Methodology For Determining Bearing Capacity Of Subgrade Of Sand Dunes Under Vibrodynamic Effects

Ergashev Zukhritdin Zaydinovich

Abstract: The article discusses the methodology for determining the bearing capacity of a subgrade of sand dunes under vibrodynamic effects, taking into account the volume forces of inertia and a decrease in the strength characteristics of sand dunes under the influence of a vibrodynamic load, describe the ultimate equilibrium of subsoil subgrade only until the discontinuity of the subgrade. This is achieved by creating some initial, possibly triaxial, stress σstart> 0, in the presence of which at any point the absence of tensile stresses under vibrodynamic action is guaranteed, i.e. σ ≥ 0.

Index Terms: Vibrodynamic, effects, load, determining, bearing, capacity, subgrade, sand dunes.

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1. INTRODUCTION

The bearing capacity of the railway subgrade, covered with sand dune, perceiving the vibrodynamic load, is determined by the magnitude and nature of the distribution of the vibrodynamic effects on the body of the canvas, the sensitivity of sand dune to it and its structural features. In this case, the bearing capacity of the subgrade is understood as the greatest load determined by the first group of limit states, which causes such a stress state when its minimal increase causes a violation of the existing equilibrium with the formation of a soil displacement surface. The fundamental basis of calculation methods for assessing the bearing capacity of a railway subgrade is the theory of ultimate equilibrium of soils. The practical significance of the solutions of the theory of limit equilibrium remains even now that numerical methods for the analysis of elastic-viscous-plastic deformation of soils have become very widespread. The solution of the problem of the limit equilibrium of the subgrade, covered with sand dunes, under the action of vibrations is reduced to the joint solution of the differential equations of motion and the conditions of the ultimate stress state with strength characteristics that change under the influence of vibrodynamic load. Such a decisionn was received by Professor I. Prokudin.

2 METHODS OF RESEARCH

Thus, the main system of equations consists of the equations of motion of the soil medium and the condition of the maximum equilibrium of Coulomb:

$$\begin{cases} \dfrac{\partial\sigma_z}{\partial z}+\dfrac{\partial\tau_{zy}}{\partial y}=\gamma\cdot cos\theta+\rho\cdot\dfrac{\partial^2U}{\partial t^2} \\ \dfrac{\partial\tau_{yz}}{\partial z}+\dfrac{\partial\sigma_y}{\partial y}=\gamma\cdot sin\theta+\rho\cdot\dfrac{\partial^2V}{\partial t^2} \\ \sigma_1-\sigma_2=(\sigma_1+\sigma_2+2\cdot C_{dyn}\cdot ctg\varphi_{dyn})\cdot\sin\varphi_{dyn} \end{cases} \qquad (1)$$

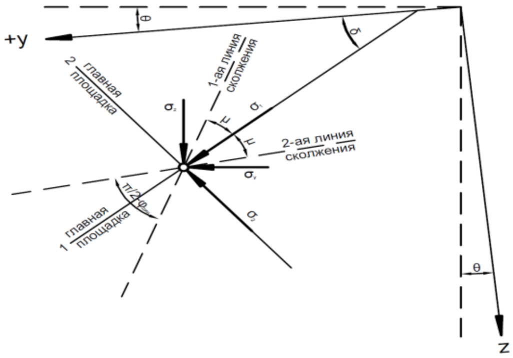
where ρ is the mass of soil;
g - is the acceleration of gravity, g = 981 cm / s2;
γ -is the bulk density of the soil;
U, V - displacements during oscillations in the direction of the axes z and y;
σ_1 and σ_2 are the maximum and minimum principal stresses;
(c_{dyn} and φ_{dyn}) - adhesion and angle of internal friction of sand dune, perceiving vibrodynamic load;
To obtain a solution, we perform a system transformation. Stresses σz, σy, τzy are expressed in terms of principal stresses using the conditions of Fig. 1 and fig. 2 and the properties of the Mohr circle.

$$\sigma_y=\frac{1}{2}(\sigma_1+\sigma_2+(\sigma_1-\sigma_2)\cdot cos2\delta \qquad (2)$$

$$\sigma_z=\frac{1}{2}(\sigma_1+\sigma_2-(\sigma_1-\sigma_2)\cdot cos2\delta \qquad (3)$$

$$\tau_{zy}=\frac{1}{2}(\sigma_1-\sigma_2)\cdot sin2\delta \qquad (4)$$

We denote the voltage characteristic as follows:



(5)

Fig. 1. *The relationship of the slip lines and the main sites with current stresses.*

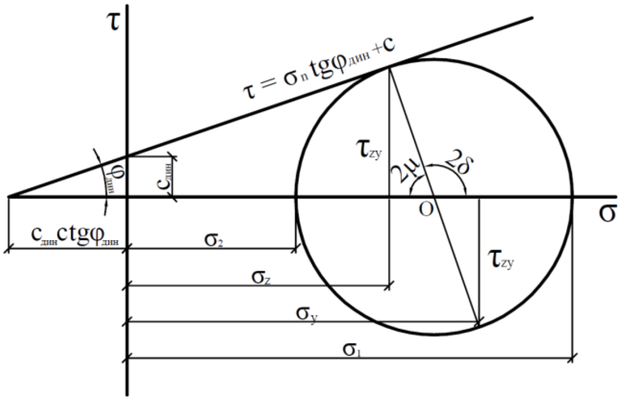


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***Fig. 2**. The range of ultimate stresses for sand dune perceiving a vibrodynamic load.*

If we substitute expression (5) into the third equation of system (1), then we obtain the following:

$$\sigma_1 - \sigma_2 = 2\sigma sin\varphi_{dyn} + 2c_{dyn}cos\varphi_{dyn} \qquad (6)$$

Using the last two equalities, we represent expressions (2), (3) and (6.4) in the following form:

$$\sigma_z = \sigma\left(1 - sin\varphi_{dyn}cos2\delta\right) - c_{dyn}cos\varphi_{dyn}cos2\delta \qquad (7)$$

$$\sigma_y = \sigma\left(1 + sin\varphi_{dyn}cos2\delta\right) + c_{dyn}cos\varphi_{dyn}cos2\delta \qquad (8)$$

$$\tau_{zy} = \sigma sin\varphi_{dyn}sin2\delta + c_{dyn}cos\varphi_{dyn}sin2\delta \qquad (9)$$

Expressions (7), (8) and (9) must be differentiated along the coordinate axes and substituted into the left side of the first two equations of system (1). It should be noted that under the action of a vibrodynamic load, the values of specific adhesion and the angle of internal friction of the sand dunes functionally depend on the amplitude of the oscillations. Therefore, the strength characteristics of sand dunes are unstable and fall under the differential sign in z and y. The angle of internal friction and the specific adhesion of the sand dunes laid in the railway subgrade are determined by the action of vibrodynamic loading under conditions of triaxial compression. In this case, the magnitude of the vibrodynamic effect is determined by the calculation obtained or measured in nature by the maximum resulting amplitude of vibrations. The resulting vibration amplitude of sand dunes at any point of the subgrade and beyond is determined by the formula:

$$A_{zy} = A_0 e^{nz - \delta_1^0\varphi(y) + \delta_3\varphi(h_{i,j})} \qquad (10)$$

Here

$$n = \ln\delta_1$$

$$\delta_1^0 = \delta_2' + \delta_2''$$

$$\varphi(y) = \begin{cases} 0 & at\ |y - 0{,}5b_0| \le 1{,}35\ \text{м} \\ |y - 0{,}5b_0| - 1{,}35 & at\ |y - 0{,}5b_0| > 1{,}35\ \text{м} \end{cases}$$

$$\delta_3 = \frac{|\ln\delta_1|}{1{,}5\ ctg\ \alpha_1}$$

$$\varphi(h_{i,j}) = \begin{cases} 0 & at\ y \le a \\ (y - a)tg\ \alpha_1 & at\ y > a \end{cases}$$

where A_0 is the resulting amplitude of the oscillations of the soils of the main site, microns;
δ1, δ2 ’, δ2’ ’- damping coefficients of oscillations in the vertical and horizontal directions;
z, y - coordinates of the considered point in the axes shown in Fig. 3;
δ_3- coefficient taking into account the influence of the slope on the damping of oscillations in the slope of the embankment;
$h_{i,j}$ – slope height above the considered point, m;
b_0 - is the size of the zone of the main site, perceiving external pressure, m;
α_1 - the angle of the slope of the embankment;
a -is the estimated width of the curb, m

$$a = \frac{b_{ele} - b_0}{2} \qquad (11)$$

where b_{ele} - is the width of the main site of the subgrade, determined for operating lines by measuring in kind, and for those designed according to current standards.

The size of the zone of the main site, which receives the load from the rolling stock, sleeper and ballast, is determined according to the following formula:

$$b_0 = l_{sl} + 2 \cdot h_{bal} \cdot tg\ 30° \qquad (12)$$

where l_{sl} is the length of the sleepers;
h_{bal} - ballast power.

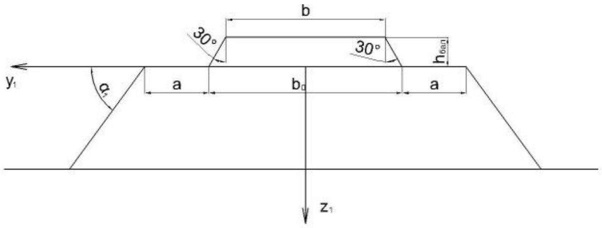

***Fig. 3**. Scheme for determining the width of the loading area*

The values of the strength characteristics of sand dunes at any point of the subgrade are calculated by the following expressions:

$$c_{dyn} = c_{st}\left[k_c' + k_c e^{-k(A_{zy} - A_n)}\right] \qquad (13)$$

$$\varphi_{dyn} = \varphi_{stat}\left[k_\varphi' + k_\varphi e^{-kA_{zy}}\right] \qquad (14)$$

$$k_c = \frac{c_{st} - c_{dyn}^{min}}{c_{stat}} \qquad (15)$$

$$k_\varphi = \frac{\varphi_{\text{ст}} - \varphi_{dyn}^{min}}{\varphi_{stat}} \qquad (16)$$

$$k_c' = \frac{c_{dyn}^{min}}{c_{stat}} \qquad (17)$$

$$k_\varphi' = \frac{\varphi_{dyn}^{min}}{\varphi_{stat}} \qquad (18)$$

After differentiating equations (7), (8) and (9), substituting the results in the equations of motion of system (6.1) and algebraic transformations, we obtain the equations of the basic system of limit equilibrium:

$$\frac{\partial\sigma}{\partial z}\left(1 - sin\varphi_{dyn}cos2\delta\right) + \frac{\partial\sigma}{\partial y}sin\varphi_{dyn}sin2\delta + \frac{\partial\delta}{\partial z}2\sigma_{dyn}sin2\delta +$$

$$\frac{\partial\delta}{\partial y}2\sigma_{dyn}sin\varphi_{dyn}cos2\delta = \gamma cos\theta - \Phi\left[\left(\delta_1^0 - |n| \cdot 0{,}667tg\alpha_1\varphi'(h_i)\right) \cdot sin2\delta + ncos2\delta\right] \cdot$$

$$\left[\varphi_{stat}k_\varphi\left(\sigma cos\varphi_{dyn} - c_{dyn}sin\varphi_{dyn}\right) + c_{\text{ст}}k_c cos\varphi_{dyn}\right] +$$

$$\rho\frac{\partial^2 U}{\partial t^2} \qquad (20)$$

Where

$$\sigma_{dyn} = \sigma + c_{dyn}ctg\varphi_{dyn}$$

$$\Phi_1 = kA_0 e^{nz - \delta_1^0 y + 1{,}35\delta_1^0 + |n| \cdot 0{,}667\varphi'(h_i)tg\alpha_1 - kA_{zy}}$$

(21)

$$\varphi'(h_i) = \begin{cases} 0 & at \quad y \leq 0,5b_{ele} \\ tg\alpha_1 & at \quad y > 0,5b_{ele} \end{cases}$$

Equations (19) and (20) in the right-hand sides contain the terms $\rho\frac{\partial^2 U}{\partial t^2}$ and $\rho\frac{\partial^2 V}{\partial t^2}$,

which are terms that take into account inertial forces arising in the oscillatory process of the soil. Research I.V. Prokudin [2], performed using harmonic analysis showed that these terms can be determined as follows:

$$\rho\frac{\partial^2 U}{\partial t^2} = \frac{\gamma}{g}1477e^{nz-\delta_1^0(y-1,35)} = 0,15\gamma H\frac{A}{A_0} \qquad (22)$$

$$\rho\frac{\partial^2 V}{\partial t^2} = \frac{\gamma}{g}38,2e^{nz-\delta_1^0(y-1,35)} = 0,04\gamma H\frac{A}{A_0} \qquad (23)$$

Where

$$H = e^{nz-\delta_1^0 y+1,35\delta_1^0+|n|\cdot 0,667\varphi(h_i)tg\alpha_1} \qquad (24)$$

A - the resulting amplitude of the oscillations of the soils of the main site within the length of the sleepers;

A_0– basic value of the amplitude of oscillations.

Equations (19) and (20) are a first-order system of hyperbolic type. Consequently, the basic system of equations of limit equilibrium is solved only under the condition that along some line lying in the zy plane, the values of the derivatives of the function σ and δ are determined with respect to the coordinates z and y. Under the action of a vibrodynamic load, the behavior of sand dunes is described by the third equation of system (1), therefore, by analogy with V.V. Sokolovsky [3], for the subgrade there are curves that are functions of the z, y coordinates and satisfy equations (19) and (20). When solving the basic system of the theory of limit equilibrium by the method of characteristics, it is important that the characteristic lines coincide with the slip lines at each point touching the area of the maximum tangential stress. After several algebraic transformations of the main system taking into account (13) and (14) I.V. Prokudin [4] obtained an equation of characteristics and a differential relation along them.

$$dz = dy\,tg\left[\delta + \frac{\pi}{4} - 0,5\varphi_{stat}(k_{\varphi'} + k_\varphi e^{-kA_{zy}})\right] \qquad (25)$$

$$dz = dy\,tg\left[\delta - \frac{\pi}{4} + 0,5\varphi_{stat}(k_{\varphi'} + k_\varphi e^{-kA_{zy}})\right] \qquad (26)$$

$$d\sigma + 2\sigma_{dyn}tg\,\varphi_{dyn}d\delta = \frac{\gamma}{\cos\varphi_{dyn}}\left[\cos(\varphi_{dyn}+\theta)dz + \sin(\varphi_{dyn}+\theta)dy\right] + \frac{B\cos(\delta-\mu) - D\sin(\delta-\mu)}{\cos\varphi_{dyn}\cos(\delta+\mu)}dy \qquad (27)$$

$$d\sigma - 2\sigma_{dyn}tg\,\varphi_{dyn}d\delta = \frac{\gamma}{\cos\varphi_{dyn}}\left[\cos(\varphi_{dyn}-\theta)dz - \sin(\varphi_{dyn}-\theta)dy\right] - \frac{B\cos(\delta+\mu) - D\sin(\delta+\mu)}{\cos\varphi_{dyn}\cos(\delta-\mu)}dy \qquad (28)$$

Where

$$B = 0,15\gamma H\frac{A}{A_0} - \Phi[(\delta_1^0 - |n|0,667\varphi'(h_i)tg\alpha_1)\,sin2\delta + n\,cos2\delta]\left[\varphi_{stat}k_\varphi\left(\sigma\,cos\varphi_{dyn} - c_{stat}\sin\varphi_{dyn}\right) + c_{stat}k_c\cos\varphi_{dyn}\right] \qquad (29)$$

$$D = 0,04\gamma H\frac{A}{A_0} + \Phi[n\sin 2\delta - (\delta_1^0 - |n|0,667\varphi'(h_i)tg\alpha_1)\cos 2\delta + n\,cos2\delta]\left[\varphi_{stat}k_\varphi\left(\sigma\,cos\varphi_{dyn} - c_{dyn}\sin\varphi_{dyn}\right) + c_{stat}k_c\cos\varphi_{dyn}\right]$$

(30)

Thus, we have two families of slip lines intersecting each other at an angle 2μ (where:

$$\mu = \frac{\pi}{4} - \frac{\varphi_{dyn}}{2}$$

and forming at each point the intersection with the first principal axis of the stress tensor σ1. Equations (25) and (27) relate to the characteristics of the first family, and equations (26) and (29) to the second family. The implementation of equalities (25), (26), (27) and (28) with respect to σ and δ will allow us to obtain the value of ultimate stresses on the main ground web taking into account the action of inertial forces, reduction of strength characteristics under the influence of vibrodynamic impact and its attenuation in the body of the subgrade and beyond. Equations (27) and (28) show that the characteristics in the zy plane are inclined to the y axis at angles δ + μ and δ-μ, respectively, i.e. as well as slip lines. This fact means that the characteristics in the zy plane are possible slip lines.

3 CONCLUSION

Consequently, it should be noted that equations (25) - (28), taking into account the volume forces of inertia and the decrease in the strength characteristics of sand dunes under the influence of a vibrodynamic load, describe the limiting equilibrium of the subgrade soils only until the discontinuity of the canvas. Taking into account the last remark, it should be noted that the solution of the problem of the theory of limit equilibrium proposed for cohesive soils can be extended to disconnected soils subject to continuity, i.e. Saint-Venant's equations must have a solution for each point of the soil structure. This is most simply achieved by creating some initial, possibly triaxial, stress σbeg> 0, in the presence of which at any point the absence of tensile stresses under vibrodynamic action is guaranteed, i.e. σ ≥ 0. Technically, the initial stress can be created by a load, for which it is advisable to use a ballast prism, the minimum thickness of which can be determined from the above conditions. Naturally, this value depends on the maximum value of the vibrodynamic effect.

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