESALs based on its makeup**
- **A typical ESAL estimate consists of:**
  1. **Traffic *count* (in the base year)**
  2. **A count or estimate of the *number of heavy vehicles* in the yearly traffic flow**
  3. **An estimated traffic (and heavy vehicle) *growth rate* over the design life of the pavement**
  4. **Select appropriate LEFs to *convert* truck+bus traffic to ESALs**
  5. **Calculate a cumulated *ESAL estimate* expected up to the end of design life**

COMPONENTS OF FLEXIBLE PAVEMENT



Prime Coat + Tack Coat

Tack Coat

Seal Coat

Surface Course (25-50 mm)

Binder Course (50-100 mm)

Base Course (100-300 mm)

Sub-base Course (100-300 mm)

Compacted Soil Subgrade (150-300 mm)

Natural Subgrade

Bituminous Concrete (BC)
It contains graded smaller aggregates and bitumen (5.2-5.4%).
Main functions: - Wearing Course

Dense Bituminous Macadam (DBM)
It contains graded aggregates and bitumen (4-4.5%).
Main Functions: - to provide binding action & strength.

Wet Mix Macadam (WMM)
It consists of laying & compacting clean, crushed, graded, aggregate and granular material, premixed with water to a dense mass.
Main Functions: - to provide structural support

Grannular Sub-base (GSB)
It contains natural sand, moorum,gravel, crushed stone or its combination and the materials should be well graded.
Main functions: - to improve **drainage** & structural support

Prime Coat: - a low viscous bituminous material/ bitumen emulsion, density= 7.3 to 14.6 kg per 10 sq.m area.

Tack Coat: - a high viscous bituminous material/ bitumen emulsion, density = 4.9 to 9.8 kg per 10 sq. m area.

Seal Coat: - to water proof the surface and to provide skid resistance, density = 6.8 to 9.8 kg per 10 sq. m area

DESIGN LIFE

- The number of years a new road will carry the volume of traffic associated with that time period without deteriorating to the point where reconstruction or major structural repair is necessary
- Design life depend upon the environmental conditions, materials used, adequacy of traffic forecast, quality of maintenance etc.
- For motorways and main roads with heavy traffic design life is 20 years, for roads with less traffic load a design life of 10-15 years is to be considered
- Design life does not be confused with *service life*, (period of use in service) which is usually *much longer*

DESIGN TRAFFIC LOAD

- **Traffic expected/forecast during design life on the design traffic lane of a road is calculated as follows:**

$$T_{DT} = \sum_{G=1}^{G=N} 365 * AADT * (HV_G\%/100) * DF * LDF * CGF_G * T_{GESALAV}$$

where

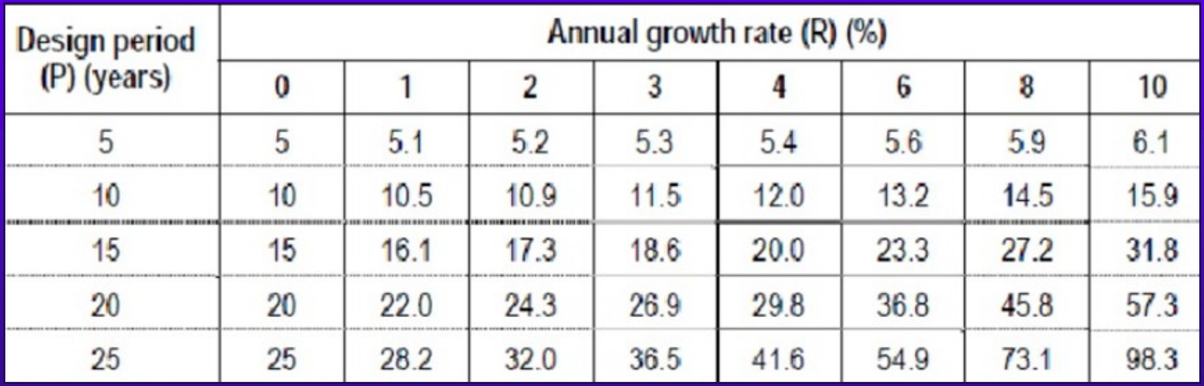
- T_{DT} = Design Traffic (million standard axle; *msa*)
- *AADT* = Annual Average Daily Traffic in the first calendar year following completion
- *DF* = Direction Factor – proportion of two-way traffic in direction of the design lane (usually 0.5)
- $HV_G\%$ = Average percentage of a given group of Heavy Vehicles (trucks & buses) in the traffic
- *LDF* = Lane Distribution Factor – proportion of Heavy Vehicles in the design lane
- *CGF* = Cumulative Growth Factor per groups of HVs
- $T_{GESALAV}$ = Average number of ESAL per groups of HVs
- *G* = Group of HVs (e. g. trucks 3.5t≤7.5t; 7.5t≤12t; 12t≤; buses)

TRAFFIC GROWTH FORECAST

- Cumulative Growth Factor

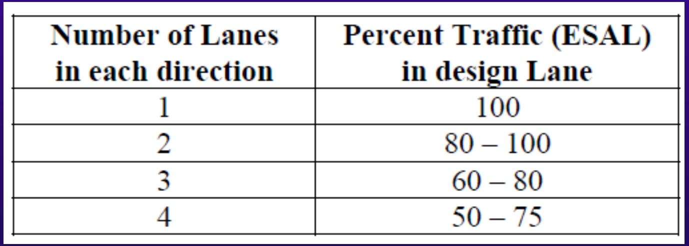
$$CGF = \frac{(1 - 0.01R)^P - 1}{0.01}$$

  - To be selected on the base of average yearly traffic growth observed during recent years:



Design period (P) (years)	Annual growth rate (R) (%)							
	0	1	2	3	4	6	8	10
5	5	5.1	5.2	5.3	5.4	5.6	5.9	6.1
10	10	10.5	10.9	11.5	12.0	13.2	14.5	15.9
15	15	16.1	17.3	18.6	20.0	23.3	27.2	31.8
20	20	22.0	24.3	26.9	29.8	36.8	45.8	57.3
25	25	28.2	32.0	36.5	41.6	54.9	73.1	98.3

- Lane Distribution Factors:



Number of Lanes in each direction	Percent Traffic (ESAL) in design Lane
1	100
2	80 – 100
3	60 – 80
4	50 – 75

DESIGN TRAFFIC LOAD GROUPS

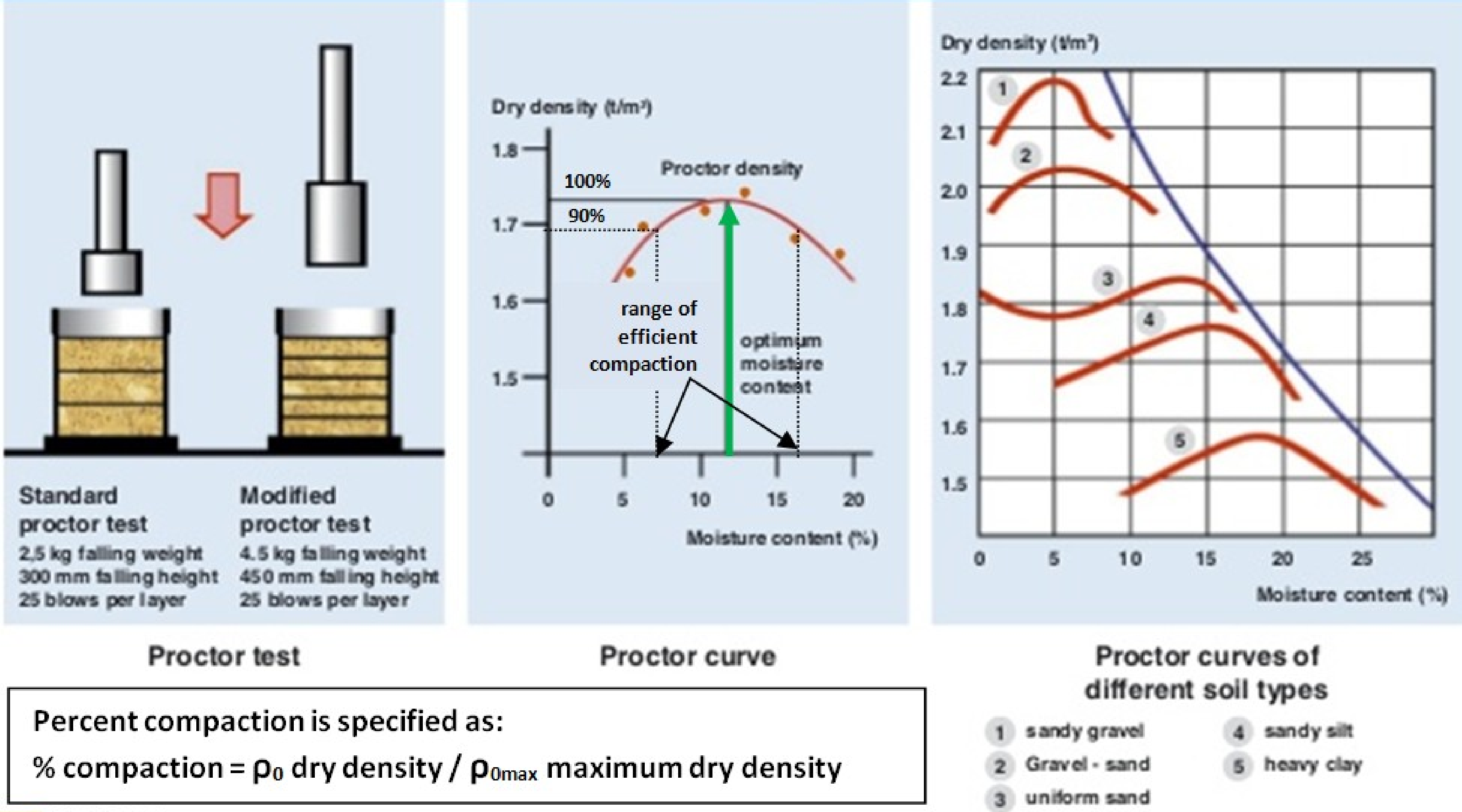
- Standardised traffic classes or groups of total design traffic load (recommended by pavement design manuals):

Traffic classes / groups for flexible pavement design	Range of cumulated traffic during design life (million ESALs)
T1 - *Extremely light*	<0.3
T2 - *Very light*	0.3 – 0.7
T3 - *Light*	0.7 – 1.5
T4 - *Lower Medium*	1.5 – 3.0
T5 - *Medium*	3.0 – 6.0
T6 - *Upper medium*	6.0 – 10.0
T7 - *Heavy*	10.0 – 17.0
T8 - *Very heavy*	17.0 – 30.0
T9 - *Extremely heavy*	>30.0

SUBGRADE FORMATION

- Aim to provide support to the pavement as its foundation
- Top 50 cm of the cutting or embankment at *formation level* in main roads is considered as *subgrade capping*
- A minimum of 100% of *standard Proctor compaction* should be attain in sand or sandy gravel subgrade capping
- For clayey soil 95% of standard Proctor compaction and moisture content of 2% in excess of optimum value required generally in subgrade capping
- Soil below subgrade should be compacted to minimum 90% of standard Proctor compaction
- When subgrade is silty or clayey soil and annual rainfall of area is more than 1000 mm, a drainage layer of 100 mm as the formation width should be provided

PROCTOR COMPACTION TEST



Proctor test

Proctor curve

Proctor curves of different soil types

Percent compaction is specified as:

% compaction = ρ_0 dry density / ρ_{0max} maximum dry density

- Proctor Compaction Test determines the optimum water content and maximum dry density of a soil

COMPACTION MACHINERY

Sheepsfoot

Pedfoot

Vibratory roller

Grid roller

Falling weight

FORMATION LEVEL OF SUBGRADE

SUBGRADE LOAD CAPACITY

- The *elastic modulus* based on the recoverable strain under repeated loads is called the *resilient modulus* (M_r), defined as $M_r = \sigma_d / \varepsilon_r$ in which σ_d is the deviator stress, which is the axial stress in an unconfined compression test or the axial stress in excess of the confining pressure in a triaxial compression test
- Determination of resilient modulus is often cumbersome, therefore, various empirical tests have been used to determine the material properties for pavement design
- Most of these empirical tests measure the strength or deformation of the material (CBR test, triaxial test, plate load test, etc.) and their results are then correlated to resilient modulus

CALIFORNIA BEARING RATIO (CBR) TEST 1

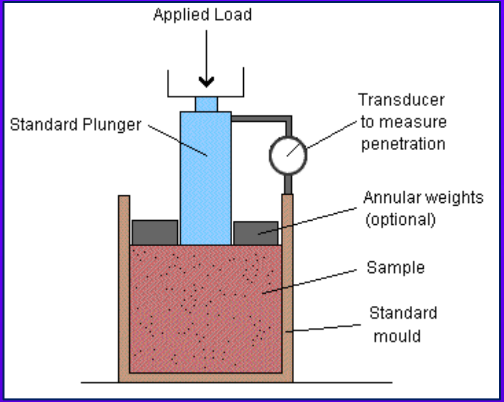
- CBR is a penetration test for evaluation of the mechanical strength of road subgrades and base courses
- The ratio of the force per unit area required to penetrate a soil mass with standard penetration plunger at a uniform rate of 1.25 mm/min., to the corresponding penetration load of the standard material or crushed stone is called CBR:

CBR (%) = 100*(Test load / Penetration load of standard material)

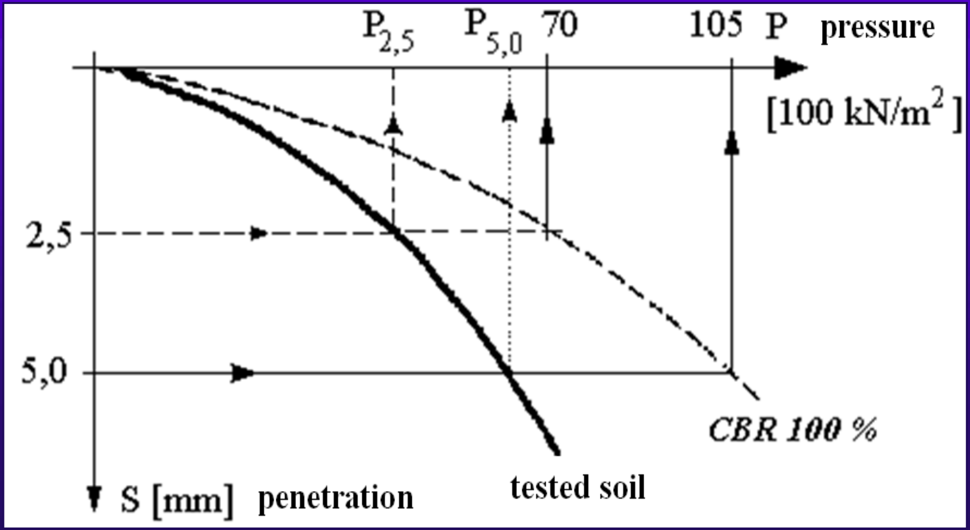
- It is generally used to classify & evaluate the soil subgrade & base course materials for flexible pavement

Type of soil	Amount of support	California Bearing Ratio (CBR%)
Fine-grained with high amounts of silt/clay	Low	2.5-3.5
Sand and sand-gravel with moderate silt/clay	Medium	4.5-7.5
Sand and sand-gravel with little or no silt/clay	High	8.5-12.0

CALIFORNIA BEARING RATIO (CBR) TEST 2



- 50 mm diameter piston/plunger advances by 1.3 mm/min rate into a saturated soil sample
- Measure load/pressure at 2.5 mm ($P_{2.5}$) and at 5.0 mm ($P_{5.0}$) penetration
- Standard (reference) pression values were measured on *crushed stone*



Calculate

$CBR\% = 100 * (P_{2.5} / 70)$ or

$CBR\% = 100 * (P_{5.0} / 105)$

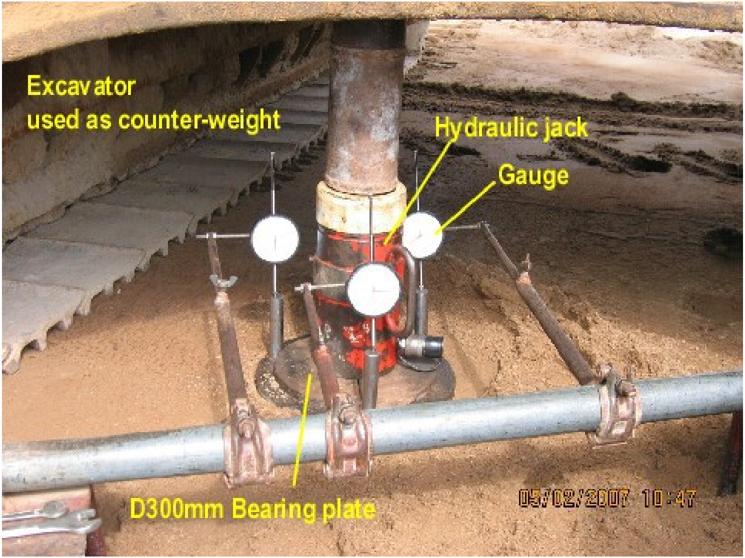
the *bigger value* prevails

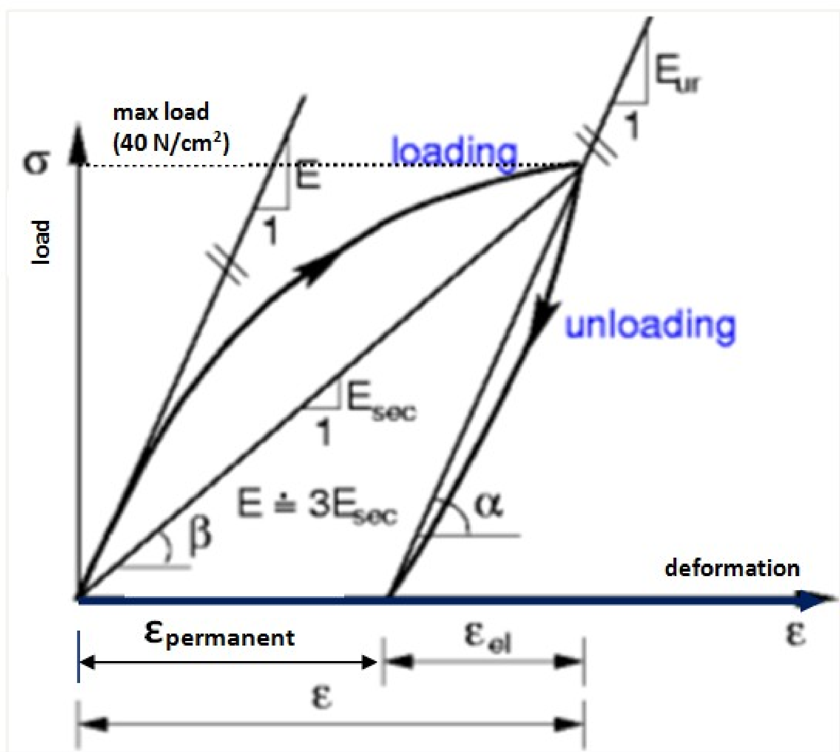
PLATE LOAD TEST 1

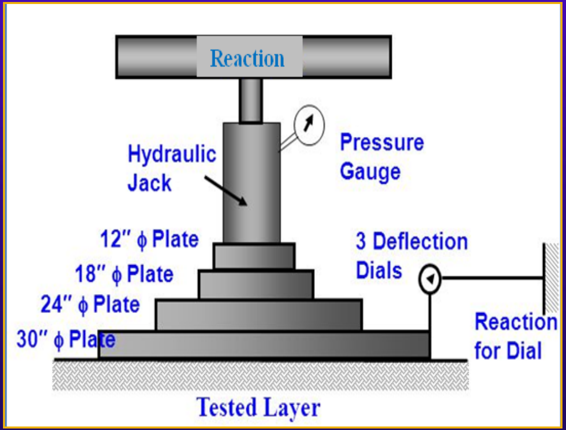
- *Plate Load Test* is a field test for determining the ultimate bearing capacity of soil and the likely settlement under a given load
- The static Plate Load Test basically consists of loading a steel plate placed at the formation and recording the settlements corresponding to each load increment
- The modulus of deformation (E_v) or modulus of elasticity (E) is determined from the load settlement line of the second load (E_{v2}); through the first loading a certain remaining deformation always appears
- A material's *resilient modulus* (M_R) is actually an estimate of its modulus of elasticity (E) and used for pavement design as a parameter of subgrade soil load capacity

PLATE LOAD TEST

2







where

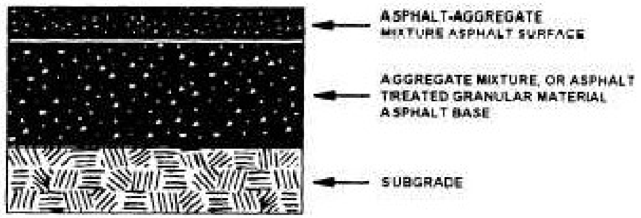
E = modulus of elasticity: $\sigma_{max}/\varepsilon_{el}$ [σ /cm]

r = 15 cm (radius of the plate)

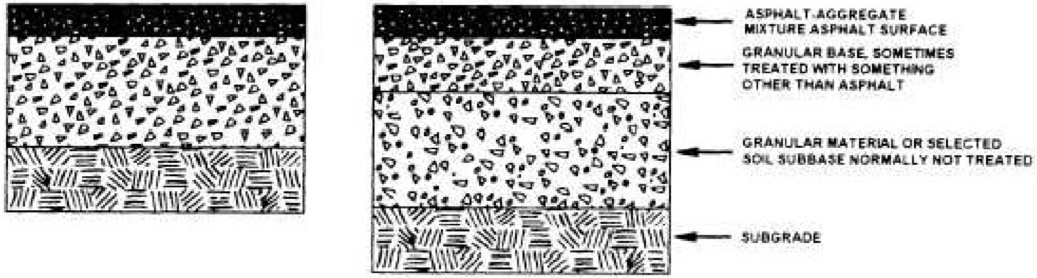
σ = load [N/cm^2]

ε_{el}= elastic deformation due to the 2nd loading [cm]

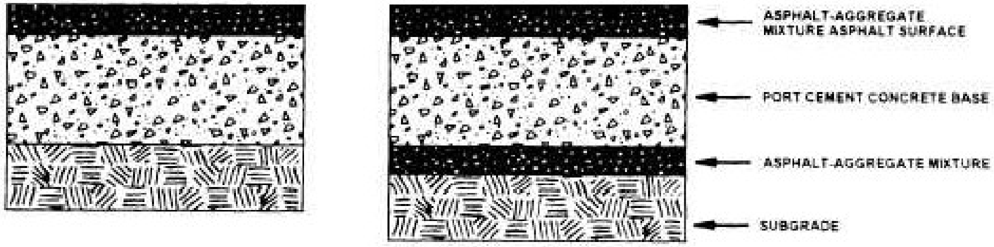
TYPICAL FLEXIBLE PAVEMENTS



FULL - DEPTH ASPHALT PAVEMENT



ASPHALT PAVEMENT WITH UNTREATED BASE (AND SUBBASE)

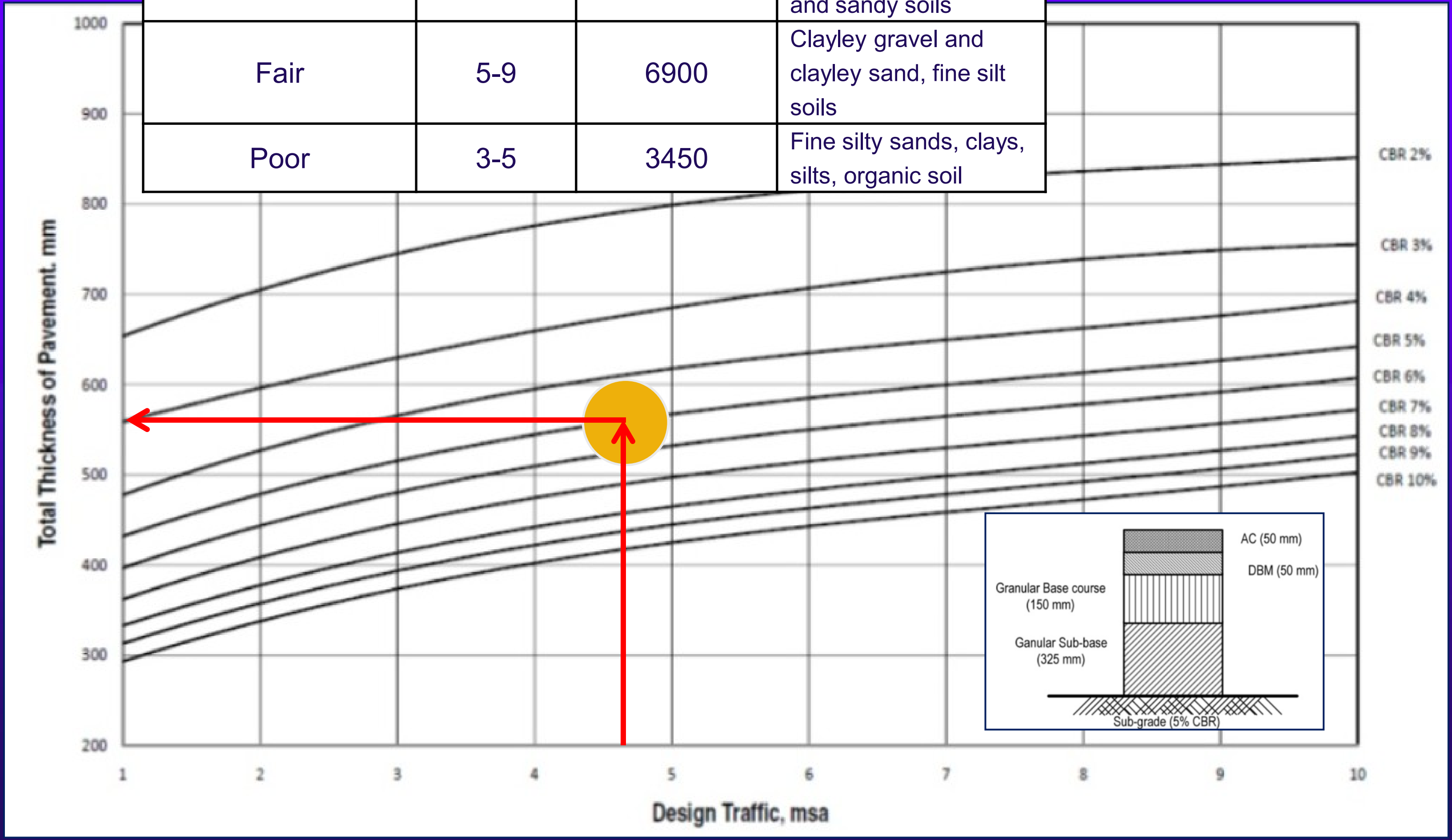


ASPHALT PAVEMENT WITH PORTLAND CEMENT CONCRETE OR COMBINED PORTLAND CEMENT CONCRETE AND ASPHALT BASE

FLEXIBLE PAVEMENT DESIGN CHART

(EXAMPLE 1)

Classification	CBR	M_R (N/cm^2)	Typical subgrade
Good	≥10	13800	Gravels, crushed stone and sandy soils
Fair	5-9	6900	Clayley gravel and clayley sand, fine silt soils
Poor	3-5	3450	Fine silty sands, clays, silts, organic soil



FLEXIBLE PAVEMENT DESIGN CHART (EXAMPLE 2)

Classification	CBR	M_R (N/cm^2)	Typical subgrade
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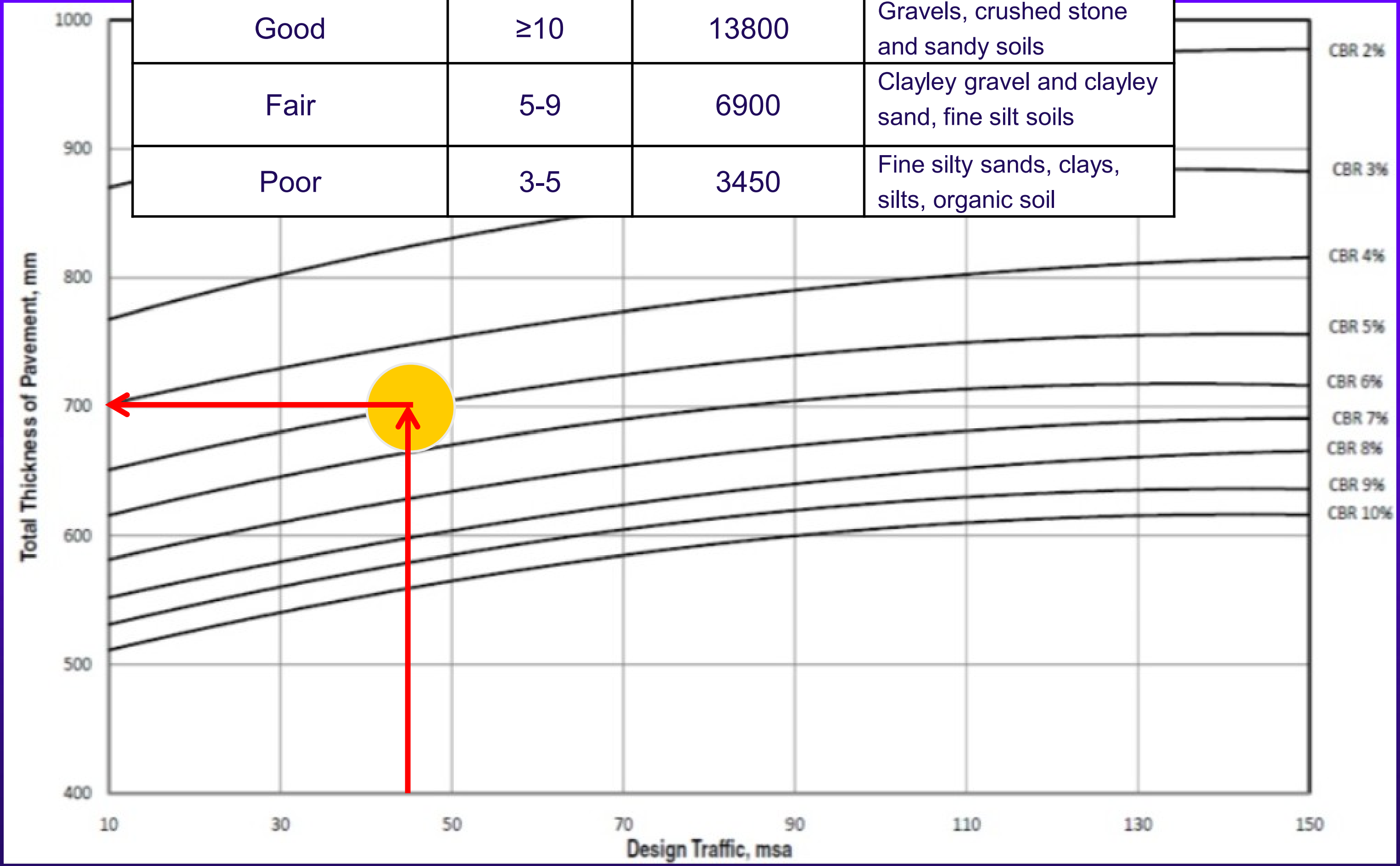
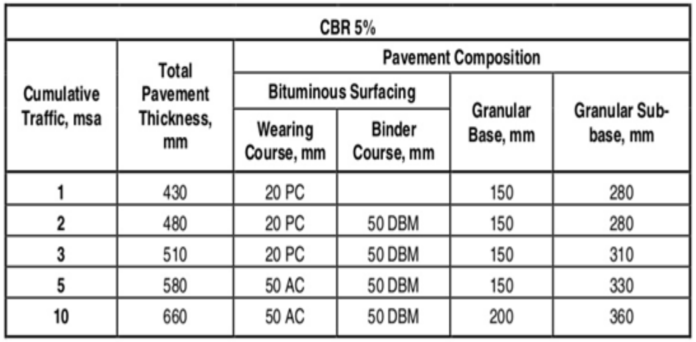
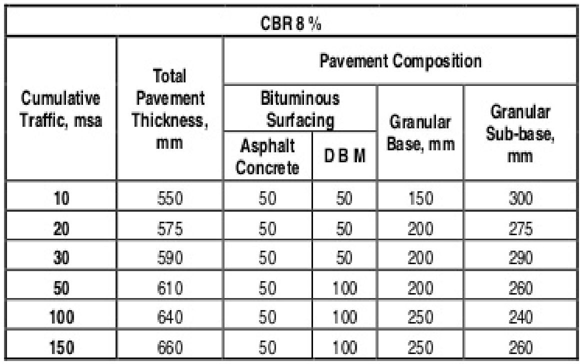


FLEXIBLE PAVEMENT DESIGN CATALOGUE (EXAMPLES)



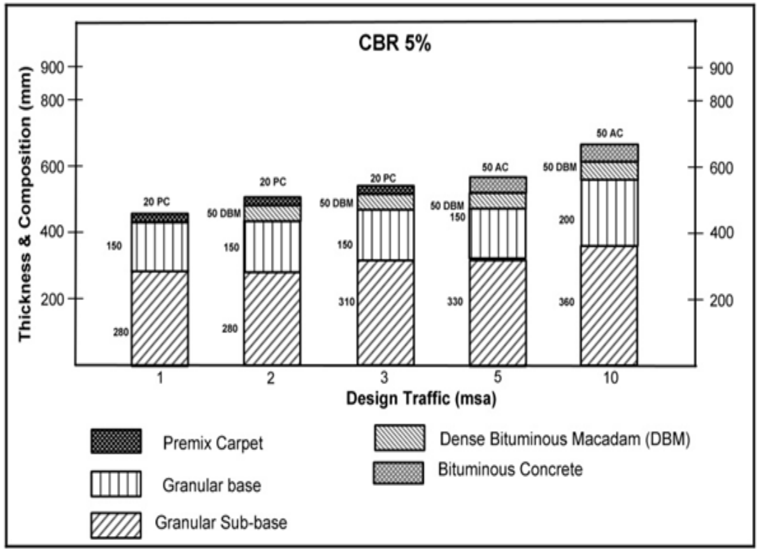
CBR 5%

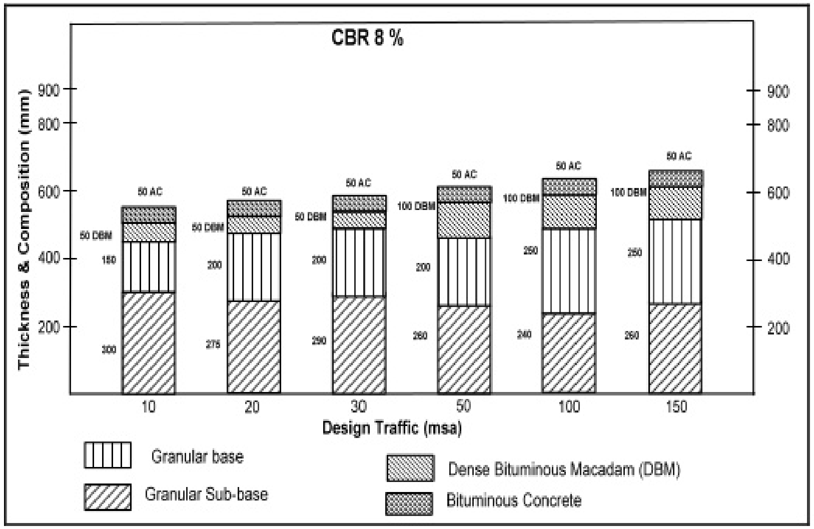
Cumulative Traffic, msa	Total Pavement Thickness, mm	Pavement Composition			
		Bituminous Surfacing		Granular Base, mm	Granular Sub-base, mm
		Wearing Course, mm	Binder Course, mm		
1	430	20 PC		150	280
2	480	20 PC	50 DBM	150	280
3	510	20 PC	50 DBM	150	310
5	580	50 AC	50 DBM	150	330
10	660	50 AC	50 DBM	200	360



CBR 8 %

Cumulative Traffic, msa	Total Pavement Thickness, mm	Pavement Composition			
		Bituminous Surfacing		Granular Base, mm	Granular Sub-base, mm
		Asphalt Concrete	D B M		
10	550	50	50	150	300
20	575	50	50	200	275
30	590	50	50	200	290
50	610	50	100	200	260
100	640	50	100	250	240
150	660	50	100	250	260





ACRONYMS OT TYPICAL MIXES

- AC = Asphalt Concrete
- BBM = Bitumen Bound Macadam
- BEMIX = Bitumen Emulsion Mix
- BM = Bituminous Macadam
- BUSG = Built Up Spray Grout
- BST = Bituminous Surface Treatment
- CRCP = Continuously Reinforced Concrete Pavement
- DBM = Dense Bitumenous Macadam
- GSB = Granular Sub-Base
- HMA = Hot Mix Asphalt (formerly AC)
- OGFC = Open Graded Friction Course
- PC = Premix Carpet
- PCCP = Portland Cement Concrete Pavement
- PPCP = Precast Panel Concrete Pavement
- RHMA = Rubberized Hot Mix Asphalt
- RSC = Rapid Strength Concrete
- SDBC = Semi-Dense Bituminous Concrete
- WBM = Water Bound Macadam
- WMM = Wet Mix Macadam
- WMA = Warm-Mix Asphalt

RIGID PAVEMENT DESIGN

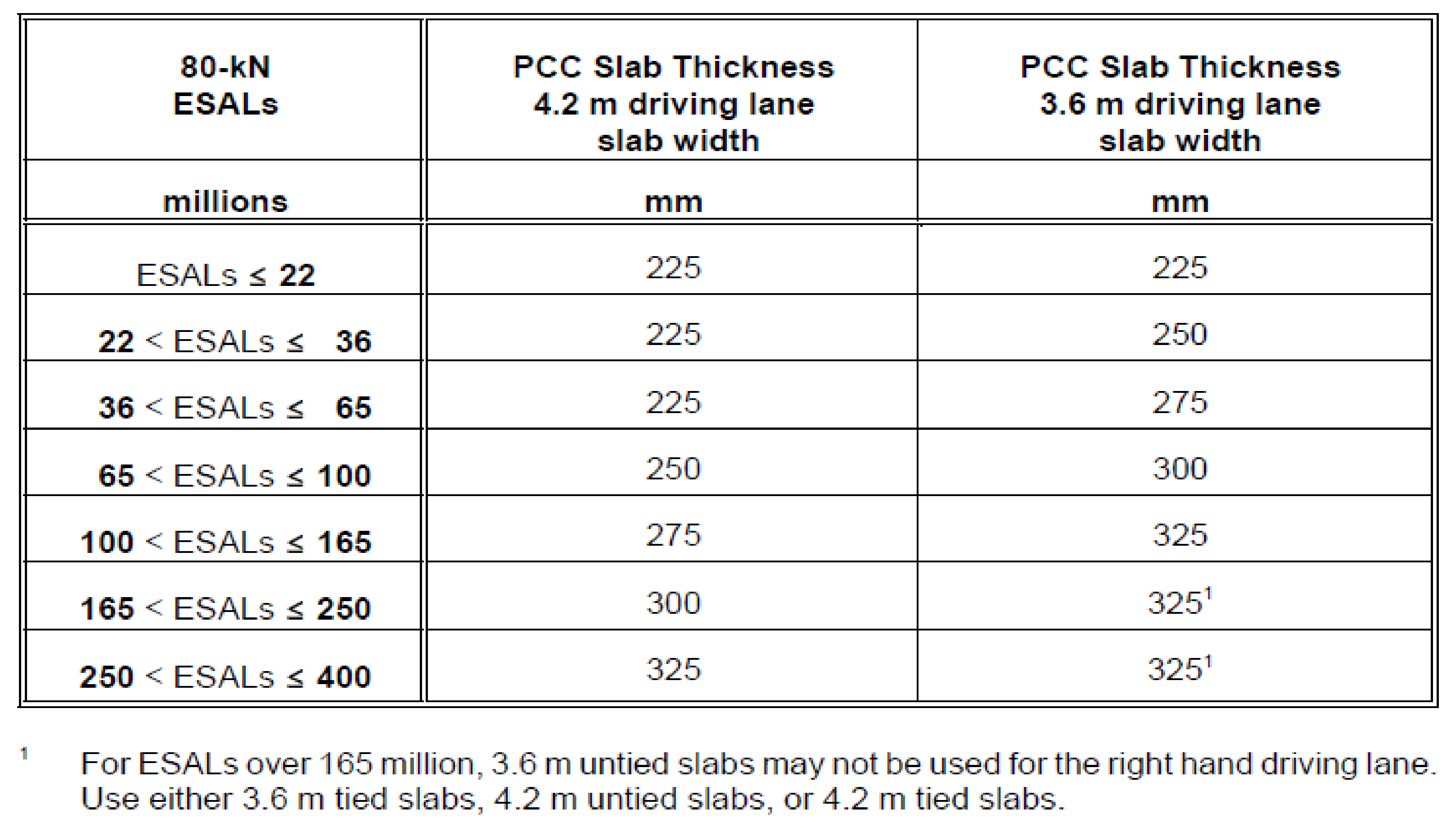
- Such pavements are "stiffer" than flexible pavements due to the high modulus of elasticity of the *Portland Cement Concrete* (PCC) material
- Further, these pavements can have reinforcing steel, which is generally used to reduce or eliminate joints
- Because of its relative rigidity, the pavement structure distributes loads over a wide area with only one, or at most two structural layers
- Although this type of pavement is salt sensitive (winter maintenance), it can serve 20 to 40 years with little or no maintenance or rehabilitation and often used in urban areas (bus stops) as well as for roads and airports with heavy traffic load (>10^7 ESALs during design life)

RIGID PAVEMENT DESIGN PROCEDURE

- Select the design life (years)
- Calculate cumulated total number of ESALs expected during design life
- Determine the subgrade *resilient modulus* (M_r) or/and CBR (%)
- Select a drainage system, including the type of permeable drainage layer (if needed)
- Determine the driving lane slab width
- Determine pavement thickness based on total number of ESALs and slab width
- Layout the transverse and longitudinal joints
- Select the individual top and base course according to the standardised selection guidelines or using a pavement type catalogue

RIGID PAVEMENT THICKNESS

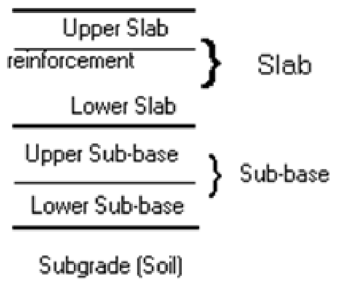
(USA)



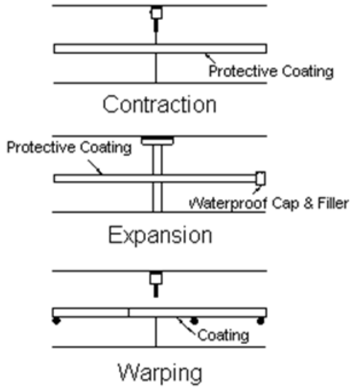
80-kN ESALs	PCC Slab Thickness 4.2 m driving lane slab width	PCC Slab Thickness 3.6 m driving lane slab width
millions	mm	mm
ESALs ≤ **22**	225	225
22 < ESALs ≤ **36**	225	250
36 < ESALs ≤ **65**	225	275
65 < ESALs ≤ **100**	250	300
100 < ESALs ≤ **165**	275	325
165 < ESALs ≤ **250**	300	325[1]
250 < ESALs ≤ **400**	325	325[1]

[1] For ESALs over 165 million, 3.6 m untied slabs may not be used for the right hand driving lane. Use either 3.6 m tied slabs, 4.2 m untied slabs, or 4.2 m tied slabs.

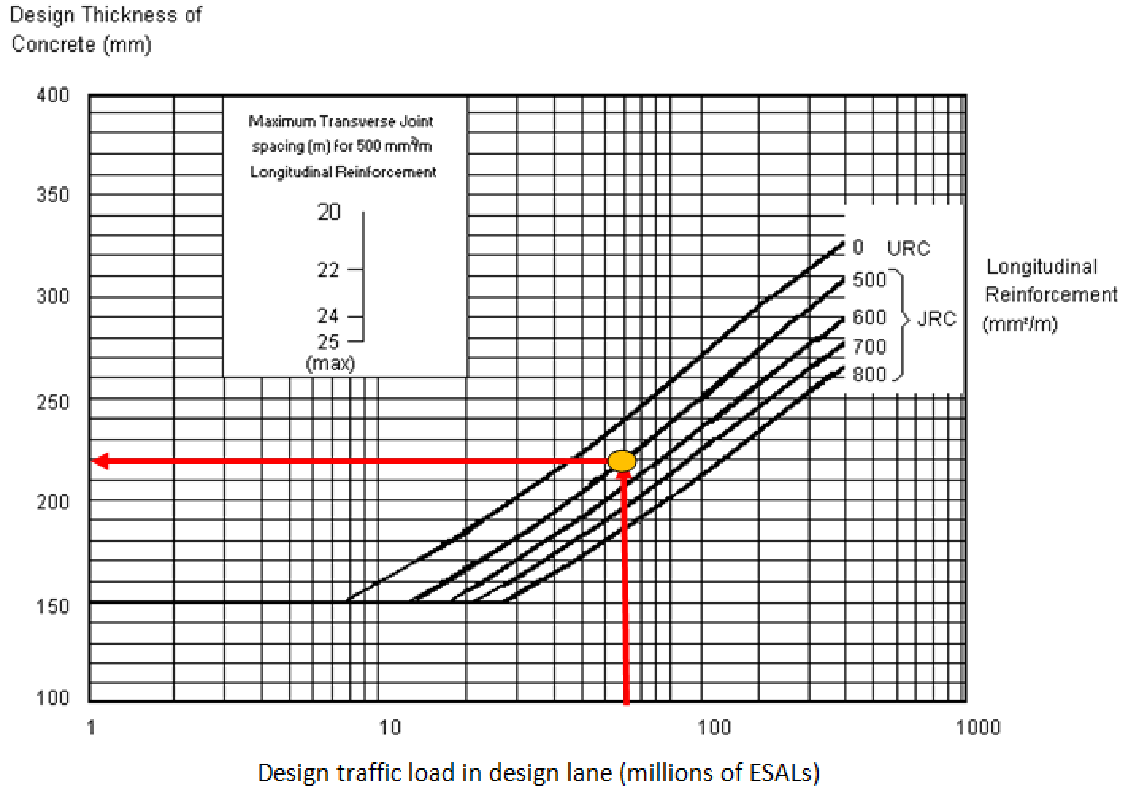
RIGID PAVEMENT DESIGN CHART



RIGID PAVEMENT LAYOUT



PAVEMENT JOINT TYPES



UnReinforced Concrete (URC) *For an URC pavement, the joint spacing is dependent on the slab thickness. For slabs thicker than 230mm contraction joints should be every 5m. For slabs under 230mm thick contraction joints should be every 4m. Expansion joints should replace every third contraction joint, ie. at a spacing of 12m or 15m.*

Jointed Reinforced Concrete (JRC) *For contraction joints this is generally at a standard distance of 25m, unless there is* $500 mm^2/m$ *of reinforcement when the spacing is taken from the design chart. For expansion joints, replace every third contraction joint with an expansion joint. For example a pavement with contraction joint spacing of 25m has an expansion joint spacing of 75m.*

WHEN HMA & PCC PAVEMENTS MEET

(M0 Motorway, HU)

STRENGTHENING OF FLEXIBLE PAVEMENTS

- *Strengthening* of pavement is defined as the process of providing the required overlays on the existing (deteriorated) pavements so, that it performs more efficiently over a given design period of time under expected dynamic and static loads, once the pavement is evaluated
- When the rate of traffic volume growth exceeds the forecast value, due to lack of traffic capacity *and* loss of loading capacity, some extra width of pavement in both sides of the road should be provided, which is known as *widening*
- Strengthening and widening of existing pavements are often implemented simultanously

STEPS IN DESIGN OF OVERLAYS

- Measurement and estimation of the strength of the existing (partly deteriorated) pavement
- Design life of pavement to be strengthened by an overlay
- Estimation of the traffic to be carried by the overlaid pavement
- Determination of the thickness and selection of the type of overlay
- Methods:
  - Effective thickness method
  - Deflection approach

EFFECTIVE THICKNESS METHOD 1

- Basic concept:
  - Thickness of overlay is the difference between the thickness required for a new pavement and the *effective thickness* of the existing pavement:

$$h_{OL} = h_n - h_{eff}$$

where

- h_{OL} = thickness of *overlay*
- h_n = thickness of new pavement
- h_{eff} = effective thickness of existing pavement calculated on the base of remaining load capacity

EFFECTIVE THICKNESS METHOD 2

- All thicknesses of new and existing materials must be converted into an *equivalent thickness* (h_e) of asphalt concrete (AC)

$$h_e = \sum_{i=1}^{n} h_i C_i$$

where

- h_i = thickness of layer i
- C_i = conversion factor for layer i

ASPHALT INSTITUTE CONVERSION FACTORS *(C)*

❖ Sub-grade	0.0
❖ Granular sub-base, reasonably well graded, hard aggregates with some plastic fines and CBR not less than 20%. Use upper part of range if Plasticity Index (PI) is less than 6; lower part of range if PI is more than 6	0.1 – 0.2
❖ Asphalt concrete surfaces and bases that exhibit appreciable cracking and crack patterns	0.5 – 0.7
❖ Asphalt concrete surfaces and bases that exhibit some fine cracking, have small intermittent cracking patterns and slight deformation in the wheel paths but remain stable	0.7 – 0.9
❖ Asphalt concrete, including asphalt concrete base, generally un-cracked, and with little deformation in the wheel-paths	0.9 – 1.0

DEFLECTION APPROACH

- The structural strength of pavement is assessed by measuring surface deflections under a standard axle load
- Larger pavement deflections imply weaker pavement and subgrade - the overlay must be thick enough to reduce the deflection to a tolerable amount
- Rebound deflections are measured with the help of a *Benkelman Beam* (which consists of a slender beam 3.66m long pivoted at a distance of 2.44m from the tip) or by *falling weight deflectometer* (FWD)
- By suitably placing the probe between the dual wheels of the loaded truck, it is possible to measure the rebound and residual deflections of the pavement structure
- FWD data are primarily used to estimate pavement structural capacity for (i) overlay design and (ii) to determine if a pavement is being overloaded

CHARACTERISTIC DEFLECTION

- Overlay design for a given section is not based on individual deflection values but on a *statistical analysis* of all the measurements in the section corrected for temperature and seasonal variations
- This involves calculation of *mean deflection*, *standard deviation* and *characteristic deflection*
- *Characteristic deflection* (D_c) for design purposes shall be taken as given in the following equations :

$D_c = D_M + 2\sigma$ ……………....for major arterial roads

$D_c = D_M + \sigma$ ……………….for all other roads

where

D_M = mean deflection, mm

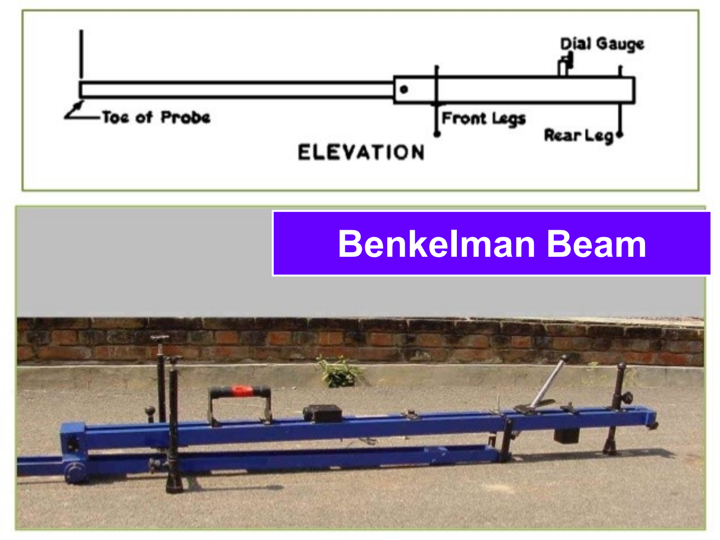
σ = standard deviation, mm

SPECIFICATIONS FOR MEASUREMENT

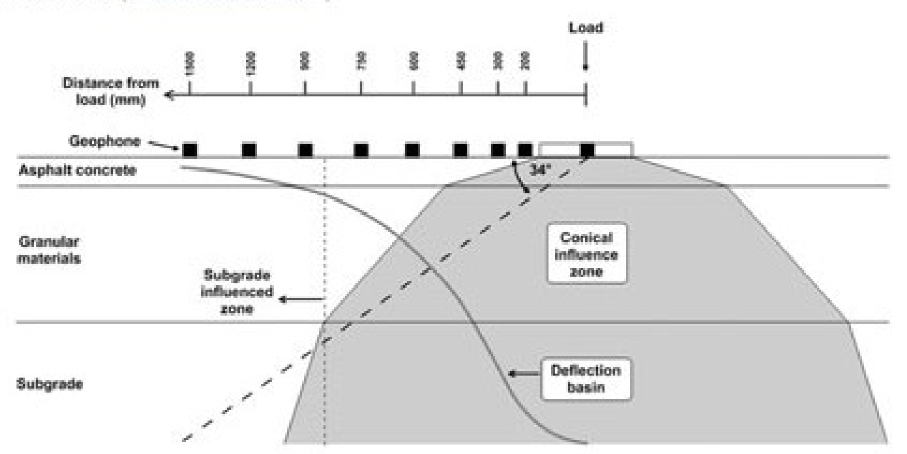
- Condition survey and deflection data are used to establish sections of uniform performance
- At least 10 deflection measurements should be made for each section per lane subject to a minimum of 20 measurements per km
- If the highest or the lowest deflection values for the section differ from the mean by more than one-third of the mean, then extra deflection measurement should be made at 25 m on either side of point where high or low values are observed
- Relationship between measured deflections:

$$D_{Benkelman} = 1.61 * D_{FWD}$$

MEASURING DEFLECTIONS



Benkelman Beam



Principles of FWD tests

Heavy and Light Falling Weight Deflectometer (FWD)

DESIGN OF OVERLAY

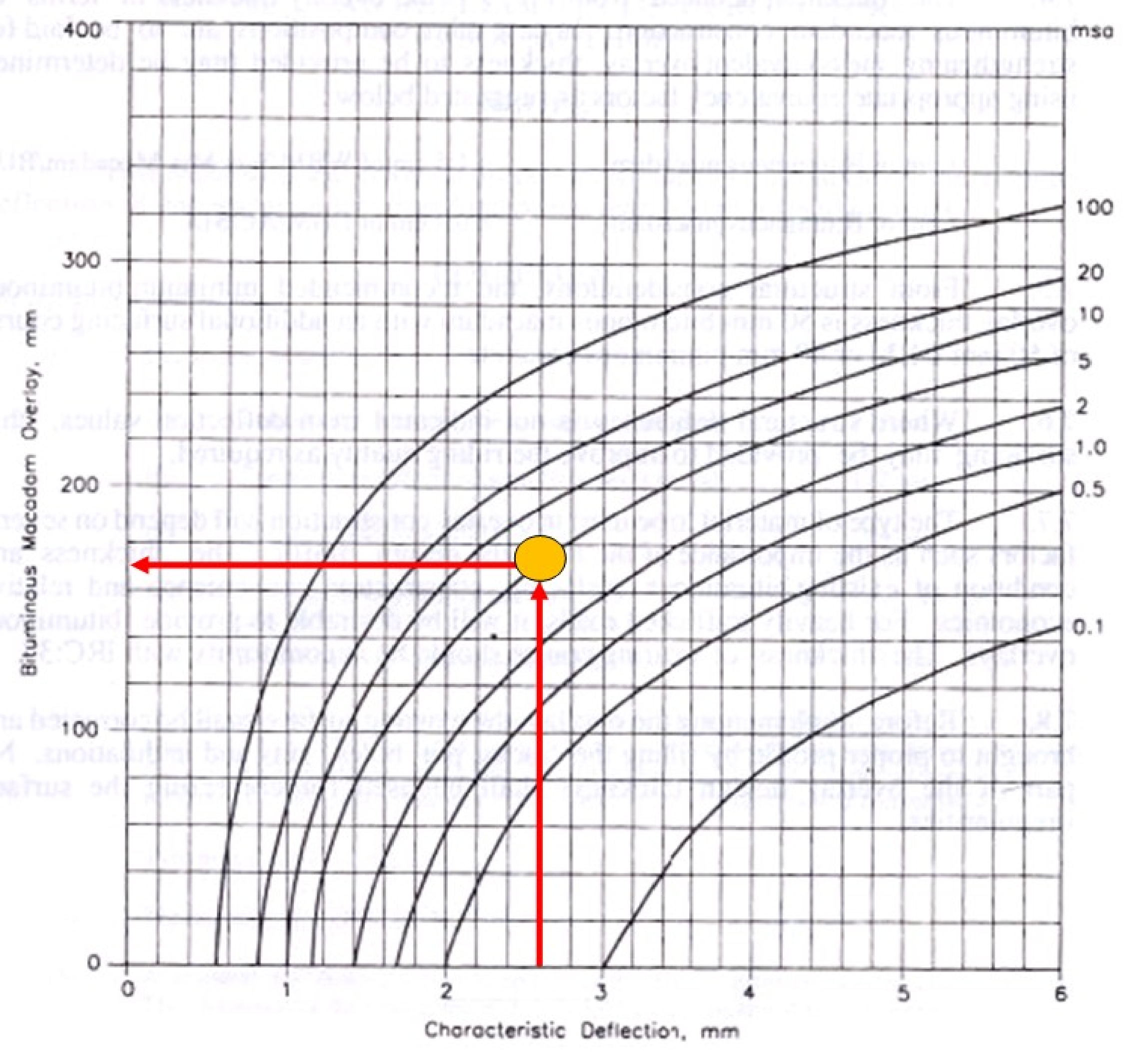
- Design curves relating characteristic pavement deflection to the cumulative number of standard axles are to be used
- Deflection of the pavement after the corrections, i. e. Characteristic Deflection is to be used for the design purposes
- The design traffic in terms of cumulative number of standard of axles is to be used
- The thickness obtained from the curves is in terms of Bituminous Macadam (BM) construction
- If other compositions are to be laid then 1 cm of

  BM = 1.5 cm of WBM/Wet Mix Macadam/BUSG and

  1 cm of BM = 0.7 cm of DBM/HMA/SDBC

OVERLAY THICKNESS DESIGN CURVES

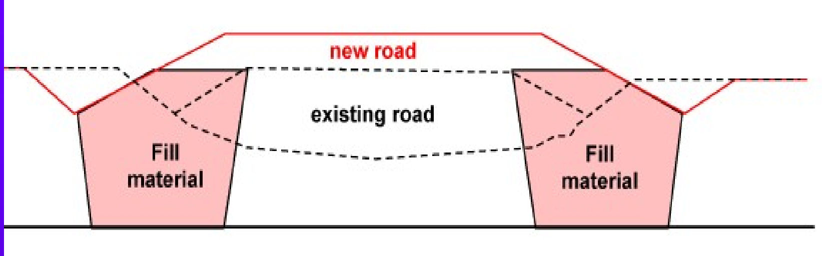
(EXAMPLE)

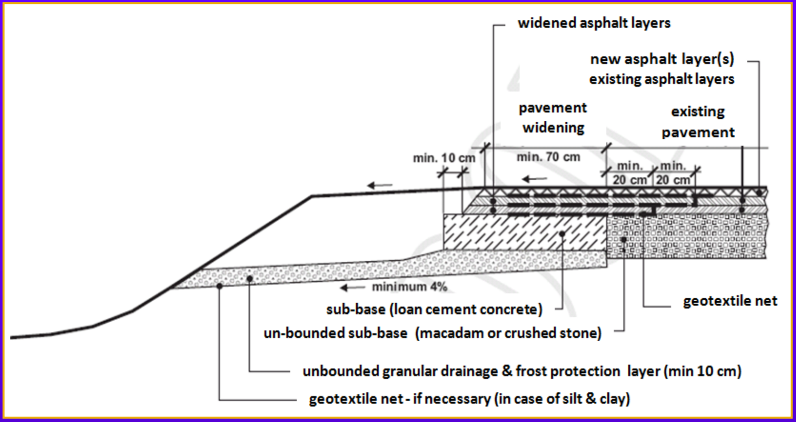


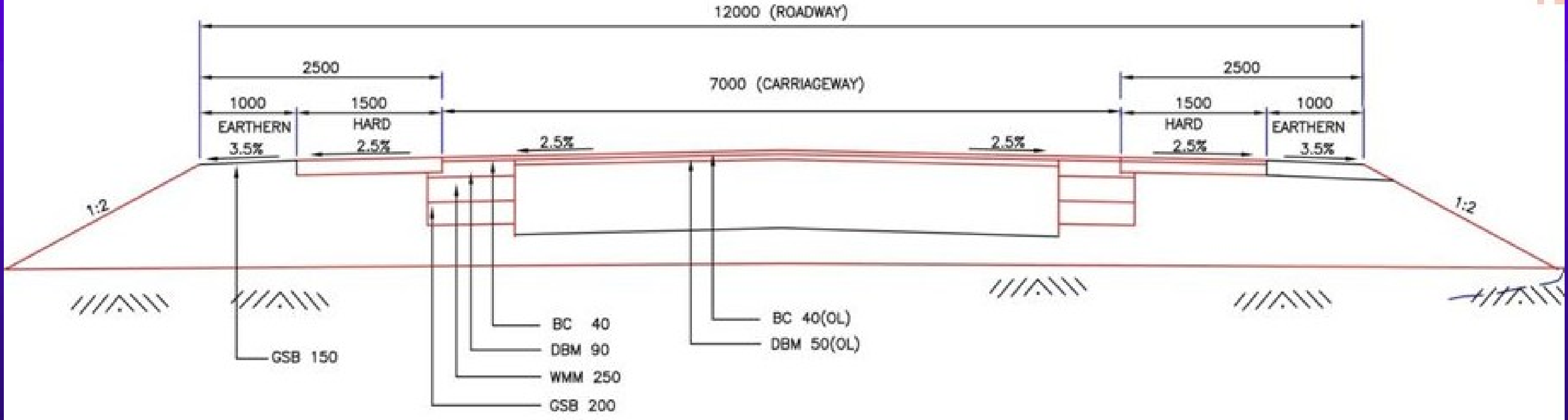
BUILDING AN OVERLAY

- Before implementing the overlay, the existing surface is to be *corrected and brought to proper profile* by filling potholes, ruts and undulations
- *No part* of the overlay thickness shall be used for the correction of surface irregularities
- If permitted deflection limits are approached, *undersealing* is recommended
- Under the widening, *drainage* and *frost protection* problems has to be thoroughly considered and duly solved

STRENGTHENING & WIDENING A PAVEMENT







TYPICAL CROSS SECTION OF STRENGHTENING & WIDENING
FOR PROPOSED 7.0m FROM 5.50 MAIN CARRIGEWAY