EFFECTS OF REDUCED INFLATION PRESSURE AND RIDE VELOCITY ON SOIL SURFACE DEFORMATION

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INTRODUCTION

Deformations of soil under vehicle loading is a result of soil strength weakness and, furthermore, a lack of bearing capacity. Heavy vehicles running on soft, moist soils cause huge deflections of soil surface, which are irreversible and immediate in the first pass of a vehicle. The total amount of soil deformation can be related to soil compaction, which should be minimized in case of agricultural tractors and machinery. That can be achieved by means of using wide low-pressure tyres, parallel wheels or by reduction of vehicles' mass. In case of commercial specialized vehicles, the higher the soil deformity, the greater the rolling resistance is, as more traction energy is consumed on soil deformation. Then, fuel consumption increases. It is not practical to use wide low-pressure tyres as their effects on tractive performance is negative for vehicles running on hard roads.

In the present study it was assumed that the reduction of inflation pressure and variable velocity may result in a significant decrease of soil deformation. Small or moderate reduction of inflation pressure applied for the off-road operations may be easily achieved and should not affect tread wear and hard pan traction. The second factor, which should hipothetically affect soil deformation, is ride velocity. The practical range of velocity for soft terrain operations is wide enough to investigate at least three vehicle's speeds and to predict an optimal value.

The authors of the present work have aimed to verify the assumption of both reduced inflation pressure and ride velocity effects on soil deformation using a newly developed measuring method. In the literature different methods for soil deformation determination in field experiments can be found.

MATERIALS AND METHODS

SOIL MATERIAL DESCRIPTION

The experiments were conducted on sandy soil, which is described in Table 1. The soil was prepared by manual homogenization up to the depth of 30 cm in the area of 50 × 50 cm, on which a rut depth sonde was installed. The water content in soil was approx. 4-6% and the experiments were conducted during a cloudy day, so the transpiration had not changed the water content significantly.

Table 1. Characterization of the sandy soil, on which the experiments were performed

1	2	3
$k_c = 39.31$ [kN/m$^{(n+1)}$] $k\varphi = 1051$ [kN/m$^{(n+2)}$] $n = 1.2269$	$S_{\max} = 103$ [kN/m^2] $K_w = 0.51$ [cm]	$C = 0.7$ [kN/m^2] $\varphi = 30$ °

1 – kc, $k\varphi$, n – parameters of soil state involved in Bekker's equation *describing* contact pressure-sinkage relationship;
2 – $S_{\max}$, K_w – parameters in Janosi equation on soil shear stress – displacement relationship;
3 – C, φ – cohesion and the angle of internal friction respectively.

THE METHOD OF SOIL DEFORMATION DETERMINATION

The vertical and longitudinal displacements of a point on soil surface were determined using an opto-electronic non-contact measuring system. The system consists of a deformable probe, which was put on the soil surface. Passing over the investigated soil causes displacements of the probe, which is moving together with the deforming soil surface. The displacements of the probe are possible in two directions: vertical and horizontal. The probe is supported in a uniball shperical bearing and there is a laser projector on the oposite end. While a wheel is passing over, a light point is moving on a semitransparent shield and those movements are recorded by a videocamera (see Fig. 1). The lengths of the deformable probe and the projector's arm were chosen to obtain an optical transmission, 2:1, where 1 mm of soil displacement results in 2 mm displacement of the light point.

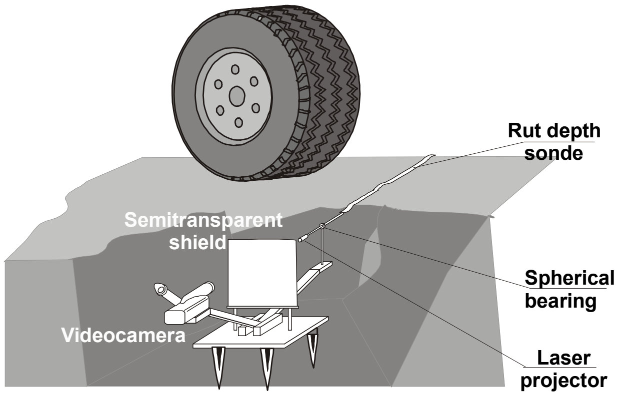

Fig. 1. A schematic view of the measuring apparatus used to determine rut depth and soil displacement

THE VEHICLES USED IN THE EXPERIMENT

Two different heavy specialized commercial vehicles were used in the experiment. The total mass of one vehicle was 14 000 and of the other one 13 500 kg. Distribution of mass as well as other vehicles' data is collected in the Table 2.

Inflation pressure was a parameter and three values were choosen: 0.6 (nominal), 0.5 and 0.4 MPa. The vehicles were driven with three velocities: 5, 10 and 15 km/h. The values of velocity were chosen with respect to the common conditions of ride when operating on a typical building place.

Table 2. Mass distribution and tyre data for the vehicles used in the experiment

Total mass (kg)	Front axle (kg)	Rear axles (kg)	Tyres
Tatra 815 W 6×6.1			
14 000	6000	2×4000	18 R 22.5
Tatra 815 C 6×6.2			
13 500	6500	2×3500	12 R 20

RESULTS AND DISCUSSION

Vertical, Z and horizontal, X co-ordinates of the light points were determined for each video grab. The absolute values of soil deformations were determined for each of the three replications and averaged. An example layout of a light point track is presented in Fig. 2. Relationships, which are functions of inflation pressure and velocity of ride, have been analysed. In Fig. 3 and 4 vertical and longitudinal deformations of soil surface for two variants of tyre are shown. In the following analysis vertical deformation will be identified with rut depth and longitudinal deformation with soil displacement.

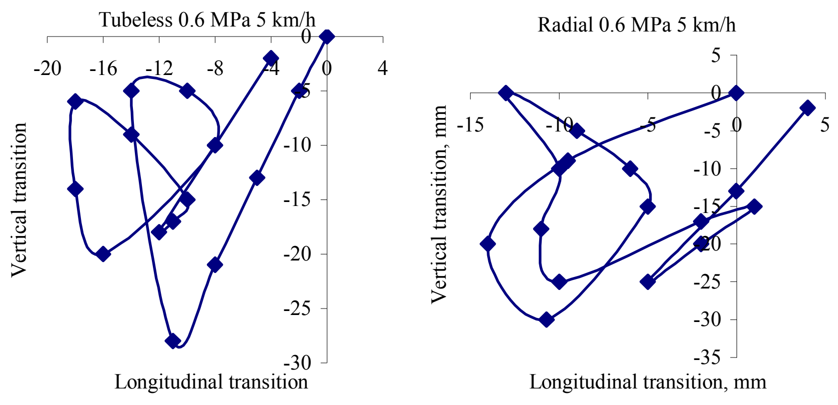

Fig. 2. Example graphs of a light point track during a single pass of the vehicle

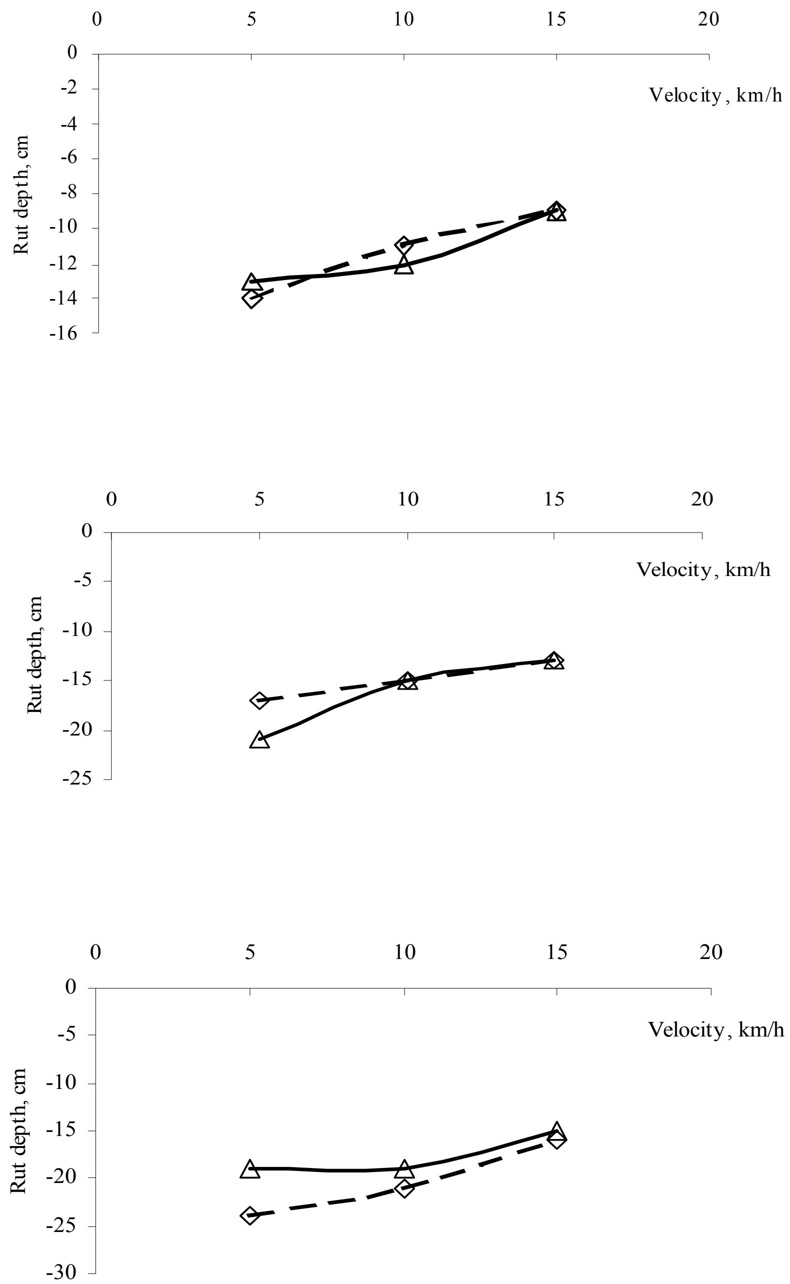

Fig. 3. Effect of reduced inflation pressure on rut depth for different velocity. Triagled line for tubeless, squared for radial tyres

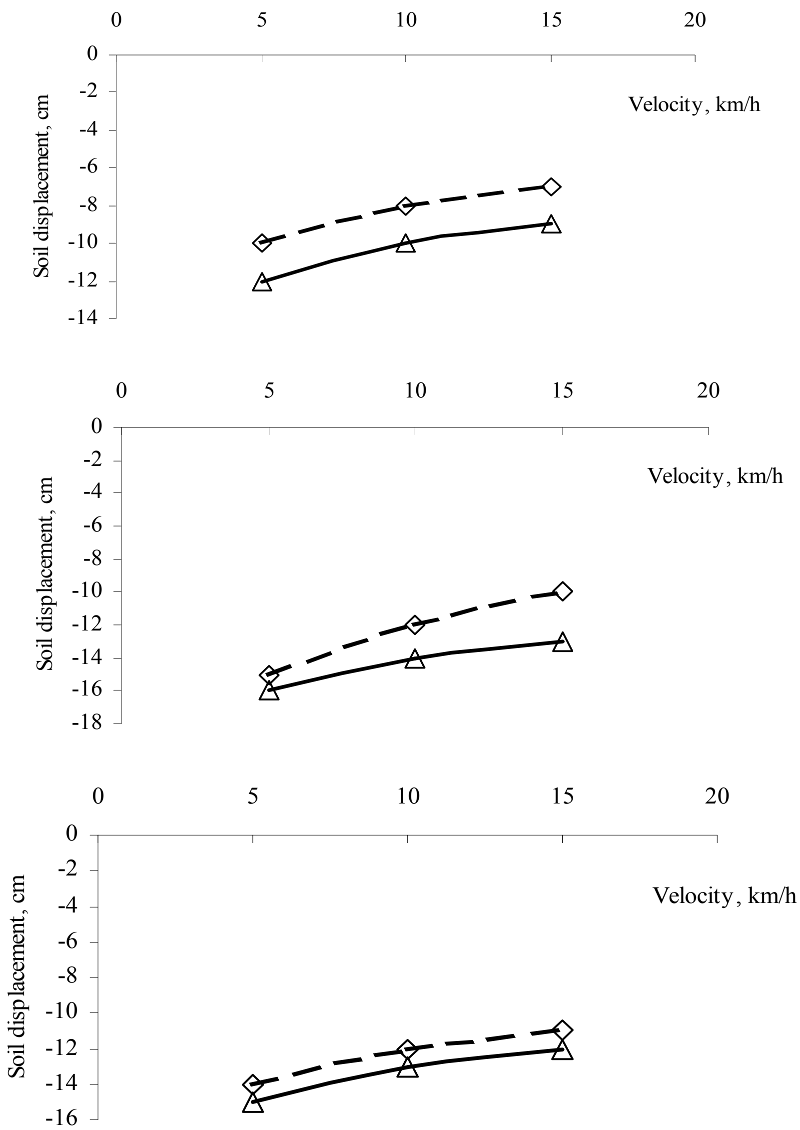

Fig. 4. Effect of reduced inflation pressure on soil displacement for different velocity. Triangled line for the tubeless, squared for the radial tyres

EFFECTS OF REDUCED INFLATION PRESSURE

Generally, reduced inflation pressure results in decrease of soil deformation in both vertical and longitudinal directions. For lower inflation pressure contact area is greater as the tyre deforms (deflects) more intensively. Moreover, contact pressure becomes smaller and the soil surface is loaded less intensively. This is easily predictable with the Bekker's equation:

$$p = (kc/b + k\varphi)zn \quad (1)$$

where:

p – contact pressure, kPa; kc,
$k\varphi$ – coefficients,
n – soil state exponent,
b – wheel width.

EFFECTS OF TYRE WIDTH

For a near identical mass of the two vehicles and for equal inflation pressure rut in most cases was deeper for a tubeless, narrow tyre. This is because of greater contact area and lower contact pressure.

For tubeless tyres there were observed relatively greater differencies in vertical deformations between front and rear roadwheels than for radial tyres. Longitudinal deformations, however, hav similar tendencies for both types of tyres.

EFFECTS OF RIDE VELOCITY

The increase of the velocity of ride always caused a decrease of soil deformation. Vertical soil deformation for the lowest value of ride velocity, 5 km/h are at least three times greater than for the highest investigated velocity, 15 km/h (30 and 10 cm, respectively). It is difficult to conclude on the effect of velocity on longitudinal deformations. In most tests, however, increased ride velocity resulted in a decrease of longitudinal deformations.

The effect of ride velocity is significant, although it is more pronounced for higher inflation pressures: the rut is even deeper for slow ride tests when inflation pressure is reduced in comparison to fast rides. A logical implementation of the above is the fact of more significant effect of reduced inflation pressure on rut depth, which was observed for smaller velocity.

CONCLUSIONS

Reduced inflation pressure has positive effects on both soil stress and minimized compaction and tractive performance of a tire. Decrease of soil deformation by reduced inflation pressure is logical and predictable.

Reduction of inflation pressure influenced rut depth. The effect of reduced inflation pressure was more significant for vertical deformation of soil surface. On the other hand, technical limitations as to reducing of the inflation pressure minimize these positive effects. It would be plausible to determine the optimum values of inflation pressure.

Further investigation should focus on improvements in measuring methodology as well as the application of other vehicles (agricultural tractors and machines, tracked vehicles) on different soil types. It would be valuable to investigate the effect of tyre slip on soil displacement and dynamic manouvers on rut depth.

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SUMMARY

Experimental investigations of the effects of reduced inflation pressure and variable ride velocity on soil deformations were carried out. A new method for the determination of both vertical and longitudinal deformations of soil surface was used. This is a non-contact opto-electronic method and allows for measurements of both vertical and horizontal displacements of a point on soil surface. Deformation of soil surface were measured for three inflation pressures: 0.6 (nominal), 0.5 and 0.4 MPa in two tyre types (radial and tubeless), which were installed in a heavy specialized vehicle of 14 000 kg mass, running with three velocities: 5, 10 and 15 km/h. The effects of both reduced inflation pressure and velocity were observed as significant. The measured vertical and longitudinal deformation of soil surface may be identified with the depth of rut z, and soil displacement j, which are variables in equations of Bekker and Janosi, respectively. For a reduced inflation pressure, rut depth and soil displacement were observed to be pronounced smaller, although the efffects are more significant for vertical than for longitudinal deformations.