HIGHWAY ENGINEERING
SAB2832

STRUCTURAL DESIGN OF FLEXIBLE PAVEMENT

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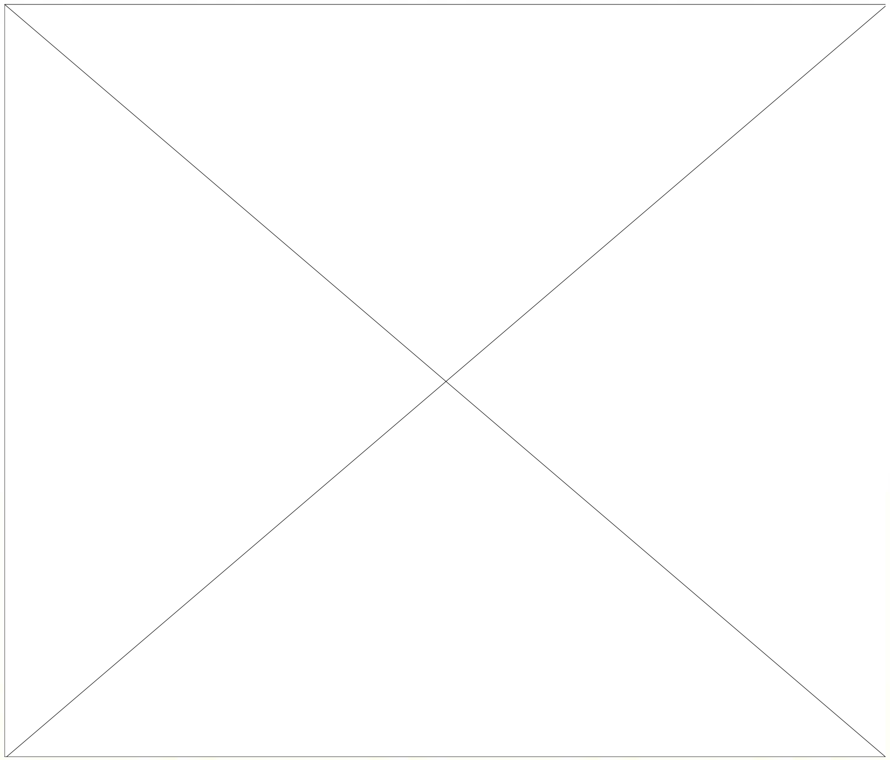
Structural design of flexible pavement

1. Introduction
2. Elements of a Flexible Pavement Structure
3. Factors to be Considered in the Design
4. Methods of Design for New Pavements
5. Malaysian Design Methods

Introduction

Aim: to design a structure that will ensure that the transmitted stresses are sufficiently reduced and do not exceed the capacity of the underlying subgrade

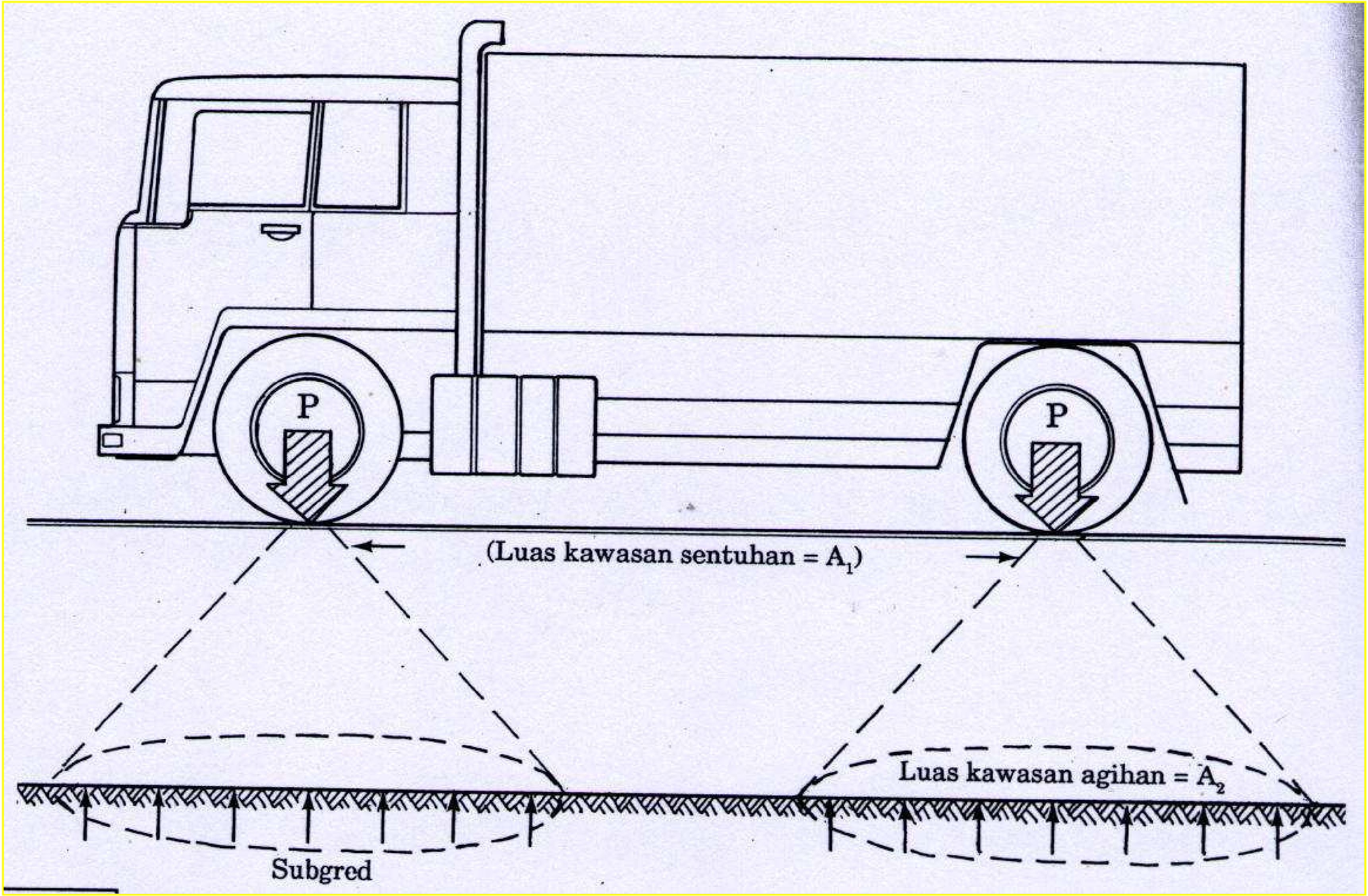


Flexible pavement structure

Elements of a flexible pavement:

1. Sub-grade – upper layer of natural soil or fill, support load transmitted from overlaying layers.
2. Sub-base – specified material, secondary load spreading layer, prevent infiltration of sub-grade into pavement, construction platform for construction traffic, drainage layer
3. Road base – specified material, main load spreading layer, provide pavement with added stiffness and resistance to fatigue
4. Surfacing – uppermost layer, provide safe & comfortable riding surface, withstand traffic stresses, protect lower layers, impermeable and flexible, may consist of BC and WC, premix layer.

Load Distribution

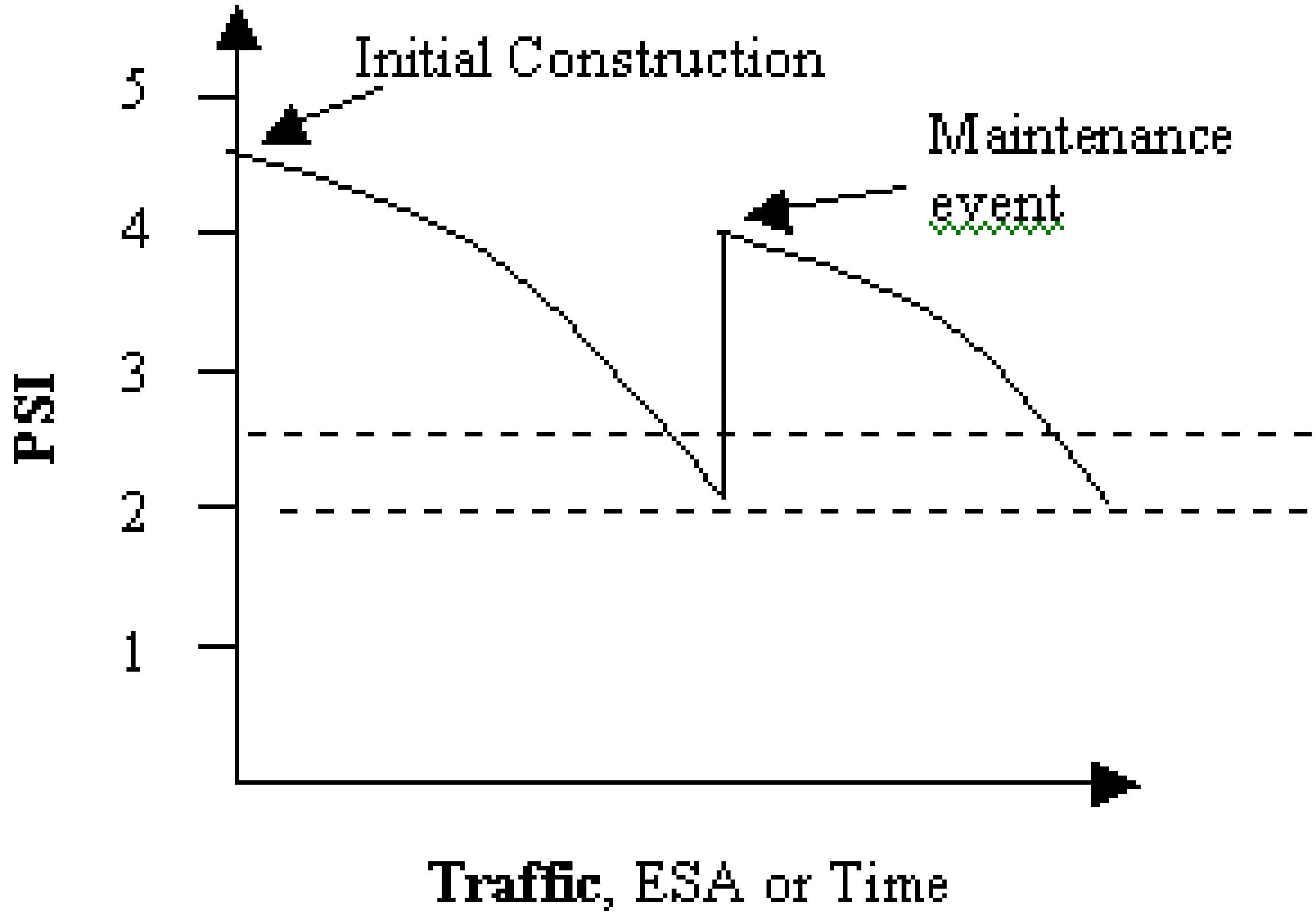


Factors to be Considered in The Design

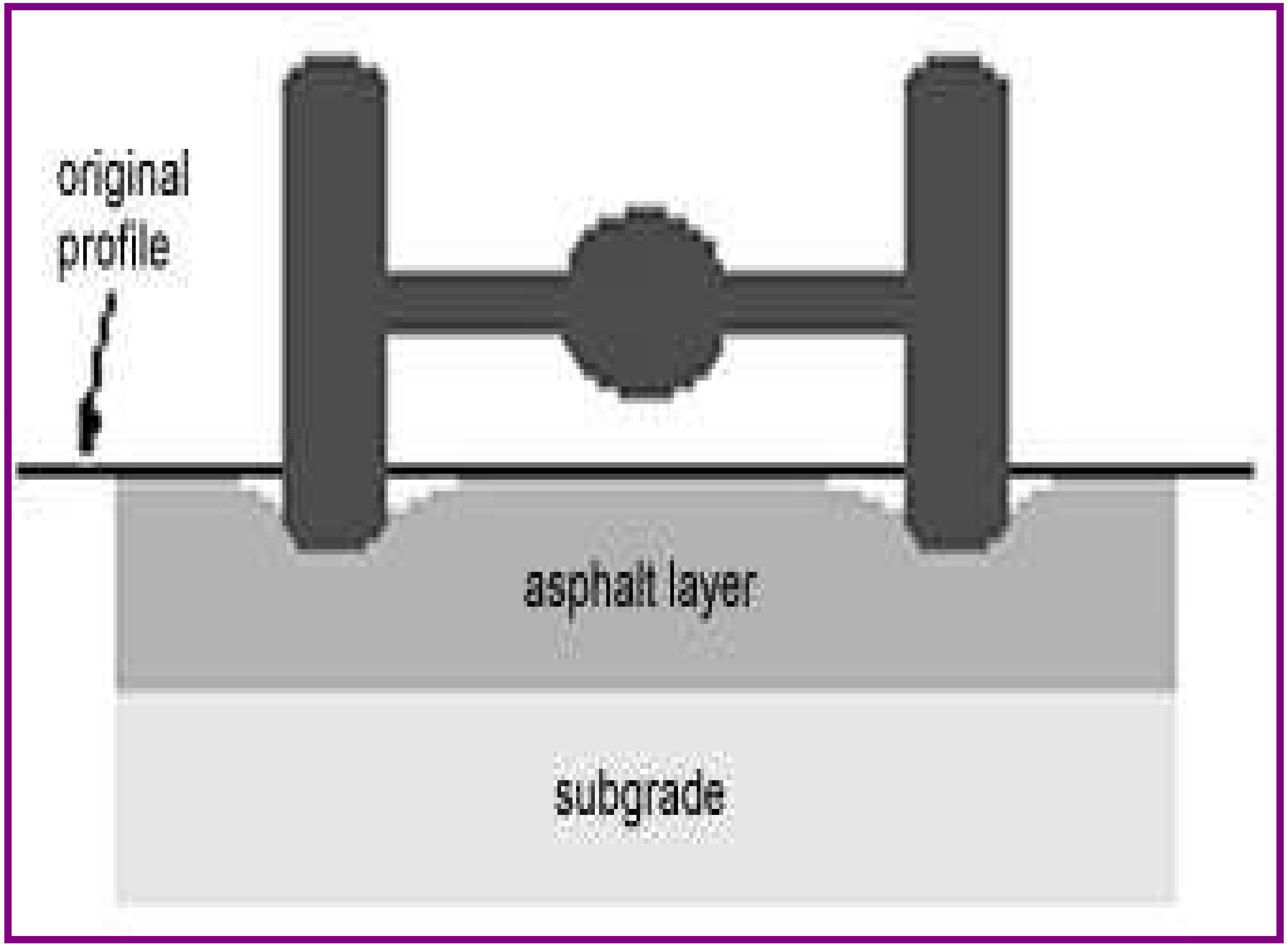
1. Failure mechanism – permanent deformation and cracking rut (accumulation of permanent strain – water ponding) crack (fracture failure under repeated or fluctuating stress – fatigue failure in the bituminous layer)

2. Traffic loading – pavement design must account for cumulative traffic loading during design life
   a. Tire loads & pressure – contact load and area
   b. Axle & wheel configuration – no of contact points
   c. Load repetition – cumulative
   d. Traffic distribution – lane, direction
   e. Speed – loading period (slow, climbing)

Present serviceability index



Rut



Factors to be Considered in The Design

f. ESA – convert wheel loads to standard loads

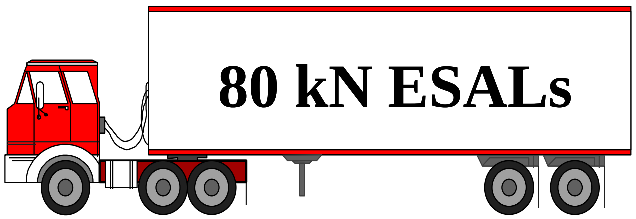
std load = 80 kN, 8160 kg, or 18000 lb

load equivalency factor, $e = (L/Ls)^n$

consider only commercial vehicles

CV (BTM > 1.5 ton, 3 ton for RN31)

3. Environmental – temperature (asfalt – brittle/soft) and moisture (safety of users and pavement)



Commercial vehicle

COMMERCIAL VEHICLE

Methods of Design for New Pavements

Objective – to determine the number, material composition, and thickness of different layers that will be suitable in a specific environment and able to sustain the anticipated traffic loading

Three methods:

1. Precedent – rule-of-thumb, std thickness for particular road classification
2. Empirical – soil classification or strength using experience, experimentation, or both
3. Theoretical/semi – mechanistic, based on mechanical model, relate pavement parameters (stress, strains, deflections) to physical causes (loads, material properties) using mathematical model

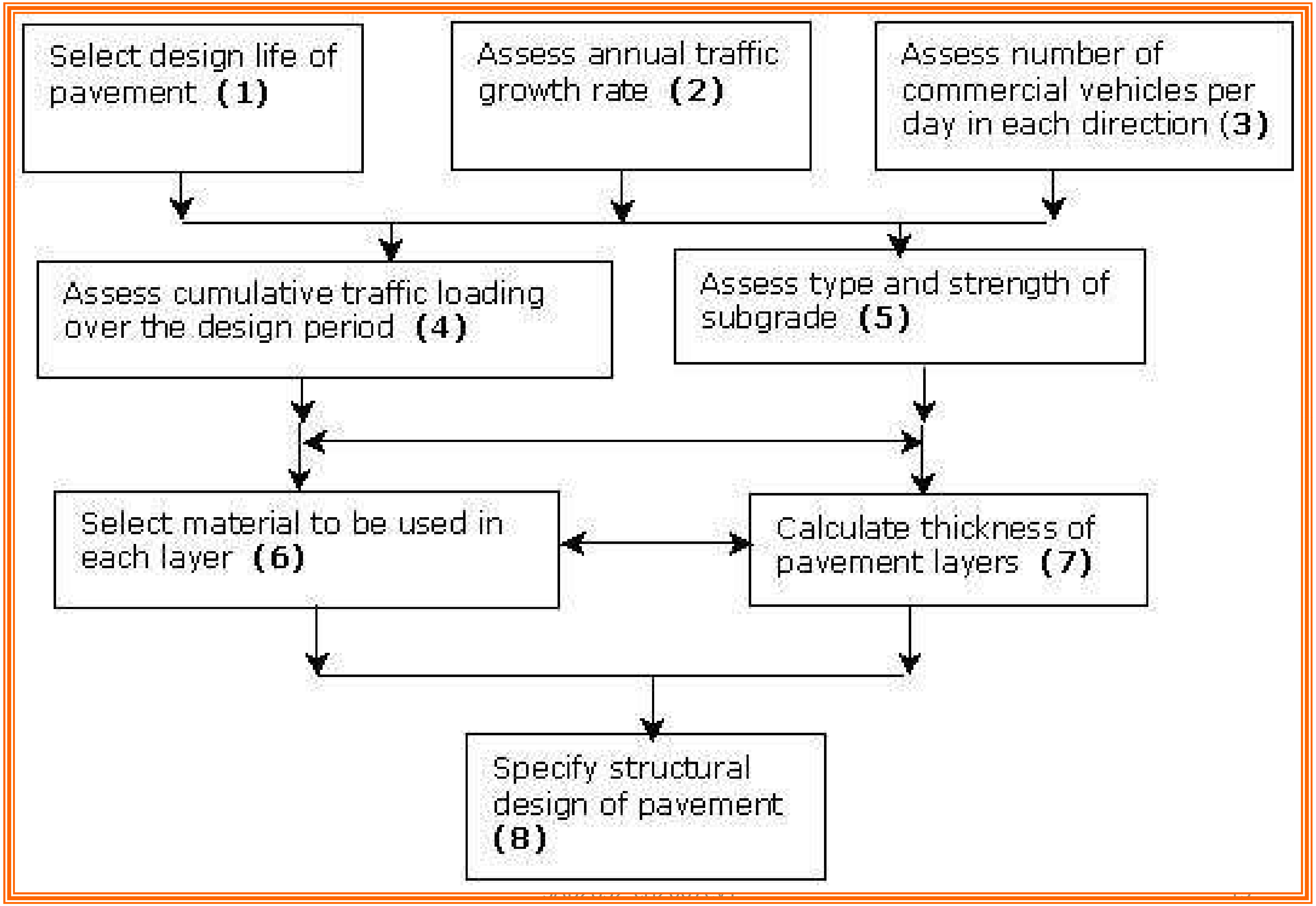
Methods of Design for New Pavements

Advantages of mechanistic-empirical:

a. Can be use for new construction and rehabilitation
b. Accomodate various load types
c. More reliable performance prediction (use material properties)
d. Accomodate environmental and aging effects on materials

Steps in design process

Design Process



Malaysian Design Methods

Adopt design method based on AASHTO Guide, and catalogue of structure method

1. Arahan Teknik Jalan 5/85 – based on AASHO road test, developed using multi-layered elastic theory. Suitable for major roads with heavy and medium traffic
2. Overseas Road Note 31 – based on research in tropical and sub-tropical countries. Design to cater traffic up to 30MSA in one direction

PAVEMENT THICKNESS DESIGN ATJ 5/85

Data required:

1. Design period, n – suggests 10 years
2. Class of roads
3. Initial Average Daily Traffic - ADT
4. Percentage of Commercial Vehicle - Pc
5. Average annual traffic growth - r
6. Sub-grade strength - CBR
7. Terrain condition

PAVEMENT THICKNESS DESIGN
ATJ 5/85

Design Procedure:

1. Calculate Vo = ADT x (1/2) x 365 x (Pc/100)
2. Calculate Vc= Vo [(1 + r)^n - 1] / r
3. Calculate cumulative ESA, ESA = Vc x e (Table 3.1 or e = 2.52)
4. Check daily capacity (Table 3.2, 3.3, 3.4)
5. Determine sub-grade CBR
6. Obtain equivalent thickness, TA' from nomograph
7. Calculate thickness for each layer (Table 3.5, 3.6, 3.7)

   $TA' = S_N = a_1D_1 + a_2 D_2 + ... + a_nD_n$
8. Sketch the designed thickness

UTM

Equivalence Factor

Percentage of selected heavy goods vehicles	0 - 15 %		16 - 50 %	51 - 100 %
Type of road	Local	Trunk		
Equivalence factor, e	1.2	2.0	3.0	3.7

Maximum Hourly capacity

Road type	Passenger vehicle unit per hour
Multilane	2000 per lane
2 lane (both ways)	2000 total for both ways
3 lane (both ways)	4000 total for both ways

Reduction Factor

Carriageway width (m)	Shoulder width (m)			
	2.00	1.50	1.25	1.00
7.5	1.00	0.97	0.94	0.90
7.0	0.88	0.86	0.83	0.79
6.0	0.81	0.78	0.76	0.73
5.0	0.72	0.70	0.67	0.64

TERRAIN FACTOR

Type of terrain	Factor
Flat	$T = 100/(100 + P_c)$
Rolling	$T = 100/(100 + 2P_c)$
Mountainous	$T = 100/(100 + 5P_c)$

LAYER COEFFICIENT

Component	Type of Layer	Property	Coefficients
Wearing and Binder Course	Asphaltic Concrete		1.00
Road Base	Dense Bituminous Macadam	Type 1: Stability > 400 kg	0.80
		Type 2: Stability > 300 kg	0.55
	Cement stabilized	Unconfined Compressive strength (7 days) 30 – 40 kg/cm^2	0.45
	Mechanically stabilized crushed aggregate	CBR $\geq$ 80 %	0.32
Sub-base	Sand, laterite, etc.	CBR $\geq$ 20 %	0.23
	Crushed aggregate	CBR $\geq$ 30 %	0.25
	Cement stabilized	CBR $\geq$ 60 %	0.28

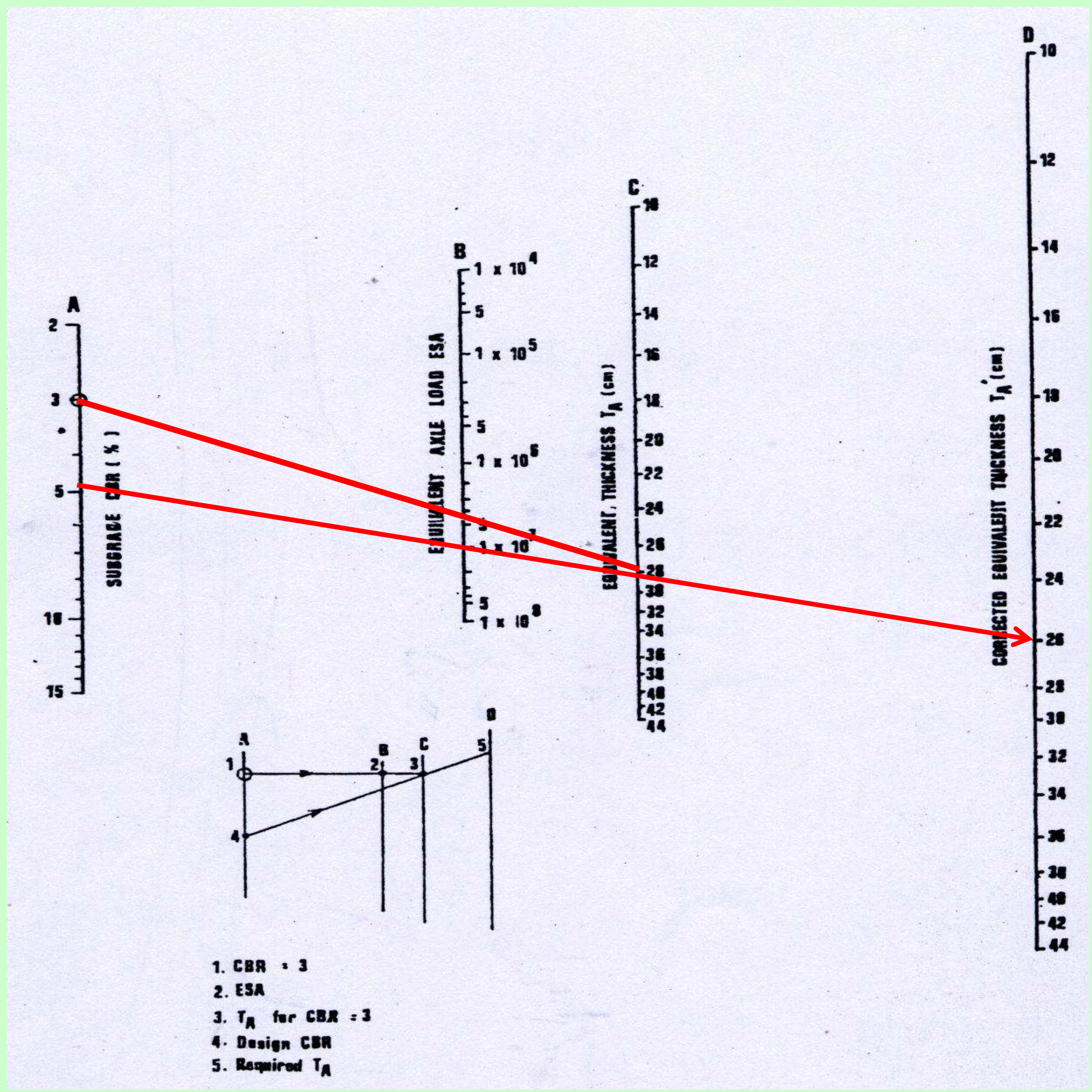
Standard and Construction thickness

Type of Layer		Standard Thickness (cm)	One Layer Lift (cm)
Wearing Course		4 - 5	4 - 5
Binder Course		5 - 10	5 - 10
Road Base	Bituminous	5 - 20	5 - 15
	Wet Mix	10 - 20	10 - 15
	Cement Stabilized	10 - 20	10 - 20
Sub-base	Granular	10 - 30	10 - 20
	Cement Stabilized	15 - 20	10 - 20

Minimum thickness of bituminous layer

TA' (cm)	Total Thickness of bituminous Layer (cm)
< 17.5	5.0
17.5 - 22.5	10.0
23.0 - 29.5	15.0
> 30.0	17.5

Nomograph



A
2
3
5
10
15
SUBGRADE CBR (%)
B
1 x 10^4
5
1 x 10^5
5
1 x 10^6
5
1 x 10^7
5
1 x 10^8
EQUIVALENT AXLE LOAD ESA
C
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
EQUIVALENT THICKNESS T_A (cm)
D
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
CORRECTED EQUIVALENT THICKNESS T_A' (cm)
A
B
C
D
1
2
3
4
5
1. CBR = 3
2. ESA
3. T_A for CBR = 3
4. Design CBR
5. Required T_A

PAVEMENT THICKNESS DESIGN ATJ 5/85

In case of varying CBR for 1m depth of sub-grade, mean CBR is determined as follows:

$$CBR_m = [(h_1 CBR_1^{1/3} + h_2 CBR_2^{1/3} + \ldots + h_n CBR_n^{1/3}) / (1000)]^3$$

where:

CBR_m = mean CBR for that location

$CBR_1, CBR_2, \ldots CBR_n$ = CBR of soil strata

$h_1, h_2, \ldots h_n$ = thickness of soil strata (mm)

$h_1 + h_2 + \ldots + h_n = 1000$ mm

Example:

PAVEMENT THICKNESS DESIGN ATJ 5/85

Design Example:

JKR 05, carriageway width = 7.5m, shoulder = 2.0m

ADT = 6600

Pc = 15 %

r = 7 %

Sub-grade CBR = 5 %

Rolling Terrain

Material:

Surfacing = AC

Road base = wet mix Macadam

Sub-base = sand

PAVEMENT THICKNESS DESIGN
ROAD NOTE 31

- Designed for tropical and sub-tropical countries to carry up to 30M CSA
- Heavy vehicle > 3 ton
- Equivalence: $e = (L/Ls)^{4.5}$

Design procedure:

1. Estimate CSA for design life >>> T (Table 3.8)
2. Assess sub-grade strength >>> S (Table 3.9, 3.10)
3. Select combination of material and thickness from structure catalogues based on T and S

PAVEMENT THICKNESS DESIGN
ROAD NOTE 31

Emphasis on 5 aspects:

1. Influence of tropical climate on moisture conditions in road sub-grades
2. Severe conditions imposed on exposed bituminous surfacing by tropical climates
3. Interrelationship between design and maintenance
4. High axle load and tyre pressures
5. Influence of tropical climate on the nature of the soils and rocks used in the road building

Traffic Classes

Traffic classes	Range (10^6 ESA)
T1	< 0.3
T2	0.3 - 0.7
T3	0.7 - 1.5
T4	1.5 - 3.0
T5	3.0 - 6.0
T6	6.0 - 10
T7	10 - 17
T8	17 - 30

Sub-grade Classes

Class	Range (CBR %)
S1	2
S2	3 - 4
S3	5 - 7
S4	8 - 14
S5	15 - 29
S6	30+

Estimation of Sub-grade Classes

Depth of water table from formation (m)	Subgrade strength class				
	Non-plastic sand	Sandy clay PI = 10	Sandy clay PI = 20	Silty clay PI = 30	Heavy clay PI > 40
0.5	S4	S4	S2	S2	S1
1	S5	S4	S3	S2	S1
2	S5	S5	S4	S3	S2
3	S6	S5	S4	S3	S2

Material Definition

	Double surface dressing, SD
	Flexible bituminous surfacing
	Bituminous surface (Wearing and binder course)
	Road base, RB
	Granular road base, GB1 – GB3
	Granular sub-base, GS
	Granular capping layer or selected subgrade fill, GC
	Cement or lime stabilized road base 1, CB1
	Cement or lime stabilized road base 2, CB2
	Cement or lime stabilized sub-base, CS

Granular base, surface dressing

	T1	T2	T3	T4	T5	T6	T7	T8
S1	SD	SD	SD	SD	SD	SD		
	150	150	200	200	200	225		
	175	225	200	250	300	325		
	300	300	300	300	300	300		
S2	SD	SD	SD	SD	SD	SD		
	150	150	200	200	200	225		
	150	200	175	225	275	300		
	200	200	200	200	200	200		
S3	SD	SD	SD	SD	SD	SD		
	150	150	200	200	200	225		
	200	250	225	275	325	350		
S4	SD	SD	SD	SD	SD	SD		
	150	150	200	200	200	225		
	125	175	150	200	250	275		
S5	SD	SD	SD	SD	SD	SD		
	150	150	175	200	225	250		
	100	100	100	125	150	175		
S6	SD	SD	SD	SD	SD	SD		
	150	150	175	200	225	250		

GRANULAR BASE, STRUCTURED SURFACE

	T1	T2	T3	T4	T5	T6	T7	T8
S1						100	125	150
						200	225	250
						225	225	250
						350	350	350
S2						100	125	150
						200	225	250
						225	225	250
						200	200	200
S3						100	125	150
						200	225	250
						250	250	275
S4						100	125	150
						200	225	250
						175	175	175
S5						100	125	150
						200	225	250
						100	100	100
S6						100	125	150
						200	225	250

PAVEMENT THICKNESS DESIGN
ROAD NOTE 31

Design Example 1:

ADT = 250/day.dir, Pc = 55 %, r = 5 %, CBR = 7 %

Design Example 2:

CSA = 12M, PI > 45, WT = 3m below formation

QUESTIONS?

- *Thank You*