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SIMPLIFIED CHARTS FOR OVERLAYING DESIGN OF FLEXIBLE REPAVED ROADS STRUCTURE

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ABSTRACT

The roads need to be repaved are those possessing a lot of damage, rutting causing many problems for vehicles and drivers. Two methods of repaving roads are introduced in this paper. The first method includes constructing two layers of pavement structure above the road directly without removing the old wearing surface of this road. The second includes constructing the same two layers of pavement structure above the road after removing the old wearing surface to the surface of the old base course. The two layers are leveling layer from crushed aggregate and new overlay surfacing layer from asphaltic concrete. The effect of these layers is to reduce the stresses and deflections to permissible limits of old foundation. This piece of paper uses the elastic theory and Excel program to establish an approach for overlaying design of flexible repaved road structure. Using this approach, the designer may be able to determine the suitable thicknesses of pavement layers of overlaying flexible repaved road structure.

Kay words: Flexible pavement – Repaved road – Pavement cracks – Elastic layer theory – Stresses – Strains.

1. Introduction

Failure of flexible pavement surfacing layer may appear in the form of rutting or cracking. Rutting is formed when the road is subjected to over-loading by vehicles. The pavement crack is formed because of long term exposure to the normal load of vehicles and expansion / contraction due to temperature changes. So, this road must be repaved to overcome these problems. Re-surfacing of damage roads with asphalt macadam offers a solution to the problem caused by it. The damage roads may be reclaimed with a non-skid surface that will last for many years without an annual treatment of a sticky surfacing material, and at an extremely low cost [1].

Two methods of repaving road are introduced in this paper. The first method includes constructing two layers of pavement structure above the old pavement directly without removing the old wearing surface of this road. The second method includes constructing the same two layers of pavement structure above the road after removing the old wearing surface pavement to the surface of the old base course. The two layers are leveling layer from crushed aggregate and new overlay surfacing layer from asphaltic concrete. The leveling layer consists of crushed aggregates stabilized or unstabilized with a cementing material like Portland cement, lime, fly ash or asphaltic cement. This layer has engineering properties better than the old base course layer. This layer can be considered as the primary layer that distributes the traffic loads to the old layers. The top layer is new overlay resurfacing layer, which is a mixture of asphalt cement and aggregate. The purpose of this layer is to protect the leveling layer from abrasion due to wheels of vehicles and provides a skid resistance surface that is important for safe vehicle slopes [2]. Figures 1 and 2 show the typical cross sections of overlay flexible repaved road structure.

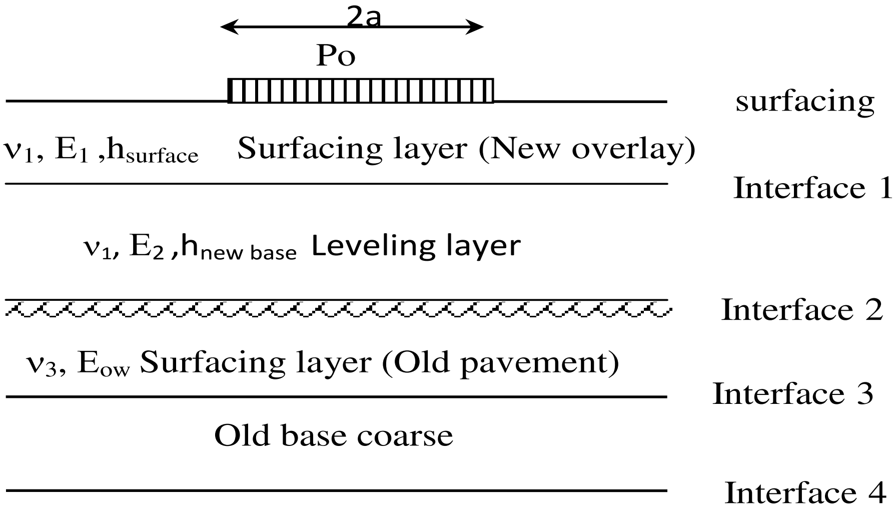

Fig. 1. Typical cross section of two layers overlay old wearing surface (case one)

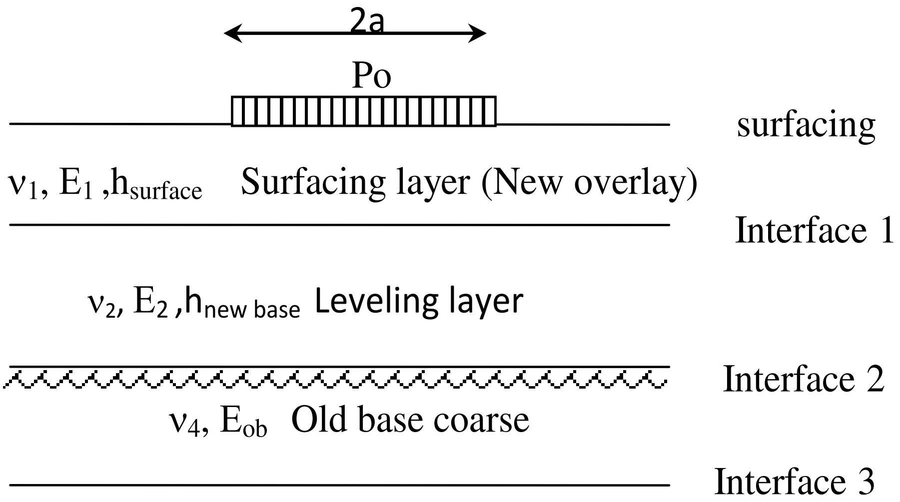

Fig. 2. Typical cross section of two layers overlay old base course (case two).

According to AASHTO, the design of flexible pavement is based on an application of elastic layer theory in which the asphalt pavement is characterized by a multilayered elastic system [3]. Boussinesq's theory is more mathematically oriented method for estimating soil pressures and deflections at various points in homogenous soil. Yoder and Witezak [4], Palmer and Barber [5], Ahivin et al. [6], Abd Alla [7] and Hashem [8] presented influence charts and equations for determination of stress and deflection in elastic soil masses. Also, the behavior of layered pavement system under static loads is investigated to indicate load transmission through layers. These charts can be used for determining the various construction layers. Also, the behavior of layered pavement system under static loads is investigated to indicate load transmission through layers. The effect of thickness and properties of pavement layers on the stresses through layers are also investigated.

This piece of present research aims to investigate the effect of changing the type and strength of pavement layer materials and their thickness on the stress of the surface of the road. Also, an approach for overlaying design of flexible repaved road structure is presented basing on an application of elastic layer theory in which the asphalt pavement is characterized a multilayered elastic system using Excel Program. Using this method, the designer may be able to determine the suitable thicknesses of pavement layers of overlaying flexible repaved road structure. The parameters used in this study are modulus of elasticity of each layer, allowable stress on the road surface, tire pressure applied on the road surface and thickness of each layer. It depends on the modulus of elasticity of each layer of flexible pavement.

2. Boussinesq equation for the stress and displacement

The design method of theory of elastic behavior is based on elastic response of the pavement to traffic stresses. To design a pavement structure, the stresses and deflections in the pavement system must be calculated. The Boussinesq theory gives equations for the stress and displacement at any point within the solid due to a point load acting normal to the surface [2]. The basic equation for the stress at a point in the system is:

$$\sigma_Z = \frac{P}{z^2} \cdot \frac{3}{2\pi} \cdot \frac{1}{\left[1+(r/z)^2\right]^{5/2}} \tag{1}$$

The maximum vertical stress σ_z at any point below an earth mass due to a uniformly distributed circular loaded area according to Boussinesq is as follows:

$$\sigma_z = p_0 \left\{1 - \frac{1}{\left\{(a/z)^2 + 1\right\}^{3/2}}\right\} \tag{2}$$

Where:

P = wheel load.

z = depth of the point.

a = equivalent load radius

r = radial distance from the centerline of the point load to another point.

σ_z = maximum vertical stress at distance z below the center of circular loaded area.

A schematic representation of one layer elastic system is shown in Fig. 3.

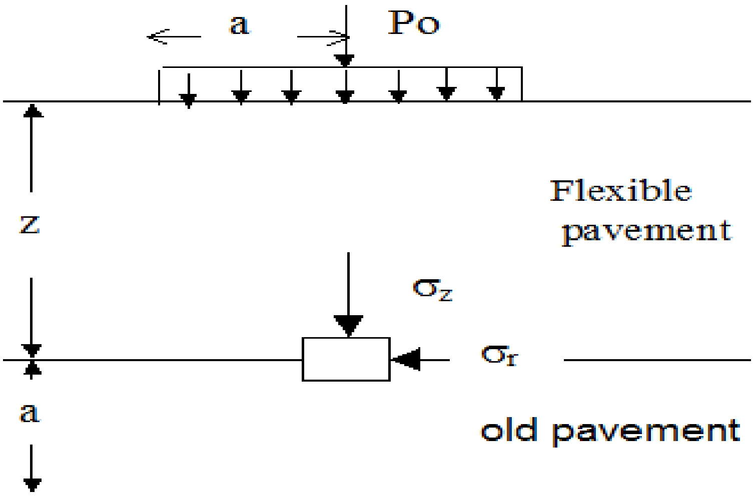

Fig.3. Stresses acting on an element**.**

3. Scope of research

The elastic stresses and deflections in the pavement structure are obtained depending upon the type of material in each layer. These values of stresses and displacements distributions are calculated considering the applied stress at the surface as unity.

3.1. Case I: Two layers above the surface of the old wearing surface

In this case, two layers of different materials are constructed directly above old pavement without removing the old wearing surface. The two layers are leveling layer from crushed aggregate and new overlay surfacing layer from asphaltic concrete. Fig.1 shows typical cross section of this case. Two parameters are taken in this case. The first parameter is the modulus of elasticity **E** for both new overlay surfacing layer**,** leveling layer and old wearing surface pavement and is taken as: 1000, 1500, 2000, 2500, 3000 and 3500 kg/cm^2 for new overlay surfacing layer (E_1), 125, 250, 500, 750 and 1000 kg/cm^2 for leveling layer (E_2) and 2000 kg/cm^2 as a min. value for old wearing surface pavement (E_{ow}) respectively. The second parameter is the thicknesses of both leveling layer and new overlay surfacing layer and is taken as: 10, 20, 30, 40, 50 and 60 cm for leveling layer and 2.5, 5, 7.5, 10, 12 and 14 cm for new overlay surfacing layer .

3.2.Case II: Two layers above the surface of old base course

In this case, two layers of different materials are constructed above old flexible pavement after remove the old wearing surface to the surface of old base course. The two layers are leveling layer and new overlay surfacing layer. Fig.2 shows typical cross section of this case. Also, two parameters are taken in this case. The first parameter is the modulus of elasticity **E** for both new overlay surfacing layer**,** leveling layer and old base course. The second parameter is the thicknesses of both leveling layer and new overlay surfacing layer. The same values of parameters are also taken in this case, except the modulus of elasticity of old base is taken as 250 kg/cm^2 as min. value.

4. Overlay design of flexible repaved road structure approach

According to Boussinesq theory as mentioned before, the max. vertical stress $\boldsymbol{\sigma_z}$ is taken as $\mathbf{P_1}$ at any point below an earth mass due to a uniformly distributed circular loaded area. $\mathbf{P_1}$ can be calculated with using equation 3 as shown in Fig. 3.

$$p_1 = p_0 \left\{ 1 - \frac{1}{\left\{ (a/z)^2 + 1 \right\}^{3/2}} \right\} \tag{3}$$

In which **a** is the radius of circular load pressure which is taken here as 30 cm to represent the contact area of the truck wheel which use the road.

This equation would be modified as:

$$\frac{P_1}{P_o} = f(z) \tag{4}$$

For multilayered pavement structure, it may be modified to an equivalent height of pavement structure and the above formula will be applied as follows:

$$\frac{P_1}{P_o} = f(h_e)_T \tag{5}$$

Where:

P_1 = maximum vertical stress at old pavement surface or at depth $(h_e)_T$.

P_o = uniformly distributed circular load at the surface = tire pressure.

$(h_e)_T$ = equivalent height of pavement layers

=sum of equivalent height of each layer .

$(h_e)_T = [(h_e)_{surfacing\ layer} + (h_e)_{leveling\ layer}]$ for case of two layers (6)

Where:

$[(h_e)_{surfacing\ layer}$ = equivalent height for asphaltic concrete surface layer.

$(h_e)_{leveling\ layer}$ = equivalent height for base layer surface.

According to Abd Alla [7] for pavement layer, the thickness h_p can be replaced by an equivalent thickness of pavement structure h_e, where:

$$h_e = h_p (E_p / E_e)^{1/3} \quad (7)$$

5. Results and analysis of pavement structure design

Charts for overlaying design of flexible repaved road structure are obtained using Excel program and the different parameters mentioned previously, such as modulus of elasticity **E** for different layers, thickness of leveling layer $\mathbf{h_{leveling\ layer}}$ and thickness of new overlay asphaltic concrete surface $\mathbf{h_{new\ surface}}$. By using Equations (2) and (7) the relationship between total equivalent height of new pavement structure $\mathbf{(h_e)_{T\ new}}$ and the relative stress above old pavement to the applied pressure at new overlay pavement surface (P/P_o) is obtained as shown in Fig.4.

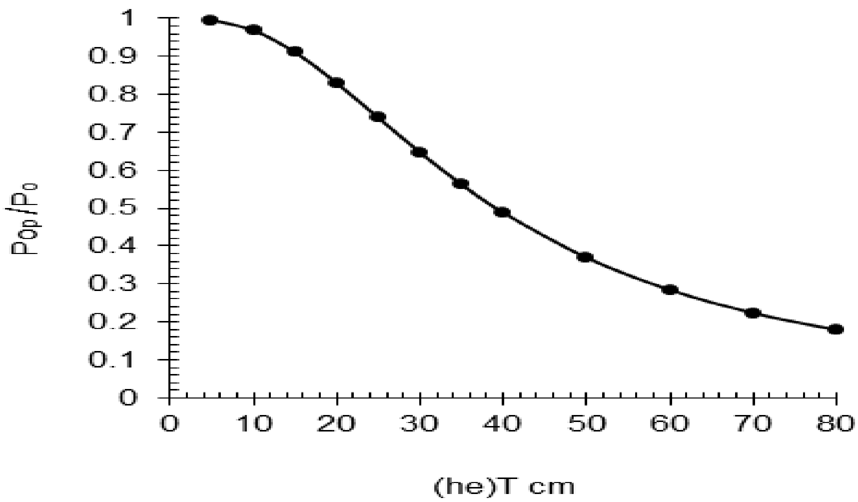

Fig. 4. New Pavement height equivalent versus relative old pavement/new overlay surfacing stress.

As shown from this figure, the total equivalent height of new pavement structure $(h_e)_{Tnew}$ decreases with the increase of the relative stress above old pavement to the applied pressure at new overlay pavement surface (P/P_o). The suggested equation which represents the relation between the total equivalent height of new pavement structure $(h_e)_T$ and the relative stress above old pavement to the applied pressure at new overlay pavement surface (P_o/P_{new}) is given as follows:

$$P/P_o = 9 \times 10^{-5}(h_e)^2_T - 0.0197\,(h_e)_T + 1.1488 \qquad (8)$$

With best correlation factor $R^2 = 0.9913$.

5.1.Case I: Two layers above the surface of old wearing surface

Figures 5 and 6 represent the relation between various construction layers thickness **h** and its equivalent heights h_e at different stiffness factor (E_1/E_{ow}), (E_2/E_{ow}). As shown from these figures, the various construction layers thickness increase with the increase its equivalent heights and decrease with the increase of elastic modulus of each layer.

Different charts which shown in Fig.7 to Fig.9 represent the relation between leveling layer thickness and relative stress above old wearing surface to the applied pressure at new overlay pavement surface. These charts are applied at different elastic modulus of each layer. The thickness of new overlay surfacing layer is kept at 5cm.

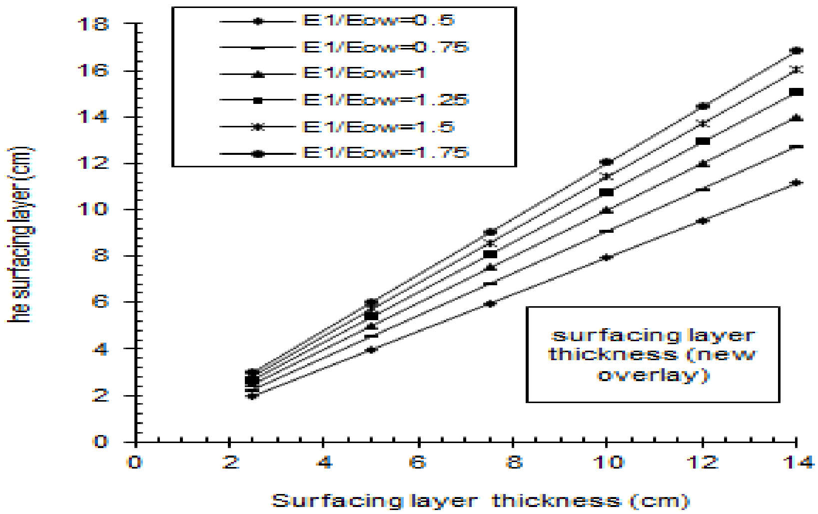

Fig. 5. Surfacing layer (new overlay) thickness versus its equivalent height case I**.**

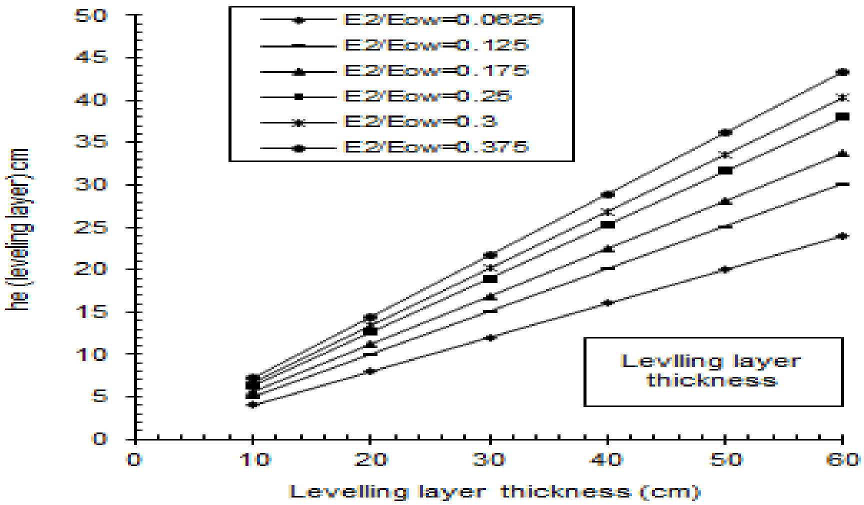

Fig. 6. Leveling layer thickness versus its equivalent height case I.

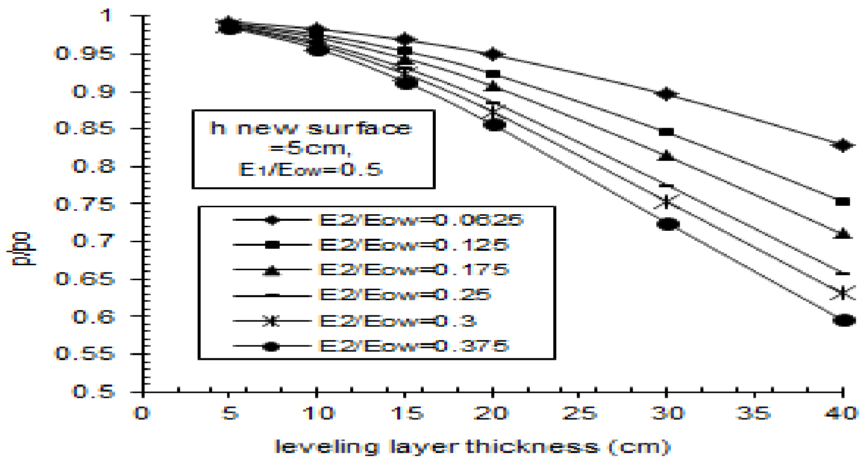

Fig. 7. Leveling layer thickness versus relative old wearing surface pavement/ new surface stresses, case ($h_{new\ surface}$ =5, E_1/E_{ow}=0.5).

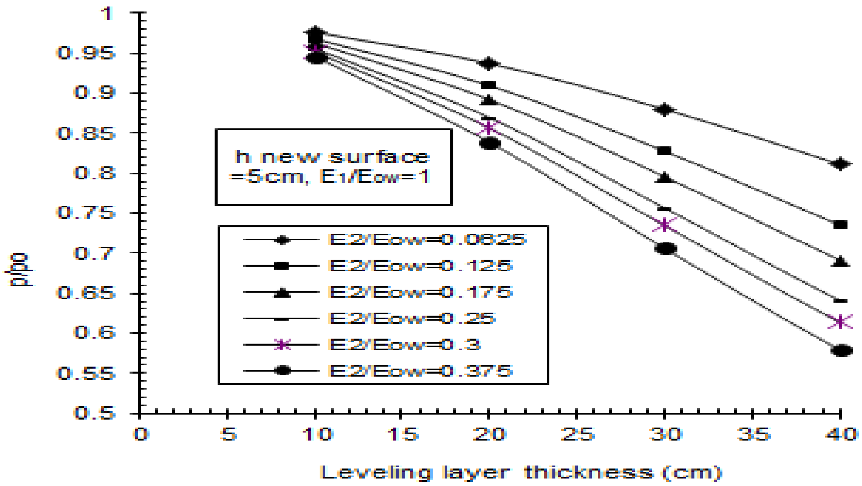

Fig. 8. Leveling layer thickness versus relative old wearing surface pavement/ new surface stresses, case, ($h_{\text{new surface}}$ =5, E_1/E_{ow}= 1).

Referring to Figures 7, 8 and 9, the results show that the leveling layer thickness decreases dramatically by the increase of the relative stress above old wearing surface to the applied pressure at new overlay pavement surface (P/P_o) and the rate of increase is almost constant regardless to the stiffness factor E_i/E_{ow}. Also, it can be shown from these figures that the leveling layer thickness decreases with the increase of the stiffness factor E_i/E_{ow}. For example, as shown in Fig.7, in case of E_2/E_{ow} = 0.125, leveling layer thickness decreases from 40 cm at relative stress P/P_o = 0.75 to 23 cm at relative stress P/P_o = 0.90 (about 43 % decrease), while the corresponding values for stiffness factor E_2/E_{ow} = 0.25 are 32 cm and 19 cm, respectively (about 41 % decrease). Comparing Fig.7 and Fig.9 for new overlay surfacing stiffness factor E_1/E_{ow} = 1 and E_1/E_{ow} = 1.5 at the same relative stress P/P_o = 0.9 (for example) and at the same leveling stiffness factor of E_2/E_{ow} = 0.25 (for example), the leveling layer thickness decreases from 18 cm to 16 cm respectively. This means that the leveling layer thickness decreases with the increase of new overlay surfacing stiffness factor E_1/E_{ow} as shown in these figures.

5.2.Case II: Two layers above the surface of old Base course layer

Figures 10 and 11 represent the relation between various construction layers thickness **h** and its equivalent heights $\mathbf{h_e}$ at different stiffness factor (E_1/E_{ob}) and (E_2/E_{ob}). As shown in these figures, the various construction layers thickness increase with the increase of its equivalent heights and elastic modulus of each layer.

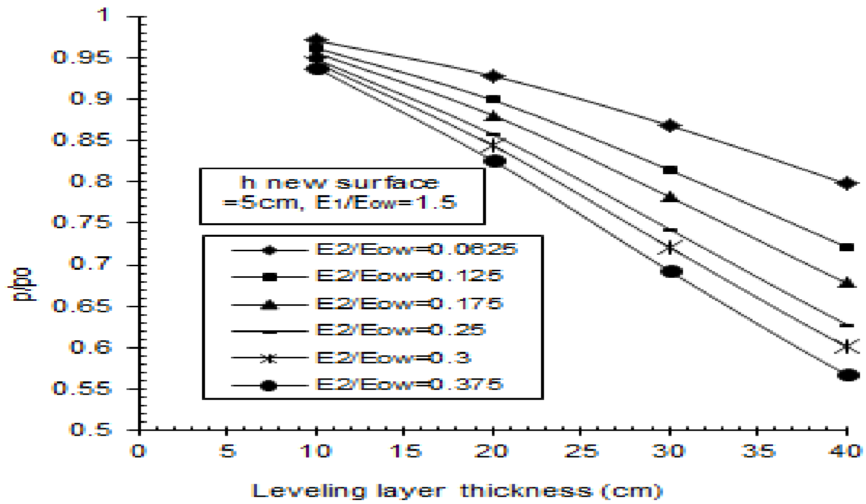

Fig. 9. Leveling layer thickness versus relative old wearing surface pavement/ new surface stresses, case, ($h_{\text{new surface}}$ =5, E_1/E_{ow}= 1.5).

Different charts shown in Figs. 12 to 14 represent the relation between base layer thickness and relative stress above old base course to the applied pressure at pavement surface. These charts are applied at different elastic modulus of each layer. The thickness of new overlay surfacing layer is kept at 5cm. Referring to Figures 12, 13 and 14, the results show that leveling layer thickness decreases dramatically by the increase of the relative stress P/P_o and the rate of increase is almost constant regardless to the stiffness factor E_i/E_{ob}. Also it can be shown from these figures that the leveling layer thickness decreases with increasing the stiffness factor E_i/E_{ob}. For example, as shown in Fig.12, in case of E_2/E_{ob} = 1, leveling layer thickness decreases from 39 cm at relative stress P/P_o = 0.4 to 14 cm at relative stress P/P_o = 0.8 (about 64 % decrease), while the corresponding values for stiffness factor E_2/E_{ob} = 3 are 27.5 cm and 9.5 cm, respectively (about 66 % decrease).

Comparing Fig.12 and Fig.14 for new overlay surfacing stiffness factor E_1/E_{ob} = 4 and E_1/E_{ob} = 12 at the same relative stress P/P_o = 0.5 (for example) and at the same leveling stiffness factor of E_2/E_{ob} = 1 (for example), the leveling layer thickness decreases from 31.5 cm to 27.5 cm respectively.

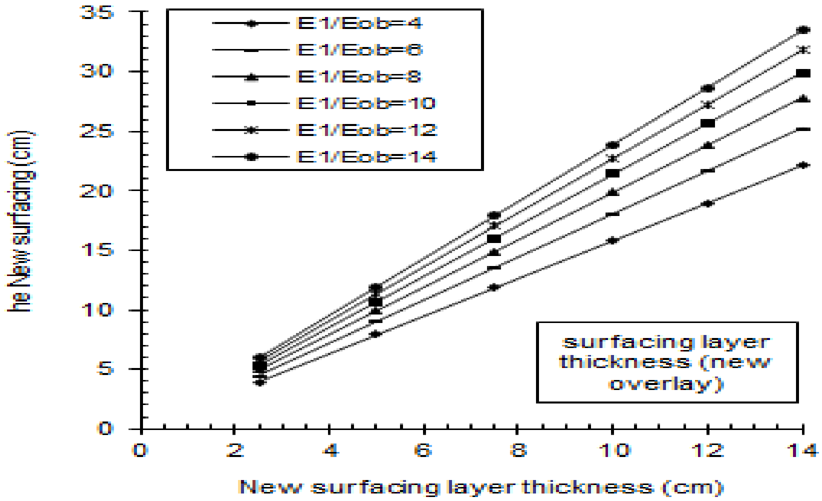

Fig. 10. Surfacing layer (new overlay) thickness versus its equivalent height case II

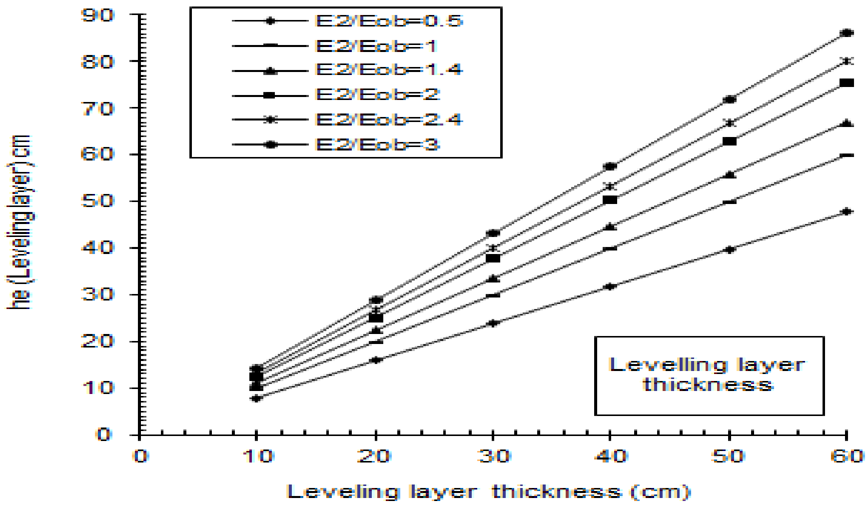

Fig.11. Leveling layer thickness versus its equivalent height case II.

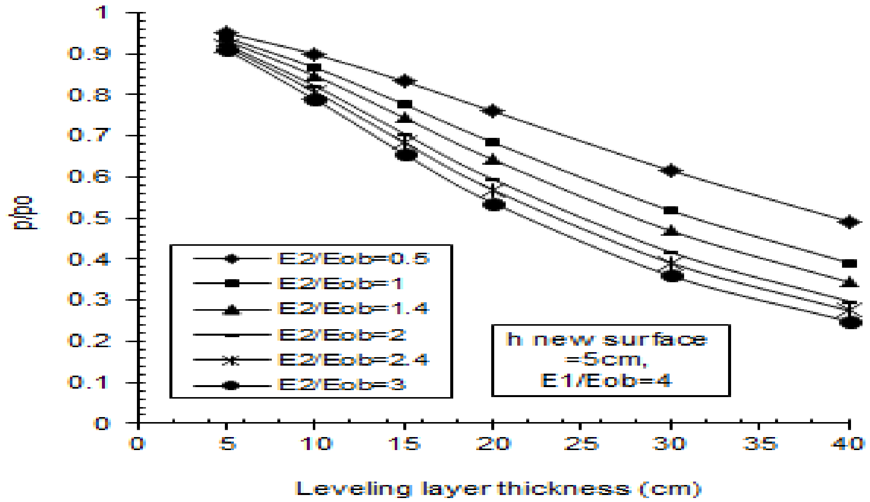

Fig.12. Leveling layer thickness versus relative old base course pavement/ new surface stresses, case, (h $_{\text{new surface}}$ =5, E_1/E_{ob} = 4).

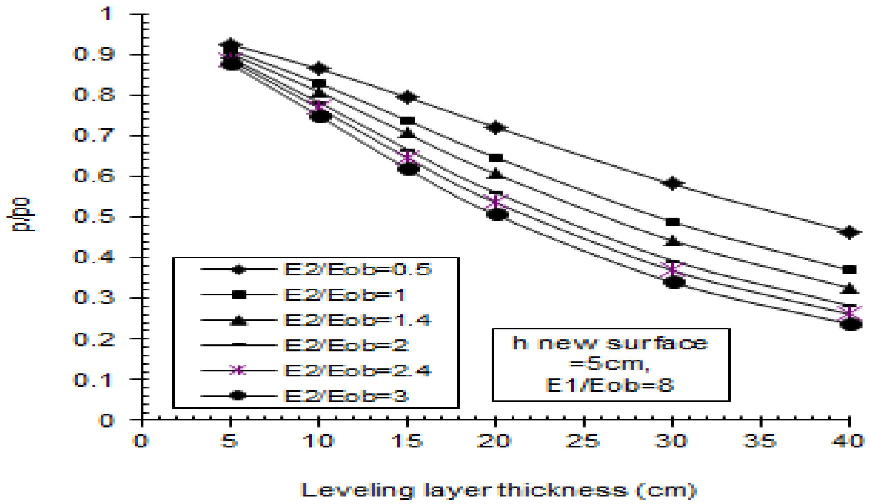

Fig.13. Leveling layer thickness versus relative old base course pavement/ new surface stresses, case, (h $_{\text{new surface}}$ =5, E_1/E_{ob}= 8).

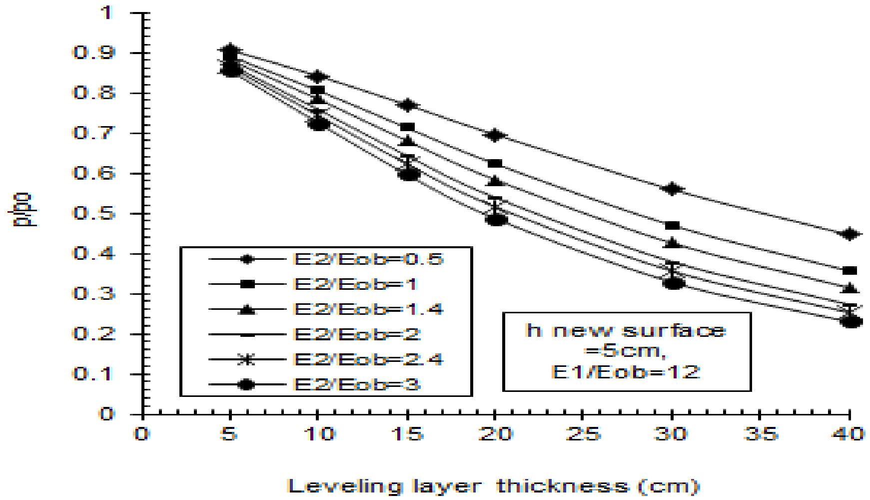

Fig.14. Leveling layer thickness versus relative old base course pavement/ new surface stresses, case (h $_{\text{new surface}}$ =5, E_1/E_{ob}= 12).

6. Illustrative example

The following data are available: tire pressure = 8kg/cm^2, allowable stress on old wearing surface pavement = 6.4 kg/cm^2, allowable stress on old base course pavement = 3.2 kg/cm^2 , modulus of elasticity of leveling layer material = 500 kg/cm^2, modulus of elasticity of new overlay wearing surface = 3000 kg/cm^2 , modulus of elasticity of old base course pavement = 250 kg/cm^2 and modulus of elasticity of old wearing surface pavement = 2000 kg/cm^2 . It is required to design flexible repaved road for the following cases:

a. Two layers above surface of old wearing pavement.

b. Two layers above surface of old base course pavement.

Solution

Data Given:

P_{ow}= 6.4 kg/cm^2

P_{ob}= 3.2 kg/cm^2

P_o = 8 kg/cm^2

E_{ow} = 2000 kg/cm^2

E_{ob} = 250 kg/cm^2

$E_1 =$ 3000 kg/cm^2

$E_2 =$ 500 kg/cm^2

First the following values must be calculated:

P_{ow}/P_o	= 6.4/8	= 0.8
P_{ob}/P_o	= 3.2/8	= 0.4
E_1/E_{ow}	= 3000/2000	= 1.5
E_2/E_{ow}	= 500/2000	= 0.25
E_1/E_{ob}	= 3000/250	= 12
E_2/E_{ob}	= 350/250	= 1.4

6.1.Two layers above surface of old wearing pavement.

1) Referring to Fig.4 the total equivalent height of pavement structure $(h_e)_T$ can be obtained by knowing allowable stress on old wearing surface pavement to applied tire pressure.

At $P_{ow}/P_o = 0.8$ then: $(h_e)_T = 21$cm.

2) The stiffness factor $E_1/E_{ow} = 1.5$ so, the chart shown in Fig. 9 can be used to find the leveling layer thickness.

At: $P/P_o = 0.8$ and $E_2/E_{ow} = 0.25$

Then: $h_{\text{leveling layer}} = 25$ cm.

3) Referring to Fig.6, equivalent height of base layer $(h_e)_{\text{leveling layer}}$ can be obtained

At: $E_2/E_{ow} = 0.25$ and $h_{\text{leveling layer}} = 25$ cm

Then: $(h_e)_{\text{leveling layer}} = 16$ cm.

4) Using Equation 5, the equivalent height of wearing surface layer can be determined as:

$(h_e)_{\text{new overlay surfacing}} = 5$ cm.

5) The thickness of new overlay wearing surface layer $h_{\text{new overlay surfacing}}$ can be obtained using chart shown in Fig.5

At: $(h_e)_{\text{surface}} = 5$ cm and $E_1/E_{ow} = 1.5$

Then: $h_{\text{surface}} = 4.4$cm.

Taken 5 cm as a min. value.

6) Finally the various thicknesses obtained are shown as:

$h_1 = h_{\text{new overlay surfaceing}}$ = 5 cm

$h_2 = h_{\text{leveling layer}}$ = 25 cm

Total thickness = 30 cm

6.2.Two layers above surface of old base course pavement.

1) Referring to Fig.4 the total equivalent height of pavement structure $(h_e)_T$ can be obtained by knowing allowable stress on old base course pavement to applied tire pressure.

   At $P_{ob}/P_o = 0.4$ then: $(h_e)_T = 46$cm.

2) The stiffness factor $E_1/E_{ob} = 12$ so, the chart shown in Fig. 14 can be used to find the leveling layer thickness.

   At: $P_{ob}/P_o = 0.4$ and $E_2/E_{ob} = 1.4$

   Then: $h_{\text{leveling layer}} = 32$ cm.

3) Referring to Fig.11, equivalent height of base layer $(h_e)_{base}$ can be obtained

   At: $E_2/E_{ob} = 1.4$ and $h_{\text{leveling layer}} = 32$ cm

   Then: $(h_e)_{\text{leveling layer}} = 36$ cm.

4) Using Equation 5, the equivalent height of wearing surface layer can be determined as:

   $(h_e)_{\text{new overlay surfacing}} = 10$ cm.

5) The thickness of wearing surface layer $h_{surface}$can be obtained using chart shown in Fig.10

   At: $(h_e)_{\text{new overlay surfacing}} = 10$ cm and $E_1/E_{ob} = 12$

   Then: $h_{\text{new overlay surfacing}} = 4.5$cm.

   Taken 5 cm as a minimum value.

6) Finally the various thicknesses obtained are shown as:

   $h_1 = h_{\text{new overlay surfaceing}}$ = 5 cm

   $h_2 = h_{\text{leveling layer}}$ = 35 cm

   Total thickness = 40 cm

7. Conclusions

Based on the results obtained the following conclusions can be drawn:

1. Repaving the flexible pavement above an old wearing surface requires less leveling layer thickness compared to over an old base course. This case can be used when the old wearing surface is in a good condition.
2. The thickness of pavement structure decreases with the increase of the relative stress above old pavement to the applied pressure at new overlay pavement surface.
3. The various constructions layer thickness increase with the increase of its equivalent heights and decrease with the increase of elastic modulus of each layer.
4. The leveling layer thickness decreases with the increase of the relative stress above old pavement to the applied pressure at new overlay pavement surface. On the contrary, it decreases with the increase of elastic modulus of each layer.
5. As a result of the analysis, design charts for flexible pavement including the effect of the thickness and material characteristics of each pavement layer are introduced.

Nomenclature

a	=radius of circular load pressure.
E_i	= elastic modulus of each material.
$(h_e)_T$	=equivalent height of pavement layers
$(h_e)_{surface}$	=equivalent height for new overlay asphaltic concrete surface layer.
$(h_e)_{leveling\ laye}$	=equivalent height for leveling layer surface.
P	= wheel load.
P_1	=maximum vertical stress at depth $(H_e)_T$.
P_o	= uniformly distributed circular load at the surface = tire pressure.
P_{ow}	=maximum vertical stress at old wearing surface pavement.
P_{ob}	=maximum vertical stress at old base course pavement.
r	= radial distance from the centerline of the point load to another point.
z	=depth below an earth mass.
σ_z	= maximum vertical stress at a distance z below the center of circular loaded area.

References

[1] Columbus, Ohio. Flexible Pavements of Ohio 37 W. Broad St., Suite 460 P.O. BOX 16186, 2000.

[2] Mannering, F.L. and Kilareski, W.P. Principles of Highway Engineering and Traffic Analysis. John Wiley & Sons, New York, 1990.

[3] AASHTO guide for design of pavement structures. American Association of State Highway and Transportation Officials, 1993.

[4] Yoder, E.J. and Witezak, M. W. , Principles Of Pavement Design. Text Book, Publisher John Wily & Sons, New York, 1975.

[5] Palmer, L.A. and Barber, E.S. Soil Displacement Under Circular Loaded Areas, Proc. Highway Research Board, 1940.

[6] Ahivin, R.G., Chou, Y.T. and Hutchinson, R.L. Structural Analysis of Flexible Airfield Pavements, Transportation Engineering Journal, August, 1974.

[7] Abd Alla, E.M. A Simplified Method for Flexible Pavement Design Using Finite Element Method (FEM). Bulletin of the Faculty of Engineering, Assuit University, Vol.25, No.2 , PP.21-28 , 1997.

[8] Hashem, M.D. A Simplified Method for Flexible Pavement Economic Design Based On Elastic Layer Theory. Al-Azhar Engineering 7th International Conference 7-10, April, 2003.

تصميم رسومات بيانية مبسطة لتحديد سمك الطبقات المستخدمة لإعادة تغطية الرصف القديم

ملخص:

الطرق التى تحتاج إلى إعادة رصف هى الطرق التى بها كثير من الاضرار والتآكل والتى تسبب كثير من المشاكل للمركبات والسائقين مستخدمي الطرق. لذا يجب إعادة رصف هذه الطرق بإعادة تغطيتها من جديد للتغلب على هذه المشاكل. وهناك طريقتان لإعادة تغطية هذه الطرق يتم تطبيقها فى هذا البحث. الطريقة الأولى تشمل إنشاء طبقتين أعلى الطبقة السطحية الأسفلتية للرصف القديم والطريقة الثانية تشمل أيضا إنشاء طبقتين ولكن أعلى طبقة الأساس القديم بعد إزالة الطبقة السطحية الأسفلتية للرصف القديم. والطبقتان هما طبقة تسوية من مخلفات المحاجر تعلوها طبقة تغطية من الخرسانة الأسفلتية. وتستخدم هذه الطبقات لتقليل الإجهادات والهبوطات الناتجه من أحمال المركبات الى الحد المسموح به. وفى هذا البحث تم استخدام برنامج الكمبيوتر (Excel) ونظرية المرونة لأستنباط طريقة مبسطة لتحديد سمك الطبقات المستخدمة لإعادة تغطية الرصف القديم. باستخدام هذه الطريقة يستطيع المصمم ان يحدد سمك طبقات الرصف المناسب لإعادة تغطية الرصف القديم.