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Structural design of flexible pavements for low traffic volume roads by using various methods

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Summary

In this study two significant structural design methods have been used. The first one is the oficial method used in this country and the second one is that developed by the Asphalt Institute from USA.

After a short introduction, presenting the general principles of flexible pavements design, the concepts of these methods are considered. Then practical examples of application of each method to a specific rehabilitation road project are given. Finally a discussion of the results obtained with these methods is made.

KEYWORDS: structural design, flexible pavements, design methods, design traffic, design charts

1. INTRODUCTION

In the design of flexible pavements, the pavement structure is considered as a multilayered elastic system, with the material in each layer characterized by certain physical properties such as modulus of elasticity, the resilient modulus and the Poisson ratio. The subgrade layer is assumed to be infinite in both the horizontal and vertical directions, whereas the other layers are finite in the vertical direction and infinite in the horizontal directions. According literature [1] application of the wheel load produces a stress distribution as shown in Fig. 1:

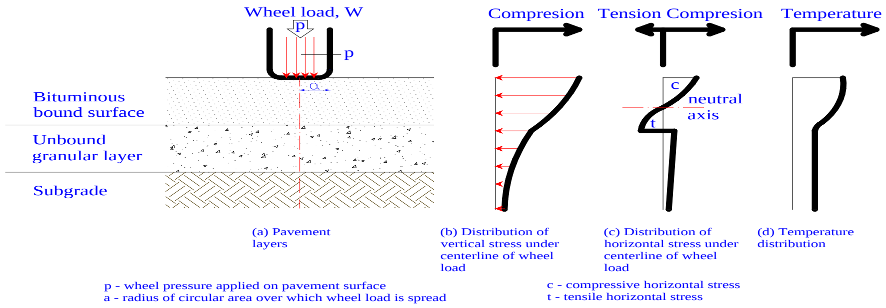

Figure 1. Typical Stress and Temperature Distributions in a Flexible Pavement under a Wheel Load [1]

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In relation with Fig.1, the maximum vertical compressive stresses occur directly under the wheel load and decrease with increase in dept from the surface. The maximum horizontal stresses and also the tensile stresses are developing under the wheel load. When the load and the pavement thickness are within certain ranges, horizontal compressive stresses will occur above the neutral axis, whereas horizontal stresses will occur below this axis. The temperature distribution within pavement structure is also important because it will have an effect on the magnitude of the stresses.

Therefore, the pavement design will be based on strain criteria that limit both vertical and horizontal strains, in order not to cause excessive cracking or excessive permanent deformation. These criteria are considered in the conditions of repeated load applications, because the accumulation of these repetitions are of significant role in the development of the pavement distresses, expressed in terms of cracking and permanent deformations. At this stage there are available several methods of design based widely or partly on theoretical analysis.

2. METHODS FOR STRUCTURAL DESIGN OF FLEXIBLE PAVEMENTS

2.1. The Romanian method for structural design of flexible pavements

According [2] the Romanian norm PD 177/2001 design of the flexible pavements is based on simultaneously observance of the following criteria:

- the admissible tensile strain at the bottom of the bituminous layers;
- the admissible compression strain at the subgrade level;

The analytical design method involves the establishing of a specific road pavement structure and verification of the loading conditions of pavement, under the design traffic. The following data are necessary to achieve the design:

- structure and intensity of traffic and their evolution;
- the geotechnical characteristics of the subgrade;
- the hydrological regime of the road pavement (type of cross section, the way of rainfall waters drainage, possibilities of drainage, level of ground water).

The design of the pavement is conducted according the following steps:

- assessment of design traffic;
- assessment of the bearing capacity at the subgrade level;
- selection of a new pavement structure;
- analysis of the road structure at the standard axle loading;
- assessment of pavement behavior under traffic loading;

- the use of the specifics software for the computation of stresses and strains in pavement structure.
- cecking the resistence of the pavement to the freeze – thaw, according Romanian standards [3][4][5].

2.2. The Asphalt Institute method for the design of flexible pavements

In accordance with the Asphalt Institute design method [1], the pavement is considered and represented (Fig.2) as a multilayered elastic system, with the wheel load W, distributed uniformly (p_0) through the tire, this uniform vertical pressure being spread through the different components of the pavement structure reaching the subgrade with much lower value p_1:

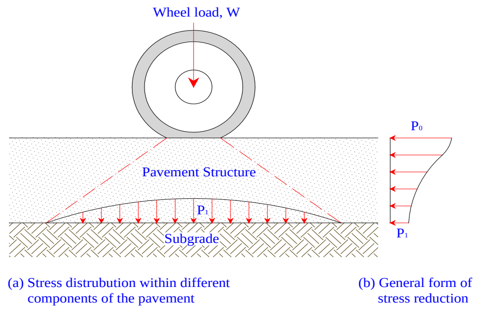

Figure 2. Distribution of Wheel Load Pressure through Pavement Structure [1]

The evaluation of the two specific tensile and compressive stress-strain conditions has been established based on experience, existing theory and test data, as shown in Fig. 3 from below, being represented the tensile and compressive stresses and strains imposed on the asphalt pavement due to the deflection caused by the wheel load.

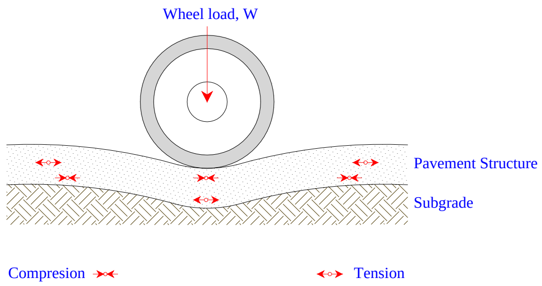

Figure 3. Schematic of Tensile and Compressive Stresses in Pavement Structure [1]

In this respect, specific computer programs and thickness design charts have been developed, based on criteria for maximum tensile strains at the bottom of the asphalt layer and maximum vertical compressive strains at the top of the subgrade layer. The principle adopted in the design procedure is to determine the minimum thickness of asphalt layer that will resist the stresses that develop for the two strain criteria involved, mainly the vertical compressive strain at the surface if the subgrade and the horizontal tensile strained at the bottom of the asphalt layer.

The design procedure consists of the following steps:

- select or determine the input data: traffic characteristics, subgrade engineering properties, subbase and base engineering properties;
- select surface and base materials;
- determine the minimum thickness required for the input data;
- evaluate feasibility of stage construction;
- carry out economic analyses of alternative design and select the best design;

3. DESIGN CASE STUDIES

In this chapter are described the procedures for structural design envisaged for the road project DJ 177 Poiana Mincului – Sucevita, located in Suceava Country (Fig. 4), by using the design methods presented in Chapter 2.

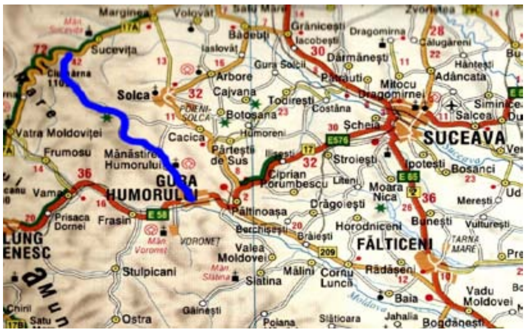

Figure 4. Framing in the area of the road

The road section Dj. 177, km 10+000-12+591 having a length of 2591 m is crossing a geographic mountain area as shown in the Figure 4, the existing road being equipped with a gravel pavement.
According to specific monographic data, [6] the climate is a temperate continental, relatively mild with a clean and refreshing air. The geological formations are sedimentary rocks, the land being framed in the area surrounding the Eastern Carpathian Mountains;

The annual average temperature is +7^{0}C, with minimum of -4^{0}C to -30^{0}C (January) and maximum 30^{0}C (July). The average annual of rainfall is 700-900 mm, the most abundant occur during the summer and the lowest during the autumn and winter.
The foundation soil/subgrade is of type P4 in accordance with [3].
The hydrostatic level of the underground water is located at the depth of approximately 500 cm. The river hydrology network is represented by the Humor river. The maximum frost depth is 110 cm from land level.

3.1. Design study conducted according Romanian method

3.1.1. Input design data

According design provisions[2], Fig. 1, this road is located in a climatic region, type III, where natural sources of quarry aggregates are relatively at a small distance from the road route. The road has been design with the have a cross sections in embankment with a maximum height of 1.00 m. The subgrade soil is claey dust, according to STAS 1243[7] and a P4 type according[2].

Traffic characteristics as recorded during 2005 year at the census station located near the studied sections on the Dj.177 are as follows:

- Trucks and derivatives with 2 axles: 48
- Trucks and derivatives with 3 axles: 7
- Trucks and derivatives with more than 3 axles: 2
- Buses: 4
- Articulated Vehicles: 5
- Special vehicles: 34

The design life, considered for this pavement is 15 years according to the tehnical class of the road[2]. (2010 to 2025).

3.1.2. Assessment of design traffic

According [2], Chapter 3, the assesment of traffic is shown in table 1.

Table 1. Assesment of the design traffic

Vehicle group	$n_{k\ 95}$	$p_{k\ 05}$	$p_{k\ 20}$	$(p_{k\ 05} + p_{k\ 20}) \times 0{,}5$	f_{ek}	col.1 x col.4.x col.5 o.s.115
Trucks and derivatives with 2 axles	48	1,2	2,6	1,9	0,30	28
Trucks and derivatives with 3 axles	7	1,0	1,4	1,2	0,44	4
Trucks and derivatives with more than 3 axles	2	1,2	2,5	1,85	1,61	6
Buses	4	1,3	3,1	2,2	0,64	6
Articulated vehicles	5	1,2	3,0	2,1	0,06	1
Special vehicles	34	1,2	2,1	1.65	0,8	45
Total axels standard 115 kN						90

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According [2], the cumulative number of standard axel loads for the specific design life of the pavement is calculated with the relation (1):

$$N_c = 365 \times 10^{-6} \times p_p \times c_{rt} \times \sum_{k=1}^{6} n_{ki} \times \frac{p_{kr} \times p_{kf}}{2} \times f_{ek}\,(m.o.s.) \qquad (1)$$

where:

N_c it is the design traffic;
365 it is the clendaristic number of day in a year;
p_p prospect period, in year;
c_{rt} coefficient of transversal repartition on traffic lanes, namely:

- for roads with two and three traffic lane c_{rt} = 0,50;
- for roads with four or more traffic lanes c_{rt} = 0,45.

n_{ki} it is the intensity of annual daily mean of vehicles from group k, according to traffic census results;

$$N_c = 365 \times 10^{-6} \times 15 \times 0,5 \times 90 = 0,246 \;\; m.o.s. \qquad (2)$$

3.1.3. Assessment of the bearing capacity of the subgrade

Corresponding to climatic type III and hydrological regime 2b, the calculation value for the dynamic modulus of elasticity of subgrade is 50 Mpa and 0,35 for the Poisson's coefficient, in accordance with [2],Table 2.

3.1.4. Selection of pavement structure

Thacking into considerations the existing gravel road pavement and the possibility to supplyes the project site with agregates from a local quarry, a flexible pavement structure as shown in Table 2 have been selected.

Table 2. The pavement structure selected for the design

Layer Name	h, cm	E, MPa	μ	Obs.
Wearing course (B.A.D. 16)	4	4200*	0,35*	[2]Table 9
Binder course (B.A.D. 25)	6	3600*	0,35*	[2]Table 9
Crushed stones optimal mix	20	500*	0,27*	[2]Table 7
Foundation 2 (Ballast new layer)	20	300**	0,27**	[2]Table 7
Foundation 1 (Existing ballast layer)	25	156***	0,27***	[2]Relation 3
Subgrade P4	∞	50	0,35	[2]Table2si3

Note, according [2] : * Item. 6.6 ;** Item. 6.4 *** Item. 6.3

Evaluation of equivalent modulus of foundation layer(s.f.), according [2], relation 3

$$E_{s.f.} = 0,20 \times h_{s.f.}^{0,45} \times E_p \quad (MPa) \qquad (3)$$

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$$E_{s.f.} = 0,20 \times 450^{0,45} \times 50 = 156 \quad (MPa)$$

Pavement structure including the subgrade had initially 6 layers. To simplify calculations and in order to apply the Calderom software considering 5 layers the existing foundation (ballast) of 25 cm thickness has been cumulated with an additional new ballast layer of 20 cm, considering in the final calculation a foundation layer with the total thickness of 45 cm, the value of the dynamic of the equivalent modulus $E_{s.f.}$, resulting according relation 3 of 156 MPa. The elasticity modulus of this foundation layer has been calculated as a weighted average according [2] point 6.8 as follows:

$$E_m = \left[\sum \left(E_i^{1/3} \times h_i\right) / \sum h_i\right]^3 \quad (MPa) \tag{4}$$

$$E_m = [\sum (300^{\frac{1}{3}} \times 20 + 156^{\frac{1}{3}} \times 25) / \sum 45]^3 = [(134 + 135)/45]^3 = 214 \quad (MPa)$$

3.1.5. Analysis of the pavement structure according [2]

Calculating the following components of strain:

- ε_r, in micro-strain, at the bottom of the bituminous layers;
- ε_z, in micro-strain, at the level of the road bed.

Rezults are given in the Table 3.

Table 3. Result of analysis of pavement structure according [2]

Design parameters		Obs.
ε_r, micro-strains.	182	[2]Calderom
ε_z, micro-strains.	340	[2]Calderom
$N_{adm.}$, m.o.s.	0,325	[2]Relation 6.b
RDO	0,757	[2]Relation 5

3.1.6. Assessment of behavior of the pavement structure under traffic loading

The admissible number loading of standard axle of 115 kN în m.o.s., $N_{adm.}$ which may be taken of the bituminouse layers, corresponding to strain condition at their bottom according [2] point 7.3.2.a is calculated with the relation (5):

$$N_{adm.} = 24,5 \times 10^8 \times \varepsilon_r^{-3,97} = \quad (m.o.s.) \tag{5}$$

$$N_{adm.} = 24,5 \times 10^8 \times 180^{-3,97} = 2,61 \quad (m.o.s.)$$

Checking the RDO condition for the proposed structural design considering RDO admisibil max. 1.0 for county and communal roads, according [2]:

$$RDO = \frac{N_c}{N_{adm.}} \tag{6}$$

$$RDO(=0,094) \le RDO_{admisibil}(=1)$$

This conditions is satisfied.

Verifications of the vertical strain at the level of subgrade according [2] using relations:

$$\varepsilon_z \le \varepsilon_{z\,adm.} \tag{7}$$

$$\varepsilon_{z.adm.} = 600 \times N_c^{-0,28} \quad (micro-strains) \tag{8}$$

$$\varepsilon_{z.adm.} = 600 \times 0,246^{-0,28} = 888 \quad (micro-strains) \tag{8}$$

$$\varepsilon_z(=340) \le \varepsilon_{z.adm.}(=888)$$

As both design criteria are satisfied the following pavement structure is proposed aat this stage of design:

- wearing course type B.A.D. 16: 4 cm
- binder course type B.A.D. 25: 6 cm
- base course crushed stones: 20 cm
- foundation 1 – new ballast layer: 20 cm
- foundation 2 – existing ballast layer: 25 cm

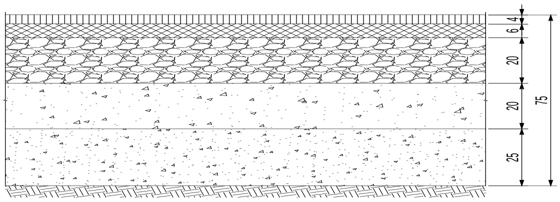

Figure 5. The proposed pavement structure

3.1.7. Design program to compute stresses and strains in pavement structure – Calderom 2000

PROJECT: Dj. 177 Poiana Mincului - Sucevita
Sector: km 10+000 - km 12+591
Input parameters:

Sarcina.....	57.50 kN
Pressure tire	0.625 MPa
Radius circle	17.11 cm

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Layer 1: Module	4200. MPa,	Poisson Coefficient	.350,	Thickness	4.00 cm
Layer 2: Module	3600. MPa,	Poisson Coefficient	.350,	Thickness	6.00 cm
Layer 3: Module	500. MPa,	Poisson Coefficient	.270,	Thickness	20.00 cm
Layer 4: Module	214. MPa,	Poisson Coefficient	.270,	Thickness	45.00 cm
Layer 5: Module	50. MPa,	Poisson Coefficient	.350 it is semifinit		

R E Z U L T S:

R cm	Z cm	Radial efort MPa	Radial deform. microdef	Vertical deform. microdef
.0	-10.00	.816E+00	.182E+03	-.258E+03
.0	10.00	-.776E-02	**.182E+03**	-.708E+03
.0	-30.00	.101E+00	.204E+03	-.319E+03
.0	30.00	.208E-01	.204E+03	-.544E+03
.0	-75.00	.333E-01	.134E+03	-.158E+03
.0	75.00	.179E-02	.134E+03	-.**340E+03**

3.1.8. Cecking the resistence of the pavement to the freeze and thaw, according Romanian standards

The pavement structure was design as wey to resist at freeze and thaw according [3],[4],[5]

- Subgrade soil type: P4
- Climatic type: III
- Hydrological regime: 2b
- Level of underground water N_{af} : 500 cm
- Depth of freezing: 110 cm

Depth at frost in the new pavement:

- foundation 2 – existing ballast layer: 25 cm
- foundation 1 – new ballast layer: 20 cm
- base course crushed stones: 20 cm
- binder course tipe B.A.D. 25: 6 cm
- wearing course tipe B.A.D. 16: 4 cm

$$Z_{cr} = Z + \Delta Z = 125 \ cm \tag{10}$$

where:

- Z = 110 – depth freeze of subgrade (according [3] fig.1 pag.3)

$$\Delta Z = H_{SR} - H_{ech.} = 15 \ cm \tag{11}$$

where:

- H_{SR} = thickness of pavements structure
- H_{SR} = 75 cm
- H_{ech}= equivalent thickness calculation to freeze (according [3] Chapter 2.4.)
- H_{ech} = 25cm x0,90+20cm x0,90+20 cm x0,70+6cm x0,60+4cm x0,50≈ 60 cm

Index of freeze is $I_{med}^{3/30}$ = 750 (according [3] fig.4, pag.7)

$H_{SR} < Z_{cr} < N_{af}$ $\Rightarrow$ 75 < 125 < 500 cm (hydrological conditions unfavorable, land very sensitive)$\Rightarrow$requires verification for freeze (according [4] pag.5, tab.3)

K_{ef} = Hech/Zcr =60/125 = 0,48 > 0,35 (according [4] tabel 4, pag. 6)$\Rightarrow$ *the proposed pavement structure satisfied the freeze-thaw conditions.*

3.2. Design study conducted according Asphalt Institute method.

According the Asphalt Institute method the fallowing input data are necessary:

- Design period (year)
- Design traffic (Nr. of vehicle m.o.s)
- The annual average temperature (^{0}C)
- Type of subgrade
- California bearing ratio (CBR)
- Elasticity modulus of subgrade (Mr)

3.2.1. Case 1

Based on the input data, and using the Design Chart for Full-Depth Asphalt, based on criteria for maximum tensile strains at the bottom of the asphalt layer and maximum vertical compressive strains at the top of the subgrade layer, from Annex 6, determine the thickness required for the full-depth asphalt layer for DJ 177 Poiana Micului – Sucevita.

- Design period it is of 15 years
- Total axles of 115 KN = 90

For the design taffic of 115kN confform Romanian norm AND 584 – 2002, it will be convert in design traffic expressed in standard axles of 80kN according Asphalt Institute design method usind data from Annex 1.

- Nc = 365 x 10^{-6} $\times$ 15 $\times$ 0,5 $\times$ 90 = 0,246 m.o.s. of 115 KN
- ESAL= 0,246 x 4,01= 0,9865 x 10^6 m.o.s. 80 kN≈1x10^6 m.o.s. 80 kN
- The annual average temperature +7^{0}C (44,5 ^{0}F)
- Type of subgrade is silty - clay P4

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According Annex 2, the subgrade is an AASHTO soil category A-6-a with CBR value of 4 (Annex 3)

- The elasticity modulus of subgrade Mr is calculated with the folowing relation according [1]:

$$M_r = 1500 \times CBR = 6000 \;\; psi = 6 \times 10^3 \, psi \tag{12}$$

$$M_r = 1500 \times 4 = 6000 \;\; psi = 6 \times 10^3 \, psi \tag{12}$$

Introducing thes input data in the appropiate chart (Annex 6) a Full-Depth Asphalt Pavement with the total thickness h=10,1 in (25,65 cm)≈(10 in – 25 cm) is obtained as shown in Fig. 6

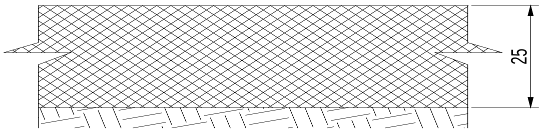

Figure 6. Full-Depth Asphalt pavement

3.2.2. Case 2.

Using the same input data as in Case 1, design a suitable asphalt pavement consisting of an asphalt concrete surface and various emulsified asphalt base, defined by the Asphalt Institute.

Note: The depth of the emulsified asphalt base is determined as the difference between the total thickness (asphalt concrete surface plus the emulsified asphalt base) as obtained from the design chart and the minimum required thickness of asphalt concrete as obteined according [1]; Annex 4.

- Type I: emulsified asphalt mixes made with processed, dens-graded aggregates; h_1=3 in(7,5 cm); h_2=10,5 in (≈27 cm); Annex 4; Annex 6.a

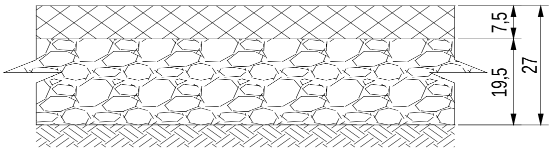

Figure 7. Final pavement structure realized with emulsified asphalt mixes with processed dens graded aggregates

- Type II: emulsified asphalt mixes made with semiprocessed, crusher-run aggregate; h_1=3 in (7,5 cm); h_2≈12 in (≈31 cm); Annex 4; Annex 6.b

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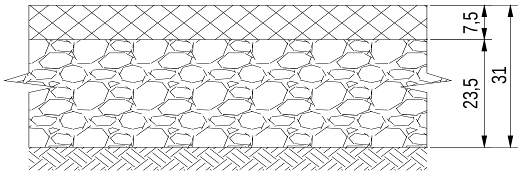

Figure 8. Final pavement structure realized with emulsified asphalt mixes made with semi-processed aggregates

- Type III: emulsified asphalt mixes made with sands and silty sands; h_1=3 in (7,5 cm); h_2=15,5 in (≈39 cm); Annex 4; Annex 6.c

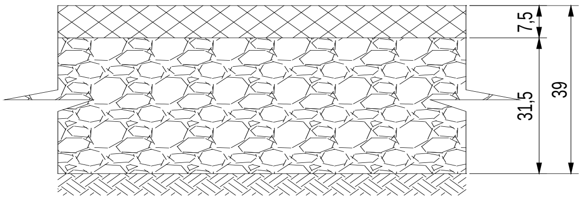

Figure 9. Final pavement structure realized with emulsified asphalt mixes made with sands and silty sands

3.2.3. Case 3

Using the same input data as in Case 1, design a suitable asphalt pavement consisting of an asphalt concrete surface and various granular untreated base course, by using the design chart from Annex 6.d, 6.e, 6.f, 6.g, 6.h, 6.i and taking into consideration the minimum thickness of asphalt concrete over untreated aggregate(granular) base given in Annex 5.

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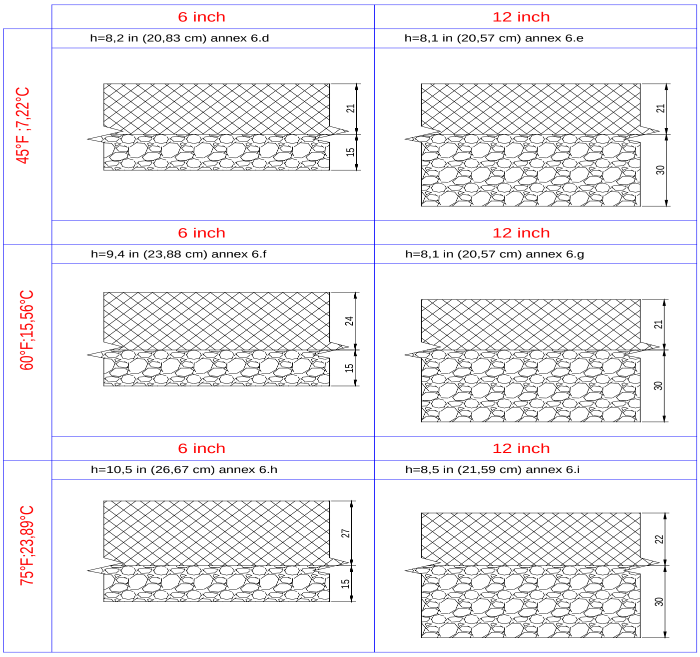

Figure 10. The various pavement structure obtained for different ambient temperatures and different thickness adopted for the untreated sub-base

4. CONCLUSIONS

- The design methods investigated in the frame of this incipient research are completely different in terms of application conditions.
- The Romanian method is more elaborated by taking into consideration the fatigue of the pavement structure under the repeated actions of traffic loads and the specific climatic conditions of Romania which involves the verifications of the pavement to the destructive action of freezing.
- The Asphalt Institute Method is less sophisticated, more practical by using specific design charts, developed for different ranges of temperature namely, 45°F-7°C; 60°F-16°C; 75°F-24°C.
- Because of these differences, the thicknesses of the pavements layers obtained with these methods are also different and at this stage they cannot be compared.
- In a future sequence of this research it is intending to apply the Romanian design methodology for verifying the Asphalt Institute structure for fatigue

and also for frost resistance, considering the specific climatic conditions of this country.

Annexes:

Annex 1: Load equivalency factors according [1];
Annex 2: Classification and characterization of subgrade AASHTO (HBR) according [1];
Annex 3: Diagram of corresponding between the subgarade type AASHTO & CBR according [1];
Annex 4: Minimum thicknes of Asphalt Concrete over Emulsified asphalt bases Type II&III according [1];
Annex 5: Minimum thikness of Asphalt Concrete over untreated aggregate base according [1];
Annex 6: Asphalt Institute Design Chart for Full-Depth Asphalt according [1]
Annex 6.a: Asphalt Institute Design Chart for Emulsified Asphalt Mix Type I according [1];
Annex 6.b: Asphalt Institute Design Chart for Emulified Asphalt Mix Type II according [1];
Annex 6.c: Asphalt Institute Design Chart for Emulsified Asphalt Mix Type III according [1];
Annex 6.d: Asphalt Institute Design Chart for Pavements with Asphalt Concrete Surface and Untreated Aggregate Base 6 inch Thick. and 45 ^{0}F MAAT according[1];
Annex 6.e: Asphalt Institute Design Chart for Pavements with Asphalt Concrete Surface and Untreated Aggregate Base,12 in. Thick. and 45^{0}F MAAT according[1];
Annex 6.f: Asphalt Institute Design Chart for Pavements with Asphalt Concrete Surface and Untreated Aggregate Base, 6 in thick. and 60 ^{0}F MAAT according [1];
Annex 6.g: Asphalt Institute Design Chart for Pavement with Asphalt Concrete Surface and Untreated Aggregate Base 12 in thick. and 60^{0}F MAAT according [1];
Annex 6.h: Asphalt Institute Design Chart for Pavements with Asphalt Concrete Surface and Untreated Aggregate Base 6 in thick. and 75 ^{0}F MAAT according [1];
Annex 6.i: Asphalt Institute Design Chart for Pavements with Asphalt Concrete Surface and Untreted Aggregate Base 12 in thick. and 75 ^{0}F MAAT according [1];

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Annex 1: Load equivalency factors according [1]

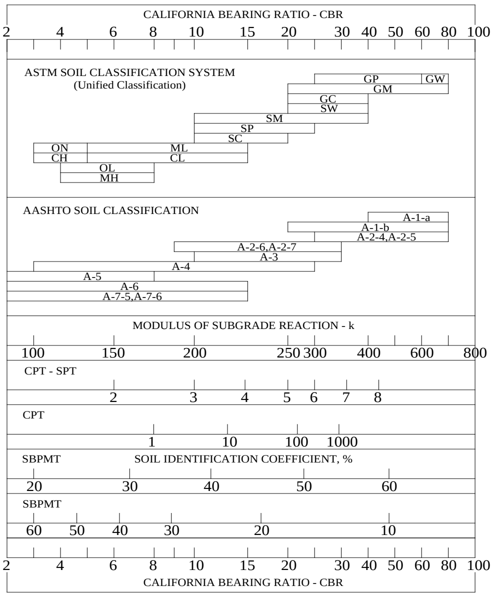
Gross Axle Load		Load Equivalency Factors		
kN	lb	Single Axles	Tandem Axles	Tridem Axles
80,0	18,000	1,00	0,077	0,017
89,0	20,000	1,51	0,121	0,027
97,9	22,000	2,18	0,180	0,040
106,8	24,000	3,03	0,260	0,057
115,6	26,000	4,09	0,364	0,080
124,5	28,000	5,39	0,495	0,109
133,4	30,000	6,97	0,658	0,145
142,3	32,000	8,88	0,857	0,191

Annex 2: Classification and characterization of subgrade AASHTO (HBR) according [1]

HRB classification	Visual description	Max, dry-weight range, lb per cu ft	Optimum moisture range, %	Anticipated embankment performance
A-1-a A-1-b	Granular meterials	115-142	7-15	Good to excellent
A-2-4 A-2-5 A-2-6 A-2-7	Granular materials with soil	110-135	9-18	Fair to excellent
A-3 A-3a*	Fine sand and sand	110-115	9-15	Fair to good
A-4a* A-4b*	Sandy silts and silts	95-130	10-20	Poor to good
A-5	Elastic silts and clays	85-100	20-35	Unsatisfactory
A-6a* A-6b*	Silt-clay	95-120	10-30	Poor to good
A-7-5	Elastic silty clay	85-100	20-35	Unsatisfactory
A-7-6	Clay	90-115	15-30	Poor to fair

Structural design of flexible pavements for low traffic volume roads by using various methods

Annex 3: Diagram of corresponding between the subgarade type AASHTO & CBR according [1]



Annex 4: Minimum thicknes of Asphalt Concrete over Emulsified asphalt bases Type II&III according [1]

Design Traffic ESAL	Type II&III(mm)	TypeII&III(in)
10^4	50	2
10^5	50	2
10^6	75	3
10^7	100	4
$>10^7$	130	5

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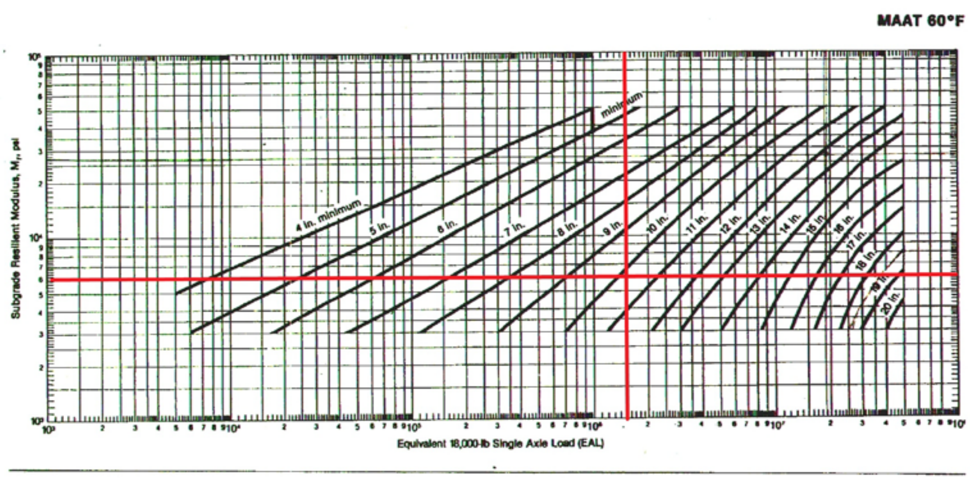
Annex 5: Minimum thikness of Asphalt Concrete over untreated Aggregate base according [1]

Traficul de calcul ESAL	Conditiile de trafic	Grosimea minima a stratului de beton asfaltic
<10^4	Parcari cu trafic usor si drumuri rurale cu trafic usor	75mm/3in
10^4...10^6	Trafic mediu	100mm/4in
<10^6	Trafic mediu spre greu	125mm/5in sau mai mult

Annex 6: Asphalt Institute Design Chart for Full-Depth Asphalt according [1]

Figure 20.5 ■ Design Chart for Full-Depth Asphalt



Source: *Thickness Design—Asphalt Pavements for Highways and Streets*, Manual Series No. 1, Asphalt Institute. Lexington, Ky., February 1991, p. 79.

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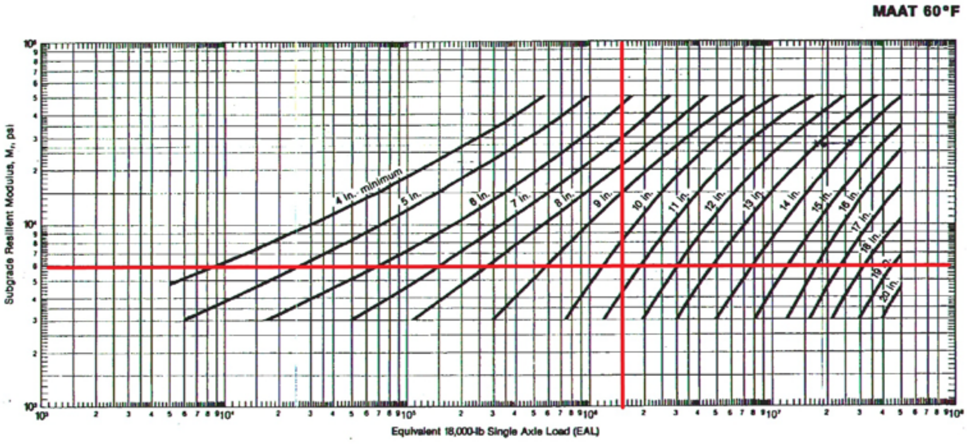
Annex 6.a: Asphalt Institute Design Chart for Emulsified Asphalt Mix Type I according [1]

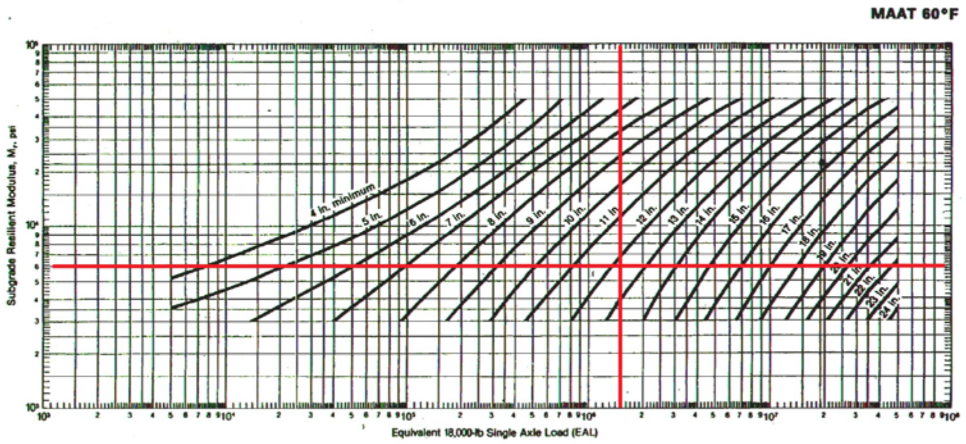
Figure 20.6 ▪ Design Chart for Emulsified Asphalt Mix Type I



Source: Thickness Design—Asphalt Pavements for Highways and Streets, Manual Series No. 1, Asphalt Institute, Lexington, Ky., February 1991, p. 80.

Annex 6.b: Asphalt Institute Design Chart for Emulified Asphalt Mix Type II according [1]

Figure 20.7 ▪ Design Chart for Emulsified Asphalt Mix Type II



Source: Thickness Design—Asphalt Pavements for Highways and Streets, Manual Series No. 1, Asphalt Institute, Lexington, Ky., February 1991, p. 81.

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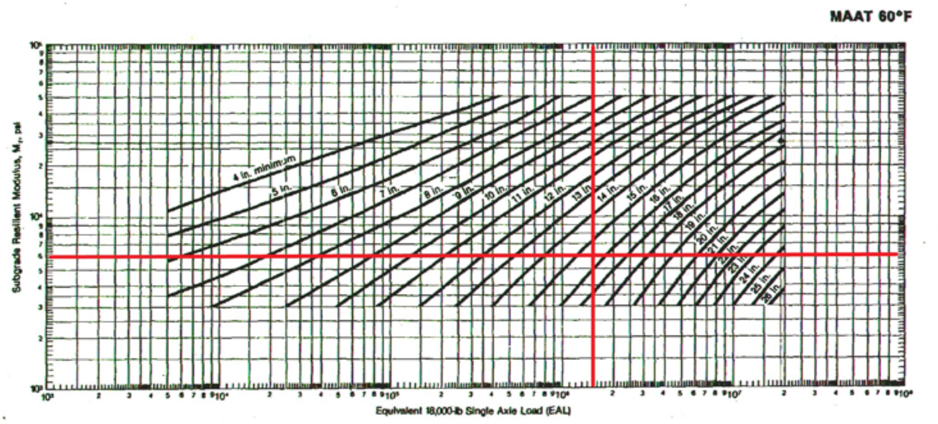
Annex 6.c: Asphalt Institute Design Chart for Emulsified Asphalt Mix Type III according [1]

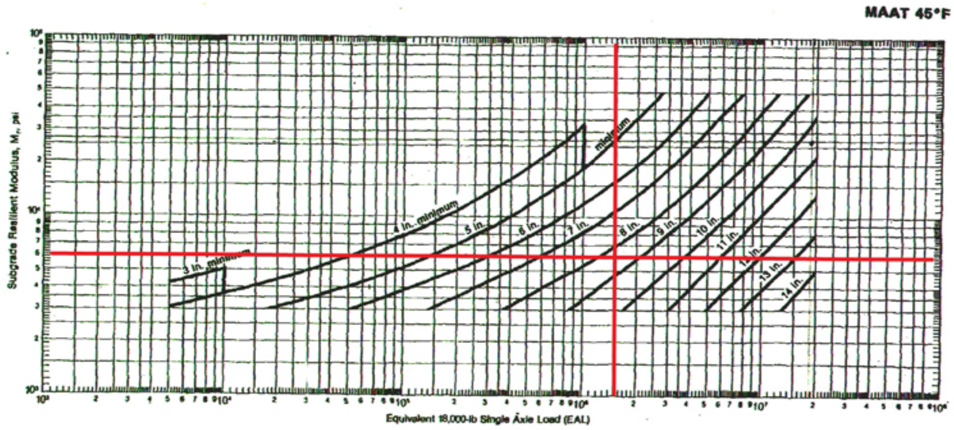
Figure 20.8 ■ Design Chart for Emulsified Asphalt Mix Type III



Source: Thickness Design—Asphalt Pavements for Highways and Streets, Manual Series No. 1, Asphalt Institute, Lexington, Ky., February 1991, p. 82.

Annex 6.d: Asphalt Institute Design Chart for Pavements with Asphalt Concrete Surface and Untreated Aggregate Base 6 inch Thick. and 45 ^{0}F MAAT according[1]

Figure 20.9 ■ Design Chart for Pavements with Asphalt Concrete Surface and Untreated Aggregate Base 6 in. Thick



Source: Thickness Design—Asphalt Pavements for Highways and Streets, Manual Series No. 1, Asphalt Institute, Lexington, Ky., February 1991, p. 77.

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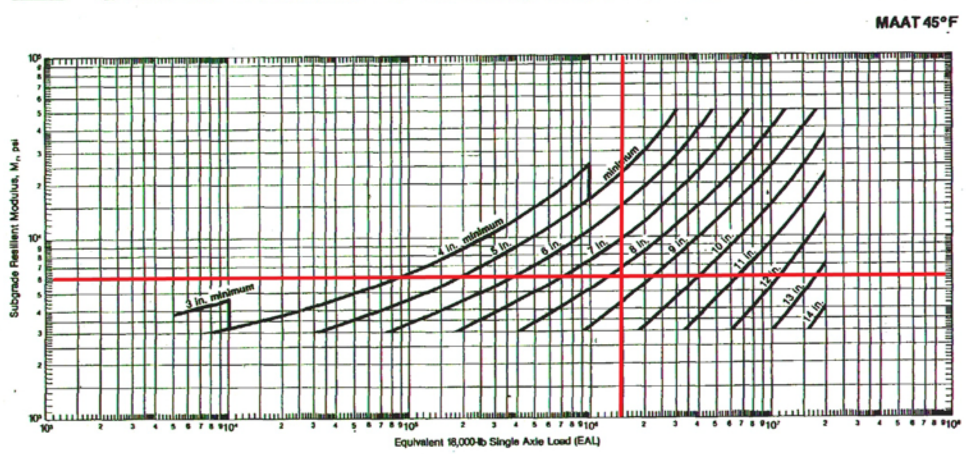
Annex 6.e: Asphalt Institute Design Chart for Pavements with Asphalt Concrete Surface and Untreated Aggregate Base,12 in. Thick. and 45^{0}F MAAT according[1]

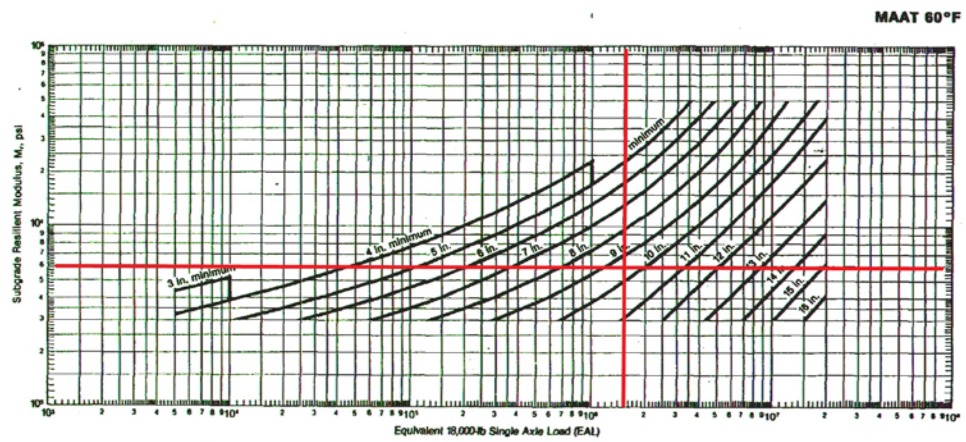
Figure 20.10 ■ Design Chart for Pavements with Asphalt Concrete Surface and Untreated Aggregate Base, 12 in. Thick



Source: Thickness Design—Asphalt Pavements for Highways and Streets, Manual Series N·

Annex 6.f: Asphalt Institute Design Chart for Pavements with Asphalt Concrete Surface and Untreated Aggregate Base, 6 in thick. and 60 ^{0}F MAAT according [1]

Figure 20.11 ■ Design Chart for Pavements with Asphalt Concrete Surface and Untreated Aggregate Base, 6.0 in. Thickness



Source: Thickness Design—Asphalt Pavements for Highways and Streets, Manual Series No. 1, Asphalt Institute, Lexington, Ky., February 1991, p. 83.

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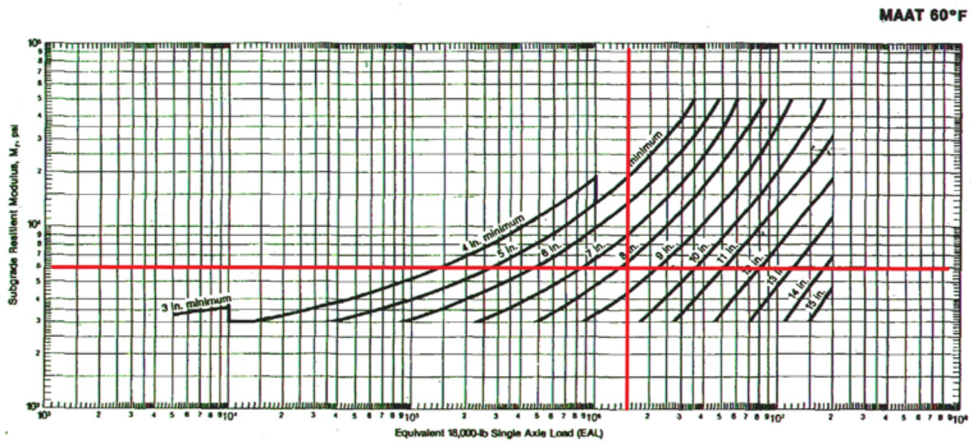
Annex 6.g: Asphalt Institute Design Chart for Pavement with Asphalt Concrete Surface and Untreated Aggregate Base 12 in thick. and 60^{0}F MAAT according [1]

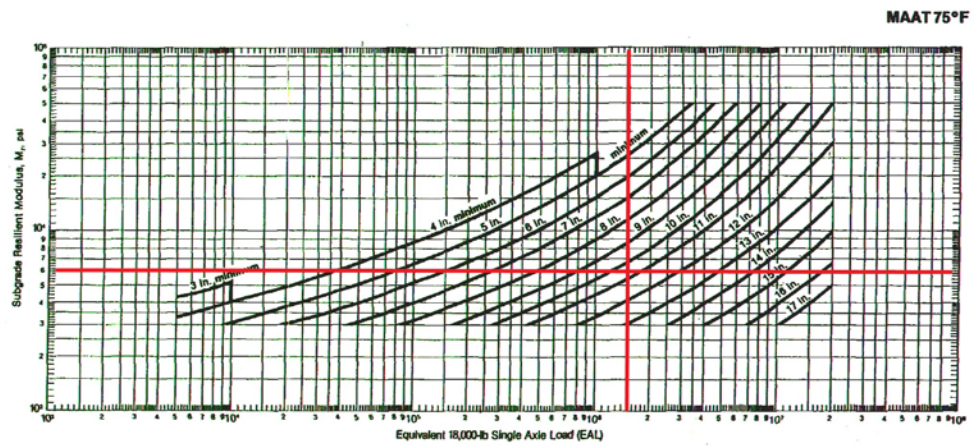
Figure 20.12 ▪ Design Chart for Pavements with Asphalt Concrete Surface and Untreated Aggregate Base 12 in. Thick



Source: *Thickness Design—Asphalt Pavements for Highways and Streets*, Manual Series No. 1, Asphalt Institute, Lexington, Ky., February 1991 p. 84.

Annex 6.h: Asphalt Institute Design Chart for Pavements with Asphalt Concrete Surface and Untreated Aggregate Base 6 in thick. and 75 ^{0}F MAAT according [1]

Figure 20.13 ▪ Design Chart for Pavements with Asphalt Concrete Surface and Untreated Aggregate Base 6 in. Thick



Source: *Thickness Design—Asphalt Pavements for High* *treets*, Manual Series No. 1, Asphalt Institute, Lexington, Ky., February 1991,

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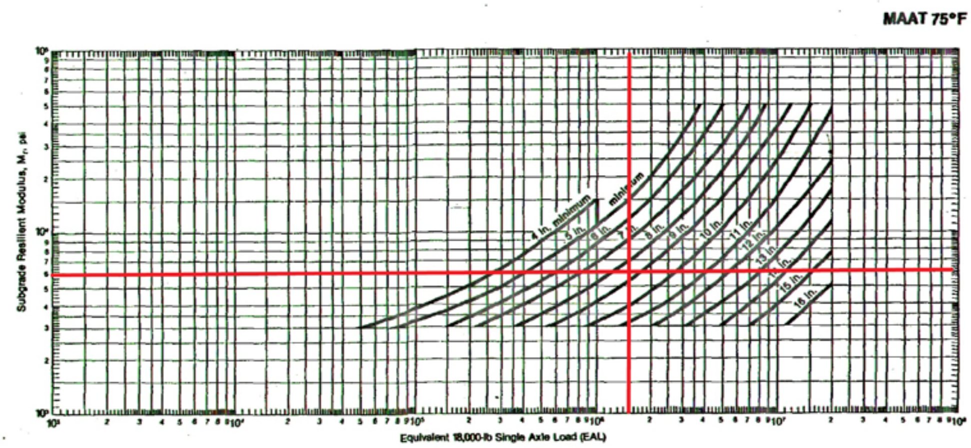
Annex 6.i: Asphalt Institute Design Chart for Pavements with Asphalt Concrete Surface and Untreted Aggregate Base 12 in thick. and 75 ^{0}F MAAT according [1]

Figure 20.14 ▪ Design Chart for Pavements with Asphalt Concrete Surface and Untreated Aggregate Base 12 in. Thick



Source: Thickness Design—Asphalt Pavements for Highways and Streets, Manual Series No. 1,