MODEL CONSTRUCTION AND DEVELOPMENT OF AN ALGORITHM FOR THE PROBLEM OF PROPAGATION OF FLEXIBLE WAVES IN A HALF-PLANE WITH PARTIAL ABOUT AN ELASTIC STRIP PLACED

ZHUZBAYEV S.[1], KHABDOLDA B.[1,2], MURATKHAN R.[2], TAKUADINA A.[3], TANIRBERGENOV A.[1], ABDYKHALYK A.[1], TASZHUREKOVA ZH.[4], ZHUMABEKOV M.[2], SEITZHAN N.[2]

[1]L. N. Gumilyov Eurasian National University, Kazakhstan, Astana
[2]Karaganda Buketov University, Kazakhstan, Karaganda
3 Karaganda Medical University, Kazakhstan, Karaganda
[4]Taraz Regional University named after M.KH.Dulaty, Kazakhstan, Taraz
Email: juzbayev@mail.ru[1], berserbol@mail.ru[1,2], raikhan.muratkhan@mail.ksu.kz[2], alyoka.01@mail.ru[3], t.adilbek@mail.ru[1], taszhurekova@mail.ru[4], merik.75@mail.ru[2], Nartai_93@mail.ru[2]

ABSTRACT

The article considers numerical solutions of some spatial non-stationary problems for elastic and elastoplastic bodies of finite dimensions in the form of a parallelepiped, and for them the laws of propagation of three-dimensional waves are studied. An explicit difference scheme based on a combination of the methods of bicharacteristics and splitting in spatial variables is presented. Based on the described method, the elastic problem of longitudinal and transverse impact on a parallelepiped with one rigidly fixed end is solved. The features of the propagation of three-dimensional waves and the influence of a change in the speed of an external load on the pattern of wave propagation are studied, and some features of the propagation of dynamic stresses in the vicinity of a rigidly fixed end are revealed. The software was developed and tested for the robustness of the numerical calculation. Results, achievements of calculations in the form of isolines of normal stresses, performed for different points in time

Keywords: *Model, Algorithm, Flexible Waves, Half Plane, Elastic Strip*

1. INTRODUCTION

The growing volume of industrial, mining, hydraulic engineering and aviation engineering makes it necessary to improve the methods for studying wave problems. Known methods for solving problems [1] cannot always fully reveal the features of contact problems of dynamics.

The features of the propagation of three-dimensional waves and the influence of a change in the speed of an external load on the pattern of wave propagation are studied, and some features of the propagation of dynamic stresses in the vicinity of a rigidly fixed end are revealed.

Within the framework of the study, the problem of dynamic bending of a rectangular orthotropic parallelepiped with one fixed end is considered. The problem, when a uniformly distributed load is applied to one side face of a parallelepiped, while the rest of its faces are stress-free, was the subject of research in one of them. In the other, oscillations of the same parallelepiped were studied under given initial conditions in the form of a displacement velocity. This problem was considered for small time intervals, which did not allow us to study the processes of interference and reflection of waves from boundary surfaces, and wave phenomena were studied only in inhomogeneous bodies of finite dimensions. The problem is devoted to the study of the propagation of dynamic waves in a half -strip during a transverse impact. To solve the stated problem, the optimized method of bicharacteristics is used with the addition of the ideas of the splitting method [2]. The solution of a number of problems based on this method contributed to the writing of an algorithm and the development of an information system for the analysis of wave processes in various media [3], including those using the technology of composite materials.

Dynamic problems of elasticity theory on numerical modeling of elastic wave propagation in 2D and 3D inhomogeneous media are considered.

The solution of the problem of elasticity theory in terms of displacement velocities and stresses is numerically realized using a difference method with a scheme on offset grids [4]. The modeling area is a parallelepiped with a rectilinear geometry of a free surface in a three-dimensional or parallelogram in a two-dimensional rectangular coordinate system. A model of an elastic medium can have an inhomogeneous structure and complex boundaries of media located inside the computational domain. The entire modeling area is assembled from a set of geometric shapes that have an analytical description. The main interest is represented

by models with inclusions in the form of three-dimensional or two-dimensional cavities, the geometry of which is similar to an ellipsoid or sphere [5]. Thus, using the developed programs, it is possible to create complex heterogeneous models with inclusions and conduct numerical modeling of the seismic field to study its structure and distinctive features

2. FORMULATION OF THE PROBLEM,

Calculation and design of buildings and structures, including responsible purposes, requires information about the level and characteristics of possible man-made or seismic impacts. This effect is determined by waves propagating from the source to the object in the geological environment. The level and characteristics of the impact are determined, among other things, by the structure of the upper part of the section of the geological environment, as well as the type and characteristics of the source of the impact. Thus, the seismic effect at a distance from the hearth is mainly determined by surface waves of the Rayleigh wave type propagating in the geophysical structure. These effects are characterized by high energy with a short duration and a low-frequency spectrum. The situation with technogenic impact is much more complicated. This impact is associated with the generation of waves in the ground by highways with heavy traffic, railways and industrial activities (powerful technological equipment of factories, construction works, etc. etc.), characterized by a sufficiently long exposure time, a relatively small distance from the source to the object of exposure, as well as a much more complex frequency composition of the generated waves [6].

For example, the problem of studying nonlinear phenomena accompanying the propagation of powerful acoustic (high-frequency seismic) pulses in depth is of great importance, another interesting problem is the analysis of the fundamental possibility of using an acoustic P-wave of the second kind in a gas-saturated porous medium for seismic sounding purposes. Of interest is the possibility of using moving vibration sources as seismovibrators, studying the characteristics of the seismic fields generated by them, searching for methods for optimal registration and processing of signals that carry information about the properties of the seismic medium, providing better spatial resolution than those traditionally used and increasing the reliability of identifying structural or other (density, elastic-mechanical) anomalies near the earth's surface. Important are the studies analyzing the ways to obtain direct classification features indicating the presence of subsurface local inhomogeneities and their location (depth, epicenter point, etc.) [7].

Plane deformation of an elastic half -strip of finite width 2 is considered l, which in the Cartesian coordinate system $x_1 \ O \ x_2$occupies the region$0 \leq x_1 \leq \infty, |x_2| \leq 1$ (Figure 1).

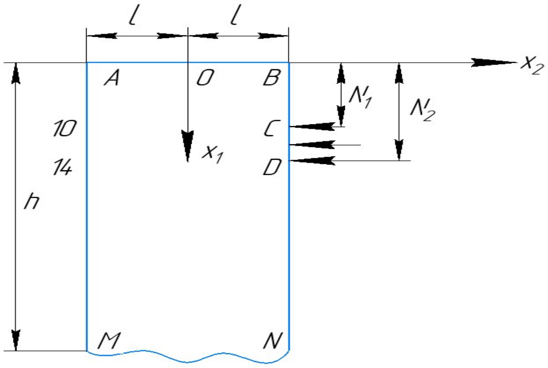

Figure 1: Study Area

The properties of linearly elastic isotropic heterogeneous $(k = 1,2)$materials are given by densities ρ_k, Lame parameters γ_k, μ_k. At the moment the $t \leq 0$body is at rest.

$$v_\alpha^{(k)} = \sigma_{\alpha j}^{(k)} = 0, (\alpha, j = 1\,,2; k = 1, 2) \qquad (1)$$

where $v_\alpha^{(k)}$, $\sigma_{\alpha j}^{(k)}$ are the components of the velocity vector and the stress tensor in the kth body. At the moment of time, the $t_n(n - 1,2, \dots, N)$upper boundary of the $x_1 = 0, |x_2| \leq 1$rectangular strip is subjected to dynamic perturbation by the normal stress, which changes according to the law

$$\sigma_{11}^{(1)} = f(t), \sigma_{12}^{(1)} = 0 \qquad (2)$$

The remaining parts of the boundary of an inhomogeneous body are considered stress-free

$$\sigma_{1j}^{(2)} = 0, (j = 1, 2)\text{at}$$

$$x_1 - L_1, l \leq |x_2| < \infty \qquad (3)$$

$$\sigma_{j2}^{(1)} = 0, (j = 1, 2)\text{at}$$

$$0 \leq x_1 \leq L_1, |x_2| - l \qquad (4)$$

The conditions at the contact boundaries meet the requirements for complete adhesion of the strip and the half-plane

$$v_\alpha^{(1)} = v_\alpha^{(2)}, \sigma_{1j}^{(1)} = \sigma_{1j}^{(2)}, (\alpha, j = 1,2)\text{at}$$

$$x_1 = L_2, |x_2| \leq l \qquad (6)$$

$$v_\alpha^{(1)} = v_\alpha^{(2)}, \sigma_{j2}^{(1)} = \sigma_{j2}^{(2)}, (\alpha, j = 1,2)\text{at}$$

$$L_1 \leq x_1 \leq L_2, |x_2| = l \qquad (7)$$

Here, $f(t)$is a given boundary function, and L_2, L_1, l are constant numbers that determine the dimensions of the strip and the contact area of the inhomogeneous medium.

Under the described conditions, it is necessary to investigate the stress-strain state of an inhomogeneous medium $D_1 \cap D_2$. To solve the problem (1), along with the initial and boundary conditions (2) - (7), a system of equations is used, consisting of the equations of motion and the relations of the generalized Hooke's law.

$$\rho_k \ddot{u}_\alpha^{(k)} - \sigma_{\alpha\beta,\beta}^{(k)}$$

$$\sigma_{\alpha j}^{(k)} = \lambda_k \varepsilon_{\beta\beta}^{(k)} \delta_{\alpha j} + 2\mu_k \varepsilon_{\alpha j}^{(k)}$$

Where $\varepsilon_{\alpha j}^{(k)} = 0.5\left(u_{\alpha,j}^{(k)} + u_{j,\alpha}^{(k)}\right); \delta_\alpha$ is the Kronecker symbol,$u_\alpha^{(k)}$, $\varepsilon_{\alpha j}^{(k)}$ are the components of the displacement vector and strain tensor.

Indices : α, β, j– take values 1.2 ; further accepted$i$ not equal to j; subscripts after the decimal point indicate derivatives with respect to the corresponding spatial coordinate; dot above denote time derivatives; for twice repeated lower Greek indices must be summed up. Finally, the index $k$determines whether a point belongs to a region $k = 1$or region of a half -space $k = 2$, not equal to [8].

3. ANALYSIS OF RESULTS

The analysis and evaluation of the efficiency of the generation of seismic waves by vibrating seismic sources are caused by the unsatisfactory state of theoretical developments in this area. Single surface force vibrators are low-efficient both in relation to the total power of elastic waves emitted by them, and with respect to volumetric P-waves, considered as the most important for exploration geophysics applications. In this regard, the study of ways to increase the efficiency of excitation and optimize the redistribution of the balance of radiation energy over different types of elastic waves is of interest. The statement on which seismic practitioners rely is not substantiated when estimating the power emitted by a vibrator in the seismic frequency range, expressed by the rule of thumb: one ton of vibration force provides one kilowatt of elastic wave power [9].

As is known, engineering and other types of seismic exploration are almost completely oriented towards various designs of vibration or pulse sources of variable strength. However, as shown in our works, an alternative option can be a source of the center of expansion (center of pressure) type, the deepening of which by a quarter of the wavelength under the surface allows not only to surpass all the above-mentioned analogues in terms of the total radiated elastic power, but also in terms of the level of only the P-wave, as well as to scan the radiation pattern of this type of wave in the angular plane [10].

The possibility of electrical control of the angular characteristics of a multi-element radiating antenna demonstrated in our works shows the persistence of the phase wave ratios of seismic radiation as it moves away from the source within areas not too large in area. This indicates a relatively high degree of correlation of sounding seismic vibrations and the insignificant role of parasitic scattering and transformation of seismic waves even in the most unfavorable seismogeological conditions - in the uppermost part of the deep section of the medium.

Seismic wave emitters in the low frequency region are poorly tunable, very bulky devices that require significant maintenance costs. In confirmation of what has been said, we can refer to our work, in which the low efficiency and weak directivity of the radiation of a static load of significant magnitude, periodically moved along the border, is investigated and confirmed. However, theoretical analysis and assessments have shown that the directivity of the parametric source of P-waves in the ground, as in hydroacoustics, is higher than that of traditional ones, and the generation efficiency is not inferior to the latter. In this regard, the theoretical consideration of the parametric generation scheme is an important stage in the study of the fundamental possibility of practical use of this type of sources along with traditional ones. It should be noted that the parametric scheme for generating P-waves of difference frequency is practically not discussed in the literature on seismic sources, although the generalized nonlinearity coefficient of soft soil is two orders of magnitude greater than that of water [11].

The unsatisfactory level of developments in the field of creating seismic phased emitting antennas, for example, in comparison with similar hydroacoustic ones, results in the need for multiple repetition of radiation stages with the transfer of the source along the profile, which is practiced in modern conditions. The conducted studies of the features of seismoacoustic fields created by moving sources indicate one of the ways in which motion should be considered as an independent physical factor that allows improving the conditions for separate reception of waves refracted by different interface boundaries. Studies of the frequency shift of surface and refracted waves are devoted to this, in which a detailed calculation is given showing the influence of all factors of motion and structure of the medium. It is also obvious that with the help of a moving and at the same time coherent source, higher efficiency can be provided during engineering seismic surveys.

As an example of a moving seismic source, but in conditions where the velocity of its movement exceeds the velocities of propagation of compression and shear waves in the near-well space, we have considered a hydroacoustic pressure pulse running through a water-filled well. When propagating at a speed exceeding the speed of either P or 8-waves in the near-well space, it will be a source of "flowing" waves of these types, the efficiency and angular characteristics of which are the subject of discussion of our work. The considered radiation mechanism is known and referred to as the Cherenkov radiation mechanism. It is rarely discussed in the acoustic literature, as well as in the literature on seismic problems, although sources of seismic wave generation based on its use could be implemented in places with a dense network of wells. This would make it possible to probe areas of practical interest in the environment in the immediate vicinity of a hydrocarbon deposit [12]

Experimental and theoretical work on the scattering of seismic waves by local surface and subsurface inhomogeneities is an independent direction. In it, you can separately distinguish problems with linear and nonlinear formulation. Since these studies in terms of practical application correspond to traditionally seismic studies that correspond to the topic, or the problem of finding anomalies in the upper part of the deep section, then, as in traditional seismics, they are divided into approaches that are more or less acceptable in different conditions, as well as meeting the implementation of different goals. In some conditions, the echolocation principle develops, in others - the impedance principle. This cycle of work was carried out to substantiate the possibilities of seismolocation of shallow local inhomogeneities in the ground. In the development of the applied aspect in the study of seismic wave scattering processes, as well as for the practical illustration of the conclusions of the theory, remote sensing of local inhomogeneities in the soil lying at different depths was carried out [14].

For our country, the successful solution of earthquake resistance problems is of great importance, since eleven republics of our country are located on the territory where earthquakes can manifest themselves with destructive intensity. The large volume of capital construction envisaged in the eleventh five-year plan in seismically hazardous areas places high demands on the reliability and economic performance of buildings and structures [15].

One of the problems of the theory of seismic resistance is that seismic loads determined by various theoretical methods do not agree with each other. Therefore, the degree of reliability of calculations performed during the design of structures or the study of their behavior in seismic conditions remains insufficiently clarified. Accordingly, the task of ensuring the reliability of buildings and structures in case of strong earthquakes is still far from a final solution and requires further research [16].

Numerical calculations were carried out for various configurations of the section of the strip included in the half-space, the size of the area of application of the external load. Figures 2-6 show the results of calculations for the following dimensions of the inclusion of the strip and the area of local impact: $l = 10h, N_1 = 4h, N_2 = 6h$ and $L_1 = 10h, L_2 = 20h$). In Figure 7, the calculation results correspond to the case when $l = 5h, N_1 = 10h, N_2 = 12h$ and $L_1 = 50h, L_2 = 70h$. Finally, the results shown in Figure 8 were obtained under the condition of a rigidly fixed strip with a half-space ($l = 5h, N_1 = 10h, N_2 = 12h$ and $L_1 = L_2 = 50h$). The calculation results presented in Figures 2-8 clearly illustrate the mutual influence of the strip and half-space on the stress distribution during an impulse transverse impact. Changes in normal $\sigma_{22}^{(k)}$ and tangential $\sigma_{12}^{(k)}$ stresses ($k = 1.2$) along the x_1 at time t=40τ in sections 1 (x_2=-15h), 2 (x_2=-10h), 3 (x_2=-5h), 4 (x_2= 0h), 5 (x_2=5h), 6 (x_2=10h) are shown by the corresponding curves in Figures 2-3. On fig. 2 normal stresses $\sigma_{22}^{(k)}$ (k=1, 2) in section 1 are not shown due to the smallness of their values, which is explained by a significant weakening of elastic perturbations when passing through their region of the half-plane [2].

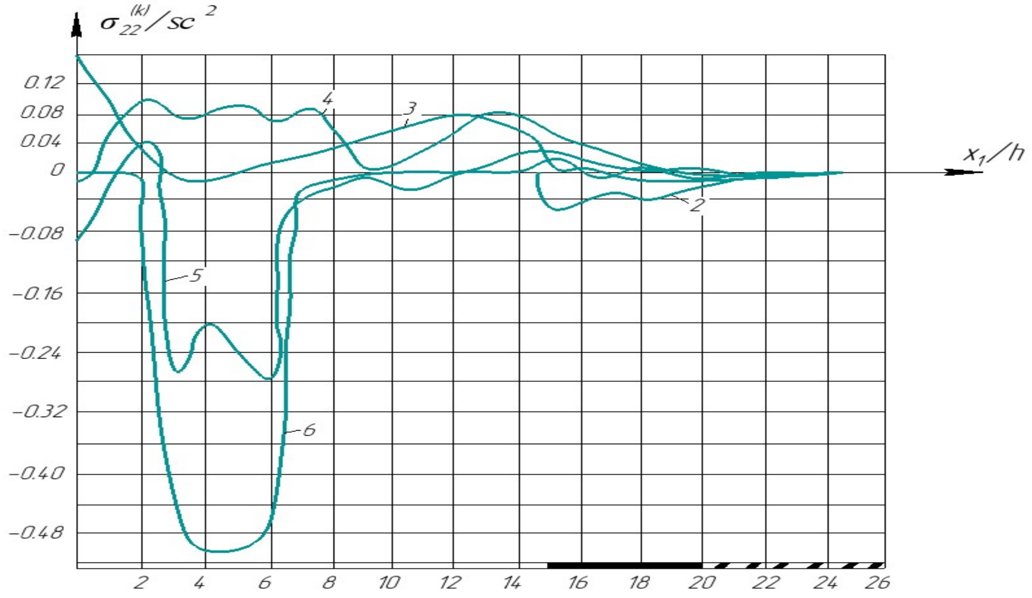

Figure 2 - Changes In Normal Stresses Σ $_{22}$ $^{(K)}$ At Time T \U003d 40 Along The X τ_1 Coordinate In Sections 1 (X $_2$ = -15h), 2 (X $_2$ = -10h), 3 (X $_2$ =- 5h), 4 (X $_2$ = 0h), 5 (X $_2$ = 5h), 6 (X $_2$ = 10h)

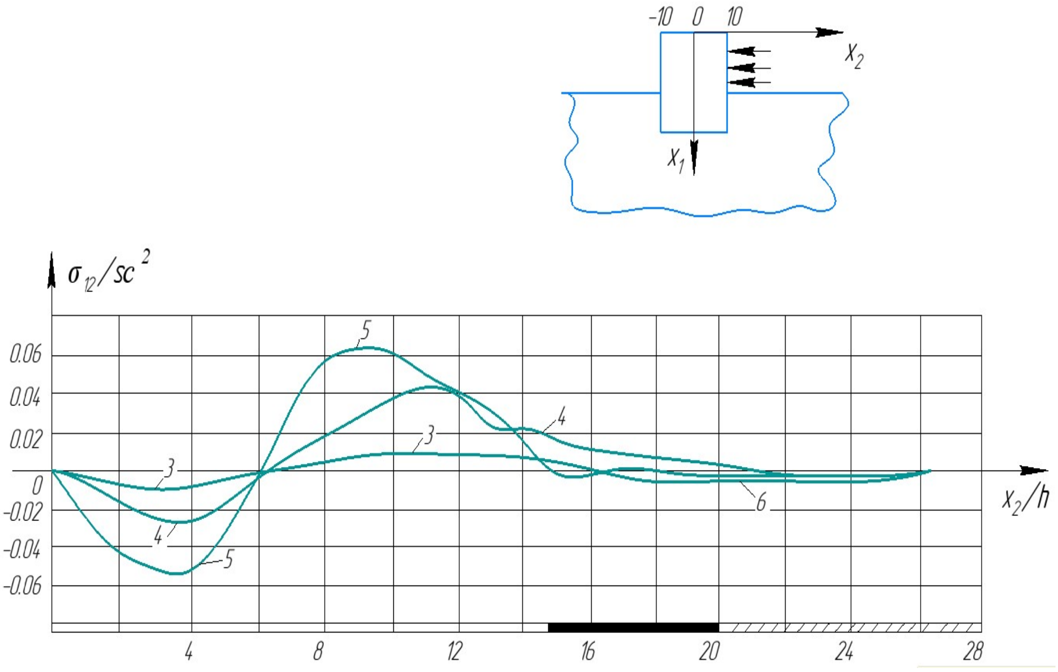

Figure 3: Changes In Normal Stresses $\Sigma_{12}^{(K)}$ At Time T =40 Along The X τ_1 Coordinate In Sections 3 (X_2 =- 5h), 4 (X_2 =0h), 5 (X_2 =5h), 6 (X2 = 10h)

In sections 4, 5 and 6 in the section ($N_1 \leq x_1 \leq N_2$, $x_2 = 1$) of the action of a local load, the normal stresses $\sigma_{22}^{(k)}$ (k = 1, 2) reach extreme values in the region of discontinuity of the boundary conditions near singular point P and on the contact surfaces of the strip and half-plane. In section 2 ($x_2 = -1$) normal stresses $\sigma_{22}^{(k)}$ (k =1, 2) in the region of the free surface of the strip are equal to zero and change abruptly in the contact region. In section 3, the normal stresses $\sigma_{22}^{(k)}$ (k =1, 2) become tensile everywhere, except for the vicinity of the discontinuity points of the boundary conditions. Tangential stresses $\sigma_{12}^{(k)}$ (k =1, 2) in sections 1 and 2 are not shown due to the smallness of their values. In sections 3, 4, 5 and 6, the shear stress curves $\sigma_{12}^{(k)}$ (k = 1, 2) are in good agreement with the nature of the incoming wave fronts. Changes in the normal stress $\sigma_{11}^{(k)}$ (k = 1, 2) along the x_2 at time t = 40τ in sections 1 (x_1 =5h), 2 (x_1=10h), 3 (x_1=15h) , 4 (x_1 = 18h), 5 (x_1 = 20h) and in sections 1 (x_1 = 5h), 2 (x_1 = 10h), 3 (x_1 = 18h), 4 (x_1 = 20h) shown as curves in Figures 4 and 5, respectively. In section 1, normal stresses $\sigma_{11}^{(1)}$ are compressive in accordance with a given local load, and then, due to the influence of waves reflected from the free surface and the strip boundaries opposite from the impact site, as well as waves diffracted from corner points, they abruptly change from compression to tension. In section 2, this effect is repeated with a small amplitude. In sections 4 and 5, a compression wave takes place in the region of the strip, which passes into a tension wave with a small level of values when it enters the half-plane region. The behavior of the normal stress $\sigma_{11}^{(k)}$ and in section 3 differs sharply from its behavior in other sections [2].

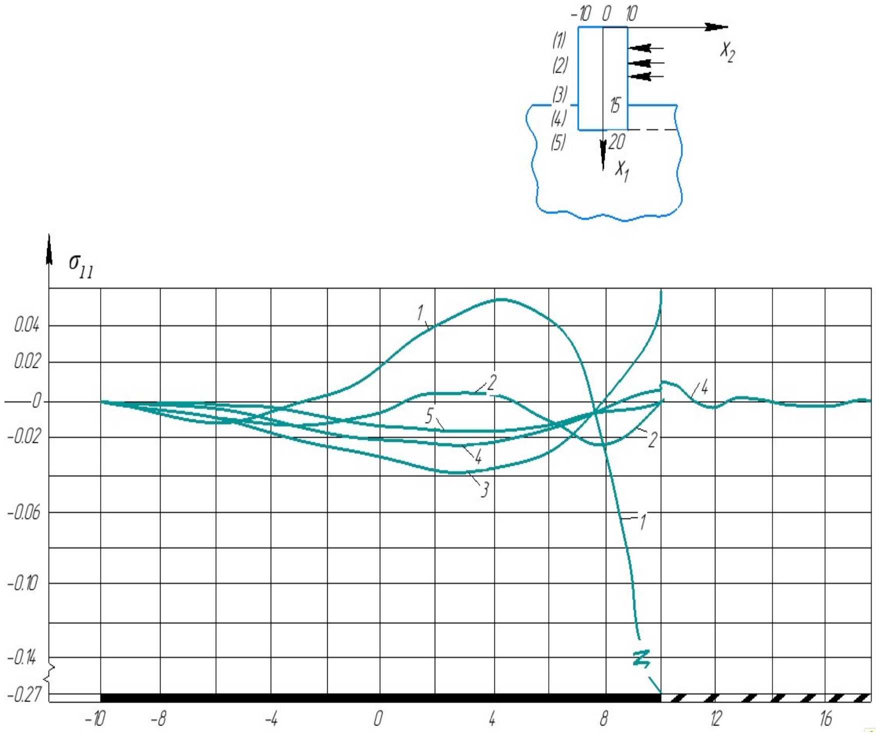

Figure 4: Changes In Normal Stresses $\Sigma_{11}^{(K)}$ At Time T = 40 Along The X τ_2 Coordinate In Sections 1 (X_1=5h), 2 (X_1 = 10h), 3 (X_1 =15h), 4 (X_1 = 18h), 5 (X_1 = 20h).

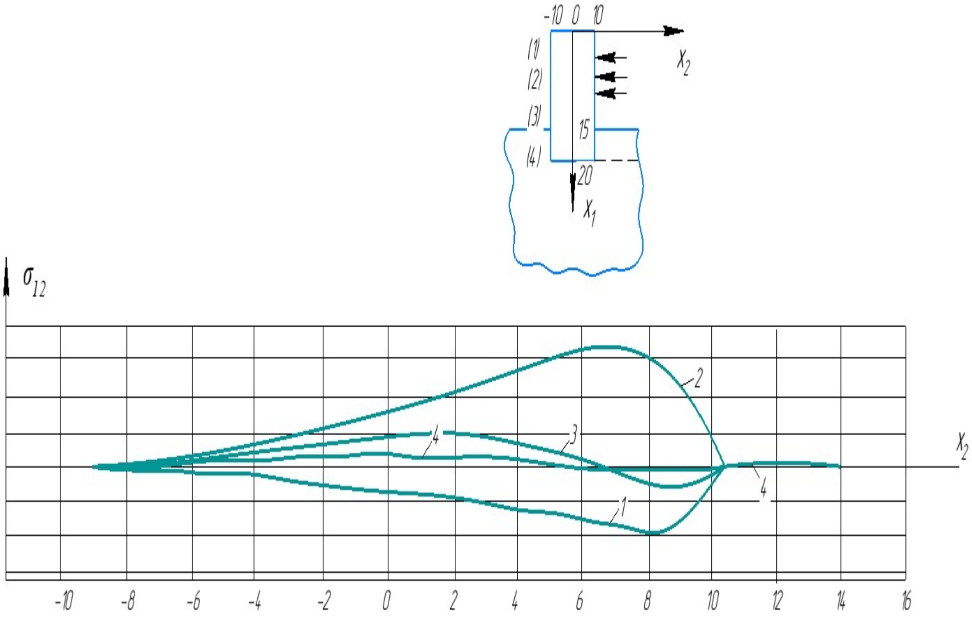

Figure 5 - Changes In Normal Stresses $\Sigma_{12}^{(K)}$ (K = 1, 2) At Time T =40 Along The X τ_2 Coordinate In Sections 1 (X_1=5h), 2 (X_1 = 10h), 3 (X_1 =15h), 4 (X_1 = 20h).

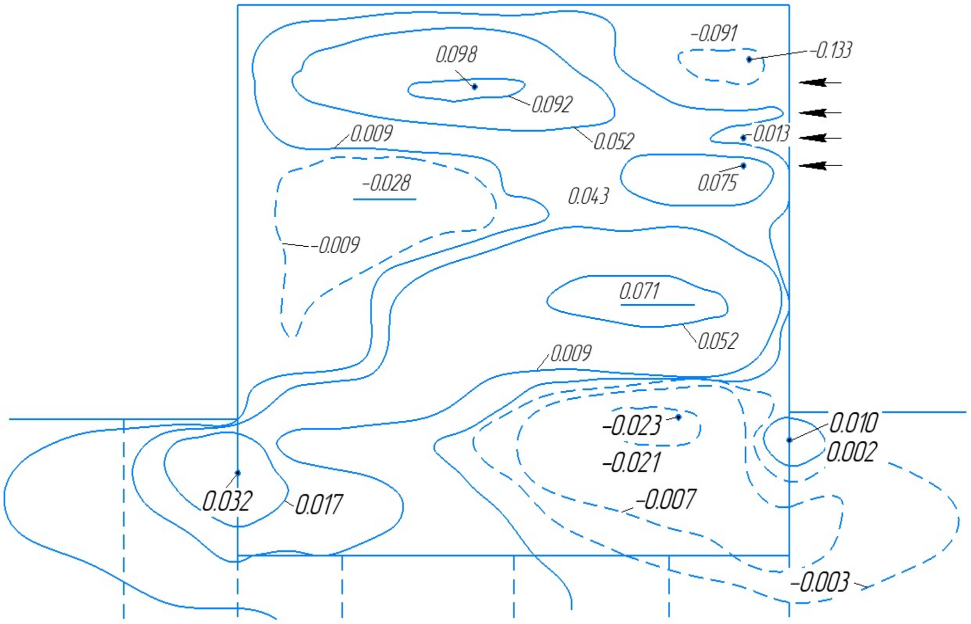

Figure 6: Isolines Of Tangential Stresses $\Sigma_{12}^{(1)}$ (10^{-2}) At Time $T = 40\ \tau$.

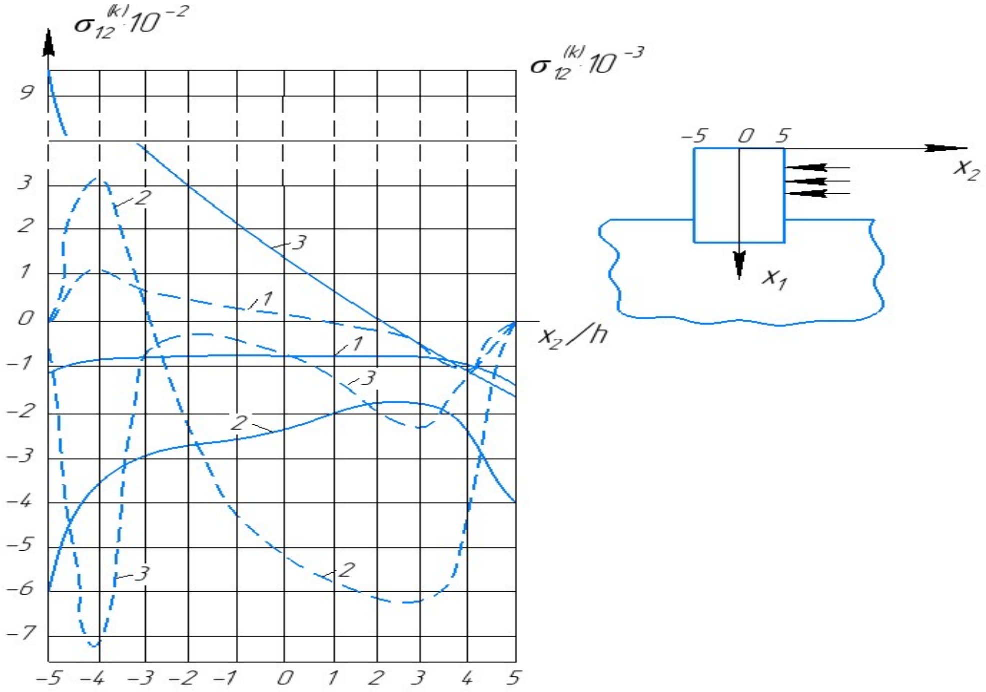

Figure 7 - Changes In Normal $\Sigma_{11}^{(K)}$ (Solid Lines) And Tangent $\Sigma_{12}^{(K)}$ (Dashed Lines) Stresses (K = 1, 2) Along The X_2 Coordinate In Sections $X_1 = 50h$ At Time Points $T = 80\ \tau$(1st Line), $T=100\ \tau$(2nd Line), $T = 120\ \tau$(3rd Line).

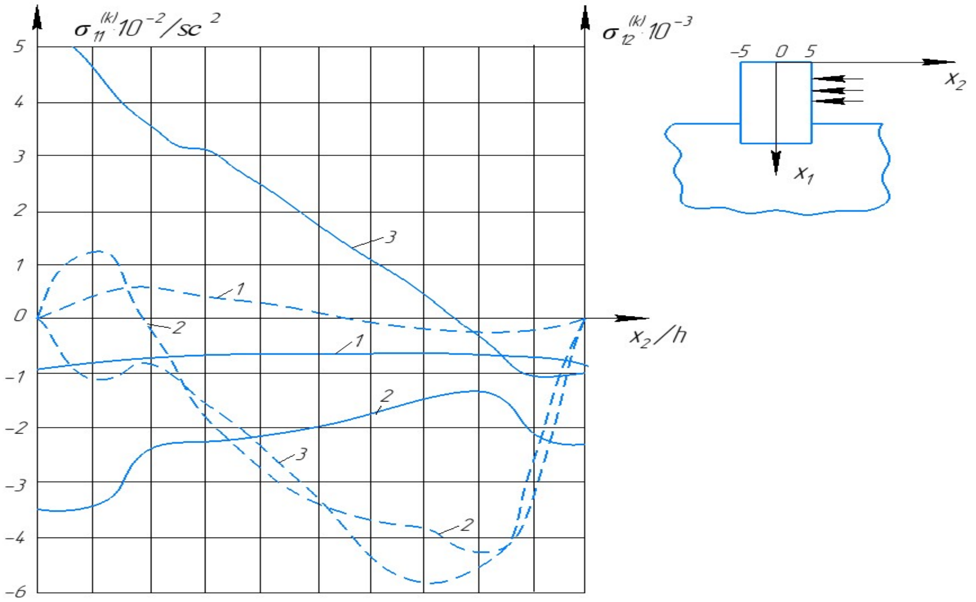

Figure 8 - Changes In Normal $\Sigma_{11}^{(K)}$ (Solid Lines) And Tangent $\Sigma_{12}^{(K)}$ (Dashed Lines) Stresses (K =1, 2) Along The X_2 Coordinate In Sections X_1=50h At Time Points T = 80 τ(1st Line), T=100 τ(2nd Line), T = 120 τ(3rd Line)

4. CONCLUSION

Near the singular point P ($x_1 = L_1$, $x_2 = 1$) tension occurs, and in the vicinity of the opposite singular point R ($x_1 = L_1$, $x_2 = -1$) - compression, which is typical for static bending. Changes in shear stresses $\sigma_{12}^{(k)}$ (k =1, 2) are in good agreement with the above described processes of wave propagation in all sections 1, 2, 3 and 4 (Figure 5). In section 1, shear stresses $\sigma_{12}^{(1)}$ have a negative sign, and in section 2 they are positive. Figure 6 shows the isolines of shear stresses $\sigma_{12}^{(k)}$ (k = 1, 2) at time t = 40τ. During this time, disturbances propagate from the local area of external influence and cover a sufficiently large part of the inhomogeneous body $D_1 \cap D_2$. The distribution of shear stresses $\sigma_{12}^{(k)}$ (k =1, 2) in an inhomogeneous medium differs sharply from their distributions in a homogeneous strip. Here there are many points where local extrema are reached. In this case, the influence of the reflected waves of the contact boundaries is quite clearly manifested. Finally, Figures 7-8 show combined graphs of changes in normal $\sigma_{11}^{(k)}$ (solid lines) and tangent $\sigma_{12}^{(k)}$ (dashed lines) stresses (k =1, 2) along the x_2 coordinate in the x_1 = 50h section at the following times: 1 (t = 80τ), 2 (t = 100τ) and 3 (t = 120 τ). The behavior of the normal stresses $\sigma_{11}^{(k)}$ (k =1, 2) in fixed sections and at the considered instants of time almost coincide. The distributions of shear stresses $\sigma_{12}^{(k)}$ (k =1, 2) differ sharply.

The calculation results presented here can be widely application in the design of various engineering structures and study of the influence of shock loads on the base of foundations various objects.

Results obtained with software allows you to analyze wave processes and determine the axis symmetry of the wave pattern, the area of stress concentration, the boundary breaking point, axle loaded, "split" phenomenon, etc.

Scientific and theoretical interest in studying the relationship between stress (stress tensor) and deformations occurring in the medium as a result of blasting remains very relevant. The problems of seismically unstable areas require consideration of this issue from the point of view of wave process modeling.

The developed numerical method showed high accuracy and stability, which, in turn, shows the wide application value of this method and the possibility of using it to solve various wave problems

REFERENCES:

[1] Semenova Yu.V. Modeling of soil response during seismic microzoning of construction sites // Geophysical Journal. - 2015. - T. 37, No. 1. - S. 137-153.

[2] Bolat, K., Serik, Z., S, S.D., A, A.A., Sandugash, S., Zh, B.K., Y, Y.A. Construction

of a Model and Development of an Algorithm for Solving the Wave Problem under Pulsed Loading (2021) International Journal of Advanced Computer Science and Applications, 12 (9), pp. 465-471.

[3] Sabitova DS, Zhuzbayev SS, Juzbayeva BG Development of an information analysis system for analyzing wave processes in a homogeneous medium // International Journal of Mechanical Engineering and Technology. - 2018. - Vol. 9(12). - P. 499-508.

[4] Akhmetova Z., Zhuzbaev S., Boranbayev S., Sarsenov B. Development of the System with Component for the Numerical Calculation and Visualization of Non-Stationary Waves Propagation in Solids. IOS Book Series: Frontiers in Artificial Intelligence and Applications (FAIA), 2016, Volume293, pp. 353-359.

[5] Kukudzhanov VN Numerical Continuum Mechanics. De Gruyter, 2012. XVIII, 425 pages.

[6] S. Tleukenov, A. Bobeev, D. Sabitova. Structure of the matriciant for systems of ordinary differential equations of first order and its applications. International journal of applied mathematics & statistics. - 2018. - V. 57 (1) . - P. 209-217.

[7] Rysbaiuly B., Yunicheva N., Rysbayeva N. An iterative method to calculate the thermal characteristics of the rock mass with inaccurate initial data. open Engineering, 2016, 6(1).

[8] Sandugash, S., Jamalbek, T., Madina, S., Akbota, Y., Ainur, A. Building a Standard Model of an Information System for Working with Documents on Scientific and Educational Activities (2021) International Journal of Advanced Computer Science and Applications, 12 (9), pp. 445-455.

[9] Zhuzbaev S.S., Sabitova D.S. Computer simulation of elastic wave propagation in a homogeneous medium. VESTNIK PGU . Physics - Mathematics series , 2018, No. 1, p . 68-82.

[10] Akhmetova Z., Zhuzbaev S., Boranbayev S. The method and software for the solution of dynamic waves propagation problem in elastic medium. Acta Physics Polonica A, Polish Academy of Sciences.- 2016, Vol.130. - pp. 352-354, ISSN 0587-4246.

[11] Zhuzbayev S., Sabitova D., Sarsenov B. Computer mathematical modeling of wave processes // 4th intern. conf. on computer and technology applications (ICCTA). – Istanbul, 2018. – P. 1-5.

[12] Golenko, Y., Ismailova, A., Shaushenova, A., Mutalova, Z., Dossalyanov, D., Ainagulova, A., Naizagarayeva, A. Implementation of machine learning models to determine the appropriate model for protein function prediction (2022) Eastern-European Journal of Enterprise Technologies, 5 (4-119), pp. 42-49.

[13] Bayegizova, A., Murzabekova, G., Ismailova, A., Aitimova, U., Mukhanova, A., Beldeubayeva, Z., Ainagulova, A., Naizagarayeva, A. Effectiveness of the use of algorithms and methods of artificial technologies for sign language recognition for people with disabilities (2022) Eastern-European Journal of Enterprise Technologies, 4 (2-118), pp. 25-31.

[14] Bayegizova, A., Murzabekova, G., Ismailova, A., Aitimova, U., Mukhanova, A., Beldeubayeva, Z., Ainagulova, A., Naizagarayeva, A. Effectiveness of the use of Algorithms and methods of artificial technologies for sign language recognition for people with disabilities (2022) Eastern-European Journal of Enterprise Technologies, 4 (2-118), pp. 25-31.

[15] Zhuzbayev S., Sabitova D. Mathematical modeling of elastic wave propagation in a homogeneous media // Vestnik East Kazakhstan _ state technical university them. D . Serikbaev. - 2018. - T. 1, No. 3, h. 3. - S. 78-90.

[16] Zhuzbayev S., Adilova A., Akhmetzhanova S., Juzbayeva B., Sabitova D. Design of composite materials using information technology. Journal of Theoretical and Applied Information Technology, 2020, 98(18), p. 3698-3711.

[17] Serik, Z., Bolat, K., Adilbek, T., Nartay, S., Lyazzat, I., Anar, S., Assem, A., Aizhan, B. DEvelopment of an algorithm and construction of a model for solving a wave problem when an elastic strip is bent, partially soldered into a half-plane (2022) Journal of Theoretical and Applied Information Technology, 100 (16), pp. 5256-5264