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Esnek Üstyapılarda Farklı Yükler Altındaki Defleksiyon Oluşumu Üzerinde Tabaka Kalınlıklarının Etkisi

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Özet: Bu çalışmada, karayolu esnek üstyapı tabaka kalınlıklarındaki değişimin üstyapı yüzeyinde oluşan defleksiyonlar üzerindeki etkisi incelenmiştir. Çalışmada, eksenel simetrik sonlu eleman yazılımı olan SDUFEM kullanılmıştır. Üstyapının en temel tabaka karakteristiklerinden birisi olan tabaka kalınlığındaki değişimi defleksiyon oluşumu ile ilişkilendirilmiştir. Üstyapı yüzeyinde yük altında oluşan defleksiyon büyüklüğünün tabaka kalınlığındaki değişime ne kadar hassas olduğu gözlenmiştir. Yakın zamana kadar üstyapının yük altındaki tepkisi elastik çok tabakalı analizlerle tahmin edilmeye çalışılmıştır. Oysa bu tür bir analiz üstyapıyı oluşturan malzemelerin doğrusal elastik davranış gösterdiği kabulünü yapmayı gerektirmektedir. Bu bağlamda, karayolu esnek üstyapılarını analiz etmek için eksenel simetrik sonlu elemanlar programı kullanılmıştır. Çalışmada, viskoelastik, doğrusal olmayan elastik davranış modelleri gibi gerçek malzeme davranış modelleri kullanılmıştır. Yük büyüklükleri ve tabaka kalınlıkları değiştirilerek, bu değişikliklerin üstyapı yüzey defleksiyon davranışı üzerindeki etkisi incelenmiştir. Sonlu elemanlar yöntemi yapısal analiz problemlerinde yaygın bir kullanıma sahiptir. Özellikle düzgün şekilli olmayan ve farklı malzeme özellikleri gösteren tabakalı sistemlerde, sonlu elemanlar yöntemi büyük kolaylıklar sağlamaktadır. Özellikle doğrusal olmayan malzeme davranış modellerini sonlu elemanlar yöntemi içerisine adapte edebilmek yöntemi oldukça çekici hale getirmektedir. Karayolu esnek üstyapılarındaki tekerlek yükleri problemi eksenel simetrik hale getirdiğinden, çözüm kolaylaşmakta ve sadece radyal ve düşey yönlerdeki tepkileri hesaplamak yeterli olmaktadır.

Anahtar Kelimeler: Esnek Üstyapı, Sonlu Elemanlar Yöntemi, Defleksiyon, Üstyapıların Analizi

On the Effect of Flexible Pavement Thicknesses on Surface Deflection Values under Different Load Applications

Abstract: The effect of variations in layer thicknesses of a flexible pavement system on surface deflections is investigated. This is conducted using axially symmetric finite element based software, SDUFEM. The variations of the surface deflections are related to the variations of layer thickness, which is one of the pavement layer properties. The analyses have been performed in order see how surface deflections are sensitive to variations of layer thickness within the pavement structure. The study has shown that if the magnitudes of the loads applied on the pavements increase, the pavements are affected considerably. Recently, flexible pavement structural response to applied loads was predicted by using elastic multilayer analysis. This kind of analysis is based on assumptions that paving and subgrade materials are linear elastic materials. In this context, an axially symmetric finite element program has been used to analyze flexible pavements. A number of material models were used to represent actual material characteristics such as visco-elasticity and nonlinear elastic material models. In this study, load magnitudes and layer thicknesses has been changed and effects of these changes on the pavement deflection behaviour are investigated using finite element method. The finite element method is increasingly being used for the structural analysis of pavements. The potential of the finite element method for the solution of difficult analysis problems and the apparent facility, material characterisation, makes this method very attractive. The method is especially attractive to simulate the nonlinear behaviour of the granular and cohesive materials used in pavements. An axially symmetric analysis was applied to available pavement systems. Because of the symmetry of the elastic multi-layer pavement system structure and its loading about the vertical axis, displacements of the pavement system will develop only in the radial and vertical directions.

Keywords: Flexible Pavement, Finite Elements Method, Deflection, Pavement Analysis

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Introduction

Every country generally has put a limit on axle loads. The axle loads not only affect the pavements design but also affect bridge design, safety and traffic engineering. Highway systems suffer from heavy loads. We can observe permanent deformation and deterioration caused by increasing axle loads. Material properties of pavement layers can be modified for decreasing the effects of axle loads. Another solution against pavement deformation is the increase of layer thickness of the pavement system. The finite-element method has been widely used in numerous engineering problems (Zienkiewictz, 1975).

This method takes into account the complexity in the geometry and material properties. So, we can model the complex problems using finite-element method. Pavement layers are vertically layered, but stiffness characteristics and material properties can be varied as well as the vertical directions. Since the finite-element method is best suited for such circumstances, a number of researchers used it in pavement analysis (Siddharthan et al., 1996). There are a number of finite-element computer programs available to compute pavement response to surface loading. In this paper, SDUFEM finite-element program

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developed in Turkey (Saltan, 1999) is used. Isoparametric elements are used in SDUFEM. Since the depth and width of a typical pavement are large, it is necessary to determine the boundaries of pavement reasonably. Along the side boundaries, it is common to allow vertical displacements, but not radial displacements whereas along the bottom boundary displacements are usually not allowed. At interior nodes, both vertical and radial displacements can occur.

The objectives of this paper are to demonstrate how the variations in flexible pavement layer thicknesses under different load applications affect the surface deflections.

Boundary of finite-element mesh

The movement of nodal points is not allowed both in vertical and horizontal directions on the bottom of the finite-element mesh (Ong et al., 1991; Siddharthan et al., 1991). At the lateral boundaries of the finite element mesh, vertical movement of the nodal points is allowed, but horizontal movement of the nodal points is not allowed (Ong et al., 1991; Siddharthan et al., 1991) (Figure 1). Also, on the nodes at long distances from the load, displacements will occur in small values. In interior nodes of the finite–element mesh, movement is allowed both in vertical and horizontal directions. (Almeida et al., 1991a).

Researchers must consider the bottom boundary of finite-element mesh. It is known that if the subgrade is weak, the depth of subgrade must be increased. (Harichandran and Yeh, 1988).

Axially symmetric pavement analysis may be carried out by the following steps:

1. Dividing the elastic continuum into a system of appropriately shaped finite-elements
2. Evaluating the stiffness matrices which relate the forces developed at the element nodal points to the corresponding element displacements.
3. Evaluating the nodal stiffness matrix for the complete structure.
4. Displacement analysis solving the nodal equilibrium equations for the nodal displacements from applied loads.
5. Computing the element stresses resulting from the computed nodal displacements, making use of the element stiffness matrices.

Since the loads are applied to pavement surface in a circular shape, we can think that the problem has an axially symmetric nature (Siddharthan et al., 1991). Because of the symmetry of the structure and its loading about the vertical axis, z, the displacements of the system will be developed only in the radial and vertical directions. Thus, from a mathematical point of view, this class of system is two-dimensional in nature and may be represented as shown in Figure 2 (Clough and Rashid, 1965).

Finite-element formulation of used axially symmetric system

Due to the symmetry, cylindrical co-ordinates, z, r, θ, as both geometric and mechanic can be used. Radial symmetry makes the problem free from θ co-ordinate. Stresses and strains in each nodal point are the functions of vertical and radial co-ordinates. Vertical and radial displacements can be described as v and u. For the stress and strain components, following vectors are used:

$$\{\sigma\} = \begin{Bmatrix} \sigma_{zz} \\ \sigma_{rr} \\ \sigma_{\theta\theta} \\ \tau_{zr} \end{Bmatrix} \qquad \{\varepsilon\} = \begin{Bmatrix} \varepsilon_{zz} \\ \varepsilon_{rr} \\ \varepsilon_{\theta\theta} \\ \gamma_{zr} \end{Bmatrix} \qquad (1)$$

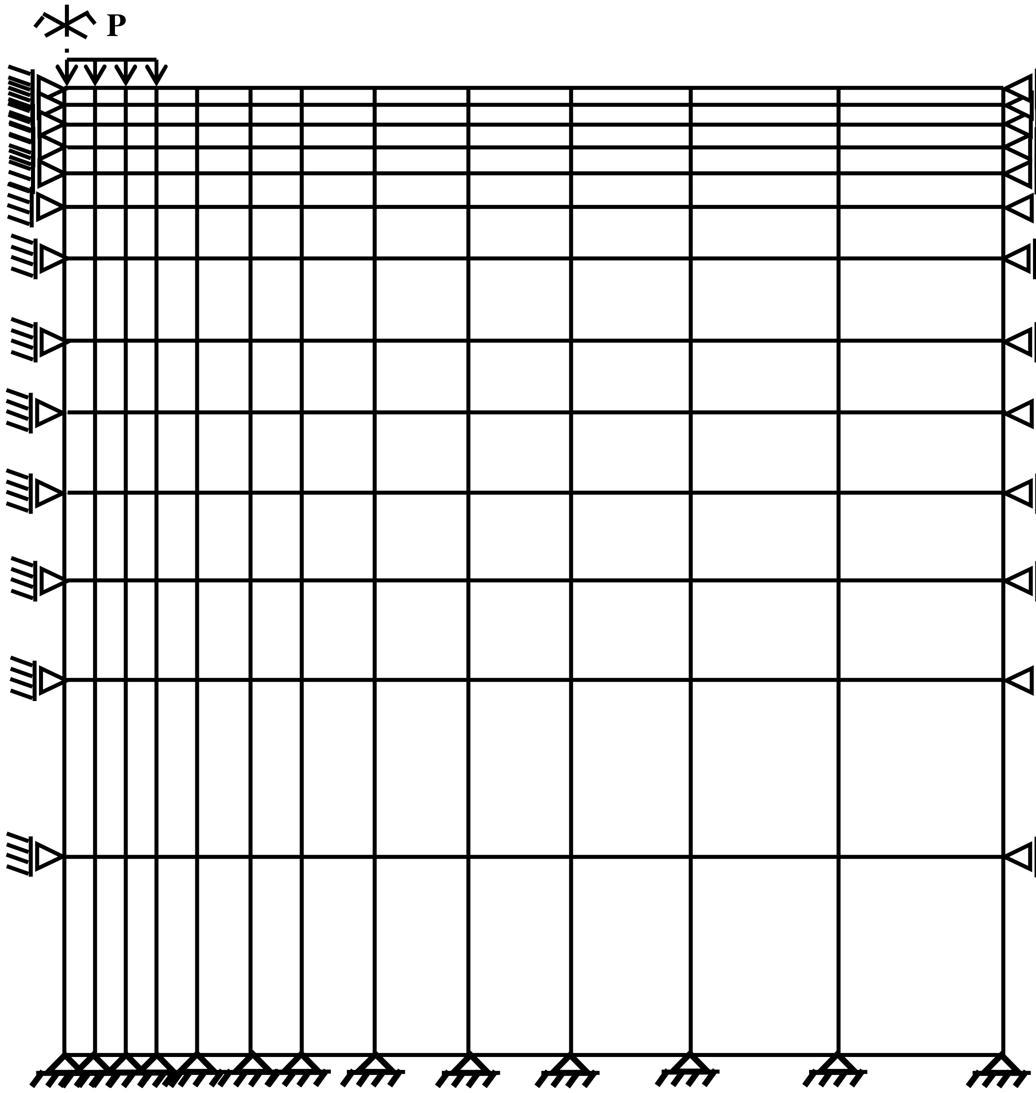

Figure 1. *Axially symmetric finite-element mesh*

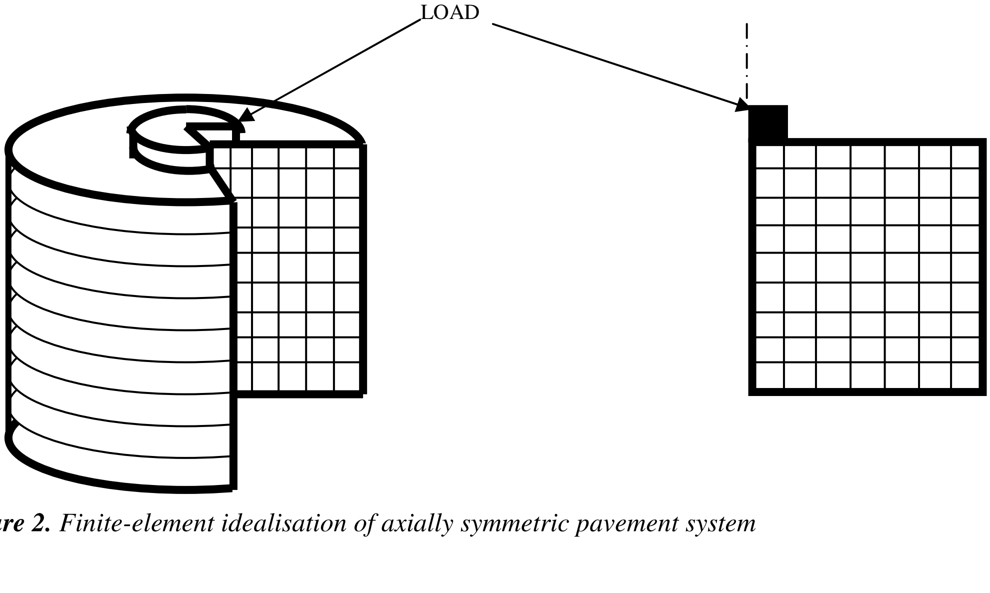

Figure 2. *Finite-element idealisation of axially symmetric pavement system*

According to small displacements hypothesis, strains can be expressed as:

$$\{\varepsilon\}=\begin{Bmatrix}\varepsilon_{zz}\\ \varepsilon_{rr}\\ \varepsilon_{\theta\theta}\\ \gamma_{zr}\end{Bmatrix}=\begin{Bmatrix}\dfrac{\partial v}{\partial z}\\ \dfrac{\partial u}{\partial r}\\ \dfrac{u}{r}\\ \dfrac{\partial v}{\partial r}+\dfrac{\partial u}{\partial z}\end{Bmatrix} \tag{2}$$

Using different operators,

$$\{\varepsilon\}=[S]\{r\} \tag{3}$$

S and r can be explicitly written as:

$$[S]=\begin{bmatrix}\dfrac{\partial}{\partial z} & 0\\ 0 & \dfrac{\partial}{\partial r}\\ 0 & \dfrac{1}{r}\\ \dfrac{\partial}{\partial r} & \dfrac{\partial}{\partial z}\end{bmatrix} \quad \text{and} \quad \{r\}=\begin{Bmatrix}v\\ u\end{Bmatrix}$$

In respect of the pavement materials being homogen, isotropic and elastic, there is a relation between stresses and strains (Westman, 1968; Almeida et al., 1991b):

$$\{\sigma\}=[D]\{\varepsilon\} \tag{4}$$

Where $[D]$ is an elastic constants matrix.

To obtain the displacements of a point from nodal points, interpolation functions or shape functions must be determined. These kinds of functions are generally polynomial and should have the same number of terms as the nodal displacements in each element.

Finite-element equations are based on virtual work principle. For each arbitrary displacement in a component subjected to external forces, spiritual deformation energy of the component must be equal to the work originated from forces. Nodal displacements are determined solving linear equation systems. In general, Gauss-Elimination Method is used. After determining the nodal displacements, strains and elastic stresses can be determined. Stress computation is done in four Gauss points for each element.

Example Analyses

In the study, the finite element based software developed by the first author has been used to analyse the pavement system. This pavement system is composed of bituminous course, granular base and subgrade (Figure 3). Contact radius was chosen as 15 cm. While keeping the contact radius constant, applied load has been gradually increased as such 6 t, 7 t, 8.2 t, 9 t, 10 t, 11 t, and 12 t. Pressures corresponding to applied loads are as follows: 0.85 MPa, 0.99 MPa, 1.16 MPa, 1.27 Mpa, 1.415 MPa, 1.556 MPa, and 1.698 Mpa. Mechanical properties of the pavement chosen are given in Table 1.

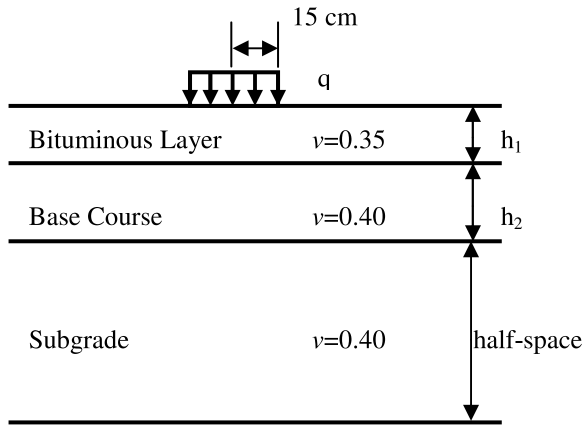

Figure 3. *Pavement system used in the example*

Table 1. *Selected mechanical properties of the pavement structure.*

Course	Elasticity Modulus(Mpa)	Poisson's Ratio	Thickness(cm)
Bituminous	2500	0.35	4-12
Unbound base	1000	0.40	15-24
Subgrade	400	0.40	Half-space

Between 4 to 12 cm for bituminous and 15 to 24 cm for base course layer thickness values were used for computing the three different surface deflection values. By using axially symmetric finite element computations, the effect of surface layer thickness values on the three different surface deflections has been investigated and the results are shown in Figures 4, 5 and 6. Especially, up to 7 cm surface layer thickness, surface deflection values decrease in parallel for each loading condition. It is observed that the obtained surface deflection values for the different loads are close to each other. For the high surface layer thickness values from 7 cm, the layer thickness has a positive effect on the central surface deflection values. The effect of the layer thickness on the surface deflection values at the high distances from the loading centre is not significant.

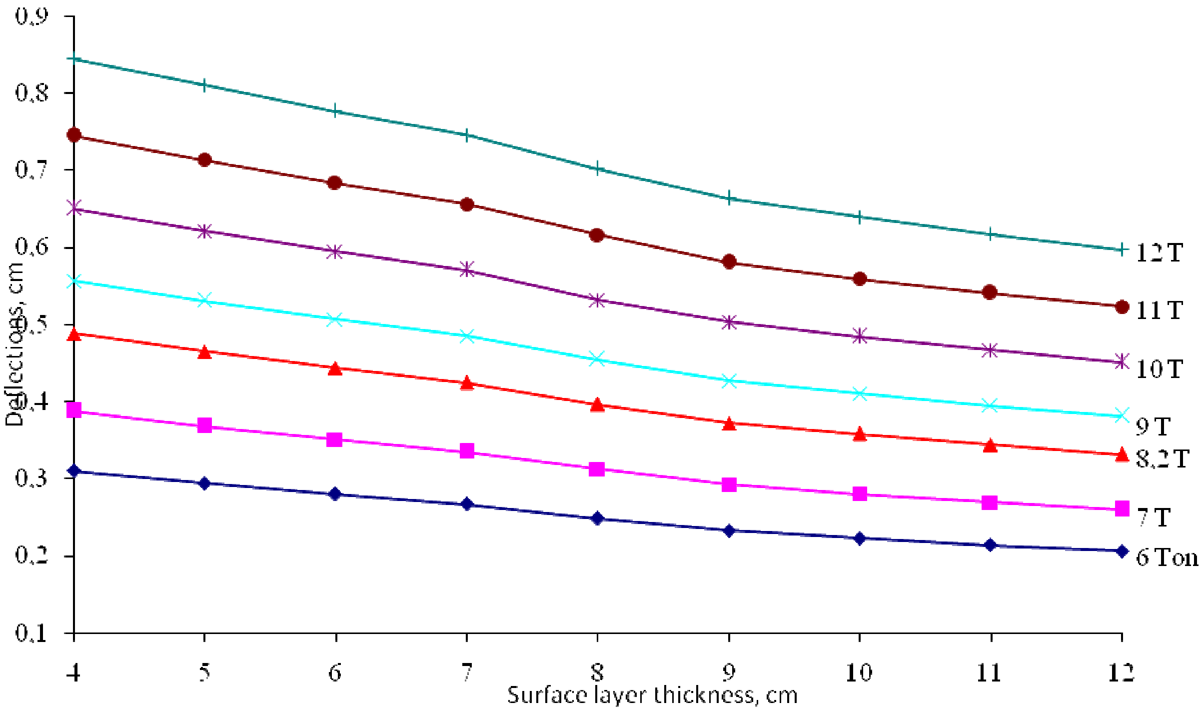

Figure 4. *Effect of surface layer thickness on loading centre deflection*

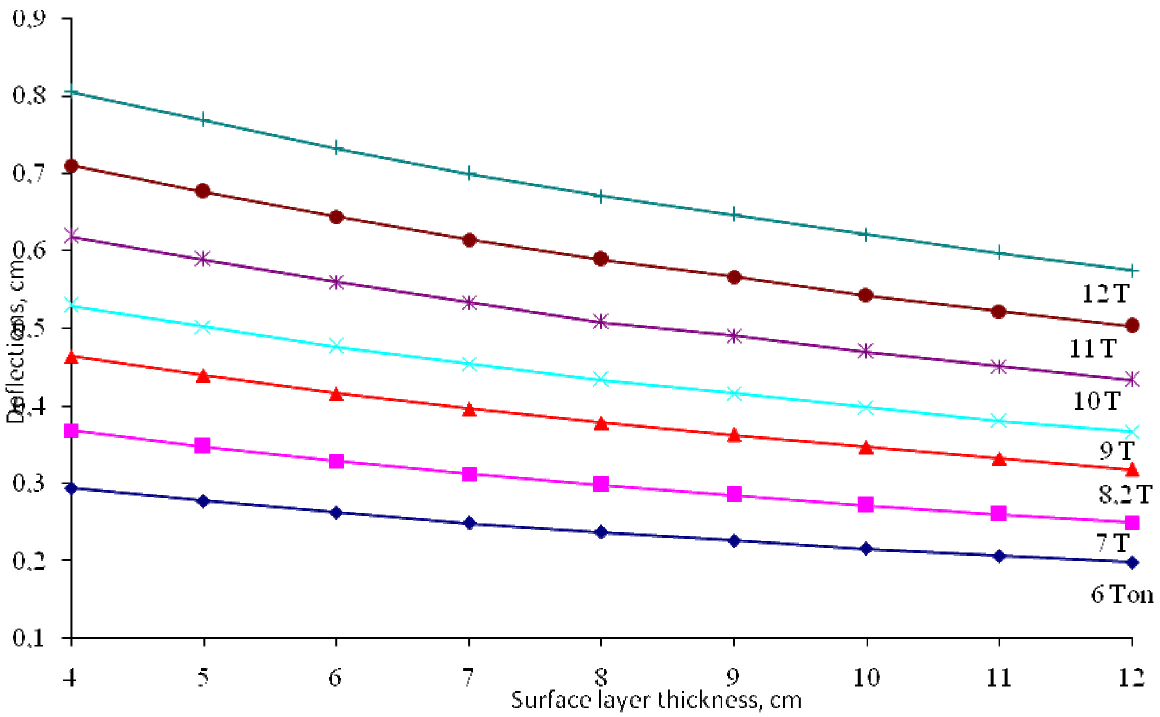

Figure 5. *Effect of surface layer thickness on first outer deflection from loading centre*

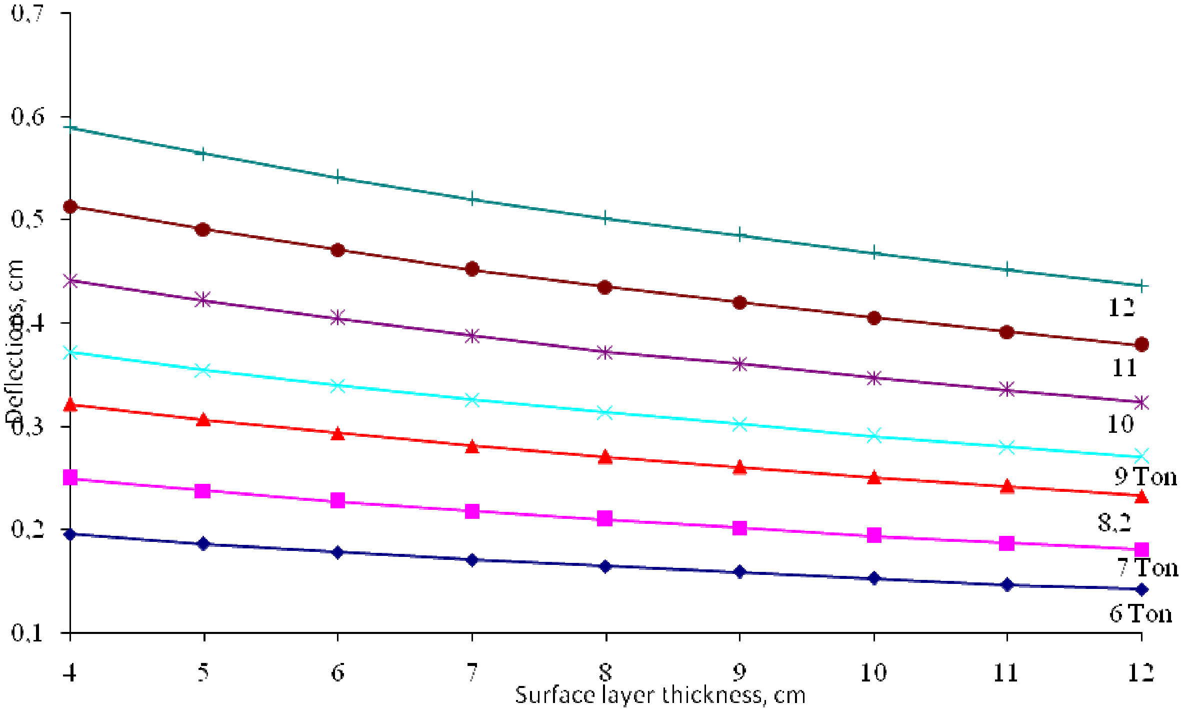

Figure 6. *Effect of surface layer thickness on second outer deflection from loading centre*

As seen from Figures 7, 8 and 9, the base course thickness affects the second outer deflection values. As the base course thickness values increase, the second outer deflection values also increase. But the layer thickness of the base course has a little effect on the deflections under the loading centre and the first distance to the loading centre. At 19-20 cm of the base course thickness, 8.2 tons loading has a different effect on the second outer deflection values. As seen from Figure 9, at this base course layer thickness for 8.2 tons, one can observe a sharp decrease and then again an increase on the second outer deflection values. Furthermore, the effects of increasing loads are obvious as illustrated in Figures 4-9. The bituminous layer and the base course suffer from the increasing loads.

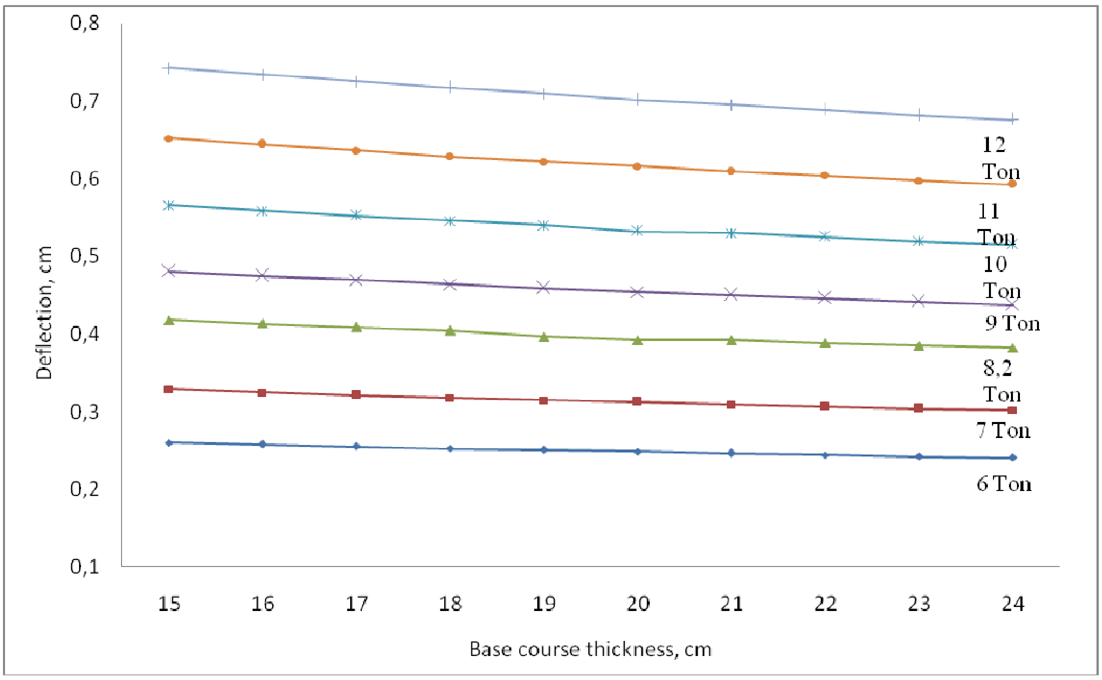

Figure 7. *Effect of base course thickness on loading centre deflection*

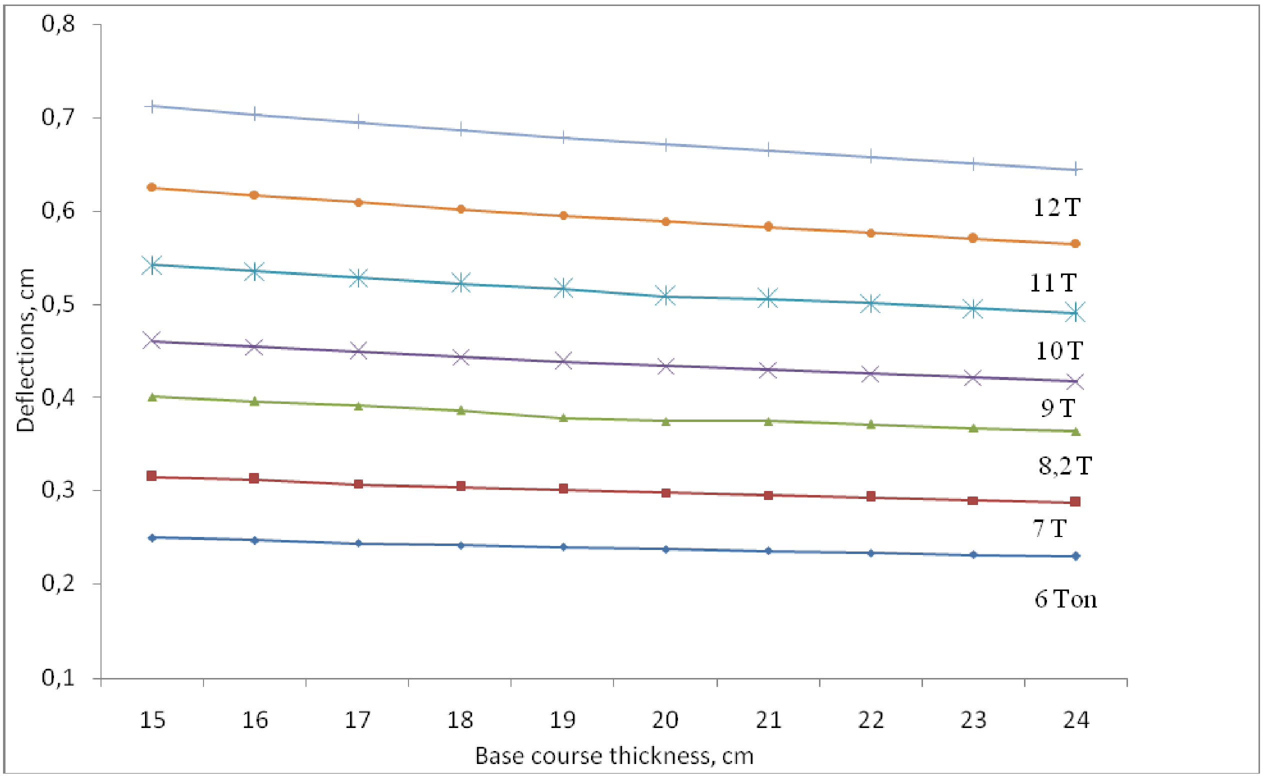

Figure 8. *Effect of base course thickness on first outer deflection from loading centre*

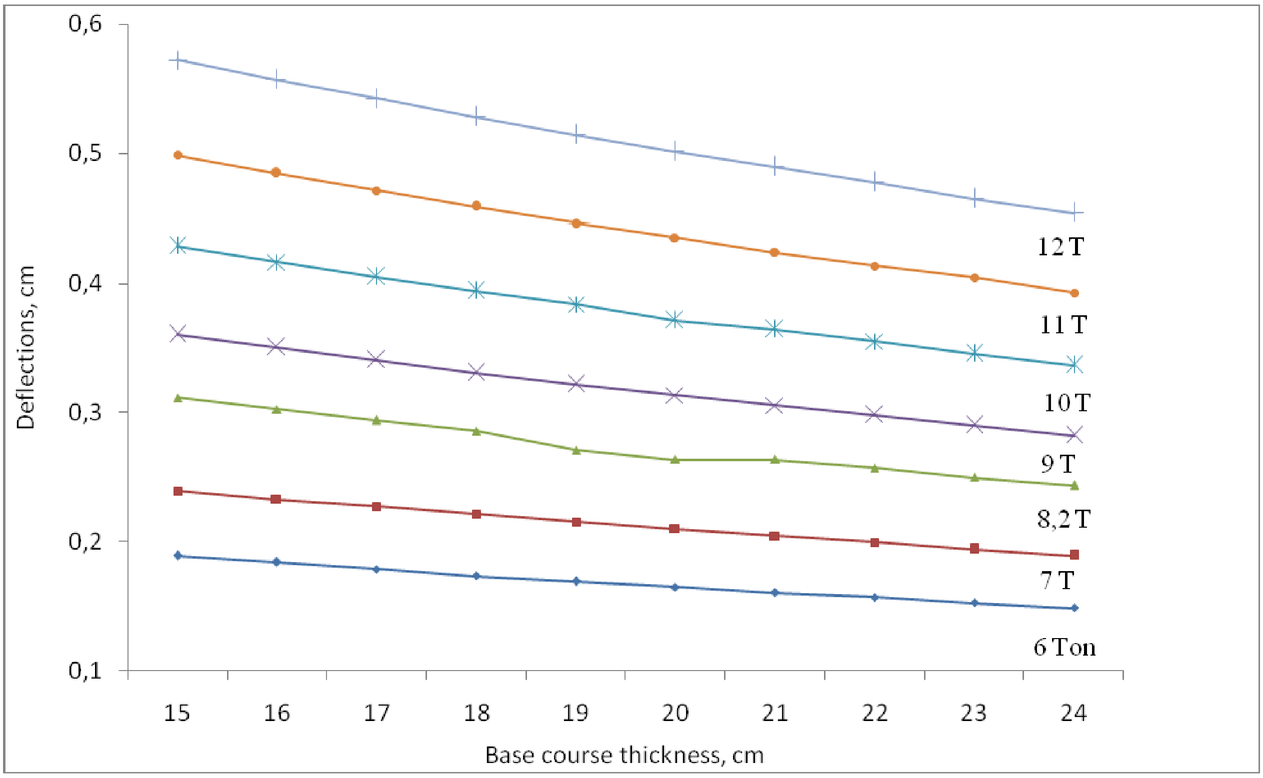

Figure 9. *Effect of base course thickness on second outer deflection from loading centre*

Conclusions

There are many kinds of trucks and long vehicles. Therefore the flexible pavement systems are subjected to heavy loads, thus pavement distresses are frequently seen on the pavement system. To prevent these distresses, highway agency of a country may increase the layer thickness values of bituminous and the base course. In this study, 4 to 12 cm for the bituminous and 15 to 24 cm for the base course layer thickness values have been used to compute the three different surface deflection values. By using the axially symmetric finite element computations, the effects of the surface layer thickness values on the three different surface deflections have been examined. From the axially symmetric finite element computations, it is obtained that the surface deflection values under the load application for the different surface layer thickness values are found to be close to each other. For the higher surface layer thickness values from 7 cm, layer thickness has a positive effect on the central surface deflection values. The effect of the layer thickness on the surface deflection values at the high distances from the loading centre has been found to be insignificant. Particularly, the base course thickness affects the second outer deflection values. As the base course thickness values increase, second outer deflection values also increase. But the layer thickness of the base course has a little effect on the deflections under loading centre and the first distance to loading centre. At 19-20 cm of the base course thickness, 8.2 tons loading has a different effect on the second outer deflection values. A sharp decrease and then again increase on the second outer deflection values can be observed for 19-20 cm base layer thickness values under 8.2 tons load application. Furthermore, as the applied loads increases, the bituminous layer and the unbound base layer are affected and high deflection values are obtained.

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