TO‘G‘RI TO‘RTBURCHAK SHAKLDAGI CHEGARALANGAN PLASTINKA EGILISHLARINI KOLLOKATSIYA METODI YORDAMIDA HISOBLASH

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ANNOTATSIYA: **Maqolada tashqi ta’sir natijasida hosil bo‘lgan har xil turdagi, ayniqsa to'rtburchaklar shaklidagi plitalarning egilishini hisoblash, shuningdek, tashqi ta'sirlar natijasida plastinka deformatsiyasi holatlarini o'rganish ko'rib chiqiladi. ko‘rib chiqiladi. Buning uchun biz egilish va tashqi kuchlarning o'tkazilishini tavsiflovchi plastinkaning yon tomonlarini deformatsiyasini tahlil qilamiz.**

KALIT SO’ZLAR: **kollokatsiya, plastinka, qobiq, tashqi ta’sir, ichki ta’sir, egilish, zo‘riqish, deformatsiya, sonli qator.**

Keyingi vaqtlarda fan va texnikaning rivojlanishi ko‘pgina injinerlik konstruksiyalari mustahkamligini hisoblash metodlarini takomillashtirishni talab qilmoqda. Qurilish konstruksiyalari va ishlab chiqarishning birqancha sohalarida ko‘p uchraydigan to‘g‘ri to‘rtburchak shakldagi plastinkaning chiziqli elastik deformasiyalanish jaroyoniga duch kelamiz. Bu turdagi masalalar bilan ishlash jarayonlarida qatnashayotgan muhandislik elementlarining, deformasiyalanganlik holatlarini yetarli darajada aniqlikda o‘rganish muhim ahamiyatga ega.

Turli ko‘rinishdagi plastinkalarni tashqi ta‘sirlar natijasida kuchlangan, deformatsiyalangan holatlarni o‘rganish, tekshirish ishlarini tahlil qilish, plastinka tomonlarining hamda tashqi kuchning berilishi bilan bog‘liq deformatsiyalanishini atroflicha bosqichma - bosqich o‘rganib chiqish imkonyati mavjud va bu imkoniyat muxandislik ishlarida muhim hisoblanadi. Plastinkalar va qobiqlar nazariyasining qator masalalari, berilgan chegaraviy shartli va xususiy hosilali differensial tenglamalarga keltiriladi. Bu tenglamalarni yechish va olingan yechimlar asosida plastinkaning egilshlari, zo‘riqish holatlarini o‘rganish muhim ahamiyat kasb etadi. Bu tenglamalarning ko‘p hollarda aniq yechimini topish qiyin bo‘ladi. Shuning uchun sonli usullarga murojaat qilinadi.

Kollokatsiya usuli - plastinkalarni egilishga hisoblashda juda samarali usul hisoblanadi. Yarim taqribiy usul - differentsial tenglamalarni berilgan chegaraviy shartlarni qanoatlantiruvchi analitik yechimini topishga ko‘maklashadi. Ushbu ishda bajarilgan hisob metodikasidan qurilmalar hisobining turdosh masalalarini yechishda, qurilmalar elementlarini loyihalashtirishda foydalanish mumkin.

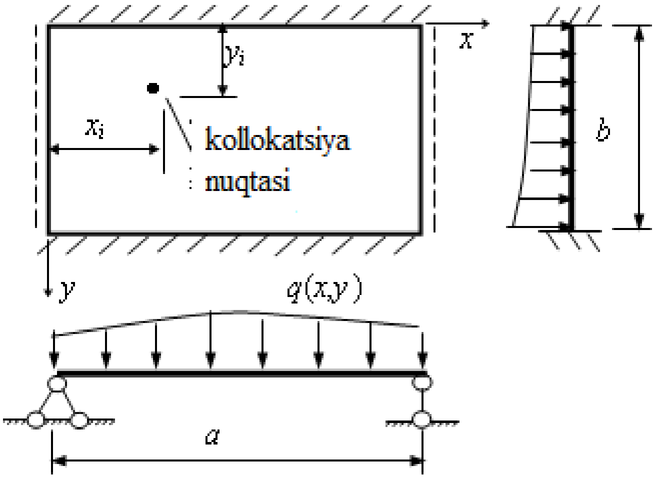
Masalaning qo‘yilishi. To‘g‘ri to‘rtburchak shakldagi plastinkani qaraymiz (1-rasm). Plastinka egilish tenglamasi quyidagi ko‘rinishda ifodalanadi [1]:

$$\nabla^4 w(x_i, y_i) = \frac{q(x_i, y_i)}{D} \qquad (1)$$

Plastinka egilish funksiyasini quyidagicha tanlaymiz:

Bu yerda $X_m(x)$, $Y_m(y)$ - funksiyada

$x = 0$, $x = a$ va $y = 0$, $y = b$ tomonlardagi chegaraviy shartlarni qanoatlantiradi; A_m - noma’lum koeffitsientlar.



1-rasm

$$w(x,y)=\sum_{m=1}^{M}\sum_{n=1}^{N}A_{mn}X_m(x)Y_n(y), \qquad (2)$$

Berilgan kollokatsiya nuqtalari $x_{i,}, y_i$, $i=1,2,...K$; $K=M\times N$ - kollokatsiya nuqtalari soni qatorning hadlari soniga teng bo'ladi.

Kollokatsiya nuqtasi plastinka muvozanat tenglamasini qanoatlantiradi:

Masalaning yechilishi.

(1) ga (2) yechimni qo'yib quyidagini hosil qilamiz:

$$\sum_{m=1}^{M}\sum_{n=1}^{N}A_{mn}\left(\frac{\partial^4 w_{mn}(x_i,y_i)}{\partial x^4}+2\frac{\partial^4 w_{mn}(x_i,y_i)}{\partial x^2\partial y^2}+\frac{\partial^4 w_{mn}(x_i,y_i)}{\partial y^4}\right)=$$

$$=\sum_{m=1}^{M}\sum_{n=1}^{N}A_{mn}\left[X_m^{IV}(x_i)Y_n(y_j)+2X_m''(x_i)Y_n''(y_j)+X_m(x_i)Y_n^{IV}(y_j)\right]=\frac{q(x_i,y_i)}{D}. \qquad (3)$$

Tomonlari sharnirli mahkamlangan to'g'ri to'rtburchak shakldagi o'lchamlari $0\le x\le a$, $0\le y\le b$ ga teng plastinkani qaraymiz.

Plastinka uchun chegaraviy shartlar quyidagicha ifodalanadi [2]:

$$w(0,y)=w(a,y)=0; \quad M_x(0,y)=M_x(a,y)=0;$$

$$w(x,0)=w(x,b)=0; \; M_y(x,0)=M_y(x,b)=0 \qquad (4)$$

Eguvchi momentlarni egilish funksiyasi orqali ifodasidan quyidagi ifodalarni olamiz:

$$\frac{\partial^2 w(0,y)}{\partial x^2}=\frac{\partial^2 w(a,y)}{\partial x^2}=0; \quad \frac{\partial^2 w(x,0)}{\partial y^2}=\frac{\partial^2 w(x,b)}{\partial y^2}=0. \qquad (4, a)$$

Chegaraviy shartlarni hisobga olgan holda yechimni quyidagi ko'rinishda $X_m=\sin m\pi\frac{x}{a}$, $Y_n=\sin n\pi\frac{y}{b}$, ikki karrali qator ko'rinishida tanlaymiz:

$$w(x,y)=\sum_{m=1}^{M}\sum_{n=1}^{N}A_{mn}\sin m\pi\frac{x}{a}\sin n\pi\frac{y}{b}. \qquad (5)$$

(2) yechim (4) chegaraviy shartlarni qanoatlantiradi.

Eguvchi momentlar quyidagi formulalar yordamida topiladi:

$$M_x=-D\left(\frac{\partial^2 w}{\partial x^2}+\nu\frac{\partial^2 w}{\partial y^2}\right)=D\frac{\pi^2}{a^2}\sum_{m=1}^{M}\sum_{n=1}^{N}A_{mn}\left(m^2+\nu\lambda^2 n^2\right)\sin m\pi\frac{x}{a}\sin n\pi\frac{y}{b}$$

$$M_y=-D\left(\nu\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}\right)=D\frac{\pi^2}{a^2}\sum_{m=1}^{M}\sum_{n=1}^{N}A_{mn}\left(\nu m^2+\lambda^2 n^2\right)\sin m\pi\frac{x}{a}\sin n\pi\frac{y}{b},\quad \lambda=\frac{a}{b}. \qquad (6)$$

(1) tenglamalar sistemasiga kollokatsiya metodini qo‘llab quyidagiga kelamiz:

$$\frac{\pi^4}{a^4}\sum_{m=1}^{M}\sum_{n=1}^{N}A_{mn}\left[m^4+2\lambda^2m^2n^2+\lambda^4n^4\right]\sin m\pi\frac{x_i}{a}\sin n\pi\frac{y_i}{b}=\frac{q(x_i,y_i)}{D},\quad i=1,2,3...K;\quad \lambda=\frac{a}{b},$$

yoki

$$\sum_{m=1}^{M}\sum_{n=1}^{N}A_{mn}C_{mn}\sin m\pi\frac{x_i}{a}\sin n\pi\frac{y_i}{b}=\frac{q(x_i,y_i)}{D}\frac{a^4}{\pi^4}, \qquad (7)$$

Bu yerda $C_{mn}=m^4+2\lambda^2m^2n^2+\lambda^4n^4$.

Qatorning bitta hadi uchun hisoblashlarni tekshiramiz. Kollokatsiya nuqtalari sifatida plastinka markaziy nuqtasini tanlaymiz ($x_1=a/2$, $y_1=b/2$). U holda quyidagilar o‘rinli bo‘ladi:

$$C_{11}=1+2\lambda^2+\lambda^4;\qquad \sin\pi\frac{x_1}{a}=\sin\pi\frac{y_1}{b}=\sin\frac{\pi}{2}=1;\qquad A_{1,1}=\frac{q(a/2,b/2)}{D\left(1+2\lambda^2+\lambda^4\right)}\frac{a^4}{\pi^4}.$$

Tekis taqsimlangan yuklanishlar ta‘sirida kvadratik plastinka markaziy nuqtasi ko‘chish va eguvchi momentlarini hisoblaymiz:

$$a=b,\quad \lambda=1,\quad \nu=0{,}3;\quad w\left(\frac{a}{2},\frac{a}{2}\right)=\frac{1}{4\pi^4}\frac{qa^4}{D}=0{,}00257\frac{qa^4}{D};$$

$$M_x\left(\frac{a}{2},\frac{a}{2}\right)=M_y\left(\frac{a}{2},\frac{a}{2}\right)=qa^2\frac{1{,}3}{4\pi^2}=0{,}0329\,qa^2.$$

Birinchi yaqinlashishda natijalarni ko‘chish va eguvchi momentlarning aniq yechimlari bilan solishtiramiz [2]:

$$w_c^{aniq}=0{,}00406\frac{qa^4}{D};\quad M_c^{aniq}=0{,}0479qa^2.$$

$$\delta w_c=\frac{0{,}00406-0{,}00257}{0{,}00406}100=32{,}4\,\%;\quad \delta M_c=\frac{0{,}0479-0{,}0329}{0{,}0479}100=31{,}3\,\%.$$

To‘g‘ri to‘rtburchakli plastinka uchun $\lambda=1{,}5$ holda hisoblashlarni bajaramiz:

$$C_{11}=1+1{,}5^2+1{,}5^4=10{,}5625;\qquad w\left(\frac{a}{2},\frac{b}{2}\right)=\frac{1}{10{,}5625\pi^4}\frac{qa^4}{D}=0{,}972\cdot10^{-3}\frac{qa^4}{D};$$

$$M_x\left(\frac{a}{2},\frac{b}{2}\right)=\frac{1+0{,}3\cdot1{,}5^2}{10{,}625\pi^2}qa^2=0{,}0160\,qa^2;\quad M_y\left(\frac{a}{2},\frac{b}{2}\right)=\frac{0{,}3+1{,}5^2}{10{,}625\pi^2}qa^2=0{,}0243\,qa^2;$$

$\lambda=1{,}5$ bu hol uchun aniq yechim quyidagiga teng [2]:

$$w_c^{aniq}\Big|_{\lambda=1{,}5}=1{,}525\cdot10^{-3}\frac{qa^4}{D};\quad M_{xc}^{aniq}\Big|_{\lambda=1{,}5}=0{,}0360qa^2;\quad M_{yc}^{aniq}\Big|_{\lambda=1{,}5}=0{,}0546qa^2.$$

Qatorning bitta hadi uchun yechim aniqligini tog‘ri to‘rtburchak plastinka $\lambda=1{,}5$ uchun baholaymiz:

$$\delta w_{c|\lambda=1{,}5}=\frac{1{,}525-0{,}972}{1{,}525}100=36\,\%;$$

$$\delta M_{xc|\lambda=1{,}5}=\frac{0{,}360-0{,}160}{0{,}360}100=55\,\%;\quad \delta M_{yc|\lambda=1{,}5}=\frac{0{,}546-0{,}243}{0{,}546}100=55\,\%.$$

Yechim aniqligi qatorning bitta hadi uchun yetarli emas. Hisoblashlarni qatorning dastlabki uchta hadi uchun plastinka markaziy kesimiga nisbatan simmetrik yuklanishlarda qaraymiz:

$$w(x,y)=A_{11}X_1(x)Y_1(y)+A_{13}X_1(x)Y_3(y)+A_{31}X_3(x)Y_1(y);$$

$$X_1(x)=\sin\pi\frac{x}{a};\ \ Y_1(y)=\sin\pi\frac{y}{b};\ \ X_3(x)=\sin 3\pi\frac{x}{a};\ \ Y_3(y)=\sin 3\pi\frac{y}{b}.$$

Toq nomerli hadlar yechimni plastinka markaziga nisbatan simmetrikligini ta‘minlaydi. Kollokatsiya nuqtalarini quyidagicha tanlaymiz:

$$1)\ x_1=\frac{a}{2},\quad y_1=\frac{b}{2};\qquad 2)\ x_2=\frac{a}{2},\quad y_2=\frac{b}{4};\qquad 3)\ x_3=\frac{a}{4},\quad y_3=\frac{b}{2}.$$

U holda: $C_{11}=1+\lambda^2+\lambda^4$; $C_{13}=1+18\lambda^2+81\lambda^4$; $C_{31}=81+18\lambda^2+\lambda^4$;

$$X_1(x_1)=X_1(x_2)=Y_1(y_1)=Y_1(y_3)=\sin\frac{\pi}{2}=1;\quad X_3(x_1)=X_3(x_2)=Y_3(y_1)=Y_3(y_3)=\sin\frac{3}{2}\pi=-1$$

;

$$X_1(x_3)=Y_1(y_3)=\sin\frac{\pi}{4}=0{,}7071;\quad X_3(x_3)=Y_3(y_2)=\sin\frac{3}{4}\pi=0{,}7071.$$

$\lambda=1$ kvadratik plastinka uchun ($C_{11}=4$, $C_{13}=C_{31}=100$) tekis taqsimlangan yuklanishlarda $q(x_1,y_1)=q(x_2,y_2)=q(x_3,y_3)=q$ tenglamalar sistemasining ikkinchi va uchinchilarini $\sin\frac{\pi}{4}=\sin\frac{3\pi}{4}=0{,}7071$ ga bo‘lib quyidagiga ega bo‘lamiz:

$$\begin{pmatrix}4 & -100 & -100\\ 4 & 100 & -100\\ 4 & -100 & 100\end{pmatrix}\begin{pmatrix}A_{1,1}\\ A_{1,3}\\ A_{3,1}\end{pmatrix}=\begin{pmatrix}1\\ 1{,}4142\\ 1{,}4142\end{pmatrix}\cdot\frac{q_2a^4}{\pi^4D}$$

Tenglamalar sistemasini yechib, koeffisientlarni aniqlaymiz:

$$A_{1,1}=3{,}63\cdot10^{-3}\frac{qa^4}{D}\ ;\quad A_{1,3}=0{,}0213\cdot10^{-3}\frac{qa^4}{D};\quad A_{3,1}=0{,}0212\cdot10^{-3}\frac{qa^4}{D}.$$

Plastinka markaziy nuqtalari ko‘chishlarini hisoblaymiz:

$$w\left(\frac{a}{2},\frac{a}{2}\right)=(A_{1,1}-A_{1,3}-A_{3,1})\frac{qa^4}{D}=(3{,}63-2\cdot0{,}0212)\cdot10^{-3}\frac{qa^4}{D}=0{,}00359\frac{qa^4}{D}.$$

yechim aniqligini baholaymiz: $\delta w_c=\frac{0{,}00406-0{,}00359}{0{,}00406}100=11{,}6\ \%$

Plastinka markazida eguvchi momentlar $\nu=0{,}3$ bo‘lgan holda quyidagicha topiladi:

$$M_x\left(\frac{a}{2},\frac{a}{2}\right)=M_y\left(\frac{a}{2},\frac{a}{2}\right)=qa^2\pi^2[(1+0{,}3)\cdot3{,}63-$$

$$-(1+0{,}3\cdot9)\cdot0{,}0212-(9+0{,}3)\cdot0{,}0212]\cdot10^{-3}=0{,}0438qa^2;$$

yechim aniqligini baholaymiz: $\delta M_c=\frac{0{,}0479-0{,}0438}{0{,}0479}100=8{,}6\ \%.$

To‘gri to‘rtburchak plastinka uchun $\lambda=1{,}5$, kollokatsiya nuqtalarini quyidagicha tanlaymiz: $x_1=\frac{a}{2}$, $y_1=\frac{b}{2}$; $x_2=\frac{a}{2}$, $y_2=\frac{b}{4}$; $x_3=\frac{a}{4}$, $y_3=\frac{b}{2}$, u holda quyidagi natijalarga ega bo‘lamiz:

$$C_{11}=1+1{,}5^2+1{,}5^4=10{,}56;\quad C_{13}=1+18\cdot1{,}5^2+81\cdot1{,}5^4=451{,}56;$$

$$C_{31}=81+18\cdot 1{,}5^2+1{,}5^4=126{,}56;$$

$$X_1(x_1)=X_1(x_2)=Y_1(y_1)=Y_1(y_3)=\sin\frac{\pi}{2}=1;$$

$$X_3(x_1)=X_3(x_2)=Y_3(y_1)=Y_3(y_3)=\sin\frac{3}{2}\pi=-1;$$

$$X_1(x_3)=Y_1(y_3)=\sin\frac{\pi}{4}=0{,}7071;\quad X_3(x_3)=Y_3(y_2)=\sin\frac{3}{4}\pi=0{,}7071.$$

$$\begin{pmatrix}10{,}56 & -451{,}56 & -125{,}56\\ 10{,}56 & 451{,}56 & -125{,}56\\ 10{,}56 & -451{,}56 & 125{,}56\end{pmatrix}\begin{pmatrix}A_{1,1}\\ A_{1,3}\\ A_{3,1}\end{pmatrix}=\begin{pmatrix}1\\ 1{,}4142\\ 1{,}4142\end{pmatrix}\cdot\frac{q_2a^4}{\pi^4 D}.$$

Tenglamalar sistemasini yechib, quyidagilarni topamiz:

$$A_{11}=1{,}374\cdot 10^{-3}\frac{q_2a^4}{D};\quad A_{13}=-0{,}00471\cdot 10^{-3}\frac{q_2a^4}{D};\ A_{31}=0{,}0169\cdot 10^{-3}\frac{q_2a^4}{D};$$

Plastinka markazida ko‘chish va eguvchi momentlarni hisoblaymiz:

$$w\left(\frac{a}{2},\frac{b}{2}\right)=(A_{1,1}-A_{1,3}-A_{3,1})\frac{qa^4}{D}=(1{,}374-0{,}00471-0{,}0169)\cdot 10^{-3}\frac{qa^4}{D}=1{,}352\frac{qa^4}{D}.$$

yechim aniqligi: $\delta w_c=\frac{1{,}525-1{,}374}{1{,}525}100=11{,}3\ \%$

Eguvchi momentlar plastinka markazida $\nu=0{,}3$ uchun quyidagicha aniqlanadi:

$$M_x\left(\frac{a}{2},\frac{b}{2}\right)=qa^2\pi^2\left[\left(1+0{,}3\cdot 1{,}5^2\right)\cdot 1{,}374-\left(1+0{,}3\cdot 1{,}5^2\cdot 9\right)\cdot 0{,}00471-\right.$$
$$\left.-\left(9+0{,}3\cdot 1{,}5^2\right)\cdot 0{,}0169\right]\cdot 10^{-3}=0{,}02105qa^2;$$
$$M_y\left(\frac{a}{2},\frac{b}{2}\right)=qa^2\pi^2\left[\left(0{,}3+1{,}5^2\right)\cdot 1{,}374-\left(0{,}3+1{,}5^2\cdot 9\right)\cdot 0{,}00471-\right.$$
$$\left.-\left(0{,}3\cdot 9+1{,}5^2\right)\cdot 0{,}0169\right]\cdot 10^{-3}=0{,}0328qa^2;$$

yechim aniqligi: $\delta M_{xc}=\frac{0{,}036-0{,}02105}{0{,}036}100=41{,}5\ \%$; $\delta M_{yc}=\frac{0{,}0546-0{,}0328}{0{,}0546}100=40\ \%$.

Qaralgan misollardan ko‘rinadiki yechimni aniqligi faqat qatorning hadlari soniga bog‘liq emas, balki plastinka tomonlari orasidagi munosabatga ham bog‘liq ekan.

Kvadratik plastinka uchun aniqlik qatorning dastlabki uchta hadi olingan hol bilan bitta had olingandagi natijalar solishtirilganda aniqlik egilishlarda va eguvchi moment son qiymatlarida uch marta oshadi. To‘g‘ri to‘rtburchak shakldagi $\lambda=1{,}5$ plastinkalarda esa bu aniqlik oshishi faqat egilishlarda kuzatiladi, eguvchi moment uchun esa o‘zgarmaydi.

Natijalar aniqligi kollokatsiya nuqtalarining tanlanishiga bog‘liqligini ko‘rsatamiz. Qatorning uchta hadi uchun kollokatsiya nuqtalarini almashtiramiz:

$$x_1=\frac{a}{2},\quad y_1=\frac{b}{2};\quad x_2=\frac{a}{2},\quad y_2=0{,}15b;\quad x_3=0{,}15a,\quad y_3=\frac{b}{2}.$$

Bu holda kvadratik plastinka uchun kollokatsiya metodini qo‘llaymiz $\lambda=1$:

$$w\left(\frac{a}{2},\frac{a}{2}\right)=0{,}00443\frac{qa^4}{D};\quad M_x\left(\frac{a}{2},\frac{a}{2}\right)=M_y\left(\frac{a}{2},\frac{a}{2}\right)=0{,}0529\,qa^2;$$

yechim aniqligi:

$$\delta w_c = \left|\frac{0{,}00406 - 0{,}00443}{0{,}00406}\right| 100 = 9{,}2\,\%;\ \delta M_c = \left|\frac{0{,}0479 - 0{,}0529}{0{,}0479}\right| 100 = 10{,}4\,\%;$$

To‘g‘ri to‘rtburchak plastinka uchun $\lambda = 1{,}5$;

$$w\left(\frac{a}{2}, \frac{b}{2}\right) = 0{,}00167\frac{qa^4}{D};\ M_x\left(\frac{a}{2}, \frac{a}{2}\right) = ,0247\,qa^2;\quad M_y\left(\frac{a}{2}, \frac{a}{2}\right) = 0{,}0397\,qa^2;$$

yechim aniqligi: $\delta w_c = \frac{1{,}525 - 1{,}67}{1{,}525} 100 = 9{,}4\ \%;$

$$\delta M_{xc} = \frac{0{,}036 - 0{,}0247}{0{,}036} 100 = 31{,}4\ \%;\quad \delta M_{yc} = \frac{0{,}0546 - 0{,}0397}{0{,}0546} 100 = 27{,}2\ \%.$$

Xulosa. Olingan natijalardan ko‘rinadiki, kvadratik plastinka uchun kollokatsiya nuqtalarini to‘g‘ri tanlash egilishlar qiymatlari aniqligini oshiradi, eguvchi momentlar aniqligini kamaytiradi. Bunda ham egilish ham momentlarning qiymatlari aniq bo‘lishi hamda mos aniq hisob qiymatlaridan kichikroq bo‘lishi lozim.

To‘gri to‘rtburchak plastinka uchun kollokatsiya nuqtalarini to‘g‘ri tanlash egilishlar qiymatlari aniqligini oshiradi, eguvchi momentlar aniqligini esa yanada oshiradi.

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