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STUDY ON NONLINEAR PAVEMENT RESPONSES OF LOW VOLUME ROADWAYS SUBJECT TO MULTIPLE WHEEL LOADS

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Abstract. This paper describes numerical analyses on low volume roads (LVRs) using a nonlinear three-dimensional (3D) finite element model (FEM). Various pavement scenarios are analyzed to investigate the effects of pavement layer thicknesses, traffic loads, and material properties on pavement responses, such as surface deflection and subgrade strain. Each scenario incorporates a different combination of wheel/axle configurations and pavement geomaterial properties to analyze the nonlinear behavior of thinly surfaced asphalt pavement. In this numerical study, nonlinear stress-dependent models are employed in the base and subgrade layers to properly characterize pavement geomaterial behavior. Finite element analysis results are then described in terms of the effects of the asphalt pavement thickness, wheel/axle configurations, and geomaterial properties on critical pavement responses. Conclusions are drawn by the comparison of the nonlinear pavement responses in the base and subgrade in association with the effects of multiple wheel/axle load interactions.

Keywords: low volume road, three-dimensional finite element analysis, nonlinear pavement responses, multiple wheel/axle loads, geomaterial properties.

1. Introduction

Consisting of thin surface layers over base materials, low volume roads (LVRs) are generally designed to bear less than 500 vehicles per day. In the United States, the current pavement design method for the LVRs follows the American Association of State Highway and Transportation Officials (AASHTO) guideline (American Association of State Highway and Transportation Officials 1993). This design method usually leads to a minimal pavement thickness, which in turn makes the pavement vulnerable to surface distresses such as surface deflection and rutting (Dawson *et al.* 2007; Worel and Clyne 2007). In fact, it is not difficult to find many existing LVRs deteriorated or even failed by these surface distresses in the early phase of their lives. Thus, it is important to incorporate these aspects into the LVR design to reduce the possibility of the distress or failure of the pavement.

Surface deflection and rutting are generally influenced by traffic loads and pavement material properties. The traffic loads refer to the effects of multiple wheel/axle loading configurations, and the material properties denote the qualities of the base and subgrade materials. The following studies proved the effects of wheel/axle configurations and loading combinations on the low volume roadways. Hajek and Agarwal (1990) found the axle configurations and wheel loads of vehicles have significant influences on surface deflection. Salama *et al.* (2006) showed the wheel/axle configurations considerably affect rutting. Suleiman and Varma (2007) even furthered these two previous studies and found the effects of axle configurations on the permanent deformations. Pavement material properties are also significant factors affecting the LVR. Kim and Tutumluer (2008) found load spreading and nonlinear modulus distributions in the pavement materials significantly impact surface deflection. The study also shows both traffic loads and base layer thickness considerably influence the subgrade responses.

In the mechanistic approach, the pavement is treated as a layered structure, and the components of the structure must be properly understood as the constituent materials. The current AASHTO method, however, applies an empirical approach to design the pavement layers considering soil factors, R–value, and soil testing results (American Association of State Highway and Transportation Officials 1993). This approach is ineffective in evaluating the responses from interactions of traffic loads and material properties in the LVR pavement responses. Since the asphalt layer is very thin, the wheel loads are more effective in the LVR than thick surfaced roadways. The pavement responses in the LVR are thus more responsive to the base and subgrade materials. It has been believed that these pavement responses are on account of the nonlinear behavior of the geomaterial layers, which can be better analyzed by a mechanistic approach using a three-dimensional (3D) nonlinear finite element model (FEM) (Kim and Tutumluer 2008; Saad *et al.* 2005;

Schwartz 2002). In addition, the nonlinear resilient modulus of the base and subgrade materials has been used to evaluate the behavior of the pavement structures using mechanistic design approach (National Cooperative Highway Research Program 2004; Schwartz 2002; Thompson and Robnett 1979). Previous study shows that a nonlinear material modeling in the base and subgrade layers shows much different pavement responses due to repeated loads compared to those with constant single modulus (Kim and Tutumluer 2006).

In order to investigate the mechanisms and factors affecting the LVR pavement responses in this study, 3D FEM analyses are conducted by applying a nonlinear stress-dependent model of resilient geomaterial modulus in the base and subgrade layers.

Although pavement responses may also be influenced by asphalt surface layers in structural pavement analysis, emphasis should be given to nonlinear material modeling in the base and subgrade layers based on triaxial test results.

2. Nonlinear pavement analysis model

2.1. Finite element model (FEM) configuration

Fig. 1 shows typical highway vehicle wheel/axle configurations that are used to represent the effects of multiple axle loads interaction (Huang 2004). A uniform tire pressure of 0.55 MPa over a circular area of 107 mm radius is applied to model a single axle load. The same pressure distribution is applied under each individual tire for tandem and tridem axle loads. The space between wheels is 343 mm and 1,219 mm between axles.

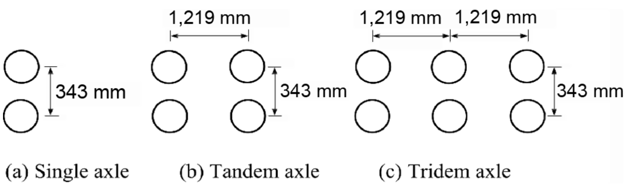


Fig. 1. Typical highway vehicle wheel/axle configurations

The 3D FEM incorporates the resilient behavior of pavement geomaterials and the multiple wheel/axle load configurations. In building a model, a user-defined material subroutine (UMAT) in ABAQUS (Hibbit *et al.* 2005) is used. In order to model a loading configuration shown in Fig. 1, the wheel loads were approximated as a uniform pressure over a circular area as shown in Fig. 2. Fig. 2 details the model which is consisted of the first order 8–noded isoparametric linear hexahedron element with a 6,096×6,096×21,336 mm finite element mesh. The FEM domain is determined to compute accurate pavement responses considering the wheel loads and axle configurations (Kim and Tutumluer 2008). All vertical boundary nodes are configured as roller supports, while horizontal boundary nodes at the bottom of the mesh are fixed.

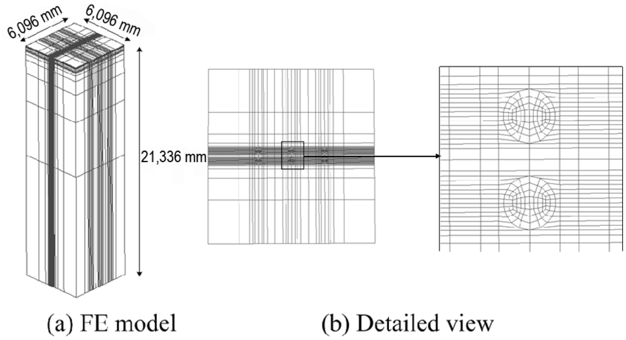


Fig. 2. Finite element model (FEM) for multiple axle configurations

2.2. Materials characterization

Under the repeated application of traffic loads, most of the pavement deformations are recoverable and thus considered elastic. It has been customary to use resilient modulus (M_R) for the elastic stiffness of pavement materials. M_R is defined as the deviator stress divided by the recoverable strain and well-known to be dependent on the current material stress state. Repeated load triaxial tests are commonly employed to evaluate the resilient modulus of base materials and subgrade soils to perform nonlinear material modeling in the pavement geomaterials. For mechanistic analysis, the resilient behavior of material is characterized using mathematical models.

Two numerical analysis models are used to incoporate reaalistic material characterizations in the pavement layers. Witczak and Uzan's Universal model (1988) is used for the base material; and Thompson and Robnett's Bilinear model (1979) is applied to the subgrade in this study. These models are used to compute pavement responses under multiple wheel/axle loads in order to investigate the behaviors of pavement and geomaterials on the LVRs. The following details the considerations incorporated into the nonlinear 3D FEM analyses.

Three types of base materials and four types of subgrade soils are also analyzed to investigate the effects of geomaterial properties on the pavement responses. The resilient model of the base materials are based on the data collected by Allen and Thompson (1974) at the U.S. Army Corps of Engineers Construction Engineering Research Laboratory at Champaign, Illinois. Base materials are classified into three types: crushed stones (HD–1), gravel lime stones (HD–2), and blend (HD–3) which is the mix of crushed stones and gravels at equal percentage. Table 1 shows the material properties of three different test specimens used in the analyses. All specimens are 152 mm by 305 mm in size. Stresses applied to each specimen are $\sigma_1/\sigma_3 = 1.5$ to 9. The density and moisture content of high density materials are equaled to the maximum density and the optimum moisture from the AASHTO compaction test. Fine-grained subgrade soils are classified into four types: very weak subgrade (VWS), weak subgrade (WS), medium subgrade (MS), and strong subgrade (SS).

Table 1. Material properties of test specimen (Allen and Thompson 1974)

Specimen	Material	Density (kg/m^3)	Moisture (%)	Saturation (%)
HD–1	Crushed stone	2,208	5.7	78
HD–2	Gravel	2,230	6.3	82
HD–3	Blend	2,232	6.3	88

Note: HD stands for high density

The Universal model considers the effects of confining and octahedral shear stresses in order to model the stress dependent modulus distribution of base materials. This model considers material characteristics in all three directions, so that it is suited to 3D finite element pavement analyses. The Universal model is expressed in Eq. (1):

$$M_R = K_1 p_a \left(\frac{I_1}{p_a}\right)^{K_2} \left(\frac{\tau_{oct}}{p_a}\right)^{K_3}, \quad (1)$$

where M_R is resilient modulus, $I_1 = \sigma_1 + \sigma_2 + \sigma_3$, $\tau_{oct} = 1/3\sqrt{(\sigma_1-\sigma_2)^2 + (\sigma_1-\sigma_3)^2 + (\sigma_2-\sigma_3)^2}$, p_a is atmospheric pressure, and K_1, K_2, and K_3 are material coefficients from multiple regression analyses of the repeated load triaxial test data. The resilient modulus represents the ratio of the repeated deviator stress to recoverable lateral strain, based on the results of constant-confining-pressure triaxial tests.

Table 2 shows the material coefficients used for the Universal model. K_1, K_2, and K_3 are multiple regression constants obtained from a repeated load triaxial test on granular materials.

Table 2. Model parameters for Universal model

Specimen	K_1	K_2	K_3
HD–1	2,318	0.64	0.065
HD–2	1,079	0.57	–0.176
HD–3	5,988	0.63	–0.18

The Bilinear model is one of the most commonly used resilient modulus models for subgrade soils (Thompson and Robnett 1979). The resilient modulus of a fine-grained subgrade soil is dependent upon the current stress state. The Bilinear model is expressed in Eq. (2):

$$M_R = K_1 + K_3(K_2 - \sigma_d) \text{ when } \sigma_d \le K_2,$$

$$M_R = K_1 - K_4(\sigma_d - K_2) \text{ when } \sigma_d \ge K_2, \quad (2)$$

where M_R is resilient modulus, σ_d is deviator stress, K_1, K_2, K_3, and K_4 are model parameters obtained from repeated load triaxial tests.

Fig. 3 shows the Bilinear model represented by the resilient modulus of fine-grained subgrade soils and deviator stress. Typically, the resilient modulus decreases as the repeated deviator stress increases, which exhibits stress-softening in fine-grained subgrade soils. The model parameters, K_1, K_2, K_3 and K_4, are obtained from a study by Thompson and Elliott (1985).

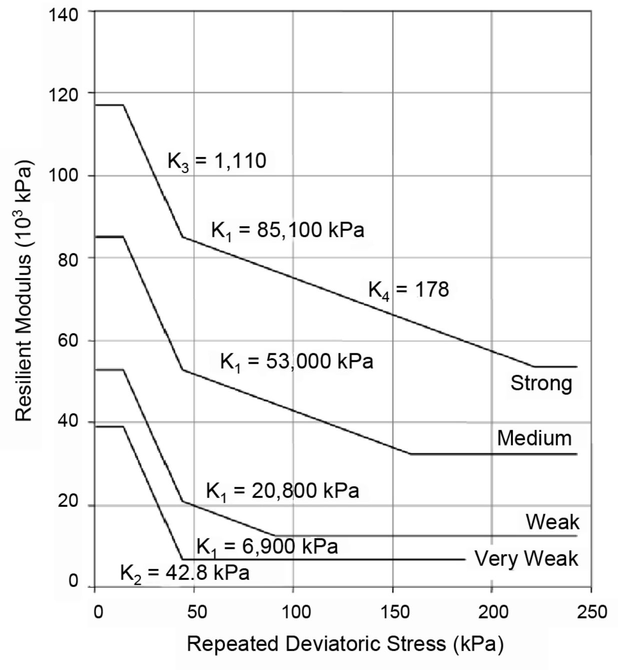


Fig. 3. Resilient modulus and deviatoric stress for subgrade soils (Thompson and Elliott 1985)

Table 3 lists the material coefficients used for the Bilinear model.

Table 3. Model parameters for Bilinear model

Specimen	K_1 (kPa)	K_2 (kPa)	K_3	K_4
SS (strong subgrade)	85,100	42.8	1,110	178
MS (medium subgrade)	53,000			
WS (weak subgrade)	20,800			
VWS (very weak subgrade)	6,900			

2.3. Previous studies for model validation

The Universal and Bilinear models were validated by Kim and Tutumluer (2006) and Kim *et al.* (2009) computing nonlinear resilient modulus distributions within the base and the subgrade layers subject to single wheel loading. The 3D finite element model was then validated by Kim and Tutumluer (2008) comparing nonlinear FEM analysis results under multiple wheel loadings with the field-measured pavement responses of a traffic testing conducted by the National Airport Pavement Test Facility (NAPTF). According to Kim and Tutumluer (2006; 2008), the overall results of FEM analyses using the Universal and Bilinear models were consistent with the measured responses of the test section. Particularly, the analysis results of subgrade vertical stress and surface deflection were in accordance with the measured values in the testing section.

3. Pavement analysis scenarios

In this study two pavement analysis scenarios are analyzed to explore the effects of nonlinearity of the pavement responses in terms of surface deflection and subgrade strain on the LVRs. For the purpose of analyzing the critical pavement responses under multiple wheel loads, two different conventional flexible pavement geometries are examined: 38 mm thick asphalt concrete (AC), Pavement 1 (PAV1), and 76 mm thick asphalt concrete, Pavement 2 (PAV2), over 304 mm thick base layers. These thicknesses of pavement sections in Table 4 are to represent a broad range of a typical LVR design as well as the comparison of the responses in terms of the top layer thickness.

Table 4. Pavement scenarios and geometries

Pavement scenario	Thickness of AC (mm)	Thickness of base (mm)
Pavement 1 (PAV1)	38	304
Pavement 2 (PAV2)	76	304

Each scenario applies a different combination of wheel/axle configuration and geomaterial to investigate the nonlinear behavior focusing on the rutting type failure mechanism. As mentioned above, nonlinear models of stress-dependent pavement geomaterial modulus are employed in the base and the subgrade layers together with thinly surfaced asphalt pavements considering an elastic modulus. In order to focus on the nonlinear stress-dependent behavior of the base and the subgrade materials in the LVRs, linear asphalt concrete material is assumed. Critical pavement responses on the LVRs are investigated in terms of the different qualities of unbound granular base materials constructed over a range of very weak to strong fine-grained subgrade soils. Table 5 shows material properties and nonlinear model parameters assigned to the pavement layers.

In each scenario, several 3D FEM analyses are performed for single, tandem, and tridem axle configurations applying multiple wheel loads on the specified layers in Table 4. Critical pavement responses, such as surface deflection on the asphalt concrete surface and vertical strain on top of the subgrade, are obtained under the single, tandem, and tridem axle load configurations to investigate the effects of multiple wheel load interactions on the LVRs. Table 6 summarizes the results of the FEM analysis conducted in this study.

Table 5. Pavement layers and material properties

Layer	E	ν	Material Model
AC	2,759 MPa	0.35	Isotropic and linear elastic
Base	Nonlinear Elastic	0.40	Nonlinear: Universal model by Witczak and Uzan (1988)
Subgrade	Nonlinear Elastic	0.45	Nonlinear: Bilinear model by Thompson and Robnett (1979)

4. Pavement responses

4.1. Effect of asphalt layer thickness on pavement responses

The effect of the asphalt layer thickness is investigated as it is one of the main considerations in the LVR. Table 6 shows that PAV1 with 38 mm asphalt layer is more responsive to the wheel/axle load configurations and geomaterial properties than PAV2 with 76 mm asphalt layer. In other words, the thinner the asphalt surfaced layer thickness is, the more pavement responses are generally yielded when the other conditions are the same.

Also, the thinner asphalt layer is more sensitive to the changes of the other variables. For instance, Table 7 shows a comparison of the differences in surface deflection measurements in PAV1 and PAV2 under a single axle load. The differences in surface deflection in PAV1, in bold, are computed by subtracting the surface deflection measurement under one condition from the other. The values of PAV2 are presented in parentheses for comparison. Overall, the differences of surface deflection in PAV1 are greater than those in PAV2.

Table 6. FEM analysis results

PAV1						PAV2				
Wheel/Axle Load	Base Material	Subgrade Material	Surface Deflection (mm)	Subgrade Strain (με)		Wheel/Axle Load	Base Material	Subgrade Material	Surface Deflection (mm)	Subgrade Strain (με)
Single	HD–1	SS	–0.63	–616		Single	HD–1	SS	–0.52	–453
		MS	–0.74	–814				MS	–0.60	–565
		WS	–0.90	–843				WS	–0.75	–618
		VWS	–1.08	–1,030				VWS	–0.90	–761
	HD–2	SS	–0.54	–501			HD–2	SS	–0.43	–376
		MS	–0.63	–635				MS	–0.51	–473
		WS	–0.79	–664				WS	–0.64	–543
		VWS	–0.98	–808				VWS	–0.81	–633
	HD–3	SS	–0.52	–495			HD–3	SS	–0.42	–376
		MS	–0.60	–629				MS	–0.50	–471
		WS	–0.75	–643				WS	–0.63	–520
		VWS	–0.92	–832				VWS	–0.75	–609

PAV1					PAV2				
Wheel/Axle Load	Base Material	Subgrade Material	Surface Deflection (mm)	Subgrade Strain (με)	Wheel/Axle Load	Base Material	Subgrade Material	Surface Deflection (mm)	Subgrade Strain (με)
Tandem	HD–1	SS	–0.75	–602	Tandem	HD–1	SS	–0.55	–418
		MS	–0.85	–753			MS	–0.65	–516
		WS	–1.04	–882			WS	–0.85	–583
		VWS	–1.21	–998			VWS	–1.00	–665
	HD–2	SS	–0.59	–485		HD–2	SS	–0.48	–358
		MS	–0.69	–618			MS	–0.56	–448
		WS	–0.88	–664			WS	–0.74	–524
		VWS	–1.05	–781			VWS	–0.90	–606
	HD–3	SS	–0.56	–480		HD–3	SS	–0.47	–357
		MS	–0.66	–606			MS	–0.55	–445
		WS	–0.85	–623			WS	–0.73	–511
		VWS	–1.01	–764			VWS	–0.89	–600
Tridem	HD–1	SS	–0.72	–585	Tridem	HD–1	SS	–0.60	–396
		MS	–0.84	–712			MS	–0.71	–478
		WS	–1.05	–865			WS	–0.90	–607
		VWS	–1.25	–1,020			VWS	–1.04	–699
	HD–2	SS	–0.64	–469		HD–2	SS	–0.52	–340
		MS	–0.76	–596			MS	–0.63	–423
		WS	–0.96	–748			WS	–0.82	–552
		VWS	–1.17	–893			VWS	–0.96	–643
	HD–3	SS	–0.61	–463		HD–3	SS	–0.51	–339
		MS	–0.73	–588			MS	–0.62	–419
		WS	–0.94	–732			WS	–0.81	–525
		VWS	–1.14	–884			VWS	–0.95	–632

Table 7. Comparison of differences in surface deflection due to changes of other variables

	HD–1 and VWS	HD–3 and VWS
HD–1 and SS	**0.447 mm** (0.381 mm)	**0.293 mm** (0.229 mm)
HD–3 and SS	**0.558 mm** (0.477 mm)	**0.405 mm** (0.325 mm)

4.2. Effect of wheel/axle configuration on pavement surface deflection

Pavement surface deflection is measured to investigate the effects of wheel/axle configurations on the structural capability and performance of the LVR pavement. The analyses incorporate multiple wheel/axle configurations and geomaterial properties to explore the effects of these two factors on surface deflection.

Fig. 4 compares the surface deflection measurements when the base material is HD–3 (Y–axis) according to the variations of the wheel/axle configurations, the subgrade soil types, and the thickness of the asphalt layer (X–axis). In Fig. 4, the maximum deflection of 1.14 mm is computed when a tridem axle load is applied on PAV1 over the very weak subgrade (VWS). Notice that the surface deflection measurement increases as the number of axles increases when the same base material is considered. Thus, with all the other factors constant, more surface deflection is induced by the tridem axle load than the single and tandem axle loads.

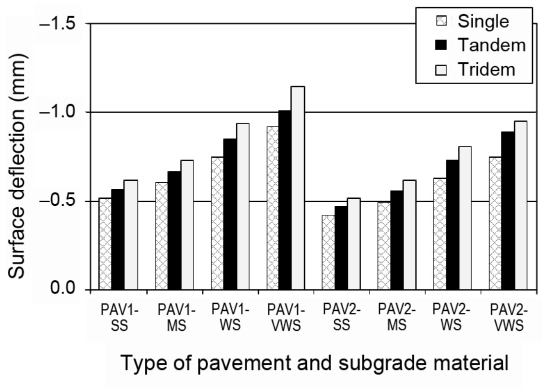
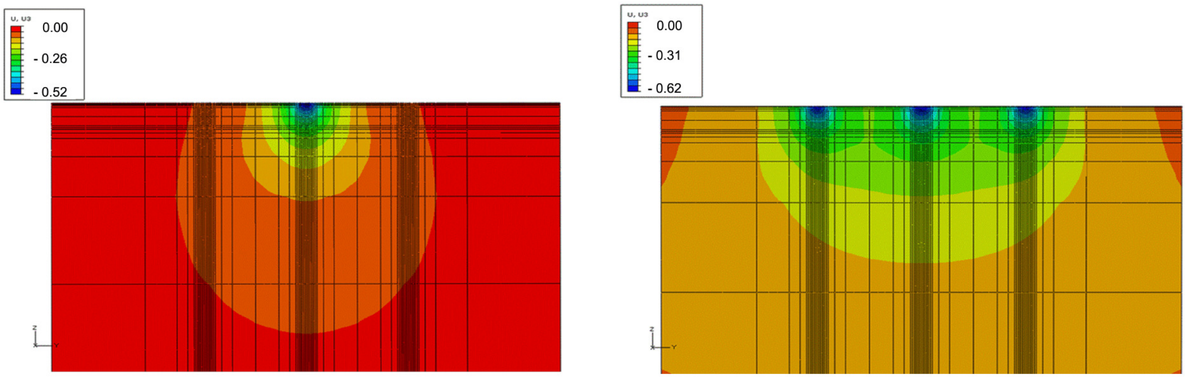


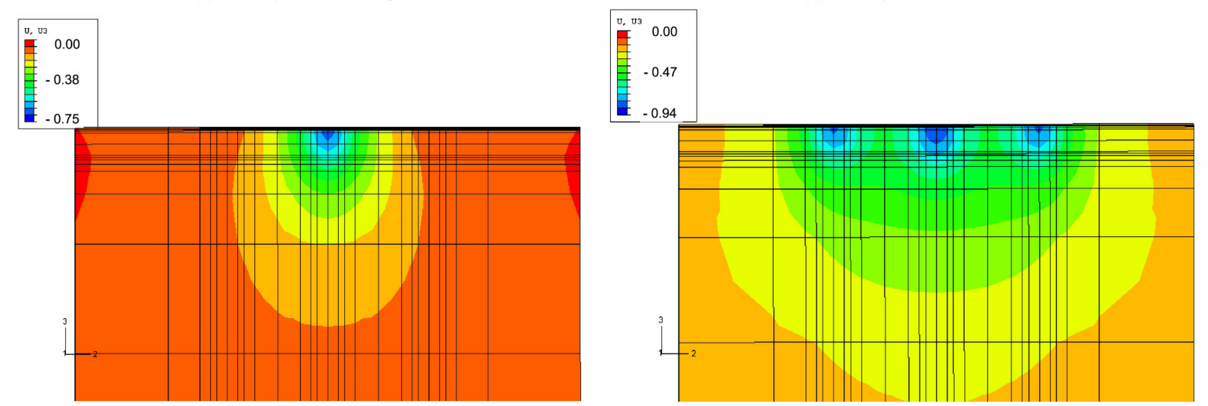
Fig. 4. Surface deflection according to wheel/axle configurations with HD–3 base layer

Fig. 5 compares the surface deflection basins under single and tridem axle loads. As noticed, the surface deflection basin under the tridem axle load is greater than that under the single axle load due to the load spreading ability. The difference becomes more apparent when the subgrade is weaker.

Figs 4 and 5 collectively show the wheel/axle load interaction is a significant factor contributing to pavement surface deflection. The amount of surface deflection varies in accordance with the combination of different wheel/axle configurations and geomaterial properties.



(a) SS layer with single axle (b) SS layer with tridem axle



(c) WS layer with single axle (d) WS layer with tridem axle

Fig. 5. Contours of predicted vertical displacements of PAV1 with HD–3 base layer

4.3. Effect of geomaterial properties on pavement surface deflection

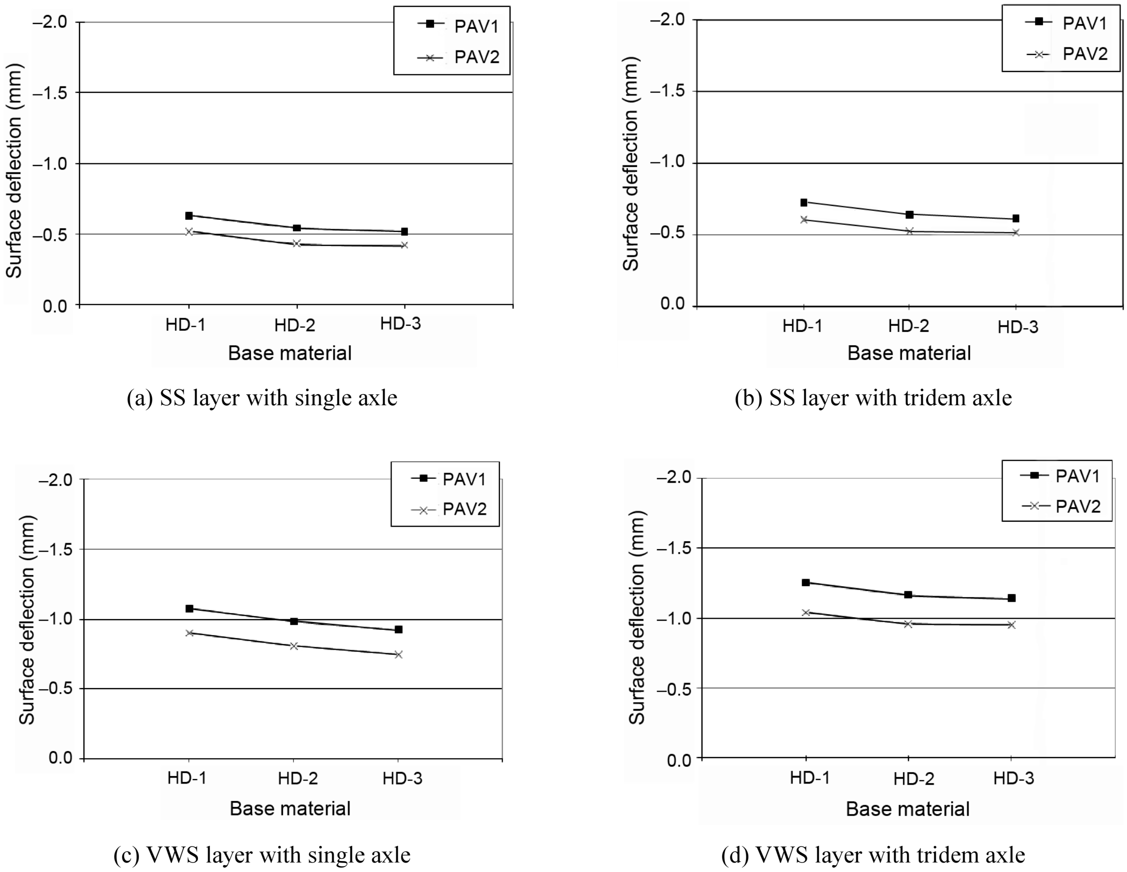
The resilient modulus characteristics of base layers and subgrade soils are also important contributing factors to surface deflection. Figs 6 and 7 illustrate the results of the FEM analyses incorporating various resilient modulus characteristics of the base and the subgrade materials. Fig. 6 shows the surface deflection measurements under single and tridem axle loads (Y–axis) according to different base material properties (X–axis). Notice that there is not much difference in surface deflection measurements observed amongst various base material types under the same axle load. The HD–3 base material has greater resilient modulus than the crushed stones (HD–1) or gravel lime stones (HD–2) based on laboratory tests (Allen and Thompson 1974). Therefore, the pavement with HD–3 has less surface deflection than the others. Among the four cases in Fig. 6, the biggest difference, 0.154 mm, is found between the HD–1 and HD–3 over the very weak subgrade when a single axle load is applied on PAV1 (Fig. 6c).

Fig. 7 compares the surface deflection measurements (Y–axis) according to different subgrade material properties (X–axis). The strong subgrade (SS) leads to substantially less surface deflection than the other subgrade layers; the very weak subgrade (VWS) yields the greatest surface deflection. In Fig. 7, the difference in the surface deflection measurement under a tridem axle load is 0.529 mm in PAV1 (Fig. 7b); while it is 0.435 mm under a single axle load in PAV2 (Fig. 7a). Figs 6 and 7 show the surface deflection measurement is more influenced by subgrade material properties than base material properties in this study. Although the subgrade is most away from the wheel loadings, the surface deflection measurements are significantly affected by the subgrade material properties in the LVR pavements with the thin surface and base layers.

4.4. Effect of wheel/axle configuration on pavement subgrade response

As mentioned earlier, numerous studies found that rutting is the leading pavement distress observed in the LVRs. One of the major factors contributing to rutting is subgrade vertical strain, which is closely related to the pavement thicknesses, material properties, and wheel load applications.

Fig. 8 shows the comparisons of subgrade vertical strains measured on top of the subgrade layers (Y–axis) according to the wheel/axle configurations and base material properties in various pavement scenarios (X–axis). Interestingly, the tridem axle load tends to yield less subgrade vertical strain than the single axle load. It appears that the vertical strain measurement under each wheel is interfered by those under adjacent wheels providing "negative effects" to one another. Thus, these interferences by neighboring wheels in the tridem axle rather decrease subgrade vertical strain measured directly under each wheel.



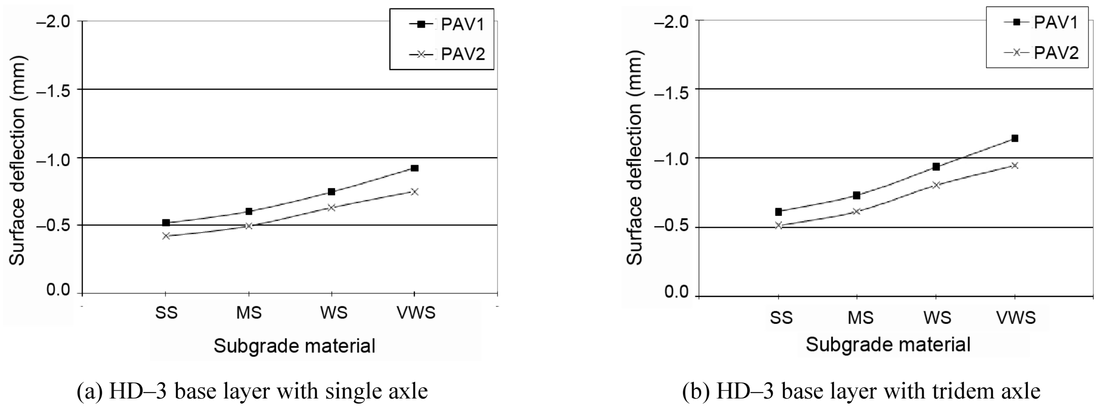
(a) SS layer with single axle

(b) SS layer with tridem axle

(c) VWS layer with single axle

(d) VWS layer with tridem axle

Fig. 6. Surface deflection according to base layer properties



(a) HD–3 base layer with single axle

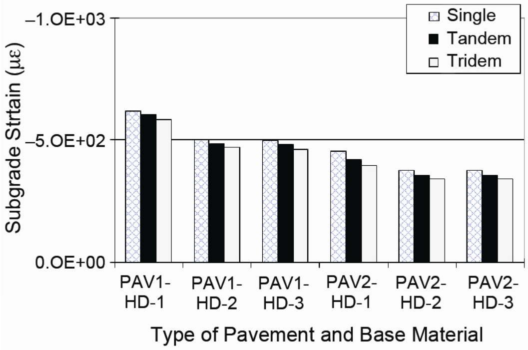
(b) HD–3 base layer with tridem axle

Fig. 7. Surface deflection according to subgrade material properties

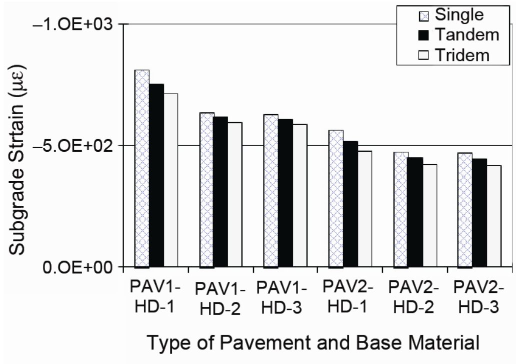
4.5. Effect of geomaterial properties on pavement subgrade response

The resilient behavior in the base and the subgrade materials is another important factor that affects subgrade vertical strains. This section presents the subgrade responses affected by various resilient modulus characteristics of the base and the subgrade materials. Fig. 9 shows the comparisons of the subgrade vertical strains (Y–axis) according to the geomaterial properties (X–axis). The minimum vertical strains occur in the pavement with HD–3 layer, while the maximum vertical strains are observed in the pavement with HD–1 layer under the same load conditions.

Fig. 10 shows subgrade vertical strains (Y–axis) according to subgrade material properties (X–axis). Pavements with the strong subgrade (SS) layer have less subgrade strains than those with other subgrade layers. The largest difference of 421με is observed between the subgrade strain measurements in the SS and the VWS when a tridem axle load is applied to PAV1 with HD–3 (Fig. 10b).

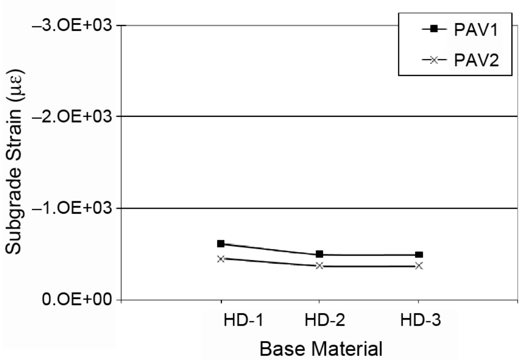


(a) Strong subgrade (SS)

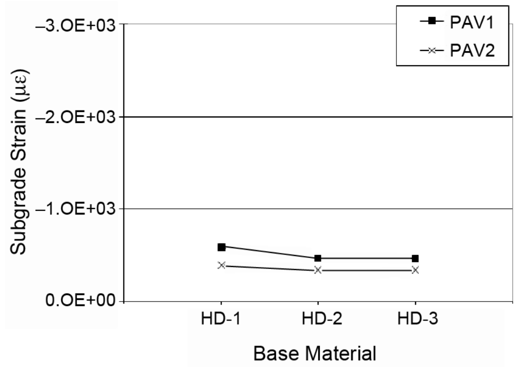


(b) Medium subgrade (MS)

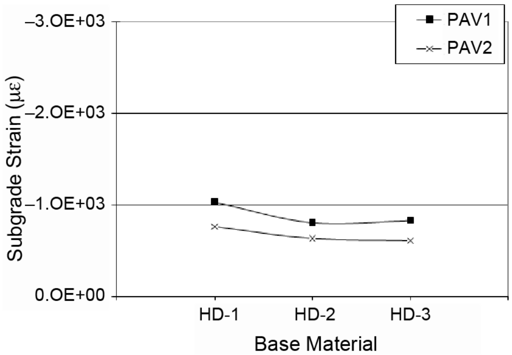
Fig. 8. Subgrade vertical strains due to multiple wheel/axle configurations



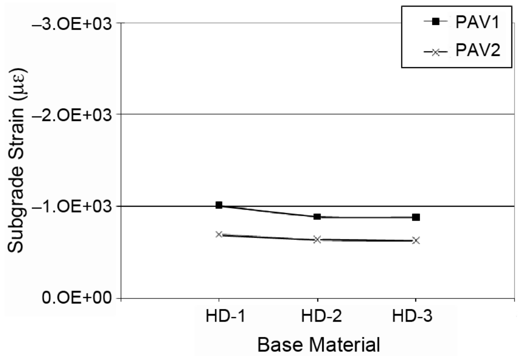
(a) SS layer with single axle



(b) SS layer with tridem axle

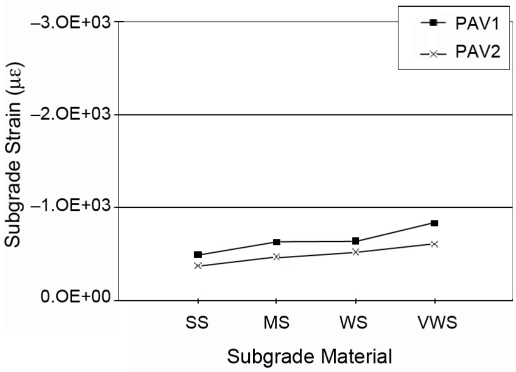


(c) VWS layer with single axle

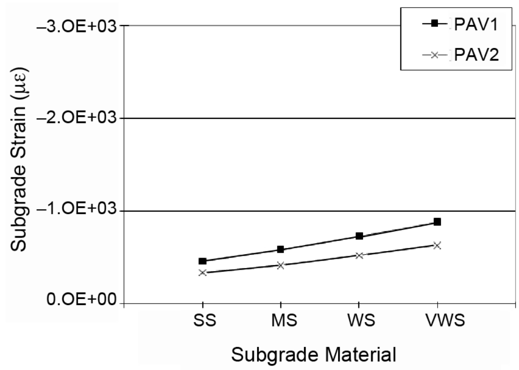


(d) VWS layer with tridem axle

Fig. 9. Subgrade vertical strains according to base material properties



HD–3 base layer with single axle



HD–3 base layer with tridem axle

Fig. 10. Subgrade vertical strains according to subgrade material properties

5. Conclusions

This paper described mechanistic analyses on low volume roads (LVRs) using a nonlinear three-dimensional (3D) finite element model (FEM). In the analysis, a nonlinear stress-dependent model of base and subgrade materials was used to analyze thinly surfaced flexible pavements focusing on various pavement geomaterial properties. Various pavement scenarios were analyzed to investigate the effects of pavement thicknesses, traffic loads, and material properties on surface deflection and subgrade strain.

The 3D nonlinear FEM analyses were conducted to analyze the flexible pavement structures for low volume roads subject to various multiple axle loads. The research findings are, however, limited to several pavement scenarios as they are specifically designed for the purpose of analyses in this study.

The effect of the asphalt surface thickness was first investigated. The thinner the asphalt layer was, the more pavement responses were generally yielded when the other conditions were the same. Also, the thinner asphalt layer was generally more sensitive to the changes of the wheel/axle load configurations and geomaterial properties.

The wheel load configurations significantly influenced the critical pavement responses in each pavement scenario. Noticeable differences in pavement responses due to single and tridem axle configurations were observed. The load spreading ability and nonlinear modulus distributions of the granular base and the subgrade layers influenced surface deflection. The geomaterial property was also an important factor to surface deflection. Generally, weak geomaterials lead to more surface deflection.

Predicted vertical strains on top of the subgrade layer were considerably affected by subgrade properties. Significant differences were observed between the SS and VWS under various load conditions. The effects of wheel/axle load configurations and base material properties on the subgrade vertical strain measurements were minimal or even negligible.

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NETIESINĖS KELIO DANGOS PRIKLAUSOMYBĖS NUO MAŽO INTENSYVUMO KELIŲ, VEIKIAMŲ DAUGKARTINĖMIS RATŲ APKROVOMIS, TYRIMAS

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Santrauka

Straipsnyje aprašoma skaitinė mažo intensyvumo kelių analizė, taikant netiesinį – erdvinį baigtinių elementų modelį. Skirtingi dangų paviršiaus variantai analizuojami siekiant ištirti, kokią įtaką kelio dangos elgsenai, t. y. poslinkiams ir kelio pagrindo deformacijoms, turi dangų sluoksnių storiai, eismo apkrovos ir medžiagų savybės. Kiekvienas kelio dangos variantas turi skirtingas ratų arba ašies ir geometrinių savybių formas, kad būtų galima išanalizuoti netiesinę plonos asfalto dangos paviršiaus elgseną. Šioje skaitinėje analizėje nagrinėjami netiesiniai įtempių modeliai, kurie buvo taikomi pagrindo sluoksniams, siekiant tinkamai apibūdinti geometrinę kelio dangos elgseną. Baigtinių elementų analizės rezultatai toliau nagrinėjami atsižvelgiant į asfalto dangos storį ar ašies formą ir geometrines savybes, priklausomai nuo kritinės kelio dangos būklės. Išvados buvo gautos lyginant netiesines kelių dangos priklausomybes pagrindo sluoksnyje, atsižvelgiant į jų sąveiką su daugkartine ratų apkrova.

Reikšminiai žodžiai: mažo intensyvumo kelias, trimatė baigtinio elemento analizė, netiesinės dangos paviršiaus priklausomybės, daugkartinės ratų arba ašies apkrovos, geometrinės savybės.

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