

Ivan SHATSKYI¹, Andrii STRUK², Maksym VASKOVSKYI³**STATIC AND DYNAMIC STRESSES IN PIPELINE BUILT
ON DAMAGED FOUNDATION****Abstract**

A deformation model of the buried pipeline under complicated geotechnical conditions of local ground failure is proposed. The effect of displacement of discontinuities in failed ground on the stressed condition and limited equilibrium of pressurized pipe has been studied.

Keywords

Buried pipeline, ground failure, kinematic perturbation, static and dynamic stress

1 INTRODUCTION

The maintenance of buried pipelines in the areas of anomalous behavior of the foundation (waterlogged and marshy terrains, karst cavities or temporary works, regions of freezing-thawing, soil settlement and slip, zones of tectonic faults, neotectonics or bench formation, earthquake and mudflow hazardous regions) involves nonstandard working conditions and requires an additional analysis together with engineering-geological monitoring and the use of rheological soil mechanics models. In spite of the diversity of these models [1–8], it is difficult to forecast the mechanical load on the pipeline in anomalous areas. To increase the safety of pipeline systems laid in mountainous regions, it is necessary to develop engineering methods and models of the calculation of stressed condition and deformation of buried pipelines in the zones of local failure of the bedrock foundation.

In this paper we develop the analytical approach offered in the articles [9, 10].

2 PROBLEM FORMULATION

The investigations were carried out within the framework of a geometrically and physically linear formulation. The buried pipeline was modeled by an infinite straight tubular rod (Fig. 1) interacting with the bedrock through a backfill layer, which is described by the linearly elastic Winkler model. In a more detailed consideration of capacity issues, the pipe was taken as a membrane shell. Reciprocal displacements of bedrock blocks along the pipe axis were described by discontinuous or piecewise differential function. This approach allows one to determine pipeline stresses not from the distribution of earth load, which is usually difficult to estimate, but from the kinematic parameters of bedrock displacements. To quantitatively implement this concept, an initial boundary value problem has been formulated:

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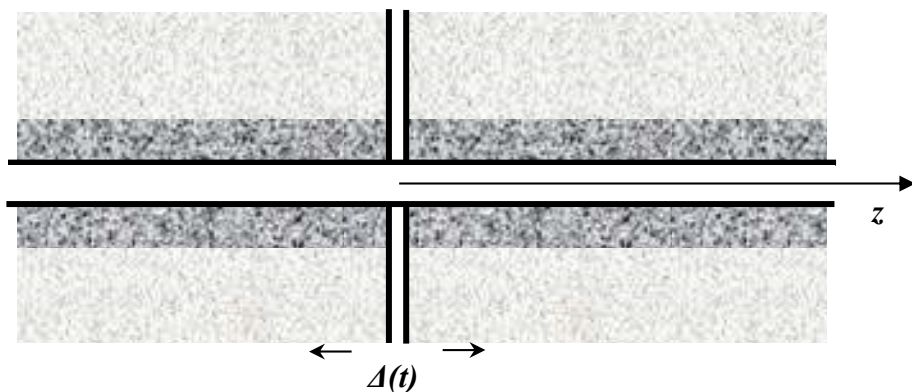


Fig. 1: Scheme of buried pipeline on damaged fondation

$$EF \frac{\partial^2 u_z}{\partial z^2} - \pi D k_\tau (u_z - u_z^0) = \rho F \frac{\partial^2 u_z}{\partial t^2}, \quad z \in (-\infty, \infty), \quad t > 0; \quad (1)$$

$$u_z(z, 0) = \frac{\partial u_z}{\partial t}(z, 0) = 0, \quad z \in (-\infty, \infty); \quad (2)$$

$$\frac{\partial u_z}{\partial z}(\pm\infty, t) = 0, \quad t > 0. \quad (3)$$

where:

z – is the coordinates section [m],

u_z – is the axial displacement of the pipeline [m],

EF – is the longitudinal rigidity of the pipe section [N],

ρ – is the density of its material [kg/m³],

D, h – are the outside diameter and wall thickness of the pipe [mm],

k_τ – is the tangential coefficient of the elastic bed [MPa/m] and

$u_z^0(z, t) = \frac{1}{2} \Delta(t) \operatorname{sgn} z$ – is given reciprocal displacement of blocks [m].

If $\Delta(t)$ is the harmonic function, then it is possible to solve the problem on the steady regime of vibration without initial conditions.

The components of the tensor stress in the pipe wall are calculated through kinematic characteristics from the formulae:

$$\sigma_z = E \frac{du_z}{dz} + \nu \sigma_\theta, \quad \sigma_\theta = p \frac{D}{2h}, \quad \tau_{z\theta} = 0,$$

where p is the internal pipeline pressure.

To analyze the limiting state of the pipe, it is expedient to make use of the energetic concept of strength:

$$\sigma_{eq} \equiv \sqrt{\sigma_z^2 - \sigma_z \sigma_\theta + \sigma_z^2 + 3\tau_{z\theta}^2} \leq [\sigma],$$

where:

σ_{eq} – is von Mises equivalent stress [Pa] and
 $[\sigma]$ – is allowable stress for the pipe material [Pa].

3 ANALYTICAL SOLUTION

3.1 Statics

Suppose the foundation blocks have moved apart by the quantity at the origin of coordinates along the pipeline axis: $\Delta(t) = \Delta = const$.

After ignoring the inertial members, the analytical solution of the static boundary problem (1) and (3) has been constructed in the class of piecewise differential functions:

$$u_z(z) = \frac{\Delta}{2} \left(1 - \exp\left(-\frac{|z|}{\gamma_z}\right) \right) \operatorname{sgn} z,$$

$$\sigma_z(z) = E \frac{\Delta}{2\gamma_z} \exp\left(-\frac{|z|}{\gamma_z}\right) + \nu \sigma_\theta(z),$$

$$\sigma_\theta(z) = p \frac{D}{2h}, \quad \tau_{z\theta}(z) = 0,$$

where:

$$\gamma_z = \sqrt{\frac{EF}{\pi D k_\tau}} \approx \sqrt{\frac{Eh}{k_\tau}} - \text{is characteristic length of the system [m] and}$$

ν – is Poisson's ratio.

Let us give an example of the calculation for the ruptural deformation of the foundation.

Particular numerical calculations were made for an underground main pipeline. The following was assumed for the pipe: $D = 1420$ mm, $h = 18$ mm, $E = 2.1 \cdot 10^5$ MPa, $\nu = 0.3$, $\rho = 7.8 \cdot 10^3$ kg/m³ for the soil $k_\tau = 2$ MPa/m. Reciprocal displacements of blocks are $\Delta = D/20 = 71$ mm or $\Delta = -71$ mm. The internal pressure is assumed such that it produces the tangential stress $\sigma_\theta = 300$ MPa. The results of the investigation are presented in Figs. 2 and 3.

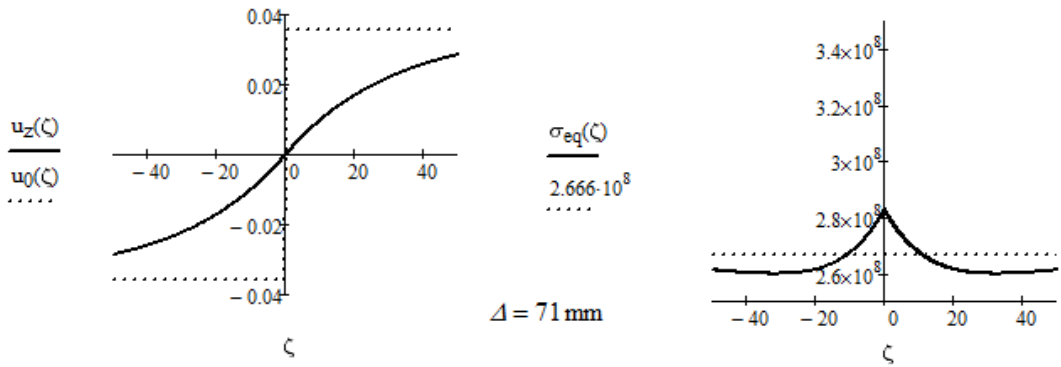


Fig. 2: Distribution of the displacement and equivalent static stress along the pipe axis in the zone of positive discontinuity of the foundation, $\zeta = z/D$ is dimensionless coordinate

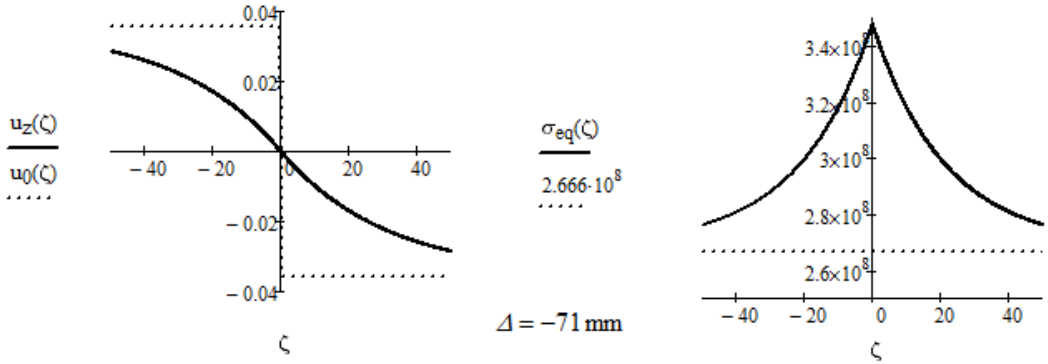


Fig. 3: Distribution of the displacement and equivalent static stress along the pipe axis in the zone of negative discontinuity of the foundation, $\zeta = z/D$ is dimensionless coordinate

The mutual approach of the foundations blocks ($\Delta < 0$) is more dangerous than the fault opening ($\Delta > 0$).

3.2 Steady dynamics

Suppose, the foundation blocks oscillate according to the law: $\Delta(t) = \Delta \sin \omega t$. The solution of the dynamical problem without initial conditions is as follows:

$$u_z(z, t) = \frac{\Delta \sin \omega t}{2 \left(1 - \frac{\omega^2}{\omega_*^2} \right)} \left(1 - \exp \left(-\frac{|z|}{\gamma_z} \sqrt{1 - \frac{\omega^2}{\omega_*^2}} \right) \right) \operatorname{sgn} z ;$$

$$\sigma_z(z, t) = E \frac{\Delta \sin \omega t}{2 \gamma_z \sqrt{1 - \frac{\omega^2}{\omega_*^2}}} \exp \left(-\frac{|z|}{\gamma_z} \sqrt{1 - \frac{\omega^2}{\omega_*^2}} \right) + \nu \sigma_\theta(z, t) ,$$

$$\sigma_\theta(z, t) = p \frac{D}{2h} , \quad \tau_{z\theta}(z, t) = 0 ,$$

where:

$$\omega_* = \sqrt{\frac{k_\tau}{\rho h}} \text{ -- is the cutoff frequency for system "pipeline -- layer-- rigid ground" [Hz].}$$

The dynamic index of stresses has been calculated as follows:

$$k_D = \frac{\max_{z,t} \sigma_{eq}^{dynamic}(z, t)}{\max_z \sigma_{eq}^{static}(z)} = \frac{\sigma_{eq}^{dynamic}(0, 1.5\pi / \omega)}{\sigma_{eq}^{static}(0)} .$$

The numerical calculations were made for the same parameter as declared above. The results are presented on Fig. 4.

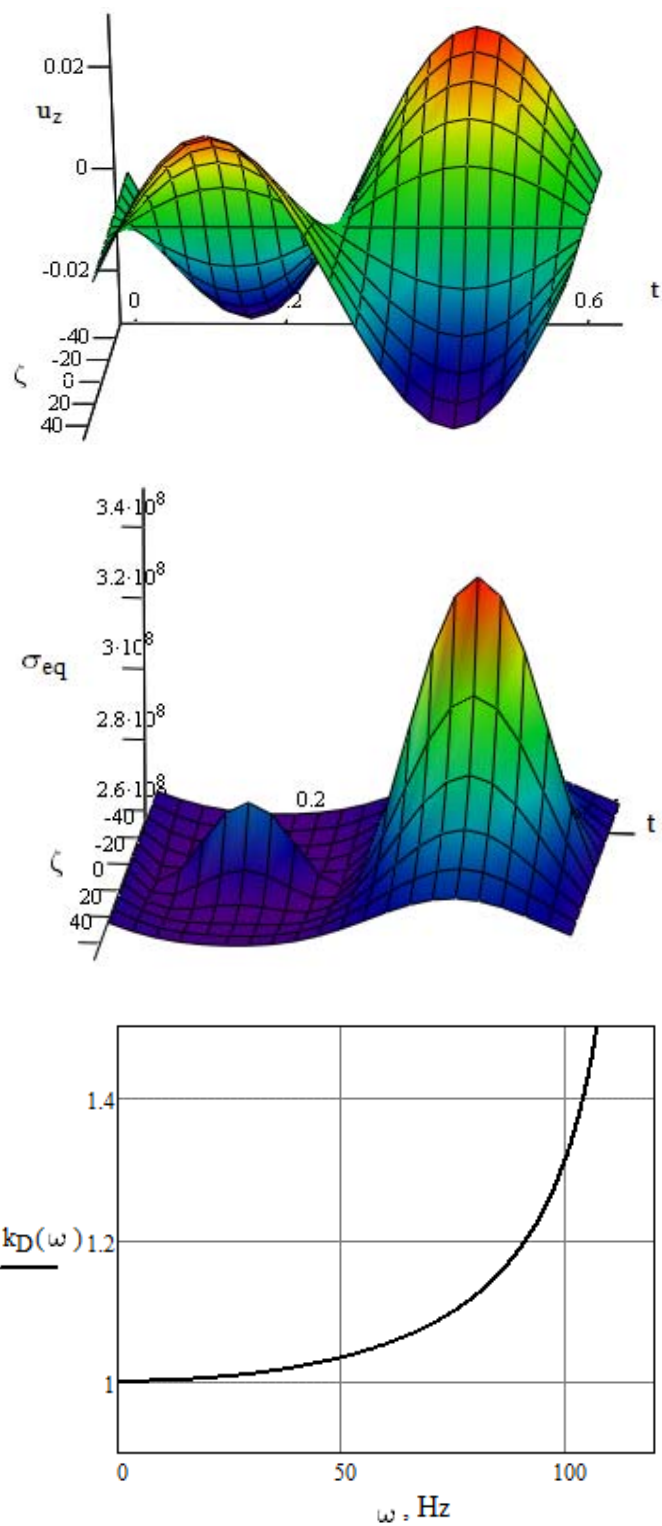


Fig. 4: The displacement and equivalent dynamic stress for $\omega = 10$ Hz and dynamic index of stress

6 CONCLUSIONS

The model developed for the deformation of the buried pipeline at places of local destruction of the foundation makes it possible to evaluate the stressed and limiting state of the pipe by the kinematic parameters of ground cracking.

In the static and dynamic regimes, the mutual approach of the foundations blocks is more dangerous than the fault opening.

LITERATURE

- [1] AINBINDER, A. B. *Strength and stability design of main and field pipelines*. A handbook, Moscow: Nedra, 1991. 287 pp. ISBN 5-247-01809-5. (in Russian).
- [2] KHARIONOVSKII, V. V. *Reliability and life of gas pipeline structures*. Moscow: Nedra, 2000. 467 pp. ISBN 5-247-03863-0. (in Russian).
- [3] Mazur, I. I. & Ivantsov O. M. *Safety of pipeline systems*. Moscow: ITs ELIMA, 2004. 1104 pp. ISBN 5-89674-011-5. (in Russian).
- [4] BORODAVKIN, P. P. *Underground main pipelines*. Moscow: Nedra, 2011. 480 pp. ISBN 978-5-9902-0524-6. (in Russian).
- [5] KARAMITROS, D. K., BOUCKOVALAS, G. D., KOURETZIS, G. P. & GKESOU, V. An analytical method for strength verification of buried steel pipelines at normal fault crossings. *Soil Dynamics and Earthquake Engineering*. 2011, XXXI, Nr. 11, pp. 1452–1464. ISSN 0267-7261. DOI: 10.1016/j.soildyn.2011.05.012.
- [6] VAZOURAS, P., KARAMANOS S. A. & DAKOULAS P. Mechanical behavior of buried pipes crossing active strike-slip faults. *Soil Dynamics and Earthquake Engineering*. 2012, XLI, pp. 164–180. ISSN 0267-7261. DOI: 10.1016/j.soildyn.2012.05.012.
- [7] TRIFONOV, O. V. & CHERNIY V. P. Elastoplastic stress-strain analysis of buried steel pipelines subjected to fault displacements with account for service loads. *Soil Dynamics and Earthquake Engineering*. 2012, XXXIII, Nr. 1, pp. 54–62. ISSN 0267-7261. DOI: 10.1016/j.soildyn.2011.10.001.
- [8] ZHANG, J., LIANG Z. & HAN C. J. Finite element analysis of wrinkling of buried pressure pipeline under strike-slip fault. *Mechanika*. 2015, XXI, Nr. 3, pp. 31–36. ISSN 1392-1207. DOI: 10.5755/j01.mech.21.3.8891.
- [9] SHATS'KYI, I. P. & STRUK A. B. Stressed state of pipeline in zones of soil local fracture. *Strength of Materials*. 2009, XLI, Nr. 5, pp. 548–553. ISSN 0039-2316. DOI: 10.1007/s11223-009-9165-9.
- [10] SHATSKYI, I. P. & STRUK A. B. Straining of underground pipeline in points of local fracture of ground. *Proc. Nat. Acad. Sciences of Ukraine*. 2009, Nr. 12, pp. 69–74. ISSN 1025-6415 (in Ukrainian).