Design of Flexible Highway Pavements

Ministry of Transport Method

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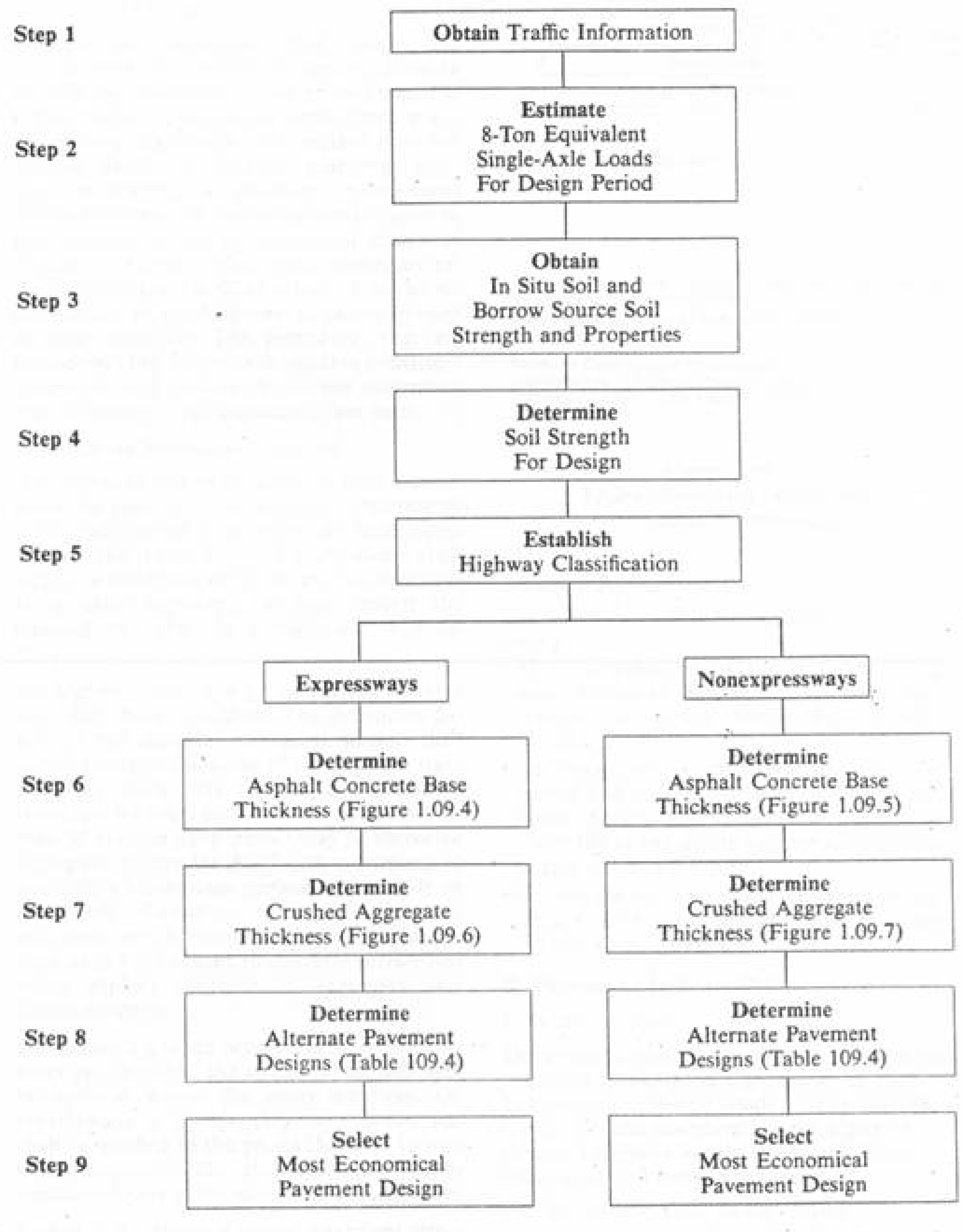
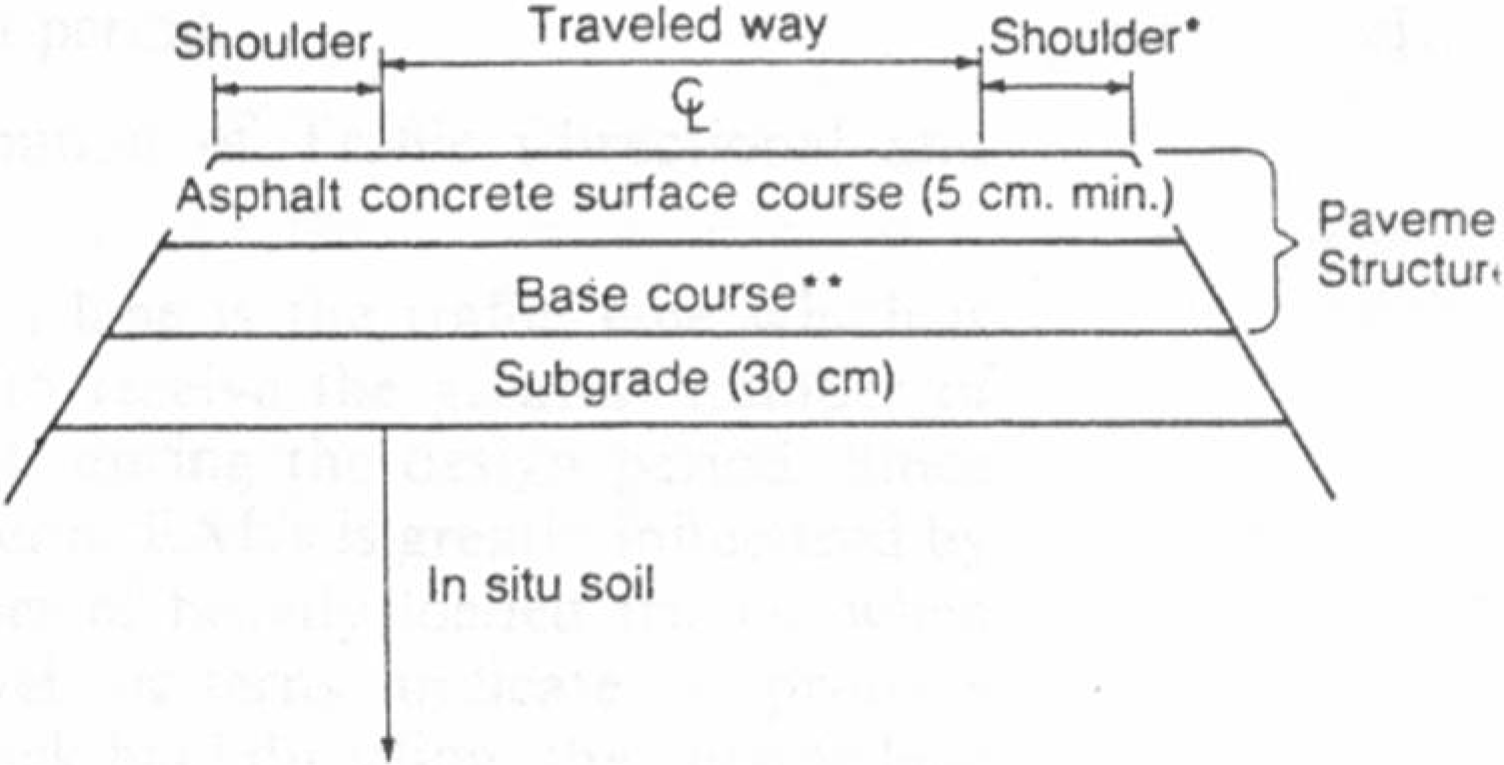


Figure 1.09.9
Design and Pavement Structure Selection



* Asphalt concrete not required on shoulder surface courses for local and low volume roads.

** Base course can include both asphalt concrete and aggregate base.

Minimum Base Course Requirements:
Expressways—15 cm asphalt concrete
Nonexpressways—5 cm asphalt concrete

Table 1.09.1
ADT (20) Growth Factors

$$\left(1 + \frac{AG}{100}\right)^{20}$$

Annual Growth (AG) %	0	2	4	5	6	7	8	10
Growth Factor (GF)	1.00	1.49	2.19	2.65	3.21	3.87	4.66	6.93

وزارة المواصلات

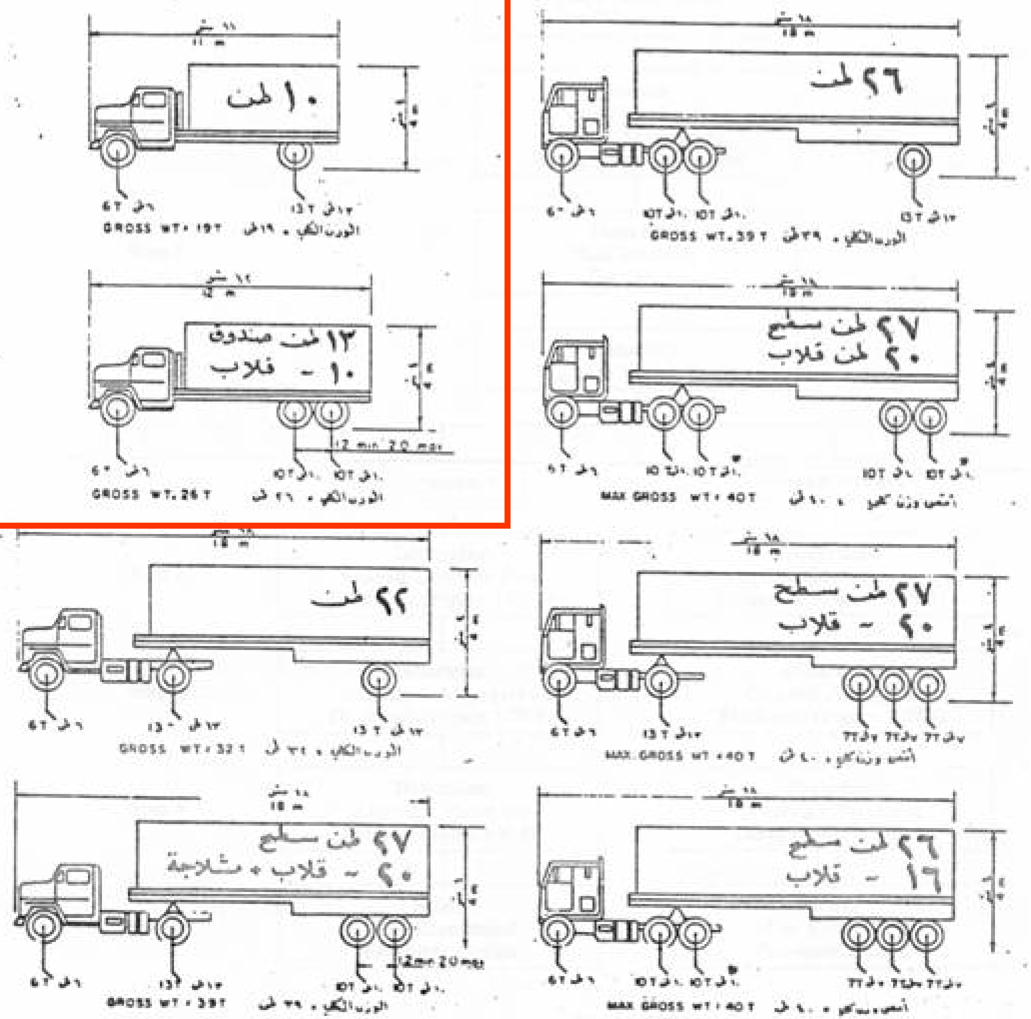
MINISTRY OF COMMUNICATIONS

الأوزان القانونية للشاحنات
LEGAL TRUCK WEIGHTS

الأرقام على صندوق الشاحنة ترمز إلى الحمولة الصافية للشاحنة .

WIDTH FOR ALL TRUCKS = 2.5 m MAX

العرض لجميع الشاحنات كحد أقصى ٢,٥ متر



إن معلومات هذا الرسم البياني مبنية على أساس أنظمة المرور لعام ١٣٩٠ هـ .

INFORMATION ON THIS CHART IS BASED ON TRAFFIC REGULATIONS (1390 H.)

* الأحمال المحورية القصوى المسموح بها على أن لا تتجاوز الوزن الإجمالي ٤٠ طن

* MAXIMUM ALLOWABLE AXLE LOADS. GROSS WEIGHT NOT TO EXCEED 40 TONS

RAJAB 1404
APRIL 1984

Table 1.09.3
Typical*
Truck Class and Weight Distributions

<table>
<tr><th>Truck Class</th><th>Type
SAL-Single Axle
TAL-Tandem Axle</th><th>Percentage Total Trucks</th><th>**
Percent of ADT In Design Lane</th><th>Gross Vehicle Weight (Ton)</th><th colspan="3">Typical
Axle Loads (Tons)
EAL Per Axle</th><th>EAL Per Vehicle</th></tr>
<tr><td rowspan="2">N.1</td><td rowspan="2">Single Unit
2 Axle
(2 SAL)</td><td rowspan="2">66</td><td rowspan="2">14.8</td><td rowspan="2">12</td><td>2.5</td><td colspan="2">9.5</td><td rowspan="2">1.82</td></tr>
<tr><td>0.01</td><td colspan="2">1.81</td></tr>
<tr><td rowspan="2">N.2</td><td rowspan="2">Single Unit
3 Axle
(1 SAL, 1 TAL)</td><td rowspan="2">13</td><td rowspan="2">2.9</td><td rowspan="2">18</td><td>3.5</td><td colspan="2">14.5</td><td rowspan="2">0.86</td></tr>
<tr><td>0.03</td><td colspan="2">0.83</td></tr>
<tr><td rowspan="2">N.3</td><td rowspan="2">Multiple Unit
4 Axle
(2 SAL, 1 TAL)</td><td rowspan="2">11</td><td rowspan="2">2.5</td><td rowspan="2">21</td><td>2.5</td><td>8.0</td><td>10.5</td><td rowspan="2">1.16</td></tr>
<tr><td>0.01</td><td>0.93</td><td>0.22</td></tr>
<tr><td rowspan="2">N.4</td><td rowspan="2">Multiple Unit
5 Axle
(1 SAL, 2 TAL)</td><td rowspan="2">10</td><td rowspan="2">2.3</td><td rowspan="2">25</td><td>3.5</td><td>10.0</td><td>11.5</td><td rowspan="2">0.53</td></tr>
<tr><td>0.03</td><td>0.18</td><td>0.32</td></tr>
<tr><td colspan="2">Totals/Average</td><td>100</td><td>22.5</td><td></td><td colspan="3"></td><td>1.48</td></tr>
</table>

**Based upon 1977 Truck Study by Italconsult and a survey by Italconsult/Rio/DarHandash, Ministry of Communication 1981.*

***Based upon Truck Volume = 50% ADT and 45% Truck in Design Lane.*

Table 1.09.2
Percentage of Total Truck Traffic In Design Lane

Number of Traffic Lanes (two directions)	Percentage of Trucks In Design Lane
2	50
4	45
6 or more	40

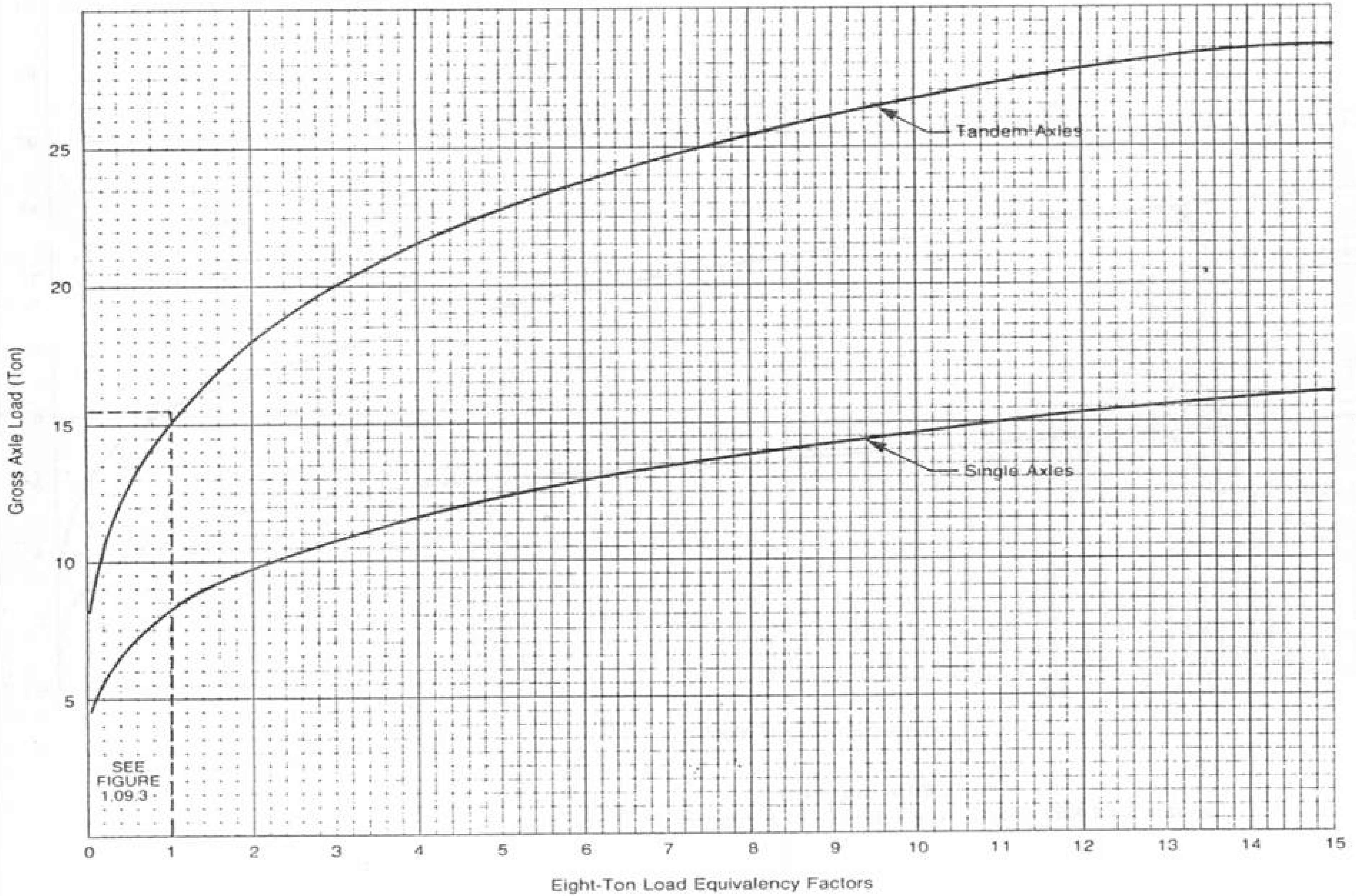


Figure 1.09.2
Eight-Ton, Single-Axle Load Equivalency (EAL) Factors

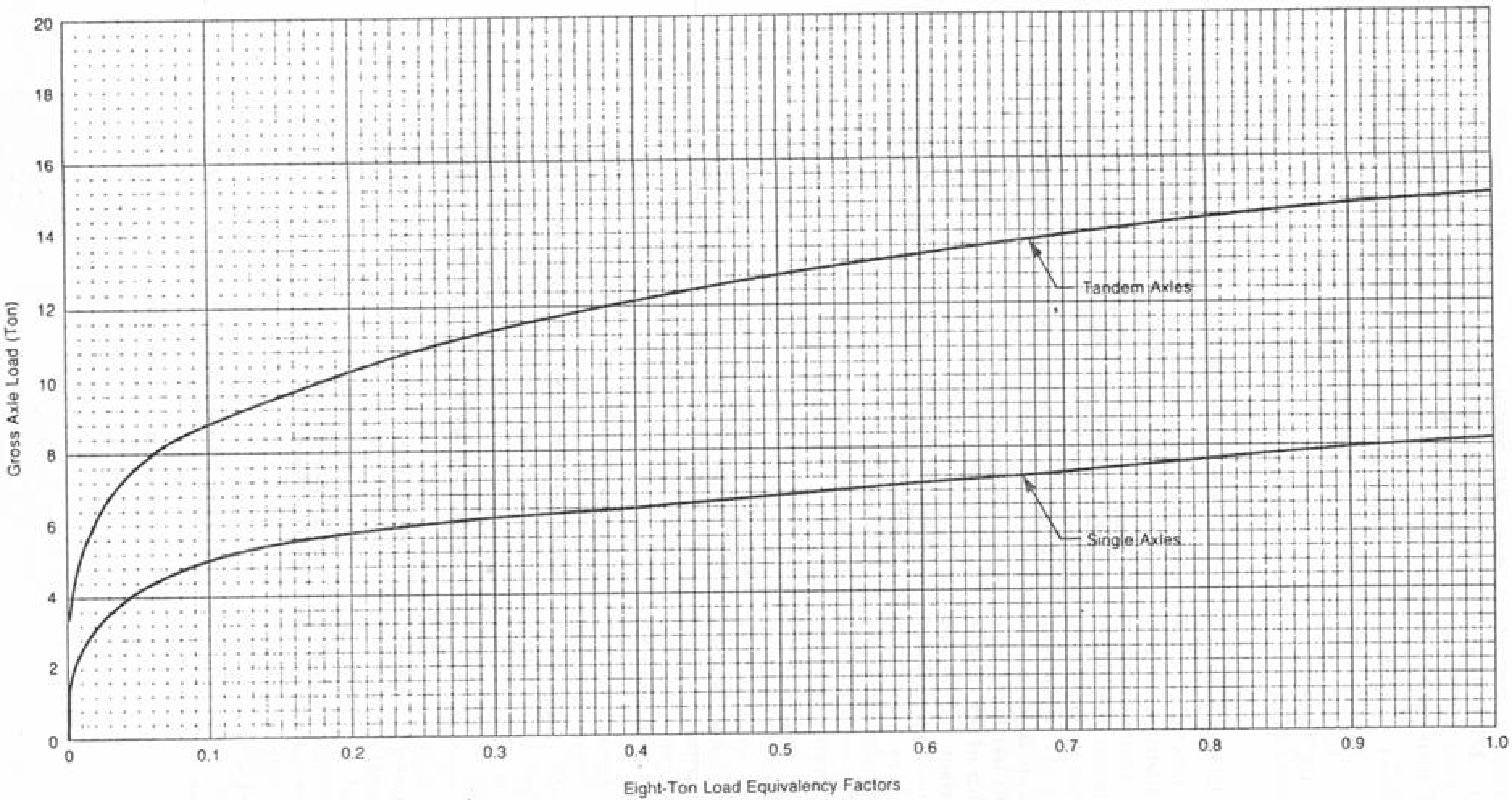
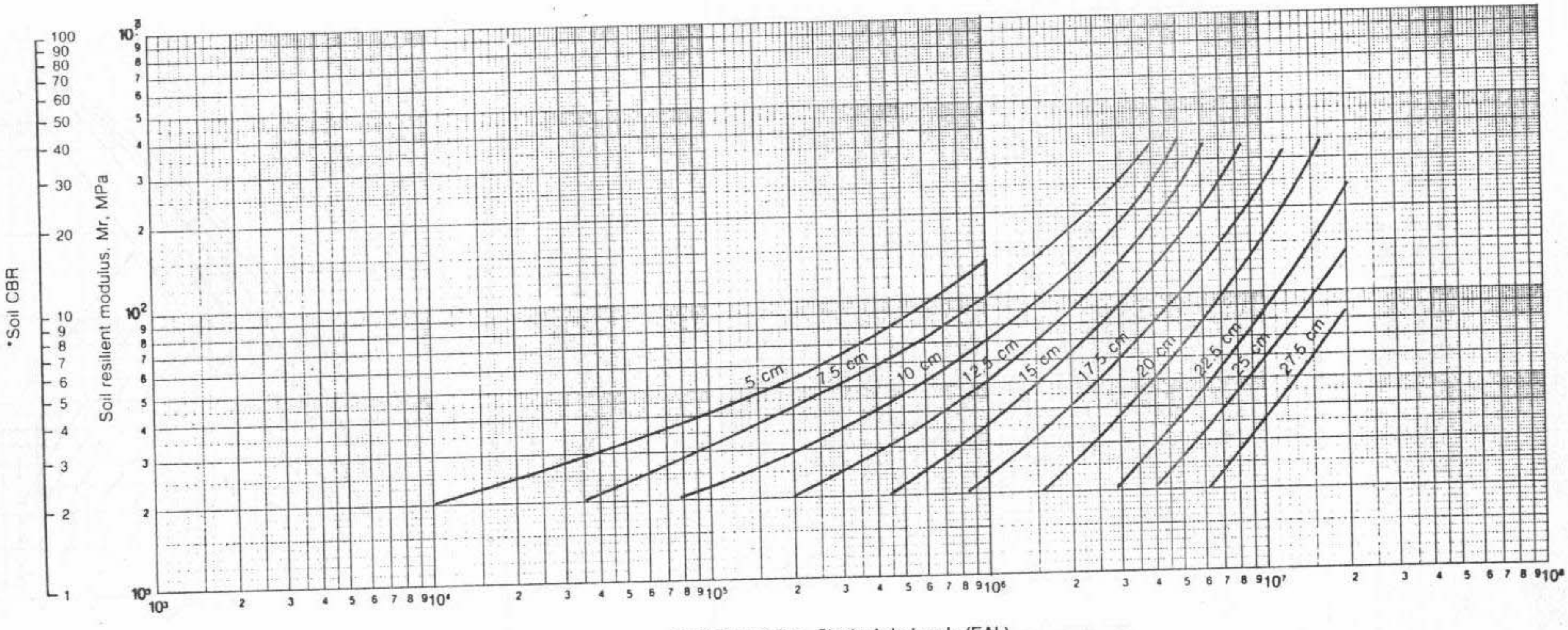


Figure 1.09.3
Eight-Ton, Single-Axle Load Equivalency (EAL) Factors



See Figure 1.09.7 for crushed aggregate base thickness

$$^{*}CBR \cong \frac{Mr}{10.320}$$

Figure 1.09.5
Asphalt Concrete Base Course Thickness Requirements For Roads Other Than Expressways

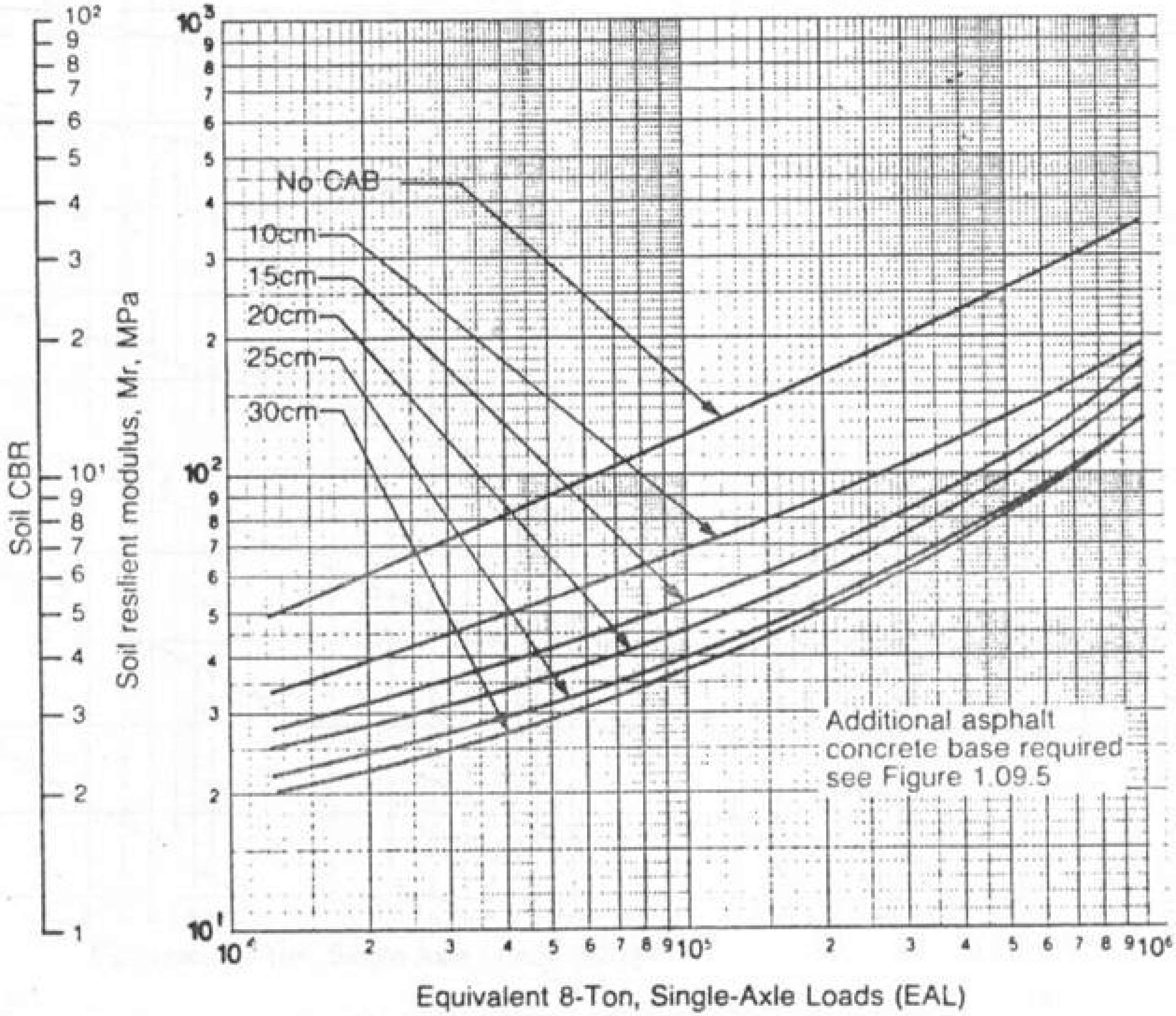


Figure 1.09.7
Crushed Aggregate Base Requirements For Roads Other Than Expressways

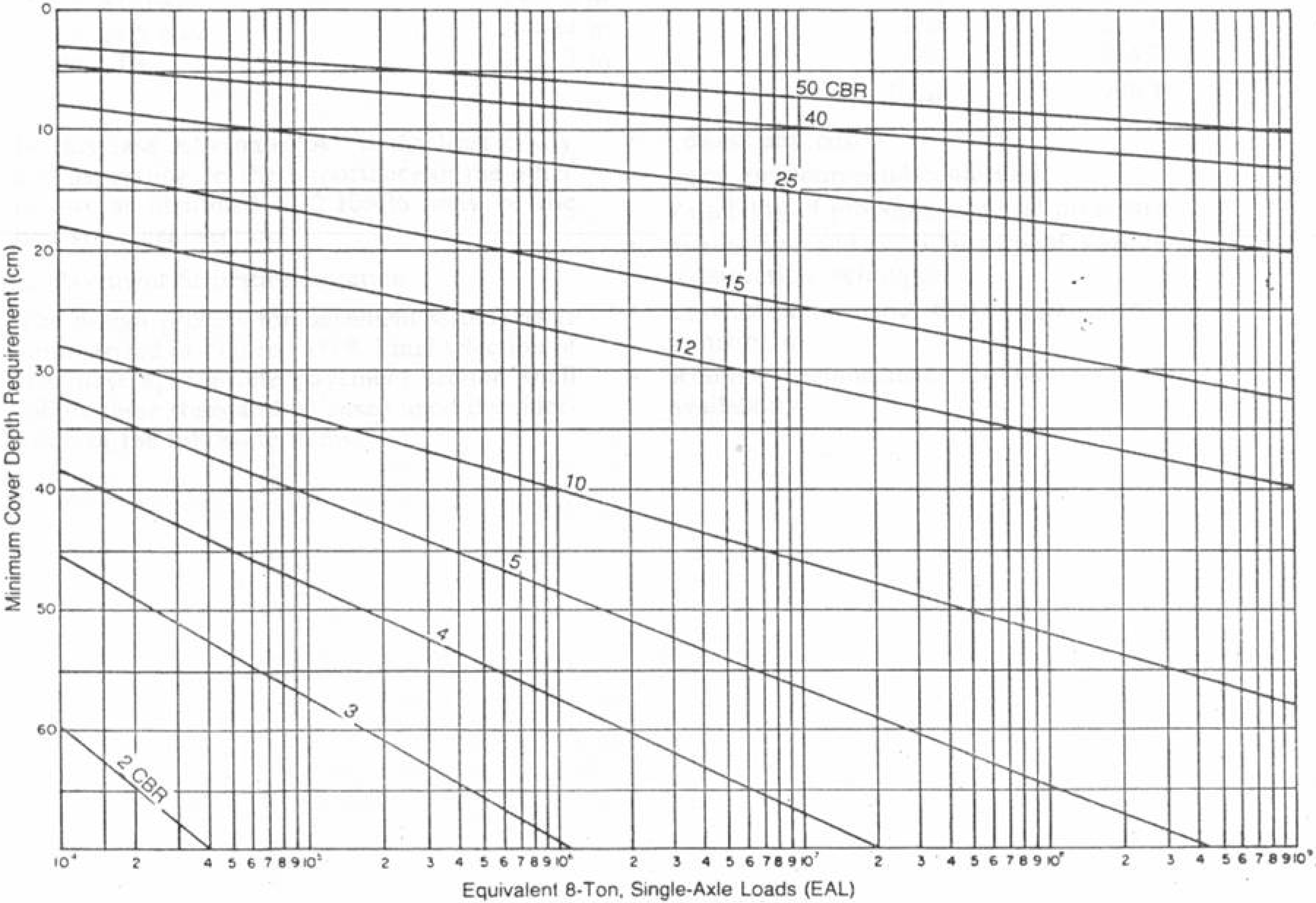


Figure 1.09.8
Cover Requirements

Table 1.09.4
Pavement Material Equivalencies

	Substitution Ratio[1]
Base Course	
Asphalt Concrete (Plant Mix)	1
Asphalt Concrete (Road Mix)	1.75
Untreated Aggregates	
Crushed Aggregate	2.5
Natural Gravels	3
Treated Aggregate	
Bituminous-Treated Aggregates	2
Lime-Treated Aggregates	2
Cement-Treated Aggregates	2
Subgrade	
Select Material (Soil)	5
Bituminous-Treated Soil	3.5
Lime-Treated Soil	3.5
Cement-Treated Soil	3.5

[1]*Millimeters of material needed to replace one millimeter of the asphalt concrete pavement.*

Example of Alternative Pavement Designs

Problem Statement: Determine the most cost-effective pavement section that is structurally equivalent to the following:

5 cm asphalt concrete surface (AC)
15 cm asphalt concrete base (AC)
22 cm crushed aggregate base (CAB)
30 cm subgrade borrow
Design soil CBR = 10
Total traffic = 2.25×10^6 EAL

Typical pavement section consists of 3.65 m travel way, 3.00 m shoulders and 4:1 fore-slopes.

Procedure: Since the asphalt concrete surface and base requirements are at minimum levels established by 2-1.09A2, only the crushed aggregate base and subgrade are subject to alternate design.

Determination of which alternate materials are to be compared should be based upon availability, feasibility, and economic analysis. Assume the asphalt concrete (AC) and lime-treated aggregate (LTA) meet these criteria for base material and the lime-treated soil (LTS) meets criteria for alternative subgrade materials.

To provide structurally equivalent sections, the following equation must be satisfied:

$$\frac{T_A \times SR_B}{SR_A} = T_B$$

where T_A = Thickness of Material A
SR_A = Substitution Ratio of Material A
T_B = Thickness of Material B
SR_B = Substitution Ratio of Material B

The thickness of lime-treated aggregates required for 22 cm of CAB is

$$\frac{(22\ \text{cm})\ (2)}{(2.5)} = T_{LTA}$$

T_{LTA} = 17.6 cm, use 18 cm

If asphalt concrete base were substituted, the required thickness would be

$$\frac{(22\ \text{cm})\ (1)}{(2.5)} = T_{AC}$$

T_{AC} = 8.8 cm, use 9 cm

The amount of lime-treated soil required to replace 30 cm of borrow soil is

$$\frac{(30\ \text{cm})\ (3.5)}{5} = T_{LTS}$$

T_{LTS} = 21 cm

From Figure 1.09.8, a soil strength CBR of 10 requires a 42 cm of cover for 2.25×10^6 EAL. Therefore, any of the following pavement structural sections except Alternative B are acceptable:

A
5 cm AC surface
15 cm AC base
22 cm CAB
30 cm subgrade borrow

B
5 cm AC surface
24 cm AC base
30 cm subgrade borrow

C
5 cm AC surface
15 cm AC base
18 cm LTA base
30 cm subgrade borrow

D
5 cm AC surface
24 cm AC base
21 cm LTS

E
5 cm AC surface
15 cm AC base
18 cm LTA base
21 cm LTS

5. Cost Comparison of Acceptable Alternatives

Alternative A	Quantity for One Meter Length	Unit Price (Riyals)	Cost
5 cm AC surface	.6525 m^3	160	104.40
15 cm AC base	1.9875 m^3	150	298.13
22 cm CAB	3.0000 m^3	50	150.00
30 cm subgrade borrow	4.2300 m^3	15	63.45
		Total	615.98

Alternative C			
5 cm AC surface	.6525 m^3	160	104.40
15 cm AC base	1.9875 m^3	150	298.13
18 cm LTA base	2.4444 m^3	110	268.88
30 cm subgrade borrow	4.2180 m^3	15	63.27
		Total	734.68

Alternative D			
5 cm AC surface	.6525 m^3	160	104.40
24 cm AC base	3.2016 m^3	150	480.24
21 cm LTS	2.8959 m^3	80	231.67
		Total	816.31

Alternative E			
5 cm AC surface	.6525 m^3	160	104.40
15 cm AC base	1.9875 m^3	150	298.13
18 cm LTA base	2.4444 m^3	110	268.88
21 cm LTS	2.9337 m^3	80	234.70
		Total	906.11

In this case Alternate "A" is the least costly and depending on the importance of the other factors as identified in 2.109B6, may be the best structural section.

6. Pavement Structure Selection

The design process for pavement structures is summarized in Figure 1.09.9. Final selection of the most appropriate pavement section shall follow these steps and be based upon consideration of the following items:

- Lowest unit cost.
- Local environmental conditions.
- Variability of proposed material properties.
- Availability and local history of required construction techniques.
- Level of performance that the pavement is to maintain.
- Routine maintenance requirements and availability.

Problem Statement: A four-lane (two lanes each direction) rural roadway is proposed. Determine the total EAL for pavement design.

Given

From Local Traffic Study (two-way traffic):

Initial Traffic	3,000 Vehicle/Day in 1983
Estimated Traffic	5,000 Vehicle/Day in 2003

50% Trucks
50% Pass. Cars

Average percentage of trucks through design period is 50 percent.

Truck Type and Axle Load Distribution: use data from Table 1.09.3

Truck Unit	Number of Trucks Units/100 Trucks		Average EAL[1] Per Truck		Total EAL
Single Units					
Two Axle	66	×	1.82	=	120.12
Three Axle or More	13	×	0.86	=	11.18
Multiunit					
Three Axle	11	×	1.16	=	12.28
Four Axle	10	×	0.53	=	05.30
Total EAL/100 Trucks				=	148.88

[1] *Individual values should be obtained from detailed truck traffic and truck weight study and analysis.*

Procedure

For single unit (two axle) average GVW is 12 ton with 2.5 ton (20.8%) on front axle and 9.5 ton (79.2%) on rear axle. From figures 1.09.2 and 1.09.3 EAL's are 0.01 and 1.81 respectively.

EAL/truck is 1.82. The same procedure is then used again to determine the EAL for each of the other travel unit categories, i.e. single unit 3 axle, multiunit 3 and 4 axles.

Average Trucks Per Day =

$$\frac{(3{,}000 + 5{,}000)}{2} \times \frac{50}{100} = 2{,}000 \text{ Trucks/Day}$$

Average Daily Trucks in Design Lane = (2,000) (.45) = 900 Trucks/Day (45% Table 1.09.2)

Total Trucks in Design Lane for Design Period = (900 Trucks/Day) (365 Days/Year) (20 Years) = 6,570,000 Trucks

Total EAL for Pavement Design =
(6.570 × 10^6 Trucks) (148.88 EAL/100 Trucks) = 9.781 × 10^6 EAL

Where detailed traffic analysis is not available and upon approval of the MOC under provisions of HDM-1-1.06B13, the following equation shall be used to determine the total number of equivalent 8-ton loads.

$$EAL = 1{,}220\ ADT\ (0) + ADT\ (20)$$

where EAL = Total number of equivalent 8-ton axle loads
ADT (0) = Initial ADT
ADT (20) = ADT at end of 20-year design period.

2. Soil Considerations

The soils directly below a pavement structure greatly contribute to the overall performance of the pavement. The strength and variability of this material must be considered in the determination of flexible pavement thickness requirements. The material may either be native soils such as in cut sections or may be imported material from designated sources as in fill sections. In either case, representative samples of this material must be collected and tested in the laboratory or in place. A minimum depth of 1.0 m below the top of the subgrade surface should be considered when selecting representative samples. Testing must only be performed on samples that are in a condition that accurately represents the after construction condition of the soil directly beneath the pavement structure. Therefore, density and moisture controls that are required during construction must also apply to remolded samples that are used for strength determinations.

The soil strength input value should be determined by either using the California Bearing Ratio (CBR) MRDTM 213 or the Resilient Modulus (see Asphalt Institute Manual MS-1). The soil support value used in the pavement design shall be equal to the 90th percentile of the representative samples of either the naturally occurring soil below the subgrade or the material proposed for subgrade construction. The lower of these 90th percentile values shall be selected as the soil strength for pavement design. An example illustrating the determination of the soil strength value is given below. The soil strength value may vary between sections within a project dependent upon economic analysis of the entire pavement structure, subgrade, and naturally occurring in situ material.

Example of Selection of Soil Strength Value

Field Samples and Laboratory Test Results	
Borrow for Subgrade CBR	**On-Site Material at Subgrade CBR**
13	12
25	18
30	8
26	17
32	20

	Highest				Lowest
Borrow CBR	32	30	26	25	13
Percent of Tests Greater Than or Equal	20%	40%	60%	80%	100%
On-Site Material CBR	20	18	17	12	8
Percent of Tests Greater Than or Equal to	20%	40%	60%	80%	100%

CBR Value

90th Percentile Values: Borrow Material CBR = 20
On-Site Material CBR = 10.5 Soil Strength of CBR = 10 is Used for Design

3. Base Course Thickness Requirements

In addition to satisfying the minimum structural requirements given in 2-1.09A2, all pavements shall meet minimum base course thickness requirements for the local soil or borrow source conditions and estimated traffic loads. Figure 1.09.4 shall be used to determine minimum asphalt concrete base thickness requirements for the soil and traffic on expressways. Figure 1.09.5 shall be used to establish minimum asphalt concrete base requirements for traffic and soil conditions on all roadways other than expressways. Figure 1.09.6 and Figure 1.09.7 shall be used to determine the amount of crushed aggregate base needed to meet requirements. When the asphalt concrete thickness values from Figures 1.09.4 and 1.09.5 exceed 15 cm and 5 cm respectively, 30 cm of aggregate base is required.