EFFECT OF VELOCITY ON SOIL STRESSES UNDER LOADS OF AN AGRICULTURAL TRACTOR

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Abstract
The paper presents an experimental study on soil stresses under loads of an agricultural tractor, running at different speeds. Among numerous factors affecting soil stress distribution, vehicle speed is important, since negative effects of wheeling could be reduced by setting an optimum speed. In the paper, we have included information on experimental setup and sample results.

1. Introduction

Soil stress state under loads of vehicle's wheels is a measure that describes (1) how a vehicle impacts the surface, (2) surface response to the loads. Soil stress measurements were of high importance for description of negative effects of wheel loads on soil structure and consequently reduced crop yield in agriculture (Horn, 1994). A general method of soil stress determination by experiments is to measure soil pressure and then identify the results with soil stresses. Traditionally, normal pressures in soil were determined with the use of load cells installed at a depth (Booling, 1986, Schwanghart, 1991, Hetherington and White, 2002). The data obtained in such experiments was useful for wheel-soil models parametrization and verification. In 1987, Nichols et al have developed a SST (Stress State Transducer), which enabled to determine soil pressures needed for calculations of stress state components: principal stresses, their direction cosines and the so called octahedral stresses (stresses acting in the octahedral stress system). The method was merely used in soil bin experiments on effects of different factors influencing soil stresses: reduced inflation pressure, wheel loading, etc. There are known versions of the SST by other researchers (Harris&Bakker, 1994, Horn et al 2003,) which were used in research for agricultural application. The authors of the present paper have built their own version of the SST and have used it in numerous research programs.

Studies on the effect of vehicle speed on soil stresses by the present authors showed that stress values decreased as velocity increased; this effect was greatest with the full load. Moreover, the effect of velocity was always greater for the front wheel. This wheel deforms the soil and the primary stress distribution occurs under it. The rear wheels follow the rut formed by the front wheel and, because the soil is already compacted, the stresses do not change (decrease) greatly.

Horn et al. 1987, reported similar results of rolling velocity effect on soil stresses. A slight decrease of stresses under wheels running at higher speed is explained as the effect of shorter contact time between the tire and the soil surface. The effect of rolling velocity is weakened, however, by various dynamic effects occurring at high speed.

The cited works have provided with results that are of qualitative character. Our goal in the present attempt was to determine the effect of speed in a more quantitative manner. We aimed

2. Experimental setup

We have used two measuring systems, the first consisted of a stress state transducer (SST), the second of four single axis pressure transducers. The SST consists of six 20mm pressure sensors, which are oriented so that (Figure 1) a complete stress state can be determined based on the indicated pressures. More detailed information on the SST can be found in the literature (Nichols et al 1987, Pytka and Dąbrowski 2001).

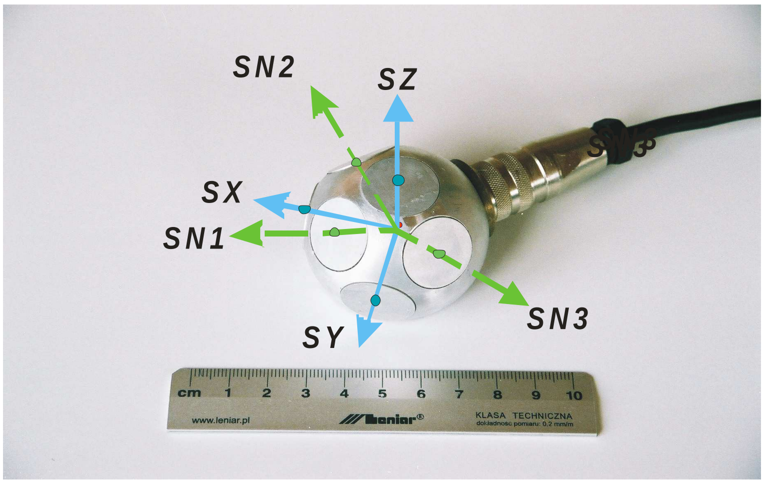

Fig. 1 Stress state transducer and the orientation of the pressure sensors

The second measuring system consisted of two pressure transducers, which design is presented in Figure 2. The transducers are encapsulated in low profile housings in order to facilitate installation in horizontal position.

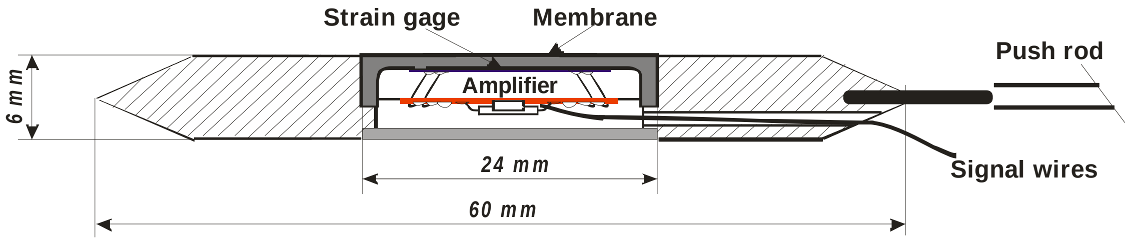

Fig. 2 Low profile pressure transducer

The both measuring systems were installed in soil at depths. The SST was installed at 10cm under the center line of the right wheels, while the low profile sensors were installed at 15, 30cm under the center line of the left tractor wheels. Installation of both SST and low profile sensors was done by simple digging a hole in soil up to the required depth (installation depth), emplacing the sensors and then filling the hole with the soil with compacting it to initial bulk density. This was done for all repetitions (5-6 times) for the five riding velocities on the two investigated soils. During installation, the points of sensor placement were precisely determined for driver's information. After installation, the signal cables were connected to the data acquisition computer and the setup was ready for the tests.

Fig. 3 Installation of the low profile sensor in soil

Fig. 4 Data acquisition computer

In the experiment, a 4 tonne agricultural tractor was used. It was equipped with 11.2x24 and16.9x30 tires (front, rear). Mass distribution was approx. 1800kg front and 2200kg rear. The tractor was driven over the investigated soil surfaces at five different velocities: 0.5, 1.0, 5.0, 10.0 and 20.0 km/h. We have calibrated the riding velocities by several measurements of time of passing a given test track (50m). It allowed to determine the RPM setting which was used by the driver during the tests. A serious problem was to drive exactly over the sensors installed in soil. Figure 5 shows the test tractor during a test ride.

Fig. 5 The test tractor during a high velocity test ride

The tests were performed on two soils: loess soil and sandy soil. Soil moisture content was determined with the use of a portable TDR meter. This device measures soil electrical permittivity coefficient and this parameter is recalculated into soil moisture. Table 1 includes soil moisture data.

Table 1 Soil moisture data indicated with the TDR meter

Depta	Less	Sand
15cm	10.96%	8.93%
30cm	16.34%	13.48%

3. Results

Sample soil pressure curves for 0.5km/h speed are shown in Figures 6 and 7, for loess and sandy soil respectively. Here we have pressures indicated by the low profile sensors (dashed lines) and by the SST (solid lines). The data are given in voltage units, knowing the scale factors for the transducers, it was recalculated into pressure units and this data is collected in Table 2. Generally, for higher velocity soil stresses decreased. This decrease for 0.5 to 20km/h range is about by 50-75%. These are primarily results and we do not conclude of any specific relationship. Further research will be performed this year and we are going to repeat the test program in moist soils (in Spring) as well as in dry soils (in august-September). Final result would include both effects of velocity, measuring depth and soil moisture content.

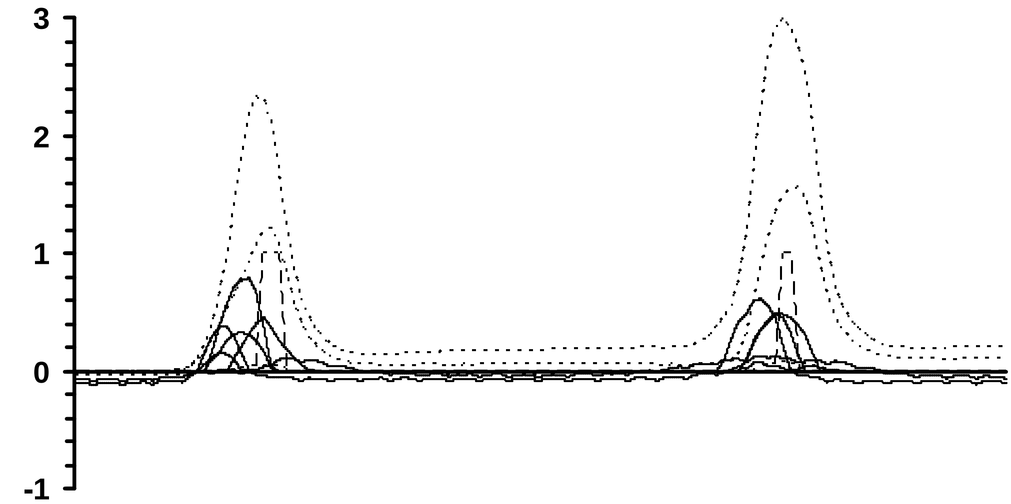

Fig. 6 Indicated pressures in loess soil under wheels of the test tractor running at 0.5 km/h.

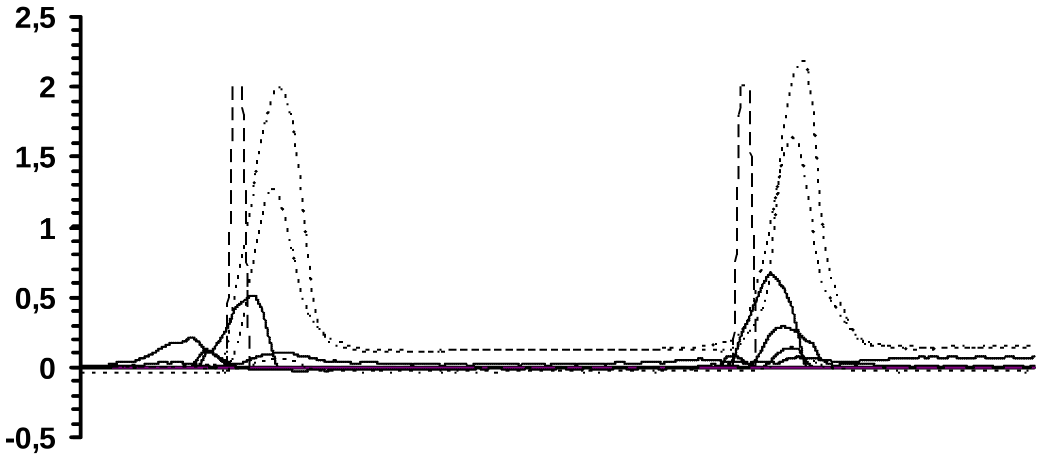

Fig. 7 Indicated pressures in sandy soil under wheels of the test tractor running at 0.5 km/h.

On the graphs in Figs. 6 and 7 you can also notice almost vertical dashed lines. The are signals from a light gate, which we have experimentally used for time correlation of measured soil pressures and the position of the wheels. A light-reflecting element was installed on the tractor exactly above the wheels centers. The purpose of this installation was to obtains synchronized data for analysis of wheel-soil dynamics effects. This will be a subject of our future research.

Table 2. Peak soil stress values at 15cm depth for the tractor speed/soil type combinations

Speed, km/h	Sandy soil		Loess soil	
	Front wheel	Rear wheel	Front wheel	Rear wheel
0.5	100,5	108,2	115,35	148,1
1.0	134,95	152,55	100,95	128,05
5.0	67,4	101,2	53,4	63,55
10.0	39,7	n.a.	30,6	26,2
20.0	26,85	51,7	18,05	n.a.

4. Conclusions

We have prepared an experiment for determining soil stresses under an agricultural tractor running at different speed, ranging from 0.5 to 20km/h. We have performed the first part of the experiment, on loess and sandy soil at soil moisture content of about 10-15%. The effect of tractor speed is that soil stress decreases for higher speed. Further research will continue and we are going to repeat the test program for moist and dry soils. We expect to develop a wheel-soil interaction model including the dynamics effect in soil medium.

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