Measurement of Stress and Strain distributions Beneath Wheels

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INTRODUCTION

The objective of this study was to examine the distribution of tyre imposed stresses, soil displacements and soil mechanical properties as function of the soil surface geometry. The study was performed using the advanced soil bin facility at Silsoe College (Cranfield University), England. Valuable experience was gained in using this type of equipment (which is not available in Australia) and several new links with overseas soils and agricultural researchers were established. The following report outlines the experiments that were performed and briefly discusses some of the outcomes from this research. Further analysis of data from these experiment is taking place at CSIRO Division of Soils.

MATERIAL AND METHODS

Traffic Treatments and Tyre Specifications. Wheeling experiments were conducted to assess the influence of tyre imposed stresses in bed/furrow systems of different geometry using the Silsoe College Soil Bin Facility. A ribbed Vredestein 20.0/70 - 20 12 ply tyre was inflated to 200 kPa and loaded with 3000 kg to simulate large tractors commonly used in Australian irrigated cotton (Blunden et al. 1992). The tyre was pulled in all experiments. Three experiments were performed. i) Single pass of the tyre on a horizontal soil surface (i.e. no furrow). ii) Single pass with the tyre bridging across the shoulders of an engineered furrow. The furrow was made by progressively slicing a thin arc of soil from the soilbin with an inclined disc. This proceedure successfully formed the desired furrow shape whilst minimising the disturbance to the adjacent soil. The furrow was 0.15 m deep and 0.45 m wide. This enabled the tyre to bridge across the shoulders of the furrow. The initial shape of the furrow can be seen in Fig. 1. iii) Multiple passes of the tyre were performed on a horizontal soil surface. the soilbin was divided into three sections so that measurements were taken during/after one, two and five passes of the tyre. After each pass the tyre was lifted from the soil and placed at the original starting position to maintain tyre travel accuracy.In each of the experiments normal stress, soil displacement and soil mechanical properties were measured during or after the passage of the tyre. Soil Properties. A uniform soil profile 1.7 m wide and 0.8 m deep was engineered. The soil used in the Soilbin was clasified as a Sandy load (Soil Survey Staff, 1975). Accurate layering and rolling of the soil ensured a uniform bulk density of 1460 kg m-3 (standard deviation 0.05 kg m-3) down and across the profile. A moisture content of 0.095 kg kg-1 (standard deviation 0.005 kg kg-1) was maintained for all wheeling experiments.

Earth Pressure Cell Measurements

Normal stresses exerted upon the soil by the passage of the tyre were recorded using the system described by Blunden et al. (1992). Sixteen Earth Pressure Cells (EPCs) were placed at a variety of depths and widths from the centreline of the tyre to describe the normal stress distribution beneath the tyre. The EPCs were installed in the soil bin by excavating a shallow trench (10 mm depth) in the prepared soil layer. The EPCs were carfully placed in an upright orientation and then covered with soil by hand. The next layer of soil was then added to the soil bin with particular attention to the maintenance of uniform bulk density. The EPCs were connected to a PC-based data logger that recorded the signal from each EPC at a rate of 200 Hz. Normal stress data were recorded for a 10 second period as the tyre was driven over the EPCs. After the traffic trials, the EPCs were carefully excavated, noting any change in their orientation and/or depth with soil strain. Traffic-induced normal stresses were calculated according to individual EPC calibration functions. Soil Dispalcement Measurement White paint lines were incorporated onto the soil during the soil bin preparation. The paint lines were approximately 2mm in diameter and were placed at horizontal distances of 0.05m across the soil bin on each 0.05m soil layer. The lines were painted in the direction of travel of the tyre so that, after wheeling, a vertical face cut into the soil across the direction of travel appeared to have a white "grid" of points. Displacement of the "grid" points (estimated by image analysis of photographs of the grid) from the original 0.05m by 0.05m spacing indicated the deformation caused by the tyre and could be used to calculate secondary quantities such as shear and volume strains.

Three replicates of the wheel rut profile was measured using a profile meter after each experiment. The initial geometry of the furrow treatments was also measured. Laboratory Soil Mechanical Measurements uniaxial compression tests Three replicate intact soil cores (60 mm diameter x 52 mm long) were sampled for the determination of uniaxial compression properties after traffic. After the single pass horizontal surface and furrow treatments, cores were sampled at the surface and at 100 mm depth increments (100-500 mm) from the initial pre-traffic soil surface at the centreline of the tyre and at 100, 200 and 300 mm distances from the centreline. After the multiple wheeling treatment three replicate cores were sampled down the centreline of the tyre at 100 mm depth increments from the surface to 500 mm. Intact soil cores were taken from the centreline of the soil bin at 100 mm depth increments for characterisation of the initial soil state. Dynamic uniaxial compression tests were carried out in a triaxial loading frame where compression occurred at a constant rate. Normal stress and change in height was measured using a load cell and a Linear Variable Displacement Transducer (LVDT) and logged at a rate of 2 Hz using the system described above. penetrometer resistance Soil penetration resistance was measured using a electronic cone penetrometer. The penetrometer had a cone of 20 mm diameter and an enclosed angle of 30o. Three replicates of penetration resistance was measured at 0.025 m depth increments and at 0.11 m spacings across the soilbin both before and after traffic direct shear tests

Thirty intact cores were sampled before traffic to determine the shear characteristics of the soil. Shear strength, lateral displacement and change in height were measured using a load cell and two Linear Variable Displacement Transducers. Shear tests were carried out at normal stress ratios of 0.1, 0.3, 0.6 and 1.0 with maximum normal stresses of 100, 200 and 300 kPa. This proceedure allows an exploration of different forms of soil behaviour, including regimes of expansion and compression during shear (Kirby, 1989).

RESULTS Data and analysis of these experiments will be reported in Kirby et al. (1995) and Blunden et al. (1995). At present, both these papers are in preparation. Tyre induced normal stresses Contour plots of EPC data are presented in Figs 2-4. The actual maximum values recorded by the EPCs are shown on the plots in their actual positions. Fig 2 Distribution of stress under a flat soil soil surface For the horizontal surface treatment, the distribution of the normal stresses is similar to that predicted by theory as early as Soehne (1956), with large stresses (190 kPa at 0.1 m depth below the tyre centreline) at the surface directly beneath the tyre decaying to lower stresses (30 kPa at 0.5 m depth below the tyre centreline). Stresses also decreased with distance away from the centreline of the tyre. Stresses measured at 0.1 m depth below the centreline of the tyre (190 kPa) were only slightly less that the tyre inflation pressure (200 kPa).

The distribution of normal stresses from the furrow surface geometry experiment was distinctly different. Large stresses are projected at an angle into the side of the furrow whislt relatively low stresses are imposed beneath the centreline of the tyre. Fig 3 Distribution of stress under a furrow soil surface The distribution of normal stresses measured in the multiple wheeling treatment is shown in Fig 4. Fig 4 Distribution of stress: Multiple wheling The magnitude and distribution of stress is similar to that of the single pass horizontal surface treatment. Between the first and fifth tyre passes neither the magnitude of the stresses nor their distribution changed appreciably. Tyre induced soil displacement Fig 5 shows the soil displacement data for each of the experiments.

Vertical soil displacement under the tyre on the horizontal soil surface showed that downwards soil movement was greatest under the centreline of the tyre. Downwards soil displacement decreased as distance from the centreline increased. At 200 mm from the centreline (where no soil/tyre contact took place), expansive, tensile failure of the soil occured giving a upwards soil displacement. As depth increased beyond 100 mm, all soil displacement occurred in the downwards direction. The magnitude of the vertical displacement decreased with increasing depth to about 300 mm depth, whereafter the magnitude of the change in soil displacement was within the measurement error.

Vertical soil displacement for the furrow treatment shows that the area of maximum influence was beneath the edge of the tyre. At 150-200 mm from the centreline of the tyre, soil displacement of 19-22 mm occurred at the soil surface. Under the centreline of the tyre, maximum vertical soil displacement was 5 mm. The maximum depth of significant detectable vertical soil displacement (ie within error tolerance) was approximately 250 mm. This is less than the corresponding maximum depth of influence for the horizontal surface. The geometry of the soil displacement in the multiple wheling experiments was similar to that measured in the horizontal soil surface experiment. The soil displacement measured after the first, second and fifth passes in the multiple wheeling experiment showed that considerable soil movement occurred after each tyre pass. However, these soil movements became less pronounced after each pass.

Soil mechanical properties

The soil mechanical data collected before and after these experiments is attached in Appendix 1. The preconsolidation data for the three experiments correspond to the stress and displacement measurements discussed above. In general, the soil become denser and stronger where the imposed tyre stresses were greatest and where soil displacements were largest. Cone penetrometer data confirm the zone of compaction caused by the apssage of the tyre. These data are shown in Appendix 2.

CONCLUSIONS

1. This data set provides a comprehensive record of stresses measured in the soil, soil movement and soil mechanical properties measured brfore, during and after the passage of a pulled tyre. These data will enable validation of soil mechanical models that predict the impact of traffic on the soil. 2. The distrubution of stresses and movement of soil beneath tyres in the horizontal soil surface experiments confirm known theory. Maximum stresses and soil movements were measured at the soil surface beneath the centre of the tyre. Smaller stresses and soil movements were recorded at increased distances from the centreline of the tyre and with increased depth.

The distribution of stresses and soil movement measured in the furrow experiment was considerably different than for the horizontal soil surface. Maximum soil stresses and movements were found beneath the tyre edges, where they came into contact with the shoulders of the engineered furrow. The soil became more compact beneath the shoulders of the furrow, possibly giving rise to reduced levels of water and air entry and increasing the density of soil within or near the root zone.

These data demonstrates the need for properly configured wheel furrows. If furrows are too narrow then tyres may bridge across the furrow thereby inducing considerable soil stresses and movements into the root zone. Furrows that enable the tyre to maintain contact with the soil on the centreline of the tyre will direct stress and soil movements directly downwards, thereby minimising the migration of compaction into the root zone.