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QO‘QON UNIVERSITETI XABARNOMASI

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TRANSVERSAL IZOTROP JISM UCHUN IKKI O‘LCHOVLI TERMOELASTIK BOG‘LIQ MASALANI SONLI MODELLASHTIRISH VA UNING DASTURIY TA'MINOTI

Nafasov G‘anisher Abdurashidovich,
Guliston davlat universiteti “Matematika” kafedrasi dosenti,
Pedagogika fanlari bo‘yicha falsafa doktori (PhD)
E-mail: gnafasov87@gmail.com
Tel: +998976348787
Abduraimov Dostonbek Egamnazar o‘g‘li,
Guliston davlat universiteti “Amaliy matematika va axborot, texnologiyalari” kafedraci katta o‘qituvchisi
E-mail: abduraimov.dostonbek@mail.ru
Tel: +998946723690
Nizomiy nomidagi TDPU professori, p.f.d. B.S.Abdullaeva taqrizi asosida

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АННОТАЦИЯ

Ushbu maqolada transversal izotrop jism uchun ikki o‘lchovli termoelastik bog‘liq masalani sonli modellashtirish va uning dasturiy ta'minoti mazmuni bayon etlgan hamda tajribasinov asosida olingan natijalarning samaradorlik darajasi anqlangan.

Kirish. Ayni damda ko‘pgina ishlab chiqarish sohalarida kompozision materiallardan foydalanish zamon talabiga aylanib bormoqda. Konstruksiyalar va ular elementlarining termoelastik holatlarini matematik modellashtirish va sonli yechimlarini aniqlash dolzarb muammolaridandir. Kompozitsion materiallarni matematik modellash-tirishda material bir jinsli va anizotrop material bilan almashtiriladi. Termoelastik masalalar qo‘yilishiga qarab bog‘liq va bog‘liq bo‘lmagan chegaraviy masalalarga ajraladi. Umumiy holda bog‘liq masalada qattiq jismning harakat tenglamalari issiqlik o‘tkazuvchanlik tenglamalari bilan birgalikda qaraladi. Bog‘liq masalalarni matematik modellarini va ularni sonli yechish algoritmlarini o‘rganish, olingan sonli natijalarga asosan yangidan-yangi kompozision materiallarni taklif etish samolyotsozlik, raketasozlik, mashinasozlik, avtomobilsozlik, qurilish, medisina va ishlab chiqarishning ko‘plab boshqa sohalarida katta foyda keltiradi.

Tadqiqot metodologiyasi. Quyida transversal izotrop jismlar uchun termoelastik masalaning dinamik bog‘liqligining matematik modeli va bu modelni sonli yechish qaraladi. Transversal izotrop jismlar uchun bog‘liq dinamik masalaning ikki o‘lchovli holda harakat tenglamalari quyidagicha:

$$C_{1111}\frac{\partial^2 u}{\partial x^2}+(C_{1122}+C_{1212})\frac{\partial^2 v}{\partial x\,\partial y}+C_{1212}\frac{\partial^2 u}{\partial y^2}-\beta_{11}\frac{\partial T}{\partial x}+X_1=\rho\frac{\partial^2 u}{\partial t^2} \quad (1)$$

$$C_{1212}\frac{\partial^2 v}{\partial x^2}+(C_{1212}+C_{2211})\frac{\partial^2 u}{\partial x\,\partial y}+C_{2222}\frac{\partial^2 v}{\partial y^2}-\beta_{22}\frac{\partial T}{\partial y}+X_2=\rho\frac{\partial^2 v}{\partial t^2} \quad (2)$$

Transversal izotrop jismlar uchun issiqlik tarqalishi tenglamasi:

$$\lambda_{11}\frac{\partial^2 T}{\partial x^2}+\lambda_{22}\frac{\partial^2 T}{\partial y^2}-c_\varepsilon\frac{\partial T}{\partial t}-T\left(\beta_{11}\frac{\partial^2 u}{\partial x\,\partial t}+\beta_{22}\frac{\partial^2 v}{\partial y\,\partial t}\right)=0 \quad (3)$$

(3) bu tenglama uchun boshlang‘ich shartlar quyidagicha

$$u(x,y,t)\big|_{t=0}=\varphi_1,\ \frac{\partial u}{\partial t}\Big|_{t=0}=\psi_1,\ v(x,y,t)\big|_{t=0}=\varphi_2,\ \frac{\partial v}{\partial t}\Big|_{t=0}=\psi_2,\ T(x,y,t)\big|_{t=0}=T_0 \quad (4)$$

va chegaraviy shartlar quyidagicha bo‘ladi

$$u(x,y,t)\big|_{x=0}=u_0;\quad u(x,y,t)\big|_{x=\ell_1}=\overline{u}_0;\quad u(x,y,t)\big|_{y=0}=u'_0;\quad u(x,y,t)\big|_{y=\ell_2}=\overline{u}'_0$$

$$v(x,y,t)\big|_{x=0} = v_0; \quad v(x,y,t)\big|_{x=\ell 1} = \overline{v}_0 \; ; \; v(x,y,t)\big|_{y=0} = v_0' \; ; \quad v(x,y,t)\big|_{y=\ell_2} = \overline{v}_0' \tag{5}$$

$$T(x,y,t)\big|_{x=0} = T_1(t); \; T(x,y,t)\big|_{x=\ell 1} = T_2(t); \; T(x,y,t)\big|_{y=0} = T_1'(t); \quad T(x,y,t)\big|_{y=\ell_2} = T_2'(t)$$

Bu yerda: σ_{ij} - kuchlar tenzori, X_i - xajmiy kuchlar, C_{ijkl} - jismni xarakterlovchi parametrlari, ε_{ij} - deformatsiya tenzori, β_{ij} - xajmiy issiqlik kengayishi koeffisenti, δ_{ij} - kroner simvoli, bunda; $\delta_{ij} = \begin{cases} 1 & , \; i = j \\ 0 & , \; i \neq j \end{cases}$ c_ε - doimiy temperaturada issiqlik sig‘im β_{ij} - issiqlik kengayish tenzori, λ_{ij} - issiqlik quyumi tenzori va Koshi munosabati, $\dot{O}$ - tempratura, ρ - zichligi, $t \geq 0, \quad 0 \leq x \leq l_1, \quad 0 \leq y \leq l_2$ да 3та: $x = ih_1, (i = \overline{0,\mathrm{k}}), y = jh_2 \; (j = \overline{0,\mathrm{k}}), \; t = n\tau \quad (\mathrm{n} = 0,1,2,\ldots)$ prallel to‘g‘ri chiziqlar oilasini qurib (1)-(3) tenglamalarni turli munosabatlarda ularning xosilalariga almashtiramiz.

$$C_{1111}\frac{u_{i+1,j}^n - 2u_{i,j}^n + u_{i-1,j}^n}{h_1^2} + (C_{1122} + C_{1212})\frac{v_{i+1,j+1}^n - v_{i-1,j+1}^n - v_{i+1,j-1}^n + v_{i-1,j-1}^n}{4h_1h_2} +$$
$$+ C_{1212}\frac{u_{i,j+1}^n - 2u_{i,j}^n + u_{i,j-1}^n}{h_2^2} - \beta_{11}\frac{T_{i+1,j}^n - T_{i-1,j}^n}{2h_1} = \rho\frac{u_{i,j}^{n+1} - 2u_{i,j}^n + u_{i,j}^{n-1}}{\tau^2} \tag{6}$$

$$C_{2222}\frac{v_{i,j+1}^n + 2v_{i,j}^n + v_{i,j-1}^n}{h_2^2} + (C_{1212} + C_{2211})\frac{u_{i+1,j+1}^n - u_{i-1,j+1}^n - u_{i+1,j-1}^n + u_{i-1,j-1}^n}{4h_1h_2} +$$
$$+ C_{1212}\frac{v_{i+1,j}^n - 2v_{i,j}^n + v_{i-1,j}^n}{h_1^2} - \beta_{22}\frac{T_{i,j-1}^n - T_{i,j-1}^n}{2h_2} = \rho\frac{v_{i,j}^{n+1} - 2v_{i,j}^n + v_{i,j}^{n+1}}{\tau^2} \tag{7}$$

$$\lambda_{11}\frac{T_{i+1,j}^n - 2T_{i,j}^n + T_{i-1,j}^n}{h_1^2} + \lambda_{22}\frac{T_{i,j+1}^n - 2T_{i,j}^n + T_{i,j-1}^n}{h_2^2} - c_\varepsilon\frac{T_{i,j}^{n+1} - T_{i,j}^n}{\tau} -$$
$$- T_0\left(\beta_{11}\frac{u_{i+1,j}^{n+1} - u_{i-1,j}^{n+1} - u_{i+1,j}^{n-1} + u_{i-1,j}^{n-1}}{4h_1\tau} + \beta_{22}\frac{v_{i,j+1}^{n+1} - v_{i,j-1}^{n+1} - v_{i,j+1}^{n-1} + v_{i,j-1}^{n-1}}{4h_2\tau}\right) = 0 \tag{8}$$

Yuqoridagi (6)-(7) va (8) - tenglamalardan $u_{i,j}^{n+1}, v_{i,j}^{n+1}, T_{i,j}^{n+1}$ larni topamiz.

$$u_{i,j}^{n+1} = \frac{\tau^2}{\rho}\left(C_{1111}\frac{u_{i+1,j}^n - 2u_{i,j}^n + u_{i-1,j}^n}{h_1^2} + (C_{1122} + C_{1212})\frac{v_{i+1,j+1}^n - v_{i-1,j+1}^n - v_{i+1,j-1}^n + v_{i-1,j-1}^n}{4h_1h_2} +\right.$$
$$\left. + C_{1212}\frac{u_{i,j+1}^n - 2u_{i,j}^n + u_{i,j-1}^n}{h_2^2} - \beta_{11}\frac{T_{i+1,j}^n - T_{i-1,j}^n}{2h_1}\right) + 2u_{i,j}^n - u_{i,j}^{n-1} \tag{9}$$

$$v_{i,j}^{n+1}=\frac{\tau^2}{\rho}(C_{2222}\frac{v_{i,j+1}^n+2v_{i,j}^n+v_{i,j-1}^n}{h_2^2}+\left(C_{1212}+C_{2211}\right)\frac{u_{i+1,j+1}^n-u_{i-1,j+1}^n-u_{i+1,j-1}^n+u_{i-1,j-1}^n}{4h_1h_2}+$$

$$+C_{1212}\frac{v_{i+1,j}^n-2v_{i,j}^n+v_{i-1,j}^n}{h_1^2}-\beta_{22}\frac{T_{i,j-1}^n-T_{i,j-1}^n}{2h_2})+2v_{i,j}^n-v_{i,j}^{n+1} \quad (10)$$

$$T_{i,j}^{n+1}=\frac{\tau}{c_\varepsilon}(\lambda_{11}\frac{T_{i+1,j}^n-2T_{i,j}^n+T_{i-1,j}^n}{h_1^2}+\lambda_{22}\frac{T_{i,j+1}^n-2T_{i,j}^n+T_{i,j-1}^n}{h_2^2}-$$

$$-T_0(\beta_{11}\frac{u_{i+1,j}^{n+1}-u_{i-1,j}^{n+1}-u_{i+1,j}^{n-1}+u_{i-1,j}^{n-1}}{4h_1\tau}+\beta_{22}\frac{v_{i,j+1}^{n+1}-v_{i,j-1}^{n+1}-v_{i,j+1}^{n-1}+v_{i,j-1}^{n-1}}{4h_2\tau}))+T_{i,j}^n \quad (11)$$

(9)-(11) tenglamalar t^{n+1} qatlamda $u(x,y,t)$, $v(x,y,t)$, $T(x,y,t)$ funksiyalarning qiymatlarini topishga imkon beradi, agar oldingi 2 ta qatlamning qiymati ma'lum bo‘lsa, 2 ta boshlang‘ich qatlamlardagi $(\mathrm{n}=0 \quad \text{âà} \quad n=1)$ boshlang‘ich shartlardan $u(x,y,t)$ va $v(x,y,t)$ funksiyalarning qiymatini topamiz, $T(x,y,t)$ funksiyaning qiymatini esa 1-qatlamda (11) munosabatdagi aralash xosilani boshqa munosabatga almashtirish orqali topamiz.

$$u_{i,j}^1=\frac{\tau^2}{\rho}(C_{1111}\frac{u_{i+1,j}^0-2u_{i,j}^0+u_{i-1,j}^0}{h_1^2}+\left(C_{1122}+C_{1212}\right)\frac{v_{i+1,j+1}^0-v_{i-1,j+1}^0-v_{i+1,j-1}^0+v_{i-1,j-1}^0}{4h_1h_2}+$$

$$+C_{1212}\frac{u_{i,j+1}^0-2u_{i,j}^0+u_{i,j-1}^0}{h_2^2}-\beta_{11}\frac{T_{i+1,j}^0-T_{i-1,j}^0}{2h_1})+2u_{i,j}^0-u_{i,j}^{-1} \quad (12)$$

$$v_{i,j}^1=\frac{\tau^2}{\rho}(C_{2222}\frac{v_{i,j+1}^0+2v_{i,j}^0+v_{i,j-1}^0}{h_2^2}+\left(C_{1212}+C_{2211}\right)\frac{u_{i+1,j+1}^0-u_{i-1,j+1}^0-u_{i+1,j-1}^0+u_{i-1,j-1}^0}{4h_1h_2}+$$

$$+C_{1212}\frac{v_{i+1,j}^0-2v_{i,j}^0+v_{i-1,j}^0}{h_1^2}-\beta_{22}\frac{T_{i,j-1}^0-T_{i,j-1}^0}{2h_2})+2v_{i,j}^0-v_{i,j}^1 \quad (13)$$

$$T_{i,j}^1=\frac{\tau}{c_\varepsilon}(\lambda_{11}\frac{T_{i+1,j}^0-2T_{i,j}^0+T_{i-1,j}^0}{h_1^2}+\lambda_{22}\frac{T_{i,j+1}^0-2T_{i,j}^0+T_{i,j-1}^0}{h_2^2}-$$

$$-T_0(\beta_{11}\frac{u_{i+1,j}^1-u_{i-1,j}^1-u_{i+1,j}^{-1}+u_{i-1,j}^{-1}}{4h_1\tau}+\beta_{22}\frac{v_{i,j+1}^1-v_{i,j-1}^1-v_{i,j+1}^{-1}+v_{i,j-1}^{-1}}{4h_2\tau}))+T_{i,j}^0 \quad (14)$$

(6) tenglamani quyidagi ko‘rinishda yozish mumkin:

$$a_iu_{i+1,j}^{n+1}+b_iu_{i,j}^{n+1}+c_iu_{i-1,j}^{n+1}=f_i \quad (15)$$

$$a_i=\frac{C_{1111}}{h_1^2} \quad b_i=-2(\frac{C_{1111}}{h_1^2}+\frac{\rho}{\tau^2}) \quad c_i=\frac{C_{1111}}{h_1^2}$$

бунда , , ва

$$f_i=\rho\frac{-2u_{i,j}^n+u_{i,j}^{n-1}}{\tau^2}-\left(C_{1122}+C_{1212}\right)\frac{v_{i+1,j+1}^n-v_{i-1,j+1}^n-v_{i+1,j-1}^n+v_{i-1,j-1}^n}{4h_1h_2}-$$

$$-C_{1212}\frac{u_{i,j+1}^n-2u_{i,j}^n+u_{i,j-1}^n}{h_2^2}+\beta_{11}\frac{T_{i+1,j}^n-T_{i-1,j}^n}{2h_1}$$

(7)- tenglamani quyidagi ko‘rinishda yozish mumkin:

$$a_iv_{i+1,j}^{n+1}+b_iv_{i,j}^{n+1}+c_iv_{i-1,j}^{n+1}=f_i \quad (16)$$

$$a_i=\frac{C_{1111}}{h_1^2} \quad b_i=-2(\frac{C_{1111}}{h_1^2}+\frac{\rho}{\tau^2}) \quad c_i=\frac{C_{1111}}{h_1^2}$$

Bunda , , va

$$f_i = \rho \frac{2v_{i,j}^n + v_{i,j}^{n-1}}{\tau^2} - (C_{1122} + C_{1212}) \frac{u_{i+1,j+1}^n - u_{i-1,j+1}^n - u_{i+1,j-1}^n + u_{i-1,j-1}^n}{4h_1 h_2} +$$

$$+C_{1212} \frac{v_{i+1,j}^n - 2v_{i,j}^n + v_{i-1,j}^n}{h_2^2} + \beta_{22} \frac{T_{i,j-1}^n - T_{i,j-1}^n}{2h_1}$$

(8)- tenglamani esa quyidagi ko‘rinishda yozish mumkin:

$$a_i T_{i+1,j}^{n+1} + b_i T_{i,j}^{n+1} + c_i T_{i-1,j}^{n+1} = f_i \quad (17)$$

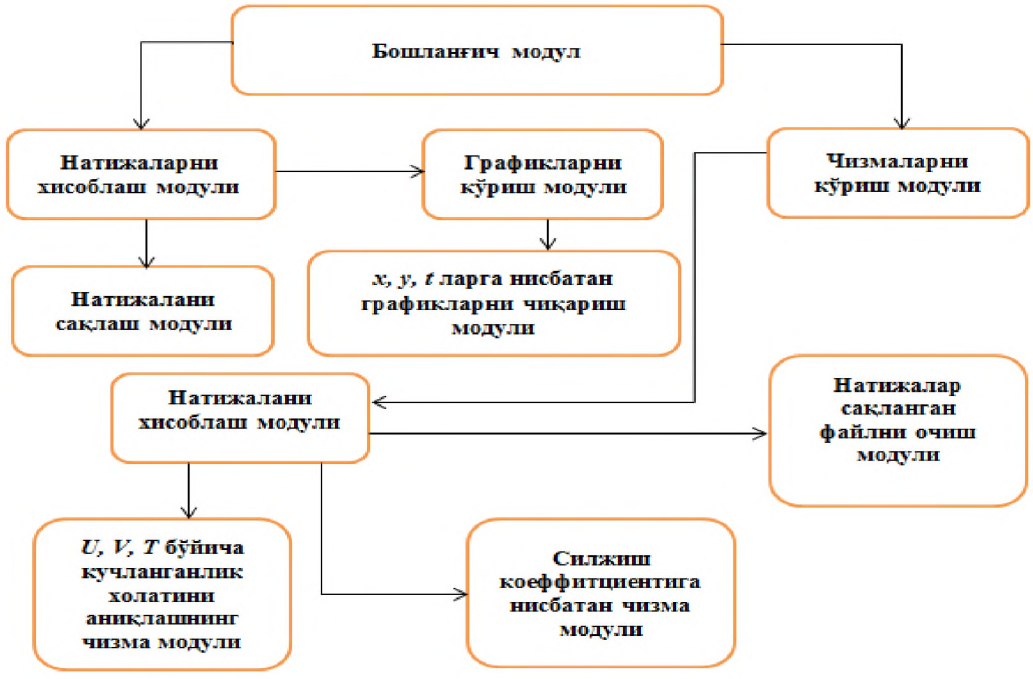
Bunda $a_i = \frac{\lambda_0}{h_1^2}$, $b_i = -\frac{2\lambda_0}{h_1^2} - \frac{C_\varepsilon}{\tau}$, $c_i = \frac{\lambda_0}{h_1^2}$ va

$$f_i = \lambda_{22} \frac{T_{i,j+1}^n - 2T_{i,j}^n + T_{i,j-1}^n}{h_2^2} - \lambda_{11} \frac{T_{i+1,j}^n - 2T_{i,j}^n + T_{i-1,j}^n}{h_1^2} - T_0 \left(\beta_{11} \frac{u_{i+1,j}^{n+1} - u_{i-1,j}^{n+1} - u_{i+1,j}^{n-1} + u_{i-1,j}^{n-1}}{4h_1 \tau} + \right.$$

$$\left. + \beta_{22} \frac{v_{i,j+1}^{n+1} - v_{i,j-1}^{n+1} - v_{i,j+1}^{n-1} + v_{i,j-1}^{n-1}}{4h_2 \tau} \right) - C_\varepsilon \frac{T_{i,j}^{n+1} - T_{i,j}^n}{\tau}$$

(15)-tenglamani $u(x,y,t)\big|_{x=\ell_1} = u_0$, $u(x,y,t)\big|_{x=\ell_1} = \bar{u}_0$ chegaraviy shartlar bilan, (16)-tenglamani $v(x,y,t)\big|_{x=0} = v_0$, $v(x,y,t)\big|_{x=\ell_1} = \bar{v}_0$ chegaraviy shartlar bilan (17)-tenglamani $T(x,y,t)\big|_{x=0} = T_1(t)$, $T(x,y,t)\big|_{x=0} = T_2(t)$ chegaraviy shartlar bilan birga, to‘rlar metodi bilan yechilgan.

Tahlil va natijalar. Transversal izotrop jism uchun ikki o‘lchovli termoelastik bog‘liq masalani sonli yechishning dasturiy ta'minotini yaratishda C++ Builder 6 dasturlash tilidan foydalanilgan.



1-rasm. Dasturning tuzilish strukturasi

Kiritiluvchi konstantalar: Lyambda11, Lyambda22 - Issiqlik quyumi tenzorlari; Betta11, Betta22 - Birinchi va ikkinchi harakat tenglamasidagi hajmiy issiqlik kengayishi koeffisientlari; C1111, C1122, C1212, C2222 - jismni xarakterlovchi parametrlari; Ro – Jism zichligi; Ce – Doimiy tempraturadagi issiqlik sig‘imi; T0 –Jismga qo‘yiladigan tempraturasi; h1 - X o‘qi bo‘yicha tugun nuqtalar orasidagi balandlik.h2 - Y o‘qi bo‘yicha tugun nuqtalar orasidagi balandlik; tao - Qalamlarning vaqt oralig‘i; n - Qadamlar soni.

Lyambda11 - 0.5, Lyambda22 - 0.3, Betta11 - 0.05, Betta22 – 0.09, C1111 – 0.75, C1122 – 0.91, C1212 – 0.9, C2222 – 0.89, Ro – 1.1, Ce – 3.4, T0 – 5, h1 – 0.1, h2 – 0.1, tao – 0.01, n – 10.

U,V,T larning ikki o‘lchovli kvadrat plastinadagi o‘zgarish xolatini quyidagicha ko‘rishimiz mumkin.Bunda kiritilgan o‘zgarmas sonlar asosida quyidagi natijalarni olamiz:

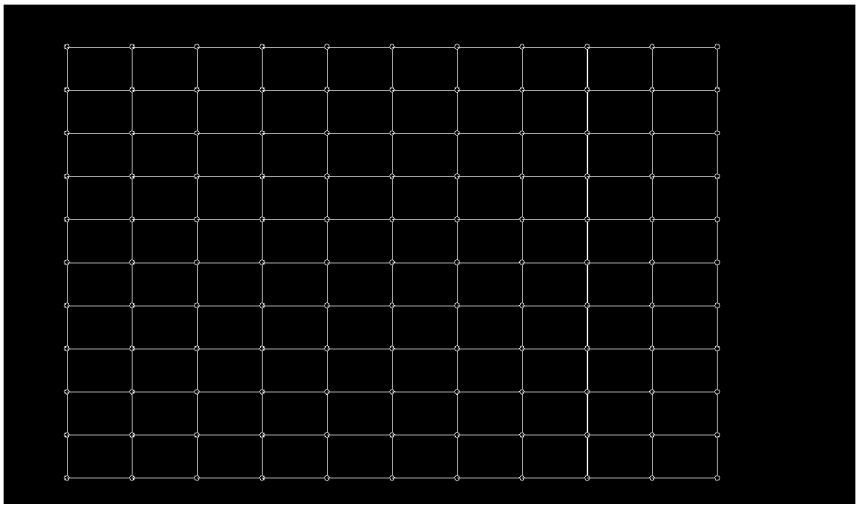
ANIQ YECHIM										
0	0	0	0	0	0	0	0	0	0	0
0	0,101126368	0,185684113	0,252046359	0,293794033	0,306812010	0,289827282	0,244466566	0,175102028	0,089235882	0
0	0,185716123	0,347549633	0,475361001	0,556720139	0,583638414	0,553483529	0,469170091	0,338856295	0,176014518	0
0	0,252108725	0,475393673	0,652158397	0,765182110	0,803379764	0,763016067	0,648003933	0,469500570	0,245683689	0
0	0,293854492	0,556752805	0,765182107	0,898817978	0,944559730	0,897934346	0,763467060	0,554216581	0,291357754	0
0	0,306870364	0,583671075	0,803379761	0,944559730	0,993372560	0,945044918	0,804268499	0,584719229	0,308571029	0
0	0,289883532	0,553516185	0,763016064	0,897934346	0,945044918	0,899740908	0,766418336	0,558025705	0,295640259	0
0	0,244554278	0,469236937	0,648038125	0,763501255	0,804302694	0,766452530	0,653617883	0,476747171	0,253830760	0
0	0,175317995	0,339074559	0,469689119	0,554406119	0,584908540	0,558213598	0,476897556	0,348830372	0,187227178	0
0	0,088738177	0,175702262	0,245366322	0,291036899	0,308247329	0,295314697	0,253503743	0,186880572	0,102176276	0
0	0	0	0	0	0	0	0	0	0	0

2-rasm. ANIQ YECHIM ning jadvaldagi ko‘rinishi

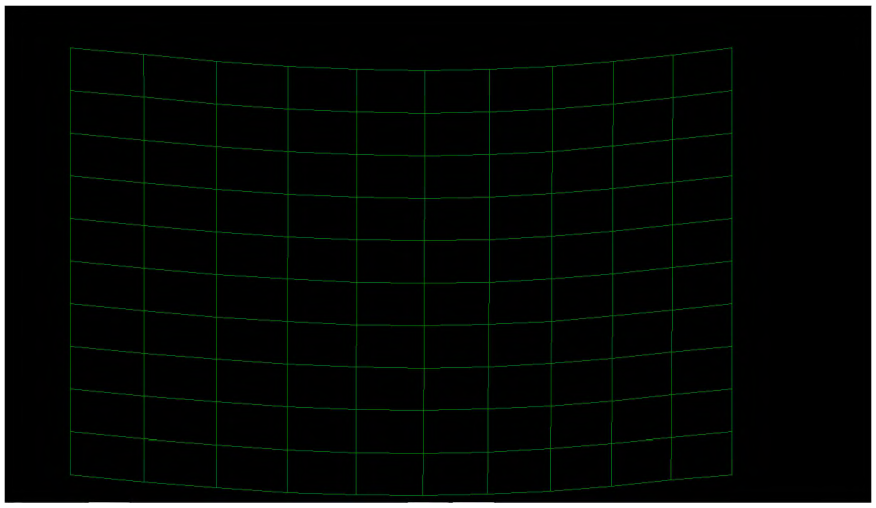
TAQRIBIY YECHIM										
0	0	0	0	0	0	0	0	0	0	0
0	0,105549970	0,188964923	0,253809616	0,293853265	0,305197493	0,286732940	0,240245674	0,170251471	0,083279559	0
0	0,188685799	0,349034689	0,475102889	0,554717880	0,580094652	0,548751650	0,463753731	0,333382823	0,170400800	0
0	0,253491026	0,475047234	0,650036831	0,761460485	0,798422663	0,757308887	0,642139591	0,464172251	0,240747894	0
0	0,293544309	0,554667643	0,761468760	0,893806578	0,938740337	0,891876030	0,757796443	0,549611962	0,287572033	0
0	0,304898947	0,580054542	0,798444389	0,938755246	0,987266580	0,939234536	0,799356105	0,581312559	0,306275057	0
0	0,286437936	0,548718727	0,757341270	0,891904370	0,939249425	0,894746628	0,762747868	0,556167422	0,295027770	0
0	0,239960051	0,463717276	0,642171625	0,757828238	0,799377211	0,762755530	0,651544417	0,476628994	0,254928568	0
0	0,169322758	0,332610087	0,463427334	0,548868133	0,580558519	0,555399514	0,475870870	0,349754743	0,189691914	0
0	0,084483256	0,171263843	0,241609536	0,288427854	0,307122398	0,295865076	0,255776242	0,190787565	0,106473675	0
0	0	0	0	0	0	0	0	0	0	0

3-rasm. TAQRIBIY YECHIM ning jadvaldagi ko‘rinishi

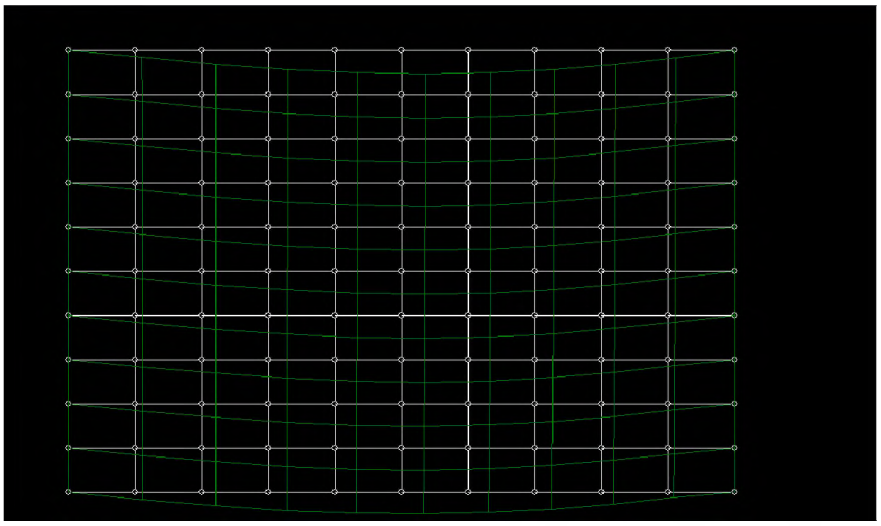
2, 3-rasmlarda keltirilgan natijalar asosida kuyidagi grafik ko‘rinishdagi natijalarni olamiz.



4-rasm. Kvadrat plastinaning dastlabki holati.



5-rasm. Kvadrat plastinaning U,V bo‘yicha siljish holati.



6-rasm. Kvadrat plastinani temperatura ta'sir qilgandagi holati bilan solishtirish.

Xulosa. Xulosa qilib aytganda, amaliyotda uchraydigan ko‘plab masalalarni matematik modellari termoelastik yoki termoplastik bog‘liq va bog‘liq bo‘lmagan masalalarni o‘rganishga keltiriladi. Kelguci tadqiqot ishlarimiz va maqolalarimizda bog‘liq masalalarga qo‘shimcha tashqi ta'sirlar orqali uning holatini o‘zgarishini, ularni sonli yechish usullarini o‘rganish va bu masalalarning dasturiy ta'minotini yaratish bilan davom ettiraman.

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