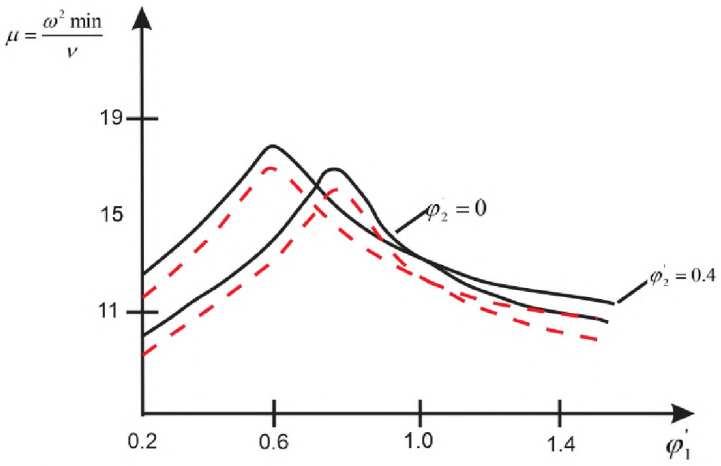


2-rasm. Qirralarning nisbiy og‘irligiga μ bog‘liq o‘zgarishlar.

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TOVUSH TEZLIGIDAN KATTA BO‘LMAGAN TEZLIKDA HARAKATLANUVCHI NUQTAVIY MANBADAN HOSIL BO‘LADIGAN TO‘LQIN XUSUSIYATLARI

Annotatsiya. *Ushbu ishda dissipativ bir jinsli bo‘lmagan qovushqoq-elastik gradiyent-elastik yarim fazo va Kossera muhitidan iborat uzun to‘lqin o‘tkazgichlarda kompleks faza tezligining bir nechta modasining to‘lqin soniga nisbatan o‘zgarishiga hamda olingan natijalar asosida to‘lqinning so‘nishiga solishtirma baho berildi. Ideal elastik muhitdan farqli qovushqoq-elastik gradiyent-elastik yarim fazo va Kossera muhitida paydo bo‘ladigan yangi ko‘ndalang to‘lqinning faza tezligi va so‘nishi tadqiq qilingan.*

Kalit so‘zlar: *Kossera muhiti, kompleks faza tezligi, qovushqoq-elastik gradiyent-elastik yarim fazo, Xevisayd funksiyasi, normal kuchlanish, normal ko‘chish.*

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СВОЙСТВА ВОЛН, СОЗДАВАЕМЫХ ТОЧЕЧНЫМ ИСТОЧНИКОМ, ДВИЖУЩИМСЯ СО СКОРОСТЬЮ, НЕ ПРЕВЫШАЮЩЕЙ СКОРОСТЬ ЗВУКА

Аннотация. *В работе дана сравнительная оценка изменения нескольких мод комплексной фазовой скорости от волнового числа в длинных волноводах, состоящих из диссипативно- неоднородного вязкоупругого градиентно-упругого полупространства и среды Коссера, и затухания волн на*

основе полученных результатов. Исследованы фазовая скорость и затухание новой поперечной волны, возникающей в вязкоупругом градиентно-упругом полупространстве и среде Коссера, которые отличаются от идеальной упругой среды.

Ключевые слова: *среда Коссера, комплексная фазовая скорость, вязкоупругое градиентно-упругое полупространство, функция Хевисайда, нормальное напряжение, нормальное смещение.*

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PROPERTIES OF WAVES GENERATED BY A POINT SOURCE MOVING AT UP TO THE SPEED OF SOUND

Annotation. *In this work, a comparative assessment of the variation of several modes of the complex phase velocity with wave number in long waveguides consisting of a dissipative inhomogeneous viscous-elastic gradient-elastic half-space and a Kossera medium and the wave attenuation based on the obtained results were given. The phase velocity and attenuation of a new transverse wave that appears in a viscous-elastic gradient-elastic half-space and a Kossera medium, which are different from ideal elastic media, are studied.*

Keywords: *Cossera medium, complex phase velocity, viscoelastic gradient-elastic half-space, Heaviside function, normal stress, normal displacement.*

Kirish. Mustaqillik yillarida mamlakatimizda yer usti va yer osti inshootlari zilzilabardoshligi sohasida qo‘llaniladigan materiallarning, shu jumladan, ko‘p qatlamli murakkab tarkibga va fizik xossalarga ega bo‘lgan muhitlarni mustahkamligini oshirishga alohida e’tibor qaratilmoqda. Bu borada materialning qovushqoq-elastiklik xususiyatini hisobga olib, dinamik masalalar yechish borasida sezilarli natijalarga erishildi. Xususan, konstruksiyalarni buzmasdan, to‘lqin tarqalish xususiyatlarini o‘rganish orqali ularning mustahkamligini baholashga alohida e’tibor berishmoqda. Eng ko‘p qo‘llanishi talab etiladigan umumlashtirilgan (klassik bo‘lmagan) muhitlar orasida mikropolyar Kossera muhiti va gradiyent-elastik muhit ushbu sinfga tegishli. Bunday muhitlarda to‘lqin tarqalishi jarayonlarini o‘rganish, metodikasi va algoritimini yaratish, sonli natijalar olish, tahlil qilish muhim vazifalardan biri hisoblanadi.

Mavzuga oid adabiyotlarning tahlili. Faraz qilaylik, yarim tekislik sirtida nuqtaviy kuch D tezlik bilan harakatlansin. Uning tezligi bo‘ylama va ko‘ndalang to‘lqin tezliklaridan oshib ketmaydi. Bu holatda muhitda to‘lqin tarqalishini ifodalovchi tenglamalar quyidagicha bo‘ladi

$$\frac{\partial \sigma_{x'x'}}{\partial x'} + \frac{\partial \sigma_{y'x'}}{\partial y'} = \rho \frac{\partial^2 u}{\partial t^2}, \qquad \frac{\partial \sigma_{x'y'}}{\partial x'} + \frac{\partial \sigma_{y'y'}}{\partial y'} = \rho \frac{\partial^2 \vartheta}{\partial t^2}, \tag{1}$$

Kuchlanish komponentlari esa quyidagi ko‘rinishda bo‘ladi

$$\sigma_{x'x'} = \overline{\lambda}\left(\frac{\partial u}{\partial x'} + \frac{\partial \vartheta}{\partial y'}\right) + 2\overline{\mu}\frac{\partial u}{\partial x'},$$

$$\sigma_{y'y'} = \overline{\lambda}\left(\frac{\partial u}{\partial x'} + \frac{\partial \vartheta}{\partial y'}\right) + 2\overline{\mu}\frac{\partial \vartheta}{\partial y'},$$

$$\sigma_{x'y'} = \overline{\mu}\left[\frac{\partial \vartheta}{\partial x'} + \frac{\partial u}{\partial y'} - l^2\left(\frac{\partial^2}{\partial x'^2} + \frac{\partial^2}{\partial y'^2}\right)\left(\frac{\partial \vartheta}{\partial x'} - \frac{\partial u}{\partial y'}\right)\right]$$

$$\sigma_{y'x'} = \overline{\mu}\left[\frac{\partial \vartheta}{\partial x'} + \frac{\partial u}{\partial y'} + l^2\left(\frac{\partial^2}{\partial x'^2} + \frac{\partial^2}{\partial y'^2}\right)\left(\frac{\partial \vartheta}{\partial x'} - \frac{\partial u}{\partial y'}\right)\right]$$

$$\mu_{x'} = 2\overline{\mu}l^2\frac{\partial}{\partial x'}\left(\frac{\partial \vartheta}{\partial x'} - \frac{\partial u}{\partial y'}\right), \mu_{y'} = 2\overline{\mu}l^2\frac{\partial}{\partial y'}\left(\frac{\partial \vartheta}{\partial x'} - \frac{\partial u}{\partial y'}\right).$$

O‘rganilayotgan masala uchun chegaraviy shartlar quyidagicha bo‘ladi:

$$\sigma_{y'y'} = -P\delta(x),\ \sigma_{y'x'} = 0, \mu_{y'} = 0.$$

Bo‘ylama va ko‘ndalang to‘lqin potensilari orqali ko‘chishlar quyidagicha topiladi:

$$u_{xk} = \frac{\partial \varphi_k}{\partial x'} - \frac{\partial \psi_{zk}}{\partial y'},$$

$$u_{yk} = \frac{\partial \varphi_k}{\partial y'} - \frac{\partial \psi_{zk}}{\partial x'}, \tag{2}$$

Agar to‘lqin tenglamalaridan foydalansak, ular quyidagi ko‘rinshiga keladi [5]:

$$\left(\frac{\partial^2}{\partial x'^2} + \frac{\partial^2}{\partial y'^2} - \frac{1}{c_{p1}^2 \Gamma_{k\lambda\mu}} \frac{\partial^2}{\partial t^2}\right)\varphi = 0,$$

$$\left(\frac{\partial^2}{\partial x'^2} + \frac{\partial^2}{\partial y'^2} - l^2\left(\frac{\partial^4}{\partial x'^4} + \frac{\partial^4}{\partial x'^4 \partial y'^4} + \frac{\partial^4}{\partial y'^4}\right) - \frac{1}{c_{s2}^2 \Gamma_{k\mu}} \frac{\partial^2}{\partial t^2}\right)\varphi = 0. \tag{3}$$

Harakatlanuvchi koordinatalar sistemasi (x,y) qo‘zgalmas koordinatalar sistemasi bilan Galiley almashtiririlishi orqali bogliq:

$$x = x' - Dt,\ y = y'. \tag{4}$$

U holda dinamik jarayonni ifodalovchi tenglamalar quyidagicha bo‘ladi:

$$(\overline{\lambda} + 2\overline{\mu} - \rho D^2)\frac{\partial^2 u}{\partial x^2} + \overline{\lambda}\frac{\partial^2 \vartheta}{\partial x \partial y} + \overline{\mu}\left[\frac{\partial^2 \vartheta}{\partial x \partial y} + \frac{\partial^2 \vartheta}{\partial y^2} + l^2 \Delta\left(\frac{\partial^2 \vartheta}{\partial x \partial y} - \frac{\partial^2 u}{\partial y^2}\right)\right] = 0,$$

$$(\overline{\lambda} + 2\overline{\mu})\frac{\partial^2 \vartheta}{\partial y^2} + \overline{\lambda}\frac{\partial^2 u}{\partial x \partial y} + \overline{\mu}\left[\frac{\partial^2 u}{\partial x \partial y} + \left(1 - \frac{\rho D^2}{\overline{\mu}}\right)\frac{\partial^2 \vartheta}{\partial x^2} - l^2 \Delta\left(\frac{\partial^2 \vartheta}{\partial x^2} - \frac{\partial^2 u}{\partial x \partial y}\right)\right] = 0, \tag{5}$$

Yuqorida keltirilgan (5) tenglamalarning yechimini quyidagicha izlaymiz:

$$u = Ae^{kqy}\sin(kx),\ \vartheta = Be^{kqy}\cos(kx). \tag{6}$$

U holda (5) tenglamalar quyidagi ko‘rinishni egallaydi:

$$\begin{aligned}
&\left[-\overline{\mu} l^2 k^2 q^4 + \overline{\mu} q^2 (1 + l^2 k^2) - (\overline{\lambda} + 2\overline{\mu} - \rho D^2)\right] A + \\
&+\left[\overline{\mu} l^2 k^2 q^3 + q(\overline{\lambda} + \overline{\mu} - \overline{\mu} l^2 k^2)\right] B = 0, \\
&\left[-\overline{\mu} l^2 k^2 q^3 - q(\overline{\lambda} + \overline{\mu} - \overline{\mu} l^2 k^2)\right] A + \\
&+\left[q^2(\overline{\lambda} + 2\overline{\mu} - \rho D^2) - (\overline{\lambda} + \overline{\mu} l^2 k^2 - \rho D^2)\right] B = 0,
\end{aligned} \tag{7}$$

Bir jinsli bo‘lgan (7) tenglamalar sistemasini yechimi mavjud bo‘lishi uchun uning asosiy aniqlovchisi nolga teng bo‘lishi kerak, u holda quyidagi dispersion tenglama olamiz:

$$\begin{aligned}
&(l^2 k^2 - \gamma + \beta_1^2) l^2 k^2 q^6 + (l^2 k^2 (1 + l^2 k^2 - \beta_1^2) + \gamma(1 + l^2 k^2)(1 - \gamma\beta_1^2) + \\
&+2 l^2 k^2 (\gamma - l^2 k^2))q^4 + ((1 + l^2 k^2)(1 + l^2 k^2 - \beta_1^2) - (\gamma - \beta_1^2)^2 + (\gamma - l^2 k^2)^2)q^2 + \\
&+(\gamma - \beta_1^2)(1 + l^2 k^2 - \beta_1^2) = 0.
\end{aligned} \tag{8}$$

Bunda

$$\beta_1^2 = \frac{\rho D^2}{\overline{\mu}}, \gamma = \frac{\overline{\lambda} + 2\overline{\mu}}{\overline{\mu}}.$$

Bu (8) transtsendent tenglamaning ildizlari cheksiz ko‘p bo‘ladi. Komleks ildizning haqiqiy qismi q>0 musbat bo‘lsin deb olamiz. U holda bo‘ylama va ko‘ndalang kuchishlar quyidagicha bo‘ladi:

$$u = \sum_{i=1}^{\infty} \int_0^{\infty} A_i e^{kq_i y} \sin kx dk, \vartheta = \sum_{i=1}^{\infty} \int_0^{\infty} \alpha_i A_i e^{kq_i y} \cos kx dk.$$

Yangi koordinatalar sistemasida potensiallar orqali berilgan tenglamalar va chegaraviy shartlar quyidagicha bo‘ladi:

$$((\eta_2^2-2)\frac{\partial^2\varphi}{\partial x^2}+2\frac{\partial^2\psi}{\partial x\partial y})\varphi=-\frac{P}{\bar{\mu}}\delta(x),$$

$$(2\frac{\partial^2\psi}{\partial x\partial y}+\eta_2^2\frac{\partial^2\psi}{\partial x^2}-2\frac{\partial^2\psi}{\partial y^2})\Big|_{y=0}=0, \qquad (9)$$

$$(\frac{\partial^3\psi}{\partial x^2\partial y}+\frac{\partial^2\psi}{\partial y^2})\Big|_{y=0}=0,$$

$$(\lambda_1^2\frac{\partial^2}{\partial x^2}-\frac{\partial^2}{\partial y^2})\varphi=0,$$

$$(\lambda_2^2\frac{\partial^2}{\partial x^2}-\frac{\partial^2}{\partial y^2}+l^2(\frac{\partial^4}{\partial x^4}+\frac{\partial^4}{\partial x^2\partial y^2}+\frac{\partial^4}{\partial y'^4}))\psi=0,$$

bunda $\eta_\alpha=\frac{D}{c_\alpha},\lambda_1^2=\sqrt{(\eta_\alpha^2-1)},\alpha=1,2.$

Yuqorida keltirilgan (9) differensial tenglamaning yechimi quyidagicha bo‘ladi:

$$\varphi(x,y)=\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty}Ae^{-i\alpha(x-\lambda_1 y)}d\alpha,$$

$$\psi(x,y)=\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty}Be^{-i\alpha(x-\lambda_2 y)}d\alpha. \qquad (10)$$

Bu yechim Furyening integral almashtirishi orqali topilgan. Bu yechimdan ko‘rish mumkinki, u cheksizlikda to‘lqin yutilish shartini qanoatlantiradi. Xuddi shuningdek, harakatlanuvchi yukdan integral almashtirish olish mumkin:

$$F[\delta(x)]=\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty}\delta(x)Be^{-i\alpha x}dx=\frac{1}{\sqrt{2\pi}}.$$

U holda quyidagi tenglamalar sistemasini olamiz:

$$-\alpha(\eta_2^2-2)A+2\alpha^2\lambda_2 B=\frac{P}{\bar{\mu}\sqrt{2\pi}}0,$$

$$2\alpha^2\lambda_1 A-\alpha(\eta_2^2+2)B=0.$$

Bu tenglamalar sistemasidan A va B ixtyoriy o‘zgarmaslarni topamiz:

$$A=\frac{(\eta_2^2-2)P}{\mu\alpha^2\sqrt{2\pi}\left[(\eta_2^2+2)(\eta_2^2-2)+4\lambda_1\lambda_2\right]},$$

$$B=\frac{4\lambda_1 P}{\mu\alpha^2\sqrt{2\pi}\left[(\eta_2^2+2)(\eta_2^2-2)+4\lambda_1\lambda_2\right]} \qquad (11)$$

Hisoblashlarda quyidagi belgilashlardan foydalanilgan:

$$\gamma_1=\eta_2^2+2,\gamma_2=\eta_2^2-2,\Delta=\gamma_1\gamma_2+4\lambda_1\lambda_2.$$

U xolda A va B lar quyidagi ko‘rinishni egalaydi:

$$A=\frac{\gamma_2 P}{\mu\alpha^2\sqrt{2\pi}\Delta},$$

$$B=\frac{4\lambda_1 P}{\mu\alpha^2\sqrt{2\pi}\Delta} \qquad (12)$$

Tadqiqot metodologiyasi. Agar kiritilgan bo‘ylama va ko‘ndalang to‘lqin potensiallarini hisobga olsak, muhit nuqtalarining ko‘chishini quyidagicha yozish mumkin:

$$u = \frac{iP}{2\pi\overline{\mu}\Delta}\int_{-\infty}^{\infty}(\gamma_2 e^{i\lambda_1\alpha y} + 2\lambda_1\lambda_2 e^{i\lambda_2\alpha y})\frac{e^{-i\alpha x}}{\alpha}d\alpha,$$
$$\vartheta = \frac{iP}{2\pi\overline{\mu}\Delta}\int_{-\infty}^{\infty}(\gamma_2 e^{i\lambda_1\alpha y} - 2\lambda_1 e^{i\lambda_2\alpha y})\frac{e^{-i\alpha x}}{\alpha}d\alpha. \quad (13)$$

Ko‘chishlar (13) haqiqiy funksiya bo‘lgani uchun uni quyidagi ko‘rinishga yozish mumkin:

$$u = -\frac{P}{2\pi\overline{\mu}\Delta}\left[\gamma_2\int_{-\infty}^{\infty}\frac{\sin\alpha(x-\lambda_1 y)}{\alpha}d\alpha - 2\lambda_1\lambda_2\int_{-\infty}^{\infty}\frac{\sin\alpha(x-\lambda_2 y)}{\alpha}\right].$$
$$\vartheta = \frac{P}{2\pi\overline{\mu}\Delta}\left[\gamma_2\lambda_1\int_{-\infty}^{\infty}\frac{\sin\alpha(x-\lambda_1 y)}{\alpha}d\alpha - 2\lambda_1\int_{-\infty}^{\infty}\frac{\sin\alpha(x-\lambda_2 y)}{\alpha}\right]. \quad (14)$$

Yuqorida keltirilgan harakat tenglamasi (1) va chegaraviy shartlar uchun Furyening integral almashtirishlarini qo‘llaymiz, u holda normal kuchlanishi quyidagicha bo‘ladi:

$$\sigma_{zz}^{*} = \frac{1}{2\pi}\int_{-\infty}^{\infty}\frac{\Delta_1(r_0\Omega)e^{j\Omega t}}{\Omega_1[\Delta_2\Delta_3+\Delta_4\Delta_5]}d\Omega, \quad (15)$$
$$\Delta_1(r_{01}\Omega) = (\Delta_3+\tau_0 E)\left[2\Omega H_{n-1}^{(1)}(\Omega) - \left((2n^2+2n)+\Omega^2\right)H_n^{(1)}(\Omega)\right] +$$
$$+\left[\tau_0\Delta_2-\Delta_4\right]\left[2n(n+1)H_n^{(1)}\left((C_{P1}/C_{S1})\Omega\right) + \frac{2C_P n\Omega}{C_{S1}}H_{n-1}^{(1)}\left(\frac{C_P}{C_S}\Omega\right)\right].$$

Bunda $\Delta_k\ (k=1,2,3,4,5)$ning ifodalari [3] ishda keltirilgan. (15) dagi xosmas integralni EHMda hisoblash quyidagi tartibda amalga oshiriladi. Integralni cheksiz oraliqda hisoblashni tassavur qilish qiyin. Shuning uchun uni chekli oraliqda integrallaymiz:

$$\sigma_{zzn}^{*} = \frac{1}{2\pi}\int_{\omega_a}^{\omega_b}\frac{\Delta_1(r_{01}\Omega_1)}{\Omega_1[\Delta_2\Delta_3+\Delta_4\Delta_5]}e^{-i\Omega t}d\Omega. \quad (16)$$

(16)-integralning chegarasi ω_a, ω_b tushadigan to‘lqinning ta’sir etish davriga bog‘liq bo‘ladi. $\sigma_{zz}^{(i)F}(\Omega)$ning spektral zichligi tushadigan to‘lqin xossalariga ham bog‘liq bo‘ladi. ω_a, ω_b bu chegaralarning qiymatlari, hisoblash jarayonida integral osti funksiyaga bog‘liq o‘zgaradi. Integrallash oralig‘ini tanlash talab etiladigan hisoblash aniqligiga ham bog‘liq bo‘ladi. Boshqa tomondan, taqribiy integral, ya’ni chegarasini $-\infty$ dan ω_a va ω_b dan $+\infty$ olinishi qanday xatoliklarga olib kelishi muammosi ochiqligicha qolgan.

(16) integralni cheksiz hadli qator bilan almashtirib, sonli hisoblash ham mumkin bo‘lmagan ish. Boshqa tomondan, [3] ishda ko‘rsatilganki, n-ning katta qiymatlarida hadlar (n- tartibli bir va ikkinchi jinsli Bessel va Xankel funksiyalari) uchun asimptotik formulalar mavjud ekan. Cheksiz qatorni chekli sondage hadlari yig‘indi orqali baholash imkoni mavjud. Hisoblashlar ikkita algoritmni hisoblashga olib keladi.

Olingan

$$(2\overline{\mu}_n+\overline{\lambda}_n)grad\,div\vec{U}_n - (\overline{\mu}_n+\overline{\lambda}_n)rot\,rot\vec{U}_n + 2\alpha_n rot\vec{\Omega}_n + \rho_n\omega^2\vec{U}_n(z) = 0,$$
$$(\overline{\beta}_n+2\overline{\gamma}_n)grad\,div\vec{\Omega}_n - (\overline{\gamma}_n+\overline{\varepsilon}_n)rot\,rot\,\vec{\Omega}_n + 2\alpha_n rot\vec{U}_n - 4\overline{\alpha}_n\vec{\theta}_n + j_n\omega^2\vec{\Omega}_n = 0, \quad (17)$$

yechimni Xevisayd funksiyasi orqali ifoda qilamiz,

$$H(z)=\begin{cases}0, z<0\\ 0.5,\ z=0,\\ 1.0,\ z>0.\end{cases}$$

U holda

$$H(z)=0.5+\frac{1}{\pi}\int_0^{\infty}\frac{\sin\alpha x}{\alpha}d\alpha.$$

(17) tenglamaning yechimi quyidagi ko‘rinishni egallaydi:

$$u=-\frac{P}{\overline{\mu}\Delta}\left[\gamma H(x-\lambda_1 y)-2\lambda_1\lambda_2 H(x-\lambda_2 y)\right]+const,$$

$$\vartheta=-\frac{P}{\overline{\mu}\Delta}\left[\gamma\lambda_1 H(x-\lambda_1 y)+2\lambda_1\lambda_2 H(x-\lambda_2 y)\right]+const.$$

Ko‘chish va kuchlanishlar ifodasini EHMda hisoblash uchun bir qarashda qiyinchilik yo‘qqa o‘xshaydi. Lekin Bessel, Hankel funksiyalarni EHM da hisoblash murakkabdir.

Tahlil va natijalar. Bessel funksiyasi $J_n(x)$ ni hisoblash qiyinchilikka ega bo‘lmaydi. Chunki bu qatorning 10 ta hadini yig‘sak, 11 ta hadi yig‘indisi umumiy yig‘indiga 10^{-8} ni qo‘sh ish bilan hosil bo‘ladi. Neyman funksiyani, ya’ni, $N_n(x)$ ni ko‘rsak, bu funksiya argumentning 0 ga yaqin qiyamtlarida logarifmik maxsuslikka ega bo‘ladi. Qator juda sekin yaqinlashadi. Bu funksiya qatorni yig‘indisini topishda kamida 20 ta had olish kerak. Lekin 20 va undan ortiq hadini hisoblashda katta sonlar 20 yoki 30 faktoriallarni hisoblashga to‘g‘ri keladi. Bularni ustida matematikadagi to‘rt amalni bajaradi. Natijada mashina xotirasining to‘lib qolishi (perepolneniya berish) ehtimoli bo‘ladi.

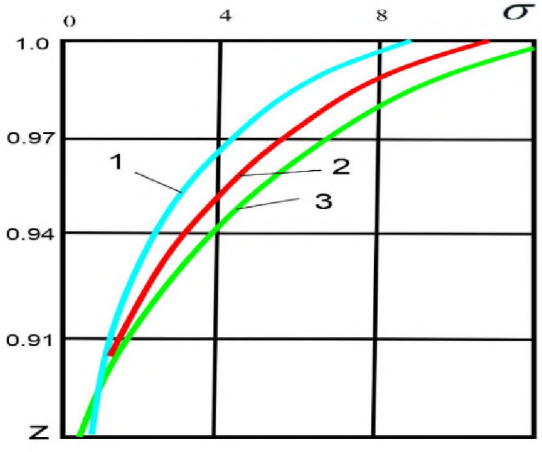
Majburiy tebranishlarni o‘rganishda mavhum xususiy chastotalarni o‘rganish ahamiyatga ega hisoblanadi. Elastik muhitda joylashgan bo‘shliqning xususiy chastotalari radiusi bilan ko‘ndalang va bo‘ylama to‘lqinlarning tezligiga bog‘liq bo‘ladi. Mavjud diskret chastotalar yer osti truba quvurlarni hisoblashda katta rol o‘ynaydi. Xuddi shunday, elastik muhitda joylashgan silindrik qobiqning erkin tebranishlari o‘rganiladi. Materialning qovushoqligini hisobga olish uchun Rjanitsin–Koltunovning uch parametrli kuchsiz singulyar yadrosi qo‘llaniladi: [19,20] $R(t)=\frac{Ae^{-\beta t}}{t^{1-\alpha}}$. Parametrlar quyidagi ko‘rinishga qabul qilingan:

$$A=0{,}048;\quad \beta=0{,}05;\quad \alpha=0{,}1, \nu_1=\nu_2=0{,}14;$$

Buning uchun quyidagi kattaliklardan foydalanilgan:

$$\overline{\rho}=19250kg/m^3, \rho=2700kg/m^3, \overline{\lambda}=1994\cdot10^9 Pa, \lambda=55.94\cdot10^9 Pa,$$

$$\overline{\mu}=158.56\cdot10^9 Pa, \mu=23.94\cdot10^9 Pa, \overline{c}_l=5180m/s, c_t=3100m/s$$

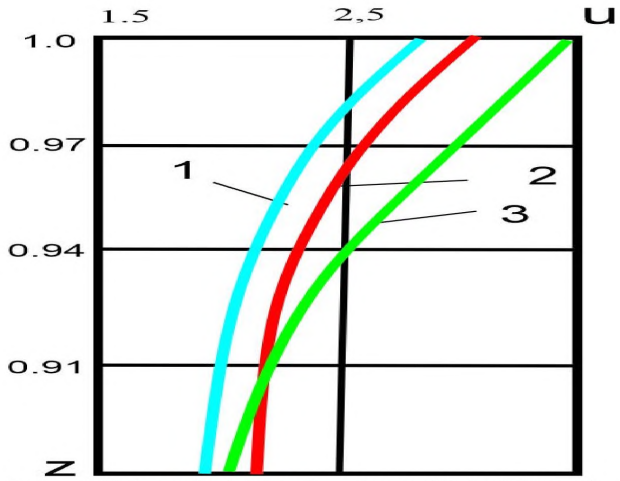


1-rasm. Normal kuchlanishning chuqirlik bo‘yicha o‘zgarishi.

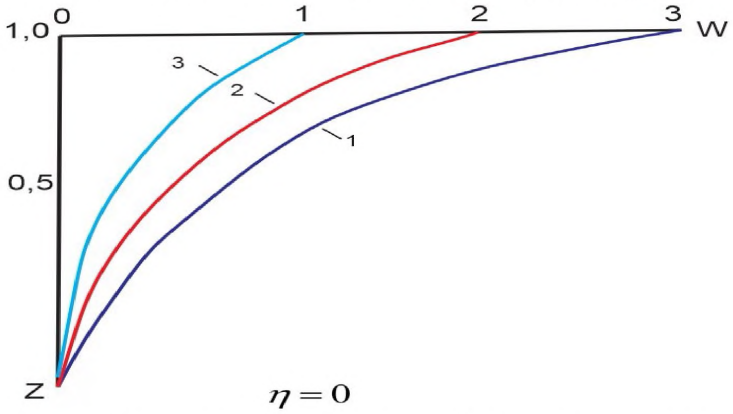
Sonli natijalar olindi va tahlil qilindi. Qovushoq-elastik yarim muhitda joylashgan doirasmon ko‘ndalang kesimli quvurda garmonik to‘lqin ta’sirida hosil bo‘ladigan kuchlanish-deformatsiya holati masalasini ko‘rib chiqamiz. Sonli natjalar 1 – 6-rasmlarda keltirigan.

Normal kuchlanishning chuqirlik bo‘yicha o‘zgarishi 1-rasmda keltirilgan (1. Klassik muhit. 2.Gradiyent qovushoq-elastik muhit. 3. Kossera qovushoq-elastik muhiti). Urinma ko‘chishning chuqurlik bo‘yicha o‘zgarishi 2-rasmda keltirilgan (1. Klassik muhit. 2. Gradiyent qovushoq-elastik muhit. 3. Kossera qovushoq-elastik muhiti).

Normal ko‘chishning chuqirlik bo‘yicha o‘zgarishi 3-rasmda keltirilgan (1. Klassik muhit. 2. Gradiyent qovushoq-elastik muhit. 3. Kossera qovushoq- elastik muhiti). Yuqorida keltirilgan rasmlardan kurinib turibdiki, chuqirlik ortishi bilan ko‘chish va kuchlanishlar eksponensional qonuniyat bo‘yicha kamayib borar ekan.

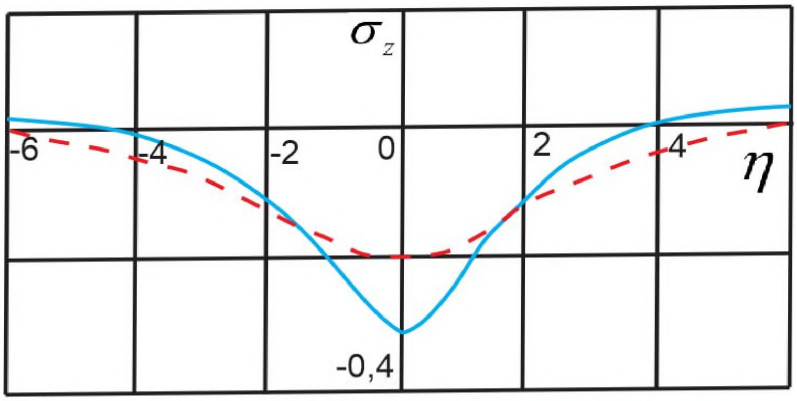


2-rasm. Urinma ko‘chishning chuqurlik bo‘yicha o‘zgarishi.

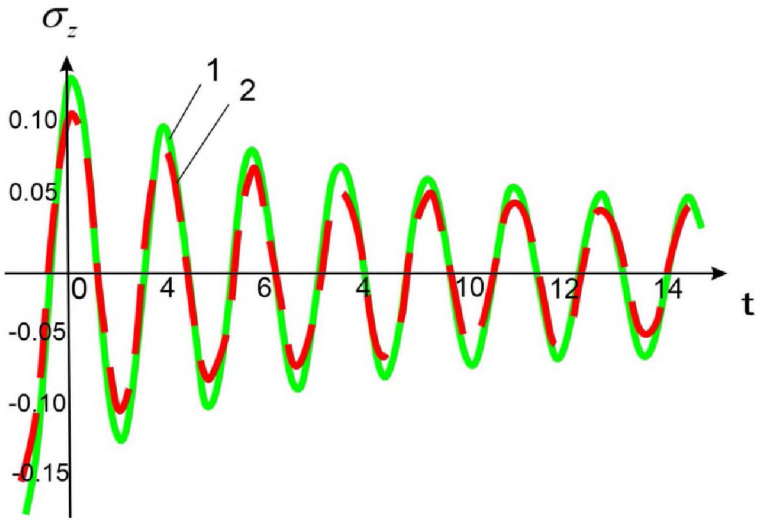


3-rasm. Normal ko‘chishning chuqurlik bo‘yicha o‘zgarishi.

4-rasmda normal kuchlanishning koordinataga bog‘liq o‘zgarishi keltirilgan (tutash chiziq-Kossera muhiti uchun olingan natijalar, yuliq chiziq-klassik muhit uchun olingan natijalar).

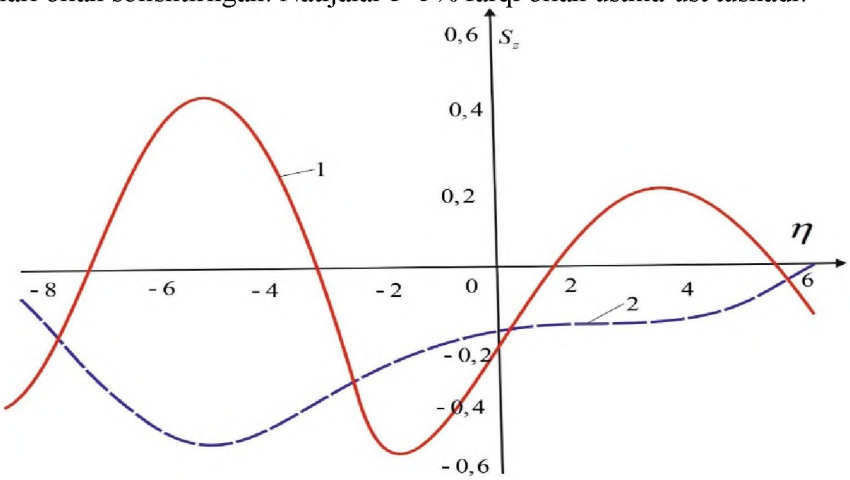


4-rasm. Normal kuchlanishning koordinataga bog‘liq o‘zgarishi.



5-rasm. Normal kuchlanishning vaqtga bog‘liq o‘zgarishi.
1. Yerofeyev natijalar. 2. Dissertatsiya natijalari.

Normal kuchlanishning vaqtga bog‘liq o‘zgarishi 5-rasmga keltirilgan. Bu rasmda olingan natijalar Yerofeyev [4] natijalari bilan solishtirilgan. Natijalar 3–5% farqi bilan ustma-ust tushadi.



6-rasm. Urinma kuchlanishni kordinataga bog‘liq o‘ggarishi.

Urinma kuchlanishning koordinataga bog‘liq o‘zgarishi 6-rasmda keltirilgan. Rasmdan kurinib turibdiki, yarim tekislik sirtida harakatlanuvchi kuch ta’siridagi harakat ham to‘lqinli bo‘lar ekan. Bu rasmda tutash chiziq-Kossera yarim tekisligi uchun olingan natijalar. Yuliq chiziq – gradiyent elastik qovushoq-elastik muhit uchun olingan natijalar.

Xulosa. Harakatlanuvchi kuch ta’siridagi neoseysimetirik kuchlanishga ega bo‘lgan yarim tekislikda hosil bo‘ladigan kuchlanishlar-deformatsiya holatini aniqlash metodikasi va algoritmi Furyening integral almashtirilishi, Romberg usuli, Gauss va Myuller usullariga asoslangan holda ishlab chiqildi, hamda dasturi yaratildi. Kuchlanishlar va ko‘chishlar yarim tekislik sirtidan chuqirlika qarab eksponensional qonuniyat bo‘yicha kamayib borishi topildi. Kuchlanishlar va ko‘chishlar gradiyenti elastik muhitga qaraganda Kossera muhitida 10 – 20% ko‘p bo‘lishi topildi.

Foydalanilgan adabiyotlar ro‘yxati:

[1]. Ерофеев В.И., Мальханов А.О. Нелинейные локализованные продольные магнитоупругие волны в пластине, находящейся в произвольно ориентированном магнитном поле. Вычислительная механика сплошных сред. 2012, т. 5, № 1, с. 79–84.

[2]. Герасимов С.И., Ерофеев В.И., Камчатный В.Г., Каныгин И.И. Оценка резонансоопасных гармоник при колебаниях упругой направляющей с движущимся по ней двухопорным объектом. Проблемы прочности и пластичности. 2015, т. 77, № 4, с. 412–424.

[3]. Zhao, X., Liew, K.M. A mesh-free method for analysis of the thermal and mechanical buckling of functionally graded cylindrical shell panels. Comput. Mech, 2010, 45, p. 297–310.

[4]. Erofeyev V.I. Wave Processes in Solids with Microstructure. New Jersey, London, Singapore et al: World Scientific Publishing 2003, p. 256.

[5]. Derov A.V., Maximov G.A., Lazarkov M.Y., Kashtan B.M., Bakulin A.N. Verification of wave field excitation in thin fluid-filled fracture of finite size and its interaction with a borehole. Days oa Diffraction, 2008, June 3 – 6, 2008, St.Petersburg, Russia.

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“TO‘RTBURCHAKLAR” USULI VA UNING XOSSALARI

Annotatsiya. *Mazkur ish sonlar nazariyasi fanining rivojlanishida muhim omillardan biri bo‘lib, ishda bir noma’lumli birinchi darajali taqqoslamalarni yechishning amaliy jihatdan qulay, eng effektivli, qolaversa, ancha foydali bo‘lgan “To‘rtburchaklar” usuli va uning xossalari ($ax \equiv b \pmod m$)-taqqoslamani uzluksiz kasrlarga yoyish, “Taqqoslama uchburchagi”) batafsil yoritilgan hamda ularning tatbiqlari kabi masalalar o‘rganilib, yangi natijalar isbotlangan. “To‘rtburchaklar” usulning mohiyati shundaki, “Tenglamani berilgan noma’lumga nisbatan yechish”, “Taqqoslamani bajarishda sinfdagi chegirmalarni m modulga ko‘ra o‘zaro almashtirish”. Bularning natijasida bir noma’lumli birinchi darajali taqqoslama ko‘rinishini $ax - m = mx_1 + b$ tenglikdan foydalanib, yechimlari o‘zaro bog‘liq bo‘lgan ancha soddaroq taqqoslamaga keltiriladi.*

Kalit so‘zlar: *son, chegirma, sinf, modul, taqqoslama, noma’lum son, tenglama, koeffitsiyent, yechim, uzluksiz kasr, taqqoslama uchburchagi, xossa, forma, yuza, Dekart koordinatalari sistemasi, to‘rtburchak, taqqoslama uchburchagi, usul, taqqoslanuvchi.*

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МЕТОД «ПРЯМОУГОЛЬНИКОВ» И ЕГО СВОЙСТВА

Аннотация. *Данная работа является одним из важных факторов развития науки теории чисел. В работе подробно рассматривается метод «Прямоугольников», который практически удобен, наиболее эффективен, а также весьма полезен для решения уравнений первого порядка с одним неизвестным, и его свойства ($ax \equiv b \pmod m$),разложение уравнения в цепные дроби, «Уравнение треугольника»), а также такие вопросы, как их приложения, и доказываются новые результаты. Суть «прямоугольного» метода – «Решение уравнения относительно заданного неизвестного», «Перестановка вычетов в классе по модулю m при выполнении сравнения». В результате вид уравнения первого порядка с одним неизвестным сводится к гораздо более простому уравнению, решения которого связаны между собой с помощью равенства $ax - m = mx_1 + b$.*

Ключевые слова: *число, остаток, класс, модуль, сравнение, неизвестное число, уравнение, коэффициент, решение, цепная дробь, треугольник сравнения, свойство, форма, площадь, декартова система координат, прямоугольник, треугольник сравнения, метод, сравнимое число.*

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“RECTANGLES” METHOD AND ITS PROPERTIES

Annotation. *This work is one of the important factors in the development of the science of number theory. The work covers in detail the “Rectangular” method, which is practically convenient, most effective, and also very useful for solving first-order equations with one unknown, and its properties ($ax \equiv b \pmod m$) expanding the equation into continued fractions, “Equation triangle”), as well as issues such as their applications, and new results are proven. The essence of the “Rectangular” method is “Solving the equation for a given unknown”, “Interchanging the deductions in the class according to the m module when performing the comparison”. As a result, the appearance of a first-order comparison with one unknown is reduced to a much simpler comparison whose solutions are interconnected using equality $ax - m = mx_1 + b$.*

Key words: *Number, residue, class, modulus, congruence, unknown number, equation, coefficient, solution, continued fraction, congruence triangle, property, form, area, Cartesian coordinate system, rectangle, congruence triangle, method, congruent number.*