Republic of Iraq

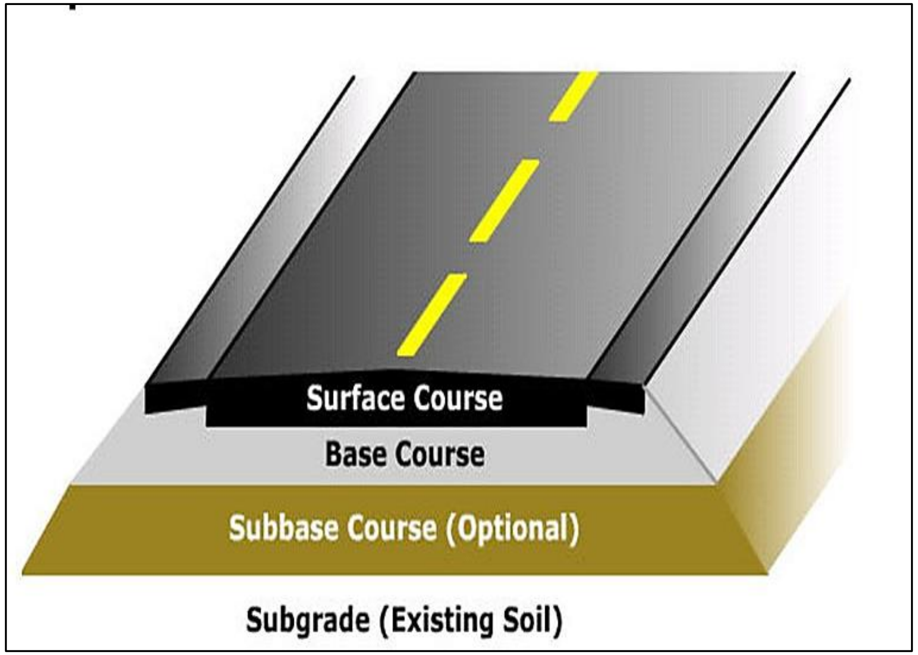
Ministry of Higher Education & Scientific Research

Al-Mustaqbal University College

Department of Building & Construction Engineering Technology

"HIGHWAY ENGINEERING" 3rd Grade

((Thickness Design of Flexible Pavement تصميم الطرق الاسفلتية المرنة))



Prepared by The Senior Lecturer: Mr. Tameem Mohammed Al Musawi

Thickness Design of Flexible Pavement

By different methods [due to: methods pf traffic analysis, failure definition (structural & users), evaluation of properties, & environmental effects].

1) AASHO (AASHTO) Guide method.

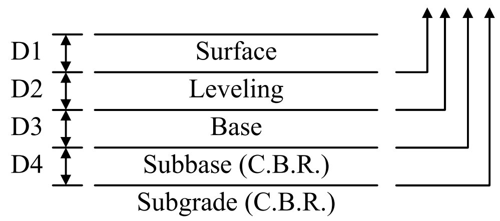
2) T. A. I. method (The asphalt institute method).

3) N. C. S. A. (National Crushed Stone Association).

AASHTO method:

D or h = f (W_{t18}, ρ_t, S, & R)

SN = f (S, R)



Note: h (for each layer) > max. size of agg. * 2

Where:

a) W_{t18} = Equivalent (18kips) (≈8.2ton) single axle applications.

W_{t18} = f (axle type, axle load magnitude, ρ_t, design life, & SN)

$W_{t18} = \Sigma\ T*A*F$ $\quad Wt_{18} = T \times \sum A \times F$

Where:

T = Future trucks / Day / Direction = (Future ADT * %Truck * D.D)

A = Axle / Truck

F = Damage factor

b) ρ_t = Terminal Serviceability:

Lowest serviceability allowed at the end of design period before resurfacing or reconstruction.

By:

Arbitrary scale (named present serviceability index: 5 for best riding quality, and 0 for worst)

ρ_t = 2.5 for main highway

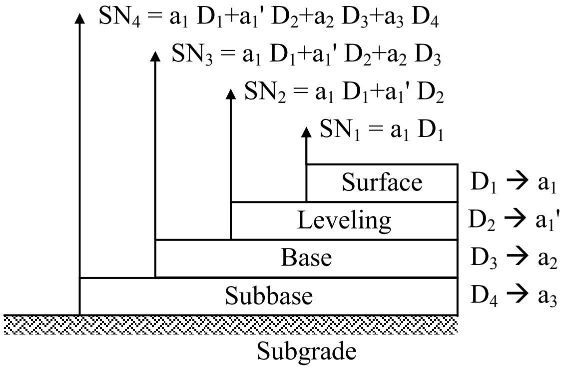
ρ_t = 2.0 for secondary highway

c) S = Road bed support value

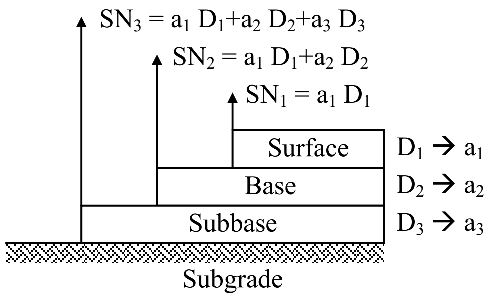
d) R = Regional factor

e) SN = Structural number:

Index number derived from analysis of traffic (W_{t18}), road bed support number (S), regional factor (R) [from monograph], which may be converted to thickness of various layers by using suitable layer coefficient.



Case (2) Ideal Arrangement



Case (1) General

<u>ملاحظة</u>: ($SN_1 = a_1 D_1$) المطلوب (D_1) نستخرج (SN_1) من المخططات (P.509) و(a_1) من المخطط (P.514) نجد (D_1) بالانج ويقرب لأقرب نصف ("0.5").

For case (1) General:

a_1 = Layer coefficient for Surface — D_1 = Thickness of Surface (inch)

a_2 = Layer coefficient for Base — D_2 = Thickness of Base (inch)

a_3 = Layer coefficient for Subbase — D_3 = Thickness of Subbase (inch)

Design monographs and tables: Yoder (Table 4.9 P.164, 165), (Fig. 15.1 P.509), (Table 15.1 P.510), (Fig. 15.3 P.514, 515), (Fig. 15.5 P.516)

Ex.:

A main rural highway has been built or designed for (200) daily 18-kips single axle load repetition. Regional factor (R) = 1.2 & the characteristics of pavement materials as following:

Subgrade	→	C. B. R. = 5%	(Plastic clay)
Subbase	→	C. B. R. = 20%	(Sand-gravel)
Base	→	C. B. R. = 80%	(Crushed stone)
Surface	→	$E = 4.3*10^5$ psi	(Asphalt concrete)

Sol.:

From graph (P.514, 515)

Surface	$a_1 = 0.42$	(Modulus E = 4.3)
Base	$a_2 = 0.13$	(C. B. R. = 80%)
Subbase	$a_3 = 0.095$	(C. B. R. = 20%)

$SN_1 = a_1 D_1$

$W_{t18} = 200$

From graph (P.516)

قيم (C. B. R.) للطبقة التي قبلها

S_1 (@ 80% C.B.R.) = 8.5 → $SN_1 = 1.95$

S_2 (@ 20% C.B.R.) = 6.2 → $SN_2 = 2.82$

S_3 (@ 5% C.B.R.) = 4 → $SN_3 = 3.78$

$SN_1 = a_1 D_1$

$1.95 = 0.42*D_1$ → $D_1 = 4.64"$ use $D_1 = 5"$

$SN_2 = a_1 D_1 + a_2 D_2$

$2.82 = 0.42*5 + 0.13*D_2$ → $D_2 = 5.54"$ use $D_2 = 6"$

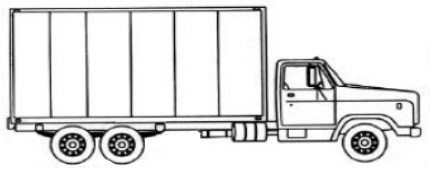
SN3 = a1 D1 + a2 D2 + a3 D3

$3.78 = 0.42*5 + 0.13*6 + 0.095*D_3$ → $D_3 = 9.47"$ use $D_3 = 9.5"$

H.W.:

Secondary highway, ADT (1994) = 400vph, truck = 40%, D. D. = 50%, annual rate of traffic growth = 6%, design life = 20 years, wet (saturated road bed).

Truck type:



Materials	Properties	
Asphalt concrete wearing course	M. S.	≥ 800 kg
Asphalt concrete leveling course	M. S.	≥ 700 kg
Crushed stone base	C. B. R.	80 %
Subbase	C. B. R.	30 %
Subgrade	C. B. R.	2%

Determine thickness of layers in (cm)

Note: let D_1 = 8 cm

Ans.: D1 = 8cm (3"), D2 = 11cm (4.5"), D3 = 12cm (5"), D4 = 57cm (22.5")

1kg = 2.20462 lb

HOMEWORK SOLUTION: FLEXIBLE PAVEMENT

$FADT = CADT \times (1+r)^{x+n}$; $\rho_t = 2.0$

n: design life (20-25) years

r: annual rate of traffic growth (6-9%)

x: years of constructions ($\simeq$ 2 years)

$(1+r)^{x+n}$: Traffic Projection Factor (TPF)

$FADT = 400 \times (1+0.06)^{2+20} = 1441$ vpd

T = FADT × % Trucks × D.D = 1441×0.4×0.5 = 288 Trucks/day/direction

Note 1: two layers on the surface (wearing + leveling) with two stability values, in this case we shall consider them as one layer with critical stability (**the minimum value = 700 kg**) in order to determine the layer coefficient $\mathbf{a_1}$

M.S = 700 kg × 2.205 = 1544 Ib

$a_1 = 0.38$ from chart page (08-5)

A = axle/truck = 1 for single and tandem

F1 for 13 kips single axle = 0.27   chart page (08-10)

F2 for 40 kips tandem axle = 2.15   chart page (08-10)

$W_{t18} = T \times \sum A \times F = 288 \times (1 \times 0.27 + 1 \times 2.15) = 700$ daily

$a_2 = 0.13$; $a_3 = 0.11$ from chart pages (08-5) & (08-6)

$S_1 = 8.5$, $S_2 = 6.75$, $S_3 = 2.5$ from chart page (08-7)

Note 2: wet saturated roadbed ……. From table in page (08-7) we shall consider the value of regional factor (**R = 4.0**) the minimum critical value

$SN_1 = 2.8$, $SN_2 = 3.6$, $SN_3 = 6$ from chart page (08-9)

$SN_1 = a_1D_1 \Longrightarrow D_1 = 7.5''$

$SN_2 = a_1D_1 + a_2D_2 \Longrightarrow D_2 = 6''$

$SN_3 = a_1D_1 + a_2D_2 + a_3D_3 \Longrightarrow D_3 = 22''$

Note 3: D_1 shall be divided to D wearing = 3" & D leveling = 4.5"

Surface	D_1 = 3" = 8 cm
Leveling	D_2 = 4.5" = 11 cm
Base	D_3 = 6" = 15 cm
Sub-base	D_4 = 22" = 56 cm

Subgrade

Ex 2: Flexible pavement of a secondary hyw consist of the following layers. Find the number of trucks per day per direction (T) which can travel on the hyw without any failure. The effective axles/100 trucks as below (R = 4)

Axle type	**No. of axles/100 trucks**
Single 16 kips	30
Tandem 26 kips	40

Materials	**Layer thickness (in)**	**Layer coefficient (a)**	**S value**
Asphaltic Concrete	4	0.42	7
Sand-gravel	6	0.1	3

SOLUTION:

$\rho_t = 2.0$

A_1 for 16 kips single axle load = 30/100 = 0.3 ; F_1 = 0.61 chart p (08-10)

A_2 for 26 kips tandem axle load = 40/100 = 0.4 ; F_2 = 0.36 chart p (08-10)

$W_{t18} = T \times \sum A \times F = T \times (0.3 \times 0.61 + 0.4 \times 0.36) = 0.327\ T$ ……… (1)

$SN_1 = a_1D_1 = 0.42 \times 4 = 1.68$; $S_1 = 7$

$SN_3 = a_1D_1 + a_2D_2 + a_3D_3 = 1.68 + 6 \times 0.1 = 2.28$; $S_3 = 3$

From chat in page (08-9)

W_{t18} = 10 ESAL DAILY

$W_{t18} = 0$

USE W_{t18} = 10 DAILY

Sub in eq. 1 $\Longrightarrow$ T = 31 Trucks/day/direction

Ex 3: In flexible pavement design of a road section by AASHTO method, the structural numbers needed for pavement layers were found to be:

$$SN_1 = 1.5\ ,\ SN_2 = 3.5\ ,\ SN_3 = 4.2$$

Check the adequacy of the following design & if it is not adequate redesign it.

Layer	**Layer Coefficient (a)**	**Thickness (in)**
Surface	0.42	4
Base	0.14	12
Subbase	0.11	6

SOLUTION:

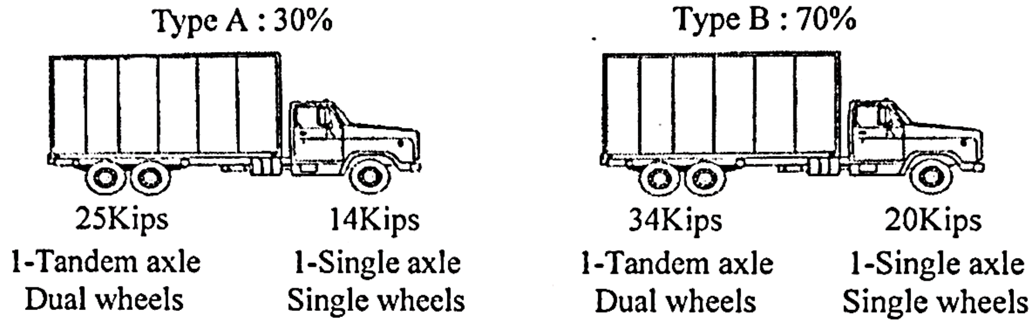
$SN_1 = a_1D_1 \Longrightarrow D_1 = 1.5/0.42 = 3.57'' = 4''$ O.K

$SN_2 = a_1D_1 + a_2D_2 \Longrightarrow D_2 = (3.5 - 4\times0.42)/0.14 = 13''$ NOT O.K

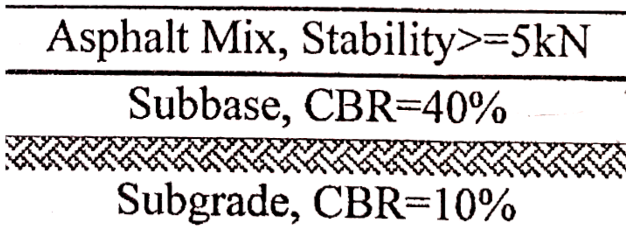
USE $D_2 = 13''$

$SN_3 = a_1D_1 + a_2D_2 + a_3D_3 \Longrightarrow D_3 = (4.2 - (4\times0.42 + 13\times0.14))/0.11 =$ $6.4'' = 6.5''$ NOT O.K USE $D_3 = 6.5''$

Ex 4: A main highway with the following information: DHV = 100 vph, %Trucks = 40%, D.D = 60%, and the type of trucks as follows:



Design the flexible pavement (by AASHTO) method using the following information: (R = 4)



SOLUTION:

DHV = 0.15 ADT ⟹ ADT = 100/0.15 = 667 vpd

$FADT = CADT \times (1+r)^{x+n}$; $\rho_t = 2.5$ (main hyw)

Assume:

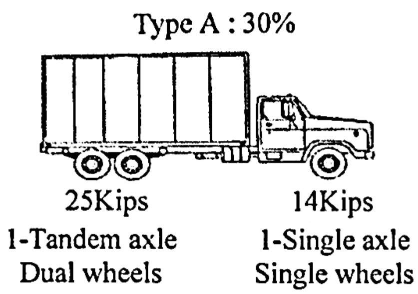
n: design life (20-25) years = **20** years

r: annual rate of traffic growth (6-9%) = **6%**

x: years of constructions ($\simeq$ 2 years)

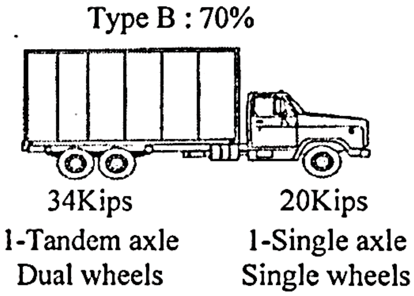
$FADT = 667 \times (1+0.06)^{22} = 2404$ vpd

T = FADT × % Trucks × D.D = 2404 × 0.4 × 0.6 = 577 Truck/day/direction



$A_1 = 0.3$, $F_1 = 0.4$

$A_2 = 0.3$, $F_2 = 0.365$



$A_3 = 0.7$, $F_3 = 1.49$

$A_4 = 0.7$, $F_2 = 1.11$

$W_{t18} = T \times \sum A\times F = 577 \times (0.3\times0.4+0.3\times0.365+0.7\times1.49+0.7\times1.11)$

$= 1183$ ESAL DAILY

M.S = 500 × 2.205 = 1102.5 Ib

$a_1 = 0.31$, $a_3 = 0.12$ from chart pages (08-5) & (08-6)

$S_1 = 7.2$, $S_3 = 5.2$ from chart page (08-7)

$SN_1 = 4$ from chart page (08-9)

$SN_1 = a_1D_1 \Rightarrow D_1 = 4/0.31 = 12.9'' = 13''$

$SN_3 = 5.1$ from chart page (08-9)

$SN_3 = a_1D_1 +$ ~~a_2D_2~~ $+ a_3D_3 = D_3 = (5.1 - 0.31\times13)/0.12 = 8.9'' = 9''$

Surface $D_1 = 6''$

Leveling $D_2 = 7''$

Subbase $D_3 = 9''$

Subgrade

Ex 5: A flexible pavement of main hyw consists of three layers as shown below. Find the number of trucks which can travel on it without failure. The effective axle per 1000 trucks = 150 single axle (18kips) & the regional factor R = 1.5

Layers	**Layer thickness (D)**	**Layer Coefficient (a)**	**(S) Value**
Asphalt Concrete	4"	0.42	7
Crushed Stone	6"	0.14	5
Sand-Gravel	6"	0.1	3

SOLUTION:

ρ_t = 2.5 (main hyw)

$SN_1 = a_1D_1 = 0.42 \times 4 = 1.68$, $S_1 = 7$

$SN_2 = a_1D_1 + a_2D_2 = 1.68 + 6 \times 0.14 = 2.52$, $S_2 = 5$

$SN_3 = a_1D_1 + a_2D_2 + a_3D_3 = 2.52 + 0.1 \times 6 = 3.12$, $S_3 = 3$

$(W_{t18})_1$ = 18 ESAL Daily

$(W_{t18})_2$ = 30 ESAL Daily

$(W_{t18})_3$ = 23 ESAL Daily

نختار دائما الاقل:

W_{t18} = 18 ESAL Daily

$18 = T \times \sum A \times F = T \times \{(150/1000) \times 1\} \Longrightarrow T = 120$ Trucks/day/direction