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FACTORS AFFECTING ROADS SYSTEM AND PAVEMENT ANALYSIS METHODS

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Abstract

Today, pavement analysis is an important issue due to the development of the building and road construction industry. Different pavement analysis methods have been presented and each one has its own strengths and weaknesses. The logic of layer theory and finite element theory are two main methods to analyze these problems. It is clear that the use of each method will require meeting basic assumptions and certain conditions governing it. What is mentioned in this project is to introduce two main methods for flexible pavement analysis, the theory of elasticity and layered system and the finite element method, and it has been tried to study layered system and consequently method for layer solution and to present more details of its mathematical algorithm. In Burmister approach, to find stresses and deformations in the soil layered environment, a stress function is selected assuming the half-space environment with the axial symmetry and resulting differential equations are solved and the required responses are obtained considering the continuity conditions and boundary conditions.

Key words: Pavement system, Road, Software, Algorithm

Introduction

Today, road is an important factor in communication and transportation of passengers and things and is one of the most important factors that many discussions and conferences are held in conjunction with it. In high traffic roads, bituminous or concrete materials are used for pavement construction. These types of pavement can be deformed under load which causes horizontal tensile stresses in the pavement layer so that if these stresses exceed the tensile strength of materials, cracks will be created. Actually road pavement is a series of layers designed with materials on reinforced layers of natural ground. Normally natural ground has not adequate resistance and density therefore the embankment layers with narrowly defined thicknesses are spread and are rammed to reach a predetermined height for pavement bed. Pavement layers are a function of traffic on the road and whatever traffic is higher, the pavement should be designed stronger and more durable. For example, on sub-grade iii (rural) roads the traffic is very low-volume so we can use claypavement. For sub-grade ii or regional roads with higher traffic volumes we can use cold asphalt, and if we have high traffic route or main road, we can use concrete surface or hot asphalt. In countries such as Iran where bitumen production is high and it is cheap, hot asphalt is used and maybe almost all projects around the country are constructed of asphalt on the contrary, in countries with high cement production where cement is cheaper, concrete pavements are justifiable. Concrete surfaces act like reinforced slab, in the country and in the city there are also places that have made of concrete (a part of the airport, a part of the terminal, etc.). So it can be concluded that the factors that affect pavement design are as follows:

1. Pavement bed soil: that must be examined in terms of material and permeability.
2. Pavement materials: that must be examined in terms of strength and durability.
3. Traffic volume: that must be designed based on anticipated axes during the pavement lifetime.
4. Climate factors: pavement should maintain its stability in cold, heat, repeated rainfalls and glacial.

Pavements with concrete surfaces are called hard pavements and pavements with asphalt surfaces are called flexible pavements. In flexible pavements because vehicles tire pressures are exerted on the pavement bed in a smaller contact area, thereby understanding soil behavior in the pavement bed is very important for this type of pavement.

Problem statement

In pavement maintenance management, pavement quality in terms of destruction and driver satisfaction should be expressed as a quantitative index. Factors that are usually selected as measures for pavement evaluation are as follows:

- Road roughness
- The friction between pavement and vehicle tires
- Adequacy of pavement bearing capacity
- Destruction of the pavement

In pavement maintenance management system to express pavement quality in a format, an evaluation method is used. So that a series of specific parameters are determined as pavement quality measures(for example, cracks or the pavement roughness).Then a time is given to combine these parameters and obtain one or more indicators. Whatever the number of parameters involved in the index estimation is more, this index can express pavement quality with higher sensitivity. On the other hand, the large number of parameters requires more evaluation time, which reduces the efficiency of the system. So this conflict is always seen in all evaluation methods. With the popularity of computer systems and increasing the storage in the processing, in some cases, automated evaluation operation and data collection, evaluation methods have been developed toward the use of more accurate methods and more parameters against the models. Here some evaluation methods are presented and the way to obtain a composite index of pavement quality is expressed.

KENLAYER software is the software which is used to analyze the stresses and strains. The interface conditions in this software which are particular to flexible pavements, are considered in finite or infinitestates(Young, 1953). To analyze stress and strain under loading, interface conditions are defined as finite without internal friction, or infinite with internal friction (0)and several cases that may occur during implementation, are applied in the analyses.

Flexible pavement analysis methods

Several methods have been proposed to analyze flexible pavements that the finite element method and multi-layered method are two most important of them. In this section, each of methods described above with the corresponding equations are introduced and the advantages and disadvantages of each methods are described.

Basic equations

Like the classical theory of elasticity, the stress function for each layer is considered so that the following differential equation to be satisfied.

$$\nabla^4 \phi = \circ \quad \text{(2-1a)}$$

For systems with an axially symmetric stress distribution, we have:

$$\nabla^2 = \left(\frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r} + \frac{\partial^2}{\partial Z^2}\right)\left(\frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r} + \frac{\partial^2}{\partial Z^2}\right) \text{(2-1b)}$$

Where r and z are radial and vertical coordinates in cylindrical coordinate system. After calculating the stress, stresses and displacements can be calculated as follows:

$$\sigma_t = \frac{\partial}{\partial z}\left[(\nu\nabla^2\phi - \frac{1}{r} - \frac{\partial^2\phi}{\partial r}\right] \qquad \text{(2-2a)}$$

$$\sigma_r = \frac{\partial}{\partial z}(\nu\nabla^2\phi - \frac{\partial^2\phi}{\partial r^2}) \qquad (2\text{-}2b)$$

$$\sigma_t = \frac{\partial}{\partial r}\left[(1-\nu)\nabla^2\phi - \frac{\partial^2\phi}{\partial z^2}\right] (2\text{-}2c)$$

$$\tau_z = \frac{\partial}{\partial r}\left[(1-\nu)\nabla^2\phi - \frac{\partial^2\phi}{\partial z^2}\right] (2\text{-}2d)$$

$$w = \frac{1+\nu}{E}\left[(1-2\nu)\nabla^2\phi - \frac{\partial^2\phi}{\partial r^2} + \frac{1}{r}\frac{\partial\phi}{\partial r}\right] (2\text{-}2e)$$

$$u = -\frac{1+\nu}{E}\left(\frac{\partial^2\phi}{\partial r\partial z}\right) (2\text{-}2f)$$

According to that the equations (2-1) and (2-2) are fourth-degree equations, stresses and displacements include four constants of integration which should be obtained with respect to the boundary conditions and continuity conditions.

Assuming $\rho = r/h$ and $\lambda = Z/H$ where H is the distance between the surface to the upper boundary of the lower layer, as shown in Figure 2-2,Burmistershowed that the following equation is the stress function of layer that satisfies equations (1-2).

$$\phi_i = \frac{H^3 J_\circ(m\rho)}{m^2}\left[A_i e^{-m(\lambda_1-\lambda)} - B_i e^{-m(\lambda-\lambda_{i-1})} + C_i m\lambda_e^{-m(\lambda_i-\lambda)} - D_i m\lambda e^{-(\lambda-\lambda_{i-1})}\right] \qquad (2\text{-}3)$$

Where, $J_\circ$ is the zero order Bessel function of the first kind, m is a specific parameter and A, B, C, D are constants of integration which are obtained with respect to the continuity conditions and boundary conditions. The index ithat varies from 1 to nis the indicator of quantities related to the layer i.

$$(\sigma_z^*)_i = [\ -mJ_\circ(m\rho)\{[A_i - C_i(1-\nu_i - m\lambda]e^{-m(\lambda_i-\lambda)} \qquad (2\text{-}4a)$$

$$+[B_i + D_i(1-2\nu_i + m\lambda)e^{-m(\lambda-\lambda_{i-1})}\}$$

$$(\sigma_z^*) = -mJ_\circ(m\rho - \frac{J_1(m\rho)}{\rho}]\{[A_i + C_i(1+m\lambda)]_e^{-m(\lambda_i-\lambda)} \qquad (2\text{-}4b)$$

$$+[B_i - D_i(1-m\lambda)e^{-m(\lambda-\lambda_{i-1})}\} + 2\nu_i mJ_\circ(m\rho)[C_i e^{-m(\lambda_i-\lambda)} - D_i e^{-m(\lambda-\lambda_{i-1})}$$

$$(\sigma_t^*)_i = \frac{J_1(m\rho)}{\rho}\{[A_i + C_i(1+m\lambda)e^{-m(\lambda_i-\lambda)} \quad (2\text{-}4c)$$

$$+[B_i - D_i(1-m\lambda)]_e^{-m^{(\lambda-\lambda_{i-1})}}\} + 2v_i mJ_\circ(m\rho)[C_i e^{-m(\lambda_i-\lambda)} - D_i e^{-m(\lambda-\lambda_{i-1})}$$

$$(\tau_{rz}^*)_i = mJ_1(m\rho)\{[A_i + C_i(2v_i + m\lambda)]e^{-m(\lambda_i-\lambda)} \quad (2\text{-}4d)$$

$$-[B_i + D_i(2v_i - m\lambda)e^{-m(\lambda-\lambda_{i-1})}\}$$

$$(w^*)_i = \frac{1+\nu_i}{E_i} J_\circ(m\rho)\{[A_i - C_i(2-4v_i - m\lambda)]e^{-m(\lambda_i-\lambda)} \quad (2\text{-}4e)$$

$$-[B_i + D_i(2-4v_i + m\lambda)e^{-m(\lambda-\lambda_{i-1})}\}$$

$$(u^*)_i = \frac{1+\nu_i}{E_i} J_1(m\rho)\{[A_i + C_i(1+m\lambda)]e^{-m(\lambda_i-\lambda)} \quad (2\text{-}4f)$$

$$-[B_i - D_i(1-m\lambda)e^{-m(\lambda-\lambda_{i-1})}\}$$

Where, σ_z is the vertical stress, σ_r is the radial stress, σ_t is the tangential stress, τ_{rz} is the shear stress, W is the vertical displacement, u is the radial displacement, J_1 is the zero order Bessel function of the first kind and i indicates layer i. Also, * on stresses and strains indicates that these values are not actual values under the influence of the uniform circular load q, and are obtained under vertical load $-mJ_\circ(mp)$.

To find the stresses and displacements caused by the uniform circular load with a radius of a, Hankel transform method should be used. Hankel transform is defined as follows:

$$\bar{f}(m) = \int_\circ^\alpha q\rho J_\circ(m\rho)d\rho = \frac{q\alpha}{m} J_1(m\alpha) \quad (2\text{-}5)$$

Where, $\alpha = \frac{\alpha}{H}$. Hankel inverse transform $\bar{f}(m)$ is defined as follows:

$$q(\rho) = \int_\circ^\infty \bar{f}(m)\, mJ_\circ(m\rho)dm = q\alpha\int_\circ^\infty J_\circ(m\rho)J_1(m\alpha)dm \quad (2\text{-}6)$$

If R^* is the stress or strain obtained from equations (2-4), under the influence of loading $-mJ_\circ(mp)$ and R is the stress or strain under the influence of load q, and if the tension is marked negative, then:

$$R = q\alpha\int_{\circ}^{\infty}\frac{R^*}{m}J_1(m\alpha)dm \qquad (2\text{-}7)$$

According to subjects mentioned above a layered system analysis can be summarized as follows:

1- Taking into account different values for "m" from 0 to a large enough positive number so that the equation (2-7) becomes convergent.

2- Calculating constants of integration A_i, B_i, C_i, Disaccording to the given mind continuity conditions and boundary conditions.

3- Replacing constants of integration in equations (2-4) and calculating R^*.

4- Calculating R values using equation (2-7).

Boundary and continuity conditions

In the upper surface of the layered system, where i=1 and λ= 0, the boundary conditions are as follows:

$$(\sigma_z^*) = -mJ_\circ(m\rho) \qquad (2\text{-}8a)$$

It means that just at the point under the load, the vertical stress of the pavement is equal to the vehicle tire load.

$$(\tau_{rz}^*)_1 = \circ \qquad (2\text{-}8b)$$

It means that lateral loads on the surface of pavement are ignored and assuming that the vehicle is constant and is moving at a steady speed (non-accelerated motion), the shear stress at the top of pavement is considered to be zero.

As a result, the following equation is obtained:

$$\begin{bmatrix} e^{-m\lambda} & 1 \\ e^{-m\lambda_1} & -1 \end{bmatrix}\begin{Bmatrix} A_1 \\ B_1 \end{Bmatrix} + \begin{bmatrix} -(1-2\nu_1)e^{-m\lambda_1} & 1-2\nu_1 \\ 2\nu_1 e^{-m\lambda_1} & 2\nu_1 \end{bmatrix}\begin{Bmatrix} C_1 \\ D_1 \end{Bmatrix} = \begin{Bmatrix} 1 \\ \circ \end{Bmatrix} \qquad (2\text{-}9)$$

All the following equations are obtained assuming fully bounded layers and the same vertical stress, shear stress, vertical displacement and radial displacement for points on the interface between the layers. Therefore, if $\lambda = \lambda_1$the continuity conditions are defined as follows:

$$(\sigma_z^*)_i = (\sigma_z^*)_{i+1} \qquad (2\text{-}10a)$$

$$_{i+1}(\tau_{rz}^*)_i = (\tau_{rz}^*) \qquad (2\text{-}10b)$$

$$(w^*)_i = (w^*)_{i+1} \qquad (2\text{-}10c)$$

$(u^*)_i = (u^*)_{i+1}$ (2-10d)

As a result, four equations are obtained as follows:

A n-layered system has 4n constants of integration. Considering $A_n = C_n = \circ$, 4n-2 remains constant which can be obtained using 4n-2 equations. The above equations include two equations (2-9) and 4(n-1).

A suitable method to reduce the equations solving time by computers is to solve 2 equations instead of 4n-2 equations. This can be done using the following transform:

$$\begin{Bmatrix} A_i \\ B_i \\ C_i \\ D_i \end{Bmatrix} = \begin{bmatrix} 4\times 4 \\ \text{matrix} \end{bmatrix} \begin{Bmatrix} A_{i+1} \\ B_{i+1} \\ C_{i+1} \\ D_{i+1} \end{Bmatrix} \qquad (2\text{-}15)$$

Using sequential multiplication, the relationship between constants of the first and the last layer is obtained as follows:

$$\begin{Bmatrix} A_i \\ B_i \\ C_i \\ D_i \end{Bmatrix} = \begin{bmatrix} 4\times 2 \\ \text{matrix} \end{bmatrix} \begin{Bmatrix} B_n \\ D_n \end{Bmatrix} \qquad (2\text{-}16)$$

By dividing equation (2-16) into the equation (2-9), two equations with two unknown parameters D_n, B_n are obtained. After calculating parameters D_n, B_n and replacing this parameter in equation (2-15) and assuming $A_n = C_n = \circ$ constants of layer (n-1) are obtained. This method is continued to calculate constants of all layers.

If layer i is not fully bounded, continuity of shear stress and vertical displacement should be considered zero on both sides of the interface:

$(\sigma_z^*)_i = (\sigma_z^*)_{i+1}$ (2-17a)

$(w^*)_i = (w^*)_{i+1}$ (2-17b)

$(\tau_{2z}^*) = \circ$ (2-17c)

$(\tau_{2z}^*)_{i+1} = \circ$ (2-17d)

So the following equation replaces equation (2-11).

$$\begin{bmatrix} 1 & F_i & -1(2\nu_{i+1}-m\lambda_i) & (1-2\nu_{i+1}+m\lambda_i)F_i \\ 1 & F_i & 1+m\lambda_i & -(1-m\lambda_i)F_i \\ 1 & -F_i & 2\nu_i+m\lambda_i & (2\nu_i-m\lambda_i)F_i \\ \circ & \circ & \circ & \circ \end{bmatrix} \begin{bmatrix} A_i \\ B_i \\ C_i \\ D_i \end{bmatrix} \quad (2\text{-}18)$$

$$= \begin{bmatrix} F_{i+1} & 1 & -(1-2\nu_{i+1}-m\lambda_i)F_{i+1} & (1-2\nu_{i+1}+m\lambda_i) \\ R_iF_{i+1} & R_i & (1+m\lambda_i)R_iF_{i+1} & -(1-m\lambda_i)R_i \\ \circ & \circ & \circ & \circ \\ F_{i+1} & -1 & (2\nu_{i+1}+m\lambda_i)F_{i+1} & (2\nu_{i+1}-m\lambda_i) \end{bmatrix} \begin{bmatrix} A_{i+1} \\ B_{i+1} \\ C_{i+1} \\ D_{i+1} \end{bmatrix}$$

Where, F_i, E_i are the same values as before.

The solution process is quite the same as before, only the initial boundary conditions will be different.

Analysis of the effects of different interface conditions on the performance

Pavement lifetime

In studies, different states of iterations allowed for each case are compared to the ideal state in which the properly implementation has been done and tack coat and prime coat have good performances.

The effects of poor tack coat implementation (implementation state)

When the primer layer and surface do not bound together and can move on each other, pavement life time is reduced due to the incensement of tensile and compressive strains. Table 3 displays pavement life time for various pavements and various axes during the service life time (associated with the potholes caused by trucks)and Figure 3 performs a comparison between the reductions in life time.

Table-1:Calculating the service lifetime for pavements under various vertical loads(the number of axles in million) state 2.

Pavement state	Axleweight TON	State 1	Implementation state 2	The percentage of pavement life time reduction
Strong permanent-strong bed	8.2	12.89	31.9	61.4
Poor pavement-poor bed		0.467	1.67	72.04
Poor pavement-strong bed		0.424	1.380	69.3
Strong permanent-strong bed	13	3.92	11.90	88.2
Poor pavement-poor bed		0.180	0.684	73.68

Poor pavement-strong bed		0.183	0.792	76.89
Strong permanent-strong bed	21	3.56	24.80	85.65
Poor pavement-poor bed		0.298	1.25	76.16
Poor pavement-strong bed		0.265	1.10	75.91

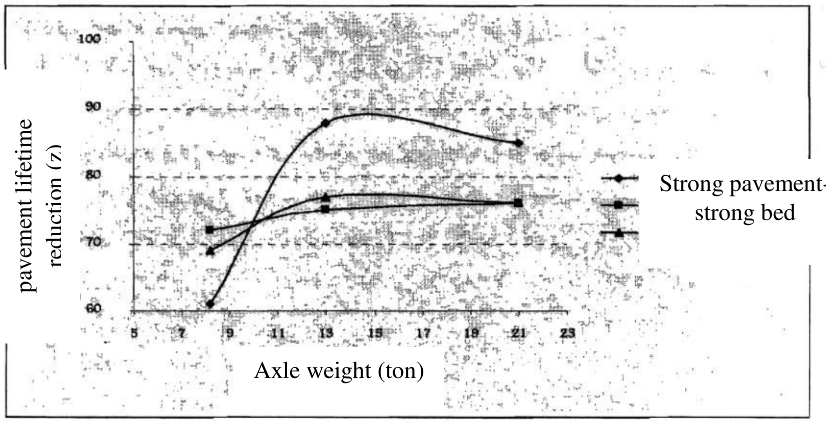

Figure 1: Diagram of the percentage of pavement lifetime reduction by axial load in the state 2

The effects of reducing poor prime coat implementation (implementation state 3)

In the case that there is nosufficientbound between the primer layer and base layerand there is possibility of displacement between these layers,as shown in Table 2, thepavement lifetime is reduced. The average reduction in pavement lifetime in this state is equal to 87% which is greater than this value in the state 2 which is equal to 74%.

Table 2: Calculating the fatigue life for different pavements under different vertical loads (the number of axles in million) implementation state 3.

Pavement state	Axle weight TON	State 1	Implementation state 2	The percentage of pavement life time reduction
Strong permanent-strong bed	8.2	12.89	47	72.57
Poor pavement-poor bed		0.467	1.26	62.94
Poor pavement-strong bed		0.424	1.34	68.35
Strong permanent-strong bed	13	3.92	15.2	74.21
Poor pavement-poor bed		0.180	0.212	85.1
Poor pavement-strong bed		0.183	0.665	74.15
Strong permanent-strong bed	21	3.56	24.7	71.59
Poor pavement-poor bed		0.298	0.493	65.56
Poor pavement-strong bed		0.265	0.892	70.29

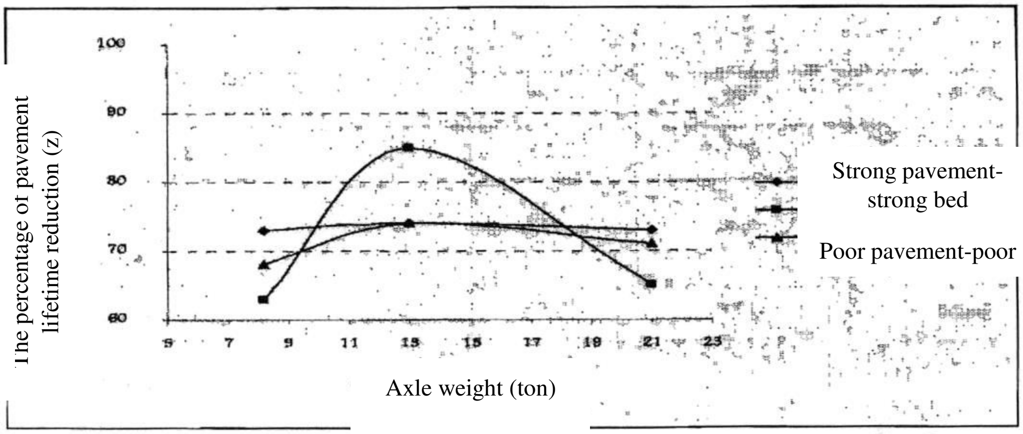

Figure 2: Diagram of the percentage of pavement lifetime reduction by axial load in the state 3.

The effects of poor interfacial coating (implementation state 4)

When there is nosufficientbound between the cover surface layersand the primer layer as well as between the primer layer and base layer and there is possibility of displacement between layers, thepavement lifetime is reduced due to the incensedstresses. If we compare the pavement lifetime reduction percentage in this state, it can be seen that the average reduction in pavement lifetime in this state is equal to 65%. Table 3 and Figure 3 provide these reduction values for different pavements under different loads.

Table 3: Calculating the fatigue life for different pavements under different vertical loads (the number of axles in million) implementation state 4.

Pavement state	Axle weight TON	State 1	Implementation state 4	The percentage of pavement life time reduction
Strong permanent-strong bed	8.2	12.89	26.03	59.51
Poor pavement-poor bed		0.467	1.87	60.25
Poor pavement-strong bed		0.424	0.728	41.75
Strong permanent-strong bed	13	3.92	7.034	65.13
Poor pavement-poor bed		0.180	0.313	65.45
Poor pavement-strong bed		0.183	0.286	6.30
Strong permanent-strong bed	21	3.56	0.416	55.40
Poor pavement-poor bed		0.298	0.725	59.55
Poor pavement-strong bed		0.265	1.24	65.55

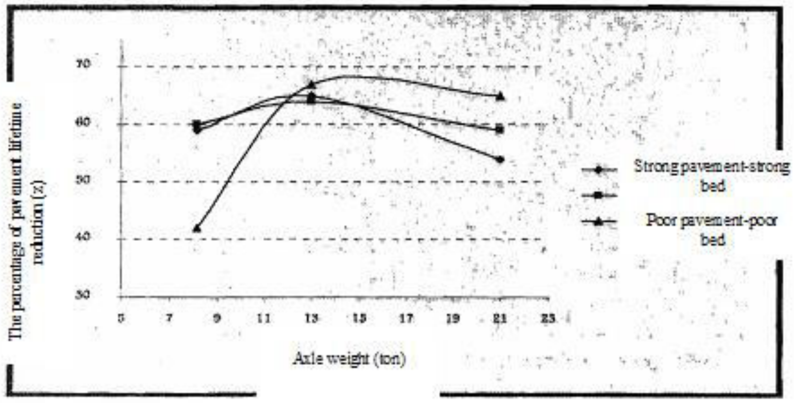

Figure 3: Diagram of the percentage of pavement lifetime reduction by axial load in the state 4

Summary and Conclusion

These studies have evaluatedthe effects of the lack of proper implementation of tack coats and prime coats which cause internal friction under vertical loads for the existing pavements in the country.The results of these studies are divided into the following points:

Due to the slip between the layers, in the presence of interlayer internal frictionpavement lifetime is reduced and the amount of reduction in pavement lifetime is related to the type of pavement and interface conditions in which there is internal friction.

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