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Numerical Analysis on the Deformation of Flexible Pavement System

MOKHAMMAD Farid Maruf[1, a *], SRI Wahyuni[1,b] and JOJOK Widodo[1,c]

[1]Civil Engineering Dept. Jember University, Jalan Kalimantan 37, Kampus Tegalboto, Jember, 68121, Indonesia

[a]farid.teknik@unej.ac.id, [b]sriwahyuni.teknik@unej.ac.id, [c]jojok.teknik@unej.ac.id
*corresponding author

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Abstract. In this paper, flexible pavement system behavior due to heavy axle load is discussed. The effects of axle load, vehicle speed, and pavement thickness are studied numerically by means of PLAXIS 2D. The simulation results show that both vehicle speed and load significantly induce the deformation. The elastic deformation varies significantly when the speed and load change. However, the plastic deformation mostly depends on the vehicle speed. The effect of load becomes significant when the speed is slowing down. The pavement thickness also play important role to increase the stiffness to reduce the pavement deformation.

Introduction

In Indonesia, overload due to heavy truck transportation is one of the most important factors to cause flexible pavement deterioration. The actual load of single axle truck reaches 20 tons that is twice of the allowable load [1]. Overlay becomes the most frequent rehabilitation method to apply for this kind of distress. It increases asphalt layer thickness to be more than 25 cm [2,3]. However, rutting still exists.

Geotechnical condition of the ground is also the most important causes of the deterioration. The lack of soil subgrade strength leads to a weak support to the pavement layer. It triggers excessive deformation to make the flexible pavement fail. Geotechnical investigation regarding its interaction with the flexible pavement becomes important. Traffic load generates plastic deformation to subgrade layer [4]. However, it can be reduced by adding geotextile to increase the subgrade surface strength [5]. Both investigations utilized finite element by means of PLAXIS 2D. The traffic load was modeled as a static load applied on the pavement surface. In fact, traffic load is a dynamic one. It is a pulse load repeated along the vehicle movement.

This paper intends to discuss the flexible pavement system behavior in the geotechnical engineering vision. The investigation utilized PLAXIS 2D. Traffic load was modeled using haversine pulse model.

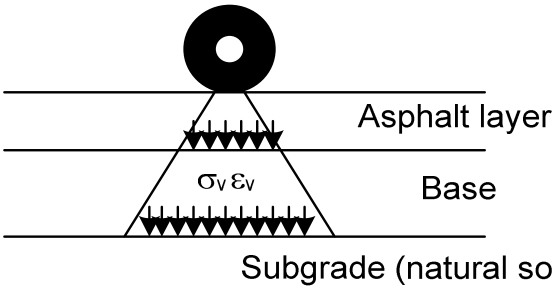


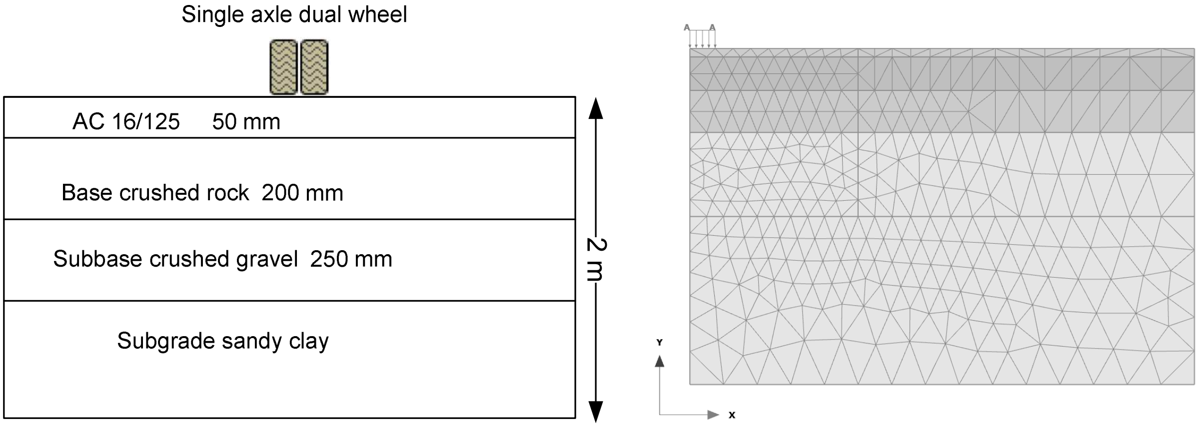
Fig. 1. Stress on the subgrade due to wheel load

Vehicle load

Vehicle applies the load to the pavement surface through its wheels. The stress generated can be illustrated by Fig. 1. The asphalt layer receives the wheel load then transfers it to the base layer and the soil. When the generated stress on the natural surface exceeds its shear strength, the natural soil fails to support the pavement system. Furthermore, the soil encounters large deformation and triggers the pavement distress.

Model Simulation Setting

The flexible pavement system to be modeled is presented in Fig. 2a. It contains of 50 mm asphalt layer, 200 mm base course and 250 mm sub base course. The underlain subgrade is sandy clay natural soil. The model geometry for simulation is illustrated in Fig. 2b. The pavement system was modeled by means of geotechnical finite element software namely PLAXIS 2D 2011. The asphalt layer was modeled as geotechnical material as all the underlain layers. The parameters for the simulation are shown at Table 1. The first three layers were similar with ones of Tanttu and Laaksonen experimental work [4]. Meanwhile sub grade layer was soft soil that easily found in Indonesia. The asphalt layer was assumed to followed elastic model, while the other were Mohr-Coulomb one.



a b

Fig. 2. a) The flexible pavement system. b) Model meshing

Table 1. Soil parameters

Material	Asphalt	Base course	Sub base	Sub grade
Thickness, mm	50	200	250	1500
Modulus, MPa	5400	300	140	7
Poisson's ratio	0.3	0.35	0.35	0.3
Unit weight, kN/m3	25	21.2	22.0	18.0
Cohesion, kPa	-	30	20	15
Friction angle (°)	-	43	44	30
Dilatation angle (°)	-	13	14	0

The vehicle load is modeled as a dynamic pulse load by haversine formula and illustrated in Fig. 3. The load duration d represents the contact times between the tire and the pavement surface. It inversely depends on the vehicle speed. Meanwhile the times gab between two pulse loads varies with the vehicle speed and length.

In 1971 Barksdale pioneered to introduce haversine formula to represent the vehicle load for finite element modeling [6]. Loulizi et al. have done extensive experimental work to investigate compressive stress induced by moving truck for various speed and depth [7]. They found that haversine formula produced the fit to the experimental data. This work utilized their proposed approach to determine the load duration which is a function of the vehicle speed v.

$$d = 1.663\ v^{-1.0409} \tag{1}$$

The formula is applicable for elastic material at near surface depth.

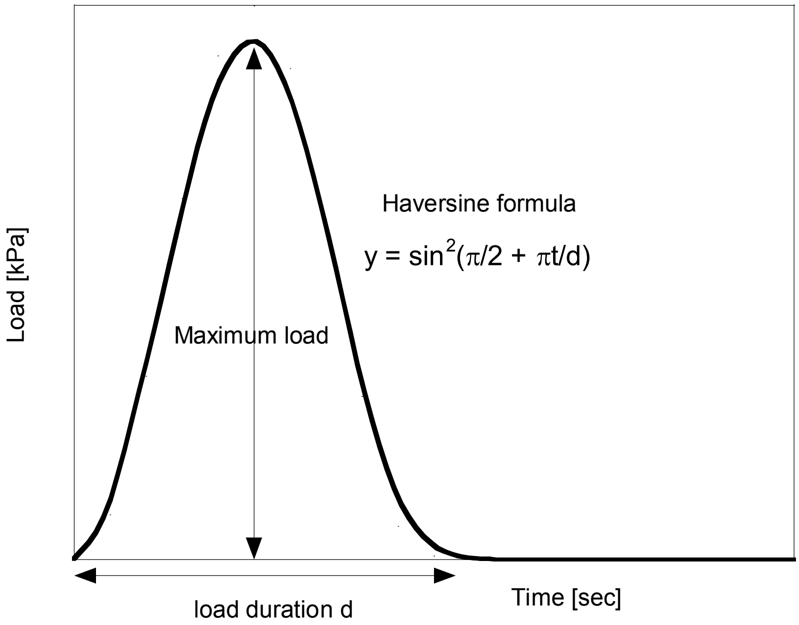


Fig. 3. Haversine pulse load illustration

The load has surface contact area of 0.15 m radius. For simulation, the maximum axle load was 13 tons that generated surface stress of 900 kPa. It was applied amplitude of the haversine load equation. Various axle loads were applied to investigate the effect of load on the deformation behavior.

The haversine model takes the vehicle speed into account. In Indonesia, heavy truck speed ranges from 30 – 60 km/hr. It was the range utilized in the simulation.

The last parameter considered in the simulation was asphalt layer thickness. All the parameters setting for simulation are presented in Table 2.

Table 2. Simulation setting

Speed (km/hr)	30	40	50	60	
Load (kPa)	600	700	800	900	
Asphalt thickness (mm)	50	75	100	125	150

Results

Fig. 4 shows the variation of the deformation due to load time. The deformation changes as load change following the haversine model. The figure indicates that deformation depends on both vehicle load and speed. Small and reversible deformation generated points that elastic deformation occurred. The induced plastic strain can be identified as the deformation difference between initial and final load. The figure shows clearly that higher speed induces smaller elastic deformation but larger plastic one. At higher speed (60 km/hr), the plastic deformation is almost independent to the load. The effect of load takes place when the speed decreases and becomes more significant with the speed reduction. On the other hand, the elastic deformation is strongly dependent to both speed and load.

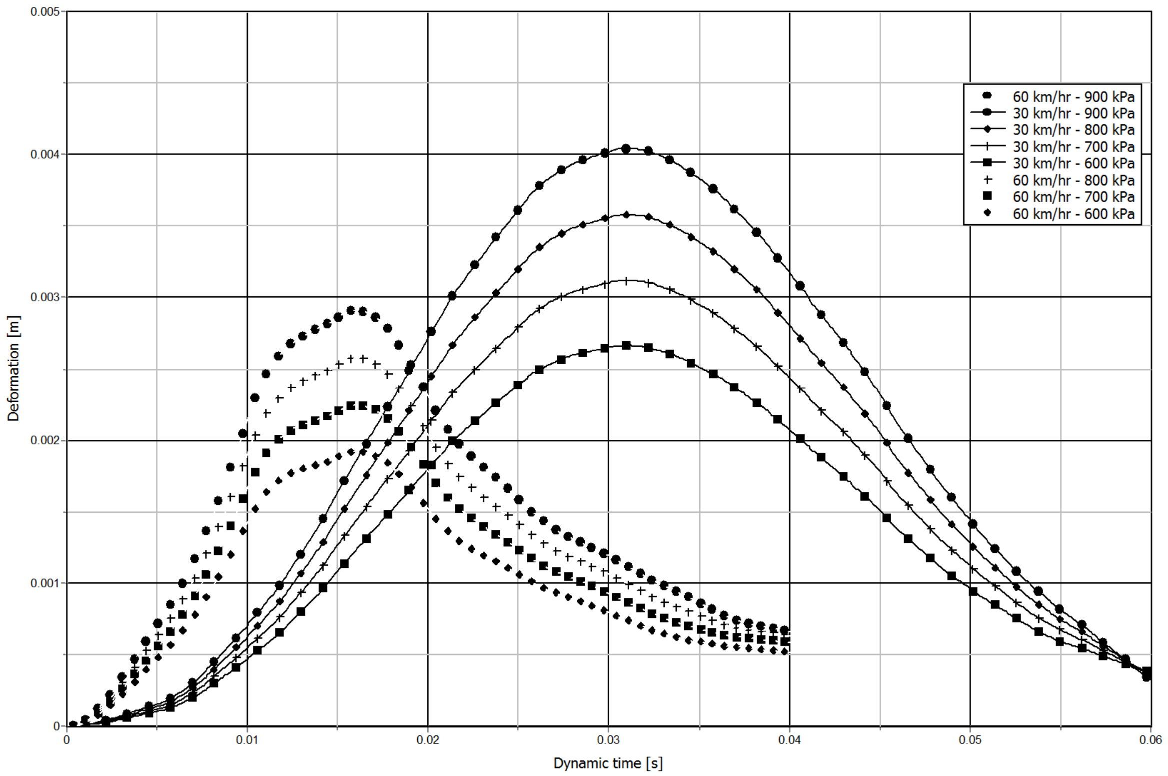


Fig. 4. Deformation variation over time

The variation of deformation due to vehicle speed and load is illustrated in Fig. 5. Increasing the speed will reduce the deformation. Increasing the load for slower speed generates higher deformation than one at faster speed. In actual condition, heavier the truck means slower the speed. Such condition causes the pavement failure takes place immediately. It agrees with the simulation results. Combination of slow speed and overload damages the pavement rapidly.

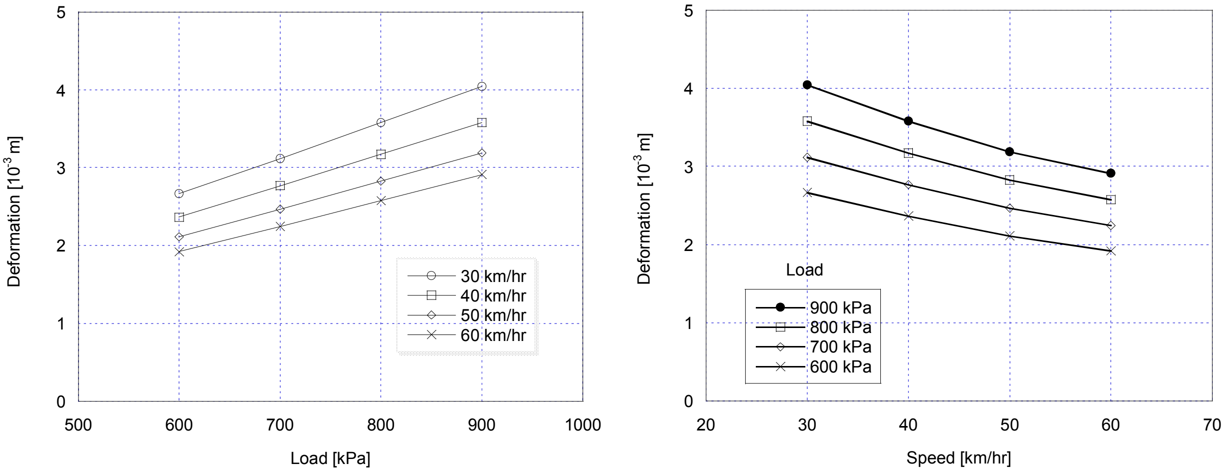


Fig. 5. Variation of deformation due to vehicle speed and load

Fig. 6 illustrates the deformation occurred for various asphalt pavement thickness. The figure indicates clearly that thickness plays important role to reduce the deformation. Thicker the asphalt pavement generates smaller the deformation. Very thick pavement behaves like structural beams that support the load by itself. When rutting exist for such a thick pavement [2,3] should not associated with geotechnical condition but the pavement alone.

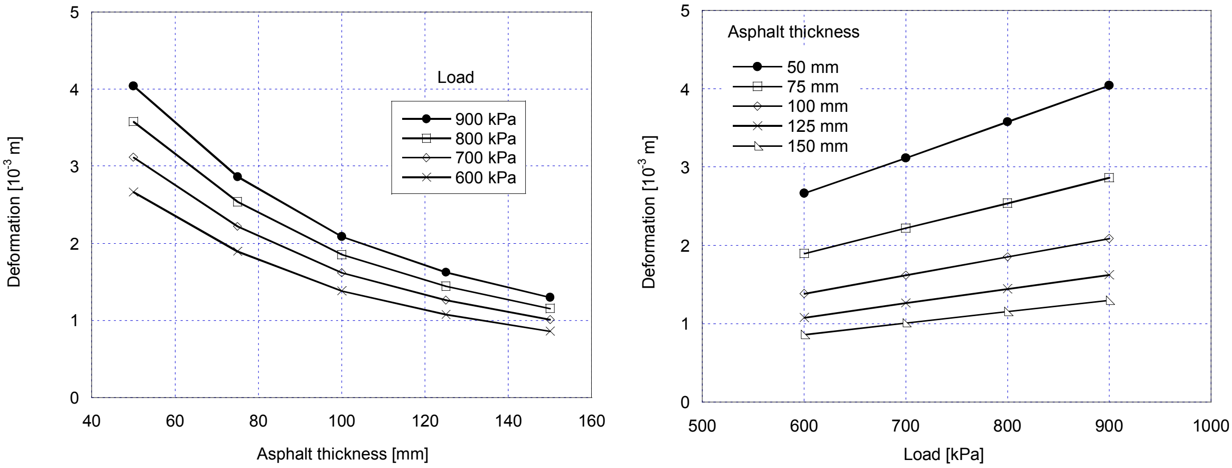


Fig. 6. Variation of deformation due to asphalt thickness

Fig. 7 presents variation of the deformation with depth. It clearly shows that asphalt thickness reduces significantly especially when the thickness changes from 50 mm to 100 mm. Increasing the thickness larger than 100 mm has small effect on the deformation. the deformation relatively constant at base course and reduces with the depth at natural soil (< -0.5 m depth). This condition can be identified also with the distribution of effective stress on the subgrade (Fig. 8). Near the surface of subgrade, the effective stress induce are denser than others. It means that effective stress change larger than other area causing larger deformation.

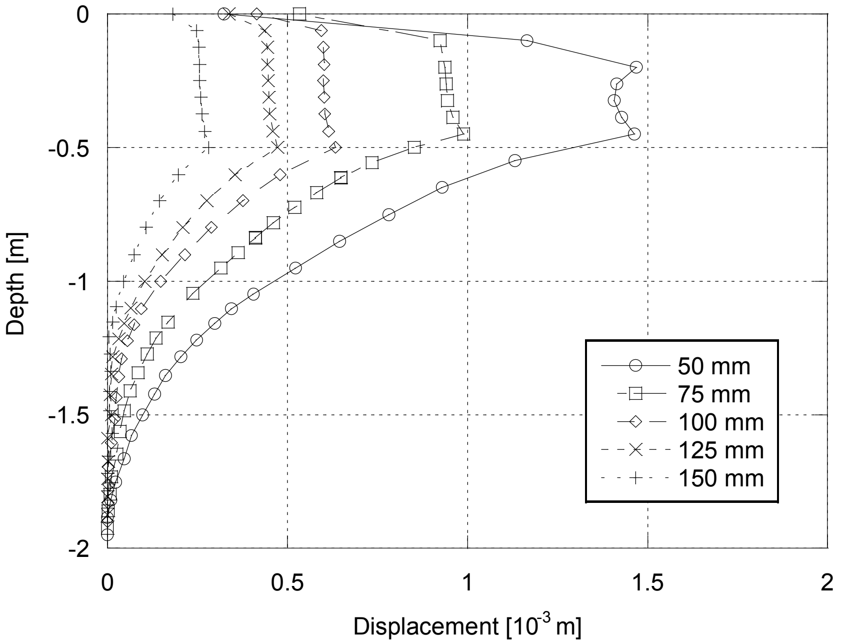


Fig. 7. Variation of deformation with depth

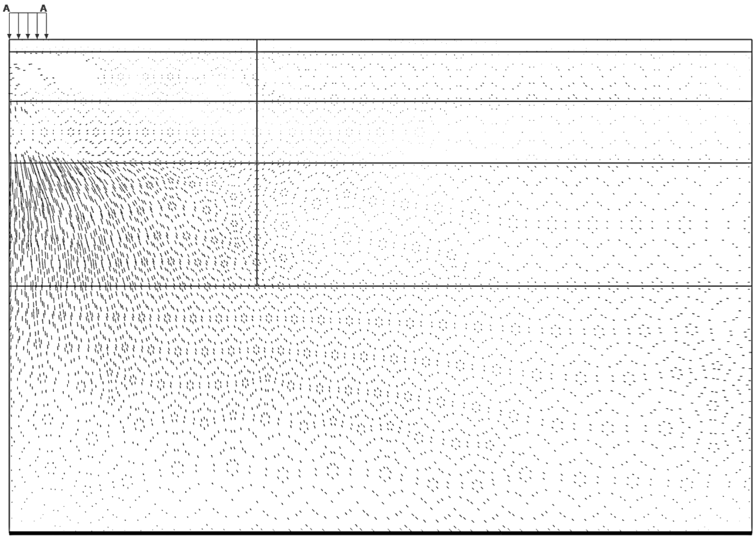


Fig. 8. Effective stress distribution

Summary

Investigation on flexible pavement behavior due to vehicle speed and load was conducted numerically. The results show that both speed and load at significant factor to cause the pavement deformation. The elastic deformation is strongly dependent on both the speed and the load. However, the plastic deformation rather relies on the combination of the speed and the load. At higher speed, the load has small effect on the plastic deformation. The effect of load increases when the speed is slowing down.

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