Numerical Study of Stress-Deformation Response of Flexible Pavement

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Abstract

The highway network performs as the most important transportation system in the economic growth of a nation. In Bangladesh, the maximum portion of all the goods delivered annually are transported (through the highway) by heavy trucks. The heavy truck wheel loadings on pavements might increase the rate of degradation of the flexible pavement structures. Therefore, a comprehensive knowledge on the interaction of truck wheel loads with the road pavement structure is necessary for design and maintenance of the highway network. In this study, an advanced three-dimensional (3D) finite element model was developed using ABAQUS software to investigate the stress-deformation response of flexible pavement layers. The geometry of the model was chosen as per the specifications of Roads and Highways Department of Bangladesh. Various factors were considered, including tire-pavement contact pressure, pavement layer thickness, modulus of elasticity of pavement layer materials, for better understanding of the stress-deformation response of the flexible pavement layers. The results of the finite element analyses demonstrated that stress distributions in the flexible pavement layers vary significantly for the various parameters that were considered in the investigation. The outcomes of this study are critically analyzed and their useful consequences in relation to flexible pavement design, construction and management are discussed.

Keywords: *finite element analysis; flexible pavement; stress-deformation response; tire-pavement contact pressure.*

1. Introduction

Among different modes of transportation system, roadways is very popular because of its fastest and flexible transportation mode. Heavily loaded trucks causes higher stresses and excessive deformation on the roadway pavement layers, consequently occurs various types of pavement failure. To minimize or avoid the pavement failure and develop a proper design and maintenance of the track, a detailed study on the stress-deformation behavior of the flexible pavement is essential.

Among different methods, three dimensional (3D) finite element model (FEM) can be used confidently to analyze the stress-deformation response of the pavement layers (Zaghloul and White, 1993). Several studies (e.g., Park, 2008; Rahman et al., 2010; Alkaissi and Al-Badran, 2018) are available in the literature to investigate the behavior of the flexible pavement layers for different track parameters. Most of the studies considered the effect of shape of tire imprint area, contact stress, effect of tire type and non-parametric value of material properties. However, the other truck-track parameters, including the tire contact pressure, pavement layer thickness, modulus of elasticity of pavement layer materials, magnitude of wheel load have significant effect on the stress-deformation response of the flexible pavement, which is the main consideration of this paper.

2. Methodology

Among different numerical solutions, the advanced three dimensional (3D) finite element (FE) modelling was used for conducting the study. The FE model of the flexible pavement was developed in 3D using ABAQUS software, as it can simulate more practical situations compared to two dimensional and axisymmetric modelling. The materials properties, contact conditions, tire contact area and wheel load were chosen based on practical conditions available the previous studies (Zaghloul and White, 1993). Afterward, all truck-track parameters were varied for investigating the stress-deformation response of the flexible pavement.

2.1 FE Modelling of the Flexible Pavement

Flexible pavement layers namely surface course, base course, sub-base course and subgrade, were modelled according to the specifications of Roads and Highways Department of Bangladesh (Roads and Railways Division, 2004). For simplicity the materials are considered as linear elastic which is represented by modulus of elasticity and Poisson's ratio. All the track nominal parameters associated with each layer is given below in Table 1. Fixed boundary conditions are used to support subgrade soil layer, whereas displacement is allowed at the side boundaries. As there are different layers, so tie constraint is used between layers for connecting subsequent layers.

Table 1. Track nominal parameters

Layer name	Material property	Value
Surface course	Elastic modulus, E (MPa)	4000
	Poisson's Ratio, v	0.35
	Thickness, H_s (mm)	50
Base course	Elastic modulus, E (MPa)	450
	Poisson's Ratio, v	0.40
	Thickness, H_b (mm)	150
Sub base course	Elastic modulus, E (MPa)	300
	Poisson's Ratio, v	0.40
	Thickness, H_{sb} (mm)	150
Sub-grade	Elastic modulus, E (MPa)	60
	Poisson's Ratio, v	0.45
	Thickness, H_{sg} (mm)	4000

3. Stress-deformation Response

The analysis results shows certain behavior of pavement in terms of stress and deformation. The analysis was done according to the nominal track parameters given in Table 2. Stress and deformation gradually decreases with the increase in depth of pavement which is shown in color scheme in Figure 1.

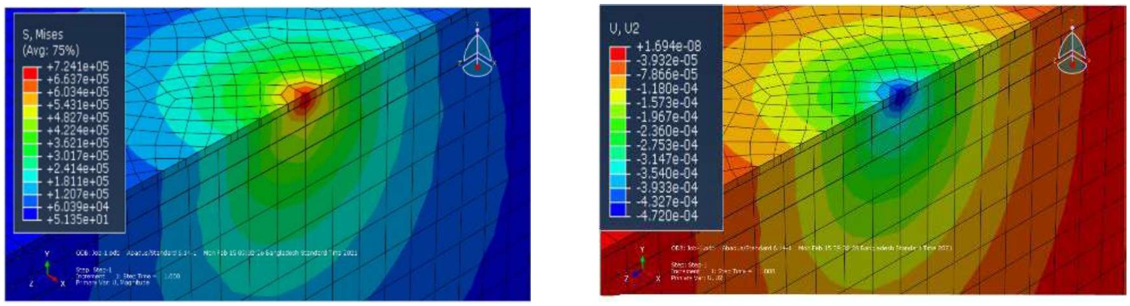

Figure 1. Stress-deformation behaviour of flexible pavement

4. Parametric Study

It is not practical that the nominal track properties and loading conditions will remain same at all time. Furthermore to observe the significant changes of stress-deformation response with the changes in properties, it is also necessary to use parametric values. To observe the impact of certain parameters (thickness of different layers, modulus of elasticity of different layer's materials, magnitude of wheel loads) on stress-deformation of flexible pavement, several analyses were done. The value of different parameters are given in Table 2.

Table 2. Parametric value of truck parameters

Parameters name	Range of values
Elastic modulus of surface course, E_s (MPa)	3000-4500
Elastic modulus of base course, E_b (MPa)	300-600
Elastic modulus of sub-base, E_{sb} (MPa)	150-600
Elastic modulus of subgrade, E_{sg} (MPa)	15-150
Thickness of base course, T_b (mm)	150-450
Thickness of sub-base course, T_{sb} (mm)	150-300
Thickness of subgrade, T_{sg} (mm)	2000-6000
Contact pressure, Tp (kPa)	480-720

4.1 Impact of Elastic Modulus

Elastic Modulus *(E*) plays a very important role in the stress-deformation response of the flexible pavement. Figure 2 presents the impacts of different values of elastic modulus for surface course, base course, subbase course and subgrade on the stress and deformation response in the flexible pavement. It can be seen that the vertical deflection increases with the decreases of elastic modulus of any layer. It can also be seen that among the elastic modulus of the flexible pavement layers, the subgrade elastic modulus has the greatest effect on the vertical deflection. After comparing the stress distribution with depth in the pavement layers, it can be noted that with the increase of elastic modulus of the surface and base courses, the top surface stresses increases. In other cases, the variation in stress distribution with depth is negligible.

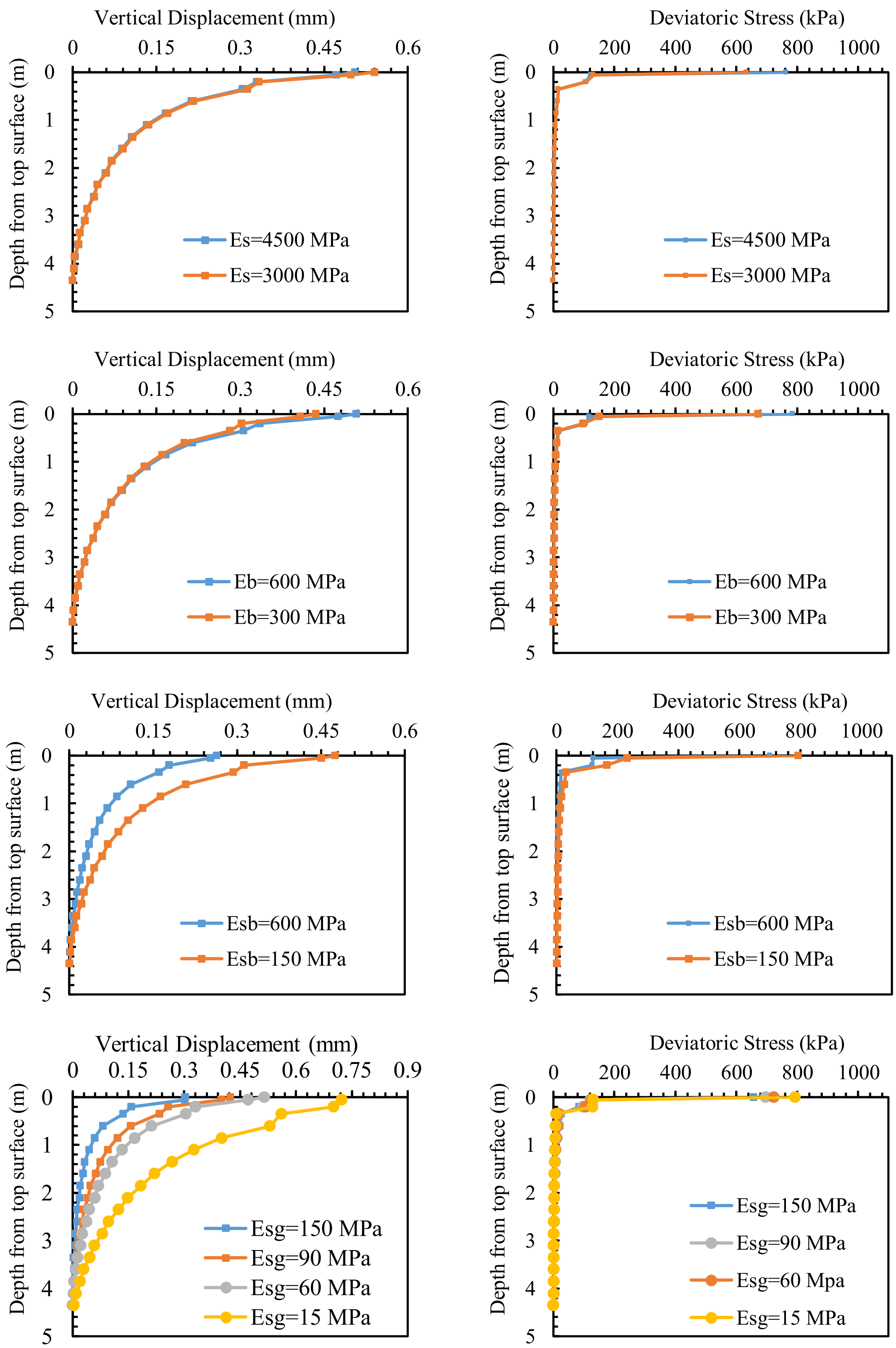

Figure 2. Impact of elastic modulus

4.2 Impact of Thickness

Figure 3 shows the stress and deflection response for various thicknesses of base, sub-base and subgrade layer of the flexible pavement. It can be seen that with the increase of thickness of base and sub-base layer, the vertical deflection decreases, whereas with the increase of subgrade layer thickness, the total vertical deflection increases. It can also be noted that with the increase of base and sub-base layer thickness, the top surface stresses decreases, however, the trend is totally opposite in the case of subgrade layer thickness.

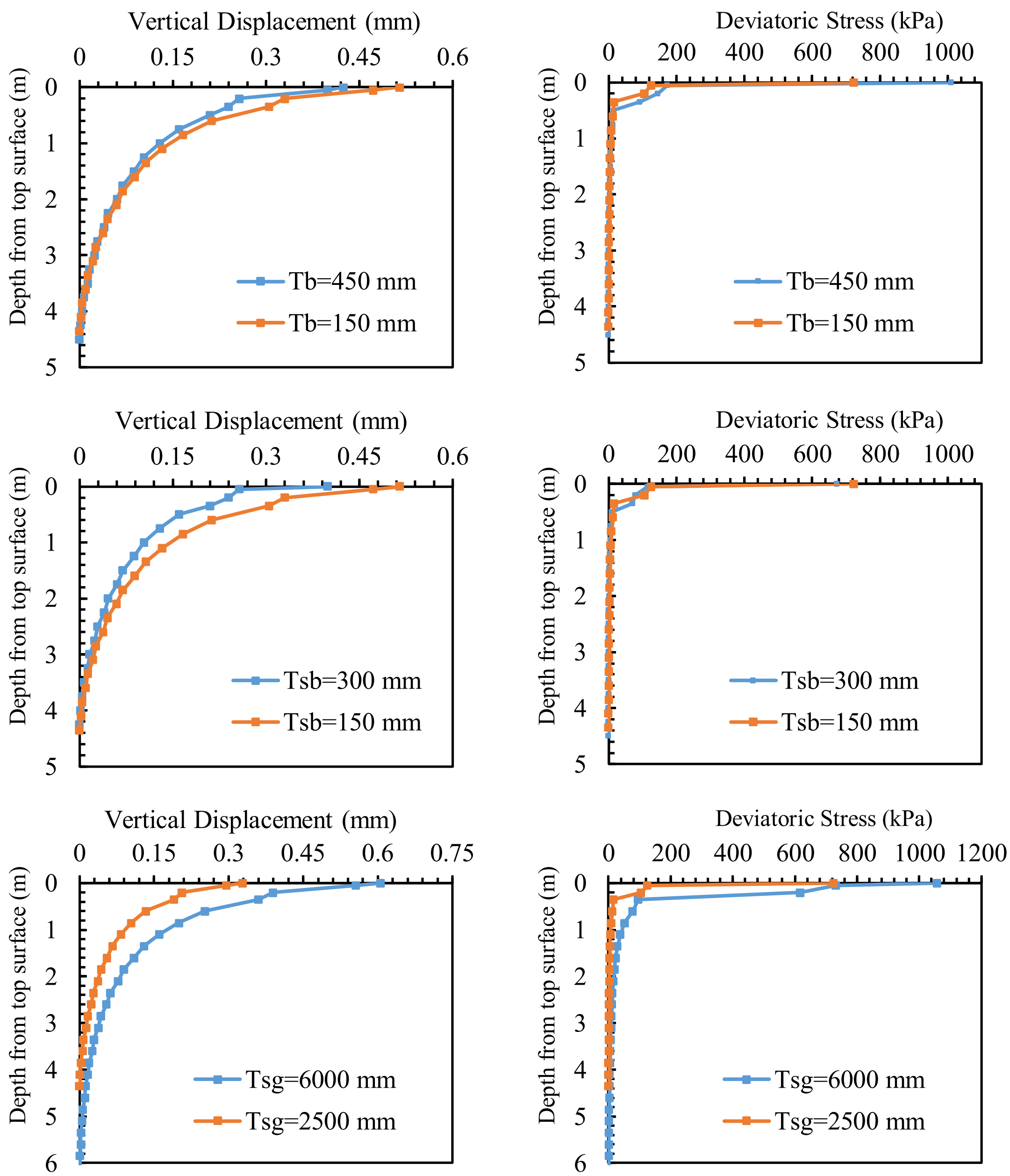

Figure 3. Impact of pavement layer thickness

4.3 Impact of Tire Contact Pressure

The impact of stress-deformation response is different with the change in tire contact pressure which is observed in Figure 4. It is shown that there is a significant variation of stress distribution with depth for two different contact pressure. If a tire of 720 kPa pressure is run on the pavement it causes 28 % more stresses than that of 480 kPa whereas the displacement is increased by 29 % at the top of the flexible pavement.

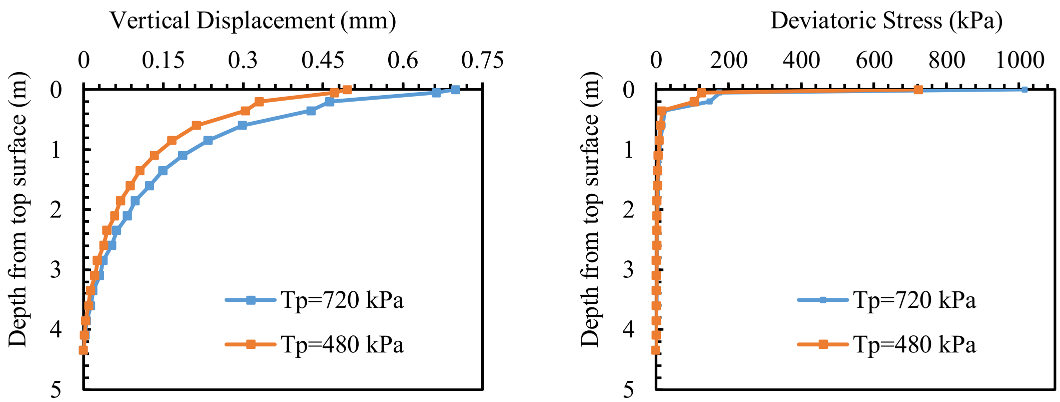

Figure 4. Impact of tire contact pressure

5. Conclusions

In this paper, the stress and deformation behavior of flexible pavement was investigated using 3D finite element model. Various parameters of the flexible pavement including elastic modulus and thicknesses of the surface course, base course, sub-base course and subgrade layer were considered in the investigation. It was found that the subgrade layer has the most significant impact on the deflection and stress response of the flexible pavement. In addition, tire contact pressure has also significant impact on the flexible pavement.

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