Yuri Chigarev, Rafał Nowowiejski
Akademia Rolnicza w Szczecinie

WHEEL-SOIL INTERACTION ON ELASTIC, TENSILE-STRONG AND PLASTIC SOIL

Most of wheeled tractors and field machinery are known to cause physical changes in soil thus disturbing its fertility. Modernisation of the wheel propelling agents or even a complete changeover to some more efficient technology having a permissible effect on soil can only be based on thorough studies of the wheel-soil interaction phenomenon. The satisfaction of this problem depends on a right choice of rheological models of contact bodies and on analytical or numerical solution of contact problem.

Until recently the physical and mechanical properties of soil and wheel had been described in terms of one or two parameters. Most of the studies had assumed wheel a rigid body and strained deformation in it was described by a linear ratio. However, experiments reveal that mechanical properties of a tyre and soil in the process of non-elastic deformation can be described by a greater number of values. Therefore, the actual process of body deformation in the contact area in rheological models can be adequately described only with due account of all basic mechanical properties of wheel and soil. Studies with more complex models of wheel and soil provide more adequate and true picture of deformation process.

An elastic wheel rolling upon a ground surface with elastic, tensile-strong and plastic properties is described in this study. Fig. 1 presents the model of this ground surface.

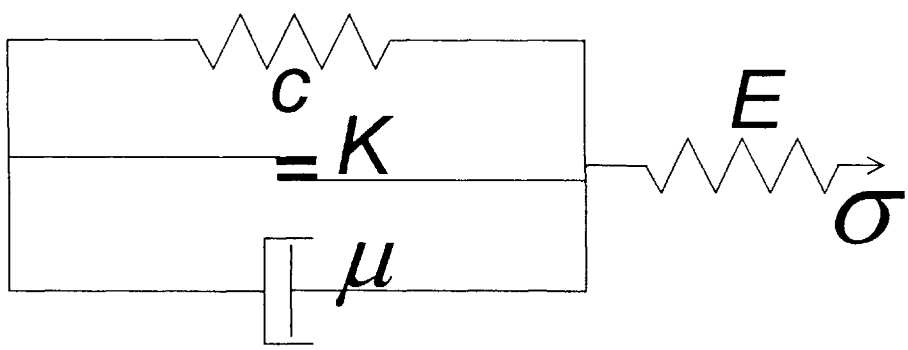

Fig. 1. The model of ground surface

The model is based on three principle mechanisms of ground deformation: elasticity, plasticity and tensile strength. The condition of ground plasticity is assumed of the form

$$\sigma - c e_r^p - \mu \dot{e}_r^p = k(P); \quad \dot{e}_r^p = \frac{de_r^p}{dt}, \tag{1}$$

where σ - indicates strain in contact area, e_r^p – indicates plastic deformation, c - is modulus of strengthening, K – is coefficient of plasticity, P – is pressure, t – is time parameter.

Rheological equation describing strengthened and deformed state of ground in this case is assumed of the form

$$\mu \dot{\sigma} + (E_r + c)\sigma = E_r\, c\, e_r + \mu\, E_r\, \dot{e}_r + E_r\, k \tag{2}$$

where $\dot{\sigma} = \frac{d\sigma}{dt}$; E_r - indicates Young's modulus, e_r – is complete deformation composed of elastic deformation e_r^e and plastic deformation e_r^p.

Under the condition of an even motion of the wheel the shear displacement of ground surface can be assumed stable in respect to the co-ordinates system Ox_1y_1, moving transitionally together with the wheel's centre. Assuming that the wheel rotates at the constant angular velocity ω = const and its axle moves at velocity v, then the section $a_1 \le x \le a_2$ of the axle $0x_1$ corresponding to the contact line moves along the axle $0x$ at the velocity v. The interrelation between the co-ordinates $0x_1$ and $0x$ of one and the same point in the contact area can be assumed of the form $x_1 = x - v \cdot t$.

Dependence of the radial deformation e_r on the normal contact stresses σ can be assumed of the form:

$$\sigma = e_r \cdot E_r \tag{3}$$

where e_r indicates tyre deformation. Interrelation between deformation and normal shear displacements can be fit in the form of the Koshi formula

$$e_r = \frac{du_r}{dy}; \qquad e_{sh} = \frac{du_{sh}}{dy} \tag{4}$$

Normal shear displacements in both of the bodies are defined in the loading area (0, a_1):

$$u_{sh} = \frac{1}{2\eta_1}(a_1^2 - \zeta^2) - u_r \tag{5}$$

In the unloading area (0, a_2):

$$u'_{sh} = \frac{1}{2r_2}(a_2^2 - \zeta^2) - u'_r \tag{6}$$

Herein after apostrophes indicate values belonging to the unloading area, $r_{1(2)}$ indicate radii. The values of r_1 and r_2 are determined as a function of stress P and tyre inflation pressure P_w.

The contact line (a_1, a_2) in the loading and unloading areas can be obtained by rotating the radius r in plane xy with a constant angular velocity ω, thus assuming that point M moves along the radius at the velocity proportionate to the distance OM (Fig. 2).

Let the point A correspond to the angles $\alpha = \beta = 0$. Let r_0 indicate the distant from the centre 0 to the point A. According to the assumption made the loading area can be described:

$$\frac{dr_1}{dt} = m_1 r_1 \tag{7}$$

And the unloading area:

$$\frac{dr_2}{dt} = m_2 r_2 \tag{8}$$

Provided $m_1 = m_2 = 0$ the problem of a rigid wheel rolling over a deformed ground appear. After integration the equations (7) and (8) take the following form:

$$r_1 = r_0 \cdot e^{m_1 t}; \qquad r_2 = r_0 \cdot e^{m_2 t} \tag{9}$$

or

$$r_1 = r_0 \cdot e^{\delta_1 \alpha}; \qquad r_2 = r_0 \cdot e^{\delta_2 \beta} \tag{10}$$

where $\delta_i = m_i / \omega$ is no-size value (i = 1, 2). Relation between r_1 and r_2 can be written down as follows:

$$r_2 = r_1 e^{(\delta_2 \alpha - \delta_1 \beta)} \tag{11}$$

This first equation in (10) can obtain the following form (refer to Fig. 2);

$$r - h_r = r_0 \cdot e^{\delta_1 \alpha} \tag{12}$$

where h_r is radial transfer of the wheel's point during the deformation process.

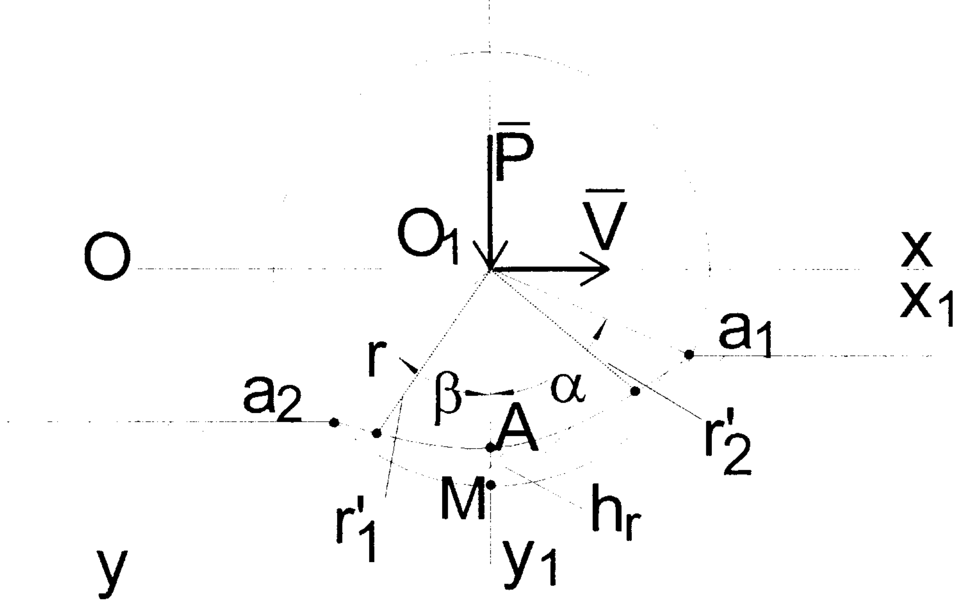

Fig. 2. The schematic diagram of interaction between wheel and soil

One can also write down that

$$r - r_0 = h_r = \lim_{\alpha \to 0} h_r \cos\alpha = \lim_{\alpha \to 0} (r - r_0 e^{\delta_1 \alpha}) \cos\alpha \tag{13}$$

Small angles α corresponding to elasticity, non-elastic and residual ground deformation fit the equation

$$\frac{r \cos\alpha - h_r}{r_0 \cos\alpha} = e^{\delta_1 \alpha} \tag{14}$$

from which

$$\delta_1 = \frac{1}{\alpha} \ln \frac{r \cos\alpha - h_r}{r_0 \cos\alpha} \tag{15}$$

After (15) placed in (10):

$$r_1 = r_0 \left(\frac{r}{r_0} - \frac{h_r}{r_0 \cos\alpha} \right) \tag{16}$$

The relation between normal bending flexure as a function P of load and tyre inflation pressure can be described by the formula

$$h_r = \frac{\Gamma}{1+P_w}\sqrt[4]{P^3} \tag{17}$$

where Γ is coefficient defined by tests with the following numerical values:

1. for low-pressure cross-ply tyres 0.41-0.74
2. for controlled pressure tyres 0.45-0.63
3. for wide section tyres 0.25-0.50

Then with respect to (17):

$$r_1 = \left[r - \frac{1}{\cos\alpha} \frac{\Gamma}{(1+P_w)} \sqrt[4]{P^3} \right] \tag{18}$$

Thus for any point of contact line r_1 can be determined.
Radius r_2 is determined by similar consideration

$$r_2 = \left[r - \frac{1}{\cos\beta} \cdot \frac{\Gamma}{(1+P_w)} \sqrt[4]{P^3} \right] \tag{19}$$

By using ratios

$$\dot{\sigma} = \frac{d\sigma}{dx}\dot{x}; \qquad \dot{e} = \frac{de}{dx}\dot{x} \tag{20}$$

and assuming that $\dot{x} = -v$ equation (2) is of the form:

$$\sigma^* = E_r \cdot e_r^* \tag{21}$$

where $$\sigma^* = \left[(E_r + c)\cdot\sigma - \frac{1}{c} v \mu \frac{d\sigma}{dx} - \frac{1}{c} E_r \mathrm{K} \right]$$

$$e_r^* = e_r - \frac{1}{c} v \mu \frac{de_r}{dx} \tag{22}$$

Equation (21) indicates a linear relation between values of fictitious pressure and deformation. To evaluate pressure on the contact line the conjugation method can be used. After necessary transformations:

$$\sigma^* = \frac{\sqrt{(\zeta_0 + a_1)\cdot(a_2 + \zeta_0)}\cdot(1+P_w)}{N\cdot\pi\cdot\left[r_{1(2)}(1+P_w) - \Gamma\sqrt[4]{P^3} \right]} \int_{-\alpha_2}^{\alpha_1} \frac{\varsigma\, d\varsigma}{(\varsigma + a_1)(a_2 + \varsigma)} \tag{23}$$

Where $N = \frac{E_r\, E_{sh}}{12}$ and ς_0 is a contact point. From (22) with respect to (23) true strain is obtained:

$$\sigma = \left(E_r + \frac{\mathrm{K} E_r + \mu\omega\sigma^*}{E_r - c} \right) \left[1 - e^{-\frac{E_r - c}{\mu v}(a_1 - \varsigma)} \right] \tag{24}$$

Thus the dependence of pressure σ on ground and tyre properties can be expressed by formula (24).

Fig. 3 presents the graph of dependence of the radius r'_p on the values of the coefficient Γ and the angle α for values of the stress concentration coefficient i.e. $\nu = 3, 4, 5$. Other values assumed are $P_w = 400$ N; $P = 300$ N.

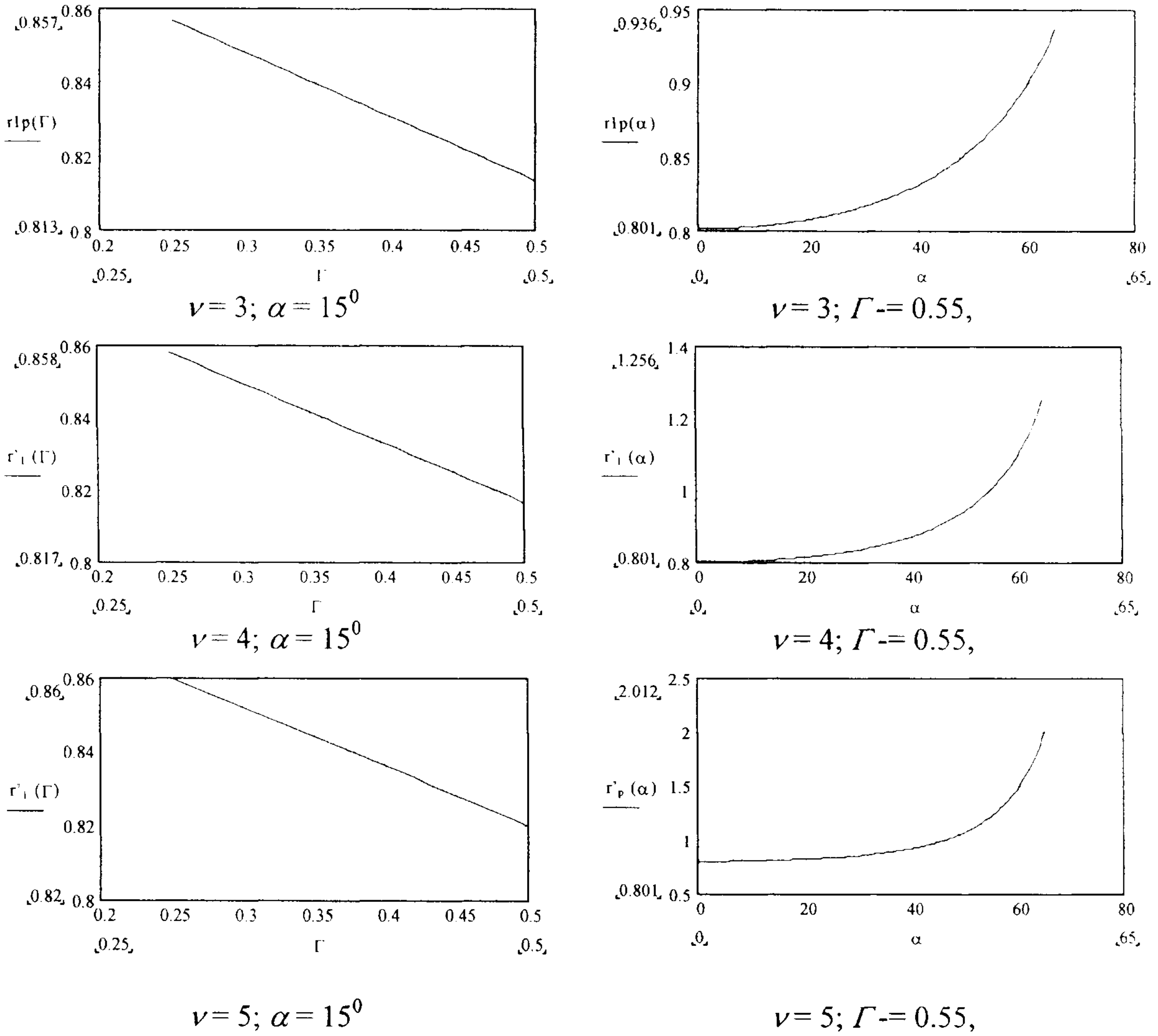

Fig. 3. Dependence of the radius r'_p on the values of the coefficient Γ and the angle α for various values of the stress concentration coefficient

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WZAJEMNE ODDZIAŁYWANIE KOŁA I GLEBY O WŁAŚCIWOŚCIACH SPRĘŻYSTO-PLASTYCZNYCH

Jurij Czigarew, Rafał Nowowiejski

Streszczenie

Wiadomym jest, że większość ciągników kołowych i maszyn polowych wywołuje zmiany w fizycznych właściwościach gleby upośledzając w ten sposób jej żyzność.

Modernizacja układów napędowych czy nawet ich kompletna zmiana na inne mające, będący do zaakceptowania, wpływ na glebę może być oparta jedynie na wszechstronnych studiach zjawiska wzajemnego oddziaływania koła i gleby. Zrealizowanie tego zadania wymaga właściwego wyboru modeli reologicznych stykających się ciał oraz na analitycznym lub numerycznym rozwiązaniu tego zagadnienia.

Do niedawna fizyczne i mechaniczne właściwości gleby i koła opisywane były w kategoriach jednego lub dwóch parametrów. W większości badań przyjmowano koło jako ciało sztywne a jego odkształcenie opisywane było przez zależność liniową. Jednakże doświadczenia wykazały, że właściwości mechaniczne opony i gleby w procesie odkształcenia niesprężystego powinny być opisane przez większą liczbę wielkości. Dlatego też rzeczywisty proces odkształcenia ciała w obszarze kontaktu może być właściwie opisany poprzez ich modele reologiczne jedynie z uwzględnieniem wszystkich podstawowych właściwości mechanicznych koła i gleby. Badania z użyciem bardziej złożonych modeli zapewnią bardziej właściwy i prawdziwy obraz procesu odkształcenia.

W artykule opisany jest model sprężystego koła toczącego się po powierzchni gleby. Model oparty jest na trzech podstawowych mechanizmach odkształcenia gleby: sprężystości, plastyczności i wytrzymałości na naprężenia osiowe. Wyprowadzono wzór określający wartość naprężeń na powierzchni kontaktu koła z glebą.

ВЗАИМОДЕЙСТВИЕ МЕЖДУ КОЛЕСОМ И ПОЧВОЙ НА УПРУГОЙ, ЭЛАСТИЧНОЙ И ПЛАСТИЧНОЙ ПОЧВЕ

Юрий Чигарев, Рафаель Нововейски

Резюме

Известно, что большинство колесных тракторов и сельскохозяйственных машин вызывают физические изменения в почве, нарушая тем самым ее плодородие. Модернизация колесных движителей, или даже переход к какой-либо более рациональной технологии с приемлемым воздействием на почву, должна быть основана на тщательном изучении взаимодействия колеса с почвой. Решение этой задачи зависит от правильного выбора реологических моделей соприкасающихся тел и от аналитического или цифрового решения проблемы соприкосновения.

До недавних пор физические и механические свойства почвы и колеса описывали при помощи одного или двух параметров. В большинстве исследований колесо рассматривалось как жесткое тело и его деформацию описывали линейным уравнением. Однако эксперименты показали, что механические свойства шины и почвы в процессе неупругой деформации можно описать гораздо большим числом показателей. Поэтому реальный процесс деформации тела в зоне соприкосновения может быть адекватно описан в реологических моделях только с учетом всех основных механических свойств колеса и почвы. Исследования с использованием более сложных моделей колеса и почвы дают в результате более адекватную и соответствующую действительности картину процесса деформации.

В данной работе дается описание упругого колеса, катящегося по упругой, эластичной и пластичной поверхности. Модель основана на трех основных механизмах деформации почвы: упругости, пластичности и сопротивлении растяжению. Выведенные формулы определяют величину напряжения на поверхности соприкосновения колеса с почвой.

Recenzent: Tadeusz Rawa