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Research Article

Design of Flexible and Rigid Pavement Based on ERA Manual (2013) Empirical Method and Mechanistic Approaches: The Case of Study Dire Dawa – Harar

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Abstract

Flexible pavements usually consist of a bituminous surface under laid with a layer of granular material and a layer of a suitable mixture of coarse and fine materials. Traffic loads are transferred by the wearing surface to the underlying supporting materials through the interlocking of aggregates, the frictional effect of granular materials, and cohesion of fine materials. Rigid highway pavements are normally constructed of Portland cement concrete and may or may not have a base course between the subgrade and the concrete surface. The traffic class of flexible pavement is T6, it has been derived (with a total of ESAs on the order of 8.89 million over the design period). From the table given on ERA, for that class of traffic, it is readily apparent that the use of the design charts in the catalog of structures. From types of rigid pavement the selection is CRCP design in ERA method design consideration. Because CRCP shall basically be considered only for rather high design traffic (>30msa) so, the ESAL values is $85.41*10^6$. They can also be included for less heavily trafficked schemes where the advantage of lower maintenance throughout the design life may be worthwhile. They are particularly suitable were settlement of the sub-soil is expected. For instance, for heavily traveled facilities in congested locations, the need to minimize the disruptions and hazard to traffic may dictate the selection of CRCP. The continuous reinforcement increases the resistances of slabs but the compressive strength remain limited and the slab is prone to expansion failure. It is thus preferable to cast CRCP slabs during the hottest time of the year to limit the potential of thermal expansion.

Keywords

Flexible Pavement, Rigid Pavement, Traffic Analysis

1. Introduction

Road flexible pavements are intended to limit the stress created at the subgrade level by the traffic traveling on the pavement surface so that the sub-grade is not subject to significant deformations. In effect, the concentrated loads of the vehicle wheels are spread over a sufficiently larger area at the subgrade level. At the same time, the pavement materials themselves should not deteriorate to such an extent as to affect the riding quality and functionality of the pavement. These goals must be achieved throughout a specific design period. [1, 4, 7, 8, 12, 17]

Pavements do deteriorate, however, due to time, climate, and traffic. Therefore, the goal of the pavement design is to

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limit, during the period considered, deteriorations that affect the riding quality, such as, in the case of flexible pavements, cracking, rutting, potholes and other such surface distresses to acceptable levels. At the end of the design period, a strengthening overlay would normally be required, but other remedial treatments, such as major rehabilitation or reconstruction, may be required. The design method aims at producing a pavement that will reach a relatively low level of deterioration at the end of the design period, assuming that routine and periodic maintenance are performed during that period [2, 3, 15].

The deterioration of *paved roads* caused by traffic results from both the magnitude of the individual wheel loads and the number of times these loads are applied. It is necessary to consider not only the total number of vehicles that will use the road but also the wheel loads (or, for convenience, the axle loads) of these vehicles. Equivalency factors are used to convert traffic volumes into cumulative standard axle loads. Traffic classes are defined for paved roads, for pavement design purposes, by ranges of a cumulative number of equivalent standard axles (ESAs) [2, 3, 5, 6, 13].

The objectives are listed below.

The general objective is as follows:

The general objective of the project is to design a rigid and flexible pavement based on the Empirical Method of the ERA Design Manual (2013) and the Mechanistic approach based on pavement performance.

The specific objectives are as follows:

1) To provide two design alternatives for pavement structure using the ERA design manual.
2) To compare their strength capacity with the structural number concept incorporating the subgrade strength and regional condition.
3) To predict the pavement life of the alternatives.

2. Literature Review

1) Design of Pavements

The skid resistance of wearing surfaces depends both on the aggregate and on the mixture characteristics. The most frequently sought-after characteristics of a skid-resistant aggregate are its resistance to polish and wear and its texture, shape, and size [1, 14, 16, 17].

2) Factors Influencing Deflections

The major factors that influence deflections include loading, climate, and pavement conditions.

These factors must be carefully considered when conducting nondestructive tests [1, 9-11, 16].

1) Loading

The magnitude and duration of loading have a great influence on pavement deflections. The NDT device should be able to apply a load to the pavement similar to the actual design load (e.g., a 9000-lb (40-kN) wheel load).

2) Climate

Temperature and moisture are the two climatic factors that affect pavement deflections. For asphalt pavements, higher temperatures cause the asphalt binder to soften and increase deflections.

3) Pavement Conditions

Pavement conditions have significant effects on measured deflections. For asphalt pavements, deflections obtained in areas with cracking and rutting are normally higher than those in areas free of distress. For concrete pavements, voids beneath concrete slabs will cause increased deflections, and the absence or deterioration of load transfer devices will affect the deflections measured on both sides of the joint.

3. Methodology

The methods of analysis and design of the flexible pavement incorporate the use of the following: Empirical Approach by ERA Flexible Pavement Design Manual 2013.

4. Results and Discussion

4.1. Design Considerations of Flexible Pavement in the AASHTO Method

The primary factors considered under pavement performance are the structural and functional performance of the pavement. Structural performance is related to the physical condition of the pavement concerning factors that harm the capability of the pavement to carry the traffic load. In the AASHTO design method, the traffic load is determined in terms of the number of repetitions of an 18,000-lb (80-kilo newton's (kN)) single-axle load applied to the pavement on two sets of dual tires. This is usually referred to as the *equivalent single-axle load* (ESAL). The total ESAL applied on the highway during its design period can be determined only after the design period and traffic growth factors are known and then calculate ESAL for the design of flexible pavement using the following formulas.

$$EALF = \left(\frac{Lx}{Ls}\right)^4$$

$$\mathrm{Grn} = [(1 + \mathrm{r})^{\mathrm{n}} - 1]/\mathrm{r}$$

$$\mathrm{ESALi} = \mathrm{fd}*\mathrm{Grn}*\mathrm{AADTi}*365*\mathrm{Ni}*\mathrm{FEi}$$

$$\text{Truck Factor} = \frac{\sum(\text{number of axles x load equivalency factor}}{\text{number of vehicles}}$$

$$\text{TFi} = \sum\frac{Ni*EALF}{ADT}$$

Roadbed Soils (Subgrade Material) the 1993 AASHTO guide also uses the resilient modulus (*MR*) of the soil to define its property. However, the method allows for the conversion of the CBR or *R*-value of the soil to an equivalent *MR* value using the following conversion factors:

Materials of Construction: The quality of the material used is determined in terms of the layer coefficient, $a3$, which is used to convert the actual thickness of the sub-base to an equivalent SN.

Base Course Construction Materials: selected should satisfy the general requirements for base course materials. A structural layer coefficient, $a2$, for the material used also should be determined.

Surface Course Construction Materials: The most commonly used material is a hot plant mix of asphalt cement and dense-graded aggregates with a maximum size of 1 inch. The structural layer coefficient ($a1$) for the surface course can be extracted from the table.

The modification of Drainage is carried out by incorporating a factor *mi* for the base and sub-base layer coefficients ($a2$ and $a3$). The *mi* factors are based both on the percentage of time during which the pavement structure will be nearly saturated and on the quality of drainage, which is dependent on the time it takes to drain the base layer to 50 percent of saturation.

Reliability: It has been noted that the cumulative ESAL is an important input to any pavement design method. However, the determination of this input is usually based on assumed growth rates which may not be accurate. The design depends on this value of the table.

Structural Design: The objective of the design using the AASHTO method is to determine a flexible pavement Structural Number (SN) adequate to carry the projected design ESAL. This design procedure is used for ESALs greater than 50,000 for the performance period. The design for ESALs less than this is usually considered under low-volume roads. But in this design, the ESALs value is $6.4 * 10^6$ so the road design is high volume.

Using the AASHTO Method, first calculate the ESAL from the following given table.

Table 1. *Axle load.*

Axle load (KN)	No. of axels per day	Axle load (KN)	No. of axels per day
10-30	100	90-110	200
30-50	225	110-130	100
50-70	250	130-150	50
70-90	300	150-170	10

Table 2. *Mid axle load and number of axles per day.*

Mid axle load (KN)	20	40	60	80	100	120	140	160
No axle per day	100	225	250	300	200	100	50	10

$$EALF = \left(\frac{Lx}{Ls}\right)^4$$

(20/81.6)^4 =0.0036 (40/81.6) ^4 =0.058 (60/81.6) ^4 =0.29 (80/81.6) ^4 =0.92
(100/81.6)^4 =2.26 (120/81.6)^4 =4.68 (140/81.6)^4 =8.66 (160/81.6)^4=14.7

EALF/day = ∑EALFi*Ni =0.0036*100+225*0.058+250*0.29+300*0.92+200*2.26+10*4.68+50*8.66+10*14.7= 1862.26

$$\text{TFi} = \sum\frac{Ni*EALF}{ADT}$$

$$Ti = \sum \frac{1862.26}{1235} = 1.5$$

$$\mathrm{ESAL_i} = \mathrm{f_d} \times \mathrm{G_{\{rn\}}} \times \mathrm{AADT_i} \times 365 \times \mathrm{N_i} \times \mathrm{F_{\{Ei\}}}$$

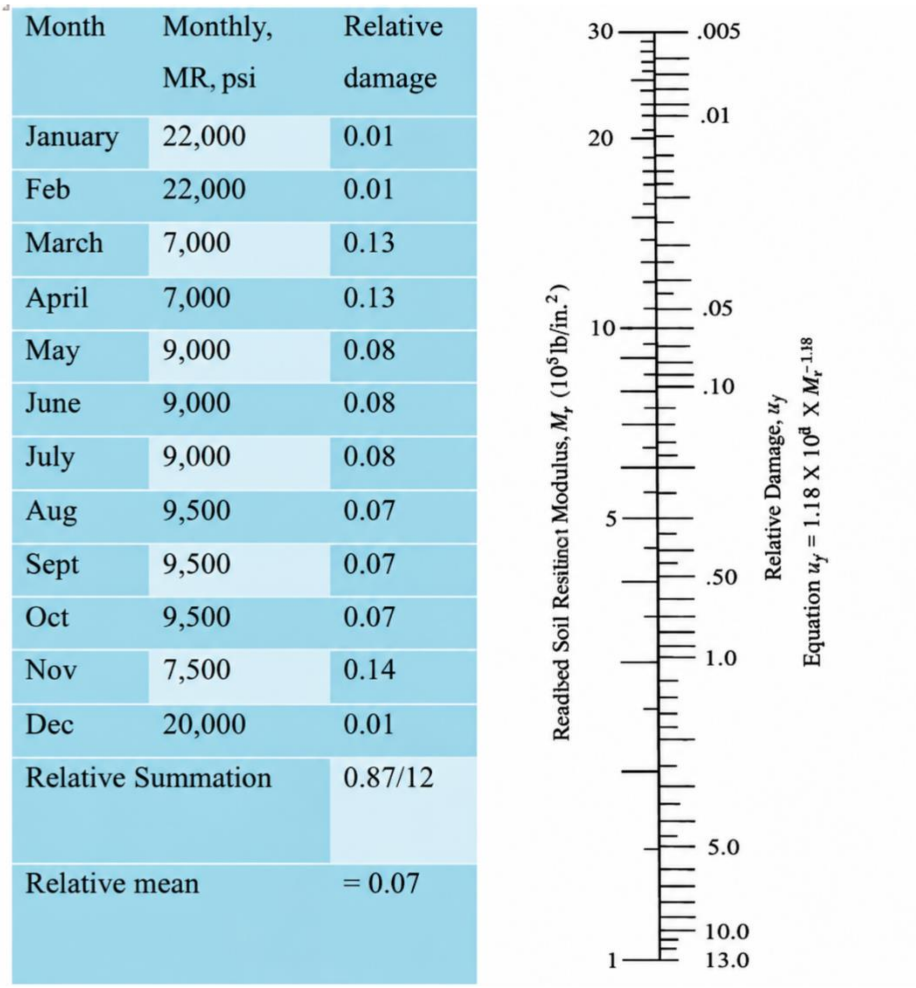
ESAL= 1862.26*365*(1.05) ^10)-1)/0.05*1.5 =1282426.12/2 = $6.4 * 10^6$

Next, determine the resilient modulus of subgrade from the following given table of effective roadbed soil resilient modulus data

Table 3. Mid axle load and number of axle per day.

Mid axle load (KN)	20	40	60	80	100	120	140	160
No of axle per day	100	225	250	300	200	100	50	10

First determine the relative damage from the figure



Month	Monthly, MR, psi	Relative damage
January	22,000	0.01
Feb	22,000	0.01
March	7,000	0.13
April	7,000	0.13
May	9,000	0.08
June	9,000	0.08
July	9,000	0.08
Aug	9,500	0.07
Sept	9,500	0.07
Oct	9,500	0.07
Nov	7,500	0.14
Dec	20,000	0.01
Relative Summation		0.87/12
Relative mean		= 0.07

Figure 1. Determine relative modulus.

Mr (psi)=9500, Mr (psi) = 9500

Estimating Effective Roadbed Soil Resilient Modulus for Flexible Pavements Designed Using the Serviceability Criteria

From Figure 1 MR =9500psi

Mi from the table 1.15+1/2 =1.1

Table 4. *Quality of drainage.*

Percent of Time Pavement Structure Is Exposed to Moisture Levels Approaching Saturation

Quality of Drainage	Less Than 1%	1 to 5%	5 to 25%	Greater Than 25%
Excellent	1.40–1.35	1.35–1.30	1.30–1.20	1.20
Good	1.35–1.25	1.25–1.15	1.15–1.00	1.00
Fair	1.25–1.15	1.15–1.05	1.00–0.80	0.80
Poor	1.15–1.05	1.05–0.80	0.80–0.60	0.60
Very poor	1.05–0.95	0.95–0.75	0.75–0.40	0.40

The monograph in Figure 1 is used to determine the design SN through the following steps.

Step 1: Draw a line joining the reliability level of 90% and the overall standard deviation of 0.45, and extend this line to intersect the first TL line at point A.

Step 2: Draw a line joining point A to the ESAL of $6.4 * 10^6$, and extend this line to intersect the second TL line at point B.

Step 3: Draw a line joining point B and the resilient modulus (MR) of the roadbed soil, and extend this line to intersect the design serviceability loss chart at point C.

Step 4: Draw a horizontal line from point C to intersect the design serviceability loss (_PSI) curve at point D. In this problem, PSI = 4.5 – 2.5 = 2.0

Step 5: Draw a vertical line to intersect the design SN value from the following figures

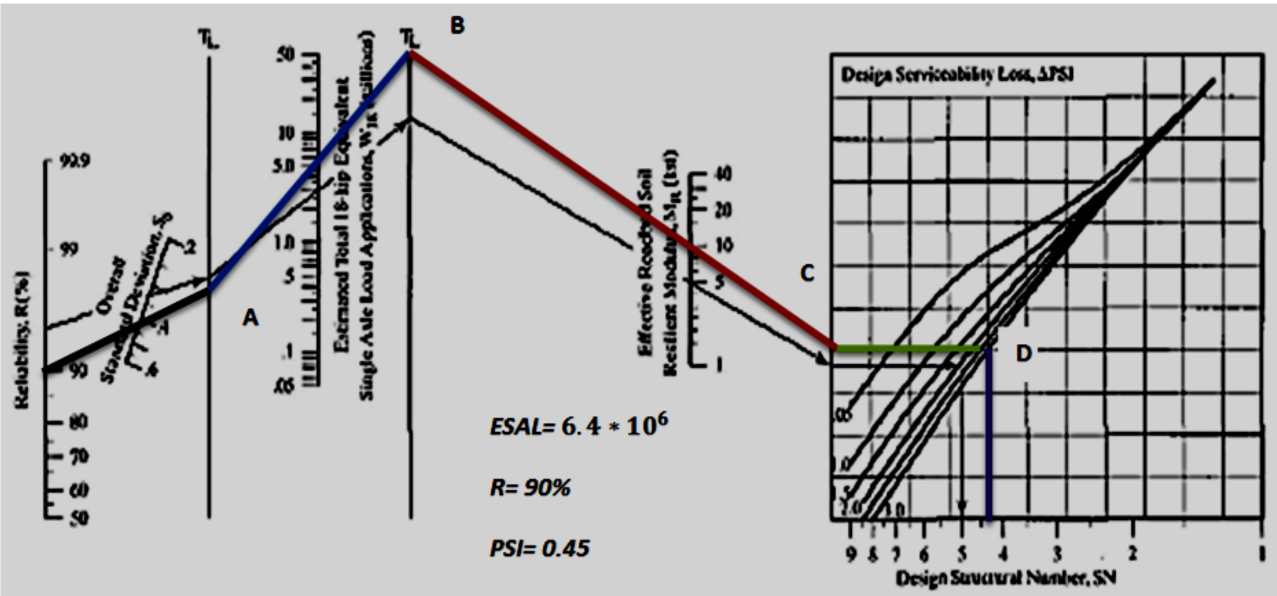


Figure 2. *The design of flexible pavement.*

Step 6: Determine the appropriate structure layer coefficient for each construction material.

1) Resilient value of asphalt =500,000psi From Figure 5 a1 = 0.40.
2) CBR of base course material =100 and Resilient value of base 30923psi. From Figure 4, a2 = 0.14.
3) CBR 30% and Resilient value of sub-base course material 14450psi From Figure 3, a3 =0.11.

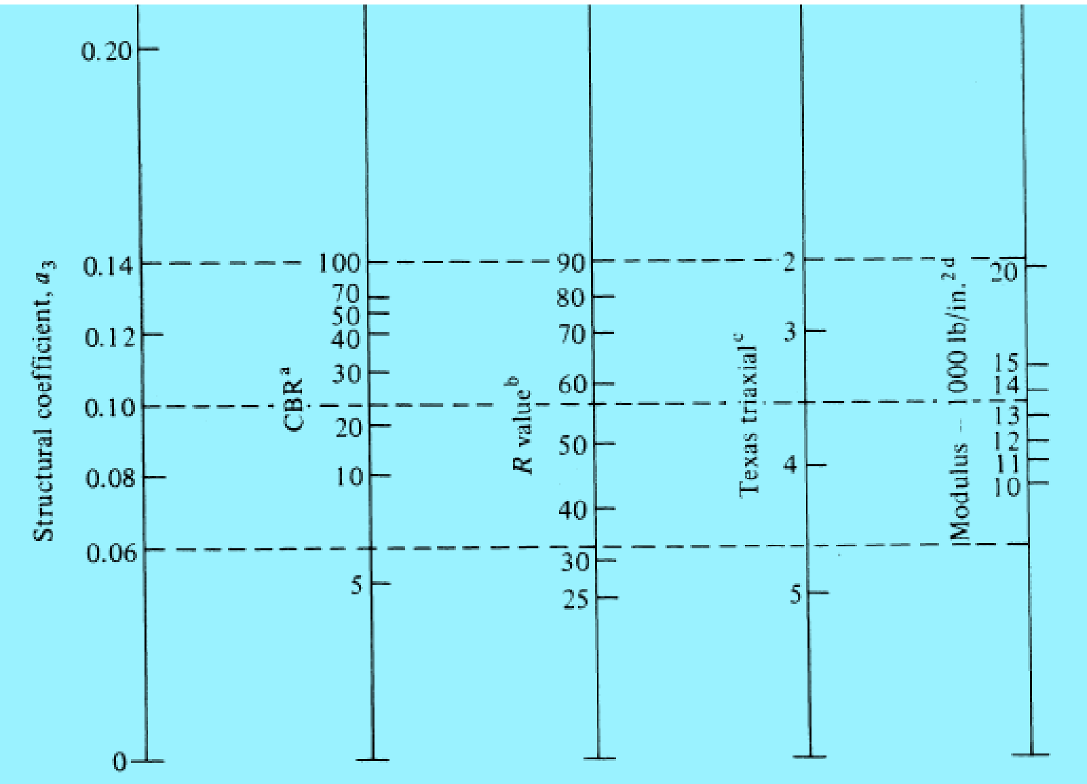


Figure 3. Determine the value of a3.

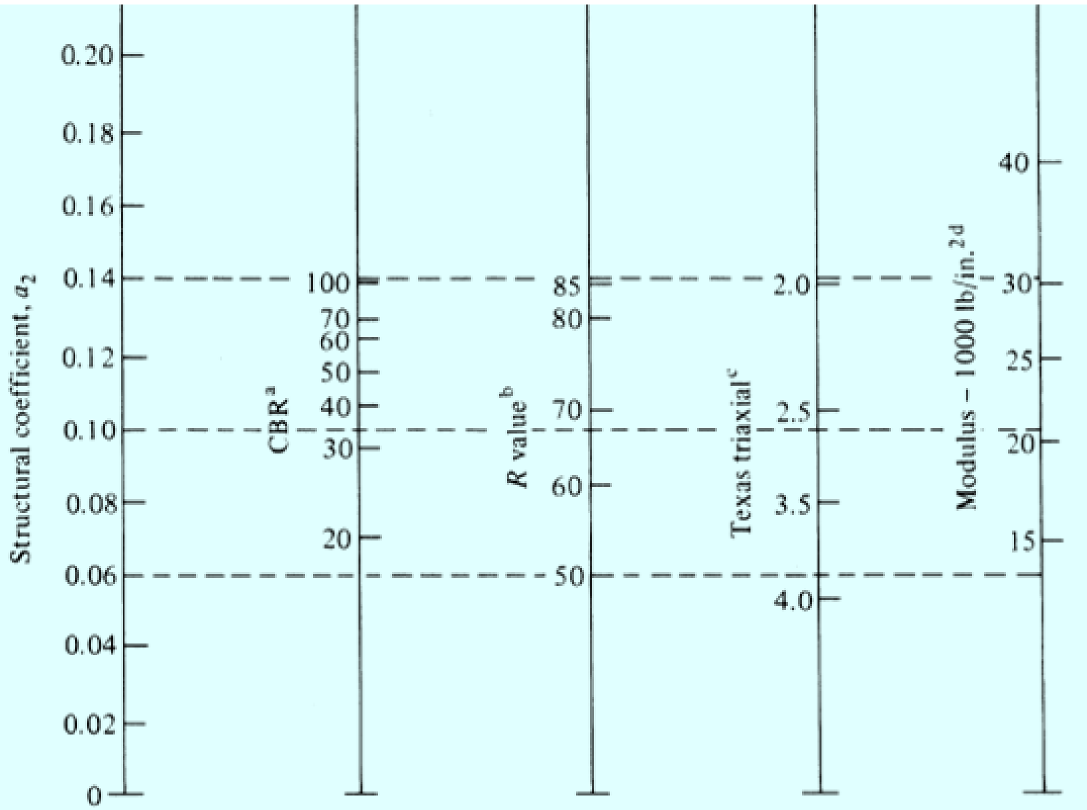


Figure 4. Determine the value of a2.

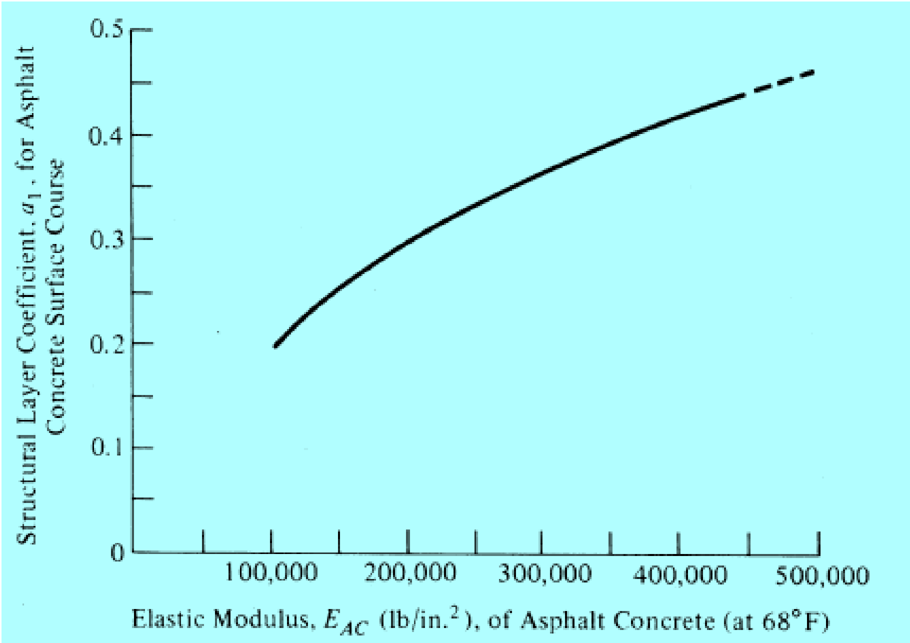


Figure 5. *Determine the value of a1.*

Step 7: Determine appropriate drainage coefficient mi. Since only one set of conditions is given for both the base and sub-base layers, the same value will be used for m1 and m2. The time required for water to drain from within the pavement is one day, and from Table drainage quality is good. The percentage of time pavement structure will be exposed to moisture levels approaching saturation = 25%, and from Table 2 mi = 1.10.

Step 8: Determine appropriate layer thicknesses values of D1, D2, and D3 from

$$\mathrm{SN} = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3$$

To determine D1, D2 & D3 first determine SN1, SN2 & SN3 from the table using MR of the base, sub base, and subgrade value. Layer thicknesses, however, are usually rounded up to the nearest 0.5 inches. The table below lists the minimum thicknesses suggested by AASHTO.

Table 5. *AASHTO-Recommended Minimum Thicknesses of Highway Layers.*

Minimum thickness (in)		
Traffic ESALs	**Asphalt concrete**	**Aggregate base**
Less than 50000	1.0	4
50001-150000	2.0	4
1500001-500000	2.5	4
500001-2000000	3.0	6
2000001-7000000	3.5	6
Greater than 7000000	4.0	6

Taking into consideration that a flexible pavement structure is a layered system, the determination of the different thicknesses should be carried out as indicated in Figure 6. The required SN of the subgrade is first determined, and then the required SNs of the base and sub-base layers are determined using the appropriate strength of each layer. The minimum allowable thickness of each layer can then be determined using the differences in the computed SNs as shown in Figure 6.

SN1 = 2.5, SN2= 3.5, SN3 = 4.5

So, D1 =SN1/a1 = 2.5/0.4 =6inch

$$D2 = \frac{SN2 - a1D1}{a2m2} = \frac{3.5 - 2.4}{0.15} = 8inch$$

$$D3 = \frac{SN3 - a1D1 - a2D2m2}{a3m3} = \frac{4.5 - 2.4 - 1.2}{0.121} = 7inch$$

SN3 = a1D1+ a2D2m2+D3a3m3
=0.4*6+0.14*8*1.1+0.11*7*1.1

SN3 = 4.5

The flexible pavement design has a 6inch surface, 8inch base, and 7inch sub base

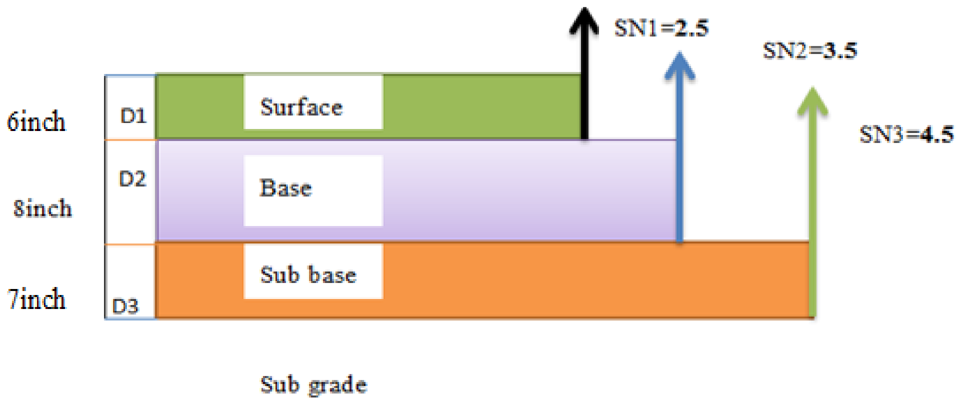


Figure 6. Final design of flexible pavement by AASHTO method.

4.2. Design Considerations of Flexible Pavement in the ERA Method

The choice of the chart was depend on a variety of factors but should be based on minimizing total transport costs. Factors that needed to be taken into account in a full evaluation include:

1) The likely level and timing of maintenance
2) The probable behavior of the structure, etc.

For many roads, especially those that are more lightly trafficked, the local experience was dictate the most appropriate structures and sophisticated analysis will not be warranted.

Using the ERA Method, first calculate the ESAL from the following given table.

Table 6. Axle load.

Axle load (KN)	No. of axels per day	Axle load (KN)	No. of axels per day
10-30	100	90-110	200
30-50	225	110-130	100
50-70	250	130-150	50
70-90	300	150-170	10

Table 7. Mid axle load and number of axles per day.

Mid axle load (KN)	20	40	60	80	100	120	140	160
No axle per day	100	225	250	300	200	100	50	10

$$EALF = \left(\frac{Lx}{Ls}\right)^{4.5}$$

(20/81.6)^4.5 =0.0018 (40/81.6)^4.5 =0.04 (60/81.6)^4.5 =0.25 (80/81.6)^4.5 =0.91
(100/81.6)^4.5 =2.50 (120/81.6)^4.5 =5.7 (140/81.6)^4.5 =11.34 (160/81.6)^4.5=20.7
EALF/day =∑EALFi*Ni =0.0018*100+225*0.04+250*0.25+300*0.91+200*2.5+10*5.7+50*11.34+10*20.7= 2188.68

$$\text{TFi} = \sum\frac{Ni*EALF}{ADT}$$

$$Ti = \sum \frac{2188.68}{1235} = 1.77$$

$$ESALi = fd*Grn*AADTi*365*Ni*FEi$$

$$ESAL= 2188.68*365*(1.05)\ \hat{}10)-1)/0.05*1.77 = 177885098.71/2 = 8.89 * 10^6$$

9500= 1500CBR => CBR= 6.3

The traffic class T6 has been derived (with a total of ESAs on the order of 8.89 million over the design period). From the table given on ERA, for that class of traffic, it is readily apparent that the use of the design charts in the catalog of structures is Charts 1, Charts 2, Charts 3, Charts 4 Charts 5 Charts 6 Charts 7, and through Charts 8. The subgrade strength has been calculated from the MR of the subgrade to be represented by CBRs in the range of 5 to 7, considering that some portions of the alignment which might exhibit higher strength are so limited in number and extent that it makes it impractical to consider several designs. The subgrade strength class to be assigned to this project was therefore S3.

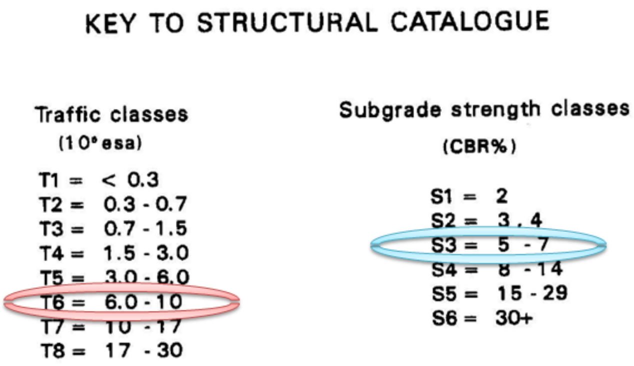


Figure 7. Structural Catalogue.

Table 8. Possible Pavement Structures.

Design Number	Chart 1	Chart 2	Chart 3	Chart 4	Chart 5	Chart 6	Chart 7	Chart 8
Flexible bituminous	-	_	50mm	50mm	_	_	50mm	-
Bituminous surface	-	_	-	_	100mm	100mm	_	-
Bituminous road base	-	_	-	_	_	_	150mm	-
Granular road base	225mm	150mm	200mm	150mm	200mm	150mm	_	-
Granular sub base	350mm	_	350mm	_	250mm	_	275mm	-
Granular capping layer	-	125mm	-	150mm	_	125mm	_	125mm
Cement CB2	-	125mm	-	250mm	_	175mm	_	200mm
Lime stab. sub base	-	-	-	-	_	-	-	200mm

Table 9. Relative Unit Costs of Materials.

MATERIAL	THICKNESS	RELATIVE UNIT COST
Flexible bituminous (AC)	50mm (5cm) thickness	0.33
Bituminous surface	100mm (10cm) thickness	0.45
Bituminous road base	150mm (15cm) t thickness	0.75
	150mm (15cm) thickness	0.56
Granular road base	200mm (20cm) thickness	0.75
	225mm (22.5cm) thickness	0.84
Granular sub base	250mm (25cm) thickness	0.36

MATERIAL	THICKNESS	RELATIVE UNIT COST
	275mm (27.5cm) thickness	0.40
	350mm (35cm) thickness	0.50
Fill or Granular capping layer	125mm (12.5cm) thickness	0.16
	150mm (15cm) thickness	0.20
Cement CB2	125mm (12.5cm) thickness	1.17
	175mm (17.5cm) thickness	1.64
	200mm (20cm) thickness	0.73
	250mm (25cm) thickness	2.34
Lime stabilized sub base	200mm (20cm) thickness	1.16

Table 10. Relative Costs of the Possible Alternate Pavement Structures.

Alternate Pavement Structure No.	Description	RELATIVE UNIT COST
1	225mm Granular road base 350mm Granular sub base	1.34
2	150mm Granular road base 125mm Granular capping layer 125mm Cement CB2	1.89
3	50mm Flexible Bituminous 200mm Granular road base 350mm Granular sub base	1.58
4	50mm Flexible Bituminous 150mm Granular road base 150mm Granular capping layer 250mm Cement CB2	3.43
5	100mm bituminous surface 200mm Granular road base 250mm Granular sub base	1.56
6	100mm bituminous surface 150mm Granular road base 125mm Granular capping layer 175mm Cement CB2	2.81
7	50mm Flexible Bituminous 150mm Bituminous road base 275mm Granular sub base	1.48
8	125mm Granular capping layer 200mm Cement CB2	2.05

Alternate Pavement Structure No.	Description	RELATIVE UNIT COST
	200mm Lime stab. sub base	

From the alternative of calculation, alternative one has the least costs which means 1.34 is the relative unit cost but the material is not full. So, the selected alternative was seven., the cost is the least from the other six alternatives which means 1.48, and CBR is less than 20% it requires an additional thickness of the capping layer of 150mm. The cost of capping layer unit cost is 0.20, so the total cost is = 1.48+0.20 = 1.68 relative cost selected.

Table 11. Relative Costs of the Possible Alternate Pavement Structure's final design.

Alternate Pavement Structure No.	Description	RELATIVE UNIT COST
7	50mm Flexible Bituminous 150mm Bituminous road base 275mm Granular sub base 150mm (15cm) capping layer	0.33 0.75 0.40 0.20 ∑= 1.68

The final design of flexible pavement by ERA method is described in the following figure

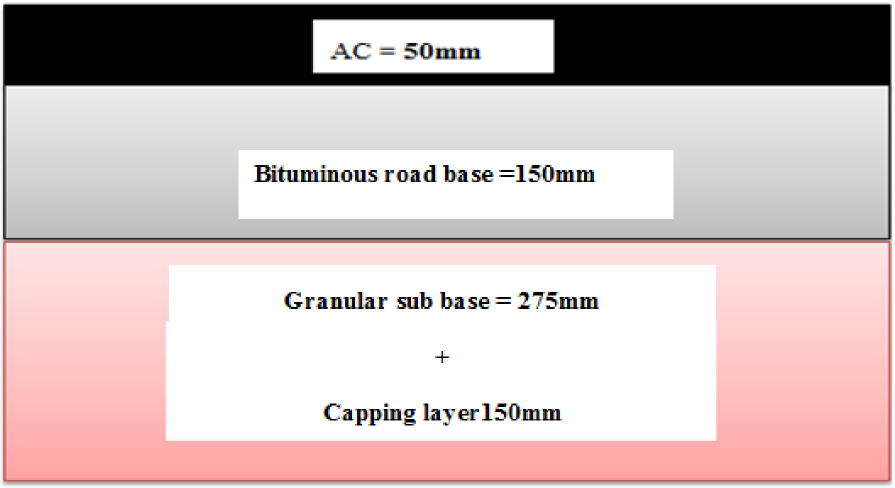


Figure 8. Final design of flexible pavement by ERA method.

4.3. Design Considerations of Flexible Pavement in the Asphalt Institute (AI) Method

Design Criteria

Two types of strains have frequently been considered the most critical for the design of asphalt pavements. One is the horizontal tensile strain εt at the bottom of the asphalt layer, which causes fatigue cracking; the other is the vertical compressive strain εc on the surface of the subgrade, which causes permanent deformation or rutting. These two strains are used as failure criteria in the Asphalt Institute method.

Design Chart for Full Depth HMA

We have ESALs and sub-grade resilient modulus

ESALs $= 8.89 * 10^6$ from the above calculation subgrade resilient modulus = 9500 psi from the above calculation

The thickness for full-depth HMA is 13.5inch as determined from the following figure. If the HMA surface is 2 inches, then the thickness of the HMA base is 11.5 inches.

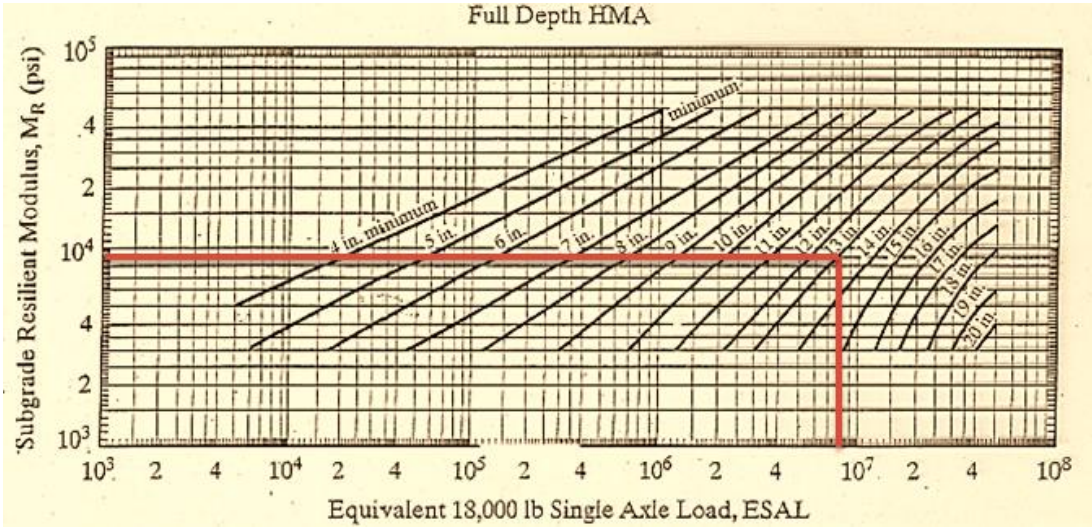


Figure 9. Full depth.

1) The thickness for emulsified asphalt mix to be placed directly on the subgrade is 15.5 inches as obtained from the following figure. If the HMA surface is 2 inches, then the thickness of the emulsified asphalt base is 13.5 inches.
First, determine the combined thickness and minimum HMA thickness from the following
figure the combined thickness = 15.5 inch and minimum HMA thickness = 3inch
if the minimum thickness is used the thickness of the emulsified asphalt base is 15.5 inch - 3inch =12.5inch

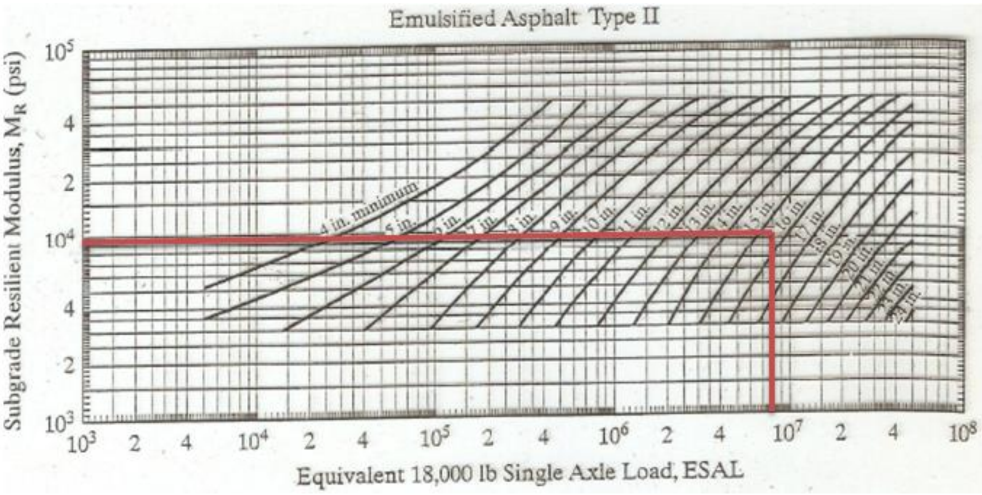


Figure 10. Emulsified Asphalt mix Type –II.

2) The substitution ratio is 13.5/11.5 = 1.17.
3) The thickness of HMA over an 8-inch untreated aggregate base is 11.5 inches, as shown in the following figure.

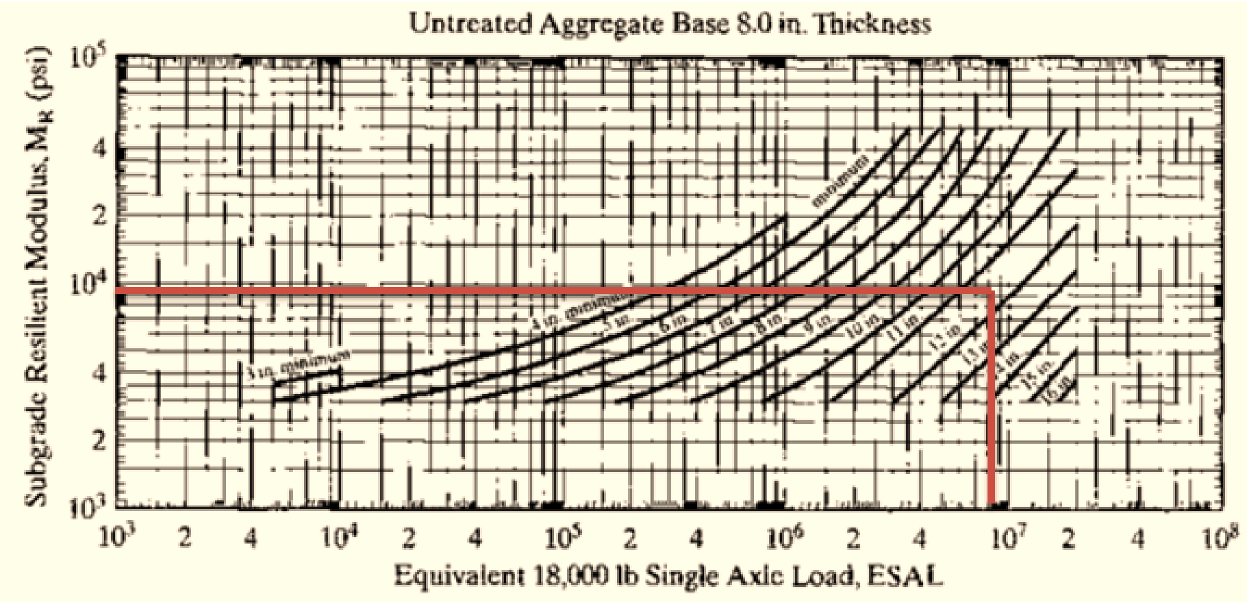


Figure 11. *Untreated Aggregate base 8.0-inch thickness.*

4) From the following, the minimum HMA thickness is 3 inches, so 3.5 inches of HMA base must be replaced by the emulsified asphalt base

Table 12. *Of the minimum thickness of HMA over emulsified.*

Traffic level ESALs	HMA thickness type I	HMA thickness type II and III
10000	1	2
100000	1.5	2
1000000	2	3
10000000	2	4
Greater 10000000	2	5

5) The thickness of the emulsified asphalt base is 3.5 *1.17 = 4.1 inch. The final design consists of 3 inches of HMA, 4.1 inches of an emulsified asphalt base, and 8 inches of untreated aggregate base, or a total thickness of 15.1 inches.

4.4. Design Considerations of Rigid Pavement in the AASHTO Method

Rigid highway pavements can be divided into three general types: plain concrete pavements, simply reinforced concrete pavements and continuously reinforced concrete pavements. The definition of each pavement type is related to the amount of reinforcement used. The main objective of rigid pavement design is to determine the thickness of the concrete slab was adequate to carry the projected traffic load for the design period.

Calculation by AASHTO Method is as follows:

Design Factors: - Subgrade and sub-base support is defined by the modulus of subgrade reaction, k. Methods for determining the modulus of subgrade reaction.

The following points were considered for the rigid pavement design

1) Concrete Modulus of Rupture

2) Traffic and Design Period 40 Year

$$EALF = \left(\frac{Lx}{Ls}\right)^4$$

(20/81.6)^4 =0.0036 (40/81.6) ^4 =0.058 (60/81.6) ^4 =0.29 (80/81.6) ^4 =0.92
(100/81.6)^4 =2.26 (120/81.6)^4 =4.68 (140/81.6)^4 =8.66 (160/81.6)^4=14.7
TFi= ∑EALFi*Ni =0.0036*100+225*0.058+250*0.29+300*0.92+200*2.26+10*4.68+50*8.66+10*14.7= 1862.26

$$\text{TFi} = \sum \frac{Ni*EALF}{ADT}$$

$$\text{Ti} = \sum \frac{1862.26}{1235} = 1.5$$

$$\text{ESALi} = \text{fd*Grn*AADTi*365*Ni*FEi}$$

$$\text{ESAL} = 1862.26*365*(1.05)\ \text{^}40)-1)/0.05*1.5 = 123165921.7/2 = 61.6 * 10^6$$

In which Wt18 is the number of 18-kip (80-kN) single axle load applications to time "t" is an assumption as the following

1) Modulus of elasticity of concrete E, = 4.2 x 106 psi (29 GPa)
2) Modulus of rupture of concrete Se = 690 psi (4.8 MPa)
3) Modulus of subgrade reaction k = 60 PCI (16 MN/m3)
4) Load transfer coefficient J = 3.2 and drainage coefficient Cd = 1.0.
5) The sub-base thickness 7inch

We have the following value from the given calculation

1) Resilient modulus value of sub-base course material 14450psi
2) Resilient modulus values of sub-grade 9500psi

Then determine the composite modulus of subgrade reaction k ∞ from Figure 12 and use the value of sub base and subgrade resilient modulus

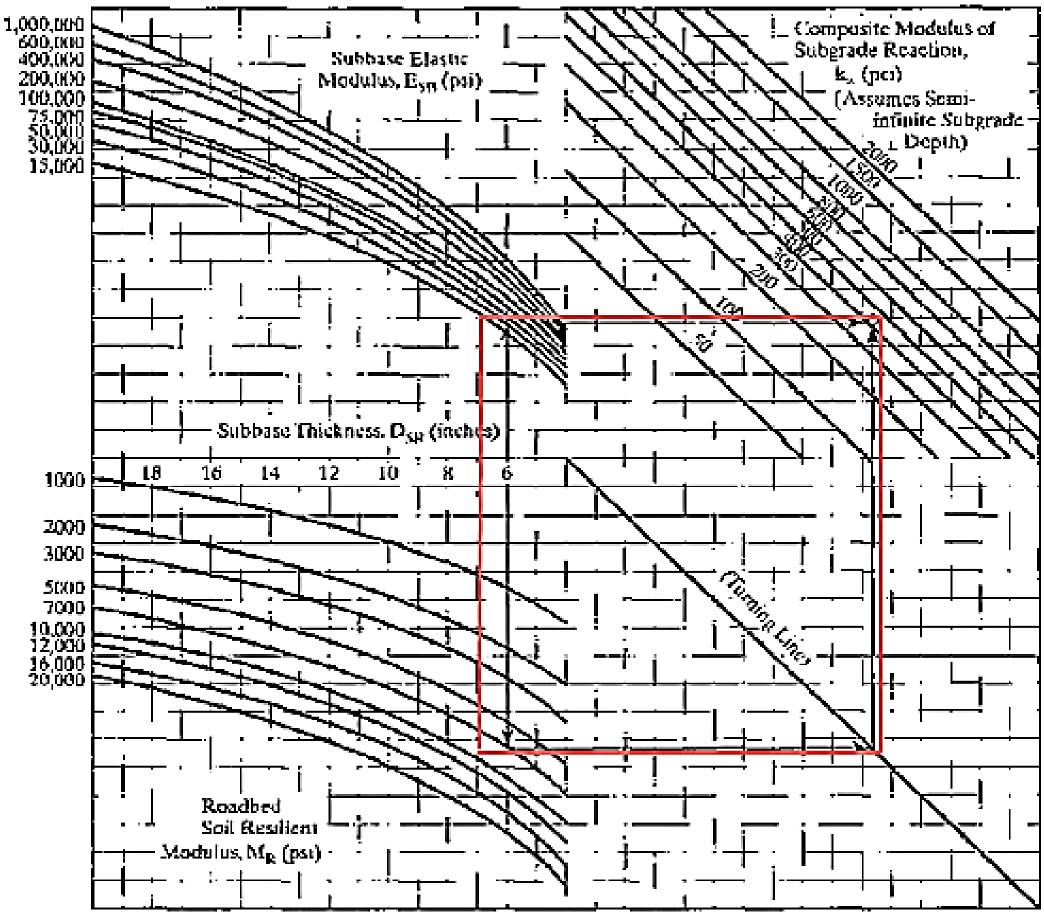


Figure 12. Composite value of sub-base and subgrade.

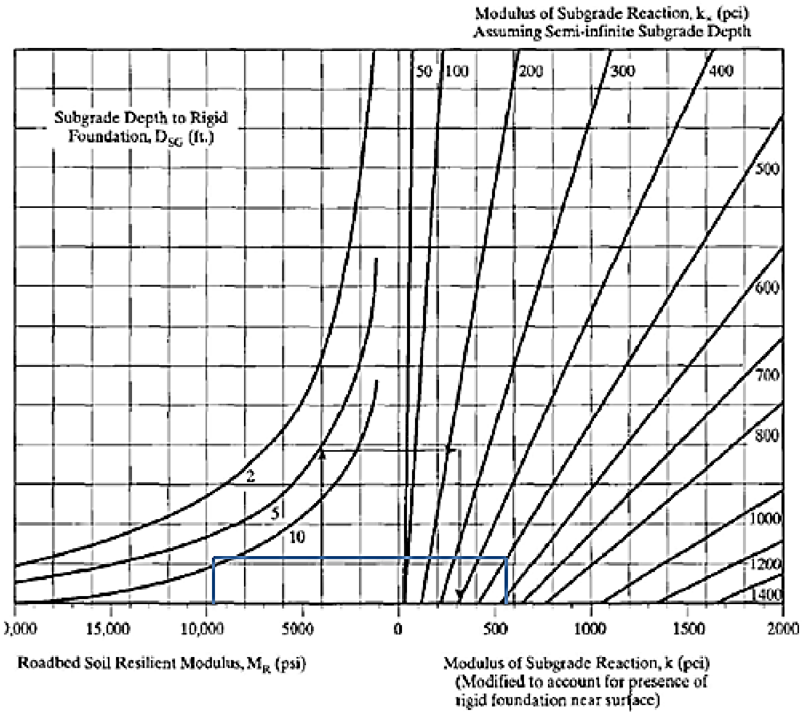


Figure 13. Subgrade reactions, k.

Modulus of Subgrade Reaction, k (PCI) (Modified to account for the presence of rigid foundation near the surface) k = 580pci

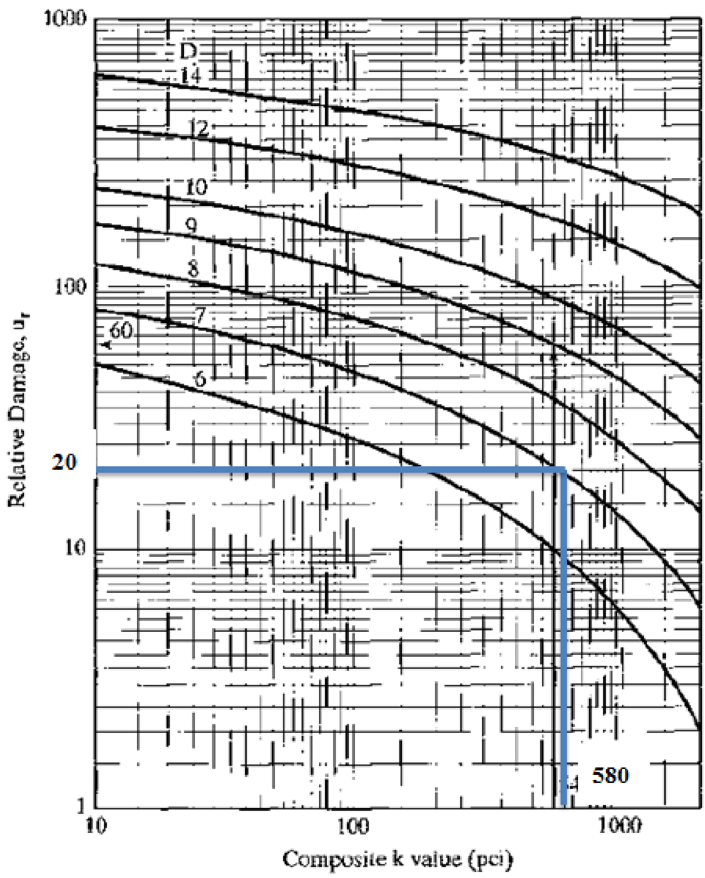
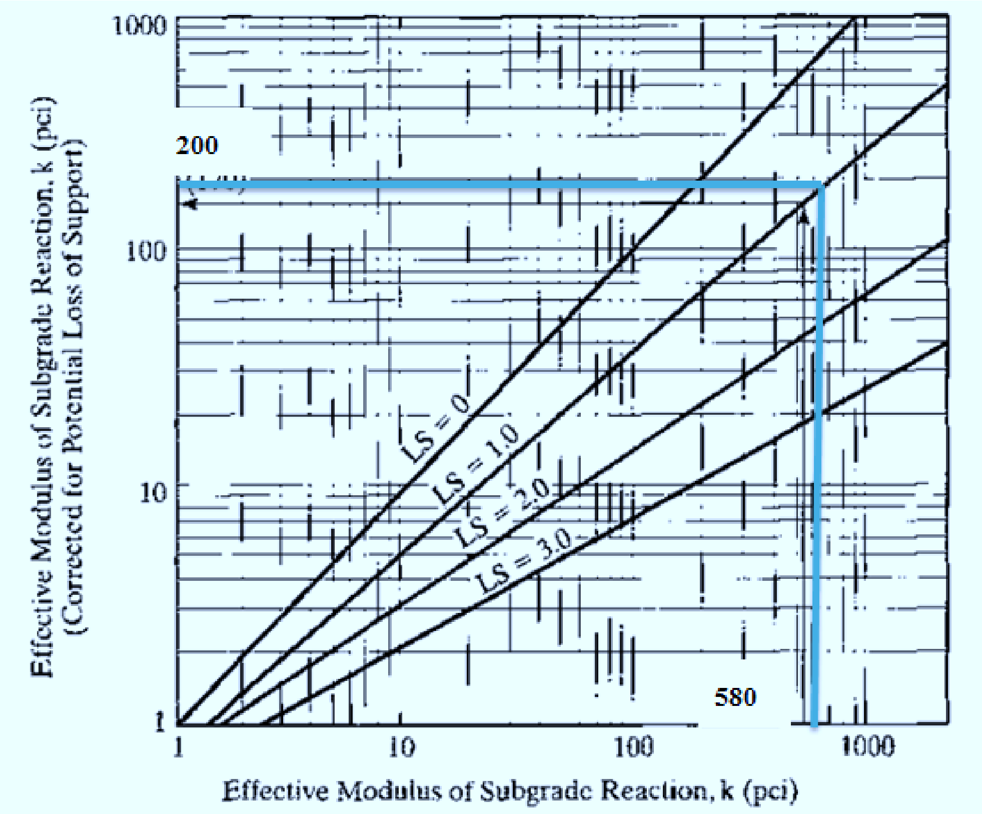


Figure 14. Relative damage.

Given D = 7 inches and k = 580 PCI, determine ur by using Equation and compare the result with Figure 15.

Solution: From of ur = [(7^0.75 – 0.39(580) ^0.25] ^3.45 = 19.57 which checks with relative damage of 20 obtained from the chart.



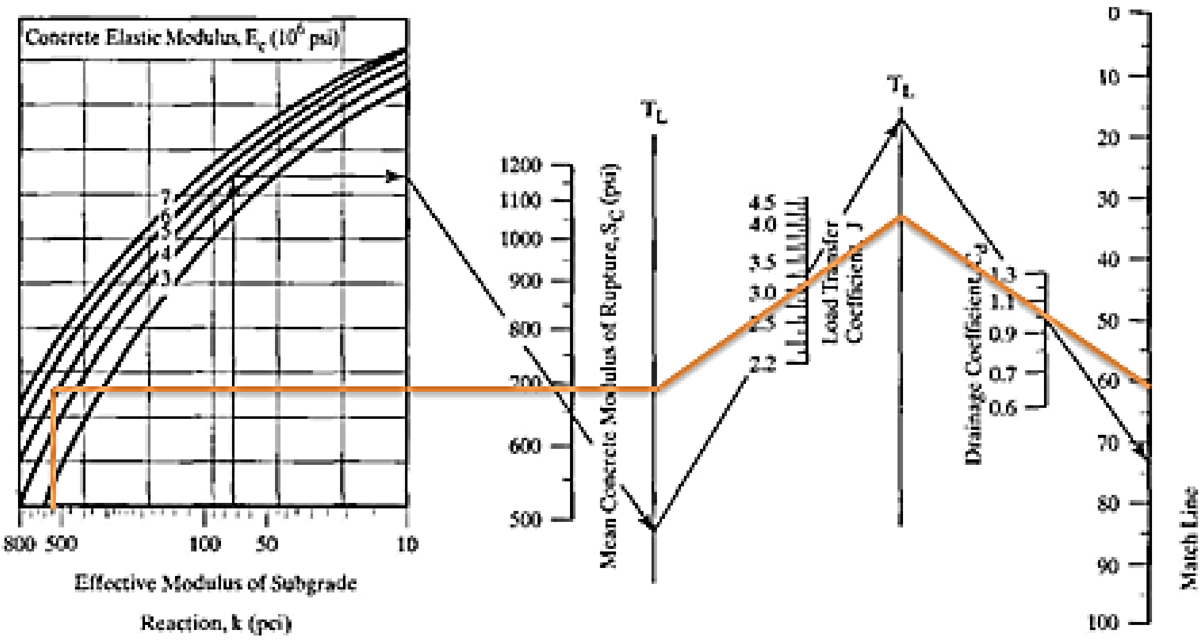


Figure 15. Effective modulus of sub-grade reaction k.

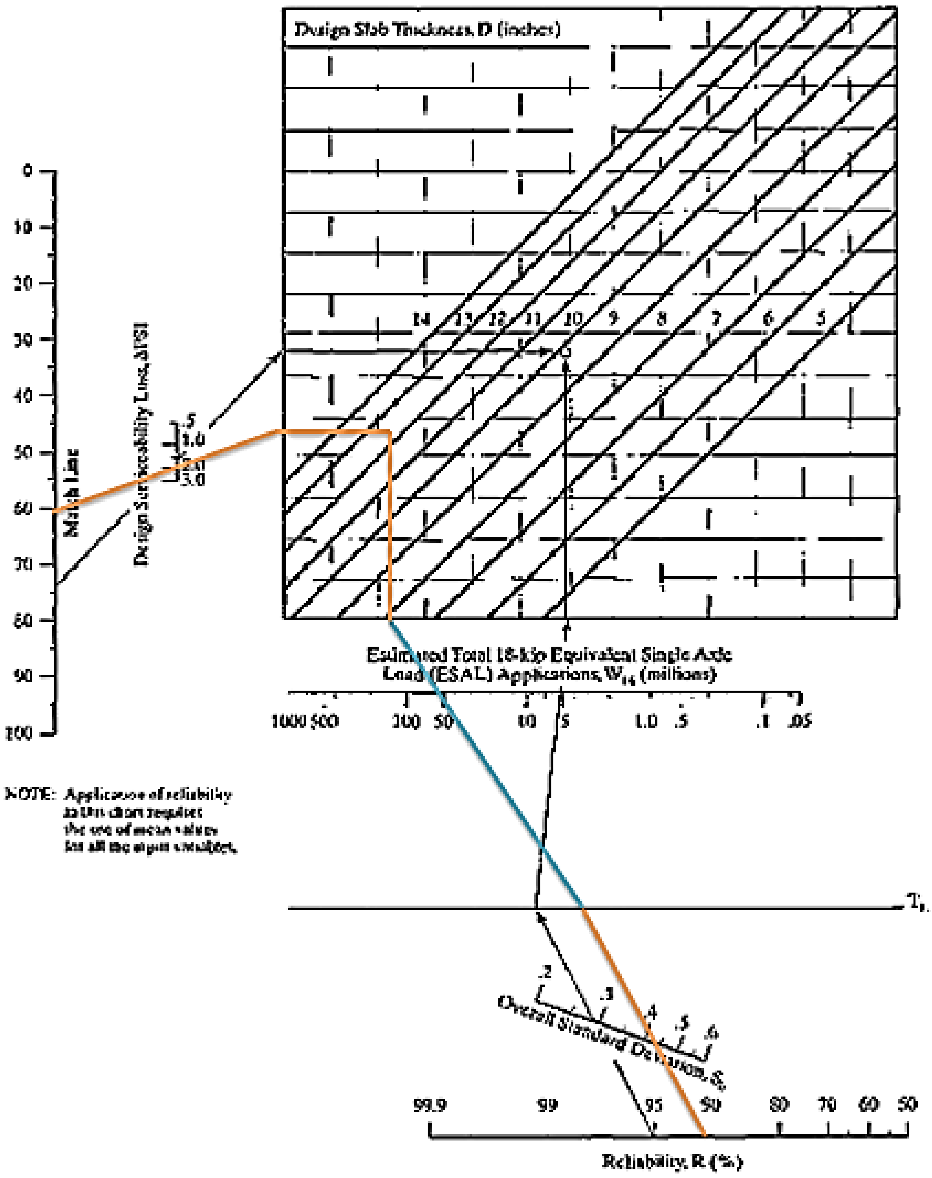


Figure 16. *Slab thickness.*

A correcting effective modulus of subgrade reaction =200 from the graph

The result of the AASHO Road Test indicates that the stresses s produced in a concrete pavement are proportional to the number of load applications it can carry, so the equivalent k value for partial contact can be obtained by varying the k values until the maximum principal stress for full contact is equal to that for partial l contact.

Generally, rigid pavement design by the AASHTO method contains the following points

1) K ∞ = 500pci from the above Figure 15
2) Modulus of Subgrade Reaction, k (PCI) (Modified to account for the presence of rigid foundation near the surface) k = 580pci from Figure 15
3) From the chart, the relative damage is = 20 using the composite k value and the depth.
4) From the above Figure 17 design slab thickness = 12inch

4.5. Design Considerations of Rigid Pavement in the ERA Method

The factors which shall intervene in the design of rigid pavements are as follows:

1) The subgrade quality
2) The quality of the steel and concrete composing the slabs
3) The traffic
4) The environment (Moisture and temperature)
5) The notional design life

Calculation by ERA Method is as follows:

First, calculate ESAL

Table 13. Mid axle load and number of axles per day.

Mid axle load (KN)	20	40	60	80	100	120	140	160
No of axle per day	100	225	250	300	200	100	50	10

$$EALF = \left(\frac{Lx}{Ls}\right)^{4.5}$$

(20/81.6)^4.5 =0.0018 (40/81.6)^4.5 =0.04 (60/81.6)^4.5 =0.25 (80/81.6)^4.5 =0.91
(100/81.6)^4.5 =2.50 (120/81.6)^4.5 =5.7 (140/81.6)^4.5 =11.34 (160/81.6)^4.5=20.7
Ti=∑EALFi*Ni =0.0018*100+225*0.04+250*0.25+300*0.91+200*2.5+10*5.7+50*11.34+10*20.7= 2188.68

$$\text{Ti} = \sum\frac{Ni*EALF}{ADT}$$

$$\text{Ti} = \sum\frac{2188.68}{1235} = 1.77$$

ESALi = fd*Grn*AADTi*365*Ni*FE

So, the design period equal to 40 years because the design period of rigid is 40 up to 60 years.

ESAL= 2188.68*365*(1.05) ^40)-1)/0.05*1.77 =170810483.8/2 = $85.41 * 10^6$

1) 9500= 1500CBR => CBR= 6%
2) CBR= 6%

Step 1 Check for Capping Layer

A design is required a capping layer because the CBR value of the subgrade is less than 15% which means 6%. The required thickness of a capping layer for a CBR value inferior to 15% can be obtained from the figure. A design is required for sub base because the CBR value of the sub-base is less than 30% or equal.

Step 2 Sub-base

Generally, the thickness of the sub-base provided was constant 15 cm and can be cement stabilized. The capping layer thickness is equal to 250mm in the following figure and the thickness of sub base is 150mm in Figure 17.

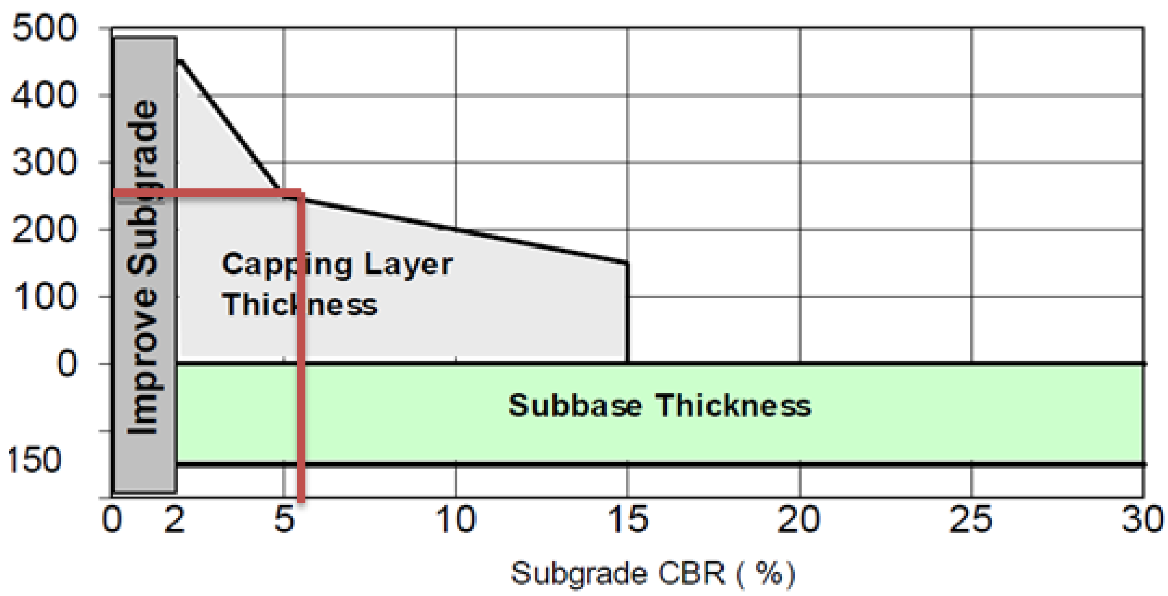


Figure 17. Capping layer sub base.

1) Capping layer thickness = 250mm
2) Sub-base thickness = 150mm
3) The thickness of the concrete slab is 200mm

Step 3 Pavement Slab

From types of rigid pavement, the selection was CRCP design. Because CRCP should be considered only for rather high design traffic (>30msa), the ESAL value is $85.41 * 10^6$. They can also be included for less heavily trafficked schemes where the advantage of lower maintenance throughout the design life may be worthwhile. They are particularly suitable where the settlement of the subsoil is expected. For instance, for heavily traveled facilities in congested locations, the need to minimize the disruptions and hazards to traffic may dictate the selection of CRCP.

The continuous reinforcement increases the resistances of slabs but the compressive strength remains limited and the slab is prone to expansion failure. It is thus preferable to cast CRCP slabs during the hottest time of the year to limit the potential of thermal expansion.

Step 4 Final Design

Longitudinal reinforcement in CRCP pavements shall be 0.6% of the concrete slab cross-sectional area, consisting of 16 mm diameter deformed steel bars. Transverse reinforcement shall be provided at 600 mm spacing, consisting of 12 mm diameter deformed steel bars, to prevent the opening of any longitudinal cracks which may form. Transverse reinforcement is required for ease of construction.

At CRCP slab ends (connection with flexible pavements, other concrete pavement types or structures) anchorage devices are required because the surface of friction is not sufficient to counterbalance the contraction and expansion stresses, which could provoke the formation of wide openings.

This can be achieved by providing a succession of reinforced concrete lugs which anchor the slab in the soil. The lugs are typically bout 1 m deep, cover the width of the slab, and are placed every 5 meters over the 30 last meters of the continuously reinforced pavement.

The thickness of the concrete slab is 200mm by design thickness for CRCP Pavement

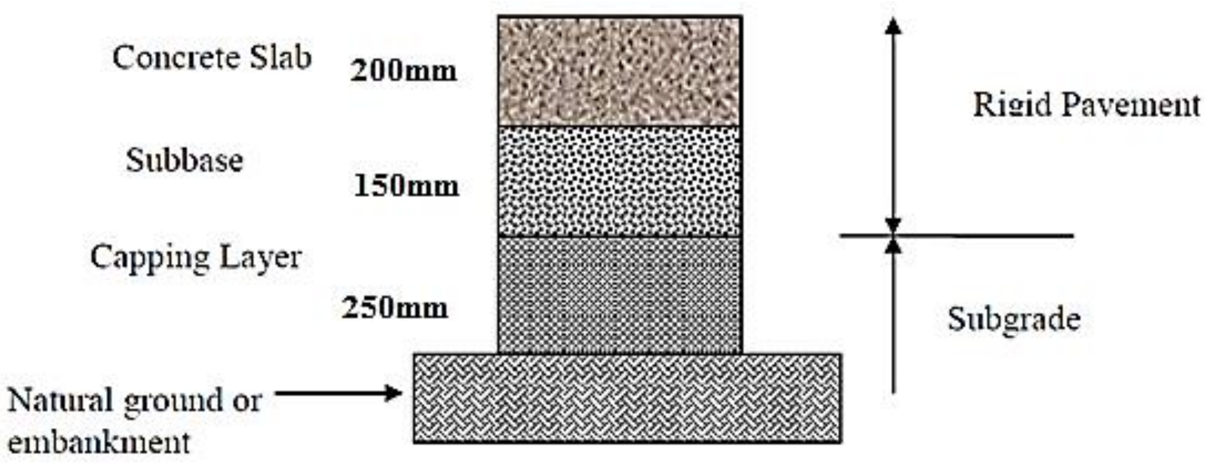


Figure 18. *CRCP rigid pavement design.*

The CRCP can be achieved by providing for each longitudinal bar, a 700mm long reinforcement bar (Dia. 20mm) centered on the joint.

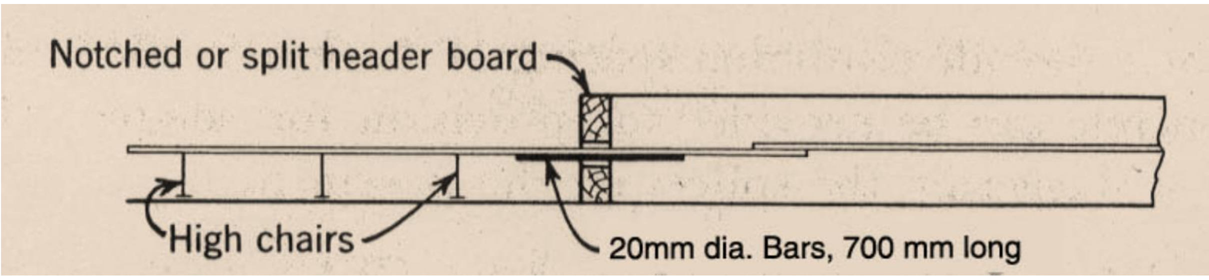


Figure 19. *transverse construction joint for CRCP slabs.*

The other reason to select CRCP pavement type is if an ESAL value greater than 30msa is considered as the project used for high traffic load. So, our ESAL values are $85.41 * 10^6$.

5. Conclusion and Recommendation

5.1. Conclusion

The design methods of different pavement types in these projects depended on their design consideration and the factor condition problem of the project areas. In these projects, there are two types of pavements (flexible and rigid) designed by using AASHTO, ERA, and AI methods. For these design methods, the point consider were the design criteria of the method and the costs of the materials that can be related to traffic, soil, weather, materials, construction, maintenance, environment, and other conditions.

The selection of different layer thicknesses of the design of flexible pavement by the AASHTO method also should be based on constraints associated with maintenance and construction practices so that a practical design was obtained. It is normally impractical and uneconomical to construct any layer with a thickness less than some minimum value.

The design of flexible pavement by the ERA method depends on the highway project data to fix the final design. From the seven alternatives of calculation, alternative five has the least cost which means 1.48 relative unit cost and CBR less than 20% it requires an additional thickness of capping layer 150mm. The costs of capping layer unit cost are 0.20, so the total cost is = 1.48+0.20 =1.68 relative cost.

The rigid pavement design by the ERA method is required a capping layer because the CBR value of the subgrade is less than 15% which means 6% and the design is required a sub-base. After all, the CBR value of the sub-base is less than 30% or equal. The thickness of the sub-base provided will be a constant 15 cm and can be cement stabilized. The rigid pavement design by the ERA method in this project was CRCP design. Because CRCP shall be considered only for rather high design traffic (>30msa), our ESAL value is $85.41 * 10^6$. The continuous reinforcement increases the resistances of slabs but the compressive strength remains limited and the slab was prone to expansion failure. It is thus preferable to cast CRCP slabs during the hottest time of the year to limit the potential of thermal expansion.

5.2. Recommendations

First, a judgment must be made on many varying factors such as traffic, soil, weather, materials, construction, maintenance, and environment. In some cases, overriding factors can dictate pavement type. For instance, for heavily traveled facilities in congested locations, the need to minimize the disruptions and hazards to traffic may dictate the selection of CRCP. So as we know from Dire Dawa to Harar heavy vehicles can be traveled. For this reason, the highway project design needed for these different types of the vehicle must be related to their load. If the load is heavy, but the design project does not address the load the project fails after a few periods.

Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
AI	Asphalt Institute
CBR	California Bearing Ratio
CRCP	Continuously Reinforced Concrete Pavement
EALF	Equivalent Axle Load Factor
ERA	Ethiopian Roads Administration
ESAL	Equivalent Single Axle Load
FHWA	Federal Highway Administration
HMA	Hot-Mix Asphalt
IRC	Indian Roads Congress
K	Modulus of Subgrade Reaction
MR	Resilient Modulus
NDT	Non-Destructive Testing
OECD	Organisation for Economic Co-operation and Development
PSI	Present Serviceability Index
SN	Structural Number
TF	Traffic Factor
Wt18	Number of 18-kip Equivalent Single Axle Load Applications

Author Contributions

Habtamu Girma Teferi: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing original draft, Writing review & editing.

Conflicts of Interest

The author declares no conflicts of interest.

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