RADIUSI O'ZGARUVCHAN, DOIRAVIY, QOVUSHOQ-ELASTIK STERJENNING BURALMA TEBRANISH MASALASI TENGLAMALARI

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ANNOTATSIYA

Ushbu maqola doirasida radiusi o'zgaruvchan sterjenning buralma tebranish tenglamalarini keltirib chiqaramiz. Bunda qobiqning ko'ndalang kesimi doiraviy bo'lsin deb, shuningdek uning materialini qovushoq-elastik deb hisoblaymiz.

Kalit so'zlar: interrodifferensial, qovushoq-elastik, radial, modifitsirlangan,

ABSTRACT

In this article, the equations of torsional vibrations of a rod of variable radius are derived. In this case, the cross section of the shell is considered round, and its material is viscoelastic.

Keywords: interdifferential, viscoelastic, radial, modified.

KIRISH

Qaralayotgan masala $\sigma_{r\theta} - F^{'}(z)\sigma_{z\theta} = \Delta f_{nS_1}(z,t).$ chegaraviy va nolga teng boshlang'ich shartlarda $M_0(\Delta_0\Psi_1) - \frac{1}{b^2}\frac{\partial^2\Psi_1}{\partial t^2} = 0;$ $0 \le r \le R$ interrodifferensial tenglamani integrallashga keltiriladi. Keltirilgan harakat tenglamasidan ko'rinadiki, qaralayotgan doiraviy sterjenning buralma tebranishlarida uning kuchlanganlik-deformatsiyalanganlik holati faqat va faqat Ψ_1 potensialdangina bog'liq bo'lishi kerak. Kuchlanganlik-deformatsiyalanganlik holatining bu potensialga bog'liq bo'lmagan boshqa parametrlari nolga aylanishlari kerak. Birinchi paragraf natijalariga ko'ra $U_\theta = -\frac{\partial\psi_1}{\partial r}$ va $\sigma_{r\theta} = M\left[\frac{1}{r}\frac{\partial}{\partial r} - \frac{\partial^2}{\partial r^2}\right]\Psi_1,$ $\sigma_{z\theta} = -M\frac{\partial^2\Psi_1}{\partial r\partial z}.$ formulalar bilan aniqlanuvchi U_θ, $\varepsilon_{z\theta}$, $\varepsilon_{r\theta}$, $\sigma_{z\theta}$, $\sigma_{r\theta}$ kattaliklar Ψ_1 potensialdan bog'liq va faqat shu kattaliklargina noldan farqlidirlar.

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MUHOKAMA

Buralma tebranish tenglamalari qaralayotgan doiraviy sterjenniki bo'lganliklari uchun uning nuqtalarining ko'chishlari bo'lgan U_θ larning bosh qismlarini ajratamiz. Buning uchun $U_\theta^{(0)}(r)$ funksiyaning $U_\theta^{(0)} = -\beta B I_1(\rho r)$ ifodasiga kiruvchi $I_1(\beta r)$ Besselning modifitsirlangan funksiyasini *r*- radial koordinataning darajalari bo'yicha darajali qatorga yoyamiz. U holda $U_\theta^{(0)}(r)$ funksiya uchun quyidagi formulaga ega bo'lamiz:

$$U_\theta^{(0)}(r) = -\sum_{n=0}^{\infty} \beta^{2n+2} \cdot B \frac{\left(\frac{r}{2}\right)^{2n+1}}{n!(n+1)!}$$

Ma'lumki qobiqlar va plastinalar nazariyalarida asosiy izlanuvchi o'zgaruvchilar sifatida qobiq yoki plastina o'rta sirti nuqtalarining ko'chishlari qabul qilanadi. [1, 2, 3, 11, 14]. Ammo, bunday qilinganida qobiqning qalinligi bo'yicha chetki yoki unga yaqin nuqtalarining ko'chishlarini topib bo'lmaydi. Bunday holda qo'shimcha gipoteza kiritadilar, ya'ni qobiqning o'rta sirtidan boshqa sirtlari nuqtalarining ko'chishlari o'rta sirt nuqtalari ko'chishi W_0 bilan biror chiziqli kz funksiyaning yig'indisidan iborat bo'lsin deb faraz qiladilar. Formula tilida ushbu gipoteza

$$W = W_0 \pm kz$$

ko'rinishda bo'ladi. Bu yerda k-o'zgarmas koeffitsiyent; z - qobiqning normali bo'ylab yo'nalgan o'zgaruvchi. Bu o'zgaruvchining boshlang'ich nuqtasi o'rta sirt ustida deb hisoblanadi.

Umuman olganda asosiy izlanuvchi kattaliklar sifatida qobiq o'rta sirti nuqtalarining ko'chishlarini tanlash yagona yo'l emas. Masalan, izlanuvchi funksiyalar sifatida qobiqning shunday sirti nuqtalarning ko'chishlarini qabul qilish mumkinki, bu sirt $r \to 0$ bo'lgan limitik holatda sterjen o'rta chizig'i yoki qobiqning ichki $r = r_1$ va yoki tashqi $r = r_2$ sirtlariga o'tsin. Bunday "harakatlanuvchi" sirt nuqtalarning ko'chishlari asosiy izlanuvchi kattaliklar sifatida qabul qilingan holda kontakt masalalarida kontakt shartlarini aniq qo'yish mumkin bo'ladi.

Yuqorida bayon qilingan fikrlar bilan bo'g'liq ravishda [8] asosiy sirt sifatida silindrik qobiqning radiusi

$$\xi = \frac{r_1}{2}\left(x - \frac{r_1}{r_2}\right)$$

formula bilan aniqlanuvchi biror "oraliq" sirtini qabul qilingan. Bu yerda x o'zgarmas son va u quyidagi tengsizlikni qanoatlantiradi.

$$2 + \frac{r_1}{r_2} \le x \le 2\frac{r_2}{r_1} + \frac{r_1}{r_2}$$

Ta'kidlash lozimki, kiritilgan x o'zgarmasning

$$2 + \frac{r_1}{r_2}; \qquad 1 + \frac{r_2}{r_1} + \frac{r_1}{r_2}; \qquad 2\frac{r_2}{r_1} + \frac{r_1}{r_2}$$

larga teng bo'lgan qiymatlarida $\xi = \frac{r_1}{2}\left(x - \frac{r_1}{r_2}\right)$ formula bilan aniqlangan "oraliq" sirt radiusi -ξ quyidagi qiymatlarni qabul qiladi (mos ravishda):

$$r_1; \frac{r_1 + r_2}{2}; \qquad r_2.$$

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Bundan ko'rinadiki tanlangan "oraliq" sirti qobiqning ichki $(\xi = r_1)$, o'rta $\left(\xi = \frac{r_1 + r_2}{2}\right)$ yoki tashqi $(\xi = r_2)$ sirtlariga o'tadi. Yuqorida ta'kidlangan limitik holda, ya'ni $r_1 = 0$ bo'lganda silindrik qobiq doiraviy sterjenga o'tadi. Bu holda "oraliq" sirt esa sterjenning o'q $(\xi = 0)$ chizig'iga aylanadi.

Biz qarayotgan masalada qobiq o'rnida sterjen kelmoqda. Shuning uchun asosiy sirt sifatida biz radiusi $r = R$ bo'lgan sirtni qabul qilamiz. Ya'ni bu holda $\xi = \frac{r_1}{2}\left(x - \frac{r_1}{r_2}\right)$ formula bilan aniqlanuvchi radius R ga teng, boshqacha aytganda $\xi = R$. Shuning uchun $U_\theta^{(0)}(r) = -\sum_{n=0}^{\infty} \beta^{2n+2} \cdot B \frac{\left(\frac{r}{2}\right)^{2n+1}}{n!(n+1)!}$ formulaga $r = R$ qiymatni qo'yamiz va almashtirilgan $U_\theta^{(0)}(r)$ -ko'chishning bosh qiymatlarini qaraymiz. Bu bosh qism qatorning birinchi hadiga teng. Uni $U_{\theta,0}^{(0)}$ orqali belgilab

$$U_{\theta,0}^{(0)} = -\frac{1}{2}\beta^2 B.$$

ifodaga ega bo'lamiz. Oxirgi $U_{\theta,0}^{(0)} = -\frac{1}{2}\beta^2 B$ formulani hisobga olsak $U_\theta^{(0)}(r) = -\sum_{n=0}^{\infty} \beta^{2n+2} \cdot B \frac{\left(\frac{r}{2}\right)^{2n+1}}{n!(n+1)!}$ ifoda $r = R$ va $n = 0$ bo'lganda

$$U_\theta^{(0)}(r) = RU_{\theta,0}^{(0)}$$

ko'rinishni oladi.Bu yerdan ko'rinadiki yangidan kiritilgan $U_{\theta,0}^{(0)}$ - funksiya deformatsiya o'lchamiga (o'lchamsiz) ega ekan.

NATIJALAR

Endi bu ishlar bajarilgach chegaraviy shartlarni almashtirishga o'tamiz. Buning uchun $\sigma_{r\theta} - F'(z)\sigma_{z\theta} = \Delta f_{nS_1}(z,t)$. shartga $f_{nS_1}(z,t) = \int_0^\infty \left.\begin{matrix} \sin kz \\ -\cos kz \end{matrix}\right\} dk \int_{(l)} f_{nS_1}^{(0)}(k,p) e^{pt} dp$,

$$\text{va } \sigma_{r\theta}(r,z,t) = \int_0^\infty \left.\begin{matrix} \sin kz \\ -\cos kz \end{matrix}\right\} dk \int_{(l)} \sigma_{r\theta}^{(0)}(r,k,p) e^{pt} dp,$$

$\sigma_{z\theta}(r,z,t)=\int_0^\infty \left.\begin{matrix}\cos kz\\ \sin kz\end{matrix}\right\} dk\int_{(l)}\sigma_{z\theta}^{(0)}(r,k,p)e^{pt}dp$, almashtirishlarni qo'llaymiz va

$$\sigma_{r\theta}^{(0)}-F'(z)\sigma_{r\theta}^{(0)}=\Delta f_{nS_1}^{(0)}(k,p),\quad r=F(z)$$

Chegaraviy shartga ega bo'lamiz. Ushbu $\sigma_{r\theta}-F^{'}(z)\sigma_{z\theta}=\Delta f_{nS_1}(z,t)$. shartning har ikkala tomoniga M-qovushoq-elastiklik operatoriga teskari M^{-1} operator bilan ta'sir etamiz. U holda

$$M^{-1}[\sigma_{r\theta}]-F'(z)M^{-1}[\sigma_{z\theta}]=\Delta M^{-1}\lfloor f_{nS_1}(z,t)\rfloor,$$

$r=F(z)$ tenglamaga ega bo'lamiz.

Bu yerdan ko'rinadiki $M^{-1}[\sigma_{r\theta}]-F'(z)M^{-1}[\sigma_{z\theta}]=\Delta M^{-1}\lfloor f_{nS_1}(z,t)\rfloor,$ shartdan foydalanish uchun avvalo $\sigma_{r\theta}$ va $\sigma_{z\theta}$ larni kiritilgan yangi $U_{\theta,0}^{(0)}$ funksiyaning originali bo'lgan $U_{\theta,0}(z,t)$ funksiya orqali ifodalash kerak. Shu maqsadda $U_{\theta,0}(z,t)$ funksiya va λ-operatorini quyidagicha kiritamiz

$$U_{\theta,0}(z,t)=\int_0^\infty \left.\begin{matrix}\sin kz\\ -\cos kz\end{matrix}\right\} dk\int_{(l)}U_{\theta,0}^{(0)}(k,p)e^{pt}dp;$$

$$\lambda^n(U_{\theta,0})=\int_0^\infty \left.\begin{matrix}\sin kz\\ -\cos kz\end{matrix}\right\} dk\int_{(l)}\beta^{2n}U_{\theta,0}^{(0)}(k,p)e^{pt}dp.$$

Endi $\sigma_{r\theta}=M\left[\frac{1}{r}\frac{\partial}{\partial r}-\frac{\partial^2}{\partial r^2}\right]\Psi_1,\qquad \sigma_{z\theta}=-M\frac{\partial^2\Psi_1}{\partial r\partial z}$ formulalardan foydalanib $\sigma_{r\theta}^{(0)}$ va $\sigma_{z\theta}^{(0)}$ larni $U_{\theta,0}^{(0)}$ orqali ifodalaymiz. Buning uchun ushbu

$$\sigma_{r\theta}=M\left[\frac{1}{r}\frac{\partial}{\partial r}-\frac{\partial^2}{\partial r^2}\right]\Psi_1,\qquad \sigma_{z\theta}=-M\frac{\partial^2\Psi_1}{\partial r\partial z}.$$ formulalarga

$$\Psi_1(r,z,t)=\int_0^\infty \left.\begin{matrix}\sin kz\\ -\cos kz\end{matrix}\right\} dk\int_{(l)}\Psi_1^{(0)}(r,k,p)e^{pt}dp$$ va

$$\sigma_{r\theta}(r,z,t)=\int_0^\infty \left.\begin{matrix}\sin kz\\ -\cos kz\end{matrix}\right\} dk\int_{(l)}\sigma_{r\theta}^{(0)}(r,k,p)e^{pt}dp,$$

$\sigma_{z\theta}(r,z,t)=\int_0^\infty \left.\begin{matrix}\cos kz\\ \sin kz\end{matrix}\right\} dk\int_{(l)}\sigma_{z\theta}^{(0)}(r,k,p)e^{pt}dp$, almashtirishlarni qo'llaymiz va mos ravishda quyidagilarni

$$\sigma_{r\theta}^{(0)}(r,k,p)=M_0(\frac{1}{r}\frac{d}{dr}-\frac{d^2}{dr^2})\psi_1^{(0)}(r,k,p),$$

$$\sigma_{z\theta}^{(0)}(r,k,p)=M_0 k\frac{\partial\psi_1^{(0)}(r,k,p)}{\partial r}.$$

Bu yerga $\psi_1^{(0)}$ ning $\Psi_1^{(0)}(r)=BI_0(\beta r)$ ifodasini qo'yamiz. U holda

$$\sigma_{r\theta}^{(0)}(r,k,p)=M_0\left\{\frac{2\beta}{r}\left[I_1(\beta r)-\beta^2 I_0(\beta r)\right]B\right\};$$

$$\sigma_{r\theta}^{(0)}(r,k,p)=-M_0\left\{k\left[\beta I_0(\beta r)-\frac{1}{r}I_1(\beta r)\right]B\right\}.$$

Olingan ifodalarning har ikkala tomonlarini M_0^{-1} operatorni ta'sir ettiramiz

$$M_0^{-1}\left[\sigma_{r\theta}^{(0)}\right]=\frac{2\beta}{r}\left[I_1(\beta r)-\beta^2 I_0(\beta r)\right]B;$$

$$M_0^{-1}\left[\sigma_{z\theta}^{(0)}\right]=\left[\frac{k}{r}I_1(\beta r)-k\beta I_0(\beta^2)\right]B.$$

Oxirgi formulalarning o'ng tomonlaridagi Bessel funksiyalarining o'rniga ularning darajali qatorlarga yoyilmalarini ishlatamiz va hosil qilingan ifodalarda *B*-o'zgarmas o'rniga uning $U_{\theta,0}^{(0)}=-\frac{1}{2}\beta^2 B$. formula bilan aniqlanuvchi qiymatini qo'yib $\sigma_{r\theta}(r,z,t)=\int_0^\infty \left.\begin{matrix}\sin kz\\ -\cos kz\end{matrix}\right\} dk\int_{(l)}\sigma_{r\theta}^{(0)}(r,k,p)e^{pt}dp$,

$$\sigma_{z\theta}(r,z,t)=\int_0^\infty \left.\begin{matrix}\cos kz\\ \sin kz\end{matrix}\right\} dk\int_{(l)}\sigma_{z\theta}^{(0)}(r,k,p)e^{pt}dp,$$ va

$$U_{\theta,0}(z,t)=\int_0^\infty \left.\begin{matrix}\sin kz\\ -\cos kz\end{matrix}\right\} dk\int_{(l)}U_{\theta,0}^{(0)}(k,p)e^{pt}dp;$$

$$\lambda^n(U_{\theta,0})=\int_0^\infty \left.\begin{matrix}\sin kz\\ -\cos kz\end{matrix}\right\} dk\int_{(l)}\beta^{2n}U_{\theta,0}^{(0)}(k,p)e^{pt}dp.$$ almashtirishlarni qo'llaymiz.

Natijada

$$M^{-1}\left[\sigma_{r\theta}\right]=2\sum_{n=0}^{\infty}\frac{(r/2)^{2n+2}}{n!(n+1)!}\lambda^{n+1}U_{\theta,0};$$

$$M^{-1}\left[\sigma_{z\theta}\right]=2\sum_{n=0}^{\infty}\frac{(r/2)^{2n+1}}{n!(n+1)!}\lambda^{n}\frac{\partial U_{\theta,0}}{\partial z}.$$

ifodaga ega bo'lamiz. Ushbu qiymatlarni
$M^{-1}[\sigma_{r\theta}] - F'(z)M^{-1}[\sigma_{z\theta}] = \Delta M^{-1}\left[f_{nS_1}(z,t)\right]$, chegaraviy shartga qo'yib izlanayotgan umumiy tenglamaga ega bo'lamiz:

$$\sum_{n=0}^{\infty}\frac{F^{2n+1}}{n!(n+1)!}\left[\frac{F(z)}{2(n+2)}\lambda - F'(z)\frac{\partial}{\partial z}\right]\lambda^n U_{\theta,0} = \left[1+F'^2(z)\right]M_0^{-1}\left[f_{nS_1}(z,t)\right]$$

Quyidagi olingan tenglamalar radiusi $R = F(z)$ qonun bilan o'zgaruvchan, doiraviy qovushoq-elastik sterjenning buralma tebranish umumiy tenglamasidir. Bu tenglamadan xususiy holda quyidagi tenglamalar kelib chiqadi:

XULOSA

a) Radiusi o'zgarmas, doiraviy, qovushoq-elastik sterjenning buralma tebranish umumiy tenglamasi.

Bu holda $R = F(z) = const$ bo'lganligi uchun uni r_0 orqali belgilaymiz, ya'ni

$$r_0 = R = F(z) = const\ ,$$

u holda $F'(z) = 0$ va demak

$$\Delta = 1 + F'^2(z) = 1,$$

Bundan tashqari $(n,\ S_1, S_2)$ koordinat sistemasini bu holda kiritishga hojat yo'q, chunki $\vec{n}$ normalni r, θ, z -silindirik koordinat sistemasining r -radial o'qi bilan, S_1 ni θ koordinat o'qi bilan va S_2 ni bo'ylama z koordinat o'qi bilan ustma-ust tushadi deb hisoblash mumkin. U holda $f_{nS_1}(s_2,t)$ funksiyani $f_{r\theta}(z,t)$ funksiya bilan almashtiramiz, ya'ni

$$f_{nS_1}(s_2,t) = f_{r\theta}(z,t)\,.$$

Hosil qilingan $r_0 = R = F(z) = const$, $\Delta = 1 + F'^2(z) = 1$, va $f_{nS_1}(s_2,t) = f_{r\theta}(z,t)$. tengliklarni, hamda $F'(z) = 0$ ekanligini hisobga olsak $\sum_{n=0}^{\infty}\frac{F^{2n+1}}{n!(n+1)!}\left[\frac{F(z)}{2(n+2)}\lambda - F'(z)\frac{\partial}{\partial z}\right]\lambda^n U_{\theta,0} = \left[1+F'^2(z)\right]M_0^{-1}\left[f_{nS_1}(z,t)\right]$ dan izlanayotgan tenglamaga ega bo'lamiz.

$$\sum_{n=0}^{\infty}\frac{(r/2)^{2n+2}}{n!(n+2)!}\lambda^{n+1}U_{\theta,0} = M^{-1}\left[f_{r\theta}(z,t)\right]$$

bu yerda

$$\lambda^n = \left[\frac{1}{b^2}M_0^{-1}\left(\frac{\partial^2}{\partial t^2}\right) - \frac{\partial^2}{\partial z^2}\right],\ b^2 = \frac{\mu}{\rho}$$

b) Radiusi o'zgaruvchan, doiraviy, elastik sterjenning buralma tebranish umumiy tenglamalari.

Bu holda $M=\mu$ deb hisoblash yetarli bo'ladi, ya'ni $M=\mu M_0$.

$$M[\zeta(t)]=\mu\zeta(t)$$

deb hisoblash yetarli. Agar $M[\zeta(t)]=\mu\zeta(t)$ o'rinli bo'lsa

$\lambda^{n}=\left[\frac{1}{b^2}M_0^{-1}(\frac{\partial^2}{\partial t^2})-\frac{\partial^2}{\partial z^2}\right],\ b^2=\frac{\mu}{\rho}$ quyidagicha yoziladi

$$\lambda^{n}=\left[\frac{1}{b^2}(\frac{\partial^2}{\partial t^2})-\frac{\partial^2}{\partial z^2}\right]^n,\ n=0,1,2,....\ b^2=\frac{\mu}{\rho}$$

Demak, elastik sterjen uchun

$\sum_{n=0}^{\infty}\frac{F^{2n+1}}{n!(n+1)!}\left[\frac{F(z)}{2(n+2)}\lambda-F'(z)\frac{\partial}{\partial z}\right]\lambda^n U_{\theta,0}=[1+F'^2(z)]M_0^{-1}[f_{nS_1}(z,t)]$ tenglamaning umumiy ko'rinishi saqlanadi, ya'ni

$$\sum_{n=0}^{\infty}\frac{F^{2n+1}(z)}{n!(n+1)!2^{2n}}\left[\frac{F(z)}{2(n+2)}\lambda-F'(z)\frac{\partial}{\partial z}\right]\lambda^n U_{\theta,0}=$$
$$=[1+F'^2(z)][f_{nS_1}(s_2,t)],$$

bu yerda λ - $\lambda^{n}=\left[\frac{1}{b^2}(\frac{\partial^2}{\partial t^2})-\frac{\partial^2}{\partial z^2}\right]^n,\ n=0,1,2,....\ b^2=\frac{\mu}{\rho}$ formula bilan hisoblanishi zarur.

c) Radiusi o'zgarmas, doiraviy, elastik sterjenning buralma tebranish umumiy tenglamalari.

Bu holda xuddi a) holatdagidek $r_0=R=F(z)=const$, $\Delta=1,\ F'(z)=0$ deb hisoblasak hamda $f_{nS_1}(s_2,t)=f_{r\theta}(z,t)$. tenglikni e'tiborga olsak

$$\sum_{n=0}^{\infty}\frac{F^{2n+1}(z)}{n!(n+1)!2^{2n}}\left[\frac{F(z)}{2(n+2)}\lambda-F'(z)\frac{\partial}{\partial z}\right]\lambda^n U_{\theta,0}=$$

$=[1+F'^2(z)][f_{nS_1}(s_2,t)]$ tenglama quyidagi ko'rinishni oladi.

$$\sum_{n=0}^{\infty}\frac{F^{2n+1}(z)}{n!(n+1)!2^{2n}}\lambda^{n+1}U_{\theta,0}=\frac{1}{\mu}f_{r\theta_1}(r,z)$$

bu yerda λ^n, $n=0,1,2,....$ operatorlar

$\lambda^{n}=\left[\frac{1}{b^2}(\frac{\partial^2}{\partial t^2})-\frac{\partial^2}{\partial z^2}\right]^n,\ n=0,1,2,....\ b^2=\frac{\mu}{\rho}$ formula bilan hisoblanishi kerak.

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