ICHKI QOVUSHOQ SUYUQLIK BILAN TA’SIRLASHUVCHI TRANSVERSAL-IZOTROP SILINRIK QATLAM NUQTALARNING KUCHLANISHLARI VA KO‘CHISHLARINI ANIQLASH

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Annotatsiya Ushbu ishda ichki qovushoq suyulik bilan ta’sirlashuvchi silindrik qatlamning bo‘ylama-radial tebranishlari natijasida qatlam nuqtalarining kuchlanishlari va ko‘chishlarini aniqlashga qaratilgan. Transversal-izotrop materiallar, xususan silindrik qatlamlar, o‘zining mexanik xususiyatlari bilan boshqa materiallardan ajralib turadi, chunki ularning xususiyatlari yo‘nalishga bog‘liq bo‘ladi. Qovushoq suyuqlikning materiallar bilan o‘zaro ta’siri, ularning deformatsiyasini va kuchlanish taqsimotini murakkablashtiradi, shuning uchun bunday sistemalar uchun maxsus usullar zarur. Ishda bo‘ylama-radial tebranish tenglamalari va elastiklik nazariyasining gipotezalari yordamida qatlamdagi kuchlanishlar va ko‘chishlar tahlil qilinadi. Ushbu matematik model, suyuqlikning qovushoqligi va qatlamning transversal-izotropik xususiyatlarini hisobga olgan holda, qatlam nuqtalarining deformatsiyasi va kuchlanish taqsimotini aniq prognoz qilish imkonini beradi. Olingan natijalar, muhandislik, materialshunoslik va boshqa sohalarda amaliy qo‘llanilishi mumkin bo‘lgan yangi yondashuvlarni taklif etadi va silindrik qatlamlar va qovushoq suyuqliklar bilan ishlashda yangi nazariy asoslar yaratish hamda muhandislik amaliyotida samarali yechimlar topishga yordam beradi.

Абстракт. В данной работе целью является определение напряжений и перемещение точек слоя в результате продольно-радиальных колебаний цилиндрического слоя, взаимодействующего с внутренней вязкой жидкостью. Трансверсально-изотропные материалы, особенно цилиндрические слои, отличаются от других материалов своими механическими свойствами, поскольку их свойства зависят от направления. Взаимодействие вязкой жидкости с материалами усложняет их деформирование и распределение напряжений, поэтому для таких систем необходимы специальные методы. В работе анализируются напряжения и перемещения в слое с использованием уравнений продольно-радиальной колебания и гипотезы теории упругости. Данная модель позволяет точно прогнозировать деформацию и распределение напряжений в точках слоя с учетом вязкости жидкости и трансверсально-изотропных свойств слоя. Полученные результаты предлагают новые подходы, которые могут быть применены в технике, материаловедении и других областях, помогают создать новые теоретические основы работы с цилиндрическими слоями и вязкими жидкостями, а также найти эффективные решения в инженерной практике.

Abstract. In this work, the objective is to determine the stresses and displacements of layer points as a result of longitudinal-radial oscillations of a cylindrical layer interacting with an internal viscous fluid. Transversely isotropic materials, especially cylindrical layers, differ from other materials in their mechanical properties, since their properties depend on the direction. The interaction of a viscous fluid with materials complicates their deformation and stress distribution, so special methods are needed for such systems. In this paper, stresses and displacements in a layer are analyzed using the equations of longitudinal-radial oscillation and elasticity theory approaches. This model allows one to accurately predict the deformation and stress distribution at layer points, taking into account the viscosity of the fluid and the transversely isotropic properties of the layer. The results obtained offer new approaches that can be applied in engineering, materials science and other fields, help to create new theoretical foundations for working with cylindrical layers and viscous fluids, and also find effective solutions in engineering practice.

Kalit so‘zlar. Doiraviy silindrik qobiq, transversal-izotrop jism, bo‘ylama-radial tebranish, kuchlangan-deformatsiyalangan holat, qovushoq suyuqlik.

Ключевые слова. Круговая цилиндрическая оболочка, трансверсально-изотропное тело, продольно-радиальная вибрация, напряженно-деформированное состояние, вязкая жидкость.

Key words. Circular cylindrical shell, transversely isotropic body, longitudinal-radial vibration, stress-strain state, viscous fluid

Kirish. Transversal-izotrop silindrik qatlam va qobiqlar qovushoq suyuqlik bilan o‘zaro nostatsionar ta’sirlashuvi ko‘plab amaliy masalalarni hal etishda muhim ahamiyatga ega. Ushbu tadqiqotlar, stukturalar va suyuqlik o‘rtasidagi dinamik munosabatlarni o‘rganishga qaratilgan bo‘lib, ularning nazariy va jihatlarini o‘z ichiga oladi. Transversal-izotrop materiallar, bir yo‘nalishda boshqa yo‘nalishlarga nisbatan farq qiladigan mexanik xususiyatlarga ega. Bunday materiallar turli muhandislik sohalarida, jumladan aerokosmik, transport, qayta ishlash va qurilish sohalarida keng qo‘llash imkonini beradi. Qovushoq suyuqlik esa, dinamik sistemalarda o‘ziga xos xususiyatlarga ega bo‘lib, uning qovushoqlik xususiyatlari tebranish jarayonlariga ta’sir ko‘rsatadi. Ushbu ishda, transversal-izotrop silindrik qatlamlar va qobiqlarning qovushoq suyuqlik bilan o‘zaro nostatsionar tebranishlari natijasida silinrik qobiq nuqtalarida kuchlanish va ko‘chishlarni aniqlash bo‘yicha muhim tadqiqotlar ko‘rib chiqiladi. Bu tadqiqotlar, materiallarning dinamik xusiyatlarini yanada chuqurroq tushunishga yordam beradi va muhandislik amaliyotida yangi yechimlar taklif etadi. Shuningdek, nazariy modellar va eksperimentlar orqali erishilgan natijalar, kelajakdagi ilmiy tadqiqotlar uchun asos bo‘lib xizmat qiladi.

Metod. Deformatsiyalanuvchi qattiq jism mexanikasining asosiy vazifasi tadqiqot ob’ekti uchun kuchlangan-deformatsiyalangan holatini aniqlashdir. Shu nuqtai nazardan qaraganda, tebranish tenglamalari bilan bir qatorda, kuchlanishlar tenzorining barcha komponentlari va ko‘chish vektorini aniqlovchi formulalarni chiqarish berilgan vazifani yechishning asosiy bosqichlaridan biridir.

Shu sababli, bunda tebranishlar tenglamalarini yechish orqali aniqlanadigan vaqt va koordinatalar bo‘yicha izlanayotgan funksiyalar orqali kuchlanishlar tenzorining barcha komponentalari va ko‘chish vektori formulalarni chiqarishni qaraymiz. Qatlam nuqtalari ko‘chishlarining U_r va U_z bosh qismlarini $U_{r,0}, U_{r,1}, U_{z,0}$ va $U_{z,1}$ orqali, nolga teng bo‘lmagan kuchlanish komponentlarini esa $\sigma_{rr}, \sigma_{zz}, \sigma_{rz}$ va $\sigma_{\theta\theta}$ lar orqali ifodalaymiz.

Bizga malum bo‘lgan

$$\bar{U}_z = \frac{1}{\alpha^2 k\bar{M}_1}\sum_{n=0}^{\infty}\left[k\bar{M}_1\alpha_1^2\alpha_2^2\left(\bar{P}_n-\alpha^2\right)\bar{U}_{z,0}-\left(\alpha_1^2-\alpha^2\right)\left(\alpha_2^2-\alpha^2\right)\bar{P}_n\bar{U}_{r,0}\right]\frac{(r/2)^{2n}}{(n!)^2}+$$

$$+\frac{1}{\bar{M}_1}\sum_{n=0}^{\infty}\eta_{3,n}(r)\left[k\bar{M}_1\left(\bar{P}_{n+1}-\alpha^2\bar{P}_n\right)U_{z,1}-\left(\alpha_1^2-\alpha^2\right)\left(\alpha_2^2-\alpha^2\right)\bar{P}_n\bar{U}_{r,1}\right]\frac{(r/2)^{2n}}{(n!)^2}; \qquad (1)$$

$$\bar{U}_r = \frac{\xi}{r}\bar{U}_{r,1}+\frac{1}{\alpha^2}\sum_{n=0}^{\infty}\left[\left(\alpha^2\bar{P}_{n+1}-\alpha_1^2\alpha_2^2\bar{P}_n\right)\bar{U}_{r,0}+k\bar{M}_1\alpha_1^2\alpha_2^2\bar{P}_n\bar{U}_{r,0}\right]\frac{(r/2)^{2n+1}}{n!(n+1)!}+$$

$$+\xi\sum_{n=0}^{\infty}\eta_{4,n}(r)\left[\left(\alpha^2\bar{P}_{n+1}-\alpha_1^2\alpha_2^2\right)\bar{U}_{r,1}+k\bar{M}_1\bar{P}_{n+1}\bar{U}_{z,1}\right]\frac{(r/2)^{2n+1}}{n!(n+1)!};$$

formulalarga

$$U_r = \int_0^{\infty}\left.\begin{matrix}\sin kz\\ -\cos kz\end{matrix}\right\}dk\int_{(l)}\bar{U}_r e^{pt}dp,\quad U_z = \int_0^{\infty}\left.\begin{matrix}\cos kz\\ \sin kz\end{matrix}\right\}dk\int_{(l)}\bar{U}_z e^{pt}dp, \qquad (2)$$

(2) Furye-Laplas alamashtirishlarini qo‘llab o‘zgartirilgan ko‘chishlar U_r va U_z ifodalarini olishimiz mumkin:

$$\begin{aligned}U_r(r,z,t) &= a_{r1}U_{r,0}+a_{r2}U_{z,0}-\xi\left(a_{r3}U_{r,1}+a_{r4}U_{z,1}\right);\\ U_z(r,z,t) &= a_{z1}U_{r,0}+a_{z2}U_{z,0}-\xi\left(a_{z3}U_{r,1}+a_{z4}U_{z,1}\right);\end{aligned} \qquad (3)$$

bu yerda

$$a_{r1} = \sum_{n=0}^{\infty}\left[P_{n+1}-\left(\gamma_2^2/\gamma_1\right)P_n\right]\frac{(r/2)^{2n+1}}{n!(n+1)!};\qquad a_{r2} = \sum_{n=0}^{\infty}\left[kM_1\left(\gamma_2^2/\gamma_1\right)P_n\right]\frac{(r/2)^{2n+1}}{n!(n+1)!};$$

$$a_{r3}=\frac{1}{r}+\sum_{n=0}^{\infty}\eta_{4,n}(r)\left[\gamma_1P_{n+1}-\gamma_2^2P_n\right]\frac{(r/2)^{2n}}{(n!)^2};\qquad a_{r4}=\sum_{n=0}^{\infty}\eta_{4,n}(r)\left[kM_1P_{n+1}\right]\frac{(r/2)^{2n}}{(n!)^2};\qquad (4)$$

$$a_{z1}=\sum_{n=0}^{\infty}\left(\gamma_2^2/\gamma_1\right)\left[P_{n-1}\gamma_1^2P_n\right]\frac{(r/2)^{2n}}{(n!)^2};\qquad a_{z2}=-\sum_{n=0}^{\infty}\left[\gamma_2^2-\gamma_1\gamma_3+\gamma_1kM_1\right]P_n\frac{(r/2)^{2n}}{(n!)^2};$$

$$a_{z3}=\sum_{n=0}^{\infty}\eta_{4,n}(r)\left[P_{n+1}-\gamma_1P_n\right]\frac{(r/2)^{2n}}{(n!)^2};\qquad a_{z4}=-\frac{1}{kM_1}\sum_{n=0}^{\infty}\left[\gamma_2^2-\gamma_1\gamma_3+\gamma_1\right]P_n\frac{(r/2)^{2n}}{(n!)^2};$$

Kuchlanishlar tenzorining σ_{ij} komponentlari uchun formulalarni chiqarish maqsadida ularni quyidagicha ifodalaymiz:

$$\sigma_{rr}=\left.\begin{matrix}\sin kz\\ \cos kz\end{matrix}\right\}dk\int_{(l)}\bar{\sigma}_{rr}e^{pt}dp,\qquad \sigma_{rz}=\left.\begin{matrix}\cos kz\\ \sin kz\end{matrix}\right\}dk\int_{(l)}\bar{\sigma}_{rz}e^{pt}dp,$$

$$\sigma_{zz}=\left.\begin{matrix}\sin kz\\ \cos kz\end{matrix}\right\}dk\int_{(l)}\bar{\sigma}_{zz}e^{pt}dp,\qquad \sigma_{\theta\theta}=\left.\begin{matrix}\sin kz\\ \cos kz\end{matrix}\right\}dk\int_{(l)}\bar{\sigma}_{\theta\theta}e^{pt}dp,\qquad (5)$$

Kuchlanish tensorining nolga teng bo‘lmagan komponentlariga $\bar{U}_r$ va $\bar{U}_z$ larni qo‘yib, ushbu (5) formulalardan foydalangan holda almashtirilgan kuchlanishlar $\bar{\sigma}_{rr},\bar{\sigma}_{rz},\bar{\sigma}_{zz}$ va $\bar{\sigma}_{\theta\theta}$ ni modifikatsiyalangan Bessel va Makdonald funktsiyalari orqali ifodalashimiz mumkin

$$\bar{\sigma}_{rr}=\left(\alpha_1\bar{A}_{11}-\frac{\alpha_1^2-\alpha^2}{\alpha_1\bar{M}_1}\bar{A}_{13}\right)\left[e_1I_0(\alpha_1r)-e_2K_0(\alpha_1r)\right]+\left(\alpha_2\bar{A}_{11}-\frac{\alpha_2^2-\alpha^2}{\alpha_2\bar{M}_1}\bar{A}_{13}\right)\times$$

$$\times\left[D_1I_0(\alpha_2r)-D_2K_0(\alpha_2r)\right]+\frac{\bar{A}_{12}-\bar{A}_{11}}{r}\left[e_1I_1(\alpha_1r)-e_2K_1(\alpha_1r)+D_1I_0(\alpha_2r)-D_2K_0(\alpha_2r)\right];$$

$$\bar{\sigma}_{rz}=\bar{A}_{44}\left\{\left(k+\frac{\alpha_1^2-\alpha^2}{k\bar{M}_1}\right)\left[e_1I_1(\alpha_1r)-e_2K_1(\alpha_1r)\right]+\left\{\left(k+\frac{\alpha_1^2-\alpha^2}{k\bar{M}_1}\right)\left[D_1I_0(\alpha_2r)+D_2K_0(\alpha_2r)\right]\right\};$$

$$\bar{\sigma}_{zz}=\left(\alpha_1\bar{A}_{13}-\frac{\alpha_1^2-\alpha^2}{\alpha_1\bar{M}_1}\bar{A}_{33}\right)\left[e_1I_0(\alpha_1r)-e_2K_0(\alpha_1r)\right]+\left(\alpha_2\bar{A}_{13}-\frac{\alpha_2^2-\alpha^2}{\alpha_2\bar{M}_1}\bar{A}_{22}\right)\times\qquad (6)$$

$$\times\left[D_1I_0(\alpha_2r)-D_2K_0(\alpha_2r)\right];$$

$$\bar{\sigma}_{\theta\theta}=\left(\alpha_1\bar{A}_{12}-\frac{\alpha_1^2-\alpha^2}{\alpha_1\bar{M}_1}\bar{A}_{13}\right)\left[e_1I_0(\alpha_1r)-e_2K_0(\alpha_1r)\right]+\left(\alpha_2\bar{A}_{12}-\frac{\alpha_2^2-\alpha^2}{\alpha_2\bar{M}_1}\bar{A}_{13}\right)\times$$

$$\times\left[D_1I_0(\alpha_2r)-D_2K_0(\alpha_2r)\right]+\frac{\bar{A}_{12}-\bar{A}_{11}}{r}\left[e_1I_1(\alpha_1r)-e_2K_1(\alpha_1r)+D_1I_0(\alpha_2r)-D_2K_0(\alpha_2r)\right];$$

Olingan ifodalarning o‘ng qismlarini radial koordinatalar darajalari bo‘yicha qatorlarga yoyib, olingan ifodalarni Furye-Laplas almashtirishlari bo‘yicha almashtirib, quyidagilarga ega bo‘lamiz:

$$\gamma_1\sigma_{rr}=M_1^{-1}\left[a_2U_{z,0}+b_2U_{r,0}+\xi\left(c_2U_{z,1}+b_2U_{r,1}\right)\right];$$

$$\gamma_1\frac{\partial\sigma_{rz}}{\partial z}=M_1^{-1}A_{44}\left[a_1U_{z,0}+b_1U_{r,0}+\xi\left(c_1U_{z,1}+b_1U_{r1}\right)\right];\qquad (7)$$

$$\gamma_1\sigma_{\theta\theta}=f_{\theta1}U_{z,0}+f_{\theta2}U_{r,0}+\xi\left(f_{\theta3}U_{z,1}+f_{\theta4}U_{r,1}\right);$$

$$\gamma_1\sigma_{zz}=f_{z1}U_{z,0}+f_{z2}U_{r,0}+\xi\left(f_{z3}U_{z,1}+f_{z4}U_{r,1}\right),$$

Bu yerda, $a_{ji},b_{ji},c_{ji},d_{ji}\,(j,i=1,2)$ operatorlarning qiymatlarini qo‘ygan holda amaliy masalalarni hosil qilishimiz mumkin bo‘ladi.

Keltirilgan (3) va (7) formulalar transversal-izotrop qatlamning kuchlangan-deformatsiyalangan holatini aniqlashga va qatlamning bo‘ylama-radial tebranishlariga oid aniq chegaraviy masalalarini shakllantirishga imkon beradi.

Qatlam nuqtalarining ko‘chishlari (3) formulalar yordamida aniqlanishi mumkin, uning kesimlaridagi kuchlanishlarni (7) formulalar bilan aniqlash mumkin. Bunday holda, ushbu formulalarda $U_{r,0},U_{r,1},U_{z,0}$ va $U_{z,1}$ funktsiyalari o‘rniga bo‘ylama-radial tenglamalar sistemasining yechimlari bo‘lgan $U_{r,0},U_{r,1},U_{z,0}$ va $U_{z,1}$ funktsiyalaridan foydalanish kerak.

Olingan tenglamalar o‘z struturalarida doimiy tezlikda harakatlanadigan ichki qovushoq suyuqlikning reaktsiyalarini hisobga oladi. Ushbu tenglamalarni yechish orqali qaralayotgan

qobiqning tebranishlar chatotasi va to‘lqin soni, kuchlanish va koordinata, ko‘chish va koordinata orasidagi munosabatlarni aniqlashimiz mumkin.

Xulosa. Ushbu maqolada transversal-izotrop silinrik qatlam va qobiqlarning qovushoq suyuqlik bilan o‘zaro nostatsionar ta’sirlashuvi va qatlam nuqtalaridagi kuchlanish va ko‘chishlarni aniqlash o‘rganilgan. Maqolada taqdim etilgan nazariy modellar va hisoblash metodlari orqali, transversal-izotrop silindrik qatlamning dinamik xususiyatlari va ularga ta’sir qiluvchi qovushoq suuqlikning o‘zgarishlari o‘rganilgan. Tadqiqot natijalari, ayniqsa qovushoq suyuqliklarning strukturalarga ta’sirini hisobga olish orqali yangi texnik va ilmiy yechimlar ishlab chiqish imkoniyatlarni yaratadi.

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