O‘ZGARUVCHAN KUCH TA’SIRIDAGI ELASTIK-PLASTIK NAZARIYASI ASOSIDA BALKANING SOF EGILISHINI MUVOZANAT TENGLAMASI VA ALGORITMINI ISHLAB CHIQISH

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ANNOTATSIYA

Bino va inshootlar qurilishida foydalaniladigan konstruksion materiallarning kuchlanganlik-deformasiyalanganlik holatlarini o‘rganish, ularning turli yo‘nalish va o‘zgaruvchan yuklanishlar ta’siridagi elastik-plastik deformasiyalanish holatlarini sonli yoki eksperemental tadqiq etish-loyihalash institutlarida hal etilishi lozim bo‘lgan eng muxim masalalardan biridir. Mazkur ish aynan ushbu vazifani hal etishga qaratilgan.

Kalit so‘zlar: chegaraviy masala, elastinka-plastinka, eksperement, kuch, bino inshootlsr.

Chegaraviy masalani yechishda o‘zgaruvchan kuch ta’siridagi elastik-plastik nazariya asosida balkaning sof egilishini muvozanat tenglamasi va algoritmini ishlab chiqish, masalaning matematik modelini qurish, chekli ayirmalar usuli haqida asosiy tushunchalar, chegaraviy masalani chekli ayirmalar va haydash usullari yordamida yechish algoritmlari keltirilgan.

Biz dissertatsiya ishida asosan balkaning sof egilishini aniqlovchi elastik-plastik nazariyalarigi asosan, o‘zgaruvchan kuch ta’siridagi algoritmini quramiz.

O‘zgaruvchan kuch ta’siridagi elastik-plastik V.V.Moskvitin nazariyasi va T.Bo‘riyevning qo‘rsatmalari umumlashgan nazariyalariga asoslangan masalani algoritmini aniqlaymiz.

Masalaning matematik modelini qurish

Yuqorida qo‘yilgan masalani matematik modelini qurish uchun Lagranjning variasion prinsipiga asosan muvozanat tenglamasinidan foydalanamiz:

$$\delta(-\Pi + A) = -\delta\Pi + \delta A \qquad (1)$$

Bu yerda

$$\delta\Pi = \int_v \sum_{i=1}^{3} \sigma_{1i}^{(k)} \cdot \varepsilon_{1i}^{(k)} dV = \int_v \sigma_{11}^{(k)} \delta\varepsilon_{11}^{(k)} \qquad (2)$$

$$\delta A = \int_v P_1 \delta V_1 dV + \int_s q_1 dV_1 ds \Big|_x \qquad (3)$$

Ifoda potensial energiyani (2) ni tashqi kuchlarni variasiyasi (3) ni muvozanat tenglamasi (1) ga qo‘yib, integrallab, variatsalab quyidagicha, belgilashlar kiritib quyidagi ko‘rinishga ega bo‘lamiz.

$$\delta\Pi = \int_v \sigma_{11}^{(k)} \delta\varepsilon_{11}^{(k)} dV = 2G \int_x \int_y \int_z \Big[(1 - \omega^{(k)}) \varepsilon_{11}^{(k)} - \omega^{(k)} \varepsilon_{11}^{0(k-1)} +$$

$$+ \sum_{m=1}^{k-1} \omega^{0(k-m)} \left(\varepsilon_{11}^{0(k-m)} - \varepsilon_{11}^{0(k-m-1)} \right) \Big] \delta\varepsilon_{11}^{(k)} dz dy dx$$

yoki

$$\delta\Pi = \int_v \sigma_{11}^{(k)} \delta\ell_{11}^{(k)} dV = 2G \int_x \int_y \int_z \Bigg[(1 - \omega^{(k)}) Z \cdot \frac{d^2 W^{(k)}}{dx^2} - \omega^{(k)} \cdot Z \frac{d^2 W^{0(k-1)}}{dx^2} +$$

$$+ \sum_{m=1}^{k-1} \omega^{0(k-m)} \left(Z \cdot \frac{d^2 \omega^{0(k-m)}}{dx^2} - Z \cdot \frac{d^2 \omega^{0(k-m-1)}}{dx^2} \right) \Bigg] \delta \left(Z \frac{d^2 W^{(k)}}{dx^2} \right) dZ dy dx =$$

$$= 2G \int_x \left[\left(\int_y \int_z Z^2 \left(1 - \omega^{(k)} \right) dZ dy \right) \right] \frac{d^2 W^{(k)}}{dx^2} \cdot \delta \frac{d^2 W^{(k)}}{dx^2} dx - 2G \int_x \left[\int_y \int_z Z^2 \omega^{(k)} dZ dy \right] \cdot \frac{d^2 W^{0(k-1)}}{dx^2} \delta \frac{d^2 W^{(k)}}{dx^2} dx +$$

$$+ 2G \int_x \sum_{m=1}^{k-1} \left[\int_y \int_z Z^2 \omega^{0(k-m)} \left(\frac{d^2 W^{0(k-m)}}{dx^2} - \frac{d^2 W^{0(k-m-1)}}{dx^2} \right) \delta \frac{d^2 W^{(k)}}{dx^2} \right] dx \qquad (4)$$

$$\left.\begin{aligned} M_y &= \int_y\int_z z^2 dz\,dy \quad M_y^{\omega(k)} = \int_y\int_z z^2\omega^{(k)} dz\,dy \\ M_y^{0(k-m)} &= \int_y\int_z \sum_{m=1}^{k-1} z^2\omega^{0(k-m)} dz\,dy \end{aligned}\right\} \quad (5)$$

(4) formulaga (5) ni olib kelib qo‘ysak quydagicha ko‘rinishga keladi

$$\delta\Pi = 2G\int_x \Bigg[\left(M_y - M_y^{\omega(k)}\right)\frac{d^2W^{(k)}}{dx^2}\delta\frac{d^2W^{(k)}}{dx^2} - M_y^{\omega(k)}\cdot\frac{d^2W^{0(k-1)}}{dx^2}\cdot\frac{d^2W^{(k)}}{dx^2} +$$
$$+M_y^{0(k-m)}\sum_{m=1}^{k-1}\left(\frac{d^2W^{0(k-m)}}{dx^2} - \frac{d^2W^{0(k-m-1)}}{dx^2}\right)\delta\frac{d^2W^{(k)}}{dx^2}\Bigg]dx \quad (6)$$

Oxirgi (6) formuladagi variasiya belgisi ostidagi hosilani (ikkinchi tartibliga) o‘tkazib, yo‘qotish uchun bo‘laklab integrallab, o‘rniga q o‘yib, quyidagi ko‘rinishga keltiriladi.

$$\delta\Pi = 2G\left(M_y - M_y^{\omega(k)}\right)\left\{\frac{d^2W^{(k)}}{dx^2}\delta\frac{dW^{(k)}}{dx}\Bigg|_x - \int_x \frac{d^3W^{(k)}}{dx^3}\delta\frac{dW^{(k)}}{dx}dx\right\} -$$
$$-2GM_y^{\omega(k)}\left\{\frac{d^2W^{0(k-1)}}{dx^2}\cdot\delta\frac{dW^{(k)}}{dx}\Bigg|_x - \int_x \frac{d^3W^{0(k-1)}}{dx^3}\delta\frac{dW^{(k)}}{dx}dx\right\} +$$
$$+2GM_y^{0(k-m)}\left\{\sum_{m=1}^{k-1}\left[\left(\frac{d^2W^{0(k-1)}}{dx^2} - \frac{d^2W^{0(k-m-1)}}{dx^2}\right)\delta\frac{dW^{(k)}}{dx}\right]_x - \right. \quad (7)$$
$$\left. -\int_x\sum_{m=1}^{k-1}\left(\frac{d^3W^{0(k-m)}}{dx^3} - \frac{d^3W^{0(k-m-1)}}{dx^3}\right)\delta\frac{dW^{(k)}}{dx}dx\right\}$$

(7) formuladan variatsiya ostidagi ifodani yana bo‘laklab integrallaymiz va quyidagi ko‘rinishga keltirib olamiz:

$$\delta\Pi=2G\left(M_y-M_y^{\omega(k)}\right)\left\{\frac{d^2W^{(k)}}{dx^2}\delta\frac{dW^{(k)}}{dx}\bigg|_x-\frac{d^3W^{(k)}}{dx^3}\delta W^{(k)}\bigg|_x\cdot\int_x\frac{d^4W^{(k)}}{dx^4}\delta W^{(k)}dx-\right.$$

$$-2GM_y^{\omega(k)}\left[\frac{d^2W^{0(k-1)}}{dx^2}\delta\frac{dW^{(k)}}{dx^2}\bigg|_x-\frac{d^3W^{0(k-1)}}{dx^3}\delta W^{(k)}\bigg|_x+\int_x\frac{d^4W^{0(k-1)}}{dx^4}\delta W^{(k)}dx\right]+$$

$$+2GM_y^{0(k-m)}\left\{\sum_{m=1}^{k-1}\left[\left(\frac{d^2W^{0(k-m)}}{dx^2}-\frac{d^2W^{0(k-m-1)}}{dx^2}\right)\delta\frac{dW^{(k)}}{dx}\bigg|_x-\right.\right. \quad (9)$$

$$\left.-\left(\frac{d^3W^{0(k-m)}}{dx^3}-\frac{d^3W^{0(k-m-1)}}{dx^3}\right)\delta W^{(k)}\right]\bigg|_x+\int_x\sum_{m=1}^{k-1}\left(\frac{d^4W^{0(k-m)}}{dx^4}-\frac{d^4W^{0(k-m-1)}}{dx^4}\right)\delta W^{(k)}dx;$$

Tashqi kuch variasiyasini xisoblashimiz kerak bo‘ladi buning uchun:
(2) formuladan

$$\delta A=\int_V p\delta Z\frac{dW}{dx}dv+\int_S q_1\delta v_1 ds\bigg|_x+\int_x\left(\int_F\int_Z q\delta z dy\right)\cdot\delta\frac{W}{dx}dx$$

$$\int_y\int_Z qz dz dy\,\delta\frac{dW}{dx}\bigg|_x=Q^T\int_x\delta\frac{dW^{(k)}}{dx}dx+Q^\Gamma\delta\frac{dW^{(k)}}{dx}= \quad (10)$$

$$=\int_x Q^T\delta W^{(k)}+Q^\Gamma\delta\frac{dW^{(k)}}{dx}\bigg|_x$$

Bu yerda

$$Q^T=\int_y\int_Z dz dy,\qquad Q^\Gamma=\int_y\int_Z q\cdot dz dy$$

(10) , (9) formulalarni (1) ga qo‘ysak quyidagi ko‘rinishga keladi:

$$-\delta\Pi+\delta A=\left[2G\left(M_y-M_y^{\omega(k)}\right)\frac{d^2W^{(k)}}{dx^2}-Q^\Gamma\right]\delta\frac{dW^{(k)}}{dx}\bigg|_x+$$

$$+2G\left(M_y-M_y^{\omega(k)}\right)\frac{d^3W^{(k)}}{dx^3}\cdot dW^{(k)}\bigg|_x-\int_x\left(2G\left(M_y-M_y^{\omega(k)}\right)\frac{d^4W^{(k)}}{dx^4}-Q^T\right)\delta W^{(k)}dx=$$

$$=-2GM_y^{(k)}\left[\frac{d^2W^{0(k-1)}}{dx^2}\delta\frac{dW^{(k)}}{dx}\bigg|_x+\frac{d^3W^{0(k-1)}}{dx^3}\delta W^{(k)}\bigg|_x-\right.$$

$$\left.-\int_x\frac{d^4W^{0(k-1)}}{dx^4}dx\delta W^{(k)}\right]-2GM_y^{0(k-m)}\int_x\left\{\sum_{m=1}^{k-1}\left(\frac{d^2W^{0(k-m)}}{dx^2}-\frac{d^2W^{0(k-m-1)}}{dx^2}\right)\cdot dx\delta\frac{dW^{(k)}}{dx}\bigg|_x+\right.$$

$$+\left(\frac{d^3W^{(k-m)}}{dx^3}-\frac{d^3W^{(k-m-1)}}{dx^3}\right)\delta W^{(k)}\Bigg]\Bigg|_x-\int_x\sum_{m=1}^{k-1}\left(\frac{d^4W^{0(k-1)}}{dx^4}-\frac{d^2W^{0(k-m-1)}}{dx^4}\right)\Bigg\}\delta W^{(k)}dx \quad (11)$$

Muvozanat tenglamasi va unga mos chegaraviy shartlardan keltirib quyidagicha chiqaramiz.

Yuqoridagi tenglamalardan foydalanib akademik T.Bo‘riyevni umumlashgan algoritmlariga asosan [6] quydagicha yozib olishimiz mumkin bo‘ladi:

$$2G\left[-\left(M_y-M_y^{\omega(k)}\right)\frac{d^4W^{(k)}}{dx^4}\delta W^{(k)}=Q^T\delta W^{(k)}+A^{0(k-1)}+B^{0(k-m)}\right. \quad (12)$$

$$2G\left(M_y-M_y^{\omega(k)}\right)\frac{d^2W^{(k)}}{dx^2}\delta\frac{dW^{(k)}}{dx^2}\Bigg|_x+2G\left(M_y-M_y^{\omega(k)}\right)\frac{d^3W}{dx^3}\delta W^{(k)}\Bigg|_x= \quad (13)$$
$$=Q^\Gamma\delta\frac{dW^{(k)}}{dx}\Bigg|_x+A^{O\Gamma(k-1)}+B^{O\Gamma(k-m)}$$

bu yerda

$$A^{0(k-1)}=-2GM_y^{(k)}\int_x\left[\frac{d^2W^{0(k-1)}}{dx^2}\right]\delta W^{(k)}dx$$

$$B^{0(k-m)}=2GM^{0(k-1)}\int_x\sum_{m=1}^{k-1}\left(\frac{d^4W^{0(k-1)}}{dx^4}-\frac{d^4W^{0(k-m-1)}}{dx^4}\right)\delta W^{(k)}dx$$

$$A^{O\Gamma(k-1)}=2GM_y^{(k)}\left[\frac{d^2W^{0(k-1)}}{dx^2}\delta\frac{dW^{(k)}}{dx}\Bigg|_x+\left[\frac{d^3W^{0(k-1)}}{dx^3}\delta W^{(k)}\Bigg|_x\right.\right. \quad (14)$$
$$B^{0\omega(k-m)}=-2GM_y^{0(k-m)}\left\{\sum_{m=1}^{k-1}\left(\frac{d^2W^{0(k-1)}}{dx^2}-\frac{d^2W^{0(k-m-1)}}{dx^2}\right)\delta\frac{dW^{(k)}}{dx}\Bigg|_x+\right.$$
$$+\left(\frac{d^3W^{0(k-m)}}{dx^3}-\frac{d^3W^{0(k-m-1)}}{dx^3}\right)\delta W^{(k)}\Bigg|_x;$$

(13) tenglamada balkaning sof egilishini elastik-plastik o‘zgaruvchan kuchlarning ta’siridagi muvozanat tenglamasining qiymatlari, chegaraviy natijalarni ifodalaydi, (13), (14) muvozanat tenglamasini va chegaraviy shartlarini quydagicha sharxlash mumkin:

$\omega=0$ bo‘lsa, u xolda (13) tenglama va unga qo‘yilgan (14) chegaraviy shart quydagicha bo‘ladi;

ya’ni $k=0$ (1.1-rasmdagi *OM* misol ko‘rinishda).

Yuqoriridagi formulamiz quyidagicha ko‘rinishga ega bo‘ladi

$$-2GM_y \frac{d^4W^{(0)}}{dx^4}\delta W^{(0)} = Q^T \delta W^{(0)} \qquad (15)$$

$$2GM_y \frac{d^2W^{(0)}}{dx^2}\delta \frac{dW^{(0)}}{dx}\bigg|_x + 2GM_y \frac{d^3W^{(0)}}{dx^3}\delta W^{(0)}\bigg|_x = Q^T \delta \frac{dW^{(0)}}{dx} \qquad (16)$$

2) Agar elastik-plastik va kuchni olishni tasvirlovchi model quydagicha bo‘lsa.

(4) formuladan $\omega \neq 0$ bo‘lsa, u xolda (12) tenglama va unga qo‘yilgan chegaraviy shart quydagicha bo‘ladi:

$$-2G\left(M_y - M_y^{\omega(k)}\right)\frac{d^4W^{(k)}}{dx}\delta W^{(k)} = Q^{\Gamma}\delta W^{(k)} + A^{0(k-1)} \qquad (17)$$

$$2G\left(M_y - M_y^{\omega(k)}\right)\frac{d^2W^{(k)}}{dx}\delta \frac{dW^{(k)}}{dx}\bigg|_x + $$

$$+2G\left(M_y - M_y^{\omega(k)}\right)\frac{d^3W^{(k)}}{dx^3}\delta W^{(k)}\bigg|_x = Q^{\Gamma}\delta \frac{dW^{(k)}}{dx}\bigg|_x + A^{0(k-1)} \qquad (18)$$

Bajarilgan ishi doirasida olib borilgan tadqiqotning maqsadi: balkaning o‘zgaruvchan kuchlar ta’siridagi kuchlanganlik- deformasiyalanganlik holatini A.A.Ilyushin va V.V.Moskvitin nazariyalariga asosan hamda T.Buriyevning ko‘rsatmalarini hisobga olgan holda muvozanat tenglamasi keltirib chiqarilgan va unga chekli ayirmalar usuli yordamida ishchi algoritm yaratilgan. Tuzilgan dasturiy ta’minot balkaning tashqi kuchlar ta’sirida kuchlanganlik holatini aniqlash uchun yaratilgan.

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