International Conference of Agricultural Engineering
AgEng 2014 Zurich 6–10 July

Soil stresses under tracks and tyres – measurements and model development

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Abstract

In Europe, there is an increasing interest in using tracks instead of tyres on large tractors and combine harvesters. The objective of the present work was to measure soil stresses under tracks and tyres, and to develop a model to describe stresses in the contact area to make it possible to calculate stresses in the soil profile. Soil stresses were measured under different tractors at 15, 30 and 50 cm depth in the soil profile. Soil stresses under tracks were slightly higher than under dual wheels, but differences were in most cases not statistically significant. The stress under a single wheel was approximately double the stress under dual wheels at all the measured depths. Clear stress peaks were observed under the tracks, and for a Case Quadtrack with four tracks, these were only registered under the three central supporting rollers. For a tractor with two long tracks, the weight was shifted from the front to the rear part of the track when the tractor was pulling an implement compared to being without load. A first version of a model to describe stresses in the contact area under the tracks was developed, based on the principle that the bearing and supporting wheels acted as separate axles, carrying the load of the vehicle. Stress propagation in the soil profile was then calculated using equations for stress distribution under point loads. The model was incorporated into a spreadsheet, and can be a useful tool for e.g. advisors, farmers and students.

Keywords: stress distribution, stress propagation, tracks, tyres

1 Introduction

The trend towards larger machinery induces a risk of soil compaction, especially in deeper soil layers. This has led to an increased interest in replacing tyres with tracks, in order to increase the contact area and thereby reduce the stresses applied to the soil, especially for large tractors and combine harvesters.

The risk of soil compaction depends on the stress exerted on the soil. The stress at different depths can be calculated using data on the weight of the machine and the stress distribution in the contact area (Söhne, 1953; Söhne, 1958). As a rule of thumb, the maximum stress in the soil surface under a wheel can be taken as 1.5 x tyre inflation pressure (Bailey et al., 1992; Burt et al., 1992; Arvidsson and Keller, 2007; Schjønning et al., 2008). Under a track, the maximum stress can be several times higher than the average stress, calculated as tractor weight divided by track contact area, due to non-uniform stress distribution (Keller et al., 2002). This is due to peak stresses under rollers and wheels, and difficulties in distributing the weight of the tractor uniformly over the track, especially for a tractor that is pulling an implement (Blunden et al., 1992; Tijink, 1994; Keller et al., 2002). Models exist that predict the stress distribution at the tyre-soil interface from readily-available tyre and loading characteristics (e.g. Keller, 2005). However, we are not aware of any similar model that would estimate the stress distribution under tracks.

The aim of the present study was to examine soil stresses under different types of tracks and tyres fitted on tractors. A second aim was to develop a model for stress distribution under tracks, which could then be used to simulate soil stress propagation.

2 Materials and methods

2.1 Stress measurements

Soil stresses for tracks and tyres were measured using a method presented by Arvidsson & Andersson (1997). Sensors were installed at different depths in the soil profile from an excavated pit and the soil above the sensors was then subjected to traffic by all the investigated tracks and tyres. Each installation was considered as one replicate (block).

In the autumn 2013, measurements of soil stresses were made with wheeled and tracked tractors at Valstad close to Linköping in Sweden. The tractors were: John Deere 9330 equipped with dual wheels on one side and single wheels on the other side, Case IH Steiger MX 435 with dual wheels, Case Quadtrack 485 with four tracks (Fig. 1), CAT Challenger 765 B with two tracks (Fig. 2) and Valtra T191 with dual wheels. The tyres were inflated with the recommended inflation pressure for a high torque at a speed of 10 km/h. With the Valtra tractor, also a lower inflation pressure of 0.4 bar was used and compared with the recommended of 0.6 bar. Tyre and track dimensions, wheel load and inflation pressure of the tractors are presented in Table 1.

Fig 1. Tracks of the Case Quadtrack 485.

Fig 2. CAT Challenger 765 B.

Table 1. Dimensions, wheel and track load and inflation pressure for the tractors at Valstad

	Dimension	Load (kg)	Infl. pressure (bar)
JD dual wheels	650/65 R38	2550 (2000)[1]	0,6
JD single wheel	650/65 R38	4900 (4000)	1,2
Case dual wheels	710/70 R42IF	2650 (1930)	0,4
Valtra 0,4	650/65 R42	1150	0,4
Valtra 0,6	650/65 R42	1250	0,6
Case Quadtrack	185*71 cm	6400 (5430)	0,5[2]
Challenger	237*70 cm	7680	0,4

[1] Values in parenthesis show wheel load of the rear wheel. [2] Values for the tracks are calculated from the weight and the calculated track area. The length given is the distance between the wheel centers.

The CAT Challenger was driven over the sensors in two modes: without load, and pulling an implement. The implement was a 5 m wide Väderstad Top Down, working with discs and tines to a depth of approximately 20 cm, to simulate realistic working conditions in the field.

3 Results and Discussion

3.1 Measured soil stresses

Examples of stress measurements with the different tractors are shown in Figs. 3-7. For the Case Quadtrack, only the three central supporting rollers could be seen as stress peaks. At 15 cm, the peaks were very sharp, while at 30 cm the stress was more evenly distributed. The stress was evenly distributed between the front and rear of the tracks. This agrees with the study by Arvidsson et al. (2011) for a tractor with four retrofitted tracks which are allowed to rotate around a central axle.

Soil stresses at 15 cm depth for the CAT Challenger is shown in Fig. 4 without load and in Fig. 5 pulling an implement. Without load, the stress at the rear bearing wheel was very small, but increased when the tractor was pulling an implement. Compared to the study by Keller at al. (2002), soil stress in this study was relatively well distributed along the track. Soil stress for the John Deere with single wheels and the Case with dual wheels is shown in Figs. 6 and 7. The stress was similar for the front and rear tyres.

Soil stress for all tractors at the different depths is shown in Table 2. The maximum soil stress was clearly largest for the John Deere with single wheels. Soil stresses were generally lower for the dual wheels than for the tracks, although differences were in many cases not statistically significant. These results also agree with the previous study by Arvidsson et al. (2011) when comparing retrofitted tracks and tyres on a medium-sized tractor. It can be seen as surprising that the stresses of the Case Quadtrack was relatively low, since most of the load seems to have been concentrated to the three supporting rollers.

The lower inflation pressure of 0.4 compared to 0.6 bars in the dual wheels resulted in lower soil stress at 15 cm depth, although differences were not statistically significant. At 30 and 50 cm depth there were no differences, reflecting the decreasing effect of inflation pressure with depth in the soil profile. Soil stresses at 50 cm depth mainly reflected the difference in total weight for the different tyres and tracks.

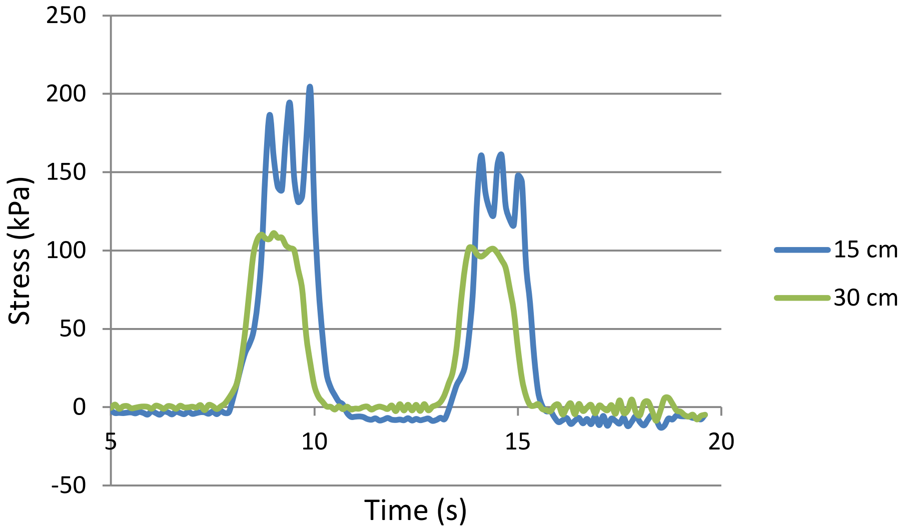

Fig. 3. Soil stress under Case Quadtrack.

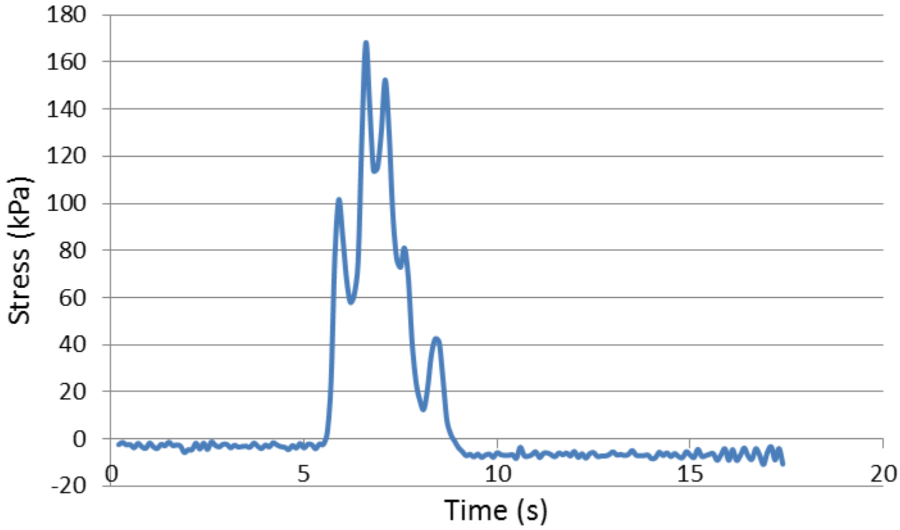

Fig 4. Soil stress at 15 cm depth under the CAT Challenger without load.

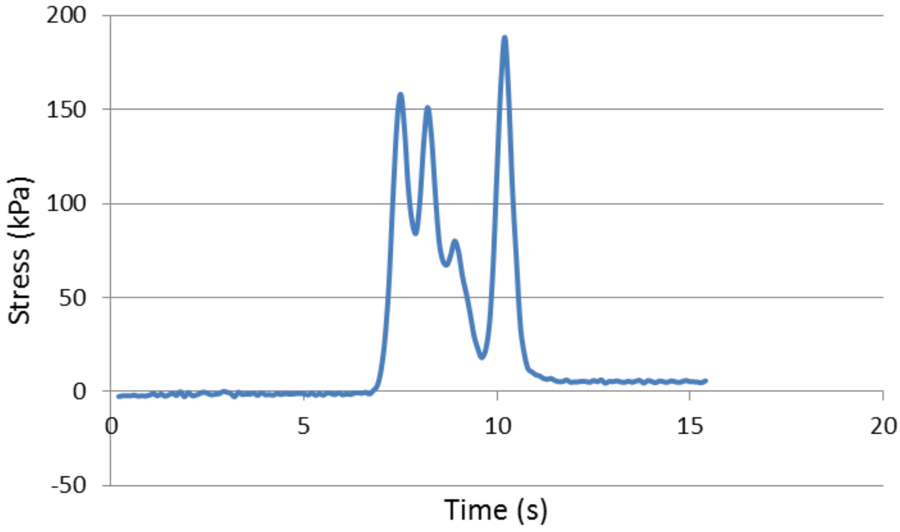

Fig 5. Soil stress at 15 cm depth under the CAT Challenger pulling a tillage implement.

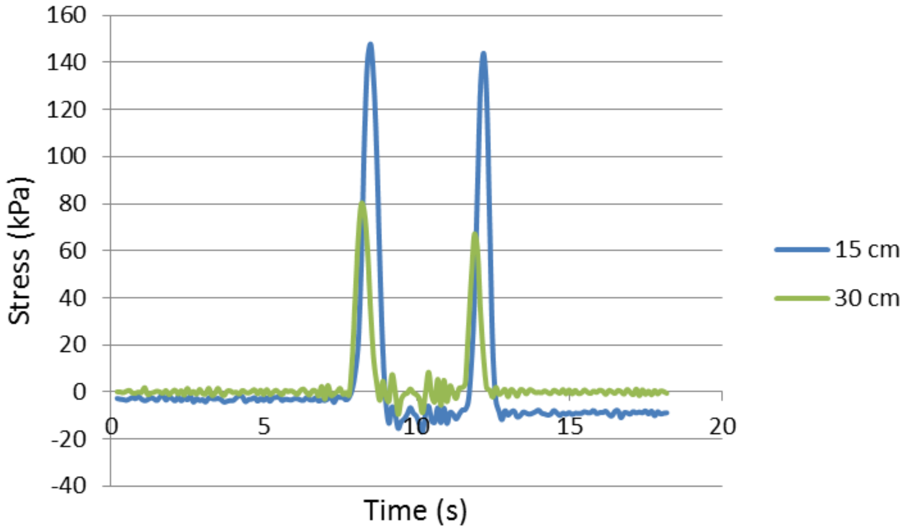

Fig 6. Soil stress at 15 and 30 cm depth for dual wheels of the John Deere tractor with an inflation pressure of 0.6 bar.

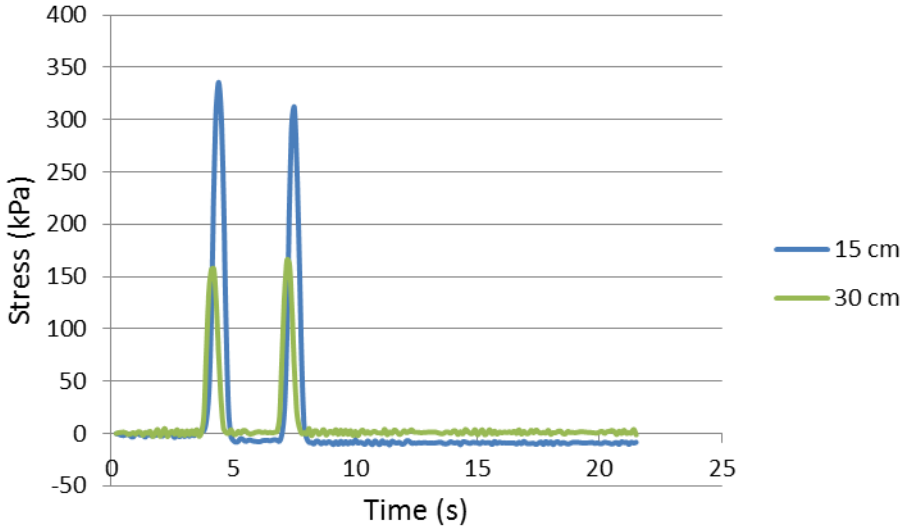

Fig 7. Soil stress at 15 and 30 cm depth for the single wheel of the John Deere tractor with an inflation pressure of 1.2 bar.

Table 2. Maximum stress at different depths. Values not sharing the same letters are significantly different (P<0.05)

	15 cm	30 cm	50 cm
JD dual wheels	147bc	96c	70bc
JD single wheel	296a	215a	151a
Case dual wheels	115cd	98bc	73bc
Valtra 0.4	99cd	51d	36cd
Valtra 0.6	111c	51d	35d
Quadtrack	126bcd	118bc	98b
Challenger no load	161b	117bc	94b
Challenger loaded	159b	142b	80b

3.2 Modelling of soil stress

We developed a first, simple and pragmatic model for generation of stress distribution at the track-soil interface based on our stress measurements. The model consists of a macro written in Visual Basic implemented in an Excel file, and requires the input of the track length and width, the load on the track, as well as the number of supporting rollers. The model assumes a diameter of 0.25 m for the rollers and a track length dependent diameter for the wheels (idler and sprocket), distributes the rollers at even distances between the wheels, and calculates the stress at the track-soil interface by assuming a parabolic stress distribution over the wheels and rollers and a minimum vertical stress of 10 kPa between rollers and roller and wheel. An example of the output is given in Fig. 8.

Stress in the soil profile was calculated using the Söhne (1953) summation procedure based on the work of Boussinesq (1885), e.g. by employing SoilFlex (Keller et al., 2007). Hereby, the stress at the track-soil interface was generated from track characteristics as described above, and used as upper stress boundary condition for the simulations.

Comparisons of simulations with measurements show that the simple model for stress at the track-soil interface yields a pragmatic and satisfactory approximation of the real stress distribution, but that the approach tends to slightly underestimate stresses in the soil. We also note that the representation of a track undercarriage with wheels of unequal diameters (such as in Fig. 2) cannot be properly represented with the simple model. Further work is therefore needed to refine the model.

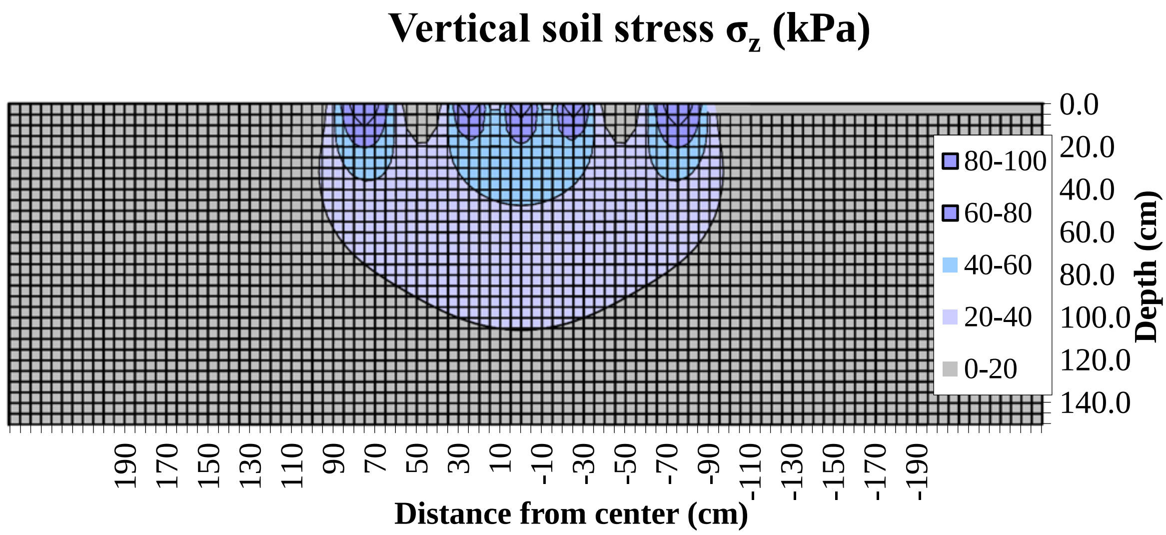

Fig. 8. Calculated vertical soil stress under a track with a load of 6400 kg, track length 185 cm and track width 71 cm.

4 Conclusions

Dual wheels reduced soil stresses to approximately half compared to single wheels at all depths: 15, 30 and 50 cm. Reduced inflation pressure in the dual wheels reduced soil stress at 15 cm depth but not in deeper layers. Soil stresses under the tracks were slightly higher than under the dual wheels, but differences were in most cases not statistically significant. Clear stress peaks were observed under the tracks, and for the Case Quadtrack, these were only registered under the three central supporting rollers. For the tractor with two long tracks, the weight was shifted from the front to the rear part of the track when the tractor was pulling an implement compared to being without load. Maximum stress was approximately the same in both cases. The proposed model for stress distribution shows promising results but will be refined using also other measurements of stresses under tracks. It then can be a useful tool for e.g. advisors, farmers and students.

5 Acknowledgements

This work was financed by the Swedish Farmers' Foundation for Agricultural Research (SLF), which is gratefully acknowledged. We also want to thank the farmers who made their tractors available for this test.

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