AN EMPIRICAL MULTILAYER THICKNESS DESIGN METHOD FOR FLEXIBLE PAVEMENT USED IN DELTA REGION OF EGYPT

ALAA M. ALI

Ph.D., Assistant Professor Misr High Institute for Engineering & Technology, Mansoura, Egypt
E-mail: allaawy@yahoo.com

Abstract- Design and construction of flexible pavements has been changed significantly during the past two decades. Since the performance of the AASHTO Road Test, many important concepts have been brought forth. Among these was the demonstration of the major influence of traffic loads and repetitions upon design thickness. Also, the quantitative definition of pavement failure based on user-oriented rather than only structural failure was a major contribution by that test. This concept led to development of the serviceability-performance method. Based on the observed performance of the AASHTO Road Test, many thickness design methods have been developed. The main purpose of this study is to incorporate mechanistic and empirical information in developing a reliable design procedure for highway asphalt pavements in Egypt. An engineering technique employing the multilayered elastic concept that has been used in worldwide thickness design methods was adopted. Environmental and climatic conditions that prevailing and applicable to the Egyptian roads were introduced. Design charts were developed in an easy way to be used. A comparison between this method and others that used by most Egyptian highways agencies are also presented. It can be concluded that the proposed pavement design method is found to be reliable, rational and reflecting Egypt own environmental conditions.

Index Terms- Asphalt pavement, thickness design, environmental condition, Multilayered

I. INTRODUCTION

The objective of any pavement design procedure is to provide a structure which will be suitable in a specific environment and be able to sustain the anticipated traffic loading. It is generally agreed that pavements deteriorate
or lose serviceability with and from traffic load repetitions. Since the publication of the results from the AASHTO Road Test in 1962 [1], most design methods that incorporated results from this project has defined the performance as "the serviceability history of a pavement". Serviceability, as measured by the present serviceability index (PSI), is defined as "the present riding quality of a pavement". This is considered as a functional performance definition and is related to the users' response or comfort provided to the traveling public. It has been known that the riding quality of a pavement is controlled by the longitudinal profile of the pavement. Till the mid-seventies no clear relationship
between serviceability and physical distress was released. Information from the AASHTO Road Test suggested that
there might be some correlation between average rut depth and serviceability while there was very little about between cracking and serviceability. During the late 70's the Asphalt Institute has succeeded in incorporating both mechanistic and empirical information in their latest pavement design procedure. The use of mechanistic procedures along with field experience has made it possible to evaluate more accurately the seasonal influence of temperature on the properties of asphalt concrete, and the loss of strength of unstabilized materials from month to month during the year. Their use of such procedures, also, provided the capability of extrapolating beyond the limits of field experience which have been considered as one of the major limitations of the AASHTO Road Test. In addition, another major improvement in the Asphalt Institute method was the inclusion of not only functional performance, but also structural performance characteristics represented in fatigue cracking and surface rutting associated with traffic. This technique is believed to facilitate the prevention of excessive physical distress and the preservation of adequate riding quality along pavement design life. In this study, the latest approach employed in the development of the Asphalt Institute thickness design manual (MS-I, 9th Edition) has been adopted [2]. Final design charts relating the traffic density as measured by the number of load repetitions of the 80KN standard axle to the subgrade strength as determined by the California Bearing Ratio and pavement thickness is also presented.

II. BASIC ASSUMPTIONS

In this proposed method of design, the pavement structure is considered as a "multilayered elastic system". The
material in each layer is characterized by a modulus of elasticity (E) and a Poisson's ratio (ε). Traffic is represented in terms of repetitions of an 80KN single axle load which applied on the pavement as two sets of dual tires. The dual tire is represented by two circular plates with a radius of 115mm spaced 345mm apart which correspond to an 80KN axle load and a 483KPa contact pressure. These assumptions allowed for the design of flexible pavements composed of as much as five layers. These layers are: an asphalt surface course, an asphalt binder course, a crushed stone untreated base course, a sandy gravel

subbase, and the bearing subgrade soil. The subgrade, lowest layer, is assumed infinite in the verticallay downward and horizontal directions. The other layers, of finite thickness, are assumed infinite in extent in the horizontal direction. Full friction is also assumed at the interface between each of the layers. Figure -1illustrates the assumed system composition.

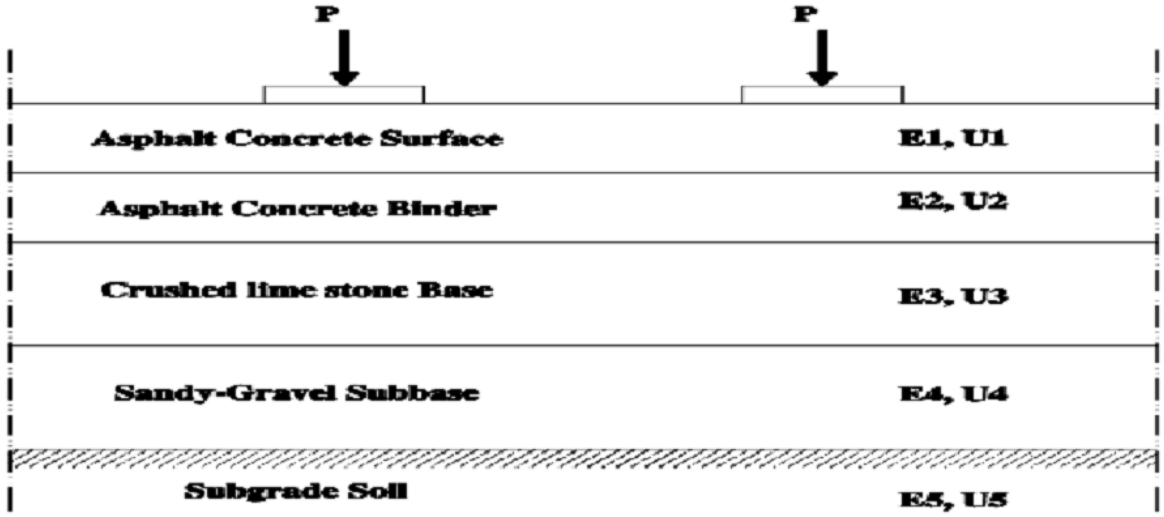


Figure-1: General Pavement System

III. DESIGN CRITERIA

Two strains are considered to be critical for design of multilayered pavement system [2]; they are;

- he horizontal tensile strain on the underside of asphalt treated layer, and
- The vertical compressive strain at surface of subgrade.

Many researchers have expressed their belief that only the response of subgrade deformation is more sensitive to
the contribution of any selected layer (surface or base) to the performance of the total system. They have formed
their thoughts on the basis of the AASHTO Road Test serviceability model in which the value of that index has
shown low sensitivity to surface cracking. However, considering the cracking of asphalt bound layer as design
criterion, in addition to subgrade strain or deformation is believed to be a better approach. Although this assumption might be on the traditional side, it is no longer traditional in a pavement design method for highways in Egypt. As Egypt land has generally a flat surface, water draining is a well known problem. Routine maintenance through regular patching and crack filling is also not always guaranteed. When an asphaltic layer is cracked by fatigue, the riding quality or serviceability may not be significantly reduced; however water intrusion of moisture through cracks will reduce the stiffness properties of lower layers in a short time period. Based on understanding of that matter, the two strains mentioned above were considered in the design criteria simultaneously.

a. Compressive Strain

The allowable subgrade strain criteria utilized in this design to limit surface rutting was adopted after the Asphalt Institute [2]. That rutting criterion was obtainer from analysis of pavements designed by the California procedure. It is more traditional than other criteria and developed from data obtained from a state that has overall environmental and climatic conditions imitating the same in Egypt. The general form of the "compressive subgrade strain" criterion is as follows:

$$\log(\varepsilon_v) = -1.98 - 0.22 \log(N_f) \qquad (1)$$

Where;
εv = Vertical compressive strain at subgrade surface, mm/mm.
Nf = No. of 80KN equivalent single axle load.
in this proposed design method, rutting should not exceed 13 mm for design traffic (Nf), as long as asphalt bound layers are well designed and other pavement layers are well compacted.

b. Tensile Strain

Based on lab to field correlation of 17 sections in loops 4 and 6 on the AASHTO toad Test during a two years
period; from 1958 to 1960, finn, et al. have come up with a fatigue cracking model which is still used in many design methods [3]. That model was further modified by others [4] to allow for fatigue prediction of a wider range of asphalt mixes. The final model computes fatigue life of a pavement as a function of the "elastic tensile strain" of asphalt layer (εt) as well as its modulus of elasticity, percent voids and asphalt content. The form of fatigue equation employed in this proposed method is:

$$\log(\varepsilon_t) = -1.91 - 0.31 \log(N_f) - 0.26 \log(E) + 1.47 [Vb/(Vb+Vv)] \quad (2)$$

Where:
Nf = No. of equivalent single axle loads
εt = Tensile strain in asphalt layer, mm/mm
E = Elastic modulus of asphalt bound layer, MPa
Vb = Volume of asphalt Percent, and
Vv = Volume of air voids, Percent

For high quality asphalt concrete; i.e., surface or binder courses, the effect of Vb and on the results of the original
model developed by Finn et al. is almost neglected. That model provides an indication of approximately 20 percent
or greater fatigue tracking area based on total pavement area or 45 percent fatigue cracking based on wheel path
area [2,3].

IV. MATERIAL CHARACTERISTICS

In the analysis of a multilayered system, material of each layer is characterized by a modulus of elasticity and a Poisson's ratio. The later was assumed to be 0.35 for all layers except for subgrade where a value of 0.45 was
assumed. These values of Poisson's ratio were kept constant through all stages of this proposed pavement design method development.

a. Asphalt Treated Layers

In developing the design charts, two asphalt treated layers were considered; surface and a binder course. The gradation limits of the two crushed lime stone aggregates for both surface and binder courses and the range of asphalt content for both layers are presented in Table-1. The asphalt cement commonly used in the production of asphalt concrete in Egypt is a 60/70 penetration type. Laboratory determined physical properties of mixes applied on surface and binder courses are given in Table-2; they are needed in determining their elastic characteristics. The elasticity modulus for asphalt treated layers was determined on monthly basis during the year using the latest model developed by Witczak [5]. The computer program was modified to allow for using that model. In general, this modulus predictive equation relates the elasticity modulus (E) as an independent variable to the major properties of the asphalt concrete, the loading frequency and the pavement temperature.

Table-1: Gradation of surface and binder courses

Sieve opening	Surface course	Binder course
25	100	100
19	88-100	100
13	55-86	86-100
10	45-72	70-90
#4	31-50	45-70
#10	19-35	30-52
#20	12-26	22-40
#40	7-20	16-30
#80	4-12	9-19
#200	0-6	3-7
Asphalt Content	4.0-6.5	4.5-7.5

Table-2: Basic properties of asphalt surface and binder courses

Property	Unit	Surface course	Binder course
Effective Asphalt content ($P_{eff.}$)*	%	10.5	8.5
Percent Air Voids (P_{air})	%	3.6	4.8
Percent Asphalt Absorbed ($P_{abs.}$)**	%	1.5	1.5
Asphalt Viscosity (n)	Poise	3.1	3.1
Load frequency (f)	Hz	10.0	10.0
Temperature (T)	°C	Varied monthly	

Notes: * *By Mix volume* ** *By Mix weight*

A loading frequency (f) of 10Hz which represents a load duration of 0.1sec was assumed in this analysis. This is close to the same duration as was obtained by Benkelman beam method and widely accepted by most
investigators [2, 6].

b. Untreated Granular Materials

In the construction of highways in Egypt it is widely accepted to use untreated crushed aggregates; lime stone or dolomite have a nominal size of 60.0 mm, as a base course material. Sometimes premixed Macadam is used as a base course; however, it has experienced low performance and fatigue life [7]. Sandy gravel is in most cases employed in subbase courses if any. Generally, the stiffness features of untreated aggregates are stress dependent. Their behavior is nonlinear in nature even when the stress is well below the yield point of the material. Here, the elastic modulus; known as the resilient modulus,

increases with an increase in the isotropic stresses. This stresss dependency is described in terms of the bulk stress

$$\theta = \sigma_x + \sigma_y + \sigma_z$$

$$M_r = k_1 . \theta^{k2} \qquad (3)$$

Where k1, k2 experimentally determined constants. Typical values of these constants are in the range of 0.32 to 0.73 for k1 and from 2900 to 12000 for k2 (when stresses are in psi) [2]. In our analysis k1 was assumed to be 0.50 for both base and subbase layers whilst k2 was assumed 8000 for a crushed lime stone base and 3000 for sandy gravel subbase

c. Subgrade Soil

It is the soil prepared and compacted to support a structure or a pavement system. As mentioned above, in a multilayered system analysis the subgrades, as well as other layers, are evaluated by their elastic properties. Therefore, the resilient modulus of subgrade soil was required as an input during the computer analysis process. However, since the resilient modulus (Mr) of soils is not a popularly used in Egypt a relation between Mr and CBR has been considered when developing the design charts. A well known approximate relationship between Mr and CBR has been developed by others [8]. Knowing the design CBR value, the Mr value of subgrade was approximated from the following equation.

$$Mr\ (MPa) = 10.35\ CBR \quad or,$$

$$Mr\ (psi) = 1500\ CBR \qquad (4)$$

V. ENVIRONMENTAL CONSIDERATION

To consider the environmental consequences on asphalt wearing and subgrade layers along the time, it was found that the most effective climatic factors need to be considered are moisture and temperature which were studied and adopted in this study in view of the following;

a. Moisture

Moisture change was considered from month to month. For design purposes the influence of water is considered by predicting the properties of materials at water contents which are assumed of those which may develop at some time subsequent to construction. Estimates of expected in-situ moisture conditions together with an indication of how these conditions might develop are needed. In this design method the strength of subgrade soil was assumed at its design value during the first two months of the year. This value was reduced 10 percent during the following seven months and 20 percent for the last three months. It was believed that these conditions are simulating the condition of ground water changes due to planting seasons, especially in Delta.

b. Temperature

Asphalt is a visco-elastic material. The temperature within a pavement section varies due to several factors. Perhaps the most importantly is the ambient temperature, while the next important factor is the solar radiation especially during the summer months. The average 29 years climatic data for the rainfall and temperature between years 1961 and 1990 was obtained from the Egyptian Metrology Association (EMA) based on five numbered stations in the Nile-Delta region at Baltim-325, Damietta-330, Mansoura-343, Tanta-349 and Cairo-368. Besides, the average same climatic data between years 1987 and 2007 was also downloaded from the World Climate web site. (http://www.worldclimate.com/cgi-bin/grid.pl?gr=N30E031)

The mean monthly air temperatures adopted in evaluating the elastic moduli of asphaltic layers are given in Table-3. Since asphalt concretes are susceptible to temperature (T), computation of their elastic properties every month during the year is important in developing design charts for Egyptian highways.

Table-3: Monthly Air Temperature in °C

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Temp.(T)	16	17	21	25	27	35	39	40	35	27	20	15

VI. TRAFFIC CONSIDERATION

For a specific pavement-loading system, each vehicle has a certain number of repetitions to failure, Ni, The unit damage or damage per pass of each vehicle is:

$$di = 1/Ni \qquad (5)$$

To simplify the traffic input requirements for the loadassociated distress models; equations [1,2], it is now widely accepted to convert mixed traffic to equivalent 80KN single axle loads using the AASHTO load equivalency factors. The traffic effect considered in this analysis as well as in presenting the design charts was represented by the number of 80KN load repetitions. The pavement is considered failed when the total damage (D) produced as a result of either subgrade compressive strain (εt) or asphalt treated layers tensile strain (εt) has reached unity. The total pavement life (EAL) is defined as the number of standard single axles that the pavement can sustain until total damage D=1.0. To help the designer overcoming the situation of lack of loadometer information, traffic was characterized to five groups adopted from the National Crushed Stone Association (NCSA) method of design [8]. These categories are shown on the design charts as occupying a range of total number of load repetitions.

These ranges were based on a 20 years design period. Details of the traffic categories are given in Table-4, where five traffic indices are defined from I1 to I5.

Table-4: Traffic Categories, after NCSA

Daily EAL[1]	Index	Traffic	Description
5	11	Light	Only passenger cars, pick up trucks and similar
6-20	12	Light-Medium	Max. 1000VPD, including max. 6% of loaded 2-axle trucks and similar
21-75	13	Medium	Max. 3000VPD, including max. 9% of loaded 2-axle trucks and 1% of loaded 3 or more -axle trucks and similar
76-250	14	Medium-Heavy	Max. 6000VPD, including max. 14% of loaded 2-axle trucks and 1% of loaded 3 or more axle trucks and similar
251-900	15	Heavy	Max. 6000VPD, including max. 15% of loaded 2-axle trucks and 17% of loaded 3 or more axle trucks and similar

Notes:

1. Daily EAL: Equivalent 80KN single axles in design lane, average daily use over a 20 years life

2. VPD = Vehicles per day, all types, using design lane.

VII. RESULTS AND DISCUSSION

In developing the charts three thicknesses of asphalt surface courses are considered. They are 10cm, 15cm and 20cm, each surface thickness level is presented in a separate chart. In any of the above surfaces, at least one half of it is a binder course. The first three charts are relating the subgrade CBR and the total number of single 80KN axles to failure to the thickness of crushed lime stone base course; no sandy gravel subbase is used. Charts are illustrated in Figures-2, where the number written on each curve presents the thickness of base. The following three charts shown in Figure-3, crushed lime stone base as well as sandy gravel subbase is considered. The number on curves denotes the subbase thickness whilst the base course thickness is grouped and distinct from one level to another. To compare thickness design using this method to other popular pavement design methods a very simple example is given below.

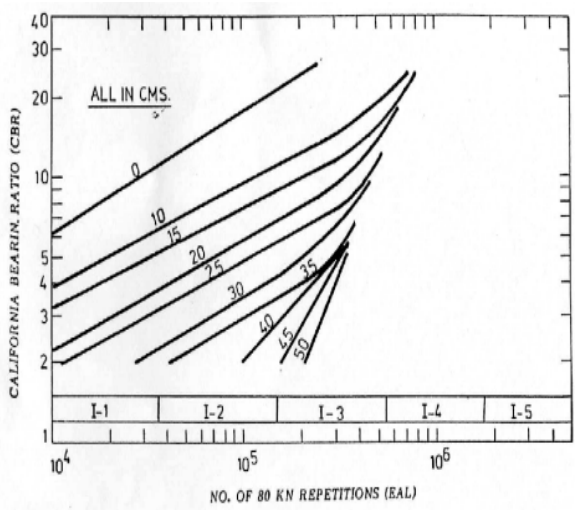


Fig-2-a: Base Thickness, Case of no subbase (surface course =10cm)

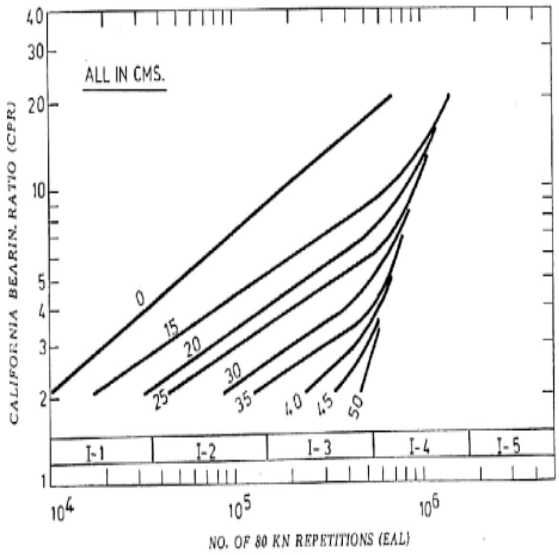


Fig-2-b: Base Thickness, Case of no subbase (surface course =15cm)

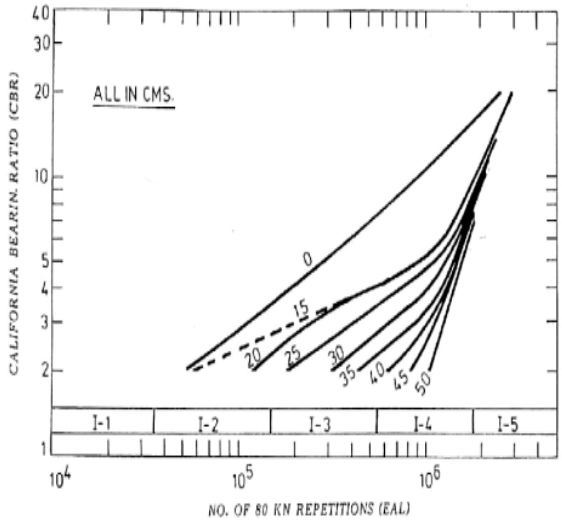


Fig-2-c: Base Thickness, Case of no subbase (surface course =20cm)

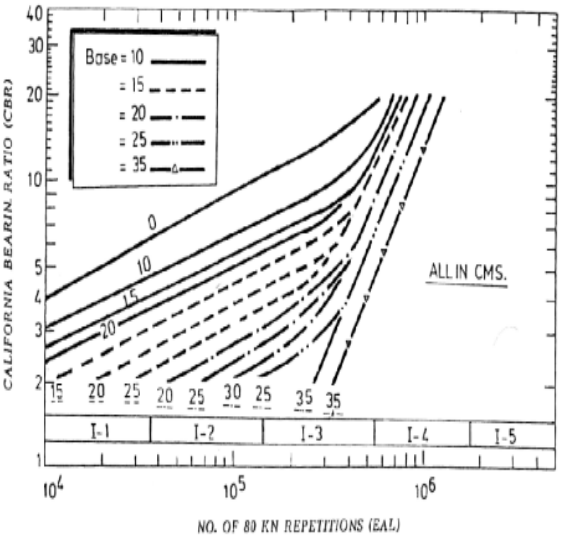


Fig-3-a: Subbase Thickness for a given Base (surface course =10cm)

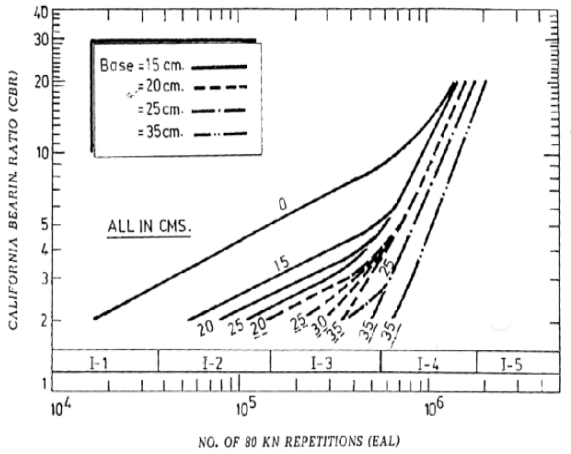


Fig-3-b: Subbase Thickness for a given Base (surface course =15cm)

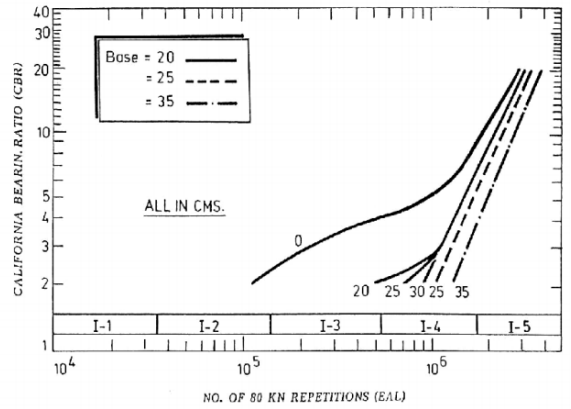


Fig-3-c: Subbase Thickness for a given Base (surface course =15cm)

VIII. COMPARISON CASE-STUDY

If it is needed to design a flexible pavement layered section with a total EAL of 500,000 and a subgrade CBR
of 5. The pavement matrix consists of asphalt concrete surface, crushed-stone base and a sandy gravel subbase
(AASHTO R is assumed 4.0). What will be the recommended thickness of each layer? Solution of the above case study using the proposed method against the three other methods; CBR, AASHTO (original method) and the Asphalt Institute (A.I.) latest method, is summarized in Table-5. Also to facilitate using the AASHTO and the CBR methods the CBR value for subbase and base course are assumed to be 15 and 70 respectively.

Table-5: Comparison between four design methods

Design Method	Layer Thickness (cm)		
	Surface	Base	Subbase[1]
AASHTO[2]	15	15	20
Asphalt Institute	15	20	---
CBR	10	10	25
Proposed Alternative (1)	15	15	15
Proposed Alternative (2)	15	28	---
Proposed Alternative (3)	10	27	27

Notes:
1. Only base course in the asphalt Institute method.
2. based on an ΔW =3.90 and R= 4.

As can be observed in Table-5,

- The thickness of base course required by the proposed method when no subbase is used is 28cm versus 20cm for the Asphalt Institute. This was expected since the A.I. method is averaged to design the pavements allover the United States where freeze is present in one state and very high temperature is experienced in another.
- In the AASHTO method of design, a minimum surface course thickness of 15cm is required. For a surface thickness of 15cm and using the proposed method we get the same base course thickness as the AASHTO whilst a lower subbase thickness; 15cm vs. 20cm. This might be due to the assumption of a regional factor of 4.0; which is considered somewhat high, when designing by the AASHTO.
- The CBR design method underestimates the pavement thickness when compared to all other methods. Although we get almost very close values for subbase thickness; 25cm from CBR and 27cm from the proposed method, only 10cm base course is required by CBR method versus 27cm in the proposed.
- Again, one can say that no indication of the effect of environmental changes during the year is known to be considered in the CBR method. Hence the proposed values are more realistic than others since the proposed method is considering the Egyptian climatic and environmental effects based on a rational elastic analysis.

CONCLUSIONS

1. Based on the study, it can be concluded that the use of elastic multilayer analysis opens the field for engineers in any country to develop their own layers design method.
2. This approach enables the designer to consider the effects of the environmental conditions in local area of interest plus the properties of available materials in pavement thickness design.
3. The charts developed for pavement design reflected the assumptions of environment and material properties available at present. It could be needed to be updated in future to be applicable.

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