THE DETERMINATION OF SOIL DEFORMATIONS AS A RESULT OF THE APPLIED PRESSURE BY THE TRACTORS ROLLING PARTS AND THE AUTO PROPELLED AGRICULTURAL MACHINES

DETERMINAREA DEFORMAȚIILOR ÎN SOL CA URMARE A PRESIUNII EXERCITATE DE ORGANELE DE RULARE ALE TRACTOARELOR ŞI MAŞINILOR AGRICOLE AUTOPROPULSATE

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Abstract: *In this paper were effectuated complex tests for validating the analysis models MEF, realizing experimental test bulletins, in the soil channel, respective on hydropulse and in terrain, of the tensions and deformations distribution in the agricultural soil in contact with the tractors and agricultural machines rolling parts.*

Rezumat: *În această lucrare s-au efectuat încercări complexe pentru validarea modelelor de analiză MEF, realizându-se buletine de încercare experimentală în canalul de sol, respectiv pe hidropuls şi în teren, a distribuției tensiunilor şi deformațiilor în solul agricol în contact cu organele de rulare ale tractoarelor şi maşinilor agricole.*

***Key words*:** *tests, deformations, soil, tractors, agricultural machines, rolling parts*
***Cuvinte cheie*:** *încercări, deformații, sol, tractoare, maşini agricole, organe de rulare*

INTRODUCTION

Because of the big contact surface of the tire with the deformable soil, the pressure on the soil is more reduced than in the case of tire rolling on a rough surface. With all these ones, the pressure on soil exceeds sometimes the admitted limit for protecting the soil structure. The imposed requirement is that the tire pressure on soil do not exceeds 1,0 daN/cm^2, at field works and 3,0 – 3,5 daN/cm^2 at transportation works on field roads. The experimental data attests that, generally, the minimum limit of 1,0 daN/cm^2 is respected by the tractors driving wheels which have tyres with big diameter and section width and, at which the pressure on soil is close to 1,0 daN/cm^2, but it is exceeded by the front wheels, of direction, at which the pressure on soil is close to 2,0 daN/cm^2. At the transportation trailers the pressure on soil exceeds often the limited pressure of 3,5 daN/cm^2. To avoid the soil settling, with all its negatives after-effects, it is necessary that in tires exploitation to be applied some measures which will conduct to the pressure reduction on soil, knowing that this depends on: load on tire, inflating pressure, tire dimensions and the rolling pattern, the tire stiffness, etc.

In theory, the tire pressure on soil (p_s) is given by the sum between the inflating pressure (p_u) and the pressure difference given by the tire casing stiffness (Δ):

$$p_s = p_u + \Delta_p \text{ (in daN/cm}^2\text{)}$$

If it's neglected the stiffness, the pressure on soil is relative equal to the tire inflating pressure. The real pressure on the deformable soil is determined experimentally by direct measurements between the soil surface and tire.

In practice it is calculated and compared the conventional pressure on soil which is the ratio of the load on the tire and the supporting surface (A) of the tire on a flat terrain, determined by direct measuring of the print or calculated with the relation:

$$A = \pi \cdot f' \sqrt{(D_e - f') \cdot (B_e - f')}\,, \quad \text{in cm}^2,$$

in which:

f is the tire radial deformation;

D_e – exterior diameter;

B_e – section width;

In this case the pressure on soil *(p_s)* is calculated by splitting the load on tire *(Q_r)* to the supporting surface *(A)*:

$$p_s = \frac{Q_r}{A} \quad (in \quad daN / cm^2)$$

The value of this pressure is given in the technical books of different tractors, agricultural machines and trailers.

MATERIALS AND METHOD

The effectuated tests were concentrated especially on:

- The determination of pressure on soil and the comportment to tires natural rolling:
  - frontal for harvester-thresher C 110H;
  - frontal and in the back for tractor U 445 (45 HP);
  - frontal and in the back for tractor U 650M (65 HP).
- static test at compression, on hydropulse (in laboratory), simulating the pressing on the field soil, for the following tires:
  - frontal for harvester-thresher C 110H;
  - frontal and in the back for tractor U 445 (45 HP);
  - frontal and in the back for tractor U 650M (65 HP).

For each of this tests: in real conditions or simulated (on hydropulse) were elaborated experimental tests bulletins (6), bulletins which contain: the tires dimensional characteristics, the exploitation testing conditions, the results of tires dynamic characteristics determination (in case of real conditions testing), respective: the compendious description of the testing way, the testing place, measuring apparatus and equipments used, calibration, static compression test, testing results (in case of hydropulse simulated tests).

In case of laboratory effectuated tests on the testing installation in simulated and accelerated regime type Hydropulse, for simulating the *static compression test of the wheels (tires) beside the soil* were used a pair of plates of 15 mm thickness, with dimensions L x l similar to the *contact stains* of the tractor/harvester wheels of which value we want to find out.

For this it was realized a box of 1 m^3 of sheet metal with thickness of 3 mm, reinforced (figure 1), with dimensions: 1 x 1 x 1 [m], specially executed for this test, in which there were mounted the *8 force sensors Flexi Force* Tekscan, type W-B201-L (maximum domain used for this test 10 N / 50,24 mm^2), specially acquired for this type of tests, for being mounted in soil at different depths (figure 2).

Figure 1

Figure 2 - The force sensor Flexi Force applied on soil before being covered by soil and to the depth of 75 cm and after it was covered to the depth of 5 cm

Figure 3- Force sensors applied to the depth of 5÷75 cm with the outputs towards the laptop and the acquisition board

Figure 4 - The tests command centre and the soil humidity measuring with humidometer type HH2

Before beginning the tests there was measured the soil humidity for each effectuated test. This was realized using a humidometer for soil, type HH2 (figure 10).

The force measuring system (the 8 sensors) was mounted in the box, beginning with 5 cm from the top level of the box (all the box was filled with soil), from 10 to 10 cm, until the depth of 75 cm. The force measuring system (the force sensors *Flexi Force* – figure 5) was connected to an adapting module (consisting of amplifiers and analogue-numeric converter on 8 bits) and coupled to the serial interface 4RS 232 for connecting it (by USB) to the adapting module (acquisition system) and laptop (figure 5).

Figure 5 – Force sensor Flexi Force , Laptop and acquisition system

Pressing on the plate was achieved with the help of a 10 kN cylinder and of some intermediary devices, assured by INMA Bucharest.

The testing equipment: Testing installation in simulated and accelerated regime type Hydropulse – Germany (figure 6).

Figure 5 – Testing installation in simulated and accelerated regime type Hydropulse

RESULTS AND DISCUSSION

For validating the analysis models MEF previously realized there were effectuated more determinations (in field and laboratory), determinations which are presented as synthesized testing bulletins (6), as follows:

- Testing bulletin no. 1 – The pressure on soil determination and the comportment to natural rolling of tires 18,4-26, 8PR D-165R3 from the harvester thresher C 110H
- Testing bulletin no. 2 – The pressure on soil determination and the comportment to natural rolling of tires 7.5-16, 8PR D-191 from the tractor U 445
- Testing bulletin no. 2 – The pressure on soil determination and the comportment to natural rolling of tires 7.5-20, 8PR D-191 from the tractor U 650
- Testing bulletin no. 4 – Static compression test for driving wheel (front) harvester C 110H;
- Testing bulletin no. 5 – Static compression test for direction wheel (front) tractor U 650;
- Testing bulletin no. 6 – Static compression test for driving wheel (back) tractor U 445;

Next it will be presented a testing bulletin model (for field determinations) and a testing bulletin model (for laboratory determinations – on hydropulse)

TESTING BULLETIN no. 1 (field determinations)

1. Product: driving wheel (front) harvester C 110H
2. Test: the pressure on soil determination and the comportment to natural rolling of tires 18.4-26, 8PR D-165R3 from the harvester thresher C 110H
3. Dimensional characteristics of tires 18.4-26, 8PR D-165R3

For determining the dynamic characteristics and the comportment to natural rolling in exploitation conditions specific to agriculture, there were tested two tires 18.4-26, 8PR D-165R3.

The tires constructive characteristics, after the data of the producing company SC DANUBIANA SA, are presented in table no. 1.

Constructive characteristics of tires 18.4-26, 8PR D-165R3

Table 1

Characteristics given by the producing company	M.U.	Value
▪ Section width	mm	467
▪ Exterior diameter	mm	1.450
▪ Static radius	mm	670
▪ Maximum load	kg	2.265
▪ Pressure at maximum load	bar	1,4
▪ Maximum working speed	km/h	30
▪ Recommended rim	-	16 x 26

4. Testing conditions in exploitation

Dynamic characteristics:

- the rolling circumference and the effective rolling radius;
- under load radial and lateral deformation;
- the supporting surface and pressure on soil.

The tires 18,4-26, 8PR D-165R3 were mounted as driving wheels, on the front axle of a cereal harvester C 110H.

The working conditions, at which the tires were subjected, were framed in the normal limits of the exploitation regime, according to table no. 2.

Table 2

Testing conditions in exploitation

Tractor on which were tested	Using domain	Load on tire [kg]	Regime pressure [bar]	Working speed	
				Agricultural works [km/h]	In transportation [km/h]
Auto propelled harvester C110H	Works in big culture and at harvesting	3.120	1.6÷1.7	1.2 ÷ 7.6	14.7 ÷ 26.3

5. The determination results of tires dynamic characteristics

In given working conditions, as the tires dynamic rolling on soil parameters, there were determined: the rolling circumference, the effective rolling radius, the pressure on soil and the lateral and radial deformation under load of the tires casings.

The values of these dynamic parameters are presented in table no. 3.

Table 3

The effective rolling dynamic parameters

Determination conditions Load [kg] / Pressure [bar]	Rolling circumference [mm]	Effective rolling radius [mm]	On soil supporting surface [cm^2]	Pressure on soil [daN/cm^2]	Under load deformations	
					Lateral [%]	Radial [%]
3.120 / 1.6	4.083	650	1.868	1.7	10.8	10.4

6. Conclusions on test

There were tested to natural rolling in agriculture specific conditions, two tires *18.4-26, 8PR D-165R3*, which were mounted on the front axle of harvester C 110H, as driving wheels.

The tested tires have diagonal profile with cord (2+4) Ny 940/2 with 128 f/dm.

The tires dynamic rolling parameters were determined in corresponding conditions of load and pressure (working speed in field of 8 km/h and a load bigger with 37% than the maximum admitted load at speed of 30 km/h).

In working conditions with a load of 3.120 kg and a pressure of 1.6÷1.7 bar, the tires rolling circumference was of 4.083 m, the rolling radius of 650 m and the pressure on soil of 1.7 daN/cm^2.

The measured lateral deformation was of 10.8% and the radial deformation of 10.4%.

TESTING BULLETIN no. 4 (laboratory determinations)

1. Product: driving wheel (front) harvester C 110H
2. Test: Static compression test;
3. Applied force: *1.000 daN*;
4. Compendious description of the testing way:

The test comprises two stages:

- stage A – calibration of the testing equipment;
- stage B – the proper test of the *driving wheel of harvester C110H* for determining the pressure on soil;

For simulating the static compression test for the frontal wheel of harvester C 110H there were used two plates of 15 mm thickness, with dimensions L x l similar to the contact stain of the frontal wheel of harvester C 110H, namely 525 x 510 [mm].

The test was realized in a 1 m^3 box, with the dimensions: 1 x 1 x 1 [m], special executed for this test, in which there were mounted the *8 force sensors Flexi Force* Tekscan, type W-B201-L (maximum used domain for his test 10 N / 50.24 mm^2), special acquired for this type of tests.

The force measuring system (the 8 sensors) was mounted in the box beginning with 5 cm from the top level of the box (the box was filled with soil), from 10 to 10 cm, until the depth of 75 cm.

The force measuring system (*the force sensors Flexi Force*- figure 6) was connected to an adapting module (formed of amplifiers and 8 bits analogue-numeric converter) and coupled to the serial interface 4RS 232 for coupling it to the acquisition system and laptop (figure 7)

The pressing on the plate was realized with the help of a 10 kN cylinder and of some intermediary devices (figure 8), assured by INMA Bucharest.

The testing equipment: Testing installation in simulated and accelerated regime type Hydropulse – Germany;

Measuring apparatus and equipments used:

- force sensors W-B201-L, maximum domain: 111 N / 71.3 mm^2.
- dynamometer (force cell) 10 kN;
- hydraulic cylinder series 9.60.61.9 / 87;
- cylinder control board – DCCH – 8, series 366.91/87/8;
- data acquisition board DAP 3200 – U.S.A.;
- soil humidometer type HH2, series 14/82;
- calliper 0 ÷ 150 mm series 14311;
- surveyor's tape 3m, series 1.

A. Calibration

By calibration it was tracked the correspondence between the provided signal by the tensometer dose and the one recorded by the acquisition board DAP 3200 – U.S.A.

B. Static compression test

Pressure variation in soil, represented in table no. 1 and figure 4.

- Effective stroke (displacement) of the piston's bar during the test*:* 11,7 mm;
- Loading period : 20.75 seconds;
- Maximum applied force*:* 1.000 daN;
- Soil humidity: 26.9 %.

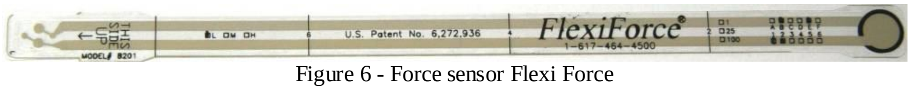

Figure 6 - Force sensor Flexi Force

Figure 7 - Used equipments at the compression test
a) laptop and data acquisition board; b) total view: testing and acquisition equipments

Figure 8 - Aspects during the static compression test

5. Test results:

Table 1

Sensor no.	Depth at which the sensor is mounted [cm]	Pressing force [N]	Contact stain surface [cm^2]	Pressure in soil [N/cm^2]
-	0.1	10.000	2.667.5	3.748828491
1	5	1.478	0.5024	2.941878981
2	15	1.914	0.5024	3.809713376
3	25	1.179	0.5024	2.346735669
4	35	1.474	0.5024	2.933917197
5	45	1.187	0.5024	2.362659236
6	25	0.8071	0.5024	1.606488854
7	65	0.5856	0.5024	1.165605096
8	75	0.03472	0.5024	0.06910828

$S_1 = 525 \times 510 = 267.750\ mm^2 = 2.667.5\ cm^2$; $S_2 = \pi \cdot R^2 = 3.14 \times 16 = 50.24\ mm^2 = 0.5024\ cm^2$;
where: R = 4 m (diameter of the contact pastille: ϕ = 8 m).

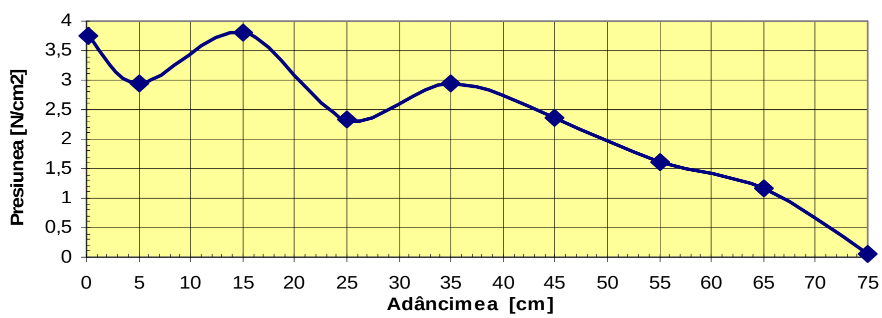

Figure 9 – Pressure exercised on soil, function of depth

6. Conclusions on test

The pressure exercised on soil was determined at 8 different depths: 5; 15; 25; 35; 45; 55; 65 and 75 cm, where there were applied in soil the 8 sensors, on the actuating direction of the pressing force.

For simulating the pressure exercised by the harvester's wheel (front) there was applied a compression force of 10.000 N with the help of a hydraulic cylinder, at soil's level, that being determined in a practical way, by weighing the harvester and finding the repartition on the two axles and finally on each wheel.

Also it was determined the contact stain size (area) too, this one being approximated with a rectangle with dimensions: 525 x 510 [mm].

The force was applied progressive until it reached the determined value in real conditions (10.000 N), moment in which there were measured too the forces in each of the 8 depths with the help of the 8 sensors.

As we can observe in diagram from figure 4, the exercised pressure on soil at depths until 35 cm has a non-uniform variation, after that following a descendant curve, once with the increasing of the depth at which there were measured the values.

CONCLUSIONS

As a result of realizing the field and laboratory experiments, there were realized experimental test bulletins on hydropulse and on terrain of the distribution of tensions and deformations in the agricultural soil in contact with the tractors and agricultural machines rolling parts. It was realized:

- Determination of the pressure on soil and the comportment to natural rolling (in real conditions) of tires:
  - frontal from harvester C 110H (B.I. no. 1);
  - frontal and from the back for tractor U 445 (T.B. no. 2);
  - frontal and from the back for tractor U 650M (T.B. no. 3);
- static compression test, on hydropulse (in laboratory), simulating the pressing on field soil, for the next tires:
  - frontal from harvester C 110H (T.B. no. 4);
  - frontal and from the back for tractor U 445 (T.B. no. 5);
  - frontal for tractor U 650M (T.B. no. 6).
  - diagrams drawing which represent the variation of pressure in soil at different depths for a given applied force equal to the load on wheel in real conditions.

LITERATURE

1. VLĂDUȚ V., GANGA M., and others – *Network constitution and technical-scientific fundametation of the research-testing methodologies corresponding to the unic market requirements (performance, safety and security in transportation, impact on environment),* Research report, INMA Bucharest, pg. 2005;
2. UCEANU E., and others – *Researches regarding the comportment to natural rolling of tires from the harvester C 110H, tractor U 445 and tractor U 650M,* Research reports, INMA Bucharest, 2003÷2006;
3. Technical documentation, *force sensors Flexi Force* Tekscan, type W-B201-L;
4. *** internet