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THE CONTACT INTERACTION DYNAMICS OF THE WORKING TOOL OF THE MOLE PLOWSHARE WITH THE SOIL DURING FORMING PROSESS A CHANNEL FOR AN ANTI-FILTRATION SCREEN

Today's realities of agriculture are increasingly prompting the need for the introduction of technologies for subsoil irrigation, as a possible tool to obtain maximum efficiency indicators of agricultural activities of agricultural enterprises. At the same time, the large-scale introduction of intra-soil irrigation technologies at the enterprises of the agro-industrial complex is significantly complicated due to the poor practical and theoretical development of its methods, as well as the lack of extensive experimental verification of this method of irrigation.

The development of many processes in the construction of irrigation and engineering structures requires substantiation of the geometric parameters and operating modes of the working bodies that are used to implement these processes. One of the working bodies that is used to form the cavity along which communication is stretched is a mole plow, which, depending on the expected working conditions, may have a different geometric configuration and size.

The results of investigations of the interaction of the mole ploughshare with the soil in cavity formation for laying the anti-filtration screen are describe in this article. The authors propose to consider the soil in the form of an elastic-viscous model. By solving the contact problem of the interaction of a rigid body with a deformed medium, the stress components in the soil on the contact surface with the ploughshare are determined, and soil compaction is determined. The components of forces that appear on the surface of the ploughshare because of its interaction with the soil are determined depending on its geometric parameters and the mechanical properties of the soil. This solution is a general approach for the analytical solution of the class of problems of the contact interaction of a rigid body with a deformable medium possessing the properties of elasticity and viscosity.

Key Words**:** *Intra-soil irrigation, mole plow, soil, contact interaction, plow surface configuration, mechanical properties of soil, stress components, components of soil resistance forces to movement of the share mole plow.*

Introduction. The development of many processes associated with changes in soil properties in the construction of irrigation and engineering structures requires the justification of the geometric parameters and tools operating modes that can be used to implement these processes. One of these tools is a share mole plow. There is a necessity of laying humidifiers together with an impervious screen for save water and for best spread it in the horizontal direction under in-soil irrigation of agricultural plants [1].

For the forming of the soil cavity, where the anti-filtration screen will be laid, a mole ploughshare can be used.

At the same time, the geometric parameters of the share must ensure a sufficient compaction of the cavity walls in the soil with minimal energy expenditure.

An analysis of recent publications shows that the most adequate method of formalizing the soil for solving problems of finding rational geometric forms and tool movement modes is the method where the soil can be represented as a continuous deformable medium with its inherent properties such as elasticity, viscosity and plasticity. [2-4].

Such solutions allow us to use analytical methods to find the components of deformations, stresses, component forces of resistance to tool movement and for determine the direction of changes in soil density or even changes in the density itself.

That is, the solution of the problem before the onset of plasticity or the destruction of soil continuity makes it possible to predict the development of further processes of changing its properties, depending on the geometric parameters and the tool movement modes.

A large number of studies have been devoted to the solution of problems on the contact interaction of a rigid body with a deformed medium. However, it should be noted that mainly experimental methods of research or methods of numerical modeling using finite element methods are used. [5-8]. This significantly limits the generality of the results obtained and does not allow them to be extended to a wider class of solved problems.

In this regard, the **aim of the research** is the determination of the stress components in the soil, its compaction and the forces components on the ploughshare surface because of its interaction with the soil, depending on soil mechanical properties, geometric parameters and motion speed of mole plowshare.

Results. When solving the problem about interaction of the ploughshare with the soil, a soil model was adopted in the form of a viscoelastic medium, which can be formalized by the Kelvin-Voigt model.

The general scheme of the interaction of the mole plowshare with the soil at the formation of the cavity for laying the anti-filtration screen shown in Fig. 1 of the article [9].

The following notation is adopted in the figure: the coordinate system xyz represents the coordinates of the soil half-space and coincides with the share mole plow coordinate system $\xi\eta\zeta$, H – the ploughshare running depth relative to the field surface fs, B_l – the working width of the ploughshare, N_l – the normal to the plane of the ploughshare.

The equation of the working part of the surface of the ploughshare in the coordinate system $\xi\eta\zeta$ idem xyz has the form of equation of plane:

$$f_l = \frac{\xi}{a} + \frac{r-\eta}{b} + \frac{(r/2)-\zeta}{c} = 0$$

The introduction of this height to equation defines the displacement of the center of the plane to the origin in the direction of the axis $o\zeta$ [9].

Based on previously published results [10], the stress components for the Kelvin-Voigt model are expressed as follows:

$$\sigma_x = \frac{4}{9} e^{\frac{Gt}{2\eta(1+\nu)}} \eta(1+\nu)(6\dot{\tau}_x - 3(\dot{\tau}_y + \dot{\tau}_z) - \frac{e^{\frac{Gt}{\eta(1+\nu)}}(1+\nu)(\dot{\tau}_x + \dot{\tau}_y + \dot{\tau}_z)}{-1+2\nu});$$

$$\sigma_y = \frac{4}{9} e^{\frac{Gt}{2\eta(1+\nu)}} \eta(1+\nu)(-3(\dot{\tau}_x - 2\dot{\tau}_y + \dot{\tau}_z) - \frac{e^{\frac{Gt}{\eta(1+\nu)}}(1+\nu)(\dot{\tau}_x + \dot{\tau}_y + \dot{\tau}_z)}{-1+2\nu});$$

$$\sigma_z = \frac{4}{9} e^{\frac{Gt}{2\eta(1+\nu)}} \eta(1+\nu)(-3(\dot{\tau}_x + \dot{\tau}_y - 2\dot{\tau}_z) - \frac{e^{\frac{Gt}{\eta(1+\nu)}}(1+\nu)(\dot{\tau}_x + \dot{\tau}_y + \dot{\tau}_z)}{-1+2\nu});$$

$$\tau_{xy} = 2e^{\frac{Gt}{2\eta(1+\nu)}}\eta(1+\nu)\dot{\gamma}_{xy}, \tau_{yz} = 2e^{\frac{Gt}{2\eta(1+\nu)}}\eta(1+\nu)\dot{\gamma}_{yz}, \tau_{xz} = 2e^{\frac{Gt}{2\eta(1+\nu)}}\eta(1+\nu)\dot{\gamma}_{xz}. \quad (1)$$

where $\sigma_x, \sigma_y, \sigma_z, \tau_{xy}, \tau_{xz}, \tau_{yz}$ – the components of normal and shear stresses; $\dot{\tau}_x, \dot{\tau}_y, \dot{\tau}_z, \dot{\gamma}_{xy}, \dot{\gamma}_{xz}, \dot{\gamma}_{yz}$ – the velocity components of normal and shear strains; G – elastic modulus of shear strains, $G = E/(2(1+\nu))$; η – the coefficient of viscosity of shear strains, E – elastic modulus of linear strains, t – deformation time, ν – Poisson's ratio.

For the specific problem in the model (1), when analyzing the interaction of the ploughshare with the soil, the following notation is adopted:

$$\sigma_x = \sigma_{xl},\ \sigma_y = \sigma_{yl},\ \sigma_z = \sigma_{zl}, \tau_{xy} = \tau_{xyl},\ \tau_{xz} = \tau_{xzl},\ \tau_{yz} = \tau_{yzl},$$
$$\dot{\tau}_x = \dot{\tau}_{xl},\ \dot{\tau}_y = \dot{\tau}_{yl},\ \dot{\tau}_z = \dot{\tau}_{zl},\ \ \dot{\gamma}_{xy} = \dot{\gamma}_{xyl},\ \dot{\gamma}_{xz} = \dot{\gamma}_{xzl},\ \dot{\gamma}_{yz} = \dot{\gamma}_{yzl}$$

The obtained expressions are cumbersome, therefore of in this paper they are not given, and graphical interpretation of components of the stresses are shown in Fig. 1 and Fig. 2.

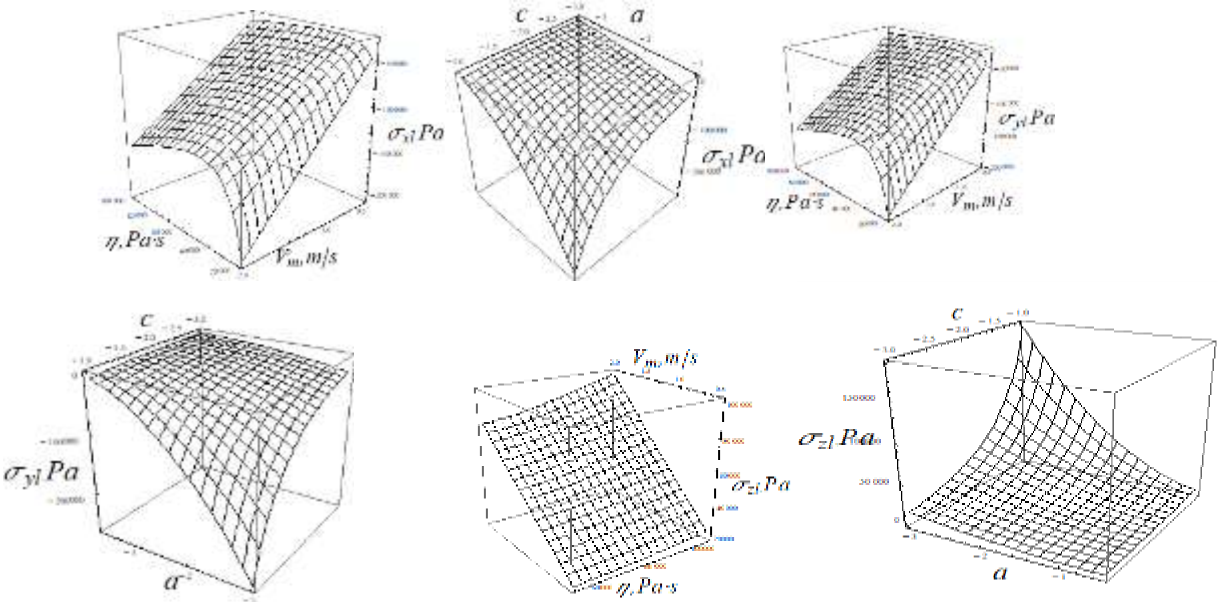
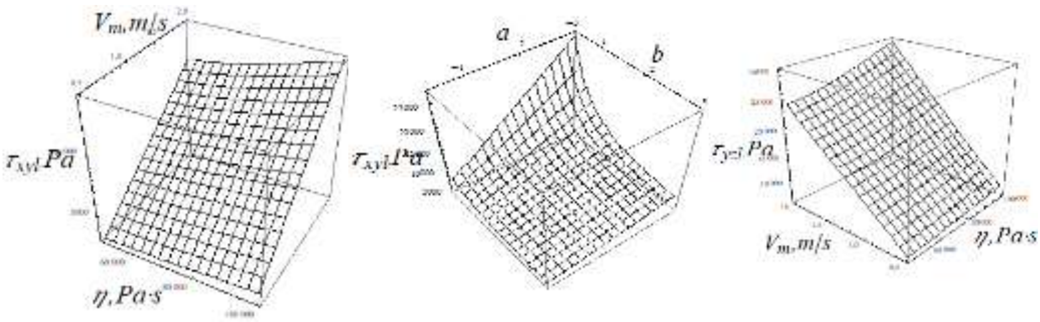


Fig. 1 Graphs of the components of normal stresses σ_{xl}, σ_{yl} depending on the soil properties E, η, on the speed V_m of the share mole plow and on the coefficients a, b, c of the equation its plane



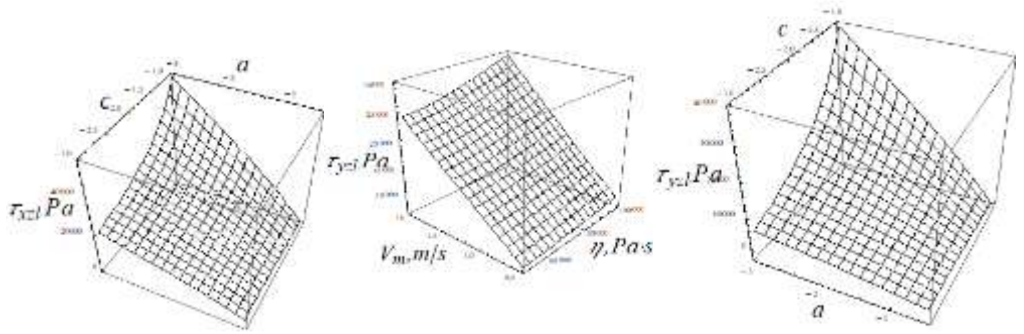


Fig. 2 Graphs of the components of tangential stresses $\tau_{xyl}, \tau_{xzl}, \tau_{yzl}$ depending on the soil properties E, η, on the speed V_m of the share mole plow and on the coefficients a, b, c of the equation its plane

The analysis of these functions of the stress components changes showed that the increase of the elastic modulus E and viscosity η leads to increase of all stress components.

The increase in the share mole plow forward speed V_m leads to a linear increase of the stresses components, which is more pronounced when the soil's viscosity modulus increases.

The influence of the slope angles of the surface normal of the share mole plow is the same that is shown for the components of the strain rates.

Under the influence of the stress-strain state of soil at the interface with the tool, the density of the soil is changed. The most well-known regression that link the density change of the soil with changes in stress are expressions [11-12]:

$$BVW = m\ \ln\left[\sqrt{\sigma_{ml}^2 + \tau_{ml}{}^2}\right] + n\left(\frac{\tau_{ml}}{\sigma_m l}\right) + b; \rho_l = \rho_0 + b\ln[\sigma_{ml}(1+\tau_{ml})], \tag{2}$$

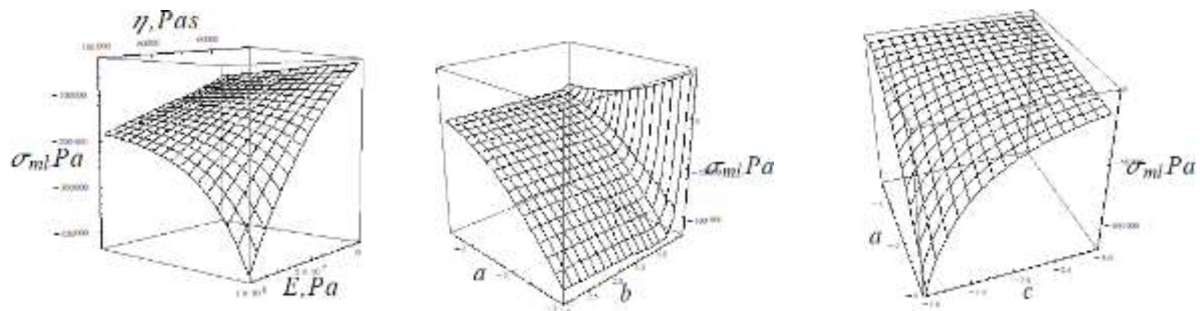
where BVW – the volume change of the soil, referred to the weight $\left[m^3/\kappa g\right]$, ρ_l – the final density of the soil $\left[\kappa g/m^3\right]$, ρ_0 – the initial density of the soil, σ_{ml} – the mean or hydrostatic stress in the considered volume, τ_{ml} – the maximum shear stress in the considered volume, m, n, b – empirical coefficients that are specific to a certain type of soil at different humidity and are subject to experimental determination.

The magnitude of the hydrostatic stress is defined as $\sigma_{mk} = \left(\sigma_{xl} + \sigma_{zl} + \sigma_{yl}\right)/3$, and the maximum shear stress for the applied solutions, according to the research Novozhilov [13], can be represented by the RMS value of the components of the tangential stresses in the form:

$$\tau_{ml} = \sqrt{\left(\tau_{xyl}{}^2 + \tau_{xzl}{}^2 + \tau_{yzl}{}^2\right)/3}.$$

Fig. 3 shows the functions of the hydrostatic stresses and maximum shear stresses from the soil properties and parameters of the share mole plow.

Using the second of the expressions (2) and considering that for a specific soil at a certain its state value $b = const$, we can construct density variation equations of the soil from its mechanical properties, geometric parameters of the tool and its speed.



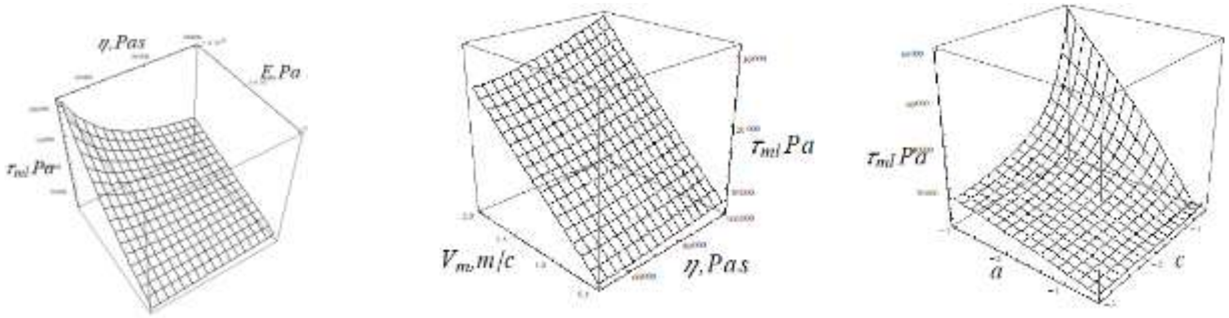


Fig. 3 Graphs of the hydrostatic stresses and maximum tangential stresses σ_{ml}, τ_{ml} in soil depending on its properties E, η, on the speed V_m of the share mole plow and on the coefficients a,b,c of the equation of its plane

These functions in the final form has not be given within the publication, and their graphic interpretation has been presented in Fig. 4.

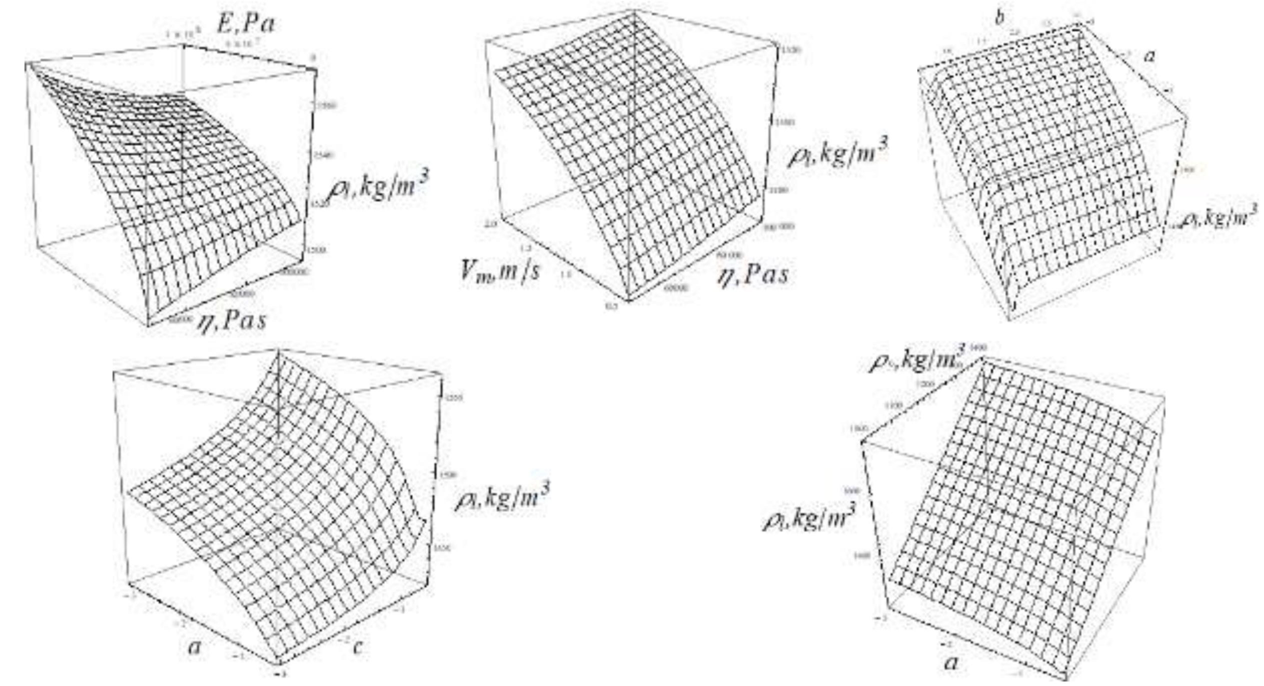


Fig. 4 Graphs of changes in soil density ρ_l in the zone of contact with the share mole plow depending on soil properties E, η, on the speed V_m of the share mole plow and on the coefficients a,b,c of the equation of its plane

The distributions of the soil pressure components to the surface of share mole plow can be determined from the equilibrium conditions on the surface:

$$dF_{xl} = \sigma_{xl} l_l + \tau_{xyl} m_l + \tau_{xzl} n_l; dF_{yl} = \tau_{xyl} l_l + \sigma_{yl} m_l + \tau_{yzl} n_l;$$
$$dF_{zl} = \tau_{xzl} l_l + \tau_{yzl} m_l + \sigma_{zl} n_l, \quad (3)$$

where $dF_{xl}, dF_{yl}, dF_{zl}$ – the projections on the corresponding coordinate axis of soil pressure components to the tool surface, l_l, m_l, n_l – the direction cosines of the normal to the tool surface.

The integration of expressions (3) on projections, which are perpendicular to the indexes of components of pressure, gives us the magnitude of the resistance forces to movement of tool in the soil:

$$F_{xl}=\int_{-r}^{r}\int_{r}^{B}dF_{xl}\,\mathrm{d}\eta_l\mathrm{d}\zeta_l;\;F_{yl}=\int_{-r}^{r}\int_{0}^{L_l}dF_{yl}\,\mathrm{d}\xi_l\mathrm{d}\zeta_l;\;dF_{zl}=\int_{0}^{B}\int_{0}^{L_l}dF_{zl}\,\mathrm{d}\xi_l\mathrm{d}\eta_l. \quad (4)$$

where $-r, r; B; L_l$ – projections of the geometric dimensions of the share mole plow on the axis oz, oy, ox, respectively.

The expressions (4) in the final form has not be given within the publication (due to their bulkiness).

The total resistance to the movement of share mole plow in the soil consists of components of soil resistance F_{xl}, F_{yl}, F_{zl} and friction forces, projected on the direction of movement on the tool surface. Then the total resistance force is expressed as follows:

$$Fxt = F_{xl}+\left(\sqrt{(F_{yl}\,ml)^2+(F_{zl}\,nl)^2}\right)tg\psi, \quad (5)$$

where ψ – the angle of external friction of soil to the surface of the share mole plow.

Fig. 5 shows the functions of total resistance to the movement and the change in soil density for the closest to the rational values of coefficients of plane.

The main change that is an achieved during the operation of share mole plow should be compaction of the soil in order to keep the space for the screen that pulling in it. At the same time, soil density should increase. Since it is impossible to influence the mechanical properties of the soil, it is possible to achieve its maximum compaction by varying the inclination angles of the normal to the surface of the share in relation to the axes of the coordinates of the soil space and by changing the speed of the translational motion of the tool.

Analysis of the influence of the coefficients a, b, c of the equation of plane to the change of the soil density (Fig. 4) showed that the slope coefficient b has no effect on the change of the soil density ρ_l, but the increase of the coefficient a leads to an increase of the soil density in the contact zone.

Similarly, the reduction of the coefficient c leads to an increase in the soil density. In addition, the increase of the speed of the translational movement V_m of the tool leads to the increase of density too. At the same time, it is necessary to take into account the change in the components of the resistance forces to the movement of the tool (Fig. 5).

Thus, increasing speed V_m, reducing of the coefficient c and increasing of the coefficient a leads to increase the resistance forces to movement of the tool. That is, to obtain the necessary compaction of the cavity walls for ensure an unobstructed pulling of the screen, need to spend a lot of effort.

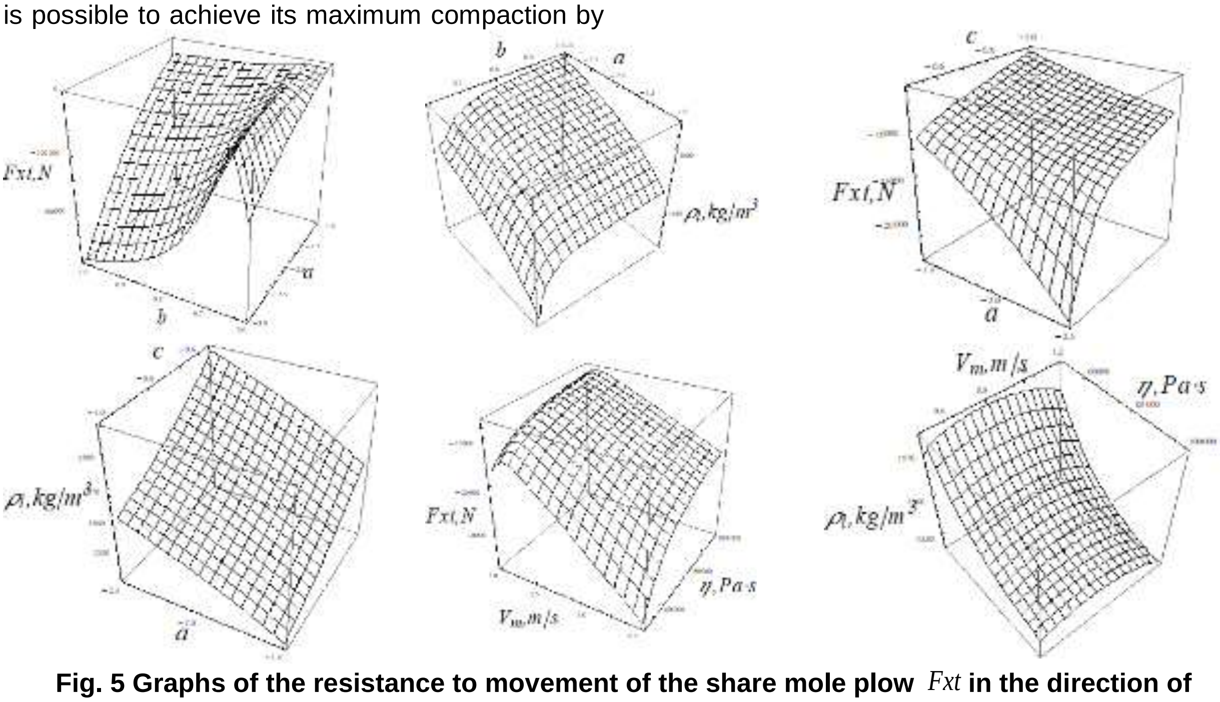


Fig. 5 Graphs of the resistance to movement of the share mole plow Fxt in the direction of movement of the tool and changes in soil density ρ_l depending on the soil's viscosity modulus η, on the speed V_m of the share mole plow and on the coefficients a, b, c of the equation of its plane

The above is a particular solution of the problem of the interaction of an absolutely rigid deformer with a deformed medium in order to ensure a change in its density.

In a more general case, this approach can be used to solve a wider class of problems of the contact interaction of an absolutely rigid deformer with a more complex geometric shape.

By solving such problems, it is possible to find the distributions of strain components, stresses, and also their functional dependencies. This makes it possible to determine the zones of possible changes in the properties of the deformable medium and the zones in which the structure discontinuity of this medium are possible.

In addition, this approach allows us to predict the energy costs for these processes, depending on the mechanical properties of the deformable medium and the geometric parameters of the deformer.

At the same time, such analytical solutions often make it possible to dispense with the use of complex computational experiments and have sufficient generality.

Conclusions. Research have shown that to ensure an unobstructed pulling of the screen (minimal friction of screen along the walls of cavity) the share mole plow can be made in the form of a plane with the lowest possible coefficients $b<1$, and $c<-1$ at that the coefficient $a \to -2$, taking into account the geometric dimensions of this plane. With these parameters, the plane of the share mole plow will provide maximum soil's compaction with least possible resistance to movement of the tool.

References

1. Akutneva, E. V. (2014). Primenenie vnutripochvennogo orosheniya v plodovodstve [The use of subsoil irrigation in fruit growing]. International Scientific Journal Theoretical & Applied Science, 18. Retrieved from; http://www.T-Science.org [in Russian].

2. Bahyrov, Y. Z. (1963). Yssledovanye deformatsyy y soprotyvlenyi hrunta s klynom pry razlychnukh skorostiakh [The study of the deformation and resistance of the soil with a wedge at various speeds]. Extended abstract of candidate’s thesis. Mynsk. VNYY zemledelyia [in Russian].

3. Vialov, S. S. (1978). Reolohycheskye osnovu mekhanyky hruntov [Rheological basis of soil mechanics]. Moskva: Vusshaia shkola [in Russian].

4. Dzhonson, U. & Mellor, P. (1979). Teoryia plastychnosty dlia ynzhenerov [Theory of Plasticity for Engineers]. Moskva: Mashynostroenye [in Russian].

5. Kovbasa, V. P., & Kurka, V. P., & Kadem, Ali Akhmed (2015). Pro podolannia trudnoshchiv pry vyrishenni kontaktnykh zadach pruzhnosti [About podolannya difficulties in the case of contact problems of spring problems]. Silskohospodarski mashyny: Zb. nauk. st. – Agricultural machinery: Coll. sciences. art, 32, 79-86 [in Ukrainian].

6. Kulen, A., & Kuypers, Kh. (1986). Sovremennaia zemledelcheskaia mekhanyka [Modern agricultural mechanics]. Moskva: Ahropromyzdat [in Russian].

7. Kushnarev, A. S. (1980). Mekhanyko-tekhnolohycheskye osnovu protsessa vozdeistvyia rabochykh orhanov pochvoobrabatuvaiushchykh mashyn y orudyi na pochvu [Mechano-technological basis of the process of the impact of the working bodies of tillage machines and implements on the soil]. Doctor’s thesis. Melytopol [in Russian].

8. Sokolovskyi, V. V. (1960). Statyka supuchei sredu [Static solids]. M.: Yzd–vo fyz.–mat. Lyteraturu [in Russian].

9. Lure, A. Y. (1955). Prostranstvennue zadachy teoryy upruhosty [Spatial problems of the theory of elasticity]. M.: Hostekhyzdat [in Russian].

10. Marton Urban, & Krisztian Kotrocz, & Gyorgy Kerenyi (2012). Investigation of the soil-tool interaction by SPH (Smooth Particle Hydrodynamics) based simulation. International Conference of Agriculture Engineering: CIGR-AgEng 2012, Valencia, Spanyolorszag 2012.07.08-2012.07.12. Valencia: Paper P-1437. Kiadvány: Valencia: 2012. [in English].

11. Ronald, B. & Brinkgreve, J. (2005). Selection of Soil Models and Parameters for Geotechnical Engineering Application. Conference Information Geo-Frontiers Congress 2005 January 24-26, 2005 Austin, Texas, United States. [in English].

12. Solona, O. V. & Kovbasa, V. P. (2019). Statyka ta dynamika vzaiemodii absoliutno tverdykh konkretsii iz sypuchym seredovyshchem [Statics and dynamics of interaction of absolutely firm nodules with a loose medium]. Vibratsii u tekhnitsi ta tekhnolohiiakh Vibrations in engineering and technology, 1(92), 12-22. [in Ukrainian].

13. Solona, O.V. & Kovbasa, V.P. (2019). Influence of geometric parameters of the treatment shower on the deformation characteristics of the soil when forming a cavity for an anti-filtration screen. Vibratsii u tekhnitsi ta tekhnolohiiakh. Vibrations in engineering and technology, 3(94), 76-83. [in English].

ДИНАМИКА КОНТАКТНОГО ВЗАИМОДЕЙСТВИЯ РАБОЧЕГО ОРГАНА КРОТОВОГО ПЛУГА С ПОЧВОЙ ПРИ ФОРМИРОВАНИИ КАНАЛА ДЛЯ ПРОТИВОФИЛЬТРАЦИОННОГО ЭКРАНА

Современные реалии земледелия все чаще побуждают к необходимости внедрения технологий внутрипочвенного орошения, как возможного инструмента получения максимальных показателей эффективности сельскохозяйственной деятельности предприятий агропромышленного комплекса. Вместе с тем, широкомасштабное внедрение технологий внутрипочвенного орошения на предприятиях агропромышленного комплекса, существенно усложняется по причине слабой практической и теоретической разработкой его приемов, а так же отсутствием широкой экспериментальной проверки этого способа полива.

Разработка многих процессов при строительстве ирригационных и инженерных сооружений, требует обоснования геометрических параметров и режимов работы рабочих органов, которые применяются для реализации этих процессов. Одним из рабочих органов который используется для образования полости по которой протягивается коммуникация является кротователь, который, в зависимости от предполагаемых условий работы может обладать различной геометрической конфигурацией и размерами.

В статье представлены результаты исследований взаимодействия лемеха кротователя с почвой при образовании полости для протягивания противофильтрационного экрана. Авторы предлагают рассматривать почву в виде упруго-вязкой модели. Путем решения контактной задачи взаимодействия абсолютно твердого тела с деформируемой средой определены компоненты напряжений в почве на поверхности контакта с лемехом, а также уплотнение почвы. Определены компоненты сил, которые возникают на поверхности лемеха в результате его взаимодействия с почвой в зависимости от его геометрических параметров и механических свойств почвы. Данное решение является общим подходом для аналитического решения класса задач контактного взаимодействия абсолютно твердого тела с деформируемой средой, обладающей свойствами упругости и вязкости.

Ключевые слова: *внутрипочвенное орошение, кротователь, почва, контактное взаимодействие, конфигурация поверхности лемеха, механические свойства почвы, компоненты напряжений, компоненты сил сопротивления почвы движению лемеха.*

ДИНАМІКА КОНТАКТНОЇ ВЗАЄМОДІЇ РОБОЧОГО ОРГАНА КРОТОВОГО ПЛУГА З ҐРУНТОМ ПРИ ФОРМУВАННІ КАНАЛА ДЛЯ ПРОТИФІЛЬТРАЦІЙНОГО ЕКРАНА

Сучасні реалії землеробства все частіше спонукають до впровадження технологій внутрішньоґрунтового зрошення, з метою отримання максимальних показників ефективності сільськогосподарської діяльності підприємств агропромислового комплексу. Разом з тим, широкомасштабне впровадження технологій внутрішньоґрунтового зрошення на підприємствах агропромислового комплексу, суттєво ускладнюється через недостатню практичну і теоретичну розробку його прийомів та відсутністю широкої експериментальної перевірки цього способу поливу.

Розробка багатьох процесів при будівництві іригаційних та інженерних споруд, вимагає обґрунтування геометричних параметрів і режимів роботи робочих органів, які застосовуються для реалізації цих процесів. До переліку таких робочих органів, що використовується для формування ґрунтових щілини по яких протягуються комунікації належить кротовий плуг, який, в залежності від умов роботи може мати різну геометричну конфігурацію та розміри.

У статті представлені результати досліджень взаємодії лемішної частини кротового плуга з ґрунтом при утворенні порожнини для протягування протифільтраційного екрана. Автори пропонують розглядати ґрунт у вигляді пружно-в'язкої моделі. Шляхом вирішення контактної задачі взаємодії абсолютно твердого тіла з деформованим середовищем визначені компоненти напружень в ґрунті на поверхні контакту з лемешем, а також ущільнення ґрунту. Визначено компоненти сил, які виникають на поверхні лемеша в результаті його взаємодії з ґру

нтом в залежності від його геометричних параметрів і механічних властивостей ґрунту. Дане рішення є загальним підходом для аналітичного рішення класу задач контактної взаємодії абсолютно твердого тіла з деформованим середовищем, що володіє властивостями пружності і в'язкості.

Ключові слова: *внутрішньоґрунтове зрошення, кротовий плуг, ґрунт, контактна взаємодія, конфігурація поверхні лемеша, механічні властивості ґрунту, компоненти напружень, компоненти сил опору ґрунту руху лемеша.*

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