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IKKI QATLAMLI NOELASTIK PLASTINKANING KO'NDALANG TEBRANISHI UMUMIY TENGLAMASINI TAHLIL QILISH

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Annotatsiya: Ushbu maqolada "O'zgaras qalinlikdagi ikki qavatli plastinkalarning tebranishlari" nomli [1] maqoladan olingan bo'laklari bir jinsli noelastik plastinkaning ko'ndalang tebranishlari uchun umumiy tenglama tahlil qilingan. Masala yechilishini soddalashtiruvchi gipotezalarni jalb qilmasdan, aniq uch o'lchovli ko'rinishda qatlamlari bir jinsli plastinalarning tebranishi o'rganilgan, ular asosida bunday plastinkalarning tebranishlarining umumiy va taqribiy tenglamalarini olgan.

Kalit so'zlar: tahlil; taqribiy; tebranish; ikki qatlamli plastinka; chegaraviy masala; kuchlanish; deformatsiya; tebranish tenglamasi.

Kirish. Ikki qavatli va ko'p qatlamli plastinkalar qurilish va texnikaning turli sohalarida keng qo'llaniladi. Ikki qavatli, uch qatlamli va ko'p qatlamli tuzilmalardan foydalanishning ko'payishi bunday elementlarni hisoblashning samarali usullariga ehtiyoj paydo bo'lishiga yordam berdi. Shu sababli, ikki qavatli plitalardan foydalanishning boshlanishi bilan birga, hisoblash nazariyalari ham paydo bo'ldi. Shu munosabat bilan plastinkalar tebranishiga oid bir nechta tadqiqot ishlari olib borilgan. Ushbu tadqiqot ishlari ko'plab maqolalarni, shu jumladan [1] maqolani o'z ichiga oladi.

Masalaning qo'yilishi va yechish usullari. Qalinligi o'zgaras, qatlamlari bir jinsli yelimshak elastik plastinkalarning [1] da berilgan tebranishlarining umumiy tenglamalari tuzilish jihatidan murakkab va x, y koordinatalari va vaqt t bo'yicha yuqori tartibli hosilalarni o'z ichiga oladi va shuning uchun amaliy masalalarni yechish hamda muhandislik hisoblashlarni amalga oshirish uchun mos emas.

Amaliy masalalarni yechish uchun umumiy tenglamalar o'rniga, hosilalarda chekli tartibni o'z ichiga olgan taqribiy tenglamalardan foydalanish maqsadga muvofiqdir.

Plastinkaning ko'ndalang tebranishlari uchun klassik tenglamalar 4-tartibdan yuqori bo'lmagan hosilalarni o'z ichiga oladi va qatlamlari bir jinsli ikki qatlamli plastinkalar uchun eng oddiy taqribiy tebranish tenglamasi oltinchi tartibli tenglama bo'ladi.

Agar [1] da berilgan (3.8) operatorlarda dastlabki ikki had bilan cheklansak, u holda (3.11) tenglamadan

$$L_1(W_2) = F_1(x, y, t)$$

bu yerda L_1 va $F_1(x, y, t)$ operatorlar quyidagi ifodalarga teng:

$$\begin{aligned} L_1 = & (M_{1(n)}K_{2(n)} - M_{2(n)}K_{1(n)})(H_{3(n)}E_{4(n)} - H_{4(n)}E_{3(n)}) + \\ & + (M_{1(n)}K_{3(n)} - M_{3(n)}K_{1(n)})(H_{4(n)}E_{2(n)} - H_{2(n)}E_{4(n)}) + \\ & + (M_{1(n)}K_{4(n)} - M_{4(n)}K_{1(n)})(H_{2(n)}E_{3(n)} - H_{3(n)}E_{2(n)}) - \\ & - (M_{2(n)}K_{3(n)} - M_{3(n)}K_{2(n)})(H_{4(n)}E_{1(n)} - H_{1(n)}E_{4(n)}) - \\ & - (M_{2(n)}K_{4(n)} - M_{4(n)}K_{2(n)})(H_{1(n)}E_{3(n)} - H_{3(n)}E_{1(n)}) + \\ & + (M_{3(n)}K_{4(n)} - M_{4(n)}K_{3(n)})(H_{1(n)}E_{2(n)} - H_{2(n)}E_{1(n)}); \end{aligned}$$

$$\begin{aligned} F_1 = & -[K_{1(n)}(H_{2(n)}E_{3(n)} - H_{3(n)}E_{2(n)}) + K_{2(n)}(H_{3(n)}E_{1(n)} - H_{1(n)}E_{3(n)}) + \\ & + K_{3(n)}(H_{1(n)}E_{2(n)} - H_{2(n)}E_{1(n)})]\{M_0^{-1}(f_z^{(0)})\} + \\ & + [M_{1(n)}(H_{2(n)}E_{3(n)} - H_{3(n)}E_{2(n)}) + M_{2(n)}(H_{3(n)}E_{1(n)} - H_{1(n)}E_{3(n)}) + \\ & + M_{3(n)}(H_{1(n)}E_{2(n)} - H_{2(n)}E_{1(n)})]\{M_1^{-1}(\frac{\partial f_{xz}^{(0)}}{\partial x} + \frac{\partial f_{yz}^{(0)}}{\partial y})\} - \\ & - (M_{1(n)}(K_{2(n)}E_{3(n)} - K_{3(n)}E_{2(n)}) + M_{2(n)}(K_{3(n)}E_{1(n)} - K_{1(n)}E_{3(n)}) + \\ & + M_{3(n)}(K_{1(n)}E_{2(n)} - K_{2(n)}E_{1(n)})]\{M_1^{-1}(f_z^{(1)})\} + \\ & + (M_{1(n)}(K_{2(n)}H_{3(n)} - K_{3(n)}H_{2(n)}) + M_{2(n)}(K_{2(n)}H_{1(n)} - K_{1(n)}H_{2(n)}) + \\ & + M_{3(n)}(K_{1(n)}H_{2(n)} - K_{2(n)}H_{1(n)})]\{M_1^{-1}(\frac{\partial f_{xz}^{(1)}}{\partial x} + \frac{\partial f_{yz}^{(1)}}{\partial y})\}; \end{aligned}$$



quyidagi taqribiy integro-differentsial teglamani
hosil qilamiz

$$Q_1 \left(\frac{\partial^4 W}{\partial t^4} \right) + Q_2 \left(\Delta \frac{\partial^2 W}{\partial t^2} \right) + Q_3 (\Delta^2 W) + Q_4 \left(\frac{\partial^6 W}{\partial t^6} \right) + Q_5 \left(\Delta \frac{\partial^4 W}{\partial t^4} \right) + Q_6 \left(\Delta^2 \frac{\partial^2 W}{\partial t^2} \right) + Q_7 (\Delta^3 W) = F_1(x, y, t). \quad (1)$$

(1) tenglamadagi Q_j va $F_1(x, y, t)$ operatorlarni aniqlash formulalari:

$$\begin{aligned} Q_1 &= M_1^{-2} (h_0 \rho_0 + h_1 \rho_1)^2; \\ Q_2 &= -2M_1^{-2} (2(h_0 P_2 D_0 + h_1 D_1)(h_0 \rho_0 + h_1 \rho_1) + (P_2 - 1)(h_0 \rho_0 (h_0 + h_1) - (h_0^2 D_0 \rho_0 + h_1^2 D_1 \rho_1))); \\ Q_3 &= 4(P_2 - 1)(h_0^2 P_2 D_0 + h_1^2 D_1 + h_1^2 D_1 + 2h_0 h_1 P_2 D_0); \\ Q_4 &= -\frac{1}{6} M_1^{-2} (h_0^2 \rho_0 M_0^{-1} (3h_1^2 \rho_1^2 + h_0 \rho_0 (h_0 \rho_0 + 4h_1 \rho_1)) (2 - D_0) + h_1^2 \rho_1 M_1^{-1} (3h_0^2 \rho_0^2 + h_1 \rho_1 (h_1 \rho_1 + 4h_0 \rho_0)) (2 - D_1)); \\ Q_5 &= -\frac{1}{6} M_1^{-2} (h_0^2 P_2 \rho_0^2 M_0^{-2} (2P_2 (4D_0 (1 - D_0) + (P_2 - 1)(4 + D_0^2)) - h_1^4 \rho_1^2 M_1^{-2} (2(4D_1^2 - 4D_1 - 1) - (P_2 - 1)D_1 (2 - D_1)) + 6h_0^2 h_1^2 (\rho_0 \rho_1 M_0^{-1} M_1^{-1} (4(P_2^2 D_0 + D_1) + (P_2 - 1)(2P_2 (1 - D_0) - P_2 D_1 (2 - D_0) + D_1 (1 + D_0))) + M_1^{-1} (\rho_0^2 + \rho_1^2)) + 2P_2 h_0 h_1 (2\rho_0 \rho_1 M_0^{-1} M_1^{-1} (h_0^2 (2 + 4D_0 - D_0^2) + h_1^2 (2P_2 - P_2 D_1 + 5D_1 - D_1^2)) + h_0^2 h_1^2 M_0^{-2} ((P_2 - 1)(4 - 3D_0) + 2D_1 (4 - D_0)) + 2h_1^2 \rho_1^2 M_1^{-2} D_0 (4 - D_1)); \\ Q_6 &= \frac{1}{3} M_1^{-2} (h_0^2 P_2 \rho_0 M_0^{-1} (2P_2 ((P_2 - 1)(2 + 9D_0 - 3D_0^2)) - 2D_0 (1 - 3P_2 + 4D_0)) + h_1^4 \rho_1 M_1^{-1} (4D_1 (1 - 2D_1) - 4D_1 + (P_2 - 1)D_1 (3 - D_1)) + 3h_0^2 h_1^2 ((4P_2 D_0 (P_2 (1 - D_1) - D_1) - (P_2 - 1)(2(P_2 - 1)D_1 (1 - D_0) - P_2 (2 - D_0 - 2D_0 D_1))) \rho_0 M_0^{-1} + (4D_1 (1 + D_0 + P_2 D_0) - (P_2 - 1)(6D_0 D_1 (P_2 - 1) - 6P_2 D_0 + D_1)) \rho_1 M_1^{-1}) - 2h_0 h_1 P_2 (\rho_0 M_0^{-1} (2h_0^2 ((P_2 - 1)(D_0^2 - 2D_0 - 1) - 2D_1 (1 + D_0)) - h_1^2 (2(P_2 - 1) + D_1 (P_2 + 3)))) - 4\rho_1 M_1^{-1} (h_0^2 + h_1^2) (2(P_2 - 1)(1 - D_1) + P_2 D_1 + (1 + D_1)))); \\ Q_7 &= \frac{2}{3} (h_0^4 P_2 D_0 (4D_0 - 5(P_2 - 1) + h_1^4 D_1 (4D_1 - (P_2 - 1))) - 3h_0^2 h_1^2 (8P_2 D_0 D_1 - (P_2 - 1)((2(P_2 + 1)D_0 D_1 - 3P_2 D_0 - D_1 (1 - D_1))) - 4h_0 h_1 P_2 D_0 (h_0^2 (P_2 - 1) + 2D_1) + h_1^2 (2(P_2 - 1) + (P_2 + 1)D_0)); \end{aligned}$$

$$\begin{aligned} Q_6 &= \frac{1}{3} M_1^{-2} (h_0^2 P_2 \rho_0 M_0^{-1} (2P_2 ((P_2 - 1)(2 + 9D_0 - 3D_0^2)) - 2D_0 (1 - 3P_2 + 4D_0)) + h_1^4 \rho_1 M_1^{-1} (4D_1 (1 - 2D_1) - 4D_1 + (P_2 - 1)D_1 (3 - D_1)) + 3h_0^2 h_1^2 ((4P_2 D_0 (P_2 (1 - D_1) - D_1) - (P_2 - 1)(2(P_2 - 1)D_1 (1 - D_0) - P_2 (2 - D_0 - 2D_0 D_1))) \rho_0 M_0^{-1} + (4D_1 (1 + D_0 + P_2 D_0) - (P_2 - 1)(6D_0 D_1 (P_2 - 1) - 6P_2 D_0 + D_1)) \rho_1 M_1^{-1}) - 2h_0 h_1 P_2 (\rho_0 M_0^{-1} (2h_0^2 ((P_2 - 1)(D_0^2 - 2D_0 - 1) - 2D_1 (1 + D_0)) - h_1^2 (2(P_2 - 1) + D_1 (P_2 + 3)))) - 4\rho_1 M_1^{-1} (h_0^2 + h_1^2) (2(P_2 - 1)(1 - D_1) + P_2 D_1 + (1 + D_1)))); \\ Q_7 &= \frac{2}{3} (h_0^4 P_2 D_0 (4D_0 - 5(P_2 - 1) + h_1^4 D_1 (4D_1 - (P_2 - 1))) - 3h_0^2 h_1^2 (8P_2 D_0 D_1 - (P_2 - 1)((2(P_2 + 1)D_0 D_1 - 3P_2 D_0 - D_1 (1 - D_1))) - 4h_0 h_1 P_2 D_0 (h_0^2 (P_2 - 1) + 2D_1) + h_1^2 (2(P_2 - 1) + (P_2 + 1)D_0)); \end{aligned}$$

va

$$F_1(x, y, t) = M_1^{-2} \frac{\partial^2}{\partial t^2} ((h_0 \rho_0 + h_1 \rho_1)(f_z^{(0)} - f_z^{(1)})) + (h_0 + h_1)(h_1 \rho_1 \left(\frac{\partial^2 f_{xz}^{(0)}}{\partial x^2} + \frac{\partial^2 f_{yz}^{(0)}}{\partial y^2} \right) + h_0 \rho_0 \left(\frac{\partial^2 f_{xz}^{(1)}}{\partial x^2} + \frac{\partial^2 f_{yz}^{(1)}}{\partial y^2} \right)) + \quad (3)$$

$$\begin{aligned} &+ (h_0^2 D_0 \rho_0 + h_1^2 D_1 \rho_1) \left(\left(\frac{\partial^2 f_{xz}^{(0)}}{\partial x^2} + \frac{\partial^2 f_{yz}^{(0)}}{\partial y^2} \right) - \left(\frac{\partial^2 f_{xz}^{(1)}}{\partial x^2} + \frac{\partial^2 f_{yz}^{(1)}}{\partial y^2} \right) \right) - \\ &- 2\Delta (2M_1^{-2} ((h_0 P_2 D_0 + h_1 D_1)(M_0 f_z^{(0)} - M_1 f_z^{(1)})) + \\ &(3) \\ &+ 2P_2 h_0 h_1 (D_0 M_0^{-1} \left(\frac{\partial^2 f_{xz}^{(0)}}{\partial x^2} + \frac{\partial^2 f_{yz}^{(0)}}{\partial y^2} \right) + D_1 M_1^{-1} \left(\frac{\partial^2 f_{xz}^{(1)}}{\partial x^2} + \frac{\partial^2 f_{yz}^{(1)}}{\partial y^2} \right)) + \\ &+ M_1^{-1} (h_0^2 P_2 D_0 + h_1^2 D_1) \left(\frac{\partial^2 f_{xz}^{(0)}}{\partial x^2} + \frac{\partial^2 f_{yz}^{(0)}}{\partial y^2} \right) + \left(\frac{\partial^2 f_{xz}^{(1)}}{\partial x^2} + \frac{\partial^2 f_{yz}^{(1)}}{\partial y^2} \right)). \end{aligned}$$

Agar plastinka bir jinsli va W - "o'rt" sirt nuqtalarining ko'ndalang - plastinka tekisligi siljishi bo'lsa, bu holda quyidagi bog'liqliklar bajariladi.

$$N_0 = N_1; \quad M_0 = M_1; \quad P_2 = 1; \quad h_0 = h_1; \quad C_0 = C_1; \quad D_0 = D_1.$$

va (1) tenglama quyida ko'rsatilgan tenglamaga aylanadi

$$\begin{aligned} &((1 - C_0)^2 \lambda_{10}^{(1)} + (1 + C_0)^2 \Delta) ((\lambda_{20}^{(1)} + \Delta) + \\ &+ \frac{h_0^2}{6} ((3D_0 (\lambda_{20}^{(1)} + \Delta)^2) + 4D_0 \lambda_{20}^{(1)} \Delta) + 4\lambda_{10}^{(1)} (\lambda_{20}^{(1)} + \Delta)) (W) = \\ &= \frac{1}{h_0} (M_0^{-2} \frac{\partial^2}{\partial t^2} ((f_z) + h_0 \left(\frac{\partial^2 f_{xz}^{(0)}}{\partial x^2} + \frac{\partial^2 f_{yz}^{(0)}}{\partial y^2} \right)) - \\ &- 4D_0 M_0^{-1} \Delta ((f_z) + h_0 \left(\frac{\partial^2 f_{xz}^{(1)}}{\partial x^2} + \frac{\partial^2 f_{yz}^{(1)}}{\partial y^2} \right))) \quad (4) \end{aligned}$$

(4) ning chap tomonda ikkita operatorning ko'paytmasi mavjud: birinchisi bo'ylama tebranish, ikkinchisi esa - ko'ndalang tebranish jarayonlarini tavsiflaydi.

Xuddi shunday, [1] da berilgan (1.3.12)

umumiy tenglamadan $\left(\frac{\partial U_1}{\partial y} - \frac{\partial V_1}{\partial x} \right)$ uchun taxminiy tenglama keltirib chiqariladi va uning ko'rinishi (5) orqali ifodalangan integro - differentsial tenglama bo'ladi

$$\begin{aligned} &(G_1 \frac{\partial}{\partial t^2} + G_2 \Delta + G_3 \frac{\partial^4}{\partial t^4} + G_4 \Delta \frac{\partial^2}{\partial t^2} + G_5 \Delta^2 + G_6 \frac{\partial^6}{\partial t^6} + \\ &+ G_7 \Delta + G_8 \Delta^2 + G_9 \Delta^3) \left(\frac{\partial U_1}{\partial y} - \frac{\partial V_1}{\partial x} \right) = F_2(x, y, t), \quad (5) \end{aligned}$$



bu yerda G_j va $F_2(x, y, t)$ operatorlar quyidagi formulalar orqali aniqlanadi:

$$\begin{aligned} G_1 &= M_1^{-1}(h_0\rho_0 + h_1\rho_1); \\ G_2 &= -(h_0P_2 + h_1); \\ G_3 &= \frac{1}{6}M_1^{-2}(h_0^2(h_0\rho_0 + 3h_1\rho_1)\rho_0M_0^{-1} + h_1^2(h_1\rho_1 + 3h_0\rho_0)\rho_1M_1^{-1}); \\ G_4 &= -\frac{1}{6}(h_0^2(2P_2h_0\rho_0M_0^{-1} + 3h_1(\rho_0M_0^{-1} + \rho_1M_1^{-1})) + h_1^2(2h_0\rho_1M_1^{-1} + 3P_2h_0(\rho_0M_0^{-1} + \rho_1M_1^{-1}))); \\ G_5 &= \frac{1}{6}M_1^{-2}(h_0^2(P_2h_0 + 3h_1) + h_1^2(h_1 + 3P_2h_0)); \\ G_6 &= \frac{1}{120}(h_0^5P_2\rho_0^2M_0^{-2}(10\rho_1M_1^{-1} + \rho_0M_0^{-1}) + h_1^5\rho_1M_1^{-1}(10\rho_0M_0^{-1} + \rho_1M_1^{-1}) + \\ &+ 5h_0h_1\rho_0\rho_1M_0^{-1}M_1^{-1}(h_0^3\rho_0M_0^{-1}(3-3D_0-D_0^2) - h_1^3P_2\rho_1M_1^{-1}(3-3D_1-D_1^2))); \\ G_7 &= \frac{1}{120}(-13(h_0^5P_2\rho_0^2M_0^{-2} + h_1^5\rho_1^2M_1^{-2}) + 20(h_0^5P_2 + h_1^5)\rho_0\rho_1M_0^{-1}M_1^{-1} - \\ &- 5h_0h_1(h_0^3\rho_0M_0^{-1}((3-3D_0-D_0^2)\rho_0M_0^{-1} - (D_0-4)\rho_1M_1^{-1}) + \\ &+ h_1^3P_2\rho_1M_1^{-1}((3-3D_1-D_1^2)\rho_1M_1^{-1} - (D_0-4)\rho_1M_1^{-1}\rho_0M_0^{-1}))); \\ G_8 &= \frac{1}{120}(23(h_0^5P_2\rho_0^2M_0^{-1} + h_1^5\rho_1^2M_1^{-2}) + 10(h_0^5P_2\rho_1M_1^{-1} + h_1^5\rho_0M_0^{-1}) + \\ &+ 5h_0h_1(h_0^3(\rho_1M_1^{-1} - (D_0-4)\rho_0M_0^{-1}) + h_1^4(\rho_0M_0^{-1} - (D_1-4)\rho_1M_1^{-1}))); \\ G_9 &= \frac{1}{120}(-24(h_0^5P_2\rho_0^2M_0^{-2} + h_1^5\rho_1^2M_1^{-2}) + 6(h_0^5P_2 + h_1^5)\rho_0\rho_1M_0^{-1}M_1^{-1} - \\ &- 6h_0h_1(h_0^3\rho_0M_0^{-1}((1-3D_0-D_0^2)\rho_0M_0^{-1} - (D_0-2)\rho_1M_1^{-1}) + \\ &+ h_1^3P_2\rho_1M_1^{-1}((3-D_1-D_1^2)\rho_1M_1^{-1} - (D_0-2)\rho_1M_1^{-1}\rho_0M_0^{-1}))); \end{aligned}$$

va

$$\begin{aligned} F_2(x, y, t) &= P_2(N_0^{-1}(\frac{\partial^2 f_{xz}^{(0)}}{\partial x^2} - \frac{\partial^2 f_{yz}^{(0)}}{\partial y^2}) + N_1^{-1}(\frac{\partial^2 f_{xz}^{(1)}}{\partial x^2} - \frac{\partial^2 f_{yz}^{(1)}}{\partial y^2})) + \\ &+ \frac{1}{2}(P_2h_1\rho_1M_1^{-1}(N_0^{-1}(\frac{\partial^2 f_{xz}^{(0)}}{\partial x^2} - \frac{\partial^2 f_{yz}^{(0)}}{\partial y^2}) - h_0^2\rho_0M_0^{-1}(N_1^{-1}(\frac{\partial^2 f_{xz}^{(1)}}{\partial x^2} - \frac{\partial^2 f_{yz}^{(1)}}{\partial y^2})))\frac{\partial^2}{\partial t^2} - \\ &- \frac{1}{2}(P_2h_1(N_0^{-1}(\frac{\partial^2 f_{xz}^{(0)}}{\partial x^2} - \frac{\partial^2 f_{yz}^{(0)}}{\partial y^2}) - h_0^2(N_1^{-1}(\frac{\partial^2 f_{xz}^{(1)}}{\partial x^2} - \frac{\partial^2 f_{yz}^{(1)}}{\partial y^2})))\frac{\partial^2}{\partial x^2}. \end{aligned}$$

(1) - tenglama taqribiy bo'lishiga qaramay, u juda murakkab. (2) - operatorlar qatlamlari bir jinsli qalinligi doimiy ikki qatlamli plastinka materialining mexanik va reologik xususiyatlarini va uning geometrik o'lchamlarini tavsiflovchi barcha parametrlar va operatorlarni o'z ichiga oladi.

(1) - taqribiy tenglama tebranish masalalarini hal qilishda alohida hollarda soddalashadi. Masalan, (2) - operatorlar platinkaning ikkala qatlamlar uchun Puasson koeffitsiyentlari doimiy va ularning qalinligi teng bo'lganda hamda boshqa hollarda ancha soddalashdi.

Masalan, agar $h_0 = h_1$ va $\nu_0 = \nu_1$ bo'lsa,

(6) dagi operatorlar Q_j quyidagi ko'rinishga ega bo'ladi:

$$\begin{aligned} Q_1 &= M_1^{-2}h_0^2(\rho_0 + \rho_1)^2; \\ Q_2 &= -2M_1^{-2}h_0^2(2D_0(P_2+1)(\rho_0 + \rho_1) + (P_2+1)(2\rho_0 - D_0(\rho_0 - \rho_1))); \\ Q_3 &= 4(P_2-1)h_0^2D_0(3P_2+1); \\ Q_4 &= -\frac{1}{6}M_1^{-2}h_0^4(2-D_0)(\rho_0M_0^{-1}(3\rho_1^2 + \rho_0(\rho_0+4\rho_1)) + \rho_1M_1^{-1}(3\rho_0^2 + \rho_1(\rho_1+4\rho_0))); \\ Q_5 &= -\frac{1}{6}h_0^4(P_2\rho_0^2M_0^{-2}(4D_0(4-D_0) + P_2(8D_0(1-D_0) + 5) + \\ &+ (P_2-1)(12-6D_0+D_0^2)) + 2\rho_0\rho_1M_0^{-1}M_1^{-1}(2(6D_0+P_2(2+5D_0) + \\ &+ P_2(2+9D_0-D_0^2)) + (P_2-1)P_2(2-3D_0+D_0^2) + D_0(1+D_0)) + \\ &+ \rho_1^2M_1^{-2}(8(1+D_0-D_0^2) + 4P_2D_0(4-D_0) + (P_2-1)D_0(2-D_0))); \\ Q_6 &= \frac{1}{3}h_0^2(\rho_0M_0^{-1}(4P_2D_0(2+5P_2-3D_0(P_2-1)) + (P_2-1)(P_2(20-8D_0-13D_0^2) + \\ &+ 6D_0(1-D_0))) + \rho_1M_1^{-1}D_0(4(4+D_0) + 4P_2(4+2P_2+5D_0) + \\ &+ 17(P_2-1)(D_0+2P_2(1-D_0)))); \\ Q_7 &= \frac{4}{3}h_0^4D_0(D_0(4-15P_2-5P_0^2) + (P_2-1)(1-13P_2)); \end{aligned}$$

(1) tenglamadagi oltinchi tartibli operator, agar plastinka elastik va Q_j koeffitsiyentlar

$$Q_2 \cdot Q_4 \cdot Q_7 = Q_1 \cdot Q_5 \cdot Q_7 + Q_3 \cdot Q_4 \cdot Q_6$$

ifoda bilan o'zaro bog'liqlikga ega bo'lsa, ikkinchi va to'rtinchi tartibli operatorlarning ko'paytmalari sifatida ifodalash mumkin.

Agar, Q_j va A_j operatorlar

$$\begin{aligned} Q_1 &= A_1A_2; \quad Q_2 = A_1A_4 + A_2A_3; \quad Q_3 = A_2A_4; \\ Q_4 &= A_1A_5; \quad Q_5 = A_2A_5; \quad Q_6 = A_1A_6; \quad Q_7 = A_2A_6; \end{aligned}$$

bog'liqliklarga ega bo'lsa, u holda ikki qatlamli elastik plastinkaning tashkil etuvchilarining berilgan qiymatlarida (7) ifoda h_2/h_1 ga nisbatan 10-chi tartibli algebraik tenglamani beradi, bunda (1) dagi oltinchi tartibli operatorni nisbatan past tartibli operatorlar ko'paytmasi ko'rinishida quyidagicha yozish mumkin



$$\left(A_1 \frac{\partial^2}{\partial t^2} + A_2 \frac{\partial^2}{\partial x^2} \right) \cdot \left(A_3 \frac{\partial^2}{\partial t^2} + A_4 \frac{\partial^2}{\partial x^2} + A_5 \frac{\partial^4}{\partial t^4} + A_1 \frac{\partial^4}{\partial x^4} \right) (W) = 0$$

XULOSALAR

1. Hech qanday farazlarni jalb qilmasdan, aniq uch o'lovchi ko'rinishda bo'lak-bo'lakli bir jinsli plastinalarning tebranishlarini o'rganish, plastiklarning tebranishlarining umumiy va ular asosida taqribiy tenglamalarini hosil qilish imkonini beradi.

2. Ikki qatlamli plastinkaning tebranishlari uchun eng oddiy taqribiy tenglama uning bo'ylama-ko'ndalang tebranishini tavsiflovchi hosilalar uchun oltinchi tartibli differensial tenglama ekanligi ko'rsatilgan.

3. Elastik ikki qatlamli plastinka uchun oltinchi tartib operator, agar plastinka qatlamlarining komponentlari ushbu komponentlarni o'z ichiga olgan keltirib chiqarilgan tenglamani qanoatlantirsa, ikkinchi tartibli - bo'ylama va to'rtinchi tartibli - ko'ndalang tebranish operatorlariga ajraladi.

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