Effects of transversal distribution of heavy vehicles on rut formation in bituminous layers

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ABSTRACT: Permanent deformation in bituminous layer is an excessive deformation of bituminous material in the wheel paths which gradually increases with increasing numbers of heavy traffic. The traffic loading is one of the most important factors in the design of road pavements and usually the number of heavy vehicle in a wheel path is considered in pavement design. However, the distribution of the heavy-goods vehicles across the width of the traffic lane is essential in estimation of rut formation in asphalt concrete pavement layers. To calculate rutting under wheel load it is therefore crucial to include the influence of lateral wandering of the traffic. The purpose of this work was to study the influence of transversal distribution of heavy-goods vehicles on rut formation in asphalt concrete layers. The predictive model used in this study, PEDRO, is based on the number of passages of wheel loads, traffic speed, axle load configuration (single or dual wheel load), tyre pressure, influence of lateral wandering of the traffic, the pavement structure and the mixture properties at various temperatures. It is also concluded that pavement design methods for rut depth development should include the influence of lateral wander of heavy vehicles.

KEY WORDS: Rut formation, lateral wander, asphalt concrete pavement, PEDRO

1 INTRODUCTION

Surface rutting in a flexible pavement originates from all pavement layers and the subgrade. Flow rutting is defined as an excessive deformation of bituminous layers in the wheel paths which gradually increases with increasing numbers of vehicle load repetitions. Flow rutting in an asphalt concrete layer is caused by two mechanisms (Eisenmann and Hilmer 1987, Sousa et al. 1991, Verstraeten 1995, Kaloush and Witczak 2002, and Blab and Harvey 2002): densification, which is a decrease in volume and increase in density of an asphalt concrete layer under repeated traffic loading, and shear deformation with the formation of upheavals, i.e. lateral and vertical displacements of material caused by traffic load induced shear stresses (Figure 1). This generates a depression under the wheel load and upheaval along the wheel path. In addition to the properties of asphalt mixture and climate factors, flow rutting is affected by traffic history, especially at high temperatures and under vehicle loading of relatively long duration, when the mix properties are dominated by the viscous character of the material. The traffic loading is one of the most important factors in the design of road pavements and usually the number of heavy vehicle in a wheel path is considered in pavement design. However, the distribution of the heavy goods vehicles across the width of the traffic lane is essential in estimation of rut formation in asphalt concrete pavement layers. To calculate rutting under wheel load it is therefore crucial to include the influence of lateral wandering of the traffic.

Traffic loading is the most important design factor for pavements, although the pavement structure, materials and climate are also essential parameters in this respect. Not only the number of heavy vehicles, but also the axle load and configuration, tire type and pressure, traffic speed, as well as the lateral wander of the traffic, which is related to the width of the lane, also have an impact (OECD 1991, Blab and Harvey 2002, Sebaaly 1998, Buiter et. al. 1989, ARA 1-37A 2004).

In this work, the algorithms of a linear viscoelastic model have been adapted to predict permanent vertical strain in a typical asphalt concrete pavement subjected to a moving load. The package used here to calculate the permanent deformation of asphalt concrete layers is called PEDRO (**PE**rmanent **D**eformation of asphalt concrete layer for **RO**ads) (Said et al. 2011).

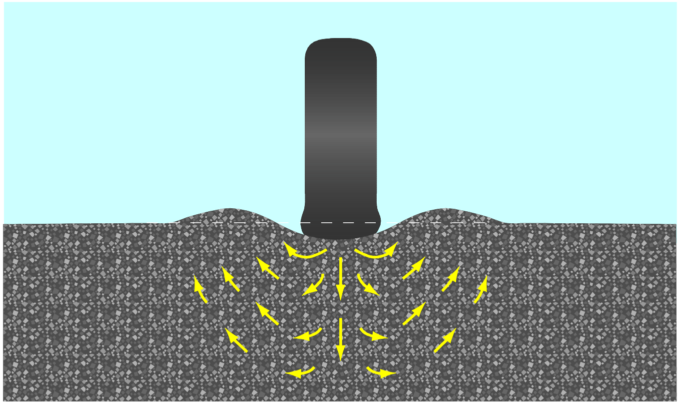

Figure 1: Illustration of mechanism of flow rutting in asphalt concrete layer.

2 OBJECTIVE

The purpose of this work was to study the influence of transversal distribution of heavy-goods vehicles on rut formation in asphalt concrete layers. The predictive model used in this study, PEDRO, is based on the number of passages of wheel loads, traffic speed, axle load configuration (single or dual wheel load), tyre pressure, influence of lateral wandering of the traffic, the pavement structure and the mixture properties at various temperatures.

3 PREDICTIVE MODEL PEDRO

The PEDRO package (Said et al 2011) has been used in this work to study the effect of traffic variables on rut formation in asphalt concrete layers. The vertical permanent strains (ε_p) encountered in the initial and secondary zones were calculated at various depths and lateral positions in the asphalt layers under a moving load using Eqn. (1). The rut depth was calculated by integrating the permanent deformation over the thickness of the asphalt concrete layer.

$$\varepsilon_p = \frac{\sigma_0 \cdot (1-2\nu)}{V \cdot \eta_A} \cdot \mathrm{Re}\left[\sqrt{(z+ix)^2 + a^2} - (z+ix)\right] + \frac{\sigma_0 \cdot z}{V \cdot \eta_A} \cdot \mathrm{Re}\left[1 - \frac{z+ix}{\sqrt{(z+ix)^2 + a^2}}\right] \quad \ldots 1$$

where

ε_p = the permanent vertical strain in m/m
σ_0 = tyre pressure in Pa
a = radius of contact area in m
ν = Poisson's ratio
z = depth from road surface in m
V = vehicle speed in m/sec
η_A = viscosity of asphalt mix in Pa s
x = distance from loading centre in m
i = $\sqrt{-1}$

The viscosity of the asphalt concrete materials was estimated as a function of the shear modulus and the phase angle by testing asphalt concrete samples using frequency sweep tests. To estimate the viscosity of an asphalt mix, researchers have generally used the complex viscosity ($\eta^*=G^*/\omega$), the real part of the viscosity ($\eta'=G''/\omega$) or the zero shear rate viscosity (ZSV) to evaluate the rutting characteristics of asphalt concrete materials (Hopman and Nilsson 2000, Björklund 1984, Collop et al. 1992, Oscarsson and Said 2012). Cores were tested at different temperatures and frequencies using the asphalt shear box (Said et al. 2011). In this work complex viscosity was used. The viscosity was estimated at the peak value of the phase angle at 30°C for roadbase (AG22 160/220) layers (5.6 x10^7 Pa s). The permanent vertical strains across the traffic lane (3.5 m), in the asphalt concrete layer, were calculated under the influence of lateral shifts of the wheel path. Afterward, the accumulation of the rutting at transversal positions was carried out with respect to number of traffic loading at various lateral positions. To evaluate the effect of lateral wander of heavy vehicles, deformations at a wheel path were calculated at different standard deviations (0 – 0.4 m) of lateral distributions of wheel load. The lateral distributions of traffic have been assumed normally distributed.

4 PAVEMENT STRUCTURE

To study the influence of lateral distribution of heavy vehicle loading on rut formation in asphalt concrete layers, a full-scale road section was chosen. It is a common flexible pavement structure according to Swedish norms. It is assumed to consist of a 90 mm typical roadbase mix called AG22 160-220 and a 35 mm conventional wearing course. Only deformations in the roadbase layer were taken into account in this study for simplicity and to limit the number of calculations. Roadbase mix AG22 pen 160/220 has a binder content of 4.2% and an air void content of 5.2%. Three specimens were subjected to sweep test analysis, mentioned above, to determine the roadbase viscosity (in average 5.6 x10^7 Pa s) needed to estimate rut depth using the PEDRO model.

5 INFLUENCE OF TRANSVERSAL DISTRIBUTION OF HEAVY VEHICLE

Rut depth estimations were calculated at a traffic speed of 110 km/h and an axel load of 100 kN with a single or dual tyres with inflation pressure of 800 kPa. Figures 2 and 3 show the influence of standard deviations of traffic on the rut profiles for dual- and single-wheels after 4 million load repetitions. The estimated pavement rutting was calibrated using a calibration factor of 0.037 (Said and Hakim, 2012). The rut depth at the centre of the wheel path and the upheavals along it increase with decreasing standard deviations of the lateral wander. In this study the upheaval effect is obvious at standard deviations less than about 0.30 m, which also increases the rut depth due to upheaval. Figure 4 shows rut development at different standard deviations of lateral wander of dual- and single-wheels. Decreasing the standard deviation from 0.3 m to 0.25 m for dual-wheel results in a 15 % increase in rut depth and at a standard deviation of 0.40 m results in approximately half the rut depth compared to the standard deviation of 0.20 m. The influence of a wide single-wheel is even larger. The significant influence of transversal distribution of heavy vehicles is clearly demonstrated in Figures 2, 3 and 4.

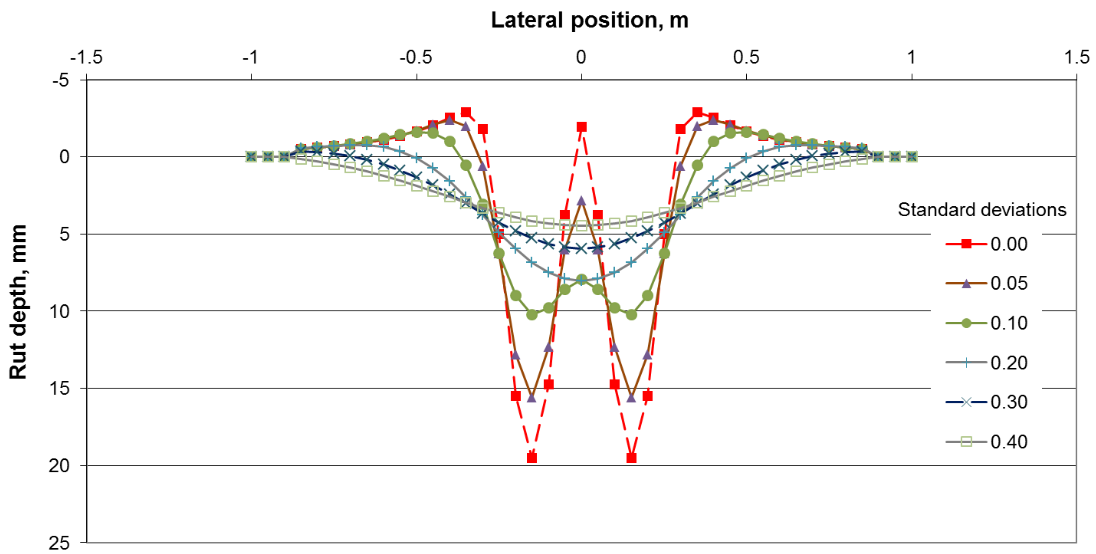

Figure 2: Estimated rut profiles in relation to lateral wander of traffic at different standard deviations of a dual-wheel load

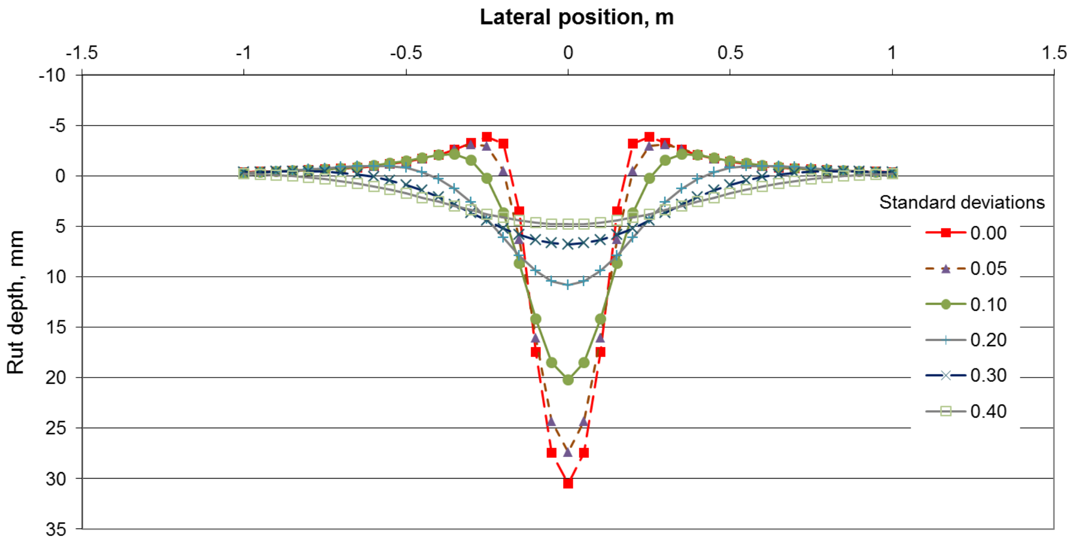

Figure 3: Estimated rut profiles in relation to lateral wander of traffic at different standard deviations of a single-wheel load

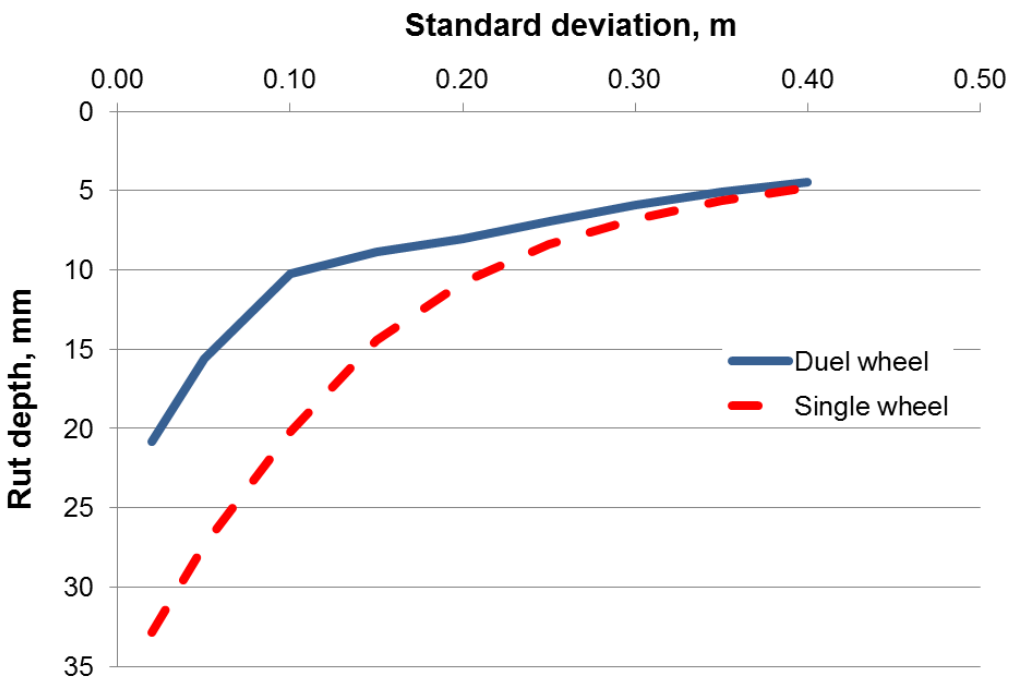

Figure 4: Influence of transversal distribution of heavy vehicles on rut depth in bituminous layer

The results from this study are comparable to the earlier studies. For example, in design of 2+1 road design to increase the traffic safety, where the traffic lanes are narrower than normal traffic lanes. Carlsson (2009) reported from field measurements that the total differences in rutting between 2- and 1-lanes sections can be more than 40 % including all types of rutting (wearing, structural and flow rutting). Erlingsson et al. (2012) reported the standard deviations of lateral traffic at 2-lanes and 1-lane sections are 0.284 m and 0.240 m respectively. The decreases in the standard deviation for 1-lane section could results in more than 20 % rutting. This study shows that pavement design methods should include estimation of the influence of lateral wander of traffic.

6 CONCLUSIONS

It is demonstrated that the PEDRO approach can be used for analysis of the influence of transversal distribution of heavy-goods vehicles in respect of rut formation in the asphalt concrete layers. The PEDRO approach results in reasonable estimation of the influence of lateral wander of heavy traffic. It is also concluded that pavement design methods for rut depth development should include the influence of lateral wander of heavy vehicles.

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