Experimental and Numerical Study of Soil Stress Induced by Dynamic Loads Applied on Soil Surface

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Abstract
The purpose of this paper is to present experimental results related to pressure induced in soils by different loads on soil surface.
Many studies have been led to estimate soil stress, in the agricultural area in order mainly to prevent soil compaction, and in the demining area in order to assess the performance of mechanical demining systems.
In this last area, tests have been carried out in the field with a force measurement sensor, in a French DGA test laboratory. The aims of these tests are to identify the physical interaction process between mechanical demining devices and mines laid or buried in soils, and to calibrate models based on experimental data, obtained on natural soils for conditions encountered in operational cases.
Apart from experimental results obtained in the field, a theoretical model, based on Boussinesq theory, is presented.
This paper presents results which are parts of a global approach aiming at the assessment of mechanical demining system performances.

Keywords: *soil stress, soil, impact loading.*

1. Introduction

Mechanical demining systems are used in military operations and humanitarian landmine clearance operations in order to neutralize mines on paths or areas. These systems are designed to apply mechanical actions, directly or indirectly on mines laid or buried in the superficial layer of the soil. In the field, there is a need to predict the success of clearance operations which can be hampered mainly by soil conditions depending on water content and compaction for a given type of soil.

2. Experimental approach

Stress has been measured in natural soils using a force measurement sensor, with a 0 - 20 kN measuring range. This sensor, shown in Fig 1, is a cylinder which has been buried in the soil. Forces are measured on its upper part, which is a 13 cm diameter disk.

Figure 1: force sensor

Series of experiments have been conducted, in ETAS, to assess forces and stress induced in natural soil while applying loads at the soil surface. Examples of measured forces in the same soil at 10 cm depth, for three types of promptings are presented in the following figures.

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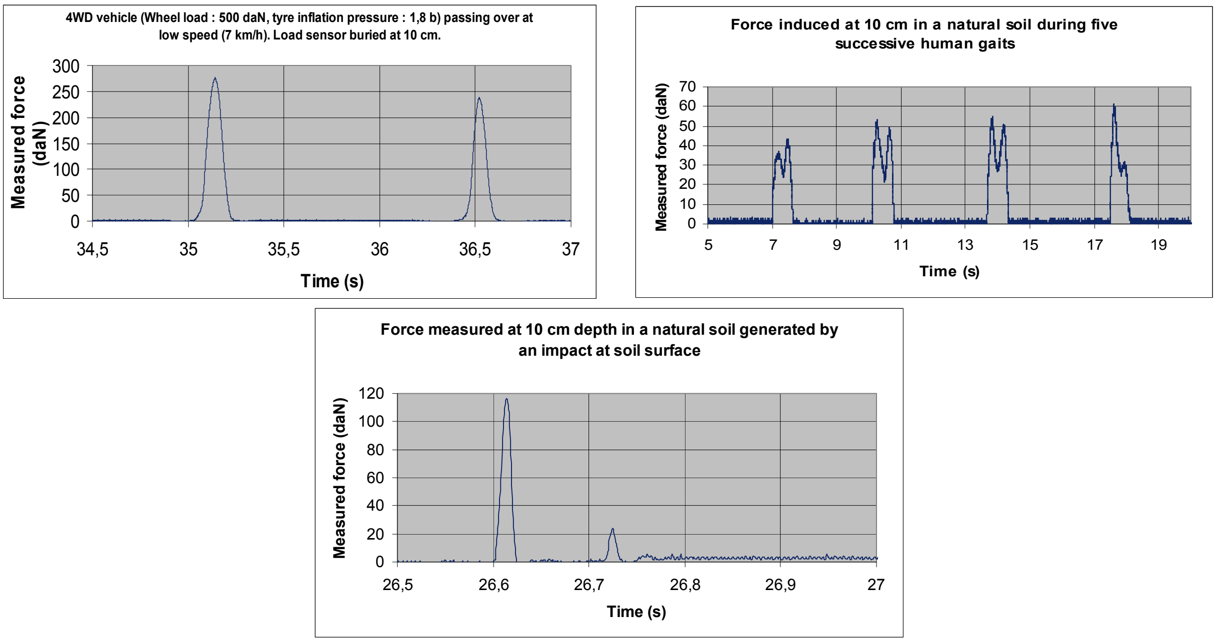

Figure 2, 3 and 4 : time plots of force measured in a natural soil, in ETAS, at 10 cm depth

Two recent papers [1] and [2], related to soil stress distribution from impact mechanisms at soil surface, give information on maximum stress level measured using a laboratory device.
The first one presents stresses induced in a sand cushion with a 10 cm thickness. Stresses are recorded at the bottom of a laboratory device.
The second one is related to an interesting study carried out at the University of Saskatchewan on a sandy clay loam. Impact loading tests carried out on a soil box show the maximum stress level as a function of depth and impact level.
Experimental results from these two papers complemented with results obtained on natural soils in ETAS, have been gathered in the following figure.

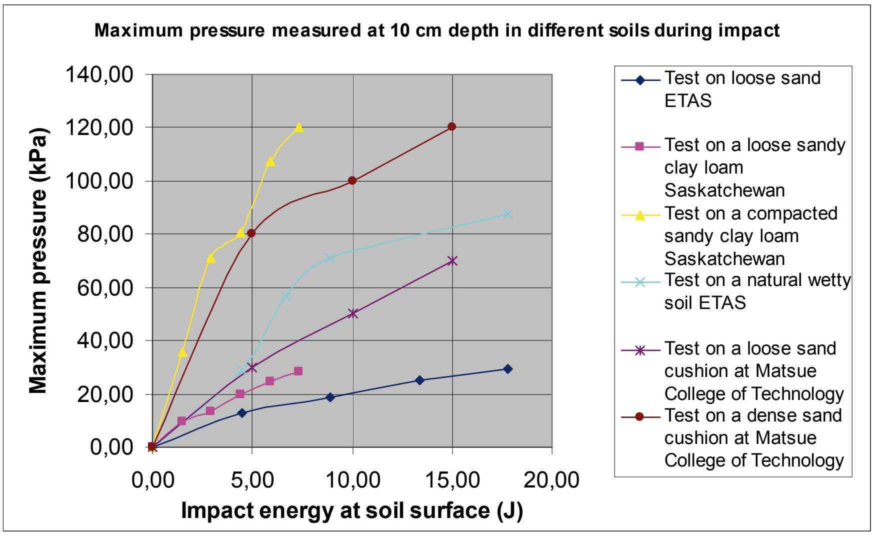

Figure 5

These results put in evidence that the impact transmission is higher in dense soils than in loose soils.
In conclusion, impact loading tests are important to predict soil response and efficiency of non intrusive demining tools.

3 Numerical approach

For estimating stresses induced in the soil by a distribution of forces applied on its surface, Boussinesq analytical solution has been used, adding all the elementary contributions of these forces on a soil surface mesh. Assumptions are then :

- continuous distribution of forces applied on the soil surface are distributed on each node of the previous mentioned mesh ;
- dynamic effects are ignored, forces are applied in a quasi static way ;
- superficial soil layer is considered as a semi-infinite homogeneous and isotropic elastic medium.

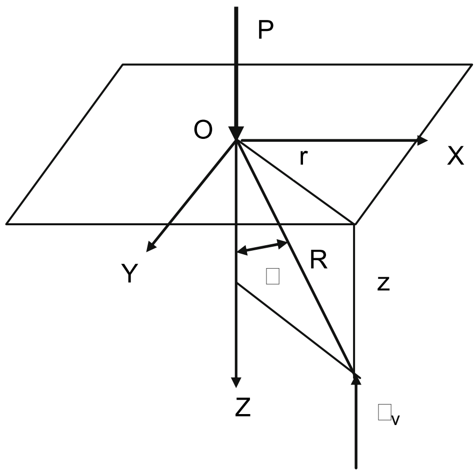

Figure 6

In the soil, at a depth z, the vertical Boussinesq stress induced by a concentrated load P at the soil surface, takes this analytical form :

$$\sigma_z = \frac{3 \cdot P \cdot z^3}{2\pi \cdot R^5} = \frac{3 \cdot P}{2\pi . R^2} \cdot \cos^3 \beta$$

Frölich has modified this equation in order to take into account soil hardness, with this formula :

$$\sigma_z = \frac{\nu \cdot P}{2\pi . R^2} \cdot \cos^{\nu} \beta$$

Where ν is a parameter whose value depend on soil hardness.
When ν =3 the stress correspond to vertical Boussinesq analytical solution.

For a given load distribution applied on the soil surface, vertical soil stress can be computed by adding the contribution of all elementary concentred loads.
This numerical model has been applied to impact load tests, assuming there is no speed effect on the propagation of impact in the soil (Boussinesq solution is valid for static loads). Comparisons have been made between the analytical solution and ETAS experimental results and impact loading tests results obtained at Saskatchewan University [2].

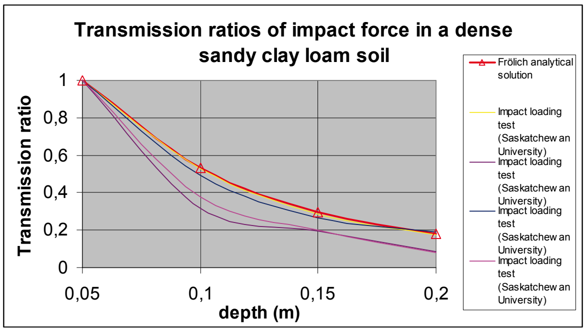

Figure 7

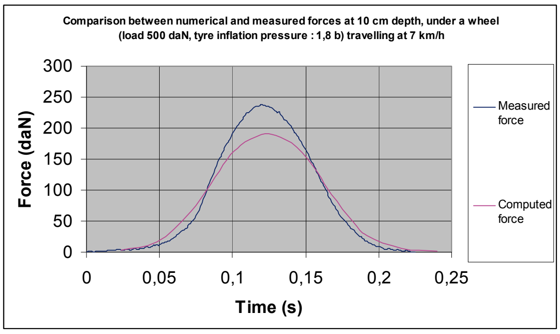

Figure 8

Assuming that impact is fully transmitted in the upper soil layer (5 cm thickness), the transmission ratio between stress at various depths and stress at 5 cm, decreases with depth (figure 7). Discrepancies between numerical and experimental values of the transmission ratio put in evidence dynamic effects on stress propagation in soil.
Measured force at 10 cm depth, under a 4WD vehicle travelling at 7 km/h, iscompared to numerical result in figure 8.

4 Conclusion

- For a same load and a same depth, the maximum pressure measured, varies significantly, with the type of soil, soil water content and soil density.
  The harder the soil, the lower must be flails speed. But Kushwaha et al. [2], have shown that the impact load transferred in soil will increase with soil compaction level.

- Before choosing which mechanical system should be employed for clearance, there is a need to collect soil mechanical properties of the zone to be treated in order to make effective clearance works.
  Impact load tests cannot be carried out in the field, so a solution to assess soil hardness, could be, for instance, to correlate transmission ratio of impact force (ratio of earth pressure to impact pressure) to cone index.

- To evaluate Mine clearance efficiency, effort should be focused on a few critical parameters :
  - mine depth ;
  - size of mines ;
  - size of the tool part in contact with soil ;
  - type of soil ;
  - density and water content of soil ;
  - soil relief.

5 References

[1] Soichiro Kawahara. Shape effect of falling weight on impact response against sand cushion.
16th International Conference of ISTVS. Torino. 2008.

[2] Jude Liu and R. Lal Kushwaha. Comparison of soil stress distribution from impact mechanism and smooth roller for neutralizing antipersonnel landmines.
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