VIBRATIONS OF THE GROUND SURFACE AT BLASTING WORKS ON THE CONSTRUCTION OF TUNNELS

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Abstract. *This work examines vibrations of the ground surface at blasting work on the construction of tunnels. To estimate the levels of vibration of the ground surface under explosive action inside a cylindrical cavity, to a first approximation we consider the plane problem of the theory of elasticity. As a result of this impact, longitudinal and transverse waves will propagate in the soil. To solve the problem, the reciprocity theorem is applied, for dynamic problems of the theory of elasticity, and the results obtained are compared by wave dynamics methods. The main goal of the work is to determine the stressed deformed state of pipelines under the influence of seismic waves. The resulting solution allows us to determine the levels of vibrations of the soil surface that occur during explosive effects inside the cylindrical cavity of the elastic half-space. The results can be used to assess the levels of ground surface vibrations that occur during the construction of shallow tunnels using the drill-and-blast method.*
Keywords: *Mechanical system, waves, vibration, cylindrical shells, solid*

Introduction. To perform a computational analysis of the dynamic state of an underground pipeline, it is considered as cylindrical bodies located in an elastic medium [1,2]. The blast load can be described by a difference in form [3]. When solving the problem, the plane problem of elasticity theory is mainly used [4,5]. The calculation uses the finite element method in the form of displacements [6,7]. The displacements of the nodal points of the finite element model are taken as the main unknowns. At the same time, to increase the efficiency of calculations, methods were used that take into account the features of matrix operations (symmetry of matrices, the presence of a large number of zero elements, etc.). The entire mass of the pipeline is considered concentrated in the nodes of the calculation model, while the distributed mass of the segment is divided equally between its beginning and end [8,9]. Calculations for seismic impact are performed in many works using the dynamic analysis method or the linear-spectral method [10,11]. In the case of calculations for one group of spectra, the displacements of all fixed nodes of the calculation model are considered the same (the “rigid” platform hypothesis). In this case, the seismic load can be specified for three mutually perpendicular directions in the form of accelerograms or response spectra [12,13]. This work, unlike others, uses numerical and analytical methods to comparatively evaluate the effectiveness.

Statement of the problem and solution methods. In underground construction and, in particular, in tunneling, excavation in hard rock is most often carried out using the explosive method [1]. Explosive effects are characterized by a large release of energy in a short period of time. For example, when one kilogram of TNT explodes with a charge length of 0.25 meters, over J is released in 40 microseconds. Stress waves propagating in the ground from the explosion site can reach the surface, which can lead to damage or destruction of ground objects. To estimate the levels of vibration of the ground surface under explosive action inside a cylindrical cavity, to a first approximation we consider the plane problem of the theory of elasticity. We will assume that as a result of an explosion inside a cylindrical cavity, uniform pressure acts on some sufficiently long part of it

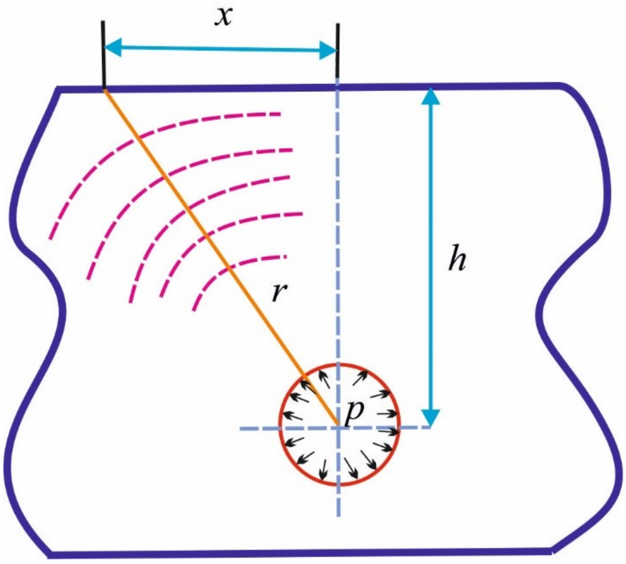


Fig. 1. Loading diagram to determine stress deformed state

As a result of this impact, longitudinal and transverse waves will propagate in the soil. To determine vibrations of the ground surface, we apply the reciprocity theorem and use well-known analytical solutions to the problem of the propagation of waves in an elastic half-space under the influence of concentrated waves applied to the surface. Let us consider two states of an elastic half-space with a cylindrical cavity. First state (I): a concentrated force is applied to the surface of the elastic half-space $F(t)$ (Fig. 1). In order to avoid singularities, we will assume that the force is distributed over a small area. Second state (II): the stress-strain state of the elastic half-space is created by uniform pressure applied to the inner surface of the $p(t)$ cylindrical cavity. To determine the displacement of ground points during the propagation of longitudinal and transverse waves from a vertical harmonic force applied to the surface of an elastic half-space $F_0 e^{i\omega t}$, we use the solution of G. Miller and N. Persey [2]:

$$u_r^\nu = \frac{F_0 \cos\varphi[1-2\delta^2 \sin^2\varphi] e^{-i\omega r/\alpha} e^{i\omega t}}{2\pi\rho\alpha^2 r\left\{[1-2\delta^2\sin^2\varphi]^2 + 4\delta^3 \sin^2\varphi\cos\varphi[1-\delta^2\sin^2\varphi]^{1/2}\right\}} \tag{1}$$

$$u_\theta^\nu = 0 \tag{2}$$

$$u_\varphi^\nu = \frac{-F_0 \sin\varphi\cos\varphi[\delta^2 - \sin^2\varphi]^{1/2} e^{-i\omega r/\beta} e^{i\omega t}}{\pi\rho\beta^2 r\left\{[1-2\sin^2\varphi]^2 + 4\sin^2\varphi\cos\varphi[\delta^2-\sin^2\varphi]^{1/2}\right\}} \tag{3}$$

where a is the speed of longitudinal waves in the soil; β - speed of transverse waves into the ground; $\delta = \dfrac{\beta}{a}$ - speed ratio,

$$r^2 = h^2 + x^2, \cos\varphi = h/r, \sin\varphi = x/r.$$

To determine the displacement of ground points during the propagation of longitudinal and transverse waves from a horizontal harmonic force applied to the surface of an elastic half-space $G_0 e^{i\omega t}$, we use the solution of J. Cheney:

$$u_r^h = \frac{G_0 \delta \cos\theta \sin\varphi \cos\varphi [1-\delta^2 \sin^2\varphi]^{1/2} e^{-i\omega r/\alpha} e^{i\omega t}}{\pi\rho\alpha^2 r \left\{ [1-2\delta^2 \sin^2\varphi]^2 + 4\delta^3 \sin^2\varphi \cos\varphi [1-\delta^2 \sin^2\varphi]^{1/2} \right\}} \quad (4)$$

$$u_\theta^h = \frac{-G_0 \sin\theta e^{-i\omega r/\beta} e^{i\omega t}}{2\pi\rho\beta^2 r} \quad (5)$$

$$u_\varphi^h = \frac{G_0 \cos\theta \cos\varphi [1-2\sin^2\varphi] e^{-i\omega r/\beta} e^{i\omega t}}{2\pi\rho\beta^2 r \left\{ [1-2\sin^2\varphi]^2 + 4\sin^2\varphi \cos\varphi [\delta^2 - \sin^2\varphi]^{1/2} \right\}} \quad (6)$$

Vertical vibrations of the ground surface transmitted by longitudinal waves during an explosion in a cylindrical cavity. The average radial displacements of an unsupported cylindrical cavity from longitudinal waves generated by a vertical force are determined by the formula

$$\Delta u_\alpha^\nu = \Delta u_r + \Delta u_\varphi + \Delta u_\theta \quad (7)$$

which, after substituting expressions for average radial displacements:

$$\Delta u_r = \frac{b}{E}\rho\alpha\dot{\imath}, \quad \frac{\nu}{1-\nu}\frac{b}{E} \quad \text{and} \quad \Delta u_\theta = -\frac{\nu^2}{1-\nu}\frac{b}{E}\rho\alpha\dot{\imath}$$

takes the form:

$$\Delta u_\alpha^\nu = \Delta u_r + \Delta u_\varphi + \Delta u_\theta = \rho\alpha\dot{\imath}\,\frac{b}{E}\ \frac{\nu}{1-\nu} - \frac{\nu^2}{1-\nu}) \quad \text{or} \quad \Delta u_r^\alpha = \alpha\rho\dot{\imath}\,\frac{b}{2\mu} \quad (8)$$

where p is the soil shear modulus (determined by the formula: $\mu = \beta^2 \rho$)

Using expression (1) and performing the necessary transformations, we reduce the resulting equation to a more convenient form [4]:

$$u_\alpha^\nu = \frac{(i\omega) b F_0 \cos\varphi [1-2\delta^2 \sin^2\varphi] e^{-i\omega r/\alpha} e^{i\omega t}}{4\pi\mu\alpha r \left\{ [1-2\delta^2 \sin^2\varphi]^2 + 4\delta^3 \sin^2\varphi \cos\varphi [1-\delta^2 \sin^2\varphi]^{1/2} \right\}} \quad (9)$$

Let us denote: P_0 - the amplitude value of the pressure during an explosion in a cylindrical cavity for a harmonic component with frequency $\omega, \Delta_{\alpha\nu}$ - the vertical movement of the ground surface, d - the distance over which the explosion pressure extends along the cylindrical cavity, r - the distance from the point at which vibrations are determined to the axis of the cylindrical cavity.

In accordance with the reciprocity theorem we have:

$$2\pi b d P_0 \Delta u_\alpha^\nu = F_0 \Delta_{\alpha\nu} \quad (10)$$

What follows:

$$\Delta_{\alpha v} = \frac{P_0 b^2 (i\omega) d \cos\varphi [1 - 2\delta^2 \sin^2\varphi] e^{-i\omega r/\alpha} e^{i\omega t}}{2\mu\alpha r \left\{ [1 - 2\delta^2 \sin^2\varphi]^2 + 4\delta^3 \sin^2\varphi \cos\varphi [1 - \delta^2 \sin^2\varphi]^{1/2} \right\}} \quad (11)$$

Horizontal vibrations of the ground surface transmitted by longitudinal waves during an explosion in a cylindrical cavity.

The parameters of horizontal vibrations during an explosion in a cylindrical cavity are determined in the same way as vertical ones, except that instead of function (1), it is necessary to use function (4). Omitting intermediate calculations, we present the final result

$$\Delta_{\alpha h} = \frac{P_0 b^2 (i\omega) d \delta \cos\theta \sin\varphi \cos\varphi [1 - \delta^2 \sin^2\varphi]^{1/2} e^{-i\omega r/\alpha} e^{i\omega t}}{\mu\alpha r \left\{ [1 - 2\delta^2 \sin^2\varphi]^2 + 4\delta^3 \sin^2\varphi \cos\varphi [1 - \delta^2 \sin^2\varphi]^{1/2} \right\}} \quad (12)$$

Taking into account that horizontal and vertical vibrations of the soil surface, transmitted by longitudinal waves, which arose during an explosion in a cylindrical excavation, occur in one phase, the amplitude of the vibrations can be determined by the formula:

$$\Delta_\alpha = \sqrt{\Delta_{\alpha v}^2 + \Delta_{\alpha h}^2} \quad (13)$$

Vertical vibrations of the ground surface transmitted transverse waves during an explosion in a cylindrical cavity. The average radial displacements of an unsupported cylindrical cavity from transverse waves generated by a vertical force are determined by the formula:

$$\Delta u_\beta^\nu = \Delta u_r + \Delta u_\varphi + \Delta u_\theta \quad (14)$$

which, after substituting expressions for average radial displacements:

$$\Delta u_\varphi = \frac{b}{E} \rho\beta i \quad \frac{\nu}{1-\nu} \frac{b}{E} \quad \text{и} \quad \Delta u_\theta = -\frac{\nu^2}{1-\nu} \frac{b}{E} \rho\beta i$$

takes the form:

$$\Delta u_\beta^\nu = \Delta u_r + \Delta u_\varphi + \Delta u_\theta = \rho\beta i \quad \frac{\nu}{1-\nu} - \frac{\nu^2}{1-\nu}) \quad (15)$$

Using expression (7.3) and performing the necessary transformations, we reduce the resulting equation to a more convenient form:

$$\Delta u_\beta^\nu = -\frac{(i\omega) b F_0 \sin\varphi \cos\varphi [\delta^2 - \sin^2\varphi]^{1/2} e^{-i\omega r/\beta} e^{i\omega t}}{2\pi\mu\beta r \left\{ [1 - 2\sin^2\varphi]^2 + 4\sin^2\varphi \cos\varphi [\delta^2 - \sin^2\varphi]^{1/2} \right\}} \quad (16)$$

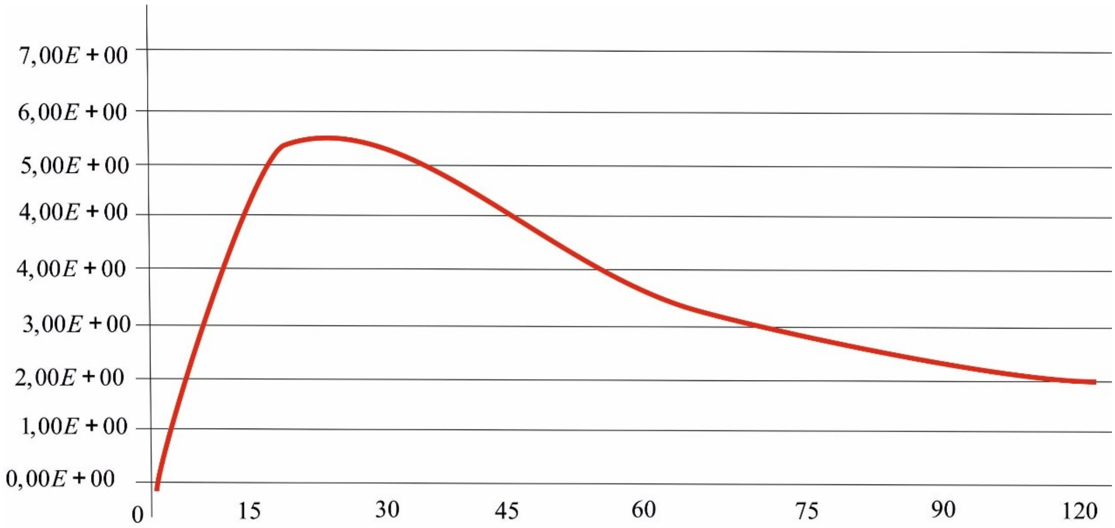
Let us denote: $\Delta_{\beta h}$ the vertical movement of the soil surface during the propagation of transverse waves, all other designations: P_0, d and r leave them unchanged. In accordance with the reciprocity theorem we have:

$$2\pi b d P_0 \Delta u_\beta^\nu = F_0 \Delta_{\beta v} \quad (17)$$

What follows

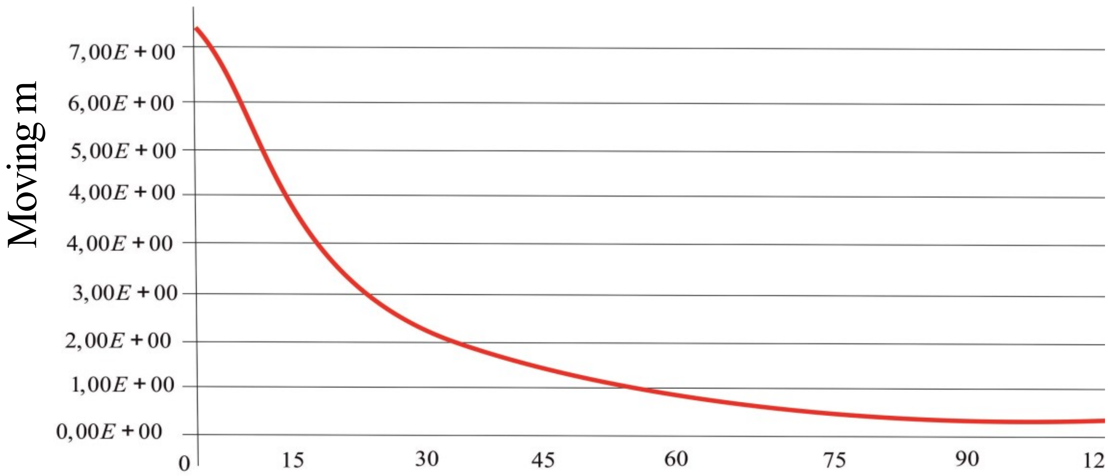
$$\Delta_{\beta v} = -\frac{P_0 b^2 (i\omega) d \delta \sin\varphi \cos\varphi [\delta^2 - \sin^2\varphi]^{1/2} e^{-i\omega r/\beta} e^{i\omega t}}{\mu\beta r \left\{ [1 - 2\sin^2\varphi]^2 + 4\sin^2\varphi \cos\varphi [\delta^2 - \sin^2\varphi]^{1/2} \right\}} \quad (18)$$

Horizontal vibrations of the ground surface transmitted transverse waves during an explosion in a cylindrical cavity.



Distance x(m)

Fig. 2. Levels of vertical displacements of the ground surface transmitted by longitudinal waves during an explosion in a cylindrical cavity



Distance x(m)

Fig. 3. Levels of horizontal displacements of the ground surface transmitted by longitudinal waves during an explosion in a cylindrical cavity

Horizontal vibrations transmitted by transverse waves during an explosion in a cylindrical cavity are determined in the same way as vertical ones, but here we use function (6). Omitting intermediate calculations, we present the final result:

$$\Delta_{\beta h} = \frac{p_0 b^2 (i\omega)\cos\theta\cos\varphi[1-2\sin^2\varphi]^{1/2} e^{-i\omega r/\beta} e^{i\omega t}}{2\mu\beta r\left\{[1-2\sin^2\varphi]^2 + 4\sin^2\varphi\cos\varphi[\delta^2-\sin^2\varphi]^{1/2}\right\}} \tag{19}$$

Considering that horizontal and vertical vibrations of the ground surface transmitted by transverse waves that occurred during an explosion in a cylindrical mine occur in one phase, the amplitude of the oscillations can be determined by the formula:

$$\Delta_\beta = \sqrt{\Delta_{\beta v}^2 + \Delta_{\beta h}^2} \tag{20}$$

An example of evaluating the vibrations of the ground surface during an explosion in a cylindrical cavity.

As an example, we will determine the movement of the soil surface from an explosion in a cylindrical cavity at the following values of the initial data [5]: $a = 600 м / сек$ - the velocity of longitudinal waves in the ground, $\beta = 350 м / сек$ - the velocity of transverse waves in the ground, $p = 1700 кг / м^3$ - the density of the soil, $\gamma = 0.0$ - the coefficient of internal friction of the soil material, $h = 20 м$ - the depth of the cylindrical cavity, $b = 2.8 м$ - the radius of the cylindrical cavity, X - the distance from the point at which the vibration levels are determined before the projection of the tunnel axis onto the ground surface, $P_0 = 2 МПа$ the amplitude value of the harmonic component of the force with frequency $\omega = 200\,Hz$, $d = 10 м$ - the section of the cylindrical cavity on which the pressure acts. The obtained solutions for harmonic forces can be used for arbitrary effects using the Fourier transform.

Conclusion.

Based on the results obtained, it was found that an increase in the thickness of the filler has a particularly significant effect on the change in the complex phase velocity at relatively small thicknesses of the filler. With an increase in the order of the mode of torsional oscillations, the density of the arrangement of curves on the plane of phase velocity and wave numbers increases. In the case of short waves, there is a limit value of the complex phase velocity.

REFERENCES

1. Мейш В.Ф., Луговой П.З., Штанцель С.Э. Вынужденные нестационарные колебания трехслойной цилиндрической оболочки с продольно-поперечным дискретным ребристым наполнителем // Прикл. мех.: Международный научный журнал. – 2005. – 41. № 2. – С. 60-67
2. Масленников А. М. Основы динамики и устойчивости стержневых систем – М.; СПб: Изд-во АСВ: Изд-во СПбГАСУ, 2000. – 203 с.
3. Андронов И.В. Рассеяние высокочастотной волны на сильно вытянутом теле. Акустический журнал, 2013, том 59, №4, с. 419-423
4. Михайловский Е. И. Игнорирование гипотез Кирхгофа в нелинейной теории жесткогибких оболочек // Нелинейн. пробл. мех. и физ. деформир. тверд. тела – СПб. гос. ун-т., 2000. – № 2. – С. 131-160
5. Андреева Е.В. Расчетные модели подземного трубопровода при воздействии поперечных сейсмических воздействий // Магистральные и промысловые трубопроводы: проектирование, строительство, эксплуатация, ремонт: сб. науч. тр. / РГУ нефти и газа им. И.М. Губкина. 2007. № 2. С. 49–54.

6. Денисов Г.В., Лалин В.В. Собственные колебания заглубленных магистральных трубопроводов при сейсмическом воздействии // Трубопроводный транспорт: теория и практика. 2013. № 4(38). С. 14–17.
7. Баженов В.Г. Численное исследование процессов деформирования, потери устойчивости и закритического поведения упругопластических оболочек вращения при квазистатических и динамических нагружениях // Материалы XIX международного симпозиума «Динамические и технологические проблемы механики конструкций и сплошных сред» имени А.Г. Горшкова (Ярополец, 18–22 февраля 2013 г.). – М.: Изд-во: ООО «ТР-принт», 2013. – С. 23–26.
8. Александров А.А., Котляровский В.А., Ларионов В.И., Лисин Ю.В. Модель динамического анализа прочности магистральных нефтепроводов на сейсмические воздействия // ЭНЖ «Нефтегазовое дело». 2011. № 5. С. 66–88.
9. Болотин В. В., Новичков Ю. Н. Механика многослойных конструкций. М. : Машиностроение,1980. 375 с.
10. Рашидов Т.Р., Сагдиев Х., Мубораков Я.Н., Сафаров И.И. О двух основных методах изучения сейсмонапряженного состояния подземных сооружений при действии сейсмических волн.ДАН УзССР,N6,1989. -с.13-15.
11. Mirsaidov M, Teshaev M, Ablokulov Sh and Rayimov D. Choice of optimum extinguishers parameters for a dissipative mechanical system. IOP Conference Series: Materials Science and Engineering. 2020 IOP Conf. Ser.: Mater. Sci. Eng. 883 012100.
12. Yunusov G. G., Esanov N. Q., Almuratov Sh. N., Ablokulov Sh.Z., Sobirova R. On numerical simulation of vibrations in radio-electronic structures // American Institute of Physics: Conference Proceedings. –USA, 2022. Vol. 2467. –P.1-10. 060038 .
13. Usmonov, B.Sh., Safarov, I.I., Teshaev, M.Kh., Nuriddinov, B.Z., Ablokulov, Sh.Z. Forced vibrations of hereditary deformable shell elements of aircraft structures in gas flow under influence of atmospheric turbulence. E3S Web of Conferences, 2023, 401, 03017.