

Qovushqoq-elastik xususiyatlarga ega tekis qatlamli muhitlarda dissipativ to'liqlarning tarqalish jarayonlarini tadqiq etish

*Qarshi davlat texnika universiteti. f-m.f.f.d(PhD), dotsent,
Saipnazarov Jonibek Muxammadiyevich
Qarshi davlat texnika universiteti, p f f d,(PhD), dotsent,
Hayitov Bahodir Yusufovich*

jonibeksaipnazarov@gmail.com

Annotatsiya. Ushbu ishda qovushqoq-elastik xossalarga ega bo'lgan tekis qatlamli to'liq o'tkazgichlarda dissipativ to'liqlarning tarqalish qonuniyatlari o'rganiladi. Modelda qatlamning mexanik parametrlari, muhitning qovushqoqligi, elastikligi hamda energiya yo'qotilish mexanizmlarining to'liq jarayonlariga ta'siri tahlil qilinadi. To'liqlarning amplitudasi, fazasi va tezligidagi o'zgarishlar matematik tenglamalar asosida tadqiq qilinib, turli dissipativ omillar ta'sirida tarqalishning barqarorligi va xususiyatlari aniqlanadi. Olingan natijalar texnik tizimlarda tebranishlarni boshqarish, diagnostika jarayonlari hamda muhit xossalarini baholashda qo'llanilishi mumkin.

Kalit so'zlar. Qovushqoq-elastik muhit, tekis qatlam, dissipativ to'liq, to'liq tarqalishi, energiya yo'qotilishi, mexanik tebranishlar, matematik model

Kirish. Dekart koordinatalar sistemasida $z = \pm h_j$ tekisliklar bilan chegaralangan cheksiz irsiy-elastik qatlamli Kossera muhitida garmonik to'liqlar tarqalishi masalasini qaraymiz. Oxz tekislikni qatlamlarning o'rta sirti (sredinnaya poverxnost) bilan ustma – ust tushiramiz va Ox o'qi yo'nalishida to'liq tarqalishi masalasini qaraymiz. Qatlamning dinamik kuchlanish-deformatsiya holati (KDX)

ni tekis masala (k-qatlamlarning tartib rakami) uchun yozilgan harakat tenglamalari orqali [1]

$$\begin{aligned}
 \frac{\partial \sigma_{11}^{(\kappa)}}{\partial x} + \frac{\partial \sigma_{12}^{(\kappa)}}{\partial y} + \frac{\partial \sigma_{13}^{(\kappa)}}{\partial z} &= \rho_{\kappa} \frac{\partial^2 u_{\kappa}}{\partial t^2} \\
 \frac{\partial \sigma_{21}^{(\kappa)}}{\partial x} + \frac{\partial \sigma_{22}^{(\kappa)}}{\partial y} + \frac{\partial \sigma_{23}^{(\kappa)}}{\partial z} &= \rho_{\kappa} \frac{\partial^2 v_{\kappa}}{\partial t^2}, (k=1,2,\dots, N) \\
 \frac{\partial \sigma_{31}^{(\kappa)}}{\partial x} + \frac{\partial \sigma_{32}^{(\kappa)}}{\partial y} + \frac{\partial \sigma_{33}^{(\kappa)}}{\partial z} &= \rho_{\kappa} \frac{\partial^2 w_{\kappa}}{\partial t^2} \\
 \frac{\partial m_{11}^{(k)}}{\partial x} + \frac{\partial m_{12}^{(k)}}{\partial e} + \frac{\partial m_{13}^{(k)}}{\partial z} &= j_k \frac{\partial^2 \Omega_{1k}}{\partial t^2} \\
 \frac{\partial m_{21}^{(k)}}{\partial x} + \frac{\partial m_{22}^{(k)}}{\partial y} + \frac{\partial m_{23}^{(k)}}{\partial z} &= j_k \frac{\partial^2 \Omega_{2k}}{\partial t^2}; \\
 \frac{\partial m_{31}^{(k)}}{\partial x} + \frac{\partial m_{32}^{(k)}}{\partial y} + \frac{\partial m_{33}^{(k)}}{\partial z} &= j_k \frac{\partial^2 \Omega_{3k}}{\partial t^2}
 \end{aligned} \tag{1}$$

Irsiy-elastik material holatining tenglamalarini Kossara muhiti uchun ko‘rib chiqamiz :

Tadqiqot metodologiyasi. Bu ishda tekis deformatsiyada bo‘lgan mexanik sistema uchun holat tenglamalarini integral operator formada (Robotnov yadrosi) olamiz: [2]

$$\begin{aligned}
 \tilde{E}_{\kappa} \frac{\partial u_{\kappa}}{\partial x} &= \sigma_{11}^{(\kappa)} - \tilde{v}_{\kappa} (\sigma_{22}^{(\kappa)} + \sigma_{33}^{(\kappa)}) \\
 \tilde{E}_{\kappa} \frac{\partial g_{\kappa}}{\partial z} &= \sigma_{33}^{(\kappa)} - \tilde{v}_{\kappa} (\sigma_{11}^{(\kappa)} + \sigma_{22}^{(\kappa)}) \\
 \tilde{e}_{\kappa} \frac{\partial \Omega_{x\kappa}}{\partial x} &= m_{11}^{(\kappa)} - \tilde{v}_{m\kappa} (m_{22}^{(\kappa)} + m_{33}^{(\kappa)}) \\
 \tilde{e}_{\kappa} \frac{\partial \Omega_{y\kappa}}{\partial z} &= m_{33}^{(\kappa)} - \tilde{v}_{m\kappa} (m_{11}^{(\kappa)} + m_{22}^{(\kappa)})
 \end{aligned} \tag{2}$$

$$\begin{aligned}
 0 &= \sigma_{22}^{(\kappa)} - \tilde{\nu}_{\kappa} \left(\sigma_{11}^{(\kappa)} + \sigma_{33}^{(\kappa)} \right) \\
 0 &= m_{22}^{(\kappa)} - \tilde{\nu}_{m\kappa} \left(m_{11}^{(\kappa)} + m_{33}^{(\kappa)} \right) \\
 \frac{1}{2} \tilde{E}_{\kappa} \frac{\partial u_{\kappa}}{\partial z} + \frac{\partial \mathcal{G}_{\kappa}}{\partial x} &= (1 + \tilde{\nu}_{\kappa}) \sigma_{13}^{(\kappa)} \\
 \frac{1}{2} \tilde{e}_{\kappa} \frac{\partial \Omega_{x\kappa}}{\partial z} + \frac{\partial \Omega_{y\kappa}}{\partial x} &= (1 + \tilde{\nu}_{m\kappa}) m_{13}^{(\kappa)}
 \end{aligned}$$

(1) va (2) tenglamalarda quyidagi belgilashlar kiritilgan: $\sigma_{ij}^{(\kappa)}, m_{ij}^{(\kappa)}$ kuchlanish tenzori komponentalari, $u_{\kappa}, \Omega_{x\kappa}$ va $\mathcal{G}_{\kappa}, \Omega_{y\kappa}$ - ko'chish vektori komponentalari, ρ_n - materialning zichligi

Shunday qilib klassik muhit uchun , quyidagi tenglamalar sistemasiga kelamiz: [3]

$$\begin{aligned}
 \frac{\partial \sigma_{11}^{(\kappa)}}{\partial x} + \frac{\partial \sigma_{13}^{(\kappa)}}{\partial z} &= \rho_{\kappa} \frac{\partial^2 u_{\kappa}}{\partial t^2} ; \\
 \frac{\partial \sigma_{31}^{(\kappa)}}{\partial x} + \frac{\partial \sigma_{33}^{(\kappa)}}{\partial z} &= \rho_{\kappa} \frac{\partial^2 \mathcal{G}_{\kappa}}{\partial t^2} \\
 \tilde{E}_{\kappa} \frac{\partial u_{\kappa}}{\partial x} &= \sigma_{11}^{(\kappa)} - \tilde{\nu}_{\kappa} \left(\sigma_{22}^{(\kappa)} + \sigma_{33}^{(\kappa)} \right) \\
 \tilde{E}_{\kappa} \frac{\partial \mathcal{G}_{\kappa}}{\partial z} &= \sigma_{33}^{(\kappa)} - \tilde{\nu}_{\kappa} \left(\sigma_{11}^{(\kappa)} + \sigma_{22}^{(\kappa)} \right) \\
 0 &= \sigma_{22}^{(\kappa)} - \tilde{\nu}_{\kappa} \left(\sigma_{11}^{(\kappa)} + \sigma_{33}^{(\kappa)} \right) \\
 \frac{1}{2} \tilde{E}_{\kappa} \frac{\partial u_{\kappa}}{\partial z} + \frac{\partial \mathcal{G}_{\kappa}}{\partial x} &= (1 + \tilde{\nu}_n) \sigma_{13}^{(\kappa)}
 \end{aligned} \tag{3}$$

Koltunov - Rjanitsin relaksatsiya yadrosi ishlatilganda, (3) YE elastiklik moduli operator ko'rinishidagi $\tilde{E}_k$ va $\tilde{e}_k$ (2) formula bilan almashtiriladi. Qovushqoq-elastik materialga misol tariqasida uch parametrlil relaksatsiya yadrosini olamiz: $R_k(t) = A_k e^{-\beta_k t} / t^{1-\alpha_k}$. Yadro funksiyasi $R_k(t - \tau)$ ga odatdagi integrallanuvchanlik,

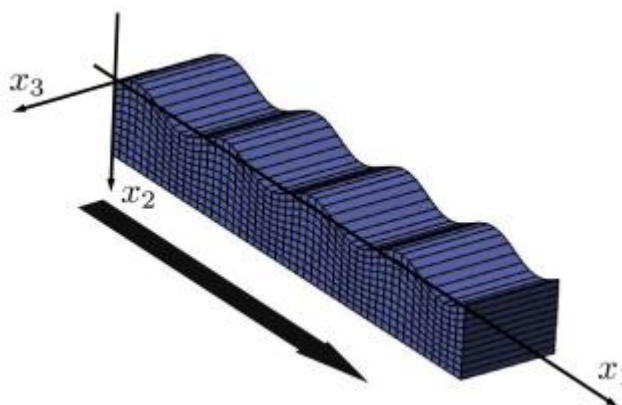
uzluksizlik ($t = \tau$ nuqtadan tashqari barcha nuqtalarda) aniq ishoraliqlik va monotonlik shartlari qo'yiladi:[4]

$$R > 0, \quad \frac{dR(t)}{dt} \geq 0, \quad 0 < \int_0^t R(t)dt < 1$$

U holda differensial tenglamalar sistemasi quyidagi ko'rinishni oladi: [5,6]

$$\begin{aligned} \frac{\partial \sigma_{11}^{(k)}}{\partial x} + \frac{\partial \sigma_{13}^{(k)}}{\partial z} &= \rho_k \frac{\partial^2 u_k}{\partial t^2}; \\ \frac{\partial \sigma_{31}^{(k)}}{\partial x} + \frac{\partial \sigma_{33}^{(k)}}{\partial z} &= \rho_k \frac{\partial^2 g_k}{\partial t^2} \\ \tilde{E}_k \frac{\partial u_k}{\partial x} &= \sigma_{11}^{(k)} - \nu_k (\sigma_{22}^{(k)} + \sigma_{33}^{(k)}) \\ \tilde{E}_k \frac{\partial g_k}{\partial z} &= \sigma_{33}^{(k)} - \nu_k (\sigma_{11}^{(k)} + \sigma_{22}^{(k)}) \\ 0 &= \sigma_{22}^{(k)} - \nu_k (\sigma_{11}^{(k)} + \sigma_{33}^{(k)}) \\ \frac{1}{2} \tilde{E}_k \left(\frac{\partial u_k}{\partial z} + \frac{\partial g_k}{\partial x} \right) &= (1 + \nu_k) \sigma_{13}^{(k)}. \end{aligned} \quad (4)$$

(4) differensial tenglamalar sistemasining yechimini quyidagi ko'rinishda izlaymiz (1 - rasm):



1 –rasm. Reley to'liqini tarqalishi

$$\sigma_{ij}^{(k)} = \sigma_{ij}^k(z) \exp(i\gamma x - i\omega t)$$

$$u_k = U_k(z) \exp(i\gamma x - i\omega t)$$

$$\mathcal{G}_n = V_\kappa(z) \exp(i\gamma x - i\omega t). \quad (5)$$

Bu yerda $\sigma_{ij}^\kappa(z)$, $U_\kappa(z)$ va $V_\kappa(z)$ - amplituda kompleks vektor funksiyalari; γ - to'liq soni; $C(C = C_R + iC_I)$ - kompleks faza tezligi; ω - kompleks chastota.

Natijalar va muhokama. Ularning fizik ma'nosini aniqlash uchun ikkita holni ko'rib chiqamiz:

1) $\gamma = \gamma_R$; $C = C_R + iC_I$, u holda (5) yechim amplitudasi vaqt bo'yicha so'navchi x koordinata bo'yicha sinusoida ko'rinishini oladi;

2) $\gamma = \gamma_R + i\gamma_I$; $C = C_R$, u holda barcha x nuqtalarda tebranish turg'un bo'ladi, lekin x bo'yicha so'nadi.

Ikkala holda xam γ_I yoki C_I ning mavhum qismlari dissipativ protsessning intensivligini xarakterlaydi. (5) yechimni (4) xususiy hosilali differensial tenglamalar sistemasiga kuyib, hosilaga nisbatan yechilgan birinchi tartibli oddiy differensial tenglamalar sistemasini olamiz:

$$\begin{aligned} \frac{\partial \sigma_{11}^{(k)}}{\partial x} + \frac{\partial \sigma_{13}^{(k)}}{\partial z} &= \rho_k \frac{\partial^2 u_k}{\partial t^2} \\ i\gamma \sigma_{11}^{(k)}(z) e^{i\gamma x - i\omega t} + \frac{d\sigma_{11}^{(k)}(z)}{dz} e^{i\gamma x - i\omega t} &= -\rho_k \omega^2 U_k(z) e^{i\gamma x - i\omega t} \\ i\gamma \sigma_{11}^{(k)}(z) + \frac{d\sigma_{11}^{(k)}(z)}{dz} &= -\rho_k \omega^2 U_k(z) \end{aligned} \quad (6)$$

$$\begin{aligned} \frac{\partial \sigma_{31}^{(k)}}{\partial x} + \frac{\partial \sigma_{33}^{(k)}}{\partial z} &= \rho_k \frac{\partial^2 g_k}{\partial t^2} \\ i\gamma \sigma_{31}^{(k)}(z) e^{i\gamma x - i\omega t} + \frac{d\sigma_{33}^{(k)}(z)}{dz} e^{i\gamma x - i\omega t} &= -\rho_k \omega^2 V_k(z) e^{i\gamma x - i\omega t} \\ i\gamma \sigma_{31}^{(k)}(z) + \frac{d\sigma_{33}^{(k)}(z)}{dz} &= -\rho_k \omega^2 V_k(z) \end{aligned} \quad (7)$$

$$\begin{aligned} \tilde{E}_k \frac{\partial u_k}{\partial x} &= \sigma_{11}^{(k)} - \nu_k (\sigma_{22}^{(k)} + \sigma_{33}^{(k)}) \\ \tilde{E}_k i\gamma U_k(z) e^{i\gamma x - i\omega t} &= \sigma_{11}^{(k)}(z) e^{i\gamma x - i\omega t} - \nu_k (\sigma_{22}^{(k)}(z) e^{i\gamma x - i\omega t} + \sigma_{33}^{(k)}(z) e^{i\gamma x - i\omega t}) \end{aligned}$$

$$\tilde{E}_k i\gamma U_k(z) = \sigma_{11}^{(k)}(z) - \nu_k \left(\sigma_{22}^{(k)}(z) + \sigma_{33}^{(k)}(z) \right) \quad (8)$$

$$\tilde{E}_k \frac{\partial \mathcal{G}_k}{\partial z} = \sigma_{33}^{(k)} - \nu_k \left(\sigma_{11}^{(k)} + \sigma_{22}^{(k)} \right)$$

$$\tilde{E}_k \frac{dV_k(z)}{dz} e^{i\gamma x - i\omega t} = \sigma_{33}^{(k)}(z) e^{i\gamma x - i\omega t} - \nu_k \left(\sigma_{11}^{(k)}(z) e^{i\gamma x - i\omega t} + \sigma_{22}^{(k)}(z) e^{i\gamma x - i\omega t} \right)$$

$$\tilde{E}_k \frac{dV_k(z)}{dz} = \sigma_{33}^{(k)}(z) - \nu_k \left(\sigma_{11}^{(k)}(z) + \sigma_{22}^{(k)}(z) \right) \quad (9)$$

$$\sigma_{22}^k = \nu_k^F \left(\sigma_{11}^k + \sigma_{33}^k \right) \quad (10)$$

$$\frac{1}{2} \tilde{E}_k \frac{\partial u_k}{\partial z} + \frac{\partial \mathcal{G}_k}{\partial x} = (1 + \nu_k) \sigma_{13}^{(k)}$$

$$\frac{1}{2} \tilde{E}_k \frac{\partial U_k(z)}{\partial z} e^{i\gamma x - i\omega t} + i\gamma V_k(z) e^{i\gamma x - i\omega t} = (1 + \nu_k) \sigma_{13}^{(k)}(z) e^{i\gamma x - i\omega t}$$

$$\frac{1}{2} \tilde{E}_k \frac{\partial U_k(z)}{\partial z} + i\gamma V_k(z) = (1 + \nu_k) \sigma_{13}^{(k)}(z) \quad (11)$$

(8) va (10) formulalardan quyidagi tenglik kelib chiqadi:

$$\begin{aligned} \tilde{E}_k i\gamma U_k(z) &= \sigma_{11}^{(k)}(z) - \nu_k \left(\nu_k \left(\sigma_{11}^{(k)}(z) + \sigma_{33}^{(k)}(z) \right) + \sigma_{33}^{(k)}(z) \right) = \\ &= \sigma_{11}^{(k)}(z) - \nu_k^2 \sigma_{11}^{(k)}(z) - \nu_k^2 \sigma_{33}^{(k)}(z) - \nu_k \sigma_{33}^{(k)}(z) \end{aligned}$$

Bu yerdan

$$\sigma_{11}^{(k)}(z) = \frac{\tilde{E}_k i\gamma U_k(z) + \nu_k^2 \sigma_{33}^{(k)}(z) + \nu_k \sigma_{33}^{(k)}(z)}{1 - \nu_k^2}$$

Bu natijani (6) tenglikka quyib quyidagi tenglikka ega bo'lamiz:

$$\begin{aligned} &\frac{-\tilde{E}_k \gamma^2 U_k(z) + i\gamma \nu_k^2 \sigma_{33}^{(k)}(z) - i\gamma \nu_k \sigma_{33}^{(k)}(z)}{1 - \nu_k^2} + \frac{d\sigma_{33}^{(k)}(z)}{dz} = -\rho_k \omega^2 U_k(z) \\ &\frac{d\sigma_{33}^{(k)}(z)}{dz} = \frac{-(1 - \nu_k^2) \rho_k \omega^2 U_k(z) + \tilde{E}_k \gamma^2 U_k(z) - i\gamma \nu_k^2 \sigma_{33}^{(k)}(z) + i\gamma \nu_k \sigma_{33}^{(k)}(z)}{1 - \nu_k^2} = \\ &= \frac{\tilde{E}_k \gamma^2 - (1 - \nu_k^2) \rho_k \omega^2}{1 - \nu_k^2} U_k(z) + \frac{i\gamma \nu_k - i\gamma \nu_k^2}{1 - \nu_k^2} \sigma_{33}^{(k)}(z) = E_{4k} \sigma_{33}^{(k)}(z) - E_{5k} U_k(z) \end{aligned}$$

$$\sigma_{11}^{(k)}(z) = \frac{\nu_k}{1+\nu_k} \sigma_{33}^{(k)}(z) + \frac{\tilde{E}_k i \gamma}{1-\nu_k^2} U_k(z) = E_{6k} \sigma_{33}^{(k)}(z) + E_{7k} U_k(z)$$

(7) formuladan quyidagi tenglik kelib chiqadi:

$$\frac{d\sigma_{33}^{(k)}(z)}{dz} = -i\gamma \sigma_{31}^{(k)}(z) - \rho_k \omega^2 V_k(z) = \delta_k \sigma_{31}^{(k)}(z) - \Omega_k^2 V_k(z)$$

(11) formuladan quyidagi tenglik kelib chiqadi:

$$\frac{\partial U_k(z)}{\partial z} = \frac{2(1+\nu_k)}{\tilde{E}_k} \sigma_{13}^{(k)}(z) - i\gamma V_k(z) = E_{3k} \sigma_{13}^{(k)}(z) + \delta_k V_k(z)$$

(10) formuladan quyidagi tenglik kelib chiqadi:

$$\begin{aligned} \frac{dV_k(z)}{dz} &= \frac{1}{\tilde{E}_k} \left(\sigma_{33}^{(k)}(z) - \nu_k \left(\sigma_{11}^{(k)}(z) + \sigma_{22}^{(k)}(z) \right) \right) = \\ &= \frac{1}{\tilde{E}_k} \left(\sigma_{33}^{(k)}(z) - \nu_k \left(\sigma_{11}^{(k)}(z) + \nu_k \left(\sigma_{11}^{(k)}(z) + \sigma_{33}^{(k)}(z) \right) \right) \right) = \\ &= \frac{1}{\tilde{E}_k} \sigma_{33}^{(k)}(z) (1-\nu_k^2) - (\nu_k + \nu_k^2) \frac{\tilde{E}_k i \gamma U_k(z) + \nu_k^2 \sigma_{33}^{(k)}(z) + \nu_k \sigma_{33}^{(k)}(z)}{1-\nu_k^2} = \\ &= \frac{1}{\tilde{E}_k} \sigma_{33}^{(k)}(z) (1-\nu_k^2) - \nu_k \frac{\tilde{E}_k i \gamma U_k(z) + \nu_k \sigma_{33}^{(k)}(z) (1+\nu_k)}{1-\nu_k} = \\ &= \frac{1}{\tilde{E}_k} \frac{1-2\nu_k^2-\nu_k}{1-\nu_k} \sigma_{33}^{(k)}(z) - \frac{\tilde{E}_k i \gamma}{1-\nu_k} U_k(z) = E_{1k} \sigma_{33}^{(k)}(z) - E_{2k} U_k(z) \end{aligned}$$

bu yerda

$$\begin{aligned} E_{1k} &= \frac{1-2\nu_k^2-\nu_k}{1-\nu_k}; E_{2k} = \frac{\tilde{E}_k i \gamma}{1-\nu_k}; \delta_k = -i \gamma; \\ E_{3k} &= \frac{2(1+\nu_k)}{\tilde{E}_k}; E_{4k} = \frac{i \gamma \nu_k - i \gamma \nu_k^2}{1-\nu_k^2}; E_{5k} = -\frac{\tilde{E}_k \gamma^2 - (1-\nu_k^2) \rho_k \omega^2}{1-\nu_k^2}; \\ E_{6k} &= \frac{\nu_k}{1+\nu_k}; E_{7k} = \frac{\tilde{E}_k i \gamma}{1-\nu_k^2}; \Omega_k = -\rho_k \omega^2. \end{aligned}$$

Xulosa. Qo'yilgan spektral masala o'Ichamsiz kattaliklarda analitik dispersion tenglama olinib Myuller usullarini ketma-ket qo'llash orqali kompleks arifmetikada yechiladi:

$$\xi_n = \frac{x}{h_n}; \quad \zeta_n = \frac{z}{h_n}; \quad t^n = \frac{c_{2n}t}{h_n}, c_{2n} = \sqrt{\frac{E_n}{2(1+\nu_n)\rho_n}}.$$

Formal ravishda dispersion tenglamalar mos elastik qatlam uchun tuzilgan dispersion tenglama [1,2,3] ko‘rinishida bo‘ladi, lekin oxirgidan farqli ravishda ular kompleks o‘zgaruvchili tenglama bo‘ladi. Shu sababli dispersion tenglamalar irsiy elastik qatlam bo‘lgan holda o‘zaro ko‘shma kompleks ildizlarga ega bo‘lmaydi.

Shunday qilib, irsiy-elastik spektrda shoxlar tarmoklanar ekan. Dispersion tenglama Myuller va Gauss usullarini birgalikda qo‘llash orqali kompleks arifmetikada yechildi. Buning dispersion tenglama analitik olinib ko‘pxad yoki aniqlovchi ko‘rinishdagi kompleks parametrli transendent tenglamaga keladi. Bu tenglama barcha hollarda Myuller usuli bilan sonli yechiladi.

FOYDALANILGAN ADABIYOTLAR

- 1.Коненков Ю.К. Об изгибной волне релеевского типа // Акустический журнал. 1960. Т. 6. № 1. С. 124–126.
- 2.Вильде М.В., Каплунов Ю.Д., Коссович Л.Ю. Краевые и интерфейсные резонансные явления в упругих телах. М.: Физматлит, 2010. 280 с.
- 3.I.E. Kuznetsova, B.D. Zaitsev, S.G. Joshi, I.A. Borodina, Investigation of acoustic waves in thin plates of lithium niobate and lithium tantalate, IEEE Trans. UFFC, 48(2001), №1, 322–328.
- 4.Савин Г. И ., Лукашов А.А., Лыско Е.М., Времеенко С.В.т Агасьев Г.Г. Распространение упругих волн в континууме Кассора со стесненным вращением // Прикл. механика. 1970. Т. 6. № 6. С. 37—41.
5. Grekova E.D., Herman G.C. Wave propagation in rocks modeled as reduced Cosserat continuum / / Proceedings of 66th EAGE (European Association of Geoscientists and Engineers) conference, Paris. 2004. P. P098.

6.Сафаров И.И. Теоретические основы динамики диссипативно-неоднородных механических систем. Ч.II. Колебания и волны в слоистых телах. Ташкент: «Фан заргари». -392с.