ანა ტაბატაძე

მიწისძვრისას კარკასული შენობების სვეტებში დარტყმის ეფექტის გათვალისიწნება

წარმოდგენილია დოქტორის აკადემიური ხარისხის
მოსაპოვებლად

საქართველოს ტექნიკური უნივერსიტეტი
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საქართველოს ტექნიკური უნივერსიტეტი

სამშენებლო ფაკულტეტი

ჩვენ, ქვემორე ხელის მომწერნი ვადასტურებთ, რომ გავეცანით ანი ტაბატაძის მიერ შესრულებულ სადისერტაციო ნაშრომს დასახელებით: „მიწისძვრისას კარკასული შენობების სვეტებში დარტყმის ეფექტის გათვალისიწნება“ და ვაძლევთ რეკომენდაციას საქარველოს ტექნიკური უნივერსიტეტის samSeneblo fakultetis სადისერტაციო საბჭოში მის განხილვას დოქტორის აკადემიური ხარისხის მოსაპოვებლად.

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ინდივიდუალური პიროვნებების ან ინსტიტუტების მიერ ზემომოყვანილი დასახელების დისერტაციის გაცნობის მიზნით მოთხოვნის შემთხვევაში მისი არაკომერციული მიზნებით კოპირებისა და გავრცელების უფლება მინიჭებული აქვს საქართველოს ტექნიკურ უნივერსიტეტს.

ავტორის ხელმოწერა

ავტორი ინარჩუნებს დანარჩენ საგამომცემლო უფლებებს და არც მთლიანი ნაშრომის და არც მისი ცალკეული კომპონენტების გადაბეჭდვა ან სხვა რაიმე მეთოდით რეპროდუქცია დაუშვებელია ავტორის წერილობითი ნებართვის გარეშე.

ავტორი ირწმუნება, რომ ნაშრომში გამოყენებული საავტორო უფლებებით დაცული მასალებზე მიღებულია შესაბამისი ნებართვა (გარდა ის მცირე ზომის ციტატებისა, რომლებიც მოითხოვენ მხოლოდ სპეციფიურ მიმართებას ლიტერატურის ციტირებაში, როგორც ეს მიღებულია სამეცნიერო ნაშრომების შესრულებისას) და ყველა მათგანზე იღებს პასუხისმგებლობას.

naSromis Sinaarsi

Tavi 1. miwisZvrisas karkasuli Senobis svetebze dartymis efeqtis gaTvaliswineba

1.1 sakiTxis dasma da misi gadawyvetis gzebi

pirvel paragrafSi mocemulia sakiTxis dasma da misi gadawyvetis gzebi. naCvenebia, rom xSirad seismuri zemoqmedebis Sedegad miRebuli rRvevis sqemebi ar Seesabameba amJamad momqmed inerciul-rxeviT Teorias. aseT SemTxvevebSi iqmneba STabeWdileba, rom konstruqciaze imoqmeda xanmokle impulsma dartymis saxiT. e.i. aucilebelia dartymis efeqtis gaTvaliswineba. aqve aRniSnulia, rom xist-plastikuri modelis Sesabamisad miRebuli rRvevis sqema (mag. xojis SemTxvevaSi) Seicavs principul sirTuleebs dasmuli sakiTxis gadawyvetis dros.

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mravalricxovani dakvirvebebis Sedegad dadgenilia, rom seismuri zemoqmedebis sawyis momentSive xdeba SenobaTa udidesi nawilis ngreva. seismuri zemoqmedeba myisierad iwvevs Senobebis svetebisa da kedlebis gadaWras ise, rom Senoba verc ki aswrebs moZraobis dawyebas, e.i. misTvis saSiSi inerciis Zalebis aRZvras. cnobilia, rom miwisZvrisas inerciul Zalebs win uswrebs yovelTvis Senobis vertikalur elementebSi ganivi Zvris talRebis warmoqmna. maSasadame, Zvris talRebi pirveladia, inerciis Zalebi ki meoradi. amitom bunebrivia, Senobebis ngrevis erT-erT mTavar mizezad miviRoT es talRebi. miuxedavad amisa, sadReisod erTaderT sayovelTaod miRebul mizezad seismuri ngrevisa iTvleba meoradi inerciuli Zalebi.

tradiciuli seismuri gaangariSeba gulisxmobs inerciuli Zalebis eqvivalenturi statikuri sidideebis gansazRvras, romlebic modebuli iqneba Senobis elementebze. magram am gziT miRebuli rRvevis sqemebi xSirad winaaRmdegobaSia realur rRvevis sqemasTan da ar SeiZleba iyos axsnili sayovelTaod miRebuli inerciuli koncefciis safuZvelze. magaliTad nageboba, romelsac aqvs moqnili karkasi da xisti diafragma. am SemTxvevaSi xist diafragmaze inerciuli Zalebisagan gamowveuli mxebi Zabvebi iqneba gacilebiT meti, vidre karkasis svetebze, radganac paralelurad momuSave elementebidan datvirTvis met nawils iRebs is elementi, romlis sixistec metia. ase, rom inerciis Zalis raRac mniSvnelobisaTvis jer unda daingres didi sixistis

elementi. realurad ki gvaqvs sapirispiro suraTi, ingreva moqnili elementi, mTeli datvirTvis amRebi xisti diafragma ki rCeba dauzianebeli. meore magaliTis saxiT SeiZleba moviyvanoT karkasuli nageboba moqnili pirveli sarTuliT. am SemTxvevaSi, maqsimaluri mRunavi momentebi warmoiqmneba svetebis boloebSi da datvirTvis raRac mniSvnelobisaTvis am kveTebSi unda warmoiqmnas plastikuri saxsrebi, rac nagebobas gadaaqcevs meqanizmad gverdiTi gadaadgilebiT. ase ingreva analogiuri CarCoebi horizontaluri Zalis moqmedebisas. miwisZvrisas ki xdeba sxvanairad. aseT konstruqciebSi warmoiqmneba myife ngrevis Zvris meqanizmi, romlis drosac xdeba svetebis gadaWra yvelaze naklebad daZabul kveTebSi. igive movlenas aqvs adgili bolo saxsrian Reroebiani karkasis SemTxvevaSic. aseve ver aixsneba inerciuli koncefciis safuZvelze Riobebiani diafragmebisa da erTnairi inerciuli ZalebiT datvirTuli sxvadasxva sisqis kedlebis erTdroulad ngrevis SemTxvevebi. moyvanili magaliTebi miuTiTeben Tanamedrove seismomedegobis Teoriis SigniT arsebul seriozul problemebze, romlebic warmoSobilia mcdari daSvebidan, TiTqos Senobebs azianebs gruntis rxeviT SenobaSi aRZruli inerciuli Zalebi [9, 10]. Catarebuli kvlevebi miuTiTeben im faqtze, rom zemoT aRwerili dazianebebi SeiZleba warmoSobili iyos mxolod Zalian xanmokle impulsebis zemoqmedebiT ganxorcielebuli Zlieri dartymebis Sedegad. es daskvna gamomdinareobs rkinabetonis mzid konstruqciebze cxra baliani miwisZvris zemoqmedebiT miRebuli dazianebebis analizisa da im energiis gamoTvlis Sedegad, romelsac SeeZlo gamoewvia aseTi saxisa da masStabis dazianebebi [11].

maSasadame sakiTxi ismis Senobis elementebze dartymis efeqtis gaTvaliswinebis Sesaxeb. kerZod, Tu ganvixilavT karkasuli Senobis pirveli sarTulis svetebis muSaobas seismuri zemoqmedebis pirobebSi saWiroa gaangariSebis gziT vuCvenoT, rom rRvevis is meqanizmi, romelic gvaqvs svetebSi miwisZvris dros, kerZod maTi gadaWra simaRlis mixedviT SuaSi, SesaZlebelia qveda boloze dartymis Sedegad. dasmuli amocana SeiZleba gadawydes rxevis gantolebis amoxsniT, romlis drosac gaanalizebuli iqneba aRZruli Zalis mniSvnelobani damrtymeli Zalis moqmedebis xangrZliobisa da ganmeoradobis gaTvaliswinebiT. aqve unda aRiniSnos dartymis amocanis Sesaxeb, romelic amoxsnilia xistplastikuri modelis gamoyenebiT. es amocana pirvelad amoxsnili iyo parkisis [4] mier. Semdeg igive amocana ganixila xojma [5]. am amocanaSi konsoluri Reros boloebze axdens dartymas masa G_0, romelsac dartymis momentSi gaaCnia siCqare Δ. xist plastikuri modelis Sesabamisad Rerom SeiZleba ganicados mniSvnelovani plastikuri deformaciebi, romlebic ganviTardeba plastikuri saxsris warmoqmnis Sedegad. plastikuri saxsari warmoiqmneba zRvruli momentis moqmedebis Sedegad da radgan es momenti amave dros iTvleba maqsimalurad, am kveTSi ganivi Zala gamodis nulis toli. zemoT naTqvamis safuZvelze ki sakiTxis dasma iTvaliswinebs dartymis Sedegad ganivi talRebis da maSasadame ganivi Zalis moqmedebis Sedegad Reros gadaWris SesaZleblobis dadgenas. amave

dros, Tu gaviTvaliswinebT im cnobil faqtsac, rom dartymis Sedegad warmoiqmneba jer rxevis maRali formebi, xist plastikuri modeli ki eyrdnoba faqtiurad rxevis pirvel formas, cxadi gaxdeba, rom Cveni amocanis gadasaWrelad aRniSnuli midgomis gamoyeneba dakavSirebuli iqneba principuli xasiaTis siZneleebTan.

1.2 ZiriTadi gantolebebi da maTi amoxsnis gzebi

Mmeore paragrafSi moyvanilia ZiriTadi gantolebebi, romlebic iTvaliswineben mxolod Runvis deformacias da gantolebebi, romlebSic gaiTvaliswineba rogorc grZivi Zalis gavlena, aseve brunvis inercia da Zvris deformacia. mxolod Runvis SemTxvevaSi moyvanilia cnobili analizuri amoxsnebi da naCvenebia, rom isini ar iZlevian ganivi Zalis gansazRvris saSualebas. igive gantolebebis ricxviTi gziT amoxsnis mizniT, wiriTi warmoebulebi Secvlilia sxvaobiani sqemiT da miRebulia Cveulebriv diferencialur gantolebaTa sistema SemdgomSi runge-kutas meTodiT amoxsnis mizniT. moyvanilia am sistemis koeficientebisa da Tavisufali wevrebis matrica, rogorc mxolod Runvis, aseve brunvis inerciisa da Zvris deformaciis gaTvaliswinebiT. ganxilulia SemTxvevebi, roca svetis qveda bolo Camagrebulia wertilovan saZirkvelSi an saZirkvlis filaSi. gaTvaliswinebulia agreTve xaxunis Zalebi, romlebic warmoiSveba Reros qveda torsul waxnagsa da grunts Soris. am SemTxvevaSic moyvanilia diferencialur gantolebaTa sistemis koeficientebis matrica.

dasmuli amocanis gadawyvetisaTvis saWiroa ganxiluli iyos Reros rxevis gantoleba. ganivi dartymis SemTxvevaSi iZulebiTi rxevis gantolebas aqvs saxe [1]:

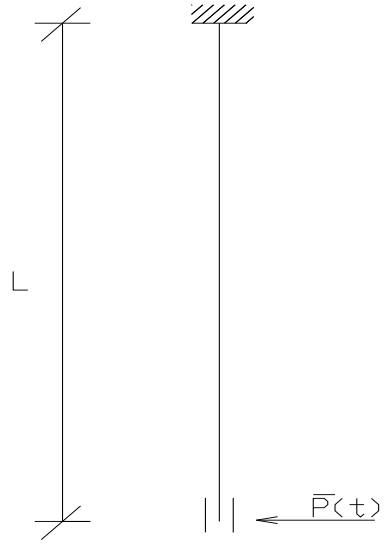
$$EI\frac{\partial^4 w}{\partial x^4}+\rho F\frac{\partial^2 w}{\partial t^2}=\overline{P}(t), \qquad (1)$$

sadac, E iungis modulia, I - kveTis inerciis momenti, ρ - masalis simkvrive, F - kveTis farTobi. $\overline{P}(t)$ warmoadgens droze damokidebul x koordinatis gaswvriv ganawilebul funqcias, romelic gamosaxavs gare Zalas. Cvens SemTxvevaSi, radganac vixilavT seismuri zemoqmedebis Sedegad ganxorcielebul dartymas Reros boloze, amitom $\overline{P}(t)$ funqcia iqneba nulis toli, yvelgan garda Reros bolosi (nax. 1.1), amitom misi sidide gaTvaliswinebuli iqneba sasazRvro pirobebSi, (1.) gantoleba ki iqneba erTgvarovani.

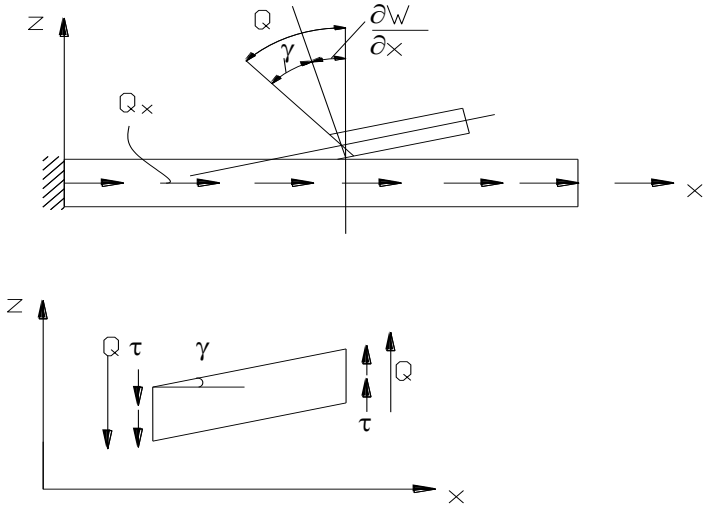
im SemTxvevaSi Tu gaviTvaliswinebT Zvris deformacias da brunvis inercias, maSin gantolebaTa sistemas eqneba saxe [2]:

$$\begin{aligned}&\rho F\frac{\partial^2 W}{\partial t^2}-\frac{GF}{k_1}\left(\frac{\partial\theta}{\partial x}-\frac{\partial^2 W}{\partial x^2}\right)-\frac{\partial}{\partial x}\left(Q_x\frac{\partial W}{\partial x}\right)=0,\\&\frac{\partial}{\partial x}\left(EI\frac{\partial\theta}{\partial x}\right)-\rho I\frac{\partial^2\theta}{\partial t^2}+\frac{GF}{k_1}\left(\theta-\frac{\partial W}{\partial x}\right)=0,\end{aligned} \qquad (2)$$

sadac G Zvris modulia, $k_1 = k_2 F(0), \quad k_2 = \int_F \frac{S^2 dF}{b^2 I}$, S ganivi kveTis gansaxilveli ordinatis zemoT moTavsebuli farTobis statikuri momenti neitraluri RerZis mimarT [3], b Reros siganea. θ elementis sruli mobrunebis kuTxea (nax..2). $\theta = \gamma + \frac{\partial w}{\partial x}$, Q_x RerZis gaswvriv moqmedi statikuri datvirTvaa.



A nax. 1.1. svet is
B. saangar iSo sqema



A nax. 1.2. Rer o Zvr is
def or maci is gaTval iswi nebi T

jer ganvixiloT (1) gantoleba. misi amoxsna SeiZleba miRebul iyos rogorc analizuri, aseve ricxviTi gziT. analizuri amoxsnebis miRebisas w warmoidgineba Semdegi saxiT:

$$w = \sum X_i(x) q_i(t), \qquad (3)$$

sadac $X_i(x)$ koWis Tavisufali rxevis normaluri harmoniuli funqciaa. misi forma dgindeba sasazRvro pirobebis safuZvelze. rac Seexeba $q_i(t)$-s, igi ganisazRvreba lagranJis gantolebaSi koWis kinetikuri T da potencialuri V energiebis mniSvnelobaTa SetaniT. ganzogadoebuli Zala Q_i tolia $P(t)X_i(c)$, sadac $P(t)$ dartymis urTierTqmedebis Zalaa, $X_i(c)$ ki dartymis c wertilis gadaadgileba. energiebis gamosaxulebebi iqneba:

$$T = \frac{1}{2}\sum \dot{q}_i^2 \rho F \int_0^L X_i^2 dx, \qquad V = \frac{1}{2}\sum q_i^2 FE \int_0^L X_i''^2 dx,$$

sadac $\dot{q}$ aRniSnavs droiT warmoebuls, X'' ki x koordinatiT warmoebuls. lagranJis gantoleba miiRebs saxes:

$$\left(\rho F\int_0^L X_i^2 dx\right)\ddot{q}_i + \left(FE\int_0^L X_i''^2 dx\right)q_i = P(t)X_i(c)$$

an

$$\ddot{q}_i + \omega_i^2 q_i = \frac{F(t)X_i(c)}{\rho F\int_0^L X_i^2 dx}, \qquad \omega_i \equiv \frac{E\int_0^L X_i''^2 dx}{\rho\int_0^L X_i^2 dx},$$

CaRunvis gamosaxuleba iqneba:

$$W = \sum X_i\left[q_0\cos\omega_i t + \frac{\dot{q}_0}{\omega_i}\sin\omega_i t + \frac{X_i(c)}{\rho F\omega_i\int_0^L X_i^2 dx}\int_0^t P(\tau)\sin\omega_i(t-\tau)d\tau\right],$$

sadac $q_0\sum X_i$ da $\dot{q}_0\sum\frac{X_i}{\omega_i}$ koWis gadaadgilebisa da siCqaris sawyisi mniSvnelobebia, τ ki saintegro cvladia. ucnobi Zala $P(t)$ SeiZleba ganisazRvros koWisa da damrtymeli masis gadaadgilebaTa tolobidan. koWisaTvis, romelic sawyis momentSi ar ganicdida araviTar gadaadgilebebs, es piroba Caiwereba Semdegnairad:

$$V_0 t - \frac{1}{m_2}\int_0^t dt\int_0^t F dt = \frac{1}{\rho F}\sum\frac{X_i^2(c)}{\omega_i\int_0^L X_i^2 dx}\int_0^t F(\tau)\sin\omega_i(t-\tau)d\tau$$

am gantolebis amoxsna SesaZlebelia mxolod ricxviTi gziT.

sakiTxis gamartivebis mizniT moviyvanoT goldsmitis mier SemoTavazebuli miaxloebiTi meTodi, romelSic moqmedi impulsi icvleba Sesabamisi sasazRvro pirobiT, rac saSualebas gvaZlevs miviRoT analizuri amonaxseni. SevitanoT (3) (1)-Si, ris Semdegac gveqneba:

$$a^4 q_i\frac{\partial^4 X_i}{\partial x^4} + X_i\frac{\partial^2 q_i}{\partial t^2} = 0 \qquad (4)$$

aqedan $\frac{\partial^4 X_i}{\partial x^4} : X_i = \xi_i^4 = -\frac{1}{a^4}\frac{\partial^2 q_i}{\partial t^2} : q_i$, sadac $a^4 = \frac{EI}{\rho F}$, ξ_i nebismieri mudmivia, xolo $\xi_i^2 a^2 = \omega_i$-s aqvs sixSiris ganzomileba. (4)-is kargad cnobili amonaxseni Caiwereba Semdegnairad:

$$W = \sum\left(A_i\sin\xi_i x + B_i\cos\xi_i x + C_i sh\xi_i x + D_i ch\xi_i x\right)\cdot \left(E_i\sin\omega_i t + H_i\cos\omega_i t\right) \qquad (.5)$$

nebismieri mudmivebi A_i, B_i, C_i da D_i ganisazRvrebian sasazRvro pirobebidan, E_i, H_i - ki

sawyisi pirobebidan.

Cvens SemTxvevaSi karkasuli Senobis pirveli sarTulis sveti SeiZleba warmodgenili iyos rogorc zeda boloTi xistad Camagrebuli Rero, romlis qveda bolo SeiZleba Camagrebuli iyos wertilovan saZirkvelSi an saZirkvlis filaSi. Reros qveda bolo ganicdis m_2 masis dartymas, roca masis siCqare tolia $V_{2,0}$. dartymis Semdeg, m_2 masa RerosTan erTad asrulebs rxevas. aseTi RerosaTvis zeda boloze nulis toli iqneba gadaadgileba W da mobrunebis kuTxe $\frac{\partial W}{\partial x}$. qveda boloze wertilovani saZirkvlis SemTxvevaSi, SeiZleba miviRoT, rom nulis tolia mRunavi momenti, e.i. $\frac{\partial^2 W}{\partial x^2}$, xolo saZirkvlis filis SemTxvevaSi mobrunebis kuTxe $\frac{\partial W}{\partial x}$. orive SemTxvevaSi ganivi Zala qveda boloze toli iqneba: $EI\frac{\partial^3 W}{\partial x^3} = m_2 \frac{\partial^2 W}{\partial t^2}$. rac Seexeba sawyis pirobebs, gadaadgileba koWis nebismier wertilSi, roca t=0 tolia nulis W(x,0)=0. sawyisi siCqaris gansazRvrisaTvis ki daSvebulia, rom damrtymeli m_2 masa, romelsac gaaCnia $V_{2,0}$ siCqare, amave siCqares aniWebs koWis usasrulo mcire ubans kontaqtis wertilSi. koWis sxva wertilebSi siCqare tolia nulis. moqmedi masis moZraobis raodenobisa da mTeli koWis moZraobis raodenobis piroba Rebulobs saxes:

$$\int \frac{\partial W}{\partial t}(x,0)dm = m_2 \mathrm{v}_{2,0}.$$

moyvanili sawyisi da sasazRvro pirobebis (5)-Si gaTvaliswinebiT (qveda boloze mRunavi momentis nulTan tolobis CaTvliT) miRebulia gaRunvisa da Reros rxevis sixSireTa gamosaTvleli gamosaxulebebi, romelTac Semdegi saxe aqvT [1]:

$$W = \frac{2V_{2,0}L^2}{a^2}\sum \frac{1}{\varphi_i^2}\frac{(\sin\varphi_i ch\varphi_i - \cos\varphi_i sh\varphi_i)(\cos\varphi_i + ch\varphi_i)(\sin\varphi_i + sh\varphi_i)}{(\sin\varphi_i ch\varphi_i - \cos\varphi_i sh\varphi_i)^2 + M(\sin\varphi_i + sh\varphi_i)^2}\cdot$$
$$\cdot\left(\frac{ch\frac{\varphi_i x}{L} - \cos\frac{\varphi_i x}{L}}{ch\varphi_i + \cos\varphi_i} - \frac{sh\frac{\varphi_i x}{L} - \sin\frac{\varphi_i x}{L}}{sh\varphi_i + \sin\varphi_i}\right)\cdot \sin\frac{\varphi_i^2 a^2}{L^2}t, \qquad (6)$$

$$M = \frac{\varphi_i(\sin\varphi_i ch\varphi_i - \cos\varphi_i sh\varphi_i)}{1+\cos\varphi_i sh\varphi_i} \qquad (7)$$

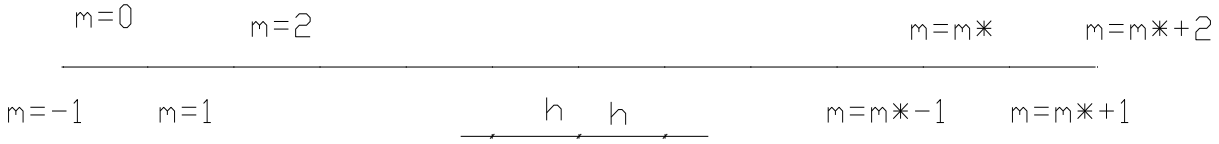
sadac, M koWis masisa da moqmedi masis Sefardebaa: $M = \frac{\rho FL}{m_2}$.

igive gamosaxulebebs, rodesac qveda bolo Camagrebulia saZirkvlis filaSi, eqnebaT saxe:

$$W = \frac{2V_{2,0}L^2}{a^2}\sum\frac{1}{\varphi_i^2}\frac{(1-\cos\varphi_i ch\varphi_i)(\cos\varphi_i - ch\varphi_i)(\sin\varphi_i + sh\varphi_i)}{(1-\cos\varphi_i ch\varphi_i)^2 + M(\cos\varphi_i - ch\varphi_i)^2}\cdot$$
$$\cdot\left(\frac{sh\frac{\varphi_i x}{L} - \sin\frac{\varphi_i x}{L}}{ch\varphi_i - \cos\varphi_i} - \frac{ch\frac{\varphi_i x}{L} - \cos\frac{\varphi_i x}{L}}{sh\varphi_i + \sin\varphi_i}\right)\cdot\sin\frac{\varphi_i^2 a^2 t}{L^2} \qquad (8)$$

$$M = \frac{\varphi_i(1-\cos\varphi_i ch\varphi_i)}{\sin\varphi_i ch\varphi_i + \cos\varphi_i sh\varphi_i} \qquad (9)$$

ganvixiloT exla (1) gantolebis integreba ricxviTi gziT. amisaTvis mivmarToT wrfeTa meTods, romlis Tanaxmadac kerZowarmoebuliani diferencialuri gantolebis integrebisas erTerTi koordinatiT warmoebulebi icvleba sxvaobiani sqemiT, ris Sedegadac vRebulobT Cveulebriv diferencialur gantolebaTa sistemas. rxevis amocanebSi Cveulebriv sxvaobiani sqemiT icvleba grZivi koordinatiT warmoebulebi, ris Sedegadac miRebul Cveulebriv diferencialur gantolebaTa sistemaSi damoukidebel cvlads warmoadgens dro. Cvens SemTxvevaSi davyoT Rero sigrZis mixedviT sakvanZo wertilebiT, romelTa Soris manZili iyos h (nax. 1.3). Tu gadavalT uganzomilebo koordinatebze $\eta = \frac{x}{L}$, maSin bijis sidide iqneba $\delta = \frac{h}{L}$.



A nax. 1.3. Rero sakvanZo wertilebiT

gamovsaxoT W-s warmoebulebi η koordinatiT sasrul sxvaobebSi:

$$\frac{\partial W_m}{\partial\eta} = \frac{L}{2\delta}(W_{m+1} - W_{m-1}),$$
$$\frac{\partial^2 W_m}{\partial\eta^2} = \frac{L^2}{\delta^2}(W_{m+1} - 2W_m + W_{m-1}),$$
$$\frac{\partial^3 W_m}{\partial\eta^3} = \frac{L^3}{2\delta^3}(W_{m+2} - 2W_{m+1} + 2W_{m-1} - W_{m-2}), \qquad (10)$$
$$\frac{\partial^4 W_m}{\partial\eta^4} = \frac{L^4}{\delta^4}(W_{m+2} - 4W_{m+1} + 6W_m - 4W_{m-1} + W_{m-2})$$

(1)-Si (10)-is SetaniT miviRebT m wertilebSi gadaadgilebis funqciis mimarT mudmivkoeficientebian Cveulebriv diferencialur gantolebaTa sistemas:

$$\frac{\partial^2 W_m}{\partial t^2} + \frac{K_0}{\delta^4}\left(W_{m+2} - 4W_{m+1} + 6W_m - 4W_{m-1} + W_{m-2}\right) = 0,$$

sadac $K_0 = \frac{EI}{\rho F L^3}$.

Tu $\frac{\partial W_m}{\partial t}$-s aRvniSnavT axali cvladiT vTqvaT V_m-iT, maSin gveqneba pirveli rigis diferencialur gantolebaTa sistema, romlis mimarTac SeiZleba gamoviyenoT kargad aprobirebuli runge-kutas meTodi.

rac Seexeba sasazRvro pirobebs, isini SeiZleba warmodgenili iyos odnav gansxvavebuli saxiT, vidre [1]-Sia ganxiluli. aseTi warmodgena Cveni azriT ukeTesad asaxavs Reros muSaobis pirobebs dartymis gaTvaliswinebiT. marTlac, sawyis momentSi, roca t=0 siCqaris gansazRvrisas SeiZleba davuSvaT, rom $V_{2,0}$ siCqariT dartymisas wertilSi gveqneba maqsimaluri siCqare V_0, mis mezobel danayofis wertilSi ki nulis toli. Tu siCqaris cvlilebas dartymis wertilidan mis mezobel wertilSi gadasvlisas miviRebT wrfivad, maSin moZraobis raodenobis mudmivobis pirobidan SegviZlia davweroT: $\frac{1}{2}\left(\rho F h + m_2\right)\cdot V_0 = m_2 V_{2,0}$, aqedan $V_0 = \frac{V_{2,0} m_2}{\frac{1}{2}\rho F h + m_2}$. Tu siCqaris cvlilebas wrfivis nacvlad aviRebT paraboluri an sxva kanoniT $\frac{1}{2}$-is nacvlad gveqneba sxva koeficienti. V_0-is miRebuli gamosaxulebebidan gamomdinareobs, rom rac ufro wvrili biji iqneba aRebuli dayofisas, miT ufro miuaxlovdeba dartymis wertilis sawyisi siCqare damrtymeli masis siCqares, rac realuria.

meore cvlileba Seexeba ganivi ZalisTvis sasazRvro pirobas. am SemTxvevaSi Cven SegviZlia gare damrtymeli Zala, e.i. ganivi Zala CavTvaloT cnobilad $Q(0,t) = Q_0(t)$ da Tanac gaviTvaliswinoT dartymis xanmokle impulsis moqmedebis xangrZlioba. damrtymeli Zala SeiZleba moqmedebdes runge-kutas meTodis Sesabamisad drois bijis garkveuli nawilis an ufro xangrZlivi drois ganmavlobaSi. aq SegviZlia miviRoT, rom ganivi Zala Reros boloSi nulisagan gansxvavebulia, mxolod winaswar gansazRvruli drois monakveTis ganmavlobaSi, danarCeni drois ganmavlobaSi ki nulis tolia, an garkveuli drois Semdeg ganmeordeba dartyma aseve drois cnobili monakveTis xangrZliobiT.

aq saWiroa xazi gaesvas im garemoebas, rom runge-kutas meTodis Sesabamisad drois H bijis H_1 monakveTSi Zalis moqmedebisas saWiroa es garemoeba gaTvaliswinebuli iyos programaSi. saxeldobr, runge-kutas meTodSi drois bijis sawyis momentSi cnobilia saZiebeli funqciis mniSvnelobani. am meTodiT viRebT maT mniSvnelobas bijis boloSi, e.i. vsazRvravT nazrdebs. es nazrdebi isazRvreba oTxjer funqciis warmoebulebis bijis sidideze gadamravlebis gziT. TiTojer bijis Tavsa da boloSi da orjer SuaSi. amave dros bijis SuaSi gansazRvrul

nazrdebSi mravldeba orze da gamoiTvleba nazrdis saSualo mniSvneloba. Cvens SemTxvevaSi bijis farglebSi warmoebuls aqvs safexurovani forma. amitom saWiroa nazrdi gamoiTvalos H_1 bijis farglebSi calke, H-is farglebSi calke da Semdeg Sejamdes.

radganac TiToeul sakvanZo wertilSi iwereba ori gantoleba, amitom gantolebaTa sistemaSi Semavali ucnobebi rom iyos danomrili mimdevrobiT, SemoviRoT axali cvladi U_m, romelic, roca m=1,2,... aRniSnavs Semdeg sidideebs:

$$U_1 = W_1, \quad U_2 = V_1 = \frac{\partial W_1}{\partial t}, \quad U_3 = W_2, \quad U_4 = V_2 = \frac{\partial W_2}{\partial t},$$

$$U_5 = W_3, \quad U_6 = V_3 = \frac{\partial W_3}{\partial t} \quad \text{da a.S.}$$

CavweroT exla sasazRvro pirobebi sakvanZo wertilebSi funqciebis daxmarebiT. gantolebebi iwereba wertilebSi m=1,2,...,m^*. rac Seexeba m=0, m=-1, m=m^*+1 da m=m^*+2 wertilebs, isini fiqtiuri wertilebia, romelTa arsebobac aucilebelia sxvaobiani sqemis gamoyenebis gamo. rac Seexeba funqciebis mniSvnelobebs, am wertilebSi isini gamoisaxebian sasazRvro pirobebis daxmarebiT da gamoTvlebSi monawileobas ar Rebuloben.

qveda boloze mobrunebis kuTxis nulTan tolobis piroba Caiwereba Semdegnairad $\frac{1}{2h}(W_2 - W_0) = 0$. aqedan

$$W_0 = W_2 = U_3 \tag{11}$$

meore warmoebulis nulTan tolobis pirobidan gveqneba:

$\frac{1}{h^2}(W_2 - 2W_1 + W_0) = 0$. aqedan

$$W_0 = 2W_1 - W_2 = 2U_1 - U_3 \tag{12}$$

ganivi Zalis piroba Caiwereba Semdegnairad:

$-EI\frac{\partial^3 W}{\partial x^3} = -\frac{EI}{2h^3}(W_3 - 2W_2 + 2W_0 - W_{-1}) = Q_0(t)$. aqedan

$$W_{-1} = +\frac{2h^3}{EI}Q_0 + 2W_0 - 2U_3 + U_5 \tag{13}$$

Tu qveda boloze mobrunebis kuTxe nulia, maSin (13)-Si W_0 Seicvleba (11)-is mixedviT da Tu momentia nulis toli, maSin (12)-is mixedviT. zeda xist CamagrebaSi $W_{m^*} = U_{2m^*-1} = 0$, aseve $\frac{\partial W_{m^*}}{\partial x} = 0$, e.i. $W_{m^*+1} = W_{m^*-1}$.

rogorc moyvanili damokidebulebebidan Cans, sasazRvro pirobebis gavlenis gamo, gansxvavebulad Caiwereba sistemis pirveli ori da bolo ori gantoleba, e.i. roca m=1,2,m^*-1 da m^*. sxva danarCen SemTxvevaSi, e.i. roca $3 \le m \le m^* - 1$ gantolebebi Caiwereba erTi formuliT.

mag. Tu m^{*}=10, maSin gveqneba 20 gantoleba da qveda boloze momentis nulTan tolobis SemTxvevaSi gantolebaTa sistemis koeficientebis matricas eqneba saxe (cxrili 1).

cxrili 1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1		1																			
2	$-c_2$		c_4		$-c_2$																$-c_2\frac{h^3}{EI}Q_0$
3				1																	
4	$+c_2$		$-c_5$		c_4		$-c_1$														
5						1															
6	$-c_1$		c_4		$-c_6$		c_4		$-c_1$												
7								1													
8			$-c_1$		c_4		$-c_6$		c_4		$-c_1$										
9										1											
10					$-c_1$		c_4		$-c_6$		c_4		$-c_1$								
11												1									
12							$-c_1$		c_4		$-c_6$		c_4		$-c_1$						
13														1							
14									$-c_1$		c_4		$-c_6$		c_4		$-c_1$				
15																1					
16											$-c_1$		c_4		$-c_6$		c_4		$-c_1$		
17																		1			
18													$-c_1$		c_4		$-c_6$		c_4		
19																				1	
20															$-c_1$		c_4		$-c_6$		

sadac $c_i = i \cdot \frac{k_0}{\delta^4}$.

ganapira wertilebSi gansxvavebulad Caiwereba ganivi Zalis gamosaxulebebic:

$$Q(1)=Q_0(t),\qquad Q(2)=-\frac{EI}{2h^3}\left(U_7-2U_5+U_3\right),\qquad Q(8)=-\frac{EI}{2h^3}\left(-2U_1+2U_{15}-U_{13}\right),$$

$$Q(9)=-\frac{EI}{2h^3}\left(3U_{17}-U_{15}\right)$$

im SemTxvevaSi, Tu qveda bolo Camagrebulia saZirkvlis filaSi, e.i. mobrunebis kuTxe udris nuls, gantolebaTa sistemis koeficientebis matrica darCeba igive, Seicvleba mxolod meore da meoTxe striqonebi. kerZod, meore striqonSi -c_2, c_4, -c_2-is nacvlad gveqneba -c_6, c_8, -c_2, xolo meoTxe striqonSi +c_4, -c_7, c_4, -c_1. rac Seexeba ganivi Zalis gamosaxulebebs, maTTvis gveqneba:

$$Q(1)=Q_0(t),\qquad Q(2)=-\frac{EI}{2h^3}\left(U_7-2U_5-U_3+2U_1\right).$$

Zvris deformaciisa da brunvis inerciis gaTvaliswinebis SemTxvevaSi, e.i. roca saqme gvaqvs (2) sistemasTan, radganac torsuli kveTis sruli mobruneba warmoadgens Zvris deformaciisa da geometriuli RerZis mobrunebis kuTxis jams $\theta=\gamma+\frac{\partial W}{\partial x}$, amitom xisti Camagrebis SemTxvevaSi mobrunebis kuTxis nulTan tolobis piroba iqneba $\theta=0$. am SemTxvevaSi ganivi Zala gamoiTvleba formuliT:

$$Q=\frac{G}{k_2}\left(\theta-\frac{\partial W}{\partial x}\right) \tag{14}$$

Sesabamisad Caiwereba qveda boloze sasazRvro piroba ganivi ZalisaTvis $\frac{G}{k_2}\left[\theta_1-\frac{1}{2h}\left(W_2-W_0\right)\right]=Q_0(t)$. Tu qveda bolo Camagrebulia saZirkvelis filaSi, maSin $\theta_1=0$ da $W_0=\frac{2k_2hQ_0(t)}{G}+W_2$; mRunavi momentis nulTan tolobis piroba ki mogvcems $M=EI\frac{\partial\theta}{\partial x}=\frac{EI}{2h}\left(\theta_1-\theta_0\right)=0$, e.i. $\theta_0=\theta_2$. zeda boloze $m=m*$ $\theta_{m*}=0,\quad U_{m*}=0$.

SemoviRoT uganzomilebo koordinatebi $\eta=\frac{x}{L}$ da $\bar{t}=\frac{t}{t_0}$. warmoebulebi grZivi koordinatiT warmovadginoT sasruli sxvaobebis daxmarebiT, maSin sistema (1.2) miiRebs saxes:

$$\begin{aligned}&\frac{\partial^2W_m}{\partial\bar{t}^2}=c_1\left(\theta_{m+1}-\theta_{m-1}\right)+c_2\left(W_{m+1}-2W_m+W_{m-1}\right),\\&\frac{\partial^2\theta_m}{\partial\bar{t}^2}=c_3\left(\theta_{m+1}-2\theta_m+\theta_{m-1}\right)+c_4\theta_m+c_5\left(U_{m+1}-U_{m-1}\right),\end{aligned} \tag{15}$$

sadac

$$c_1=\frac{t_0^2G}{2\rho k_1L\delta},\qquad c_2=-\left(\frac{G}{k_2}-Q_x\right)\frac{t_0^2}{\rho FL^2\delta^2},\qquad c_3=\frac{Et_0^2}{\rho L^2\delta^2},$$

$$c_4=\frac{Gt_0^2}{k_2\rho I},\qquad c_5=-\frac{Gt_0^2}{2k_2\rho IL\delta},\qquad c_6=c_4-2c_3.$$

Tu aqac pirvel warmoebulebs aRvniSnavT axali cvladebiT $\frac{\partial W_m}{\partial \bar{t}} = \overline{W}_m$, $\frac{\partial \theta_m}{\partial \bar{t}} = \bar{\theta}_m$, miviRebT pirveli rigis gantolebaTa sistemas. maSasadame, yovel wertilSi daiwereba oTxi gantoleba. imisaTvis, rom ucnobebi iyos danomrili mimdevrobiT, SemoviRoT Semdegi aRniSvnebi:

$$W_1 = y_1, \quad \overline{W}_1 = y_2, \quad \theta_1 = y_3, \quad \bar{\theta}_1 = y_4,$$
$$W_2 = y_5, \quad \overline{W}_2 = y_6, \quad \theta_2 = y_7, \quad \bar{\theta}_2 = y_8$$

da a. S.

sasrulo sxvaobebSi Cawerili warmoebulebi (10) moyvanilia Sua wertilebisaTvis. xist CamagrebaSi (15) sistemis Cawerisas saWiro iqneba θ-s mniSvnelobebis codna Reros gare fiqtiur wertilebSi m=0 da m=m*+1. es mniSvnelobebi ki mocemuli sasazRvro pirobebis mixedviT ar gagvaCnia, amitom θ-s pirveli da meore warmoebulebi m=1 da m=m* wertilebSi warmodgenili iqneba Semdegi saxiT:

$$\frac{\partial \theta_1}{\partial \xi} = \frac{1}{2\delta}(-3\theta_1 + 4\theta_2 - \theta_3), \qquad \frac{\partial^2 \theta_1}{\partial \xi^2} = \frac{1}{\delta^2}(\theta_1 - 2\theta_2 + \theta_3),$$
$$\frac{\partial \theta_{m^*}}{\partial \xi} = \frac{1}{2\delta}(\theta_{m^*-2} - 4\theta_{m^*-1} + 3\theta_{m^*}), \qquad \frac{\partial^2 \theta_{m^*}}{\partial \xi^2} = \frac{1}{\delta^2}(\theta_{m^*-2} - 2\theta_{m^*-1} + \theta_{m^*})$$

analogiuri mdgomareobaa zeda xist CamagrebaSi gadaadgilebis warmoebulebis Cawerisas, amitom gveqneba:

$$\frac{\partial W_{m^*}}{\partial \xi} = \frac{1}{2\delta}(W_{m^*-2} - 4W_{m^*-1} + 3W_{m^*}), \qquad \frac{\partial^2 W_{m^*}}{\partial \xi^2} = \frac{1}{\delta^2}(W_{m^*-2} - 2W_{m^*-1} + W_{m^*})$$

rac Seexeba qveda wertils, iq ganivi Zalis piroba saSualebas gvaZlevs W_0 gamovsaxoT W_2-is da $Q_0(t)$ daxmarebiT.

Tu kvlav 10 wertils aviRebT, gveqneba 40 gantoleba da qveda bolos saZirkvlis filaSi Camagrebis SemTxvevaSi diferencialur gantolebaTa sistemis koeficientebis matricas eqneba saxe (cxrili 2).

qveda boloze mRunavi momentis nulTan tolobis SemTxvevaSi, e.i. roca $\theta_0=\theta_2$ da $\theta_1\neq 0$ kvlav SegviZlia gamoviyenoT (1.10) formulebi. am SemTxvevaSi Seicvleba meore da meoTxe gantolebis koeficientebi.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
1		1																																							
2	$-2c_2$				$2c_2$		$4c_1$				$-c_1$																														$-c_2\frac{k_2Q_0(t)}{G}$
3				1																																					
4							$-2c_3$				c_3																														c_5		
5						1																																			
6	c_2				$-2\ c_2$				c_2		c_1																																
7								1																																		
8	$-\ c_5$						c_6		c_5		c_3																																
9										1																																
10					c_2		$-\ c_1$		$2\ c_2$				c_2		c_1																												
11												1																														
12					$-\ c_5$		c_3				c_6		c_5		c_3																												
13														1																												
14									c_2		$-\ c_1$		$-2c_2$				c_2		c_1																								
15																1																										
16									$-\ c_5$		c_3				c_6		c_5		c_3																								
17																		1																								
18													c_2		$-\ c_1$		$-2c_2$				c_2		c_1																		
19																				1																						
20													$-\ c_5$		c_3				c_6		c_5		c_3																		
21																						1																				
22																	c_2		$-\ c_1$		$-2\ c_2$				c_2		c_1														
23																								1																		
24																	$-\ c_5$		c_3				c_6		c_5		c_3														
25																										1																
26																					c_2		$-\ c_1$		$-2\ c_2$				c_2		c_1										

27																												1													
28																					- c_5		c_3				c_6		c_5		c_3										
29																														1											
30																									c_2		- c_1		-2 c_2				c_2		c_1						
31																																1									
32																									- c_5		c_3				c_6		c_5		c_3						
33																																		1							
34																													c_2		- c_1		-2 c_2								
35																																				1					
36																													- c_5		c_3				c_6						
37																																						1			
38																													c_2		c_1		2 c_2		4 c_1						
39																																								1	
40																													c_5		c_3		-4 c_5		-2 c_3						

Tavisufali wevrebi darCeba igive. meore gantolebaSi $4c_1$ da $-c_1$-is nacvlad gveqneba nulebi, meoTxe gantolebaSi ki $-2c_3$-is nacvlad $2c_3$, c_3-is nacvlad nuli da gaCndeba koeficienti mesame svetSi c_6.

rac Seexeba ganiv Zalebs, isini orive SemTxvevaSi yvela wertilSi, garda m=m* da m=m*-1 wertilebisa, gamoiTvleba (14) formuliT. rac Seexeba mniSvnelobebs aRniSnul or wertilSi, maTTvis, aRebul sakvanZoO wertilebis raodenobis Sesabamisad, gveqneba:

$$Q_9 = \frac{G}{2\delta k_2 L}\left(Y_{35} - Y_{29}\right), \qquad Q_{10} = \frac{G}{2\delta k_2 L}\left(Y_{29} - 4Y_{33}\right).$$

yvela zemoT ganxilul SemTxvevaSi SeiZleba gaTvaliswinebuli iyos Reros gadadgilebis Sedegad mis boloze aRZruli xaxunis Zalebi, romlebic warmoiSveba Reros qveda torsul waxnagsa da grunts Soris. es Zala garemos winaRobis Zalis analogiurad SeiZleba miviRoT gadaadgilebis siCqaris proporciulad, sadac proporciulobis koeficienti k_v damokidebuli iqneba rogorc gruntis saxeobaze, aseve Senobidan gruntze gadmocemul wnevaze. maSasadame (1) gantolebis SemTxvevaSi sasazRvro piroba ganivi ZalisaTvis Caiwereba Semdegnairad:

$$Q_1 = -EI\frac{\partial^3 W_1}{\partial x^3} = -\frac{EI}{2h^3}\left(W_3 - 2W_2 + 2W_0 - W_{-1}\right) = Q_0(t) - k_v\frac{\partial W_1}{\partial t}$$

aqedan ganisazRvreba W_{-1}. qveda boloze momentis nulTan tolobis SemTxvevaSi W_0-sTvis gveqneba (12) gamosaxuleba, mobrunebis kuTxis nulTan tolobis SemTxvevaSi ki (11), romelTa gaTvaliswinebiTac Seicvleba diferencialur gantolebaTa sistemis meore gantoleba. Sesabamisad koeficientebis matricaSi meore svetis meore striqonSi orive SemTxvevaSi gaCndeba damatebiTi koeficienti $c_k = c_2\frac{k_v h^2}{EI}$.

Zvris deformaciis gaTvaliswinebis SemTxvevaSi ganivi Zalis pirobas eqneba saxe: $\frac{G}{k_2}\left(y_3 - \frac{\partial y_1}{\partial x}\right) = Q_0(t) - k_v y_2$. aqedan ganisazRvreba y_0. misi gaTvaliswinebiT diferencialur gantolebaTa sistemis koeficientebis matricis meore svetSi, orive SemTxvevaSi, e.i. wertilovani da filovani saZirkvlebisaTvis, dagvemateba meore striqonSi $-c_{k_1} = -\frac{2c_2 k_2 k_v h}{G}$, meoTxe striqonSi ki $c_{k_2} = \frac{2c_5 k_2 k_v h}{G}$.

davubrundeT isev ganivi Zalis gamoTvlis sakiTxs. (1) gantolebis SemTxvevaSi igulisxmeba, rom $Q = -EI\frac{\partial^3 W}{\partial x^3}$, xolo (12) gantolebis SemTxvevaSi $Q_x = \frac{G}{k_2}\left(\theta - \frac{\partial W}{\partial x}\right)$. pirvel SemTxvevaSi igulisxmeba, rom ganiv sibrtyeSi Zvris moduli usasruloa da ganivi Zala gamoiTvleba drekadi wiris simrudis cvlilebis Sesabamisad. meore SemTxvevaSi Zvris moduli

sasruli sididea da ganivi Zala gamoiTvleba Zvris kuTxis Sesabamisad. realur ReroSi ganivi Zala SeiZleba gamoTvlili iyos rogorc erTi, ise meore formuliT. magram ras miviRebT im SemTxvevaSi Tu gaviTvaliswinebT orive formulas, e.i. Tu vityviT, rom ganivi Zala ReroSi aris am ori gamosaxulebis saSualo ariTmetikuli. e.i.

$$Q_x = \frac{1}{2}\left[-EI\frac{\partial^3 W}{\partial x^3} + \frac{G}{k_2}\left(\theta - \frac{\partial W}{\partial x}\right)\right]$$

Tu am gamosaxulebebs gaviTvaliswinebT (2) sistemaSi da Sesabamisad sasazRvro pirobis dawerisas, maSin saZirkvlis filis SemTxvevaSi diferencialur gantolebaTa sistemis koeficientebis matricas eqneba saxe (cxrili 3). sadac

$$c_7 = \frac{EIt_0^2}{\rho F h^4}, \quad c_8 = c_2 - 4c_7, \quad c_9 = 6c_7 - 2c_2, \quad E_1 = -\frac{EI}{2h^3}, \quad G_1 = -\frac{G}{2k_2 h},$$

$$G_2 = \frac{G_1 - 2E_1}{E_1 - G_1}, \quad E_2 = \frac{E_1}{EI - G_1}, \quad G_3 = \frac{2}{E_1 - G_1}, \quad c_{10} = c_8 + c_7, \quad c_{11} = c_7 - c_{10}E_2,$$

$$c_{12} = c_8 - c_{10}\cdot G_2, \quad c_{13} = c_8 - c_7 \cdot E_2, \quad c_{14} = c_9 - c_7 \cdot G_2, \quad c_{20} = \frac{Et_0^2}{2\rho h^3},$$

$$c_{21} = c_5 - 2c_{20}, \quad c_{24} = -(c_{21} + c_{20}), \quad c_{22} = c_{20} - c_{24}E_2, \quad c_{23} = c_{21} - c_{24}G_2, \quad c_{25} = c_{21} + c_{20}E_2$$

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.	31.	32.	33.	34.	35.	36.	37.	38.	39.	40.	41.
1.		1																																							
2.	c_9				c_{12}		$4c_1$		c_{11}		$-c_1$																														$c_{10}G_3Q_0$
3.				1																																				
4.					c_{23}		$-2c_3$		c_{22}		c_3																														$c_{24}G_3Q_0$
5.						1																																		
6.	c_8				c_{14}				c_{13}		c_1		c_7																												$c_7G_3Q_0$
7.								1																																
8.	$-c_{21}$				$c_{20}G_2$		c_6		c_{25}		c_3		c_{20}																												$-c_{20}G_3Q_0$
9.										1																														
10.	c_7				c_8		$-c_1$		c_9				c_8		c_1		c_7																								
11.												1																												
12.	$-c_{20}$				$-c_{21}$		c_3				c_6		c_{21}		c_3		c_{20}																								
13.														1																										
14.					c_7				c_8		$-c_1$		c_9				c_8		c_1																						
15.																1																								
16.					$-c_{20}$				$-c_{21}$		c_3				c_6		c_{21}		c_3																						
17.																		1																						
18.									c_7				c_8		$-c_1$		c_9				c_8		c_1		c_7															
19.																				1																				
20.									$-c_{20}$				$-c_{21}$		c_3				c_6		c_{21}		c_3		c_{20}															
21.																						1																		
22.													c_7				c_8		$-c_1$		c_9				c_8		c_1		c_7											
23.																								1																
24.													$-c_{20}$				$-c_{21}$		c_3				c_6		c_{21}		c_3		c_{20}										
25.																										1														
26.																	c_7				c_8		$-c_1$		c_9				c_8		c_1		c_7						
27.																												1												
28.																	$-c_{20}$				$-c_{21}$		c_3				c_6		c_{21}		c_3		c_{20}						
29.																														1										
30.																					c_7				c_8		$-c_1$		c_9				c_8		c_1		c_7			
31.																																1								
32.																					$-c_{20}$				$-c_{21}$		c_3				c_6		c_{21}		c_3		c_{20}			
33.																																		1						
34.																									c_7				c_8		$-c_1$		c_9							
35.																																				1				
36.																									$-c_{20}$				$-c_{21}$		c_3				c_6					
37.																																					1			
38.																													c_7				c_8		$-c_1$		c_9			
39.																																							1		
40.																													$-c_{20}$				$-c_{21}$		c_3					

ganapira wertilebSi gansxvavebulad Caiwereba ganivi Zalis gamosaxulebebic:

$$Q(1)=Q_0(t),\qquad Q(2)=-\frac{EI}{2h^3}\left(U_7-2U_5+U_3\right),\qquad Q(8)=-\frac{EI}{2h^3}\left(-2U_1+2U_{15}-U_{13}\right),$$

$$Q(9)=-\frac{EI}{2h^3}\left(3U_{17}-U_{15}\right)$$

im SemTxvevaSi, Tu qveda bolo Camagrebulia saZirkvlis filaSi, e.i. mobrunebis kuTxe udris nuls, gantolebaTa sistemis koeficientebis matrica darCeba igive, Seicvleba mxolod meore da meoTxe striqonebi. kerZod, meore striqonSi $-c_2,\ c_4,\ -c_2$-is nacvlad gveqneba $-c_6,\ c_8,\ -c_2$, xolo meoTxe striqonSi $+c_4,\ -c_7,\ c_4,\ -c_1$. rac Seexeba ganivi Zalis gamosaxulebebs, maTTvis gveqneba:

$$Q(1)=Q_0(t),\qquad Q(2)=-\frac{EI}{2h^3}\left(U_7-2U_5-U_3+2U_1\right).$$

Zvris deformaciisa da brunvis inerciis gaTvaliswinebis SemTxvevaSi, e.i. roca saqme gvaqvs (1.2) sistemasTan, radganac torsuli kveTis sruli mobruneba warmoadgens Zvris deformaciisa da geometriuli RerZis mobrunebis kuTxis jams $\theta=\gamma+\frac{\partial W}{\partial x}$, amitom xisti Camagrebis SemTxvevaSi mobrunebis kuTxis nulTan tolobis piroba iqneba $\theta=0$. am SemTxvevaSi ganivi Zala gamoiTvleba formuliT:

$$Q=\frac{G}{k_2}\left(\theta-\frac{\partial W}{\partial x}\right) \tag{14}$$

Sesabamisad Caiwereba qveda boloze sasazRvro piroba ganivi ZalisaTvis $\frac{G}{k_2}\left[\theta_1-\frac{1}{2h}\left(W_2-W_0\right)\right]=Q_0(t)$. Tu qveda bolo Camagrebulia saZirkvelis filaSi, maSin $\theta_1=0$ da $W_0=\frac{2k_2hQ_0(t)}{G}+W_2$; mRunavi momentis nulTan tolobis piroba ki mogvcems $M=EI\frac{\partial\theta}{\partial x}=\frac{EI}{2h}\left(\theta_1-\theta_0\right)=0$, e.i. $\theta_0=\theta_2$. zeda boloze $m=m*$ $\theta_{m*}=0,\quad U_{m*}=0$.

SemoviRoT uganzomilebo koordinatebi $\eta=\frac{x}{L}$ da $\bar{t}=\frac{t}{t_0}$. warmoebulebi grZivi koordinatiT warmovadginoT sasruli sxvaobebis daxmarebiT, maSin sistema (2) miiRebs saxes:

$$\begin{aligned}&\frac{\partial^2W_m}{\partial\bar{t}^2}=c_1\left(\theta_{m+1}-\theta_{m-1}\right)+c_2\left(W_{m+1}-2W_m+W_{m-1}\right),\\&\frac{\partial^2\theta_m}{\partial\bar{t}^2}=c_3\left(\theta_{m+1}-2\theta_m+\theta_{m-1}\right)+c_4\theta_m+c_5\left(U_{m+1}-U_{m-1}\right),\end{aligned} \tag{15}$$

sadac

$$c_1 = \frac{t_0^2 G}{2\rho k_1 L\delta}, \qquad c_2 = -\left(\frac{G}{k_2} - Q_x\right)\frac{t_0^2}{\rho F L^2 \delta^2}, \qquad c_3 = \frac{E t_0^2}{\rho L^2 \delta^2},$$

$$c_4 = \frac{G t_0^2}{k_2 \rho I}, \qquad c_5 = -\frac{G t_0^2}{2k_2 \rho I L\delta}, \qquad c_6 = c_4 - 2c_3 .$$

Tu aqac pirvel warmoebulebs aRvniSnavT axali cvladebiT $\frac{\partial W_m}{\partial \bar{t}} = \overline{W}_m, \quad \frac{\partial \theta_m}{\partial \bar{t}} = \bar{\theta}_m$, miviRebT pirveli rigis gantolebaTa sistemas. maSasadame, yovel wertilSi daiwereba oTxi gantoleba. imisaTvis, rom ucnobebi iyos danomrili mimdevrobiT, SemoviRoT Semdegi aRniSvnebi:

$$W_1 = y_1, \quad \overline{W}_1 = y_2, \quad \theta_1 = y_3, \quad \bar{\theta}_1 = y_4,$$
$$W_2 = y_5, \quad \overline{W}_2 = y_6, \quad \theta_2 = y_7, \quad \bar{\theta}_2 = y_8$$

da a. S.

sasrulo sxvaobebSi Cawerili warmoebulebi (10) moyvanilia Sua wertilebisaTvis. xist CamagrebaSi (15) sistemis Cawerisas saWiro iqneba θ-s mniSvnelobebis codna Reros gare fiqtiur wertilebSi m=0 da m=m*+1. es mniSvnelobebi ki mocemuli sasazRvro pirobebis mixedviT ar gagvaCnia, amitom θ-s pirveli da meore warmoebulebi m=1 da m=m* wertilebSi warmodgenili iqneba Semdegi saxiT:

$$\frac{\partial \theta_1}{\partial \xi} = \frac{1}{2\delta}(-3\theta_1 + 4\theta_2 - \theta_3), \qquad \frac{\partial^2 \theta_1}{\partial \xi^2} = \frac{1}{\delta^2}(\theta_1 - 2\theta_2 + \theta_3),$$

$$\frac{\partial \theta_{m^*}}{\partial \xi} = \frac{1}{2\delta}(\theta_{m^*-2} - 4\theta_{m^*-1} + 3\theta_{m^*}), \qquad \frac{\partial^2 \theta_{m^*}}{\partial \xi^2} = \frac{1}{\delta^2}(\theta_{m^*-2} - 2\theta_{m^*-1} + \theta_{m^*})$$

analogiuri mdgomareobaa zeda xist CamagrebaSi gadaadgilebis warmoebulebis Cawerisas, amitom gveqneba:

$$\frac{\partial W_{m^*}}{\partial \xi} = \frac{1}{2\delta}(W_{m^*-2} - 4W_{m^*-1} + 3W_{m^*}), \qquad \frac{\partial^2 W_{m^*}}{\partial \xi^2} = \frac{1}{\delta^2}(W_{m^*-2} - 2W_{m^*-1} + W_{m^*})$$

rac Seexeba qveda wertils, iq ganivi Zalis piroba saSualebas gvaZlevs W_0 gamovsaxoT W_2-is da $Q_0(t)$ daxmarebiT.

Tu kvlav 10 wertils aviRebT, gveqneba 40 gantoleba

qveda boloze mRunavi momentis nulTan tolobis SemTxvevaSi, e.i. roca $\theta_0=\theta_2$ da $\theta_1\neq 0$ kvlav SegviZlia gamoviyenoT (10) formulebi. am SemTxvevaSi Seicvleba meore da meoTxe gantolebis koeficientebia.

Tavisufali wevrebi darCeba igive. meore gantolebaSi $4c_1$ da $-c_1$-is nacvlad gveqneba nulebi, meoTxe gantolebaSi ki $-2c_3$-is nacvlad $2c_3$, c_3-is nacvlad nuli da gaCndeba koeficienti mesame svetSi c_6.

rac Seexeba ganiv Zalebs, isini orive SemTxvevaSi yvela wertilSi, garda m=m* da m=m*-1 wertilebisa, gamoiTvleba (14) formuliT. rac Seexeba mniSvnelobebs aRniSnul or wertilSi, maTTvis, aRebul sakvanZoO wertilebis raodenobis Sesabamisad, gveqneba:

$$Q_9 = \frac{G}{2\delta k_2 L}\left(Y_{35} - Y_{29}\right), \qquad Q_{10} = \frac{G}{2\delta k_2 L}\left(Y_{29} - 4Y_{33}\right).$$

yvela zemoT ganxilul SemTxvevaSi SeiZleba gaTvaliswinebuli iyos Reros gadadgilebis Sedegad mis boloze aRZruli xaxunis Zalebi, romlebic warmoiSveba Reros qveda torsul waxnagsa da grunts Soris. es Zala garemos winaRobis Zalis analogiurad SeiZleba miviRoT gadaadgilebis siCqaris proporciulad, sadac proporciulobis koeficienti k_v damokidebuli iqneba rogorc gruntis saxeobaze, aseve Senobidan gruntze gadmocemul wnevaze. maSasadame (1) gantolebis SemTxvevaSi sasazRvro piroba ganivi ZalisaTvis Caiwereba Semdegnairad:

$$Q_1 = -EI\frac{\partial^3 W_1}{\partial x^3} = -\frac{EI}{2h^3}\left(W_3 - 2W_2 + 2W_0 - W_{-1}\right) = Q_0(t) - k_v\frac{\partial W_1}{\partial t}$$

aqedan ganisazRvreba W_{-1}. qveda boloze momentis nulTan tolobis SemTxvevaSi W_0-sTvis gveqneba (12) gamosaxuleba, mobrunebis kuTxis nulTan tolobis SemTxvevaSi ki (11), romelTa gaTvaliswinebiTac Seicvleba diferencialur gantolebaTa sistemis meore gantoleba. Sesabamisad koeficientebis matricaSi meore svetis meore striqonSi orive SemTxvevaSi gaCndeba damatebiTi koeficienti $c_k = c_2\frac{k_v h^2}{EI}$.

Zvris deformaciis gaTvaliswinebis SemTxvevaSi ganivi Zalis pirobas eqneba saxe: $\frac{G}{k_2}\left(y_3 - \frac{\partial y_1}{\partial x}\right) = Q_0(t) - k_v y_2$. aqedan ganisazRvreba y_0. misi gaTvaliswinebiT diferencialur gantolebaTa sistemis koeficientebis matricis meore svetSi, orive SemTxvevaSi, e.i. wertilovani da filovani saZirkvlebisaTvis, dagvemateba meore striqonSi $-c_{k_1} = -\frac{2c_2 k_2 k_v h}{G}$, meoTxe striqonSi ki davubrundeT isev ganivi Zalis gamoTvlis sakiTxs. (1) gantolebis SemTxvevaSi igulisxmeba, rom $Q = -EI\frac{\partial^3 W}{\partial x^3}$, xolo (.2) gantolebis SemTxvevaSi $Q_x = \frac{G}{k_2}\left(\theta - \frac{\partial W}{\partial x}\right)$. pirvel SemTxvevaSi igulisxmeba, rom ganiv sibrtyeSi Zvris moduli usasruloa da ganivi Zala gamoiTvleba drekadi wiris simrudis cvlilebis Sesabamisad. meore SemTxvevaSi Zvris moduli sasruli sididea da ganivi Zala gamoiTvleba Zvris kuTxis Sesabamisad. realur ReroSi ganivi Zala SeiZleba gamoTvlili iyos rogorc erTi, ise meore formuliT. magram ras miviRebT im SemTxvevaSi Tu gaviTvaliswinebT orive formulas, e.i.

Tu vityviT, rom ganivi Zala ReroSi aris am ori gamosaxulebis saSualo ariTmetikuli. e.i.

$$Q_x = \frac{1}{2}\left[-EI\frac{\partial^3 W}{\partial x^3} + \frac{G}{k_2}\left(\theta - \frac{\partial W}{\partial x}\right)\right]$$

Tu am gamosaxulebebs gaviTvaliswinebT (2) sistemaSi da Sesabamisad sasazRvro pirobis dawerisas, maSin saZirkvlis filis SemTxvevaSi diferencialur gantolebaTa sistemis koeficientebis matricas eqneba saxe

1.3 Sesrulebuli gamoTvlebis Sedegebi da maTi analizi

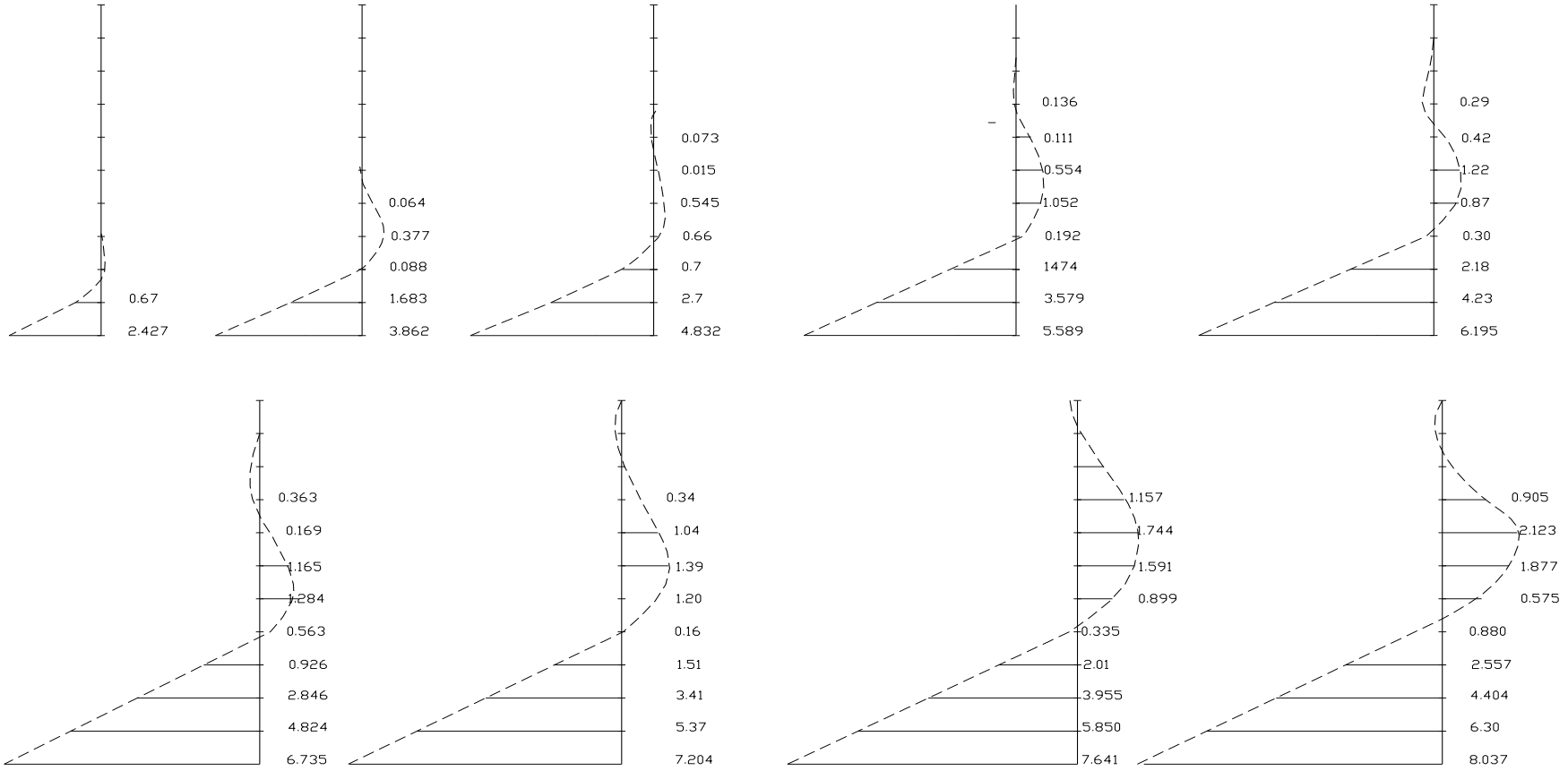
mesame paragrafSi moyvanilia gamoTvlebis Sedegebi da maTi analizi. mocemulia gadaadgilebebisa da ganivi Zalis epiurebi, rogorc wertilovani saZirkvlebis, aseve filis SemTxvevaSi. epiurebi moyvanilia rogorc erTjeradi, aseve ganmeorebiTi dartymis SemTxvevaSi.

(1) gantolebis amoxsnis Sedegad miRebuli Sedegebi svetisaTvis, romlis bolozec mRunavi momenti nulia, mocemulia nax..4÷7. es Sedegebi miRebulia RerosaTvis, romlis sigrZea 270 sm, ganivkveTis zomebia 40X40 sm. Reros sigrZe dayofilia aTi sakvanZo wertiliT cxra tol monakveTad. drois bijad aRebulia $1\cdot10^{-6}$ wm. ganivi Zala moqmedebs sawyis momentSi am bijis naxevari drois ganmavlobaSi. nax. 1.4-ze warmodgenilia gadaadgilebis epiurebi drois sxvadasxva momentisaTvis, romelTa Soris Sualedi mudmivia. drois igive momentebisaTvis (nax. 1.5) warmodgenilia ganivi Zalebis epiurebi. es ganivi Zala gamowveulia Q_0=1 damrtymeli Zalis moqmedebis Sedegad. nax. 1.6-ze warmodgenilia drois igive monakveTis pirveli dartymidan 400 bijis Semdeg ganmeorebiTi dartymis Sedegad miRebuli gadaadgilebebis epiurebi, xolo Sesabamisi ganivi Zalebis epiurebi warmodgenilia nax. 1.7. gamoTvlebi Sesrulebulia agreTve im SemTxvevisaTvis, roca qveda bolo Camagrebulia saZirkvlis filaSi, e.i. mobrunebis kuTxe nulis tolia. Sesabamisi epiurebi erTjeradi dartymisas warmodgenilia nax. 1.8, gadaadgilebis epiurebi da nax. 1.9 Sesabamisi ganivi Zalebi. ganmeorebiTi dartymisas miRebuli Sedegebi warmodgenilia Sesabamisad nax. 1.10 da nax. 1.11-ze.

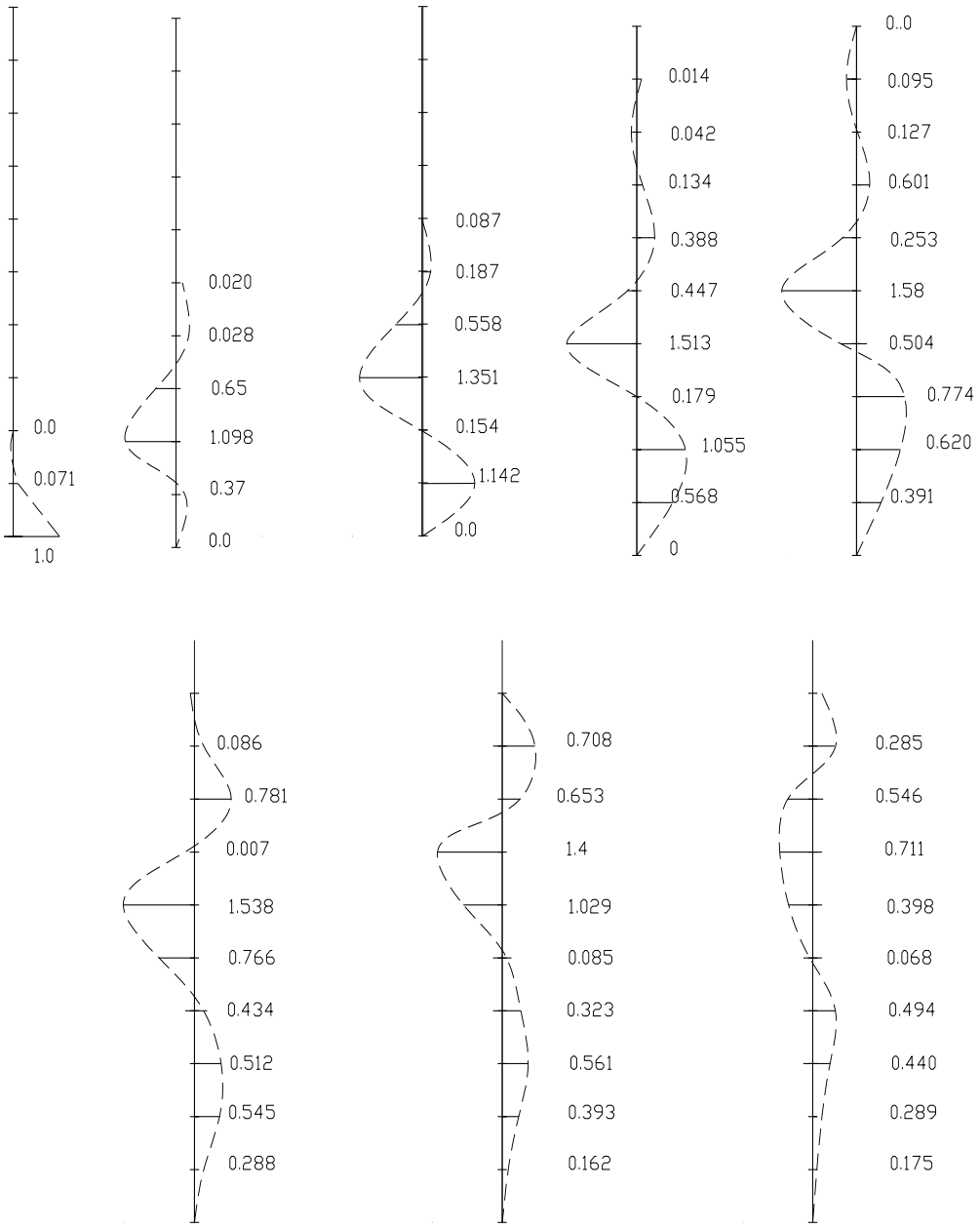
miRebuli Sedegebis analizi gviCvenebs, rom erTjeradi darymis Sedegad Reros boloSi momentis nulTan tolobis SemTxvevaSi gamowveuli gadaadgilebebi da aRZruli ganivi Zalebi vrceldeba Reros gaswvriv talRis gavrcelebis siCqariT.

CvenTvis sainteresoa ganivi Zalis amplitudis gadadgileba Reros gaswvriv da misi cvlileba drois mixedviT. ganivi Zalis amplituda sididiT metia damrtymeli Zalis mniSvnelobaze, xolo TviT ganivi Zala niSancvladia. analogiuri Sedegi miRebuli aqvs a. filins [6], romelsac ganxiluli aqvs ganawilebuli masis mqone konsoluri Reros rxevis amocana, roca konsolis boloze moqmedebs perioduli Zala P_0 sinωt. (1) gantolebis

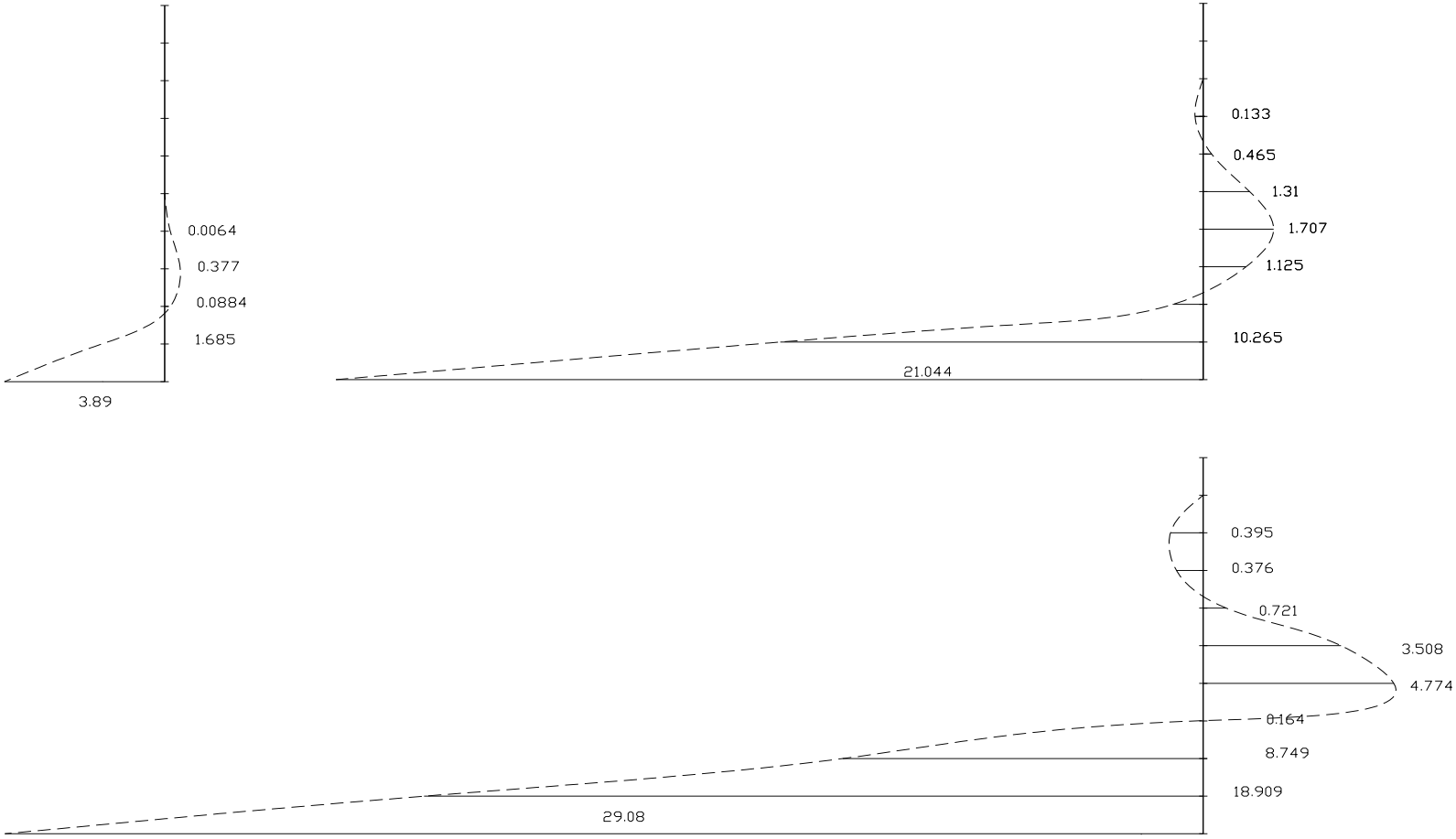
amonaxseni moZebnilia saxiT X(x)sinωt. X(x)--is epiurebi ω-s ori sxvadasxva mniSvnelobisas mocemuli (nax. 1.12). rogorc am naxazidan



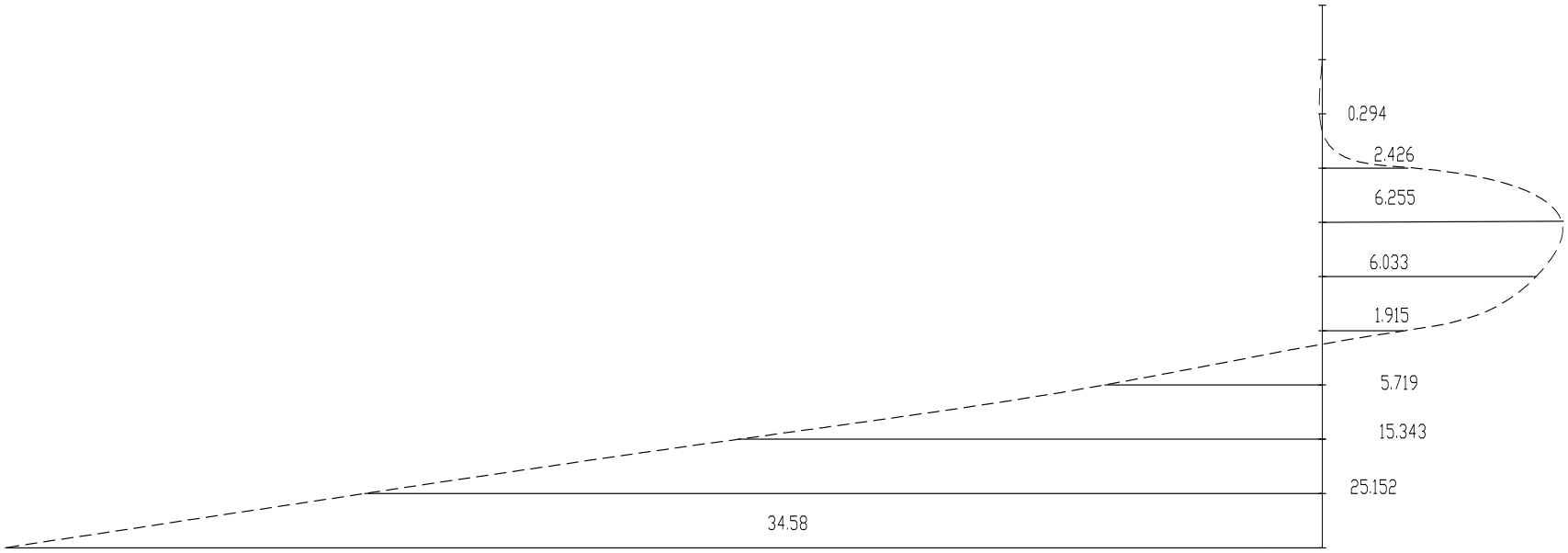
A nax. 14. gadaadgil ebis epiur ebi wert il ovani
saZir kvl is SemTxvevaSi



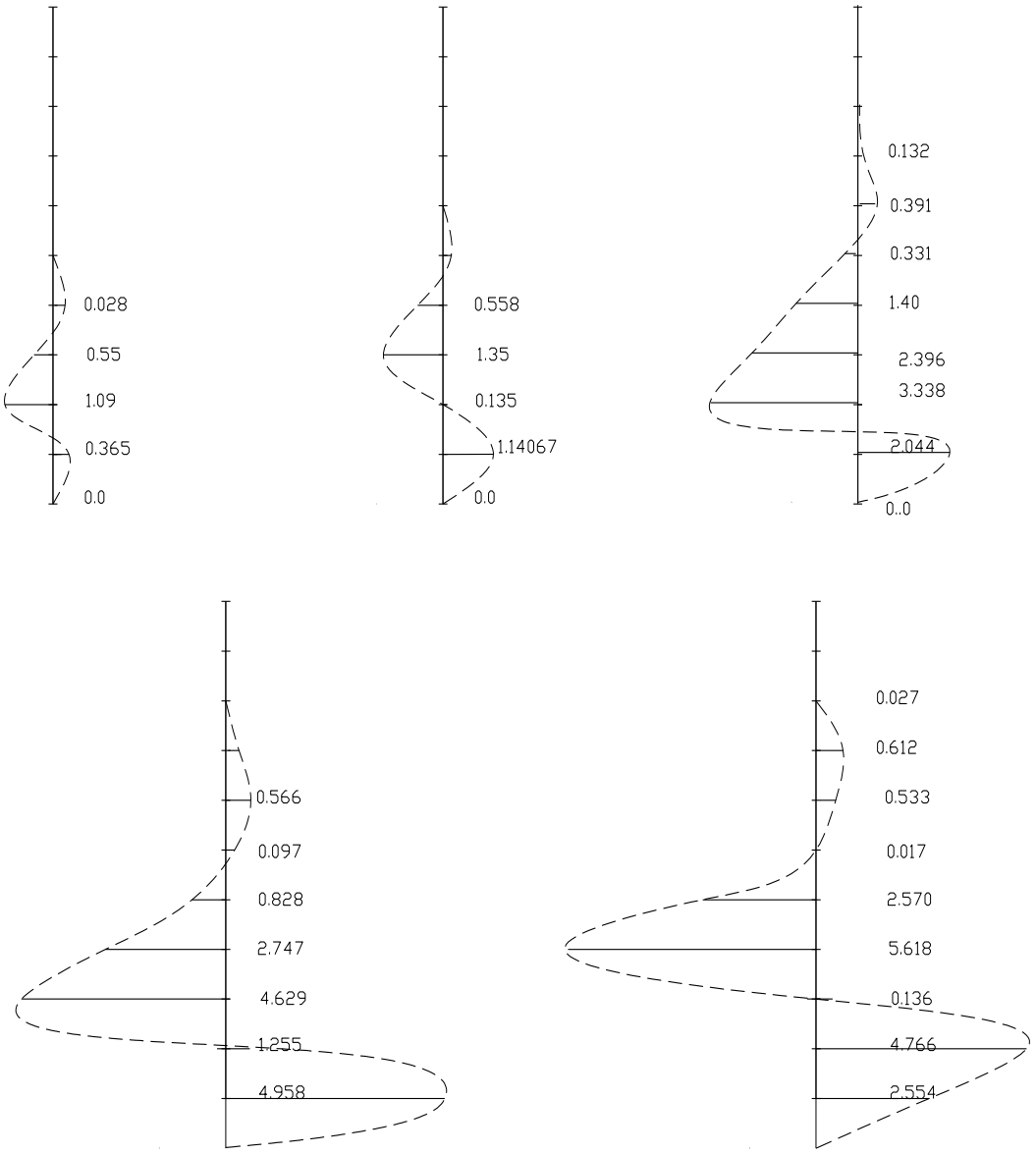
A nax. 15. ganivi Zal ebis epiurebi



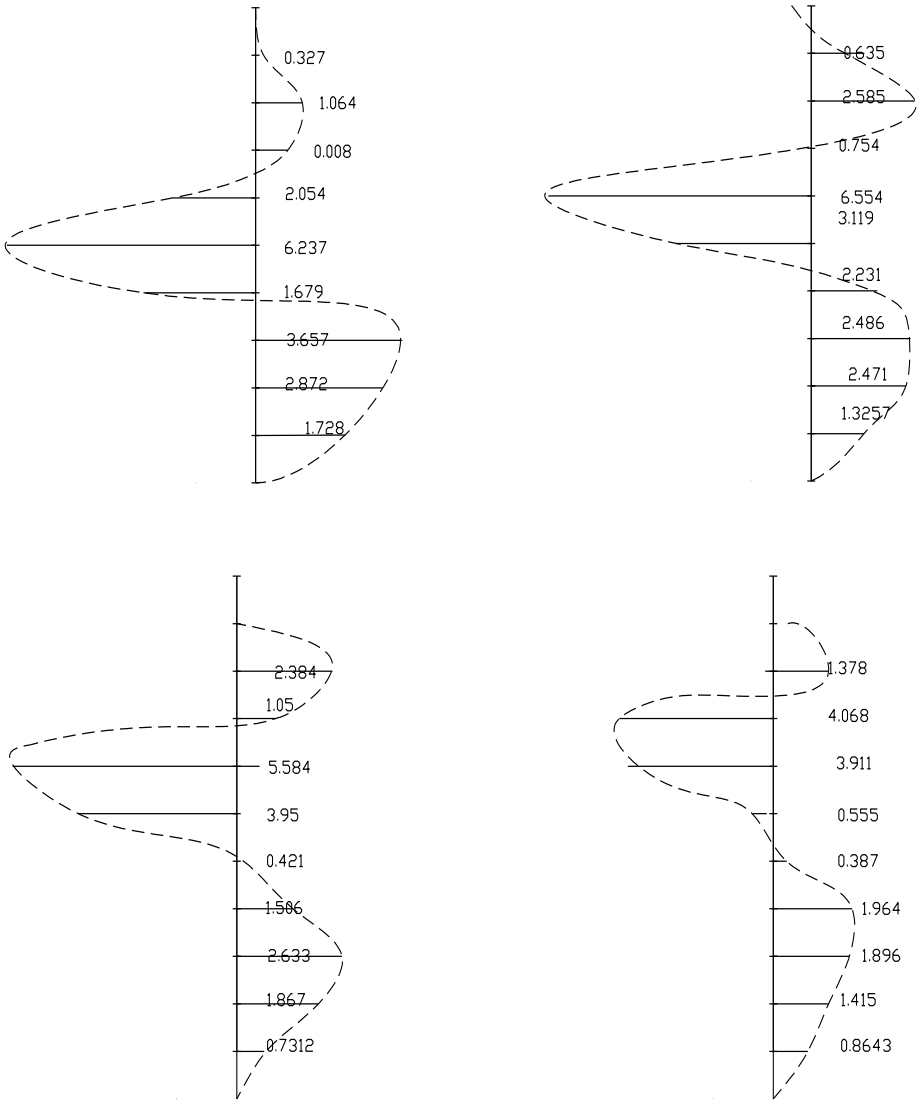
A nax. 16. gadaadgil ebis epiur ebi ganmeor ebiTi
dar tymisas



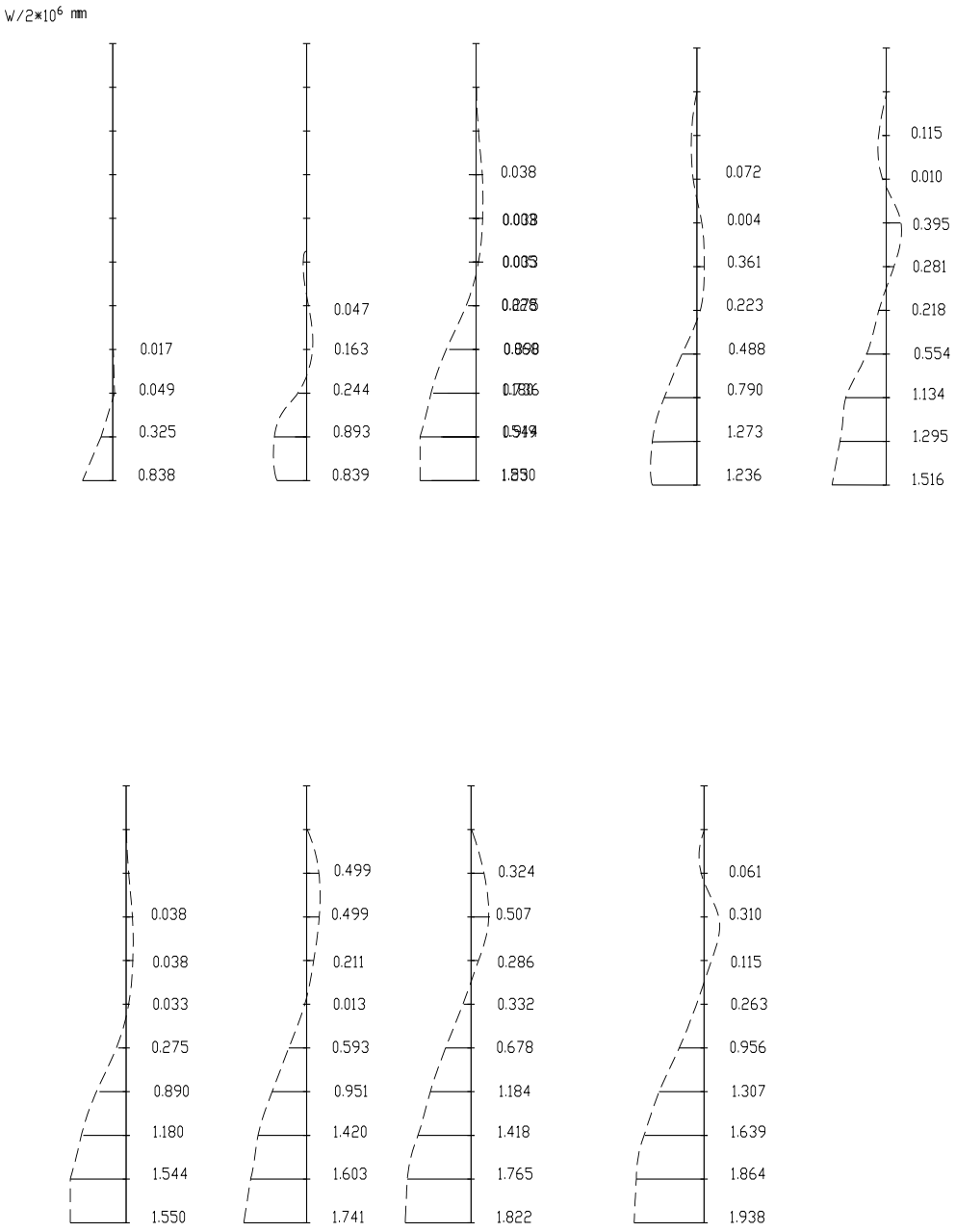
ა. nax. 16. gadaadgil ebis epiur ebi ganmeor ebiTi
dar tymisas



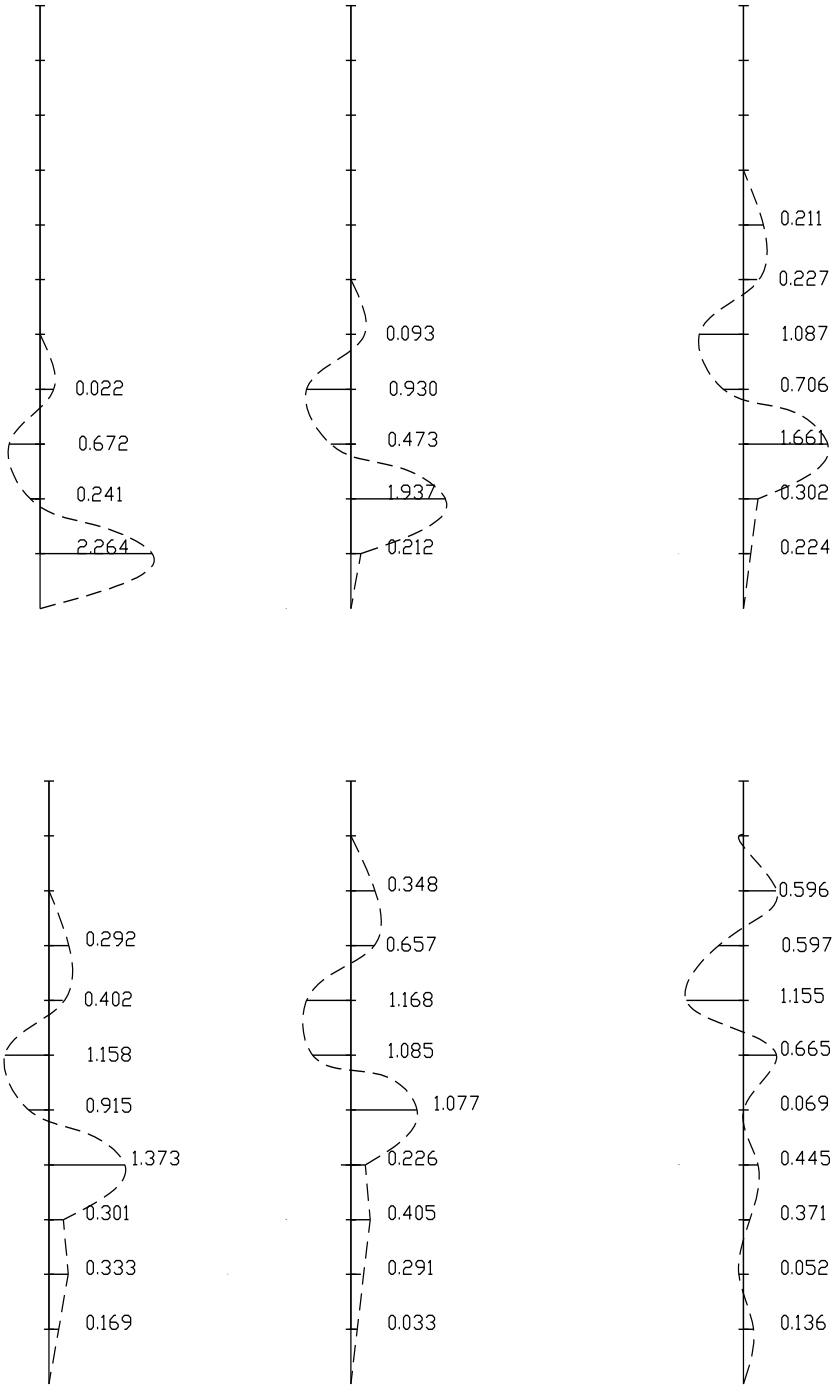
A nax. 17. ganivi Zal ebis epiur ebi ganmeor ebiTi dar tymisas



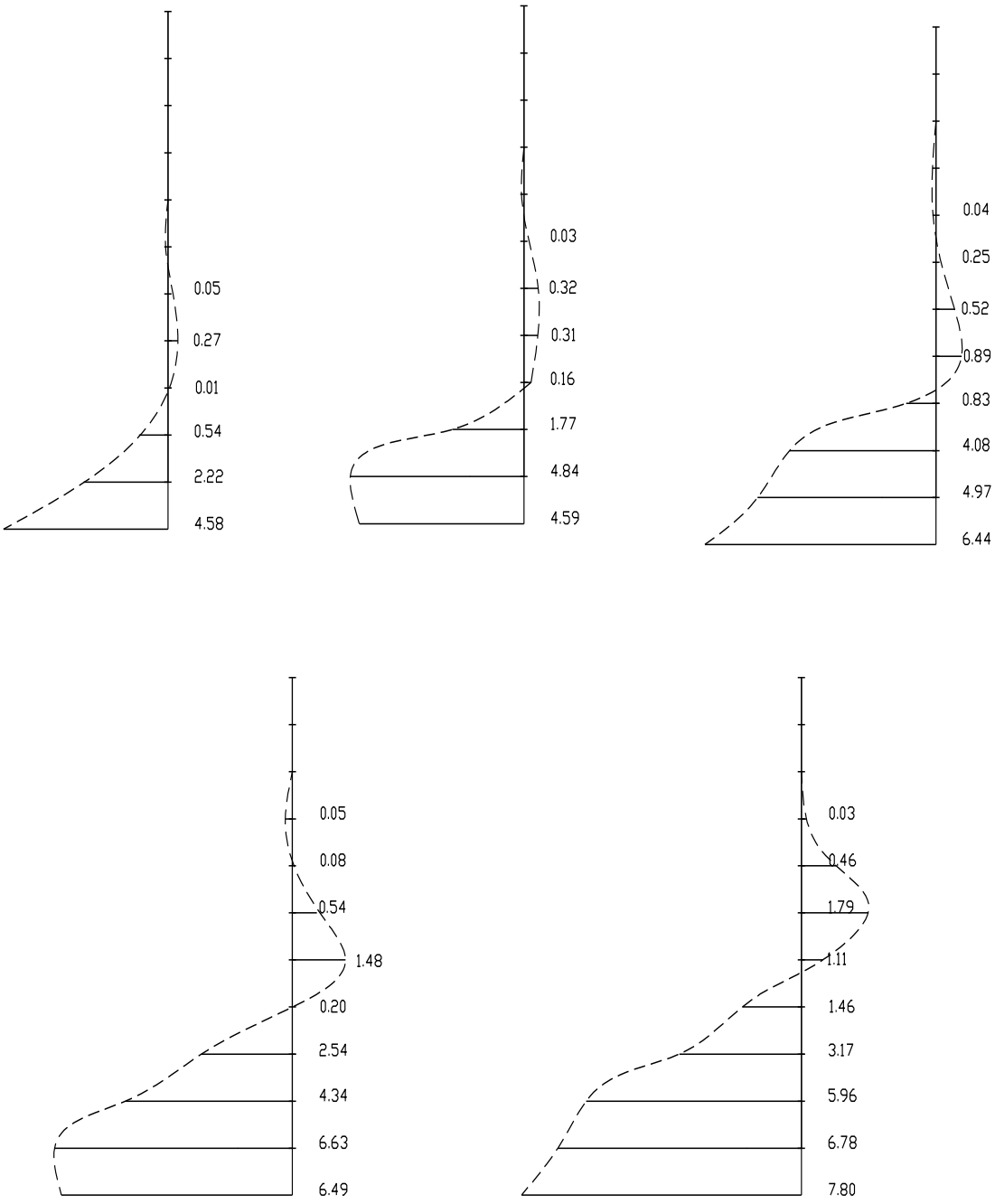
A nax. 17. ganivi Zal ebis epiur ebi ganmeor ebiTi dar tymisas



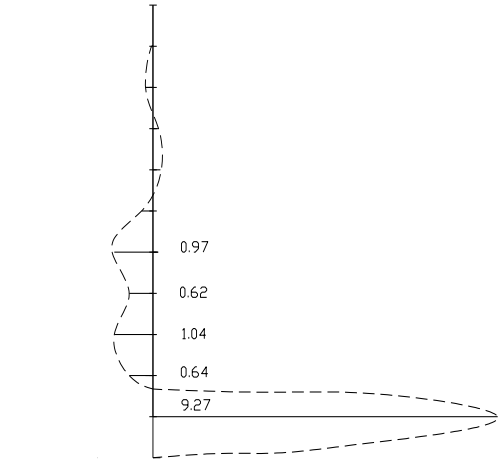
A nax. 1.8. gadaadgil ebis epiur ebi saZir kvl is fil is SemTxvevaSi (yovel i 5.10^{-5} wmis Semdeg)

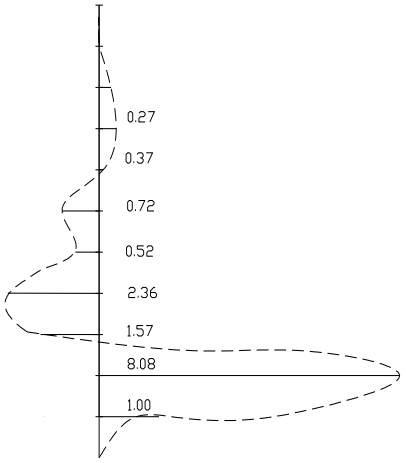


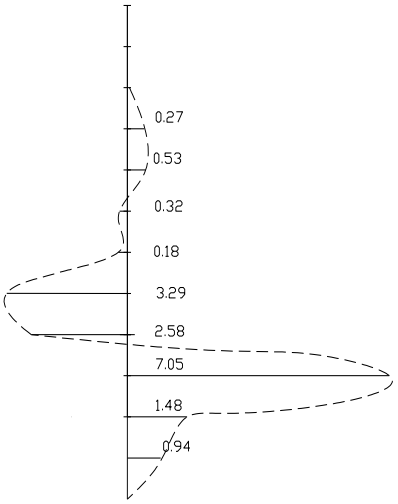
A nax. 19. ganivi Zal i s epi ur ebi

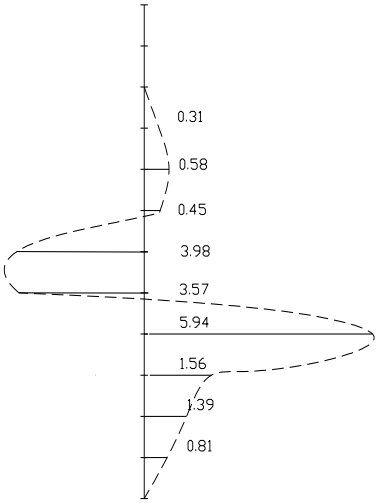


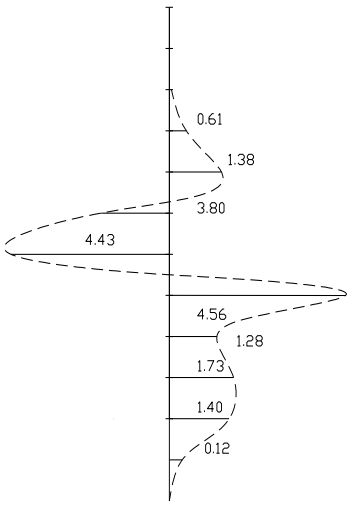
A nax. 1.10. gadaadgil ebis epiur ebi ganmeor ebiTi dar tymisas



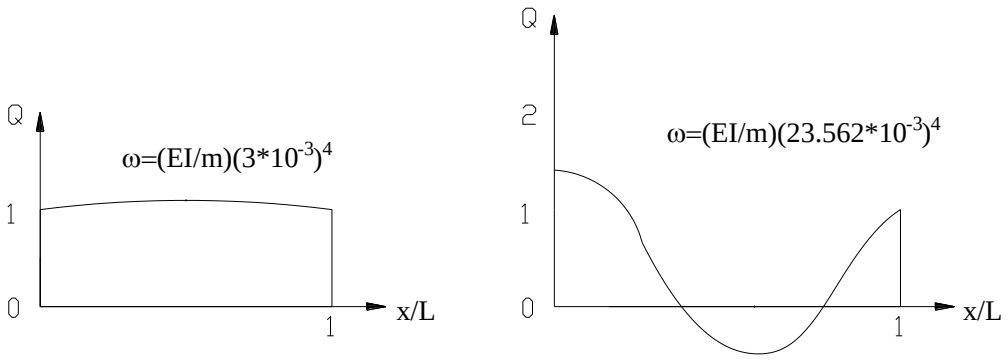








A nax. 1.11. ganivi Zal ebis epiur ebi ganmeor ebiTi dar tymisas



A nax. 1.12. ganivi Zal ebi ω-s sxvadasxva mniSvnel obisaTvis

Cans ω-s didi mniSvnelobisas ganivi Zala niSancvladia da misi maqsimaluri mniSvneloba metia P_0-ze. rac metad mniSvnelovania CvenTvis, ganivi Zala Tavis maqsimums aRwevs malis SuaSi, romelic warmoadgens yvelaze sust kveTs. es gasagebicaa amJamad moqmedi inerciul rxeviTi Teoriis mixedviT maqsimalurad daZabul kveTebs warmoadgenen Reros boloebi da misi mimdebare ubnebi. amitomac ganivi armatura am ubnebSi mowyobilia minimaluri bijiT, rac orjer da zogjer metadac mcirea malis SuaSi ganivi armaturebis bijze. miRebuli ganivi Zalebis mniSvnelobebidan gamomdinare svetebis Sua nawili ganivi Zalebis miRebis TvalsazrisiT unda iyos ara Tu naklebad, aramed ufro metad armirebuli vidre danarCeni kveTebi.

daaxloebiT analogiuri mdgomareobaa qveda boloze mobrunebis kuTxis nulTan tolobis SemTxvevaSi. aqac ganivi Zala ufro meti sididis, vidre moqmedi datvirTva, gairbens mTel Reros. mxolod im gansxvavebiT, rom maqsimaluri mniSvnelobebi gvaqvs Tavidanve ramdenime wertilSi moqmedi Zalis niSniT, xolo Semdeg ganivi Zala odnav mcirdeba, magram rCeba moqmed Zalaze meti, icvlis niSans da gadaadgildeba Reros bolosaken. xist CamagrebaSi airekleba niSnis Seucvlelad gadadgildeba qveda bolosaken, sadac kvlav airekleba, oRond ukve icvlis niSans da gadadgildeba xisti Camagrebisaken. aqac SeiZleba gakeTdes igive daskvna Reros armirebis Sesaxeb, rac gakeTebuli iyo wina SemTxvevaSi.

ganmeorebiTi dartymisas miRebuli Sedegebis analizi gviCvenebs, rom am SemTxvevaSi rogorc gadadgilebebi, aseve ganivi Zalebi ramdenjerme izrdeba da miT ufro mniSvnelovani xdeba mTeli Reros sigrZeze armirebis sakiTxi. es gasagebicaa, radgan miwisZvrisas gvaqvs mTeli rigi qaosuri dartymebisa.

gamoTvlebis gziT iyo mcdeloba Segvemowmebina mosazreba imis Sesaxeb, rom Reros gadaWra SeiZleba iyos gamowveuli pirdapiri da areklili talRebis Sekrebis Sedegad. e.i. pirveladi dartymisas areklili da meoradi dartymiT gamowveuli pirdapiri talRebisa. am mizniT ganmeorebiTi dartyma ganxorcielebuli iyo daaxloebiT im dros, roca pirveladi talRa miaRwevda xist Camagrebas, rom igi e.i. areklili talRa Sexvedroda meorad talRas SuaSi. gamoTvlebis Sedegad miviReT, rom ganivi Zalebis mniSvnelobani iseTivea, rogorc meoradi dartymisas, romelic ganxorcielda pirveladi dartymidan garkveuli drois Semdeg, roca pirvelad talRas jer ar miuRwevia CamagrebisaTvis. aqedan daskvna, rom meoradi dartyma TavisTavad iwvevs ganivi Zalebisa da gadaadgilebebis imdenad gazrdas, rom pirveladi mniSvnelobebis gavlena umniSvneloa. aq, rogorc Cans, arsebiTia is faqti, rom dartyma xorcieldeba Reroze, romelic ukve ganicdis rxevas pirveladi dartymis Sedegad.

gamoTvlebi Sesrulebuli iyo agreTve dartymis xangrZlivobis gavlenis Seswavlis mizniT. gaanalizebuli Sedegebi, rogorc aRniSnuli iyo, miRebulia drois bijis naxevris ganmavlobaSi damrtymeli Zalis moqmedebis dros. dartymis xangrZliobis cvlileba iwvevda rogorc gadaadgilebebis, aseve ganivi Zalebis adekvatur cvlilebas.

Tu SevadarebT ganiv Zalebs qveda bolos Camagrebis ganxilul SemTxvevaSi, SeiZleba davaskvnaT, rom ganivi Zalebi metia, roca qveda bolo Camagrebulia saZirkvlis filaSi, e.i., roca mobrunebis kuTxe tolia nulis.

1.4 Reros grZivi rxevis gantolebis amoxsna

meoTxe paragrafSi mocemulia Reros grZivi rxevis gantolebis amoxsna dartymis efeqtis gamoyenebiT. mocemulia rxevis gantolebis analizuri amoxsna da aRniSnulia misi naklovanebebi, rac gamoixateba erTis mxriv ararealuri gadaadgilebebis miRebaSi da meores mxriv siCqarisa da aCqarebis gansazRvris SeuZleblobaSi. aqve moyvanilia am gantolebis amoxsnis ricxviTi gza da gamoTvlebis Sedegad miRebuli gadaadgilebis siCqarisa da aCqarebis epiurebi

Reros grZivi rxevis gantolebas aqvs saxe:

$$\frac{\partial^2 W}{\partial x^2} a^2 - \frac{\partial^2 W}{\partial t^2} = 0$$

es gantoleba, rogorc misi amoxsna, cnobilia ukve didi xania da klasikuri amoxsnebis saxiT Sesulia TiTqmis yvela umaRlesi saswavleblis saxelmZRvaneloSi. miT ufro sayuradReboa is faqti, rom sul ramdenime wlis win ukraineli mecnieris kozaCukis mier aRniSnuli iyo is uzustobani, rac daSvebulia sawyisi da sasazRvro pirobebis

Camoyalibebisas da ufro metic, furies mwkrivebSi miRebuli amonaxsnebis sruli Seusabamoba am gantolebis mier aRweril rxevis procesTan. kozaCukis mier gamaxvilebulia yuradReba im garemoebazec, rom SeSfoTeba drekad sxeulSi vrceldeba ara myisierad, aramed garkveuli siCqariT, romelic warmoadgens am sxeulSi bgeris gavrcelebis siCqares. am movlenis, rogorc faqtis konstatacia xdeba TiTqos yovelTvis, magram sakiTxi amiT Tavdeba da is ar Rebulobs gamoxatulebas amocanis maTematikurad Camoyalibebis dros. kozaCukis [12, 13] mier gaanalizebulia klasikuri amoxsnebis winaaRmdegobrivi xasiaTis mizezebi da mocemulia maTi daZlevis gzebi. miuxedavad amisa Jurnal `Прикладная механика" т.41, №5, 2005 w. gamoqveynda ukraineli mecnieris plaxtienkos statia [14], sadac avtors mohyavs rxevis gantolebis amonaxseni, roca qveda boloTi xistad Camagrebuli Rero ganicdis zeda boloze impulsis zemoqmedebas. impulsi warmodgenilia dirakis funqciis saxiT $\frac{\partial u(x,0)}{\partial t} = -\delta(x-l)\cdot\nu$, iqve, e.i. Reros boloze deformacia tolia nulis $\frac{\partial u(l,t)}{\partial x} = 0$. amave dros gadaadgileba tolia nulis yvelgan sawyis momentSi da CamagrebaSi yovelTvis. e.i.

$$U(0,t) = 0, \qquad U(x,0) = 0.$$

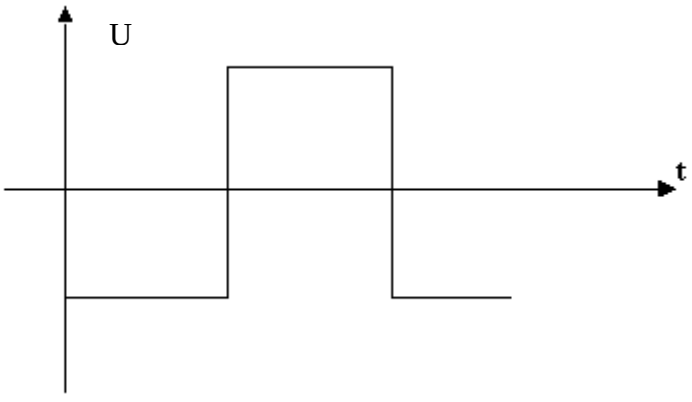
am pirobebis gaTvaliswinebiT miRebulia amonaxseni:

$$U = -\frac{4\nu}{\pi a}\sum_{k=0}^{\infty}\frac{(-1)^k}{2k+1}\sin\frac{(2k+1)\pi a t}{2l}\sin\frac{(2k+1)\pi x}{2l}.$$

advili SesamCnevia, rom mwkrivi niSancvladia, xolo mwkrivis wevrebi warmoadgenen wiladebs kenti ricxvebiT mniSvnelSi. Reros boloze gamosaxulebis mniSvneloba iqneba:

$$U_{x=l} = -\frac{4\nu}{\pi a}\sum\frac{\sin(2k+1)\pi a\, t/2l}{2k+1}.$$

misi grafikuli gamosaxuleba Semdegia:



nax. 1.13. Reros bolos gadadgilebebi

e.i. Reros bolos gadadgileba icvleba Π-s magvari sinusiT da maSasadame misi mdebareoba icvleba naxtomiseburad.

exla Tu SevecdebiT siCqaris an deformaciis gamoTvlas, e.i. Tu gavadiferencialebT t-Ti an x-iT, miviRebT ganSlad mwkrivs, radgan misi koeficientebi axlos iqneba erTTan. kidev ufro absurduli Sedegi gveqneba aCqarebis gamoTvlisas, radgan miviRebT ganSlad mwkrivs zrdadi koeficientebiT.

zemoT CamoTvlil winaaRmdegobebs Tavidan avicilebT, Tu gantolebis amonaxsens avagebT ricxviTi gziT zemoT aRwerili runge-kutas meTodis gamoyenebiT. amisaTvis wrfivi koordinatiT warmoebuli CavweroT sxvaobiani sqemiT, maSin m -uri wertilisaTvis gveqneba:

$$\frac{\partial^2 U_m}{\partial t^2} = \frac{a^2}{H^2}\left(U_{m+1} - 2U_m + U_{m-1}\right)$$

rac Seexeba sasazRvro pirobebs, isini SeiZleba Camoyalibdes ufro zustad, radganac impulsi modebuli iqneba mxolod Reros boloSi da t=0 momentisaTvis. e.i. $\frac{\partial U(l,0)}{\partial t} = -V$. Tu aviRebT m* wertilebis raodenobas, romlebSic viTvliT gadadgilebas, maSin $\frac{\partial U_{m^*}(l,t)}{\partial x} = 0$ mogvcems $U_{m^*+1} = U_{m^*-1}$. danarCeni ori piroba Caiwereba Semdegnairad

$U_1(t) = 0 \qquad U_k(0) = 0.$

wina amocanebis analogiurad aqac SemoviRoT aRniSvna $\frac{\partial U}{\partial t} = V$, maSin diferencialur gantolebaTa sistema sasazRvro da sawyisi pirobebis gaTvaliswinebiT miiRebs saxes:

$$\frac{\partial V_1}{\partial t} = V_2$$
$$\frac{\partial V_2}{\partial t} = \frac{a^2}{H^2}\left(V_3 - 2V_1\right)$$

roca 2≤k<m*

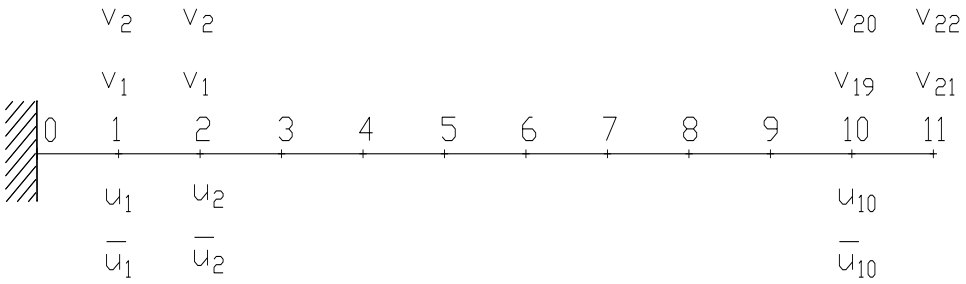
$$\frac{\partial V_{2k-1}}{\partial t} = V_{2k}$$
$$\frac{\partial V_{2k}}{\partial t} = \frac{a^2}{H^2}\left(V_{2k+1} - 2V_{2k-1} + V_{2k-3}\right)$$

roca k=m*

$$\frac{\partial V_{2m^*-1}}{\partial t} = V_{2m^*}$$

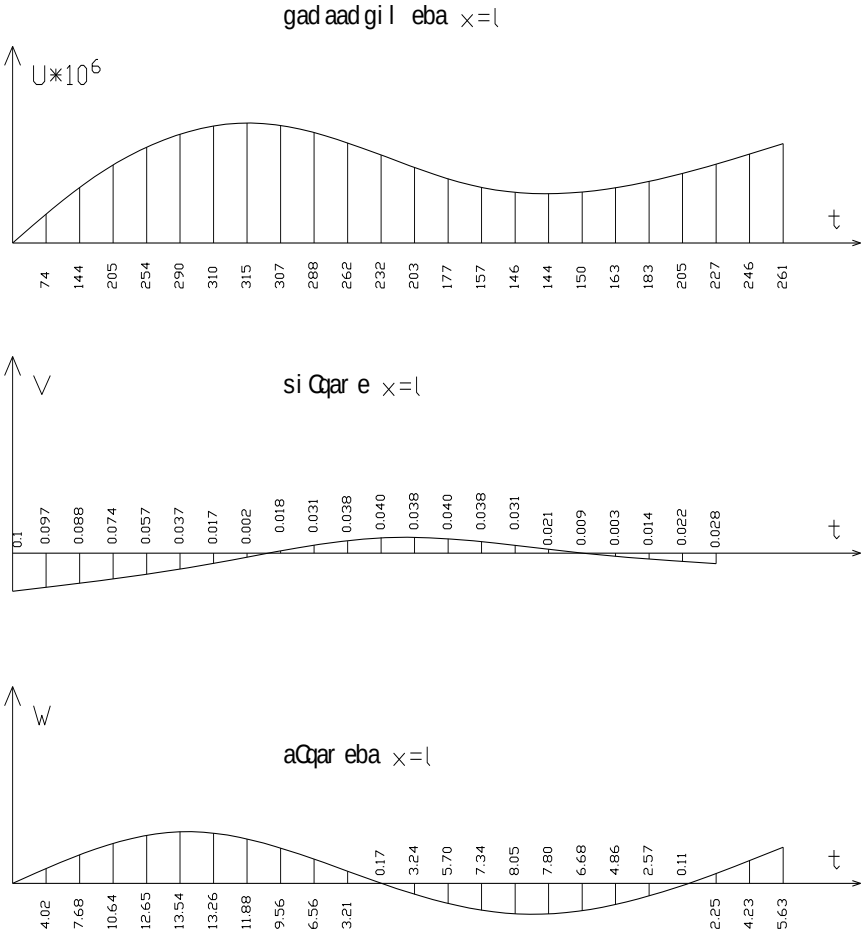
$$\frac{\partial V_{2m^*}}{\partial t} = \frac{a^2 \cdot 2}{H^2}\left(V_{2m^*-3} - V_{2m^*-1}\right)$$

gamoTvlebi Sesrulebuli iyo, roca L=300 sm, m*=10. H=30 sm, E=200000 kg/sm^2, ν=-0.1. qveda Camagrebuli kveTisaTvis m=0 (nax. 1.14).

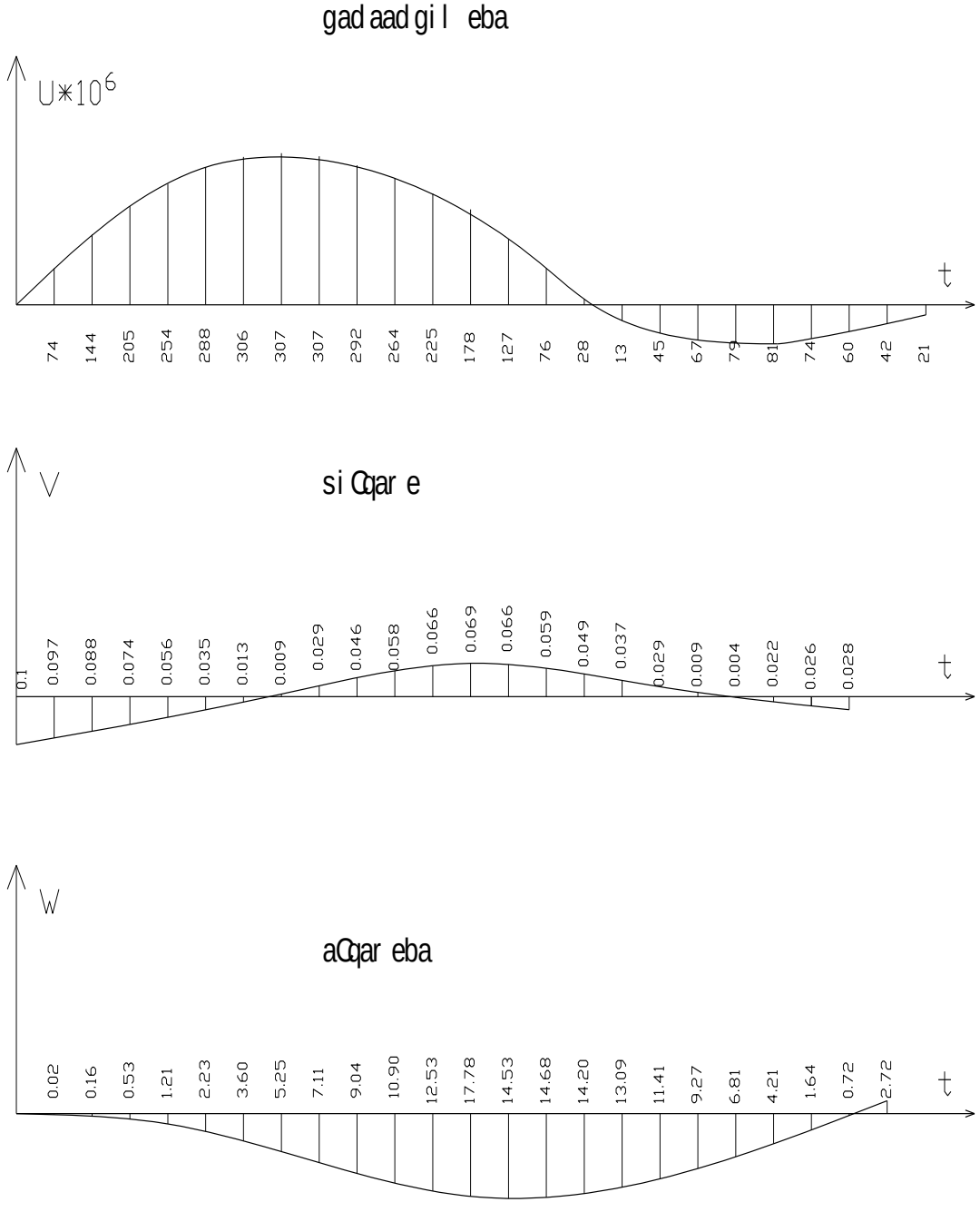


nax. 1.14 Rero funqciebiT sakvanZo wertilebSi

gadaadgilebis siCqarisa da aCqarebis epiurebi warmodgenilia naxazze (nax. 1.15).



nax. 1.15. gadaadgilebis, siCqarisa da aCqarebis mmiSvnelobani kveTSi x=l



nax. 1.16. gadaadgilebis, siCqarisa da aCqarebis
mniSvnelobani kveTSi $x=0$

gamoTvlebi Sesrulebuli iyo dartymis qveda Camagrebul boloze ganxorcielebis SemTxvevaSic. am dros $\frac{\partial U(0,0)}{\partial t} = -\nu$, rac Cven aRniSvnebSi mogvcems V_2 = - ν. Sesabamisi epiurebi mocemulia naxazze (nax. 1.16).

rogorc miRebuli Sedegebi gviCveneben rxevis gantolebebis amoxsna ricxviTi gziT gvaZlevs realur Sedegebs da saSualebas gvaZlevs Tvali gavadevnoT dartymis Sedegad rogorc gadadgilebebis, aseve siCqarisa da aCqarebis gavrcelebis process ReroSi droze damokidebulebiT.

daskvnebi

1. mxolod Runvis gaTvaliswinebiT ReroSi ganivi rxevis gantolebis analizuri amonaxsnebi konsoluri Reros SemTxvevaSi [1] ar iZlevian ganivi Zalis gansazRvris SesaZleblobas.
2. aRniSnuli gantolebis amonaxsnebi agebulia ricxviTi gziT da miRebulia rogorc gadadgilebis, aseve ganivi Zalis mniSvnelobani.
3. konsoluri Reros boloze dartymis SemTxvevaSi ReroSi gairbens ganivi Zalebi, romlebic niSancvladia da romlis amplituda daaxloebiT Tanabaria Reros mTel sigrZeze.
4. ganmeorebiTi dartymis SemTxvevaSi ganivi Zalebis ganawilebis suraTi msgavsia erTjeradi dartymisa, magram amplituda izrdeba mniSvnelovnad.
5. Reroze impulsuri moqmedebis grZivi rxevis amonaxsnebi Cawerili furies mwkrivebSi iZlevian gadadgilebis ararealur suraTs, xolo siCqare da aCqareba saerTod ar isazRvreba.
6. grZivi rxevis gantoleba impulsuri zemoqmedebisas amoxsnilia ricxviTi gziT da miRebulia gadaadgilebas, siCqarisa da aCqarebis realuri mniSvnelobani.
7. seismur zemoqmedebaze Senoba-nagebobebis gaangariSebisa da konstruirebis dros mizanSewonilia dartymis efeqtis gaTvaliswineba.

Tavi 2. Senobis rogorc diskretul-kontinualuri sistemis grZivi da grexiTi rxevebis Seswavla impulsuri zemoqmedebiT (miwisZvra, afeTqeba da sxva) gamowveuli dartymis efeqtis gaTvaliswinebiT

msoflios mraval qveyanaSi nagebobaTa seismomedegobis uzrunvelyofis mizniT gaangariSebis meTodebis damuSaveba da normatiuli dokumentebis Seqmna daiwyo meoce saukunis pirvel meoTxedSi.

ZiriTadi saangariSo modelebi da meTodebi eyrdnoboda Zvel midgomas, rac gulisxmobda gaangariSebas mudmiv statikur datvirTvaze. amiT aris ganpirobebuli dRemde arsebuli winaaRmdegobebi seismur normebSi, Tumca es winaaRmdegobebi TandaTan rbildeba sxvadasxva koeficientebiTa da SesworebebiT.

seismomedegobis Sefasebisa da seismur datvirTvaze gaangariSebis ZiriTadi meTodebi dRemde gulisxmobs gaangariSebas statikur datvirTvaze, ZiriTadad horizontalurze, romelic iTvleba seismuri datvirTvis eqvivalenturad.

Tavdapirvelad, es saangariSo statikuri datvirTebi isazRvreboda, rogorc inerciuli Zalebi, romlebic tolia nagebobis masis namravlisa gruntis seismur aCqarebaze. aseTi midgoma ki iwodeboda gaangariSebis statikur meTodad.

meoce saukunis ormocdaaTiani wlebis dasawyisSi aSS da sabWoTa kavSiris normebSi TiTqmis erTdroulad inerciuli Zalebis gansazRvrisas gruntis aCqarebis nacvlad daiwyes nagebobis masebis aCqarebebis gaTvaliswineba. es aCqarebebi miiReboda gruntis aCqarebebis gadamravlebiT dinamiurobis speqtralur koeficientze, romelic rxevis periodis mixedviT icvleboda 0.6_0.8 -dan (susti gruntebisTvis) 2.5_3 -mde (mtkice gruntebisTvis).

yvela qveynis normebi, kodebi da standartebi, romlebic exeba seismur datvirTvaze nagebobebis gaangariSebis meTodebs, eyrdnoba erTi da igive principebs. gansxvaveba aris mxolod detalebSi an koeficientebis mniSvnelobebSi.

seismur raionebSi nagebobaTa umetesobis gaangariSebisas xdeba moqmedi, ZiriTadad horizontaluri datvirTvis, romelic moicavs seismur datvirTvas, Sedareba nagebobis zidvis unarTan. seismomedegobis kriteriumebi iTvleba dakmayofilebulad, Tu zidvis unari tolia seismuri datvirTvis da maragis koeficientis namravlis.

praqtikulad yvela qveynis seismur normebSi seismuri datvirTva ganisazRvreba rogorc nagebobis masisa da aCqarebis namravli gayofili garkveul Semamcirebel koeficientze. es koeficienti, romelic amerikisa da zogierT sxva qveynebis kodebSi iwodeba reduqciis koeficientad, damokidebulia imaze, Tu ramdenad SeuZlia konstruqcias aradrekadad muSaoba da konstruqciebis tipebis mixedviT icvleba 1.25-dan 6-8-mde. Tu mas SevadarebT Cvens normebSi Sesabamisi koeficientis sidideebs, davinaxavT, rom datvirTebis Semcireba xdeba 3-4.5-jer an 6-9-jer naklebad mniSvnelovani nagebobisaTvis, e.i. realurad nagebobis gaangariSeba xdeba ramdenjerme nakleb sidideze seismuri datvirTvisa, romelic iqneboda miRebuli seismuri daraionebis rukis mixedviT miRebuli aCqarebis safuZvelze [28,29].

amave dros nagebobis saangariSo maTematikuri modeli ganixilavs nagebobas, rogorc wrfivad drekad sistemas, xolo simtkicesa da mdgradobaze gaangariSeba xdeba datvirTvis statikuri moqmedebisas.

aRniSnuli sididiT seismuri intensivobis Semcireba Seesabameba 1-2 baliT nakleb miwisZvras yoveli mocemuli samSeneblo moednisTvis.

amgvarad normebiT rekomendebuli gaangariSebis procedurebi umetes SemTxvevaSi uzrunvelyofen nagebobaTa usafrTxoebas mxolod susti miwisZvrebis SemTxvevaSi. maSin rodesac normebis Semdgenlebi da damproeqteblebi Tvlian, rom amgvarad daproeqtebuli nagebobisTvis uzrunvelyofilia usafrTxoeba Zlieri miwisZvris drosac. amis safuZvels maT aZlevs amJamad miRebuli Semdegi daSvebebi:

1. imis gaTvaliswinebiT, rom Zlieri miwisZvrebi xdeba SedarebiT iSviaTad, lokaluri dazianebebi, bzarebi da aradrekadi deformaciebi, romlebic ar iwveven globalur ngrevas, iTvlebian aucileblad da dasaSvebad [15,16,17,18,19,20,21].

2. zemoT moyvanili gaangariSebis meTodika eyrdnoba or hipoTezas: a) maqsimaluri horizontaluri gaadadgilebebi sixSiriT eqvivalenturi drekadi da aradrekadi sistemisa erTnairia [22]; b) aradrekadi deformaciebi gansazRvruli pirveli hipoTezis safuZelze dasaSvebia da ar aris saxifaTo totaluri ngrevis TvalsazrisiT.

bolo wlebSi moxdari Zlieri miwisZvrebis analizma, rogoricaa sanfernandos, aSS, 1971 w, spitakis, somxeTi, 1988 [23], kobes, iaponia [24], neftegorskis, 1995 w. [25] da sxvebis. gviCvena, rom antiseismuri gaangariSebis koncefciebi da hipoTezebi, romlebic maT udevs safuZvlad ar SeiZleba CaiTvalos sworad da universalurad.

pirveli hipoTeza, romelic exeba drekadi da aradrekadi sistemebis maqsimaluri horizontaluri gadaadgilebebis tolobas ar mtkicdeba seismuri reaqciis speqtrebis analiziT, romlebic agebulia Zlieri miwisZvrebis instrumentalurad Cawerili aCqarebebis safuZvelze. zogierT SemTxvevaSi maqsimaluri horizontaluri seismuri gadaadgilebebi aRmoCnda 2-3 rigiT maRali, vidre drekadi sistemebis maqsimaluri gadaadgilebebi. mag. 1985 wlis mexikos miwisZvris Canawerebis safuZvelze stambulis teqnikuri universitetisa da kuCerenkos sax. centraluri samecniero kvleviTi institutis mier erToblivad agebuli gadaadgilebebis grafikidan Cans, rom aradrekadi gadaadgilebebi asjer metia pirveli hipoTezis Sesabamis drekad gadaadgilebebze [26,27]. sxva miwisZvrebis SemTxvevaSic aseTive mniSvnelovani Seusabamobebia.

mxolod es Seusabamobac sakmarisia imisaTvis, rom antiseismuri daproeqtebis normebSi miRebuli gaangariSebis procedurebi CaiTvalos arasakmarisad dasabuTebulad da miuxedavad imisa, rom zogierT SemTxvevaSi iZlevian damakmayofilebel Sedegs, isini principulad ver uzrunvelyofen nagebobaTa seismomedegobas.

Tu faqtiuri gadaadgilebebi aTjer an asjer metia mosalodnelze, cxadia, isini saxifaToa da vertikalur datvirTvasTan erTad maT SeuZliaT gamoiwvion totaluri ngreva.

rogorc zemoT aRiniSna, nagebobis seismomedegobis formalur kriteriums warmoadgens seismuri datvirTvis Sedareba zidvis unarTan. aseTi kriteriumebi statikuri datvirTvisas misaRebia, magram niSancvladi dinamikuri datvirTvis SemTxvevaSi saangariSoze meti datvirTva ar niSnavs ngrevas. aseTi kriteriumi aRebulia Zveli midgomidan statikuri datvirTvebis SemTxvevaSi im gansxvavebiT, rom exla moqmedi Zala horizontaluria.

inerciuli Zalebis modeba drekad sistemaze namdvilad win gadadgmuli nabijia, magram is ver xsnis fundamentlur winaaRmdegobebs, romlebic aris nagebobis seismomedegi proeqtirebis gamoyenebiT TeoriaSi. esenia:

1. yvela qveynis specialistebis mier miRebulia seismur raionebSi daproeqtebis koncefcia, romlis Tanaxmadac maqsimaluri intensiobis miwisZvrisas dasaSvebia mniSvnelovani dazianebebi, romlebic ar iwveven adamianebis daRupvas da unikaluri sulieri da socialuri faseulolobebis ganadgurebas. amave dros Tanamedrove gaangariSebebi sruldeba imis daSvebiT, rom dazianebebi ar gvaqvs. mcire aradrekadi deformaciebis arseboba daSvebulia garkveuli arapirdapiri xerxebiT.

2. gaangariSebebSi miRebulia, rom nagebobebis ngreva xdeba horizontaluri seismuri datvirTviT (ufro zustad seismuri datvirTvis horizontaluri komponentiT).

umetes SemTxvevaSi ki ngreva gamowveulia seismuri zemoqmedebiT dazianebul nagebobaze vertikaluri Zalebis qmedebiT. Tu gaviTvaliswinebT dartymis vertikaluri mdgenelis gavlenasac, rac iwvevs nagebobis grZiv rxevebs, ufro TvalsaCino gaxdeba Tanamedrove seismomedegobis TeoriaSi arsebuli winaaRmdegobebi.

moyvanili mimoxilva saSualebas gvaZlevs davaskvnaT, rom miwisZvrisas adgili aqvs dartymis efeqts da misi gaTvaliswineba aucilebelia karkasuli Senobebis gaangariSebis dros.

pirvel paragrafSi mocemulia sakiTxis dasma da misi gadawyvetis gzebi. gaanalizebulia tradiciuli seismuri gaangariSebis ZiriTadi principebi da koncefciebi. aRniSnilia maTSi arsebuli winaaRmdegobebis Sesaxeb. moyvanilia mosazreba, romlis Tanaxmad Senobebi ziandeba ara miwisZvriT gamowveuli harmoniuli rxevebiT aramed dartymebiT. miTiTebulia Sromebi, romlebSic dafiqsirebulia miwisZvrisas dartymis efeqtis gamovlineba. ngrevis gravitaciuli modelis Sesaxeb naTqvamia, rom dartymis vertikaluri mdgenelis gaTvaliswineba ufro realurs xdis am modelis sicocxlisunarianobas. aRniSnulia, rom dartymis efeqtis gamovlenis SesaZlo ares warmoadgens teqtonikuri rRvevis mimdebare teritoria. dasmuli sakiTxis gadawyvetis SesaZlo gzad miCneulia dartymis efeqtis gaTvaliswineba konstruqciis adekvaturi saangariSo sqemis pirobebSi. aseT sqemad aRebulia diskretul-kontinualuri sqema da moyvanilia misi gaangariSebis arsebuli meTodebis mokle mimoxilva.

meore paragrafSi miRebulia Senobis rogorc diskretul-kontinealuri sistemis grZivi rxevis diferencialur gantolebaTa sistema. diskretul-kontinealuri sistema warmoadgens Seyursul masebs erTmaneTTan dakavSirebuls deformadi ReroebiT. rxevis diferencialur gantolebaTa sistema iTvaliswinebs ReroTa masebis gavlenas rxevis procesze. amave dros energetikuli meTodebisagan gansxvavebiT am sistemis miRebis dros ar aris gamoyenebuli Reros gaswvriv siCqareTa ganawilebis Sesaxeb raime saxis (wrfivi an sxva damokidebuleba) daSveba.

mesame paragrafSi mocemulia Senobis rogorc diskretul-kontinialuri sistemis grexiTi rxevis diferencialur gantolebaTa sistema ise rogorc es gakeTebulia meore paragrafSi grZivi rxevisaTvis.

meoTxe paragrafSi agebulia rxevis diferencialur gantolebaTa sistemis amonaxseni da damuSavebulia saTanado programa. amonaxseni agebulia ricxviTi gziT, runge-kutas meTodis Sesabamisi standartuli programis gamoyenebiT. imisaTvis, rom SesaZlebeli yofiliyo am programis gamoyeneba damuSavebulia mimdevrobiT miaxloebis xerxi, romelSic TiToeuli masis, romlisTvisac Cawerilia gantoleba, mezobeli masebis aCqarebebi miaxloebis yovel safexurze CaTvlilia cnobilad wina miaxloebidan. programa damuSavebulia nebismieri raodenobis masebisaTvis. aqve mocemulia amocanis sawyisi pirobebi da gare zemoqmedebis cvlilebis kanoni. gansaxilveli konkretuli SemTxvevisaTvis moyvanilia damokidebuleba xuTi Seyursuli masis SemTxvevaSi.

mexuTe paragrafSi mocemulia gamoTvlebis Sedegebi da maTi analizi. gamoTvlebi Sesrulebulia konkretuli geometriuli zomebisa da meqanikuri maxasiaTeblebis mqone oTxsarTuliani (xuTi Seyursuli masiT) SenobisaTvis. gamokvleulia ReroTa masebis gavlena konstruqciis daZabul deformirebul mdgomareobaze, roca masala emorCileba iungis an kelvin _ foxtis reologiur models. gamokvleulia agreTve sawyisi siCqarisa da siblantis koeficientis gavlena. Sedegi miRebulia rxevis grafikebis da Camoyalibebul daskvnebis saxiT.

2.1 sakiTxis dasma da misi gadawyvetis gzebi

tradiciuli seismuri gaangariSeba, rogorc zemoT aRvniSneT, mdgomareobs inerciuli Zalebis eqvivalenturi statikuri Zalebis gansazRvraSi, romlebic modebuli iqneba nagebobis masiur elementebze da gadaxurvis filebze. amave dros nagebobis elementebis urRvevobisa da simtkicis kriteriumebad miRebulia Cveulebrivi statikuri simtkicis kriteriumebi, rasac mivyavarT seriozul winaaRmdegobebamde.

seismuri ngrevis sazogadod miRebuli koncefcia mdgomareobs imaSi, rom miwisZvrisas gruntSi aRiZvreba farTo speqtri harmoniuli rxevebisa gansxvavebuli sixSireebiT. Senoba Tavisi sixSiriT rezonansSi modis am speqtris Sesabamis sixSiresTan da

ingreva. es koncefcia arasworia [8]. saqme imaSia, rom seismuri gadaadgileba ar aris rxeva, miT ufro harmoniuli. rxevisas unda warmoiSvas gadataniTi gadaadgilebebi, romlebic icvlian niSans sinusis an kosinusis kanoniT. sinamdvileSi miwisZvra warmoqmnis dartymebis qaotur sistemas, e.i. naxtomisebur calmxriv gadaadgilebebs, romlebic gamowveulia zedapiruli talRebis gavliT gruntSi. am talRebis frontze warmoiqmneba gadaadgilebis naxtomi, romelic qreba. Senobis sakuTari rxevebis Tanxvedra dartymebis qaotur sistemasTan nakleb savaraudoa.

specialistebis mier Catarebuli iyo 1992 wlis agvistoSi yirgizeTSi momxdari cxrabaliani miwisZvris Sedegebis analizi [19]. gamokvleuli iyo rkinabetonis mzid konstruqciebze am miwisZvris gavlena. kerZod, gamoTvlili iyo kedlebisa da svetebis namsxvrevebisa da bzarebis zedapiris farTobebi, rogorc maxasiaTebeli zemoqmedebis energiis intensiobisa. kvlevis SedegebiT miRebuli suraTi ewinaaRmdegeba gruntis rxevis koncefcias, rasac specialistebi Tvlian katastrofis mizezad. dazianebuli konstruqciebi stoveben STabeWdilebas, TiTqos maTze imoqmeda ara periodulma rxevam, aramed Zlierma dartymam. rogorc xorcieldeba didi energiis xanmokle impulsebis zemoqmedebis Sedegad. gamoTvlili energiis sidide aTasjer mainc aRemateba Senobis rxevis energias. aseTi energia ki SeiZleba gadaeces Senobas mxolod didi aCqarebisas, romlebic aRemateba 1000g-s. Tumca seismologebisaTvis daujerebelia aCqareba aRematebodes 2g-s, rasac isini asabuTeben seismografebis monacemebis safuZvelze. seismografebi ki warmoadgenen zambarian oscilatorebs, rac arsebiTad inerciuli sistemaa da mas ar ZaluZs daafiqsiros wamis meaTasedebSi ganxorcielebuli rxevebi. amisaTvis saWiroa gamoyenebuli iyos membranuli an lazeruli gadamcemebi, romlebsac didi xania iyeneben miwisqveSa afeTqebebis dros.

maSasadame Senobebi ziandeba ara amJamad moqmedi inerciul-rxeviTi Teoriis Sesabamisad gamoTvlili Zalebis zemoqmedebiT, aramed dartymis Sedegad aRZruli Zalebis zemoqmedebiT.

amgvari winaaRmdegobebis Tavidan acilebas gulisxmobda akademikosi nazarovi, romelic miuTiTebda seismomedegobis adekvaturi Teoriis damuSavebis aucileblobaze [31]. igi Tvlida, rom saWiroa seismuri tipis dinamikur datvirTvebze gaangariSebis gansakuTrebuli meTodebis damuSaveba, sadac gaTvaliswinebuli iqneba specialuri efeqtebi: seismuri dartymebi da biZgebi, Sinagani xaxuni da sxva. nazarovis am mosazrebas exmaureba naSromebi [28,29], romlebSic damuSavebuli seismodegebobis speqtraluri talRuri Teoria. avtoris sityvebiT damuSavebulia principulad axali modeli myari tanis moZraobisa da seismomedegobis statikuri da dinamikuri Teoriebisa. seismuri dartymebi miCneulia Senobis ngrevis erTaderT mizezad SromebSi [8,9,10,11], sadac aRniSnulia, rom umetes SemTxvevebSi seismuri ngreva xdeba pirvelive sakmaod Zlieri biZgebis Sedegad,

romlebic myisierad iwveven svetebisa da kedlebis gadaWras manam, vidre isini daiwyeben rxevas, e.i. vidre aRiZvreba inerciis Zalebi. cnobilia, rom miwisZvrisas inerciuli Zalebis aRZvras win uswrebs vertikalur elementebSi ganivi Zvris talRebis warmoqmna, e.i. Zvris talRebi pirveladia, inerciuli Zalebi ki meoradi. logikuri iqneboda migveCnia es talRebi ngrevis ZiriTad mizezad. magram jer kidev dazianebis mizezad miiCneva meoradi inerciuli Zalebi.

dartymis talRebis sasargeblod metyvelebs ruseTis akademiis Soreuli aRmosavleTis filialis seismologebis mier damuSavebuli seismuri procesebis meqanikuri koncefcia, romlis Tanaxmadac seismuri gamosxiveba warmoadgens meqanikuri impulsis gavrcelebas. impulsis gadacema sivrceSi xdeba dartymis meqanikis kanonebiT [7]. es koncefcia exmaureba SromaSi [30] gamoTqmul mosazrebas, rom miwisZvris keras warmoadgens ara teqtonikuri rRveva, aramed garkveuli moculoba. igi mcdarad Tvlis koncefcias kera-rRveva da gvTavazobs models kera-moculoba. misi azriT miwisZvris kera, e.i. miwisqveSa dartymis wyaro, esaa nivTierebis (qerqi an gare zeda mantia) garkveuli moculoba, struqtura, naoWi, naoWebis jgufi, masivi, bloki, e.i. samganzomilebiani materialuri masa, romlebSic dagrovda sakmao potencialuri energia drekadi daZabuli mdgomareobis saxiT (kumSvis, iSviaTad gaWimvis) da romelic Tavisufldeba am energiisagan TiTqmis myisieri deformaciis (gadaadgilebis) da Semdgomi aseve myisieri gaCerebiT, e.i. esaa aweva, daweva, daxra, Runva, simkvrivisa da drekadi Tvisebebis cvlileba mTel moculobaSi, romlis Sedegadac drekadi Zabvebis potencialuri energia gardaiqmneba deformaciis kinetikur energiad. amgvarad, kera es ar aris wertili an xazi (teqtonikuri rRvevis kvali dedamiwis zedapirze). es arc organzomilebiani sibrtyea. esaa samganzomilebiani materialuri masa, moculoba, romlis TiToeuli nawilaki gamoasxivebs energias misi gadadgilebis amplitudisa da siCqaris Sesatyvisad.

Tumca xazi unda gaesvas im garemoebas, rom amJamad koncefcia kera-rRveva dominirebs da mecnierTa umetesoba mas uWers mxars.

miwisZvrisas dartymis arsebobis Sesaxeb, naTqvamia SromaSi [32], sadac moyvanilia aSxabadis 1948 wlis miwisZvriT dazianebuli meCeTis Senobis deformirebuli sqema da aRniSnulia, rom dartymis Sedegad moxda Senobis zogierTi sayrdenis gadaWra. dartymis efeqtisa da am dros aRZruli ganivi Zalebis gaTvaliswinebis aucilebloba arapirdapir gamomdinareobs svetebis ngrevis SemoTavazebuli [33] gravitaciuli modelidan. am modelis Tanaxmad rxevis procesSi, maqsimaluri momentis moqmedebis kveTSi xdeba betonis msxvreva, grZivi armaturis gaSiSvleba, ganivi armaturis gawyveta, rac iwvevs grZivi Reroebis mdgradobis dakargvas. Tu mxedvelobaSi miviRebT dartymis vertikalur mdgenelsac ufro realuri gaxdeba gravitaciuli modelis sicocxlisunarianoba. darRveuli svetis

saxis mixedviT, cxadia, mdgradobis dakargva gamowveulia betonis mocilebis Sedegad. magram betonis msxvreva da mocileba SeiZleba gamowveuli iyos ganivi Zalebis qmedebiTac. miT umetes, rom maqsimaluri mRunavi momentebi inerciul-rxeviTi Teoriis Tanaxmad gvaqvs kvanZebSi. rRvevas ki adgili aqvs xSirad kvanZis mimdebare kveTSi, zogjer ki malis SuaSic, sadac dartymis efeqtis gaTvaliswinebiT maqsimaluri SeiZleba iyos ganivi Zala da ara mRunavi momenti. svetis kveTi ki yvelaze naklebad armirebuli, ganivi armaturiT, SuaSia svetis mTeli simaRlis farglebSi.

sayuradReboa analizis Sedegebi, romlebic saSualebas iZleva Sefasdes seismuri datvirTvebis sidide, rac modis miwisZvrebis SesaZlo kerebis maxloblad aSenebul obieqtebze [34]. pirveli Teoriuli Sefasebebis safuZvelze [35] gakeTda daskvna, rom maqsimaluri aCqareba miwisZvris kerasTan ar unda aRematebodes 0.5 g-s. mogvianebiT [36,37] iyo naCvenebi, rom maqsimaluri aCqareba SeiZleba iyos 1 g, xolo garkveul pirobebSi 1.5 ÷ 2 g. amasTanave keTdeboda frTxili miTiTebebi imis Sesaxeb, rom aseTi aCqarebebi SeiZleba gvqondes ara marto keris teritoriaze, aramed mis mimdebare zonebSic. bolo periodis instrumentalurma Canawerebma faqtiurad daadastures [36] da [37]-Si gamoTqmuli mosazrebebi. mag. 1985 wlis 23 dekembris nahanis (kanada) miwisZvrisas dafiqsirebuli gruntis aCqarebis horizontaluri mdgenelis sidide iyo 1..34 g, vertikalurisa ki 2..37 g. xolo 1994 wlis 17 ianvris nortrijis (aSS) miwisZvrisas 1.93 g horizontaluri mdgenelis saxiT, xolo 1.15 g vertikaluri mdgenelis saxiT. SromebSi [34] gaanalizebulia Canawerebi seismometruli sadgurebisa, romlebic ganlagebuli iyo uSualod teqtonikuri narRvevis maxloblad taivanze, kobeSi (iaponia), loma prietSi (aSS), nortrijSi (aSS), vaitierSi (aSS). gaanalizebuli iyo 402 Canaweri, romlebic dayofili iyo rogorc gruntis kategoriis mixedviT, aseve rRvevis daSorebis manZilis mixedviT. 5 km-ze metad moSorebul manZilze Cawerili iyo 321 Canaweri, 5 km-ze axlo manZilze 81. aqedan yvelaze meti Canaweri gakeTebulia meore kategoriis gruntebze, TiTqmis orjer meti, vidre pirvel da mesame kategoriis gruntebze erTad. analizis safuZvelze gakeTebulia daskvna, rom raodenobrivad SenobaTa rxevis intensioba SeiZleba 1.5÷2.5-jer aRematebodes im intensiurobas, rasac gvaZlevs 9 balis saangariSo seismuroba, rac miuTiTebs im faqtze, rom aseT zonebSi mSenebloba moiTxovs gansakuTrebul midgomas. miT ufro, Tu miviRebT, rom miwisZvrisas adgili aqvs dartymis efeqts, igi gansakuTrebiT Zlierad gamovlindeba swored aseT zonebSi.

maSasadame dasmuli sakiTxis gadawyveta moiTxovs dartymis efeqtis gaTvaliswinebas Senobis konstruqciis adeqvaturi saangariSo sqemis pirobebSi. aseT saangariSo sqemas SeiZleba warmoadgendes diskretul-kontinealuri sqema, romelic Sedgeba diskretuli (pirobiTad aradeformirebadi) masebisgan, romelic SeerTebuli erTmaneTTan

ganawilebuli masis mqone (drekadi an drekad blanti) kavSirebiT. aseTi sistemebis maTematikuri modelebis ageba dakavSirebulia garkveul maTematikur sirTuleebTan, radganac moiTxovs talRur gantolebaTa sistemis amoxsnas Seyursuli da ganawilebul masebis SeerTebis adgilas ucnobi sasazRvro pirobebiT. amitom Cveulebriv ganawilebuli masebis gavlenas ugulvelyofen, rasac mivyavarT mniSvnelovan cdomilebamde.

ganawilebuli masis mqone diskretul-kontinialuri sistemis moZraobis gantolebebis ageba xdeba ZiriTadad oTxi meTodiT [38,39,40].

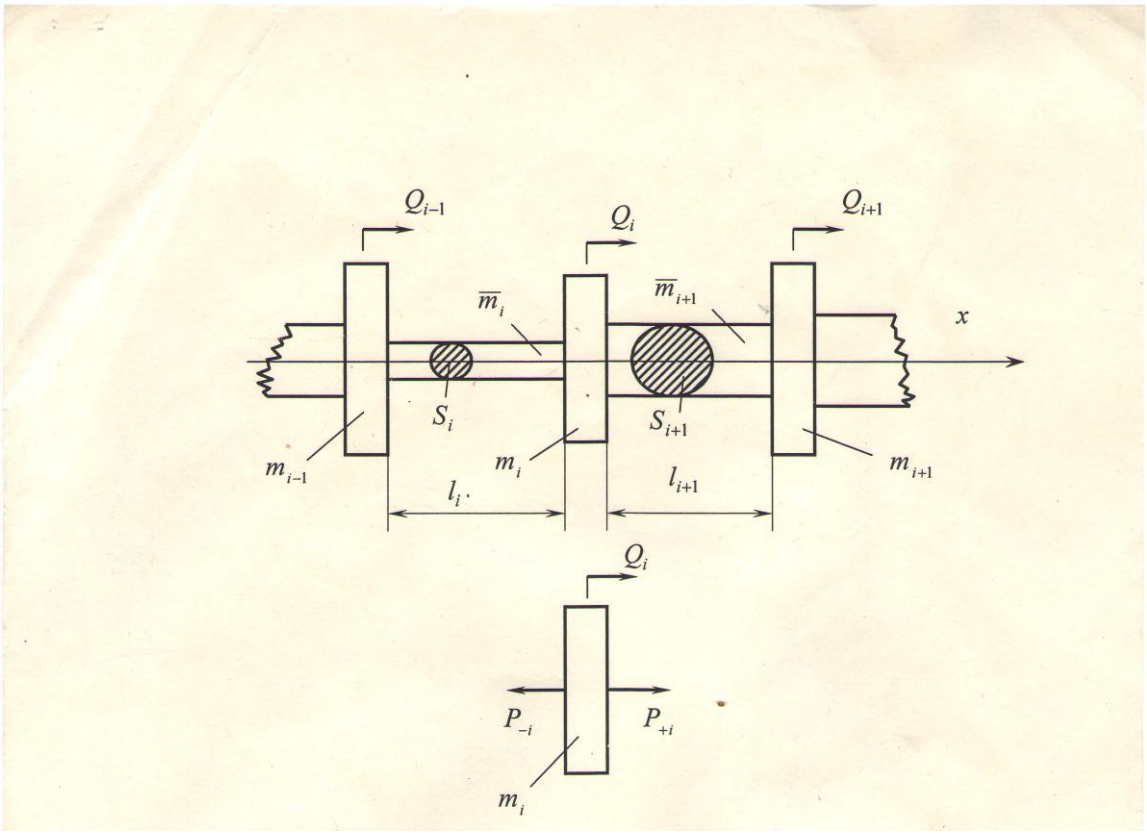
pirvel meTodSi ganawilebuli masa iyofa calkeul ubnebad, ris Sedegadac mivdivarT diskretul sistemaze. meore meTodi cnobilia energetikuli anu releis meTodis saxelwodebiT. am meTodis Sesabamisad gamoiTvleba kinetikuri da potencialuri energiebi im mdgomareobebSi roca erTerTi nulia. mesame meTodic energetikulia. aqac viRebT kinetikuri da potencialuri energiebis gamosaxulebebs da Semdeg Segvyavs isini lagranJis gantolebaSi. meoTxe meTodSi ixsneba kontinualur gantolebaTa sistema SeuRlebis pirobebiT. TiToeul am meTods gaaCnia Tavisi dadebiTi da uaryofiTi mxareebi. amitom iseTi gantolebebis gamoyeneba, romlebSic minimumamdea dayvanili naklovanebebi da realizebulia upiratesobani, warmoadgens aqtualur sakiTxs. Semdgom paragrafebSi moyvanilia grZivi da grexiTi rxevebis gantolebebi. mocemulia maTi amoxsnis algoriTmi da ricxviTi realizacia miwisZvris Sedagad aRZruli impulsuri zemoqmedebis pirobebSi.

2.2 diskretul-kontinualuri sistemis grZivi rxevis gantolebaTa sistema

ganvixiloT diskretul-kontinualuri sistema, romelic Sedgeba diskretuli m_i masebisagan da maTi damakavSirebeli Reroebisagan ganivi kveTiT s_i. vigulisxmoT rom aRmZvreli Zalebi $Q_i = Q_i(t)$

modebulia Seyursuli masebis inerciis centrebze imgvarad rom masebi asruleben mxolod grZiv rxevebs (nax. 2.1).

diskretuli masebis moZraobis gantolebebs aqvT saxe:



nax. 2.1 diskretul-kontinualur sistemis dinamikuri saangariSo sqema.

$$m_i \frac{d^2 x_i}{dt^2} - P_{+i} + P_{-i} = Q_i \qquad \text{i=1,2,....,N} \qquad (1)$$

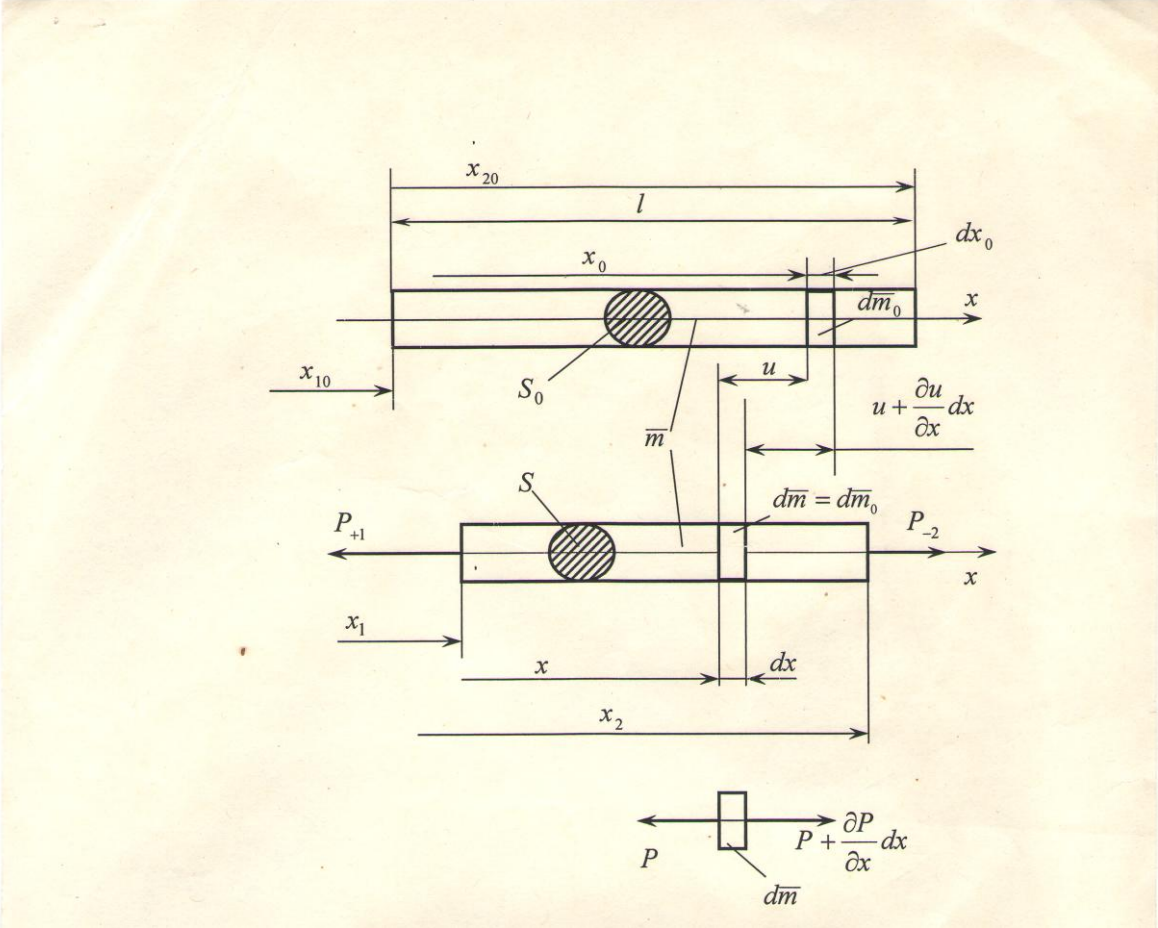
sadac $x_i = x_i(t)$ m_i masis mimdinare koordinatia, P P_{+i} da P_{-i} - uri masaze marjvnidan da marcxnidan moqmedi bmebis reaqciebia.

davamyaroT damokidebuleba P P_{+i} da P_{-i} reaqciebsa da kinematikur sidideebs (gadaadgileba, siCqare, aCqareba) Soris.

aseTi damokidebulebebis agebisas Cveulebriv an gamoricxaven bmebis inerciulobas da uSveben, rom P $P_i = P_{-(I+1)}$ [41] an kidev ixilaven erTganzomilebian talRur gantolebaTa sistemebs [39,40], romelTa realizaciac diskretul masebis SezRuduli raodenobis drosac ki ukavSirdeba seriozul maTematikur sirTuleebs. Cven SemTxvevaSi ganvixiloT kavSiri m_1 da m_2 masebs Soris da davweroT gamoyofil ganawilebul elementarul masebze dm moqmedi Zalebis wonasworobis piroba [42]. (nax. 2.2)

$$\frac{\partial P}{\partial x} dx = \frac{d^2 x}{dt^2} d\overline{m} = \frac{d^2 x}{dt^2} \rho s dx \qquad (2)$$

sadac P nebismier kveTSi moqmedi gamWimavi (mkumSavi) Zalis sididea,



nax. 2.2 sqema bmebis reaqciis gamosaxulebis misaRebad

x-mimdinare koordinatia x=x(x_0 ,t), xolo x_0 x -is sawyisi mniSvnelobaa. davweroT igivuri damokidebuleba:

$$\frac{\partial}{\partial x}(PX) = P + x\frac{\partial P}{\partial x} \qquad (3)$$

da SevitanoT masSi PP -s gamosaxuleba foxtis drekad-blanti modelis Sesabamisad:

$$P = Es\frac{\partial u}{\partial x} + \mu s\frac{\partial \dot{u}}{\partial x} \qquad (4)$$

sadac E drekadobis modulia., μ –dinamikuri siblante;

$u = x - x_0$ gadaadgileba, $\dot{u} = \dot{x} = \frac{du}{dt}$ - gadaadgilebis siCqare.

(3)-Si SevitanoT $\frac{\partial P}{\partial x}$ -is gamosaxuleba (.2)_s mixedviT, gveqneba

$$\frac{\partial}{\partial x}(Px) = Es\frac{\partial u}{\partial x} + \mu s\frac{\partial \dot{u}}{\partial x} + \rho sx\frac{d^2x}{dt^2} \qquad (5)$$

Tu mxedvelobaSi miviRebT igivur tolobas:

$$x\frac{d^2x}{dt^2}=\frac{1}{2}\frac{d^2}{dt^2}(x^2)-(\frac{dx}{dt})^2 \qquad (6)$$

da gavaintegrebT (5) miviRebT:

$$P_{-2}x_2-P_{+1}x_1=Es(u_2-u_{1)}+\mu s(\dot{u}_2-\dot{u}_1)+\frac{1}{2}\rho s\frac{d^2}{dt^2}\int_{\overline{m}}x^2d\overline{m}-\rho s\int_{\overline{m}}\dot{x}^2d\overline{m} \qquad (7)$$

Tu mxedvelobaSi miviRebT, rom

$$J_x=\rho s\int_{x_1}^{x_1}x^2dx=\frac{\rho s}{3}(x_2^3-x_1^3)=\frac{\overline{m}}{3}(x_2^2+x_1x_2+x_1^2) \qquad (8)$$

da mimdevrobiT SevuTavsebT koordinatTa saTaves Reros boloebs, im pirobiT, rom

$u_1=x_1-x_{10}$, $u_2=x_2-x_{20}$, $\dot{u}_1=\dot{x}_1$, $\dot{u}_2=\dot{x}_2$, gveqneba:

$$P_{+1}=\frac{Es}{l}(u_2-u_1)+\frac{\mu s}{l}(\dot{u}_2-\dot{u}_1)-\frac{\overline{m}}{6}\ddot{u}_2-\frac{\overline{m}}{3}\ddot{u}_1+\frac{\overline{m}}{3l}(\dot{u}^2{}_1+\dot{u}_1\dot{u}_2+\dot{u}_2^2)-2\frac{W}{l} \qquad (9)$$

$$P_{-2}=\frac{Es}{l}(u_2-u_1)+\frac{\mu s}{l}(\dot{u}_2-\dot{u}_1)+\frac{\overline{m}}{6}\ddot{u}_2+\frac{\overline{m}}{3}\ddot{u}_1+\frac{\overline{m}}{3l}(\dot{u}^2{}_1+\dot{u}_1\dot{u}_2+\dot{u}_2^2)-2\frac{W}{l}$$

sadac $2W$ warmoadgens Reros kinetikuri energiis gaormagebul mniSvnelobas da sididiT (7)_is bolo wevris tolia. misi SefasebisTvis davuSvaT, rom iseve rogorc releis meTodSi siCqareebi Reros gaswvriv nawildeba wrfivi kanoniT:

$$\dot{x}=\dot{x}_1+(\dot{x}_2+\dot{x}_1)\frac{x}{l} \qquad (10)$$

SevitanoT igi kinetikuri energiis gamosaxulebaSi

$$W=\frac{1}{2}\int_{\overline{m}}\dot{x}^2d\overline{m}=\frac{\overline{m}}{6}(\dot{u}_1^2+\dot{u}_1\dot{u}_2+\dot{u}_2^2) \qquad (11)$$

amgvarad (9) bolo ori wevri gaabaTilebs erTmaneTs da P_1 da P_2 -Tvis miviRebT:

$$P_{+1}=\frac{Es}{l}(u_2-u_1)+\frac{\mu s}{l}(\dot{u}_2-\dot{u}_1)-\frac{\overline{m}}{6}\ddot{u}_2-\frac{\overline{m}}{3}\ddot{u}_1 \qquad (12)$$

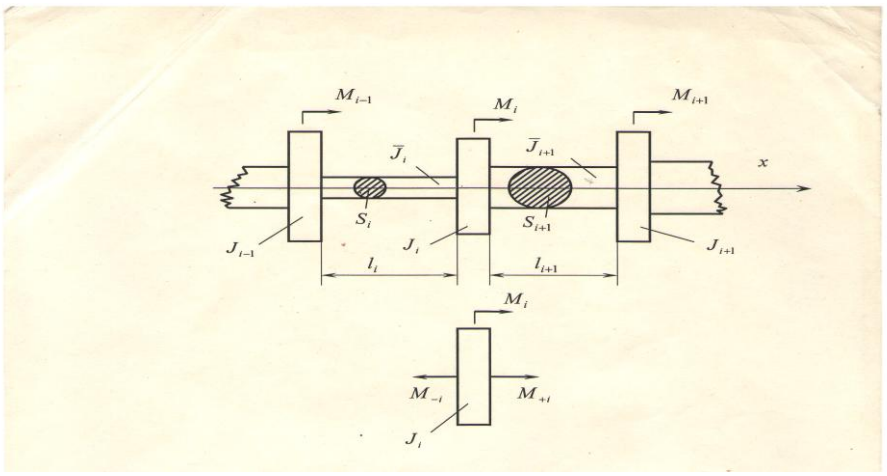
$$P_{-2}=\frac{Es}{l}(u_2-u_1)+\frac{\mu s}{l}(\dot{u}_2-\dot{u}_1)+\frac{\overline{m}}{3}\ddot{u}_2+\frac{\overline{m}}{6}\ddot{u}_1$$

Tu (12) gamosaxulebebs CavwerT i _uri RerosTvis da SevitanT (1) gantolebaSi miviRebT:

$$(m_i+\frac{\overline{m}_i+\overline{m}_{i-1}}{3})\ddot{u}_i+\frac{\overline{m}_i}{6}\ddot{u}_{i+1}+\frac{\overline{m}_{i-1}}{6}\ddot{u}_{i-1}+\frac{E_{i-1}s_{i-1}}{l_{i-1}}(u_i-u_{i-1})-\frac{E_is_i}{l_i}(u_{i+1}-u_i)+\frac{\mu_{i-1}s_{i-1}}{l_{i-1}}(\dot{u}_i-\dot{u}_{i-1})$$
$$-\frac{\mu_is_i}{l_i}(\dot{u}_{i+1}-\dot{u}_i)=Q_i \qquad (13)$$

2.3 diskretul-kontinualuri sistemis grexiTi rxevis gantolebaTa sistema

ganvixiloT igive diskretul-kontinualuri sistema mxolod im gansxvavebiT, rom amjerad Seyursul masebze moqmedeben M $M_i = M_i(t)$ mgrexi momentebi. (nax. 2.3)



nax. 2.3 diskretul-kontinualuri sistemis dinamikuri saangariSo sqema grexiTi rxevisas

grexiTi rxevisas diskretuli masebis moZraobis gantolebebi Caiwereba Semdegnairad:

$$J_i \frac{d^2\varphi_i}{dt^2} - M_{+i} + M_{-i} = M_i \qquad i = 1, 2, \ldots\ldots N \qquad (14)$$

sadac J_i diskretuli masis inerciis momentia.

grZivi rxevis SemTxvevis analogiurad gamovyoT diskretul m_1 da m_2 masebs Soris kavSiri da davweroT igivuri toloba

$$\frac{\partial}{\partial x}(MX) = M + X\,\frac{\partial M}{\partial x} \qquad (15)$$

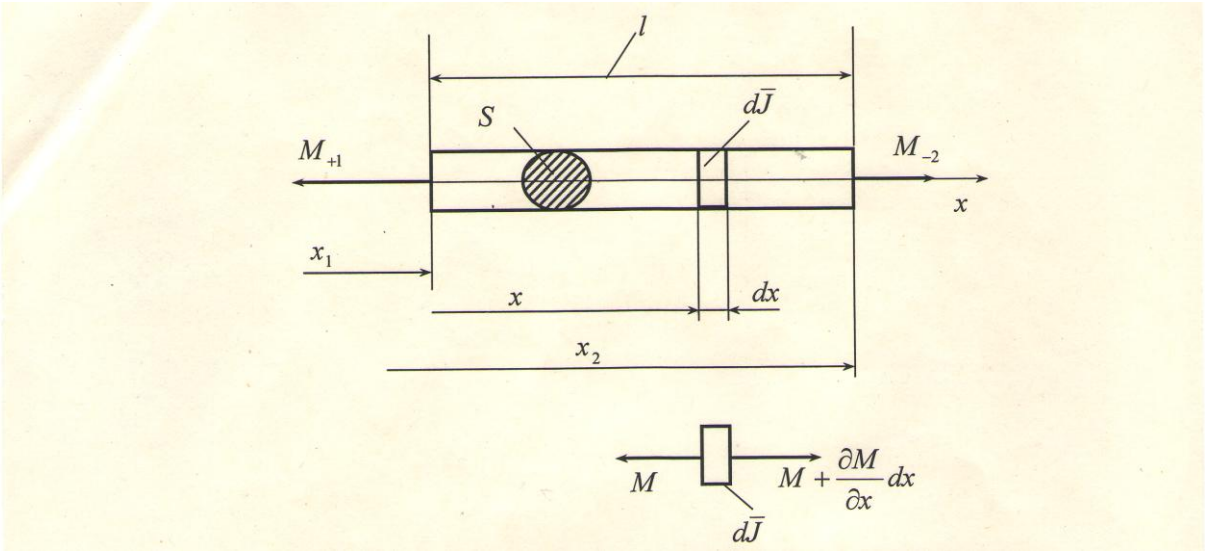
sadac M Reros nebismier kveTSi moqmedi mgrexi momentia.

CavweroT foxtis drekad-blanti modelis Sesabamisi damokidebuleba grexis SemTxvevaSi:

$$M = GI\frac{\partial\varphi}{\partial x} + \bar{\mu}I\frac{\partial\dot{\varphi}}{\partial x} \qquad (16)$$

sadac G Zvris modulia, $\bar{\mu}$ dinamikuri siblante Zvrisas, I Reros ganivi kveTis polaruli momenti, $\dot{\varphi}$ kuTxuri siCqare.

elementarul ∂v moculobaze moqmedi momentebis wonasworobis piroba Caiwereba Semdegnairad (nax. 2.4) :



nax. 2.4 sqema grexviTi rxevisas bmebis reaqciebis gamosaxulebis misaRebad

$$\frac{dM}{dx}dx = \frac{d^2\varphi}{dt^2}d\bar{J} \qquad (17)$$

sadac $d\bar{J}$ elementaruli moculobis $d\bar{m}$ masis inerciis momentia, romelic magaliTad R radiusis mqone wriuli kveTisaTvis gamoiTvleba cnobili formuliT:

$$d\bar{J} = \frac{R^2}{2}d\bar{m} = \frac{R^2}{2}\rho s dx \qquad (18)$$

SevitanoT (16), (17) da (18) (15)-Si da gavaintegroT, miviRebT:

$$M_{-2}x_2 - M_{+1}x_1 = GJ(\varphi_2 - \varphi_1) + \bar{\mu}J(\dot{\varphi}_2 - \dot{\varphi}_1) + \int_{\bar{J}} x\frac{d^2\varphi}{dt^2}d\bar{J} \qquad (19)$$

grexis deformirebuli sqemidan gamomdinareobs rom

$$dx = \frac{R}{\psi}d\varphi \quad \Rightarrow \quad x = x_1 + \int_{\varphi_1}^{\varphi_2}\frac{R}{\psi}d\varphi \qquad (20)$$

sadac ψ cilindris msaxvelis daxris kuTxea, romelic sazogadod damokidebulia x-ze.

SevitanoT (20) (19)-Si da koordinatTa saTave ($x_1 = 0$) movaTavsoT Reros boloSi, gveqneba:

$$\int_{\bar{J}} x\frac{d^2\varphi}{dt^2}d\bar{J} = \int_{\bar{J}_1}\left(\int_{\varphi_{1_1}}^{\varphi_2}\frac{R}{\psi}d\varphi\right)\frac{d^2\varphi}{dt^2}d\bar{J} \qquad (21)$$

ψ-s gamosaxuleba SeiZleba Caiweros Semdegnairad:

$$\psi = \frac{R(\varphi_2 - \varphi_1)}{l} \qquad (22)$$

sadac φ_1 da φ_2 Reros boloebis kuTxuri koordinatebia.

SevitanoT (22) (21)-Si, gaviTvaliswinoT (18) da Semdegi igivuri toloba:

$$\varphi \frac{d^2\varphi}{dt^2} = \frac{1}{2}\frac{d^2}{dt^2}(\varphi^2) - (\frac{d\varphi}{dt})^2 \qquad (23)$$

martivi gardaqmnebis Sedegad (21)-dan miviRebT:

$$\int_{\bar{J}} x\frac{d^2\varphi}{dt^2}d\bar{J} = \frac{l}{\varphi_2 - \varphi_1}(\frac{1}{2}\frac{d^2}{dt^2}\int_{\bar{J}}\varphi^2 d\bar{J} - \int_{\bar{J}}\dot{\varphi}^2 d\bar{J} - \varphi_1\frac{d^2}{dt^2}\int_{\bar{J}}\varphi d\bar{J}) \quad , \qquad (24)$$

(19), (20), (.22) da (23)-is erToblivi gardaqmnis Sedegad, imis gaTvaliswinebiT, rom $x_1 = 0$, miviRebT:

$$M_{-2} = \frac{GI}{l}(\varphi_2 - \varphi_1) + \frac{\overline{\mu}I}{l}(\dot{\varphi}_2 - \dot{\varphi}_1) + \frac{\bar{J}}{3}\ddot{\varphi}_2 + \frac{\bar{J}}{6}\ddot{\varphi}_1 + \\ + \frac{\bar{J}(\dot{\varphi}_1^2 + \dot{\varphi}_1\dot{\varphi}_2 + \dot{\varphi}_2^2) - 6W}{3(\varphi_2 - \varphi_1)} \qquad (25)$$

exla Tu koordinatTa saTaves SevuTavsebT Reros meore bolos ($x_2 = 0$) da SevasrulebT analogiur gardaqmnebs, gveqneba:

$$M_{+1} = \frac{GI}{l}(\varphi_2 - \varphi_1) + \frac{\overline{\mu}I}{l}(\dot{\varphi}_2 - \dot{\varphi}_1) - \frac{\bar{J}}{3}\ddot{\varphi}_2 - \frac{\bar{J}}{6}\ddot{\varphi}_1 + \\ + \frac{\bar{J}(\dot{\varphi}_1^2 + \dot{\varphi}_1\dot{\varphi}_2 + \dot{\varphi}_2^2) - 6W}{3(\varphi_2 - \varphi_1)} \qquad (26)$$

sadac $W = \frac{1}{2}\int_{\bar{J}}\dot{\varphi}^2 d\bar{J}$ RerZis brunviTi moZraobis kinetikuri energiaa.

axla grZivi rxevis analogiurad kuTxuri siCqare warmovadginoT Semdegnairad:

$$\dot{\varphi} = \dot{\varphi}_i + (\dot{\varphi}_2 - \dot{\varphi}_1)\frac{x}{l} \qquad (27)$$

Tu (1.18) da (1.27) SevitanT W -s gamosaxulebaSi miviRebT:

$$W = \frac{\bar{J}}{6}(\dot{\varphi}_1^{\,2} + \dot{\varphi}_1\dot{\varphi}_2 + \dot{\varphi}_2^{\,2}),$$

rac miuTiTebs imaze, rom (25)-Si da (26)-Si bolo ori wevri gaabaTileben erTmaneTs ris Sedegadac gveqneba:

$$M_{-2} = \frac{GI}{l}(\varphi_2 - \varphi_1) + \frac{\overline{\mu}S}{l}(\dot{\varphi}_2 - \dot{\varphi}_1) + \frac{\overline{J}}{3}\ddot{\varphi}_2 + \frac{\overline{J}}{6}\ddot{\varphi}_1$$

(28)

$$M_{+1} = \frac{GI}{l}(\varphi_2 - \varphi_1) + \frac{\overline{\mu}S}{l}(\dot{\varphi}_2 - \dot{\varphi}_1) - \frac{\overline{J}}{3}\ddot{\varphi}_1 - \frac{\overline{J}}{6}\ddot{\varphi}_2$$

Tu am gamosaxulebebs SevitanT (14)-Si miviRebT:

$$\begin{aligned}&(J_i + \frac{\overline{J}_i + \overline{J}_{i-1}}{3})\ddot{\varphi}_i + \frac{\overline{J}_i}{6}\ddot{\varphi}_{i+1} + \frac{\overline{J}_{i-1}}{6}\ddot{\varphi}_{i-1} + \frac{G_{i-i}I_{i-1}}{l_{i-1}}(\varphi_i - \varphi_{i-1}) - \\ &- \frac{G_iI_i}{l_i}(\varphi_{i+1} - \varphi_i) + \frac{\overline{\mu}_{i-1}I_{i-1}}{l_{i-1}}(\dot{\varphi}_i - \dot{\varphi}_{i-1}) - \frac{\overline{\mu}_iI_i}{l_i}(\dot{\varphi}_{i+1} - \dot{\varphi}_i) = M_i\end{aligned} \qquad (29)$$

2.4 rxevis diferencialur gantolebaTa sistemis amonaxsnis ageba da saTanado programis damuSaveba

miRebuli grZivi da grexiTi rxevebis diferencialur gantolebaTa sistemebis (13) da (29) Sedarebidan gamomdinareobs, rom isini formiT emTxvevian erTmaneTs. gansxvavdebian mxolod mocemuli da saZiebeli sidideebiT: gadaadgilebebis nacvlad gvaqvs mobrunebis kuTxeebi, masebis nacvlad inerciis momentebi, moqmedi gare Zalis nacvlad mgrexi momenti.

aqedan gamomdinare orive SemTxvevisaTvis sistemis amoxsnis algoriTmi iqneba erTidaigive.

maSasadame saWiroa avagoT amonaxseni gantolebaTa sistemisa, romlis raime i-uri gantoleba Seicavs i-uri masisa da misi mezobel $i-1$ da $i+1$ masebis gadaadgilebebis sidides, siCqaresa da aCqarebas. gansxvavebulia mxolod pirveli da bolo gantoleba romelTagan pirveli Seicavs mxolod pirveli da meore masebis, xolo bolo gantoleba bolo da bolos wina masebis gadaadgilebebs, siCqaresa da aCqarebas.

sistemis amonaxsens vagebT ricxviTi gziT runge-kutas meTodis gamoyenebiT. imisaTvis, rom gamoviyenoT runge-kutas meTodis Sesabamisi programa rac SeiZleba naklebi cvlilebebiTYsaWiroa Cven sistemas mivceT garkveuli saxe, rac iTvaliswinebs i -uri gantolebidan i -uri masis aCqarebis gamoyofas da danarCeni wevrebis tolobis meore mxares gadatanas. aseTi saxis sistemaSi Tu SemoviRebT axal cvlads, miviRebT pirveli rigis

Cveulebriv diferencialur gantolebaTa sistemas, romlis marjvena mxareSic gveqneba $i-1$ da $i+1$ masebis aCqarebebi. imisaTvis rom gamoviyenoT runge-kutas meTodis standartuli programa saWiroa ganvaxorcieloT mimdevrobiT miaxloeba sadac nulovan miaxloebaSi tolobis marjvena mxareSi Semavali meore warmoebulebi CaTvlilia nulad. gamoTvlebis Sedegad miviRebT meore warmoebulebis mniSvnelobebs rogorc drois bijis sawyisSi aseve SuaSi da boloSi. Semdeg miaxloebaSi kvlav amoixsneba sistema ukve wina miaxloebidan miRebuli meore warmoebulebis gaTvaliswinebiT. Semdeg miaxloebaSi procesi meordeba. miaxloebis yovel safexurze xdeba Semowmeba. mowmdeba meore warmoebulebis or momdevno miaxloebaSi miRebul mniSvnelobaTa Soris sxvaoba. roca es sxvaoba aRmoCndeba mocemul sidideze naklebi moxdeba gadasvla drois Semdgom bijze, sadac runge-kutes meTodis Sesabamisad gadaadgilebebisa da siCqaris sawyisi mniSvnelobani toli iqneba wina bijis bolo mniSvnelobebisa. rac Seexeba aCqarebebs, meore bijis sawyis wertilSi, is aiReba saSualo im mniSvnelobebisa rac miRebuli gvqonda wina bijis boloSi da rasac miviRebT miaxloebebis Semdeg meore bijis sawyisSi. kvlav Semowmdeba sizuste da ase gagrZeldeba saintegro Sualedis bolomde.

moyvanili algoriTmi saSualebas gvaZlevs runge-kutas meTodis standartuli programa gamoviyenoT nebismieri raodenobis Seyursuli masebisaTvis. moviyvanoT konkretuli damokidebulebebi da Sesabamisi gardaqmnebi xuTi Seyursuli masis SemTxvevaSi, roca isini dakavSirebuli arian erTmaneTTan ganawilebuli masis mqone ReroebiT. vigulisxmoT, rom seismur zemoqmedebas ganicdis pirveli Seyursuli masa, romelic ganlagebulia saZirkvlis doneze da warmoadgens faqtiurad saZirkvlis filas an wertilovan saZirkvels.

$$
\begin{aligned}
&a_{11}\ddot{u}_1 + a_{12}\ddot{u}_2 + b_{11}u_1 + c_{11}\dot{u}_1 + b_{12}u_2 + c_{12}\dot{u}_2 = Q_1\\
&a_{21}\ddot{u}_1 + a_{22}\ddot{u}_2 + a_{23}\ddot{u}_3 + b_{21}u_1 + c_{21}\dot{u}_1 + b_{22}u_2 + c_{22}\dot{u}_2 + b_{23}u_3 + c_{23}\dot{u}_3 = 0\\
&a_{32}\ddot{u}_2 + a_{33}\ddot{u}_3 + a_{34}\ddot{u}_4 + b_{32}u_2 + c_{32}\dot{u}_2 + b_{33}u_3 + c_{33}\dot{u}_3 + b_{34}u_4 + c_{34}\dot{u}_4 = 0, \qquad (30)\\
&a_{43}\ddot{u}_3 + a_{44}\ddot{u}_4 + a_{45}\ddot{u}_5 + b_{43}u_3 + c_{43}\dot{u}_3 + b_{44}u_4 + c_{44}\dot{u}_4 + b_{45}u_5 + c_{45}\dot{u}_5 = 0\\
&a_{54}\ddot{u}_4 + a_{55}\ddot{u}_5 + b_{54}u_4 + c_{54}\dot{u}_4 + b_{55}u_5 + c_{55}\dot{u}_5 = 0
\end{aligned}
$$

sadac koeficientebis sidideebi ganisazRvreba (13) sistemis mixedviT. (30) sistemas mivceT saxe:

$$
\begin{aligned}
&\ddot{u}_1 = \bar{a}_{12}\ddot{u}_2 + \bar{b}_{11}u_1 + \bar{c}_{11}\dot{u}_1 + \bar{b}_{12}u_2 + \bar{c}_{12}\dot{u}_2 + \bar{Q}_{11}\\
&\ddot{u}_2 = \bar{a}_{21}\ddot{u}_1 + \bar{a}_{23}\ddot{u}_3 + \bar{b}_{21}u_1 + \bar{c}_{21}\dot{u}_1 + \bar{b}_{22}u_2 + \bar{c}_{22}\dot{u}_2 + \bar{b}_{23}u_3 + \bar{c}_{23}\dot{u}_3 \qquad (31)\\
&\ddot{u}_3 = \bar{a}_{32}\ddot{u}_2 + \bar{a}_{34}\ddot{u}_4 + \bar{b}_{32}u_2 + \bar{c}_{32}\dot{u}_2 + \bar{b}_{33}u_3 + \bar{c}_{33}\dot{u}_3 + \bar{b}_{34}u_4 + \bar{c}_{34}\dot{u}_4
\end{aligned}
$$

$$\ddot{u}_4 = \bar{a}_{43}\ddot{u}_3 + \bar{a}_{45}\ddot{u}_4 + \bar{b}_{43}u_3 + \bar{c}_{43}\dot{u}_3 + \bar{b}_{44}u_{4+}\bar{c}_{44}\dot{u}_4 + \bar{b}_{45}u_5 + \bar{c}_{45}\dot{u}_5$$

$$\ddot{u}_5 = \bar{a}_{54}\ddot{u}_4 + \bar{b}_{54}u_4 + \bar{c}_{54}\dot{u}_4 + \bar{b}_{55}u_5 + \bar{c}_{55}\dot{u}_5$$

sadac $\bar{a}_{ji} = -\frac{a_{ji}}{a_{jj}}, \bar{b}_{ji} = -\frac{b_{ji}}{a_{jj}}, \overline{Q}_{i1} = \frac{Q_1}{a_{11}}$

SemoviRoT aRniSvna $\frac{\partial u_i}{\partial t} = v_{i+1}$, maSin sistema (31) miiRebs saxes:

$$\begin{aligned}
&\frac{\partial v_1}{\partial t} = v_2 \\
&\frac{\partial v_2}{\partial t} = \bar{a}_{12}\ddot{u}_2 + \bar{b}_{11}v_1 + \bar{c}_{11}v_2 + \bar{b}_{12}v_3 + \bar{c}_{12}v_4 + \overline{Q}_1 \\
&\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\
&\frac{\partial v_9}{\partial t} = v_{10} \\
&\frac{\partial v_{10}}{\partial t} = \bar{a}_{54}\ddot{u}_4 + \bar{b}_{54}v_7 + \bar{c}_{54}v_8 + \bar{b}_{55}v_9 + \bar{c}_{55}v_{10}
\end{aligned} \qquad (32)$$

rogorc cnobilia runge-kutas meTodSi gamoiTvleba tolobis marjvena mxareebi bijis jer sawyis wertilSi wina bijis bolo wertilSi miRebuli mniSvnelobebis mixedviT. yoveli meore gantolebis marjvena mxare warmoadgens saTanado Seyursul masis aCqarebas, romlis sididec zustdeba TiToeuli bijis farglebSi gamoTvlebis procesSi. e.i. Tavidan pirveli bijis dros meore warmoebulebi marjvena mxareSi nulia; gamoiTvleba maTi mniSvnelobebi sawyis, Sua da bolo wertilebSi. runge-kutas meTodSi es mniSvnelobebi mravldeba drois bijis sidideze raTa miviRoT saZiebeli funqciis nazrdi. Cven SemTxvevaSi bijis sidideze gadamravlebamde meore warmoebulebis miRebul mniSvnelobebs vaTavsebT calke masivSi da viyenebT maT miaxloebis Semdeg safexurze meore warmoebulis dazustebisaTvis. rogorc zemoT avRniSneT meore da Semdgomi bijebisaTvis meore warmoebuli aRar iqneba nulis toli da aiReba is wina bijze miRebul mniSvnelobis gaTvaliswinebiT.

rac Seexeba sawyis pirobebs TiToeuli masisaTvis rogorc gadaadgileba aseve siCqare sawyis momentSi nulia. gamonakliss SeiZleba warmoadgendes pirveli masa, romelzec moqmedebs gare Zala Q_1. aq SeiZleba mocemuli iyos sawyisi siCqarec. TviTon gare zemoqmedeba SeiZleba mocemuli iyos sxvadasxva saxiT, rac ZiriTadad damokidebulia gasaangariSebel nagebobis epicentralur zonidan daSorebis manZilze. am zonis uSualo siaxloves gruntis siaxloves gruntis moZraobis kanoni warmoidgineba impulsis saxiT romelSic figurirebs eqsponenta [43]

$$W(t) = ate^{-\beta t}$$

sadac a gruntis gadaadgilebis sawyisi siCqarea, $\frac{1}{\beta}$ ki dro, romlis miRwevisasac gadaadgileba Rebulobs maqsimalur mniSvnelobas $\frac{a}{\beta}$.

epicentridan daSorebis manZilis zrdisas icvleba gruntis moZraobis xasiaTic. impulsuri moZraoba gaiWimeba droSi, rac dmokidebulia gruntis dispersiul Tvisebebze da mis erTgvarovnebaze. kerZod, Teoriuli kvlevebi adastureben, rom impulsis gardaqmna gansakuTrebiT intensiuria, roca gvaqvs fenovani grunti, rac praqtikulad yvelganaa. aseT SemTxvevaSi sawyisi impulsuri xasiaTi gruntis moZraobisa, manZilis zrdasTan erTad gardaiqmneba cvladi periodisa da amplitudis talRebis seriad. am SemTxvevaSi moqmedi ganivi Zala SeiZleba warmodgenili iyos erTniSna an niSancvladi samkuTxa impulsis saxiT. epicentris mimdebare teritoriaze ganivi Zala gamoiTvleba moyvanili gadaadgilebebis kanonidan miRebul aCqarebis safuZvelze. aCqareba, romelic miiReba orjer gawarmoebis gziT

$$\frac{d^2W}{dt^2} = a\beta e^{-\beta t}(\beta t - 2)$$

mravldeba masaze, romelsac SeiZleba warmoadgendes pirveli Seyursuli masa, Tu dauSvebT, rom mas mieniWeba aRniSnuli aCqareba. SesaZlebelia masis sidide gamoiTvalos gruntis im masis mixedviT rac monawileobs nagebobaze zemoqmedebaSi. am SemTxvevaSi Zalis cvlilebis kanoni iqneba iseTive rac aCqarebis. amave dros cxadia sawyis pirobebSi gasaTvaliswinebeli iqneba sawyisi siCqarec $v_2(0) = a$

rogorc ukve avRniSneT diferencialur gantolebaTa sistemis amosaxsnelad viyenebT runge-kutas meTods, romlis realizacia xdeba fortranis enaze dawerili programis saSualebiT.

programa Sedgeba sawyisi monacemebisagan, romlebic moicaven rogorc gamoyofil masivebs, aseve konstruqciis geometriul zomebs da meqanikur maxasiaTeblebs. aqve Sedis damxmare gamosaxulebebis gamoTvla, romlebic qmnian diferencialur gantolebaTa sistemis koeficientebsa da Tavisufal wevrebs.

Semdeg xdeba koeficientebisa da Tavisufali wevrebis matricebis formireba, romlis Semdegac runge-kutas meTodiT warmoebs diferencialur gantolebaTa sistemis amonaxsnebis gamoTvla. bolos am amonaxsnebiT Zalebisa da gadaadgilebebis gamoTvla da miRebul Sedegebis beWvda.

2.5 Sesrulebuli gamoTvlebis Sedegebi da maTi analizi

damuSavebuli programis realizacia ganxorcielebulia oTxsarTuliani karkasuli Senobis magaliTze. Senobis mzid konstruqcias warmoadgens monoliTuri rkinabetonis svetebi ganivi kveTiT 40-40 sm da gadaxurvis monoliTuri filebi sisqiT 15 sm. Senoba saangariSo sqemaze warmodgenilia diskretul-kontinealuri sqemiT, romelSic xuTi Seyursuli masa gadaxurvebisa da saZirkvlebis doneze, dakavSirebulia erTmaneTTan dayvanili kveTis deformirebadi ReroebiT. saangariSo sqemaze gare datvirTva warmodgenilia impulsis saxiT, romelic moqmedebs qveda pirvel masaze. impulsis cvlilebis kanoni Seicavs eqsponentas da sawyis siCqares mamravlis saxiT.

ganxilulia rogorc grZivi, aseve grexiTi rxevebi. gamokvleulia rogorc Reroebis masebis, aseve sxva maxasiaTebeli parametrebis cvlilebis gavlena mTlianad konstruqciis daZabul-deformirebul mdgomareobaze.

grZivi rxevisas Reroebis gavlenis gaTvaliswinebis gareSe miRebuli gadaadgilebebi zemoqmedebis sawyis periodSi maqsimaluria pirveli da bolo masebisaTvis. meore da Semdgom masaze gadasvlisas gadaadgileba mcirdeba da Seadgens meore masisTvis pirveli masis gadaadgilebis 76%, mesamesTvis 66%, meoTxesTvis 62%, mexuTesTvis 95%-ia. (nax. 2.5)

rac Seexeba siCqareebs, meore masis siCqare 0-dan izrdeba pirvel masaze miniWebuli siCqaris 29%-mde, mesamis 20%-mde, meoTxis 17%-mde. mexuTis 22%-mde. pirveli siCqare ki ganulebis Semdeg izrdeba pirvelad miniWebuli siCqaris 55%-mde. SemdegSi absolituri sidide cxadia kidev ufro mcirdeba. ReroSi moqmedi mniSvnelobebi erTnairia Reros Tavsa da boloSi., es Zala gairbens yvela Reros Tavis maqsimalur mniSvnelobis mcire cvlilebiT.

Reroebis gaTvaliswinebisas gadaadgilebebis ganawilebis suraTi droSi analogiuria. mxolod gadaadgilebebis sidide izrdeba gansakuTrebiT mexuTe masisTvis da aRwevs 10%. analogiuria siCqareTa ganawilebac, aqac siCqareebi metia, magram umniSvnelod.

rac Seexeba Zalebis ganawilebas aq Reroebis gavlena metia Tundac imitom, rom Zalebis mniSvnelobani miiReba TiToeuli Reros Tavsa da boloSi gansxvavebuli da es gansxvaveba pirvel masisaTvis aRwevs 8%-s. danarCenebisTvis naklebia. Tu am mniSvnelobebs SevadarebT Reroebis gavlenis gaTvaliswinebis gareSe miRebul Sedegs, vnaxavT, rom pirveli masisTvis es mniSvneloba moTavsdeba Tavsa da boloSi miRebuli mniSvnelobebis SuaSi, danarCeni masisTvis ki orive mniSvneloba naklebia daaxloebiT 9%-iT. aRsaniSnavia rom es gansxvavebebi miRebulia dartymidan rxevis pirveli periodis ganmavlobaSi, SemdgomSi isini TandaTanobiT mcirdeba rogorc Tavsa da boloSi miRebul

mniSvnelobebTan SedarebiT da aseve Reros gavlenis gaTvaliswinebis gareSe miRebul mniSvnelobasTan SedarebiT.

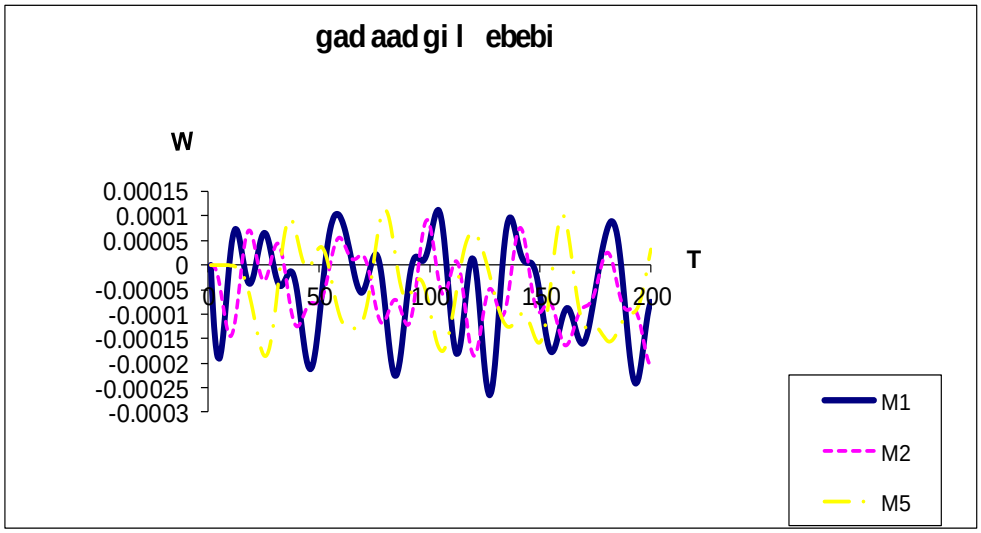
gamokvleulia agreTve sawyisi siCqaris sididis cvlilebis gavlena sistemaSi aRZrul Zalebsa da deformaciebze. rogorc mosalodneli iyo Zalebi da deformaciebi icvleba sawyisi siCqaris sididis proporciulad (nax.^2.6).

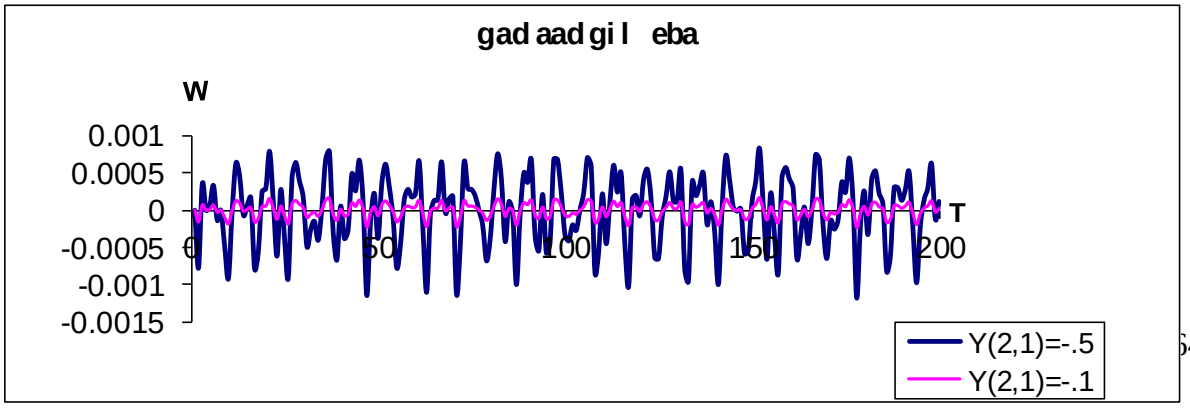
analogiuri gamoTvlebi Sesrulebulia im SemTxvevaSi, roca konstruqciis masala emorCileba foxtis models. Reroebis masebis inerciis gavlenis gaTvaliswinebis gareSe gadaadgilebaTa ganawilebis kanoni zemoqmedebis sawyis momentSi daaxloebiT igivea, rac siblantis gaTvaliswinebis gareSe im gansxvavebiT rom maqsimaluri gadaadgilebebi Semcirda daaxloebiT 13%, 26%, 22%, 36%, da 28%, masebis Sesabamisad

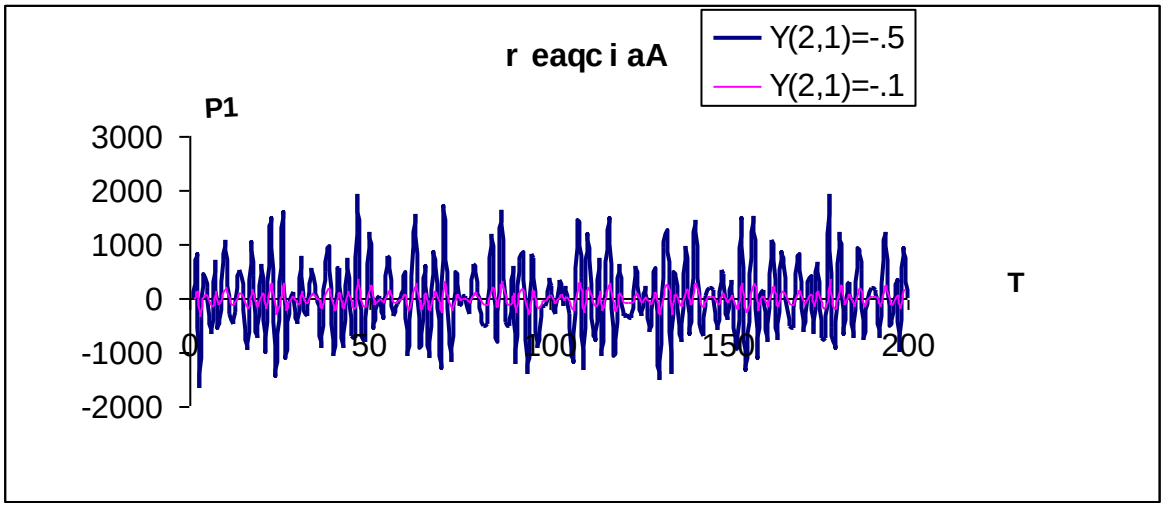
drois gasvlasTan erTad siblantis gavlena xdeba mniSvnelovani, rac gamoixateba gadaadgilebaTa sidideebis absolitur mniSvnelobaTa SemcirebaSi (nax. 2.7).

rac Seexeba siCqareebs, maTze siblantis gavlena ufro arsebiTia rogorc absoluturi mniSvnelobis TvalsazrisiT, aseve ufro intensiuri rxevis TvalsazrisiTac. Tu SevadarebT ReroebSi aRZruli Zalebis maqsimalur absolitur mniSvnelobas vnaxavT, rom maTi sidideebi zemoqmedebis sawyis momentSi mcirdeba Reroebis mixedviT Sesabamisad 10,3%; 27,8%; 36%%; 41%-iT (nax. 2.8). drois gasvlis Semdeg es Semcireba ufro mniSvnelovania.

nax. 2.5 pirveli, meore da mexuTe masis gadaadgilebebi





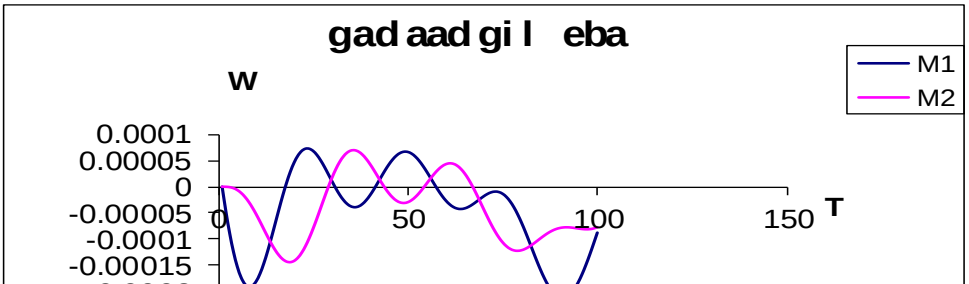


nax. 2.6 gadadgilebebi da Zalebi sawyisi siCqaris sxvadasxva mniSvnelobisaTvis

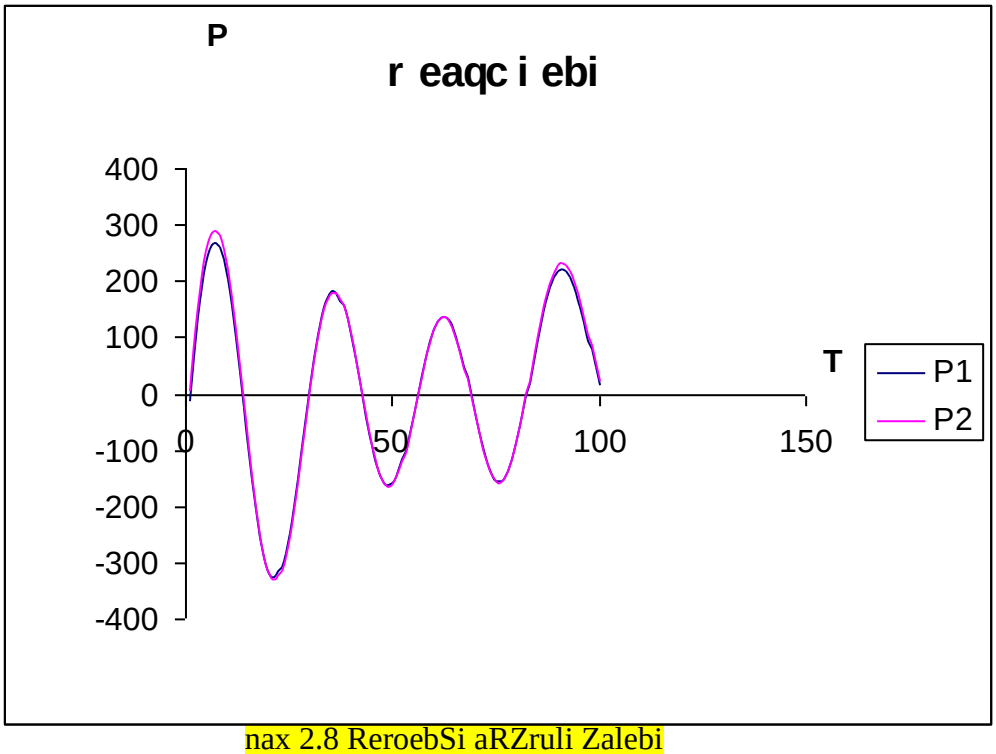
ReroTa masebis inerciis gaTvaliswineba aqac Tvisobrivad gvaZlevs daaxloebiT igive Sedegs rac gvqonda siblantis gaTvaliswinebis gareSe. gadaadgilebebi kvlav mcirdeba umniSvnelod da es Semdeg aRwevs mexuTe masisaTvis daaxloebiT 14%-s.

rac Seexeba Zalebs, zemoqmedebis sawyis periodSi, siblantis gavleniT, isini umniSvnelod mcirdeba, drois gasvlis Semdeg ki arsebiTad , SeiZleba iTqvas ramdenjerme. sawyis momentSi ReroTa masebis inerciis gavleniT Zalebis mniSvnelobani gamodis Tavsa da boloSi gansxvavebuli. am sidideebisa da Reroebis gavlenis gareSe miRebul sidideebs Soris damokidebuleba daaxloebiT iseTivea rac cocvadobis gaTvaliswinebis gareSe gvqonda.

gamokvleulia pirveli masis sididis cvlilebis gavlena zeda masebis gadaadgilebebsa da ReroebSi aRZrul Zalebis mniSvnelobaze. pirveli masis cvlileba iwvevs damrtymeli Zalis sididis proporciul cvlilebebs , magram rogorc gamoTvlebi gviCvenebs igi ar iwvevs aseve proporciulad konstruqciaSi aRZruli Zalebisa da gadaadgilebebis cvlilebebs, risi mizezic aris sawyisi siCqaris gavlena. sawyisi siCqaris cvlileba, rogorc vnaxeT, iwvevs saZiebeli sidideebis proporciul cvlilebas. rac Seexeba pirveli masis sididis cvlilebas misi gavlena Semdegia: Reroebis masebis inerciis gavlenis gaTvaliswinebis gareSe pirveli masis orjer Semcireba iwvevs masebis gadaadgilebis Semcirebas 20%-dan 50%-mde, Sesabamisad pirvelidan mexuTe masamde.



nax 2.7 pirveli da meore masis gadaadgilebebi



nax 2.8 ReroebSi aRZruli Zalebi

ReroTa masebis gaTvaliswinebiT gavlenis kanonzomiereba rCeba igive, mxolod raodenobrivad mcirdeba 10%-dan 43%-mde. daaxloebiT aseTivea gavlena Zalebze rogorc Reroebis gareSe, ise maTi gaTvaliswinebiT. gacilebiT metia masis Semcirebis gavlena foxtis modelis SemTxvevaSi.

pirveli masis garda danarCeni masebis gadaadgilebebi mcirdeba daaxloebiT 48%-iT, pirvelisa 27%-iT Reroebis gavlenis gaTvaliswinebis gareSe da daaxloebiT 3-8% naklebad Reroebis gaTvaliswinebiT. rac Seexeba Zalebs isini mcirdebian iseve rogorc gadaadgilebebi.

rac Seexeba siblantis koeficientis cvlilebis gavlenas daZabul-deformirebul mdgomareobaze, misi zrda Tavidan iwvevs Zalebisa da gadaadgilebebis intensiurobis Semcirebas. Semdgomi zrdisas ki es Semcireba Rebulobs SedarebiT mdore xasiaTs (nax. 2.9).

mgrexi momentis moqmedebis sawyis periodSi, Reroebis masebis inerciis gavlenis gaTvaliswinebis gareSe, mobrunebis kuTxis maqsimaluri mniSvneloba gvaqvs mexuTe

masisaTvis, igi 35%-iT aRemateba pirveli masis mobrunebis kuTxis maqsimalur sidides. rac Seexeba meore, mesame da meoTxe masebis mobrunebis kuTxeebs, isini 10-15%-iT naklebia pirveli masis mobrunebis kuTxeze (nax 2.10).

rac Seexeba siCqareebs, meore da mexuTe masebis brunvis siCqare izrdeba nulidan pirvel masaze miniWebul maqsimalur siCqaris 36%-mde, mesame masisa _ 29%-mde, xolo meoTxe masisa _25%-mde. ganulebis Semdeg pirveli, meore da mesame masebis siCqareebi izrdeba daaxloebiT 40-44%-mde, meoTxis 30%, mexuTis ki 62%-mde. amis Semdeg siCqareTa maqsimaluri mniSvnelobebi mcirdeba.

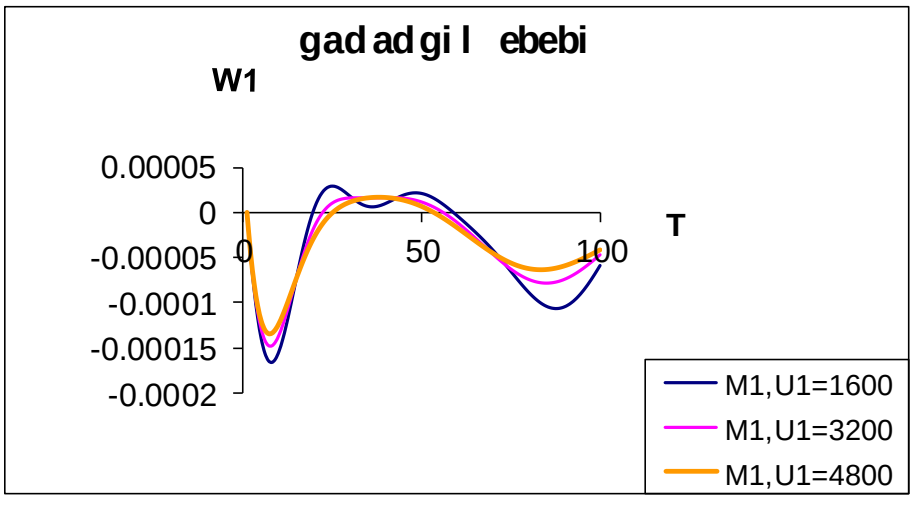
ReroSi moqmedi mgrexi momentis mniSvnelobebi maqsimaluria pirvel ReroSi, danarCenebSi mcirdeba da meoTxe ReroSi maqsimaluri sidide tolia pirvel ReroSi moqmedi Zalis 53%-sa. niSnis Secvlis Semdeg momentebi samive ReroSi daaxloebiT erTnairia garda meoTxe ReroSi, sadac mgrexi momenti daaxloebiT 38%-iT metia sxva ReroebSi moqmed maqsimalur sidideze. Semdgom periodSi ReroebSi moqmedi Zalebi aRweven garkveul maqsimalur sidideebs, magram isini naklebia meoTxe ReroSi miRebul maqsimalur mniSvnelobaze.

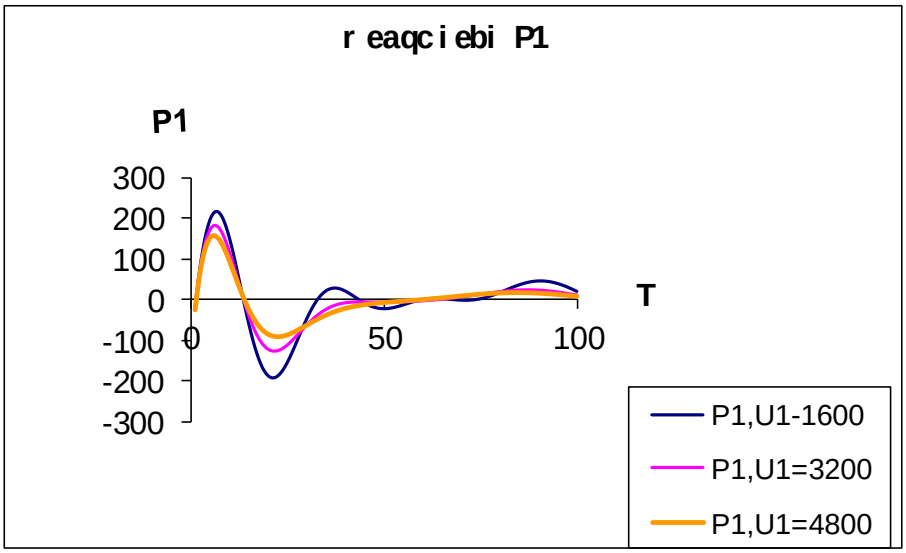
Reroebis masebis inerciis gaTvaliswinebiT mobrunebis kuTxeTa ganawilebis suraTi droSi analogiuria, rac Seexeba sidideTa absolitur mniSvnelobas isini izrdeba daaxloebiT 10%-iT.

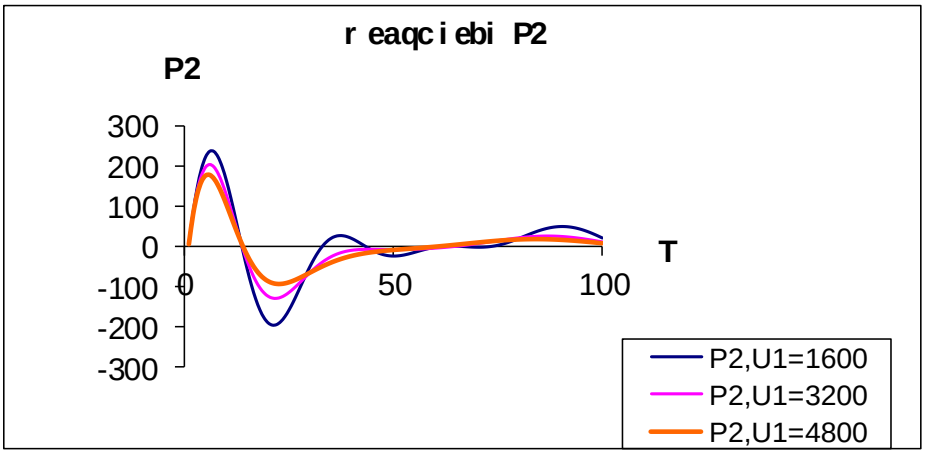
rac Seexeba Zalebis ganawilebis suraTs, igi daaxloebiT iseTivea rac Reroebis masaTa gavlenis gaTvaliswinebis gareSe gvqonda. am SemTxvevaSi Reros Tavsa da boloSi moqmedi Zalebi gansxvavdebian erTmaneTisagan magram umniSvnelod. ase rom Reros Reros masebis gavlena am SemTxvevaSi kidev ufro naklebia vidre mobrunebis kuTxeTa SemTxvevaSi.

gamokvleulia agreTve sawyisi siCqaris sididis gavlena sistemaSi aRZrul mgrex momentebsa da mobrunebis kuTxeebze. rogorc mosalodneli iyo es sidideebi icvleba sawyisi siCqaris sididis proporciulad.

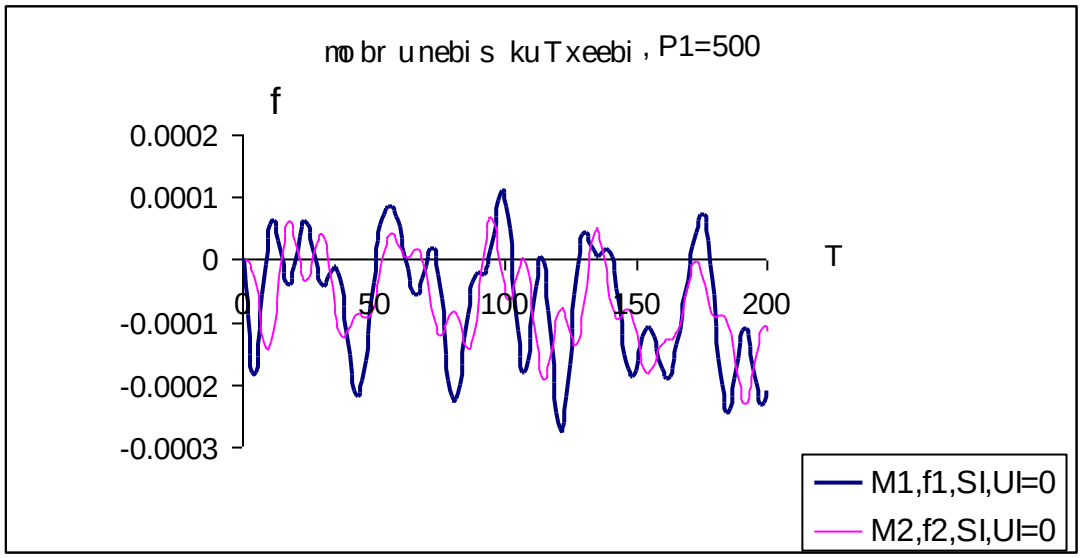
analogiuri gamoTvlebi Sesrulebulia im SemTxvevaSi, roca konstruqciis masala emorCileba foxtis models.

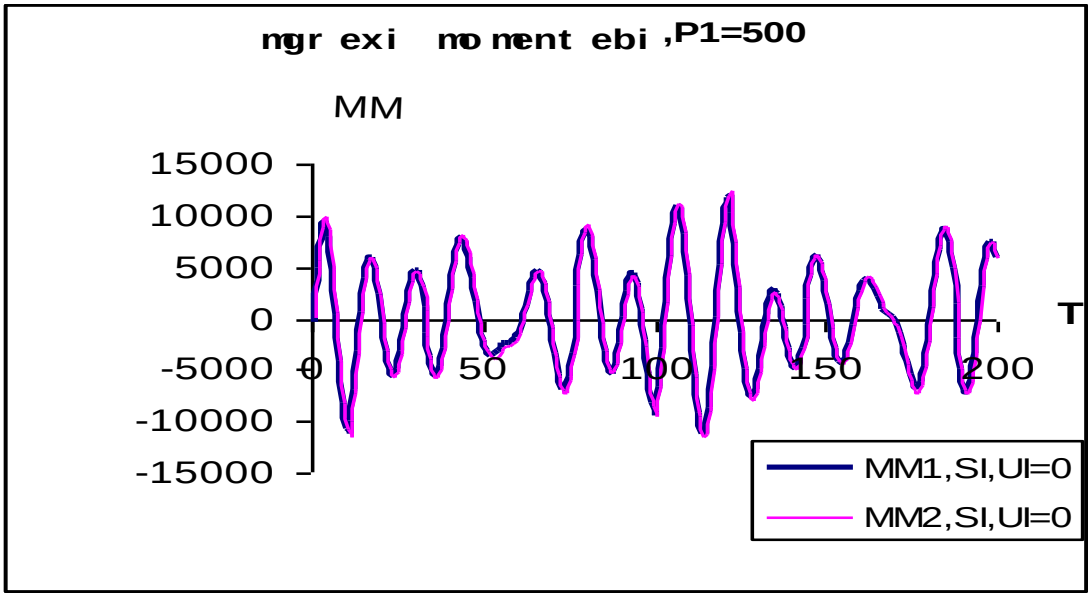






nax. 2.9 gadaadgilebebi da Zalebi siblantis koeficientis sxvadasxva mniSvnelobisaTvis





nax. 2.10 mobrunebis kuTxeebi da mgrexi momentebi hukis kanonis SemTxvevaSi

ReroTa masebis inerciis gavlenis gaTvaliswinebis gareSe mobrunebis kuTxeTa ganawilebis kanoni zemoqmedebis sawyis momentSi daaxloebiT iseTivea rac siblantis gavlenis gaTvaliswinebis gareSe gvqonda im gansxvavebiT, rom mobrunebis kuTxeTa maqsimaluri sidideebi masebis mixedviT Semcirda Sesabamisad 18, 32, 39, 35, da 46%-iT. drois gasvlasTan erTad siblantis gavlena xdeba mniSvnelovani, rac gamoixateba imaSi, rom rxeva faqtiurad aRar gvaqvs. (nax. 2.11)

rac Seexeba siCqareebs maTze siblantis gavlena ufro arsebiTia rac gamoixateba absolituri mniSvnelobaTa mniSvnelovani SemcirebiT (TiTqmis ganaxevrebiT).

aseve mniSvnelovania siblantis gavlena aRZruli mgrexi momentebis mniSvnelobaze, isini mcirdeba yvela RerosTvis gansakuTrebiT ki bolo RerosTvis sadac xdeba Semcireba daaxloebiT 2,5-jer. cxadia drois gasvlis Semdeg es Semcireba ufro mniSvnelovania.

ReroTa masebis inerciis gaTvaliswineba, rogorc mobrunebis kuTxeebis aseve mgrexi momentebis mniSvnelobaze, Tvisobrivad da raodenobrivad gvaZlevs igive Sedegs Semcirebis TvalsazrisiT rac zemoT gvqonda.

gamokvleulia pirveli masis inerciis momentis cvlilebis gavlena mobrunebis kuTxisa da mgrexi mgrexi momentebis mniSvnelobaze. cvlileba iwvevs damrtmymeli mgrexi momentis proporciul cvlilebas rac ukve aRniSnuli iyo grZivi rxevebis SemTxvevaSi.

ganxilul SemTxvevaSi pirveli masis inerciis momentis orjer Semcireba iwvevs pirvelidan mexuTe masamde mobrunebis kuTxis Semcirebas 19%-dan 42%-mde. ReroTa masebis gaTvaliswinebiT masis Semcirebis gavlenis kanonzomiereba rCeba igive, mcirdeba 2-3%-iT. daaxloebiT aseTivea gavlena aRZrul mgrex momentebze (nax. 2.12).

siblantis gavlenis gaTvaliswinebiT mobrunebis kuTxeebi mcirdeba 26%-dan 42%-mde. drois gasvlasTan erTad mobrunebis kuTxeTa absolituri mniSvnelobebi mcirdeba moyvanil procentebTan erTad.

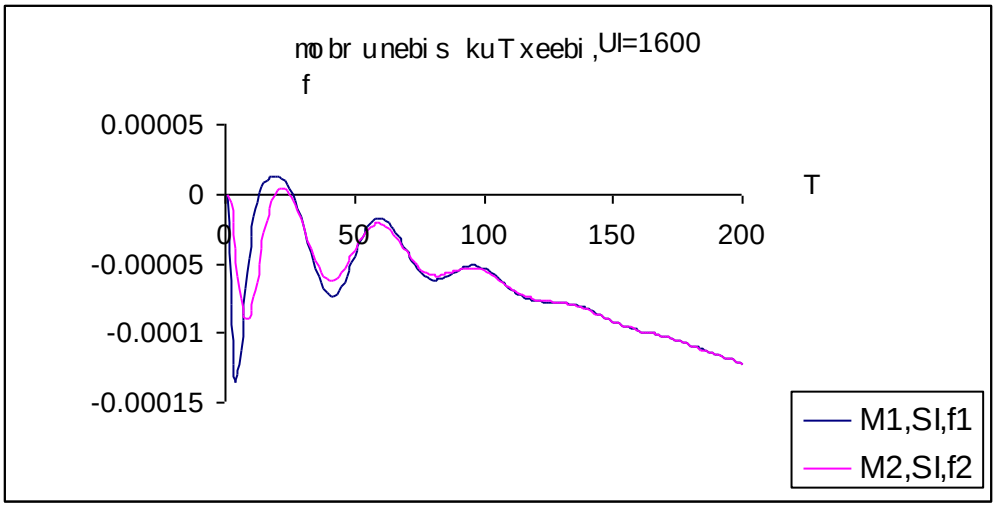
gamokvleulia agreTve siblantis koeficientis cvlilebis gavlena mobrunebis kuTxeebsa da mgrexi momentebis sidideebze. siblantis koeficientis nulidan, toli sididis bijiT zrdis SemTxvevaSi misi gavlena Tavidan intensiuria Semdeg ki TandaTanobiT mcirdeba. mag. pirveli masisTvis 26%-dan, meoresTvis 37%-dan, xolo mexuTe masisTvis 47%dan (nax. 2.13).

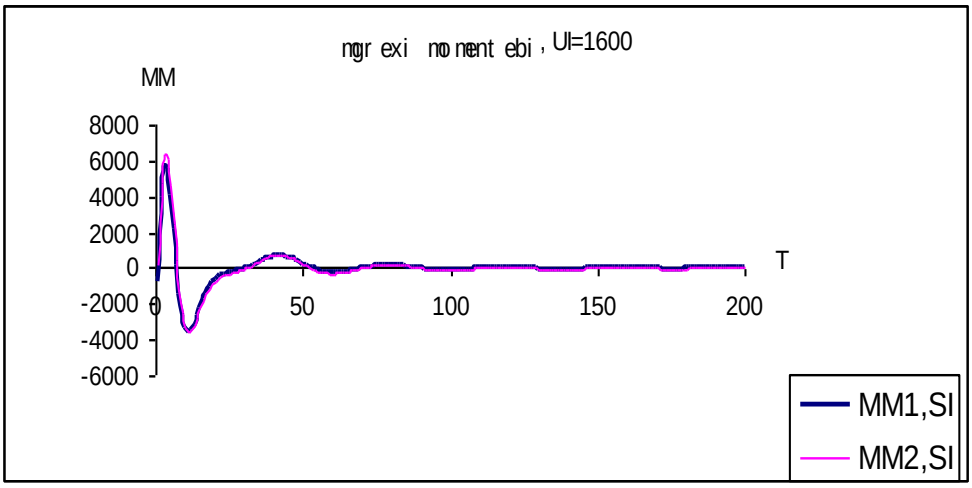
gacilebiT intensiuria siblantis koeficientis cvlilebis gavlena mgrex momentebze. mag. pirveli masisTvis mgrexi momenti mcirdeba pirvel

safexurze TiTqmis samjer, meore safexurze 1,8-jer, mesameze ki 1,4-jer. mexuTe masisTvis Semcireba gvaqvs Sesabamisad 5-jer, 2-jer da 1,7-jer.rogorc moyvanili Sedegebidan Cans gamokvleuli cvlilebis mimarT

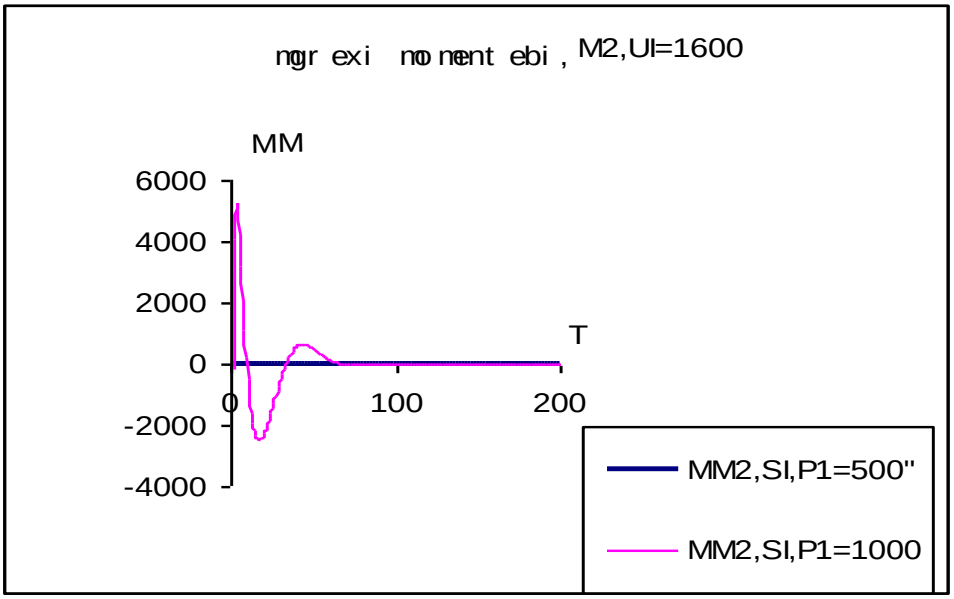
yvelaze ufro mgrZnobiarea mexuTe masa da masTan mimdebare meoTxe Rero. Semdeg pirveli masa da pirveli Rero. rac Seexeba Sua masebsa da Reroebs isini maTTan SedarebiT naklebad reagireben am cvlilebebze. es kanonzomiereba irRveva roca saqme exeba meore masis inerciis momentis cvlilebas.

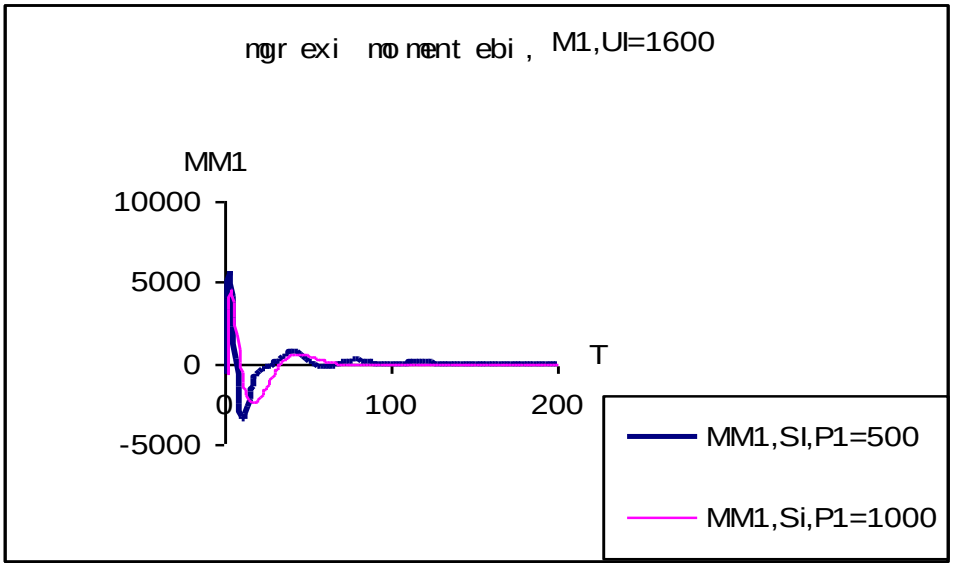
meore masis inerciis momentis orjer Semcirebis SemTxvevaSi yvela masis mobrunebis kuTxeebi izrdeba daaxloebiT 6-7%-iT. rac Seexeba Zalebs pirvel ReroSi mcirdeba daaxloebiT 15%-iT, danarCenebSi ki izrdeba: meoreSi 15%, mesame 11%, meoTxeSi 10%.



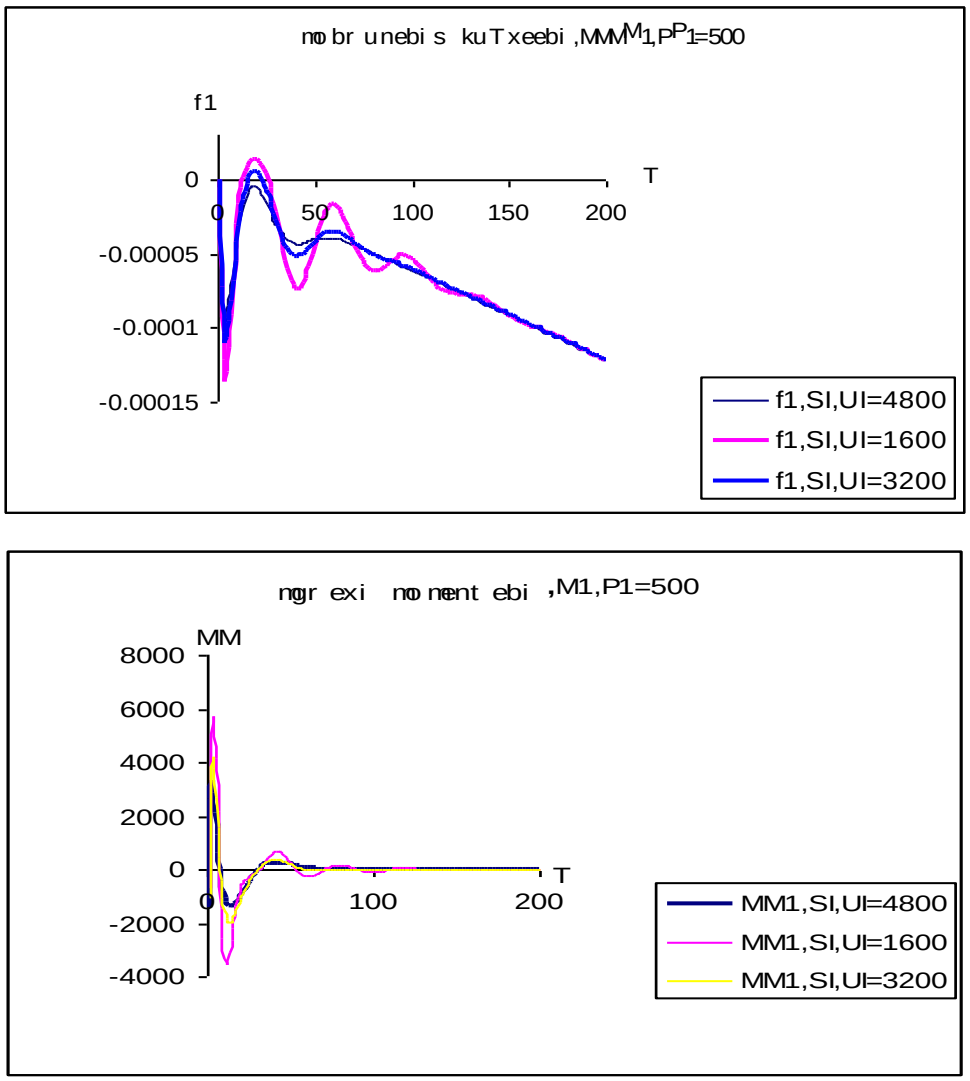


nax. 2.11 mobrunebis kuTxeebi da mgrexi momentebi kelvin foxtis modelis mixedviT

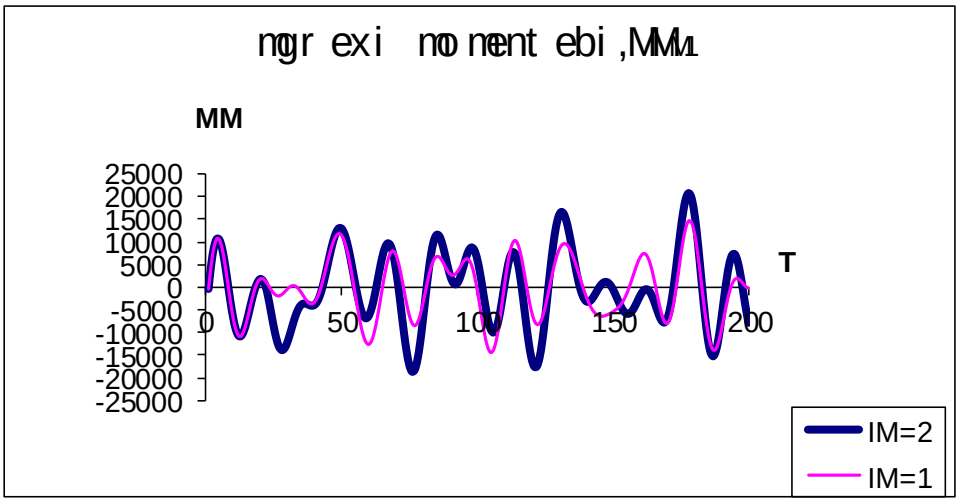




nax. 2.12 mgrexi momentebi pirveli masis sxvadasxva mniSvnelobis SemTxvevaSi



nax. 2.13 mobrunebis kuTxeebi da mgrexi momentebi siblantis koeficientis sxvadasxva mniSvnelobisaTvis



nax. 2.14 grexiTi rxevisas (siblantis gaTvaliswinebis gareSe) momentebi, erTjeradi da ganmeorebiTi dartymisas

ganxilulia ganmeorebiTi dartymis SemTxvevebic. grZivi rxevisas, roca Reroebis masala emorCileba hukis kanons. ganmeorebiTi dartyma, ganxilul konkretul SemTxvevaSi uSualod dartymis Semdeg iwvevs masebis maqsimaluri gadaadgilebis zrdas Sesabamisad 23%-iT, 53%-iT, 34%-iT, 2,8-jer da mexuTe masis 2,55-jer. Tu erTjeradi dartymisas mexuTe masis gadaadgileba iyo daaxloebiT iseTive rogorc pirveli masis, ganmeorebiTi dartymisas misi gadaadgileba TiTqmis orjer metia pirveli masis gadaadgilebaze. rac Seexeba meore da mesame masis gadaadgilebebs maTi sidideebi TiTqmis iseTivea rogorc pirveli masis (odnav naklebi), meoTxe masisa ki TiTqmis 50%-iT meti pirveli masis gadaadgilebaze.

rac Seexeba Zalebs uSualod ganmeorebiTi dartymis Semdeg izrdeba Reroebis mixedviT 41%-iT, 20%-iT, 27%-iT da 20%-iT. Reros Tavsa da boloSi Zalebis mniSvnelobani umniSvnelod (daaxloebiT 5%) gansxvavdebian erTmaneTisagan, amitom moyvanili Sefasebebi samarTliania orive mniSvnelobisaTvis (nax. 2.14).

Tu ganmeorebiT dartymas ganvaxorcielebT drois sxva monakveTis Semdeg e.i. ufro mokle an xangrZlivi drois Semdeg, gadaadgilebebisa da Zalebis cvlilebis intensioba iqneba gansxvavebuli. ase rom, mravaljeradi cdis Sedegad SeiZleba ganisazRvros drois is Sualedi, romlis Sedegac ganmeorebiTi dartyma gamoiwvevs Zalebis an gadaadgilebebis maqsimalur zrdas.

daskvnebi

1. grZivi da grexiTi rxevisas Reroebis masebis inerciis gauTvaliswinebloba amcirebs gadaadgilebebisa da Zalebis mniSvnelobas daaxloebiT 9-10%-iT.

2. konstruqciaSi aRZruli Zalebi da gadaadgilebebi sawyisi siCqaris proporciulia, magram isini ar aris proporciuli zemoqmedebis Zalisa roca gvaqvs sawyisi siCqarec.

3. gadaadgilebebi da Zalebi ar icvlebian siblantis koeficientis proporciulad. misi zrda Tavidan iwvevs Zalebisa da gadaadgilebebis ufro intensiur Semcirebas vidre misi Semdgomi zrdis procesi. grZivi rxevebis ganxilul konkretul SemTxvevaSi siblantis gaTvaliswinebam gamoiwvia, Sesabamisad pirvelidan mexuTe masebamde Semcireba 13-dan 36%-mde, Zalebisa ki 19-dan 41%-mde.

4. grexiTi rxevebis SemTxvevaSi maqsimaluri mobrunebis kuTxe gvaqvs mexuTe masisTvis, xolo maqsimaluri mgrexi momenti pirvel ReroSi, rogorc ReroTa masebis gaTvaliswinebiT aseve maT gareSe.

5. siblantis gaTvaliswinebiT mobrunebis kuTxis maqsimaluri Semcireba (46%) gvaqvs mexuTe masisTvis, mgrexi momentisa ki mimdebare ReroSi (2,5-jer).

6. pirveli masis inerciis momentis SemcirebiT mobrunebis kuTxis maqsimaluri Semcireba gvaqvs mexuTe masisaTvis (daaxloebiT 42%), rogorc siblantis koeficientis gaTvaliswinebiT, aseve mis gareSe.

7. siblantis koeficientis cvlilebis gavlena mobrunebis kuTxeebze grexis SemTxvevaSic maqsimaluria mexuTe masisTvis (47%). am cvlilebis gavlena ufro intensiuria mgrex momentebze da iwvevs ramdenjerme maT Semcirebas (I masisTvis 3-jer, mexuTe masisTvis 5-jer).

8. meore masis inerciis momentis Semcirebis gavlena umniSvneloa da iwvevs yvela masis mobrunebis kuTxis zrdas daaxloebiT 7%-iT. rac Seexeba pirvel ReroSi Zala mcirdeba, danarCenebSi ki izrdeba.

9. maSasadame grZivi da grexiTi rxevisas arsebiTia rogorc ReroTa masebis inerciis gavlena, aseve ufro metad reologiuri Tvisebebis gaTvaliswineba, rac aucilebelia gaangariSebis dros.

Tavi 3. Senobis, rogorc diskretul-kontinualuri sistemis ganivi rxevebis Seswavla impulsuri zemoqmedebiT (miwisZvra, afeTqeba da sxva) gamowveuli dartymis efeqtis gaTvaliswinebiT

miwisZvrisas dartymis efeqtis arsebobisa da Senoba-nagebobebze misi zegavlenis Sesaxeb gamoTqmulia mosazrebebi, romelTa Tanaxmadac miwisZvris Sedegad dazianebis ZiriTad mizezad SeiZleba swored dartymis efeqti iyos dasaxelebuli. damuSavebulia Teoria, romelic seismur gamosxivebas aigivebs meqanikur impulsTan, romlis gavrcelebac emorCileba dartymis meqanikis kanonebs. amave dros, specialistTa Soris midis cxare

kamaTi im debulebebis, hipoTezebisa da daSvebebis kanonzomierebis Sesaxeb, romlebic safuZvlad udevs seismomedegobaze nagebobaTa gaangariSebis meTodebs.

seismuri gaangariSebebi eyrdnoba hipoTezas, romlis Tanaxmadac aradrekadi sistemebis maqsimaluri seismuri horizontaluri gadaadgilebebi tolia sixSireebiT eqvivalenturi drekadi sistemebis gadaadgilebebis.bolo wlebis Zlieri miwisZvrebis (san-francisko, 1971, spitaki 1988, kobe 1995, neftegorski 1995 da sxva) analizma miiyvana mecnierebi im daskvnamde, rom es hipoTeza ar SeiZleba CaiTvalos misaRebad. zogierT SemTxvevaSi maqsimaluri horizontaluri gadaadgilebebi aRmoCnda 2-3 rigiT maRali, vidre drekadi sistemebis maqsimaluri gadaadgilebebi. magaliTad 1985 wlis mexikos miwisZvris safuZvelze agebuli gadaadgilebebis grafikidan Cans, rom aradrekadi gadaadgilebebi 100-jer metia hipoTezis Sesabamis drekad gadaadgilebebze. sxva miwisZvrebis SemTxvevaSic aseTive mniSvnelovani Seusabamobebia.

gasaTvaliswinebeli isic, rom maRlivi Senobebis daproeqtebis rekomendaciebSi miTiTebulia aradrekadi deformaciebis gansazRvrisa da maTi sidideebis SezRudvis aucileblobis Sesaxeb.

rogorc cnobilia seismuri zemoqmedebis xasiaTi damokidebulia epicentruli zonidan daSorebis manZilze. gruntis gadaadgilebebs impulsuri xasiaTi aqvs uSualod epicentruli zonis siaxloves. amitom dartymis efeqtis gamovlineba yvelaze metad mosalodnelia am zonaSi. gaanalizebulia rogorc uSualod rRvevaze, mdebare Senobaze zegavlenis SemTxveva, aseve teqtonikuri rRvevis maxloblad: taivanze, kobeSi, loma prietSi, nortrijSi da vaitieraSi (aSS) Canawerebi. analizis safuZvelze gakeTebulia daskvna, rom raodenobrivad SenobaTa rxevis intensioba 1.5÷2.5-jer aRemateba im intensiurobas, rasac gvaZlevs 9 balis saangariSo seismuroba, rac miuTiTebs im faqtze, rom aseT zonebSi mSenebloba moiTxovs gansakuTrebul midgomas, maT Soris dartymis efeqtis gaTvaliswinebasac, rac gansakuTrebiT Zlierad gamovlindeba swored aseT zonebSi.

maSasadame sakiTxi ismis maRliv Senobaze dartymis efeqtis gaTvaliswinebis Sesaxeb Senobis konstruqciebis aradrekadi muSaobis gaTvaliswinebiT.

drekad-plastikur garemoSi SeSfoTebis gavrcelebis sakiTxebi mecnierTa farTo wris interesebSi moeqca gasuli saukunis Sua periodidan. es gasagebicaa, radganac yovelgvari met-naklebad intensiuri dartymiTi datvirTva iwvevs plastikur deformaciebs. nagebobebis simtkicisa da mdgradobis sakiTxebi, romlebic ganicdian dartymebs an afeTqebis zegavlenas SeiZleba iyos gamokvleuli mxolod drekad-plastikur deformaciebis gavrcelebis kanonzomierebis cxadad warmodgenis gziT. Mmeores mxriv realuri masalebi (magaliTad, seismologiisa da seismomedegobis sakiTxebis ganxilvisas) ar warmoadgenen idealurad drekad sxeulebs da aucilebeli xdeba maTi plastikuri Tvisebebis gaTvaliswineba.

drekad - plastikuri sxeulebis rxevis TeoriaSi ori ZiriTadi sakiTxia: erTi esaa plastikurobis Teoriis SerCeva da meore dinamikuri amocanebis kvlevis maTematikuri aparatis SerCva.

iTvleba rom dinamikuri amocanebis gadawyvetisaTvis yvelaze ufro mosaxerxebelia mikroplastikurobis Teoria romelic ganviTarebulia mazingis, iSlinskis, beselingis, novoJilovis, kadaSeviCis, aivenas da sxvaTa SromebSi. maTematiukur aparatad ki miCneulia arawrfivi tenzoruli gantolebebis amoxsnis harmoniuli da statistikuri gswrfivebis meTodebi. aRniSnuli meTodebis gamoyeneba moiTxovs sakmao donis maTematikur momzadebas. garkveul wilad SeiZleba aRmoCndes maTi farTod gamoyenebisaTvis Semaferxebeli ara marto maTematikuri sirTuleebi, aramed gansaxilveli amocanebis farTo speqtris ganxilvis SeuZlebloba. aqedan gamomdinare aqtualuria iseTi martivi, TvalsaCino da fizikuri procesebidan gamomdinare meTodikis damuSaveba, romelic saSualebas mogvcems drekadobis farglebs gareT muSaobis gaTvaliswinebiT Seswavlil iyos nagebobebis rxevebi masze seismuri (konkretulad impulsuri) zemoqmedebis pirobebSi.

aseT meTods warmoadgens Cvens institutSi drekadi konstruqciulad arawrfivi sistemebisaTvis damuSavebuli e.w. dilei-algoriTmis meTodi, romelic warmodgenil angariSSi gamoyenebulia erTmasiani, ormasiani da erT wrfeze ganlagebuli mravalmasiani sistemebis arawrfivi rxevebis Sesaswavlad, rodesac sistema ganicdis gruntis impulsur gadaadgilebas, xolo masebis erTmaneTTan da gruntTan damakavSirebeli Reroebi muSaoben mxolod Zvraze prandtlis sqemis Sesabamisad.

angariSSi Senobis saangariSo sqema warmodgenilia diskretul-kontinualuri sqemiT, sadac sarTulSua gadaxurvis doneze Seyursuli masebi erTmaneTTan dakavSirebulia deformirebadi ReroebiT. igulisxmeba rom TiToeuli sarTulis farglebSi Rero muSaobs mxolod Zvraze, rac gamowveulia Seyursul masebsa da Reros bolos Soris aRZruli urTierTqmedebis ganivi ZalebiT, es ukanasknelni ki gruntis impulsuri gadaadgilebiT gamowveuli ganivi rxevebiT.

P pirvel paragrafSi moyvanilia im Sromebis mimoxilva, romelSic ganxilulia aradrekadi rxevebi gamowveuli impulsuri da xangrZlivi seismuri zemoqmedebiT masalis idealurad drekad-plastikuri (prandtlis sqema) pirobebSi muSaobis dros.

meore paragrafSi Seswavlilia oscilatoris arawrfivi rxevebi roca liTonis Rero muSaobs prandtlis sqemis mixedviT mxolod Zvraze. Camoyalibebulia dilei-algoriTmis arsi da moyvanilia ucnobi Zalebisa da Sesabamisi gadaadgilebebis gamosaTvleli formulebi plastikuri gadaadgilebebis gaTvaliswinebiT.

mesame paragrafSi mocemulia oscilatoris SemTxvevaSi Sesrulebuli gamoTvlebis Sedegebi. agebulia gadaadgilebebisa da Zalebis epiurebi parametrebis sxvadasxva

mniSvnelobisaTvis. naCvenebia, rom impulsuri zemoqmedebis pirobebSi arsebiTia sawyisi siCqaris da ara aCqarebis gavlena rxevis procesze. mocemulia ganmeorebiT impulsuri zemoqmedebis SemTxvevaSi nagebobis reaqcia am zemoqmedebis sxvadasxva momentisaTvis.

aqve naCvenebia, rom aRniSnuli programa SeiZleba gamoyenebuli iqnas demferebis gavlenis Sesaswavlad. plastikurobis Teoriaze dayrdnobiT ganisazRvra demferis deformaciis siCqare da Sesabamisad plastikuri gadaadgileba. Sefasebulia demferis gavlena rxevis procesze.

meoTxe paragrafSi mocemulia oscilatoris rxevebi roca liTonis Rero muSaobs prandtlis sqemis Sesabamisad mxolod Runvaze. Zala-gadaadgilebis damokidebuleba agebulia m. miqelaZis wignSi mocemuli konsolis drekad-plastikuri Runvis statikuri amocanis Sesabamisad. agebulia gadaadgilebebisa da Zalebis epiurebi da isini Sedarebulia drekadi rxevebis SemTxvevasTan.

mexuTe paragrafSi mocemulia ZiriTadi gantolebebi dilei-algoriTmis safuZvelze ori masis aradrekadi rxevebis SeswavlisaTvis.

meeqvse paragrafSi ganxilulia magaliTebi ori masis arawrfivi rxevebis Sesaxeb. gamokvleulia masebis cvlilebis gavlena rxevis procesze. mocemulia raodenobrivi Sedarebebi.

meSvide paragrafSi mocemulia ZiriTadi gantolebebi erT RerZze ganlagebuli mravali Seyursuli masis aradrekadi rxevebis SeswavlisaTvis. damuSavebulia algebrul gantolebaTa sistemis amoxsnis mimdevrobiT miaxloebis algoriTmi da Sedgenilia saTanado programa.

merve paragrafSi mocemulia damuSavebuli programis realizaciis Sedegebi, romelTa analizis safuZvelze Camoyalibebulia saTanado daskvnebi.

3.1 literaturis mimoxilva

dinamikur zemoqmedebaze nagebobaTa yofaqcevis Seswavla aradrekadi deformaciebis gaTvaliswinebiT gansakuTrebiT intensiurad mimdinareobda gasuli saukunis Sua periodSi. garkveuli Sromebi Sesrulebuli iyo Cvens institutSic T. CaCavas [44], g. qarcivaZis da r. murusiZis [45] mier. qvemoT SevexebiT ZiriTadad im Sromebs, romlebSic dasmuli amocanebi da miRebuli Sedegebi sainteresoa proeqtis SinaarsTan maTi Tanxvedris TvalsazrisiT.

ivenma [46,47] farTod gavrcelebuli aRmdgeni Zala-gadaadgilebis nacvlad gamoiyena erTmaneTTan paralelurad an mimdevrobiT SeerTebuli drekadi da plastikuri

elementebi (prandtlis sqemis Sesabamisi) sistema. igi aseTi sqemebis upiratesobad miiCnevs histereziruli…mrudebis maTematikuri Caweris SesaZleblobas da impulsuri datvirTvis istoriis martivad gaTvaliswinebas. aq saWiroa mxolod mimdevrobiT iqnes ganxiluli plastikurad deformadi elementebi gadaadgilebis dadebiTi da uaryofiTi mniSvnelobebisaTvis. miRebuli damokidebulebebi universaluria da mosaxerxebeli cikluri datvirTvis eqsperimentaluri kvlevis Sedegebis aRwerisas.

aq gamoTvlilia energiis danakargi rogorc funqcia gadaadgilebis amplitudis da aRmdgeni Zalis rxevis erTi ciklis dros. Sedarebulia eqsperimentul SedegebTan rac Catarebuli aqvs xansons [48] .aRniSnulia kargi Tanxvedra. [48]-Si gamoTvlilia agreTve Zalebi moqnilobisagan damokidebulebiT. gakeTebulia daskvna, rom roca moqniloba mcirea, Zalebi metia drekad oscilatorSi, xolo meti deformaciisas naklebia.

veletsosma [49] da poseskim [50] gamoikvlies garkveuli tipis arawrfivi sistemebi impulsuri da seismuri zemoqmedebisas. miRebulia praqtikuli meTodebi arawrfivi sistemebis deformaciebis Sefasebisa, Sesabamis wrfiv sistemebTan SedarebiT, aRmZvreli Zalis sixSiris farTo diapazonisaTvis. [49]-Si ganxilulia 1. prandtlis idealuri drekad-plastikuri diagrama. 2. histereziruli tipis wrfivi ganmtkicebis diagrama memkvidreobiTobiT elementebiT. 3. arawrfivad drekadi sistema da 4. sistema romelic drekad-plastikurad muSaobs erTi mimaraTulebiT da drekadad meore mimarTulebiT. es ukanaskneli warmoadgens drekad-plastikuri sistemas araerTgvarovani TvisebebiT da SeiZleba iyos gamoyenebuli daZabul-deformirebul mdgomareobaze sakuTari wonis gavlenis gaTvaliswinebisas. gare datvirTvas warmodgenda 6.29 wm. xangZliobis el-centros (18 maisi 1940) Canaweri da impulsuri zemoqmedeba.

agebulia gadaadgilebebi drekadi da drekad-plastikuri sistemebisaTvis.

miRebuli Sedegebis analizis safuZvelze gakeTebulia daskvna, rom plastikurobis koeficientis gavlena dabali sixSiris SemTxvevaSi 0.15-0.2 hrc. umniSvneloa da sistema muSaobs rogorc deformometri e.i amplituda iseTivea rogorc zemoqmedebis. 0.2-1 hrc.-is SemTxvevaSi drekad-plastikuri gadaadgileba naklebia sakuTari rxevisas drekad gadaadgilebaze. xolo maRali sixSiris SemTxvevaSi drekad-plastikuri gadaadgileba damokidebulia plastikurobis koeficientze da aWarbebs drekad gadaadgilebebs.

Aavtori gamoTqvams eWvs dinamikuri reaqciis gansazRvrisas wrfiv sistemaze eqvivalenturi blanti milevadobiT arawrfivi sistemebis dayvanis SesaZleblobis Sesaxeb. es imitom, rom maRali sixSireebisas aucilebeli xdeba uaryofiTi milevadobis SemoReba.

[50] avtori gvTavazobs konstruqciis zRvruli mdgomareobis parametrad moqnilobis koeficientebis nacvlad aviRoT drekadi aRmdgeni Zalis zRvruli mniSvneloba (g-s nawilebSi). erTi Tavisuflebis xarisxis mqone sistemis analizisaTvis idealizirebuli diagramiT

miRebulia sami Canaweri mcire magnitudiT, didi aCqarebiT da mokle xangrZliobiT yvelaze ufro intensiuri nawili SeSfoTebisa port xiunemSi 1957; park filSi 1966 da macuSiroSi 1966.

0.01 wm-is bijiT integrebis Sedegad miRebulia Sedegebi, romelTa Tanaxmadac ufro xangrZlivi miwisZvris (mag. el-centro) SemTxvevaSi gadaadgilebaTa speqtri drekadi sistemebisa naklebia drekad-plastikuri gadaadgilebis speqtrTan SedarebiT. aRmdgeni Zalis dabali zRvruli mniSvnelobis SemTxvevaSi sakuTari rxevisas damaxasiaTebelia mcire gadaadgilebebi drekad-plastikuri sistemebisa vidre drekadi sistemebis.

aRiniSneba, rom zRvruli aRmdgeni Zalis mniSvneloba naklebad axdens gavlenas gadaadgilebis mniSvnelobaze. mniSvnelovania am TvalsazrisiT intensiuri zemoqmedebis xangZlivoba.

proeqtirebisas dempferebis gamoyenebis efeqturoba gamokvleulia gufTa da Candrasukastis mier [53]. ganxilulia erTmasiani da mravalmasiani drekadi da drekad-plastikuri sistemebi dempferuli elementebiT taftis miwisZvrisas 1952 w. blanti dempferis gavlena sistemis reaqciaze fasdeboda β, romelic iyo Sefardeba Zvris Zalisa dempferian sistmaSi, udempferosTan da koeficientiT γ, romelic iyo Sefardeba Zvris Zalisa TviTon dempferul elementSi udempferosTan.

winaswari gaangariSebiT miRebulia, rom dempferis masa unda 10% ziriTadi sistemisa masisa, mileva 2% kritikulis, mowyobilobaTa raodenoba ara umetes xuTisa. Aam SemTxvevaSi β rCeba mudmivi. dempferebis raodenobis zrda iwvevs maTSi Zalebis Semcirebas, xolo dempferebis gadaadgilebisaTvis gansakuTrebuli mniSvneloba aqvs maTi drekadi muSaobis dones.

gamokvlevebma uCvena, rom seismomedeg konstruqciebSi dempferebis gamoyeneba ar aris mizanSewonili. magram es daskvna gakeTebulia mxolod erTi miwisZvris Canaweris mixedviT da rogori iqneba daskvna sxva saxis aRZrul Zalebis SemTxvevaSi ucnobia, amitom am daskvnis gakeTeba sistemaze ar SeiZleba.

karkasul nagebobaze seismuri zemoqmedebis ori an sami mdgenelis erTdrouli zemoqmedebisas drekad-plastikuri angariSi ganxilulia nigamisa da xauzneris [54] SromaSi.

Senobis karkasi ganixileboda rogorc sivrciTi CarCo. Zala-gadaadgilebis damokidebuleba aiReboda rTuli datvirTvis pirobebSi. drekadi sistemis SemTxvevaSi aseTi midgoma saSualebas iZleva dasabuTebuli maragis koeficientis miRebisa, xolo realuri arawrfivi sistemebis SemTxvevaSi warmoadgens aucilebel pirobas seismuri zemoqmedebisas nagebobis simtkicisa da deformaciebis obieqturi SefasebisaTvis.

miRebulia gadaadgilebebis epiurebi, roca zemoqmedeba Seesabameboda taftis 1952 wlis miwisZvras parametrebiT T_1=1 wm. T_2=0.75 wm. γ_1 =0.5 da γ_2 =0.3.

gakeTebulia daskvna, rom sistemis gadaadgilebebi naklebia drekad gadaadgilebebze. martivi da rTuli datvirTvis SemTxvevaSi gardamavali procesi erTnairia, mxolod gansxvavdeba plastikuri Zvrebi. rTuli datvirTvis SemTxvevaSi plastikuroba warmoiqmneba ufro naklebi datvirTvisas, xolo plastikuri Zvrebi ufro metia. rTuli datvirTvis SemTxvevaSi 20%-iT mcirdeba miniWebuli energia. plastikuroba amcirebs deformaciis siCqares gansakuTrebiT rTuli datvirTvisas. moqnilobis koeficienti erTnairia. bolos avtorebi aucileblad Tvlian rTuli datvirTvis ganxilvas, xolo simtkicisa da energotevadobis kriteriumad gvTavazoben moqnilobis koeficients radialuri (da ara mTavari RerZebis) mimarTulebiT da plastikuri deformaciis energiis Sefardebas drekad deformaciis energiasTan.

G guru haiderbrextis [55] SromaSi Seswavlilia mravalsarTuliani CarCoebis drekad-plastikur stadiaSi dinamikuri reaqciebis ganmsazRvreli Semdegi parametrebi:

1. rigelebze vertikaluri Zalebis sidide
2. sasargeblo datvirTvis sxvadasxva sqemebi
3. sarTulis masebSi sasargeblo datvirTvis wili
4. rigelisa da karkasis sixisteTa Sefardeba
5. rxevis milevis sidide da xasiaTi
6. seismuri datvirTis done
7. seismuri datvirTis maxasiaTeblebi.

aq sarTulis masebi mudmivia da miiReba Seyursulad, masala emorCileba prandtlis kanons. saangariSo sqema ZiriTadi nagebobisa miRebul iyo 10 sarTuliani erTmaliani CarCos saxis siganiT 6,5 m. da sarTulis simaRliT 3,65 m. mudmivi datvirTva modebulia Seyursulad (p=25t.Z) malis SuaSi. sixisteTa Sefardeba SerCeulia im pirobidan, rom statikuri datvirTvisas Zala-deformacias drekadobis farglebs gareT hqondes horizontaluri ubani. maqsimaluri mniSvneloba damyolobis koeficientisa mobrunebis kuTxeebis mimarT miRebuli iyo 4.77 .

igulisxmeboda, rom plastikuri saxsari SeiZleba warmoqmniliyo nebismier kveTSi sadac mRunavi momenti miaRwevda zRvrul (plastikur) mniSvnelobas. gaangariSebebi CamoTvlili parametrebis gansazRvrisaTvis Sesrulebul iyo el-centros (1940w.) miwisZvris aqselerogramiT maqsimaluri aCqarebisas 0.5 g.

sasargeblo datvirTvis gaTvaliswineba rogorc vertikaluri datvirTvisa rigelebze umniSvnelod cvlis reaqciis parametrebs. Seyursuli sasargeblo datvirTvis modebis wertilebis gadaadgilebiT rigelebis sayrdenebisaken maqsimaluri gadaadgilebebi da aCqarebebi izrdeba.

sarTulis masebSi sasargeblo datvirTvis wilis gazrdiT mniSvnelovnad izrdeba CarCos gadaadgilebebi da svetebisa da rigelebis damyolobis koeficientebi. amave dros aCqarebebis

maqsimaluri mniSvnelobebi mcirdeba qveda sarTulis mimarTulebiT. Sedegebis analizi gviCvenebs, rom xSirad gamoyenebuli Seyursul masebiani CarCoebis gaangariSebisas SeiZleba daSvebul iqnes arsebiTi Secdomebi dinamikuri parametrebis (gadaadgilebebi, Zalebi) gansazRvrisas.

ufro xisti rigelebis mqone CarCoebSi mniSvnelovani gadaadgilebebi da plastikuri deformaciebi vlindeba me-7, me-10 sarTulebSi. blanti milevis koeficientis zrda ar iwvevda misi parametrebis cvlilebas. mxolod sarTulis maqsimaluri aCqarebebi diapazonSi 0 - 0.1, mcirdeba 1.5 - 2-jer.

seismuri zemoqmedebis intensivobis zrdisas (aCqarebis zrdisas) parametrebi izrdeboda garkveul sididemde Semdeg ki mcirdeboda, rac gamowveuli iyo Zalebis gadanawilebiT mis elementSi aradrekadi muSaobisas. roca aRniSnavdnen gadaadgilebebis da aCqarebebis ara arsebiT cvlilebebs unda SevniSnoT, rom gamoyenebul iyo mxolod kaliforniis miwisZvris Canawerebi.

SromaSi [56] ricxviTi gziT gamokvleulia 14 sarTulian foladis karkasuli Senoba el-centros seismur zemoqmedebaze, maqsimaluri aCqareba toli iyo 0.5 g. ganivi mimarTulebiT nagebobas hqonda sami mali, grZivi mimarTulebiT xuTi. sakuTari rxevis periodi orive mimarTulebiT toli iyo 2.8 wm. mileva pirveli ori formiT Seadgens kritkulis 5%, xolo damokidebuleba mRunavi momenti – simrude warmoadgens prandtlis sqemas. gadaadgilebebs hqonda kvaziperioduli xasiaTi mniSvnelovani plastikuri ZvrebiT. plastikuri deformaciebi SeimCneoda mxolod rigelebSi da qveda sarTulis svetebSi. moqnilobis koeficientisa da maqsimaluri mRunavi momentis (drekad stadiaSi) da zRvruli drekadis (drekad-plastikurSi) gviCvenebs, rom momatebul moqniloba unda uzrunvelyofil iyos qveda sarTulebSi da me-9 sarTulze. moqnilobis koeficientis maqsimaluri mniSvneloba aRwevs 2.74. avtorebi winadadebas iZlevian [57]-is msgavsad axal zelandiur kodSi Semcirdes moqnili mravalsarTuliani nagebobisTvis saangariSo seismuri datvirTvebi an gaizardos sarTulSoris Zvrebis zRvruli mniSvneloba.

odaka, suzukis [58] mocemulia drekad plastikuri analizi ori mravalsarTuliani Senobis fundamentis mobrunebisa da gadaadgilebis gaTvaliswinebiT, romlebic daziandnen sxvadasxvanairad kantos miwisZvris dros. mravalmasiani drekad plastikuri sistemis moZraobis gantolebebi miRebulia Semdegi daSvebebis safuZvelze:

1. damokidebulebebs aRmdgeni Zala gadaadgilebas aqvs biwrfivi saxe miwiszeda nagebobisaTvis.
2. miwiszeda nagebobebis rxevis mileva xdeba histerezirebuli blanti rxevis Sesabamisad, xolo miwisqveSa kostruqciis milevis maxasiaTeblebi ganisazRvreba ganivi seismuri talRebis gavrcelebis siCqariT da seismuri zemoqmedebis sixSireebis SemadgenlobiT.

3. qveda sarTulis masa warmodgenilia virtualuri masis saxiT.

4. gruntis moqnilobis maxasiaTeblebi, rogorc mraval gamokvlevaSi miRebulia rogorc mobrunebis da gadaadgilebis sixistis koeficientebi.

tajimis SromaSi [59] ganxiluli iyo ori Senoba erTi 8 sarTuliani, liTonis dabetonebuli karkasiT da rkina- betonis gare kedlebiT. meore - 7 sarTuliani dabetonebuli liTonis karkasiT da rkinabetonis diafragmebiT. orives hqonda erTi miwisqveSa sarTuli da xis ximinjebi 15 – 16 m. gaangariSeba Catarebuli iyo taftis da tokios 1956 wlis miwisZvrebze. samivegan maqsimaluri aCqareba iyo 0,33 g. kantros miwisZvris Sedegad [58] dazianebebis Sedarebam miRebul SedegebTan aCvena rom saangariSo da eqsperimentis periodebi pirveli Senobis erTmaneTs daemTxva, siCqare V_s =270 m/wm-is, xolo meore Senobis SemTxvevaSi V_s =180 m/wm . pirvelma Senobam miiRo mniSvnelovani dazianebebi (kedlebis da karkasis bmebis rRveva), meorem umniSvnelo. Zvrebis ganawilebis kanoni iZleva saSualebas mxolod Tvisobrivad Sefasdes 3-4-5 sarTulebis dazianebebi: pirvel SenobaSi da Tanabari dazianebebi meoreSi. moqnilobis koeficienti pirveli SenobisaTvis iyo 3,5, meoresi 1,2.

kvlevam uCvena, rom dazianebebis xasiaTi mniSvnelovnad aris ganpirobebuli S talRebis gavrcelebis siCqareze. siCqaris zrdiT izrdeba deformaciebi (gadaadgilebebi, moqnilobis koeficienti, seismurobis koeficienti), romlebic maqsimums aRwevs V_s =50$\div$200 sm/wm. xolo roca $V_s \to \infty$ gruntis moqniloba ar gaiTvaliswineba reaqciis parametrebi mcirdeba.Senobis deformaciis wili srul deformaciaSi fuZis moqnilobis Sedegad maqsimums (50%) aRwevs V_s =100$\div$200 sm/wm siCqaris dros.

3.2 oscilatoris arawrfivi rxevebis Seswavla, roca liTonis Rero muSaobs, prandtlis sqemis mixedviT, mxolod Zvraze

ganvixiloT oscilatoris ganivi rxevebi, romlebic gamowveulia gruntis horizontalur impulsuri gadaadgilebis Sedegad [nax. 3.1]. dilei-algoriTmis [60,61] Tanaxmad masa da Rero ganvixiloT cal-calke maTi urTierTqmedebis S Zalis gaTvaliswinebiT [nax. 3.2] amave dros vigulisxmoT rom S Zala modebulia masis simZimis centrSi. maSasadame masis moZraoba ganpirobebulia mxolod S ZaliT, romelic warmoadgens Reros reaqcias da romelic imis mixedviT Tu ra mdgomareobaSia Rero (drekadSi Tu plastikurSi) SeiZleba iyos damokidebuli Reros bolos gadaadgilebebze wrfivad (drekadi mdgomareobis SemTxvevaSi) an raime ucnobi damokidebulebiT (plastikuri mdgomareobisas) S=F(y). igive algoriTmis

Sesabamisad davyoT rxevis dro mcire Δt monakveTebad da TiToeul monakveTSi S CavTvaloT mudmivad e.i … $S = \sum S_i$. Seyursuli masis moZraobis gantolebas eqneba saxe:

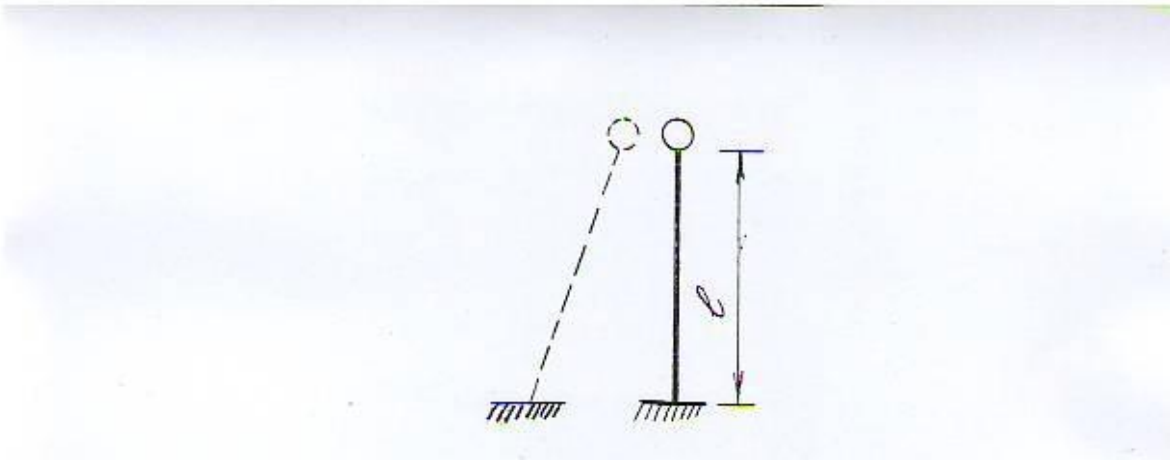
$$\frac{d^2 y}{dt^2} = \frac{S}{m} = \sum \frac{S_i}{m}$$

Tu am gantolebas gavaintegrebT nulovani sawyisi pirobebiT miviRebT :

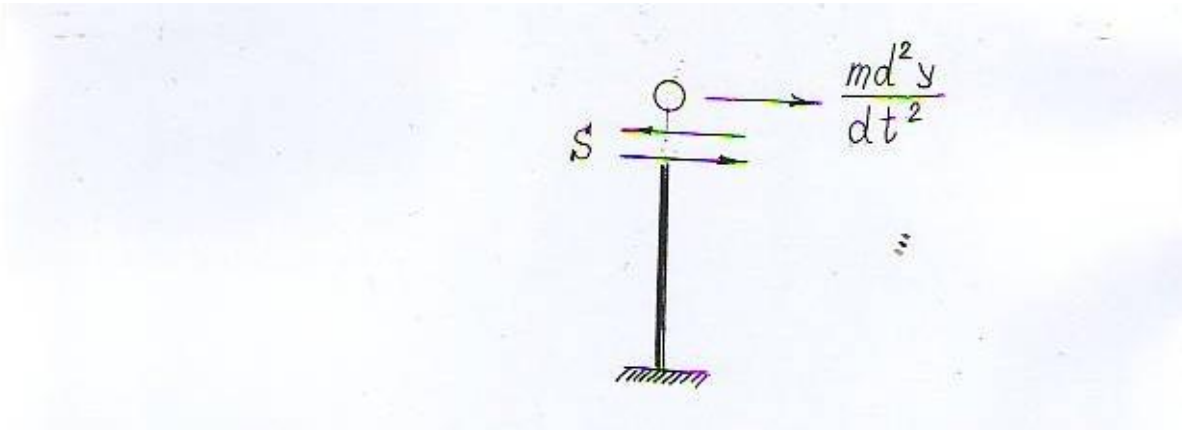
$$y = \sum_{i=1}^{I} \frac{S_i (t_I - t_i)}{2m} \qquad (1)$$

sadac t_0=0, $t_1 = \Delta t$,...., $t_1 = I \cdot \Delta t$

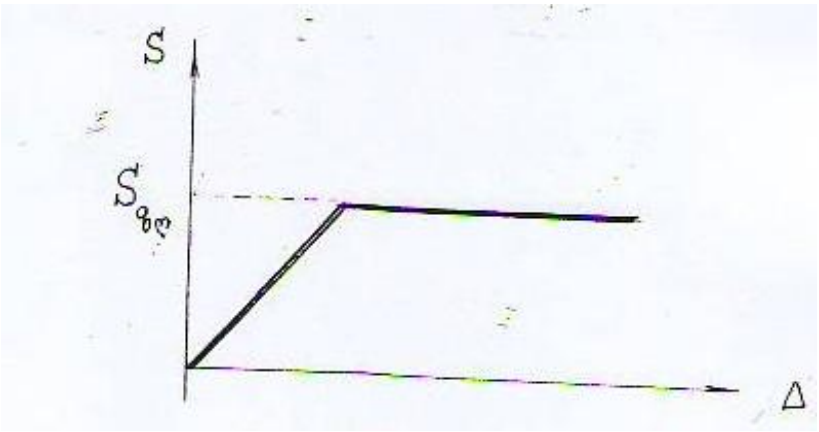
meores mxriv gvaqvs Rero, romelic ganicdis boloze Seyursuli Zalis qmedebas. rogorc avRniSneT Rero muSaobs mxolod Zvraze amitom misi bolos drekadi gadaadgileba Zvris deformaciis gaTvaliswinebiT iqneba $\frac{Sl}{GF}$,sadac GG Zvris modulia ,FF ki Reros ganikveTis farTobi. cxadia, rom rxevis procesSi, roca S miaRwevs zRvrul mniSvnelobas $S_{zR.}$ (nax.3) Reros bolos eqneba



Nnax. 3.1 oscilatori



nax. 3.2 saangariSo sqema



Nnax. 3.3 prandtlis sqema

maqsimaluri drekadi gadaadgileba $\frac{S_{zR.}\, l}{GF}$ da kidev raRac plastikuri gadaadgileba Δ_{pl} . ase, rom masisa da Reros bolos gadaadgilebaT^a uwyvetoba imis gaTvaliswinebiT Reros qveda bolom ganicada gadaadgileba Δ_{gr} Caiwereba Semdegnairad:

$$\Delta_{gr} - \frac{S_{zR}\, l}{GF} - \Delta_{zR} = \sum_{i=1}^{I} S_i \frac{(t_I - t_{i-1})^2}{2m} \qquad (2)$$

moyvanili piroba (2) samarTliania prandtlis sqemis horizontaluri ubnisTvisaTvis. drekadi ubnisaTvis $S_{zRv.}$ -is nacvlad gveqneba $S = \sum S_i$, rac Seexeba $\Delta_{pl.}$ is SeiZleba warmodgenili iyos Semdegnairad:

$$\Delta_{pl} = \sum_{i=1}^{I-1} \Delta_{pl\ i} + \Delta_{plI} \qquad (3)$$

sadac tolobis marjvena mxareSi pirveli Sesakrebi im plastikuri gadaadgilebebis jamia rac dagrovda gansaxilvel t = t_I bijamde e.i i=1 - dan
I-1-mde. analogiurad warmovadgenT (2) tolobis marjvena xaresac.

$$\sum_{i=1}^{I} S_i \frac{(t_I - t_{i-1})^2}{2m} = \sum_{i=1}^{I-1} S_i \frac{(t_I - t_{i-1})^2}{2m} + S_I \frac{(t_I - t_{I-1})^2}{2m} \qquad (4)$$

tolobis (4) marjvena mxareSi pirveli Sesakrebi cnobilia t=t_I bijisaTvis iseve rogorc (3) tolobis marjvena mxris pirveli Sesakrebi. amgvarad (2) toloba Rebulobs saxes:

$$\Delta_{gr} - \frac{Sl}{GF} - \sum_{i=1}^{I-1} \Delta_{pl\ i} - \Delta_{pl\ I} = \sum_{i=1}^{I-1} S_i \frac{(t_I - t_{i-1})^2}{2m} + S_I \frac{(t_i - t_{I-1})^2}{2m} \qquad (5)$$

exla cxadi xdeba gamoTvlebis Tanamimdevroba. drekad ubanze yofnisas Δ_{plI}=0 Sesabamisi nazrdi S_I ganisazvreba Semdegnairad:

$$S_i = \frac{\Delta_{gr} - \frac{Sl}{GF} - \sum_{i=1}^{I-1} \Delta_{pl\ i} - \sum_{i=1}^{I-1} S_i \frac{(t_I - t_{i-1})^2}{2m}}{\frac{(t_I - t_{I-1})^2}{2m}} \qquad (6)$$

Tu vimyofebiT prandtlis sqemis horizontalur ubanze, maSin cxadia $S_i = 0$ radgan Zala aRar ganicdis nazrds da me-5 tolobidan ganisazRvreba plastikuri deformaciis nazrdi Δ_{plI} romelic toli iqneba:

$$\Delta_{pl\ I} = \Delta_{gr} - \frac{S_{zR} l}{GF} - \sum_{i=1}^{I-1} \Delta_{pl\ i} - \sum_{i=1}^{I-1} S_i \frac{(t_I - t_{i-1})^2}{2m} \qquad (7)$$

aseve cxadia, rom Sesakrebi $\sum_{i=1}^{I-1} \Delta_{pl\ i}$ prandtlis sqemis horizontalur ubanze icvleba. drekad ubanze ki inarCunebs im mniSvnelobas rac mas hqonda horizontalur ubanze drekad ubanze gadasvlis momentisaTvis. plastikuri gadaadgilebis absoluturi sididis Semcireba moxdeba mxolod mopirdapire niSnis horizontalur ubanze gadasvlis SemTxvevaSi.

3.3 oscilatoris SemTxvevaSi Sesrulebuli gamoTvlebis Sedegebi

gamoTvlebi Sesrulebulia erTsarTuliani nagebobis arawrfivi rxevebis SeswavlisaTvis roca nagebobis mzidi konstruqcia warmoadgens liTonis svetebs bijiT 6 m. orive mimarTulebiT. svetebi Sedgenilia or-ori N20a Svelerisagan, romlebic gadaxurulia 20x20 m. rkinabetonis filiT sisqiT 16 sm. svetebis simaRlea 4 m. Zvraze denadobis zRvari τ_s =1600kg/sm$^{2\cdot}$, Svelerebis jamuri ganivkveis farTobi 800 sm$^{2\cdot}$ xolo rkinabetonis filis masa ki tolia 15000kg. nagebobis fuZe miwisZvris Sedegad ganicdis impulsur gadaagilebas $W = ate^{-\beta t}$ sadac a sawyisi siCqarea. $\frac{1}{\beta}$ ki dro, roca gadaadgileba aRwevs maqsimums.

imis mixedviT Tu rogoria a da … β zemoqmedeba iqneba sxvadasxva da Sedegic (rogorc Semdgom davinaxavT) Tvisobrivad gansxvavebuli.

imisaTvis rom sworad aRviqvaT miRebuli Sedegebi, gaviazroT rxevis fizikuri suraTi. gruntis moZraobis dawyebasTan erTad iwyeba ReroSi Zvris deformaciis warmoqmna romlebic CavTvaloT dadebiTad. Cven rom vixilavdeT Reros grZiv deformaciebs gveqneboda gaWimva. amave dros masa gadaadgildeba gruntis gadaadgilebis mimarulebiT. ReroSi aRZruli Zalebi izrdeba, magram Tu zemoqmedeba garkveul mniSvnelobaze naklebia maSin Zalebma SeiZleba ver miaRwion zRvrul mniSvnelobebs , ar daiwyos plastikuri deformaciebis warmoqmna. am SemTxvevaSi gvaqvs drekadi deformaciebi, masa moZraobs gruntis gadaadgilebis mimarTulebiT da garkveul momentSi daiwyeba Zalebis Semcireba, radgan gruntis gadaadgileba uaxlovdeba maqsimalur mniSvnelobas da Semdeg unda daiwyos ukan dabruneba , masa ki inerciiT gaagrZelebs moZraobas da garkveuli momentisTvis Zalebi Seicvlian niSans (grZivi Zalebis SemTxvevaSi gveqneboda kumSva). cxadia, am SemTxvevaSi masis gadaadgileba iqneba

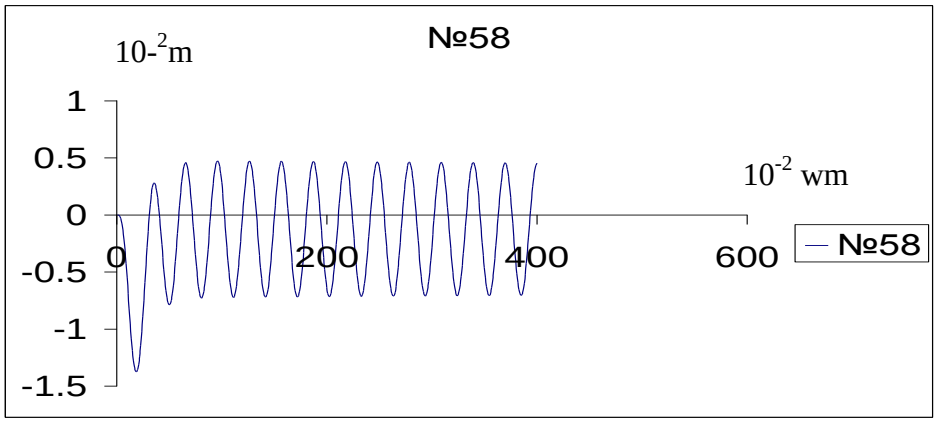
meti vidre gruntisa da Zalac iqneba absolituri sididiT meti vidre dadebiT deformaciebis SemTxvevaSi, aq SeiZleba plastikuri deformaciebis warmoqmna, romelic miaRwevs ra maqsimalur sidides aRar Semcirdeba manam sanam deformaciebi ar Seicvlis niSans da ar miaRwevs Zalebi zRvrul mniSvnelobebs mopirdapire niSniT.

im SemTxvevaSi Tu zemoqmedeba Zlieria (metia garkveul mniSvnelobaze) maSin SesaZlebelia Zalebis mniSvnelobebis zrda iqamde, rom warmoiqmnas dadebiTi plastikuri deformaciebi (grZivi Zalebis SemTxvevaSi gaWimvis), romlebic miaRweven ra maqsimalur sidides, SeinarCuneben mas vidre mopirdapire niSnis plastikuri deformaciebi ar gamoiwveven mis Semcirebas.

mas Semdeg rac damTavrdeba plastikuri deformaciebis warmoqmna da albaT ukve aRar gveqneba gruntis gadaadgilebis zegavlena, Sesruldeba Tavisufali rxeva narCeni plastikuri gadaadgilebis mimarT.

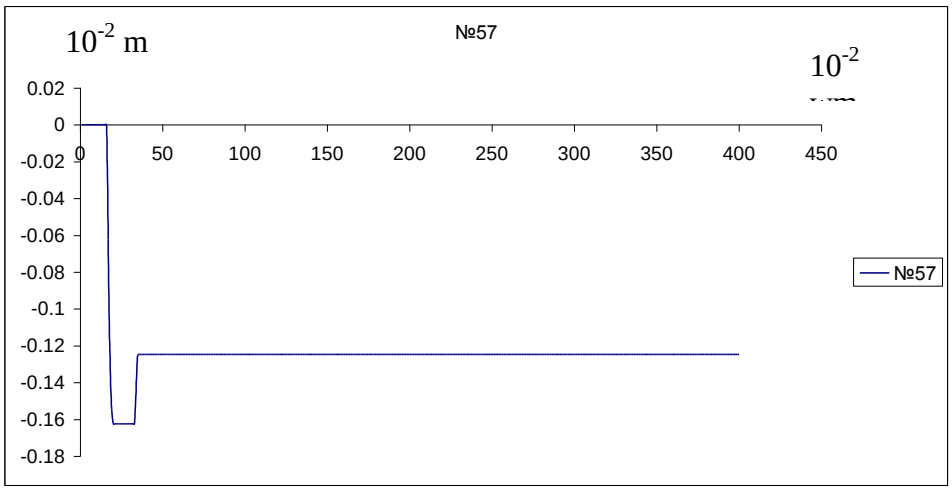
konkretuli magaliTis saxiT ganxilulia SemTxveva, roca α =10 sm\wm, $\beta = 5$ zRvruli Zala $S_{zR} = 10^6$ kg. gruntis gadadgilebis moyvanili impulsuri kanonis mixedviT aCqarebis maqsimaluri mniSvneloba tolia $2a\beta$ rac gvaZlevs daaxloebiT $0{,}1g$-s. gruntis maqsimaluri gadaadgileba tolia 0.73 sm da igi miiRweva 0.2 wm-is Semdeg. masis maqsimaluri gadaadgileba tolia 1.385 sm da igi mas aRwevs 0.35 wm-is Semdeg (nax. 3.4,3.5,3.6). Tavisufali rxeva sruldeba amplitudiT 0.61 sm, narCeni plastikuri gadaadgilebis 0.124 sm-is mimarT, maqsimaluri plastikuri deformacia toli iyo-0.162sm. rac Sexeba Zalebs, isini cxadia ar aRemateba 10^6 kg-s. Tavisufali rxevisas ki Zalebi aRwevda mxolod daaxloebiT 9×10^5 kg. aRsaniSnavia, rom sruli drekadi rxevisas maqsimaluri gadaadgileba tolia 1.387 sm. Tavisufali rxeva ki xdeba amplitudiT 0.77 sm. rac Seexeba Zalis maqsimalur mniSvnelobas gvaqvs $1{,}29.10^{-6}$, Tavisufali rxevisas ki $1{,}22\times10^6$ kg. rac miuTiTebs im faqtze, rom plastikuri deformaciebis gaTvaliswineba mniSvnelovnad amcirebs Zalebs. (nax. 3.7,3.8). impulsis forma mocemulia nax. 3.9-ze.

igive maqsimaluri aCqareba SeiZleba miRweul iyos a da β -s sxva mniSvnelobisas mag. $a = 5, \beta = 10$. am SemTxvevaSi masis maqsimaluri



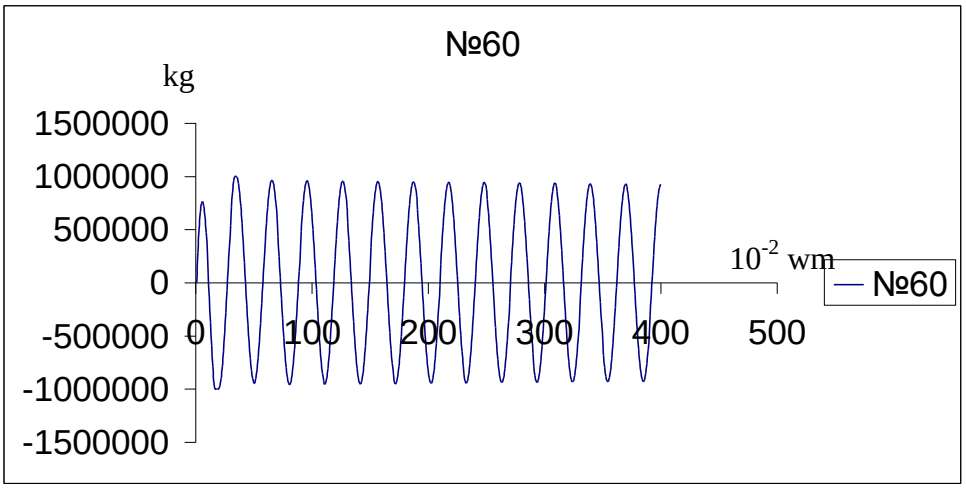
a=10
β=5

nax. 3.4 drekad-plastikuri oscilatoris gadaadgilebebi



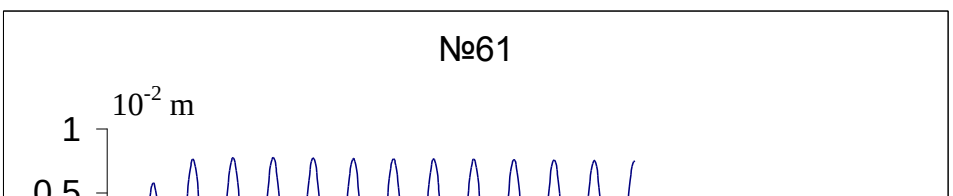
a=10
β=5

nax. 3.5 plastikuri gadaadgilebebi



a=10
β=5

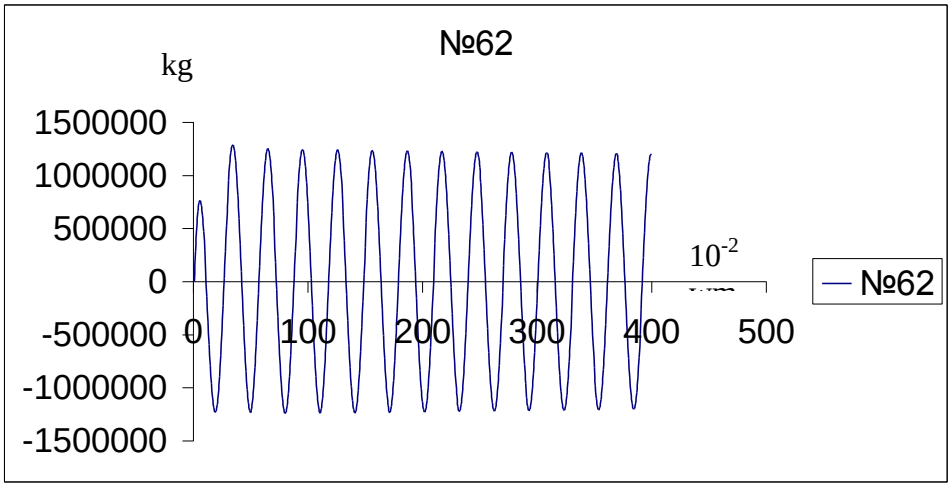
nax. 3.6 Zalebi drekad-plastikur oscilatorSi



a=10

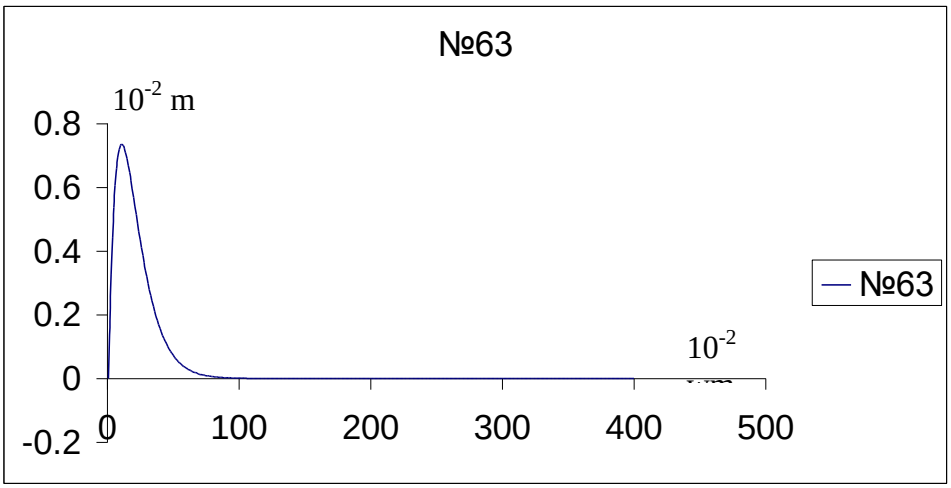
β=5

nax. 3.7 drekadi oscilatoris gadaadgilebebi



a=10
β=5

nax. 3.8 drekadi oscilatoris gadaadgilebebi



a=10
β=5

nax. 3.9 gruntis impulsuri gadaadgileba

gadaadgileba aris -0.3 sm. Tavisufali rxeva xdeba $\approx 0{,}25$ sm-is amplitudiT. rac Seexeba Zalebs maTi mniSvneloba ar aRemateba $0{,}4\times10^{6}$ kg-s. rogorc vxedavT ganxiluli impulsuri

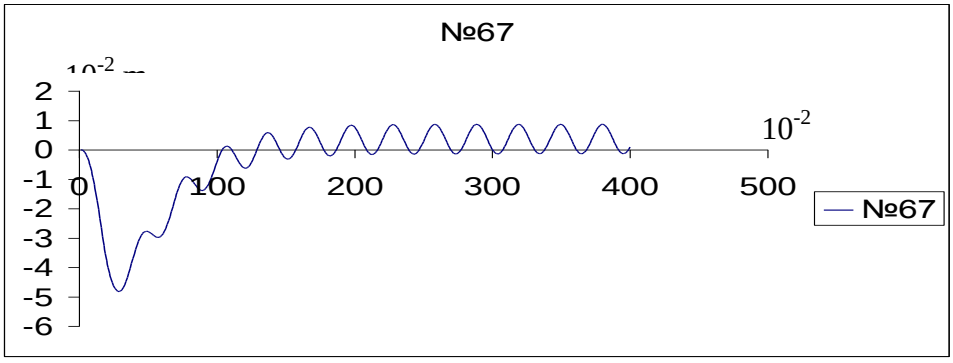
zemoqmedebis pirobebSi arsebiTia siCqare da ara aCqareba. siCqaris orjer Semcirebam orjer da metad Seamcira Zalebi, ufro metad ki gadaadgilebebi.

igive kanonzomierebas iZleva Semdegi SemTxveva: $a = 25, \beta = 2.$ aqac aCqarebaa $0{,}1g$. magram maqsimaluri gadaadgileba tolia 4.8 sm, Tavisufali rxeva amplitudiT 0.35 sm. xdeba narCeni plastikuri gadaadgilebis 0.37 sm-s mimarT. rac Seexeba maqsimalur plastikur gadaadgilebas igi tolia 1.58 sm. (nax. 3.10, 3.11). Zalebis maqsimaluri mniSvneloba cxadia 10^6 kg-ia, Tavisufali rxeva ki xdeba 83×10^4 kg amplitudiT (nax. 3.12) gruntis gadaadgileba tolia 4.6 sm. (nax. 3.13). igive a da β-s SemTxvevaSi sruli drekadi gadaadgileba 7,1 sm-is tolia. Tavisufali rxeva amplitudiT 2,7 sm sawyisi mdebareobis mimarT. rac Seexeba Zalebs isini aRweven $4{,}0\times10^6$ kg da rxeva ki xdeba amplitudiT… $3{,}7\times10^6$ kg. (nax. 3.14, 3.15)

moyvanili Sedegebi miuTiTeben im faqtze, rom Tu zemoqmedebis xasiaTi axloa ganxilul impulsur zemoqmedebasTan, maSin seismuri daraionebis zomad aRebuli unda iyos ara aCqareba aramed siCqare.

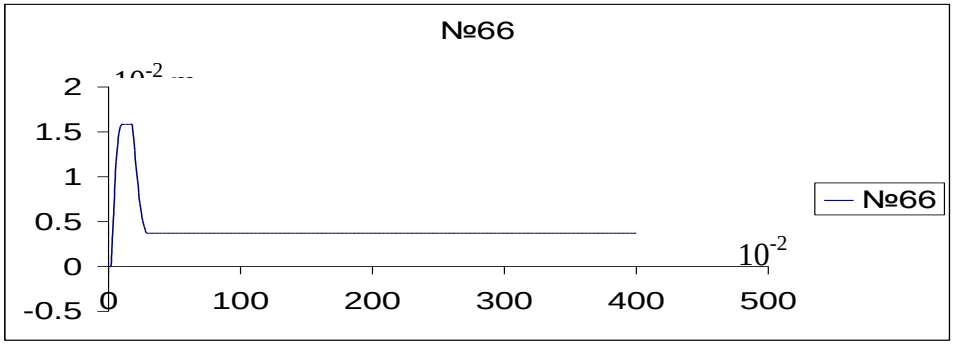
gamokvleulia agreTve ganmeorebiTi dartymis SemTxvevebic, roca garkveuli drois Semdeg igive impulsi moqmedebs nagebobaze. imisgan damikidebulebiT Tu rxevis ra momentSi xdeba ganmeorebiTi dartyma, Sedegi iqneba sxvadasxva. cxadia, rom masalis fizikuri kanonidan gamomdinare Zala ar SeiZleba aRematebodes zRvrul mniSvnelobas, SemcirebiT ki SeiZleba mniSvnelovnad Semcirdes. daaxloebiT igive situaciaa gadaadgilebebis mimarT im gansxvavebiT, rom gadaadgileba ar aris SezRuduli da is SeiZleba mniSvnelovnad gaizardos.

rogorc erTjeradi aseve ganmeorebiTi dartymebis SemTxvevaSi ganxilulia SemTxvevebi roca garkveul momentSi masala xdeba mTlianad drekadi (aRar gvaqvs horizontaluri ubani).



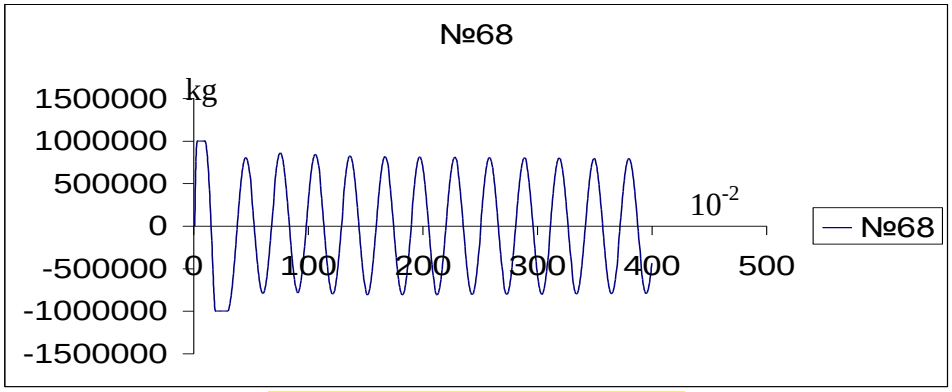
a=25
β=2

nax. 3.10 drekad-plastikur oscilatoris gadaadgileba



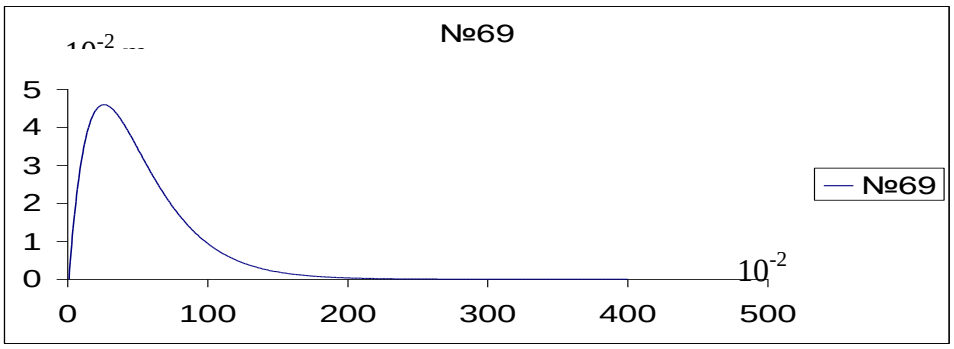
a=25
β=2

nax. 3.11 plastikuri gadaadgilebebi



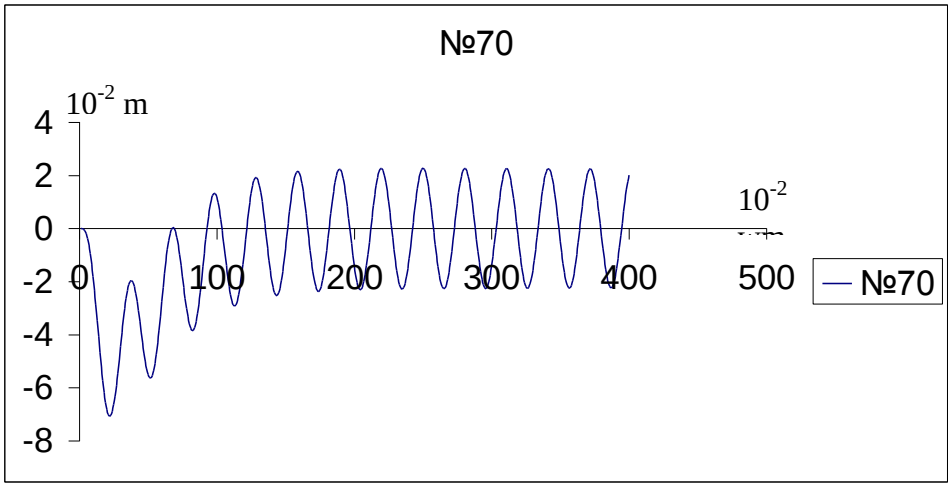
a=25
β=2

nax. 3.12 gruntis gadaadgilebebi



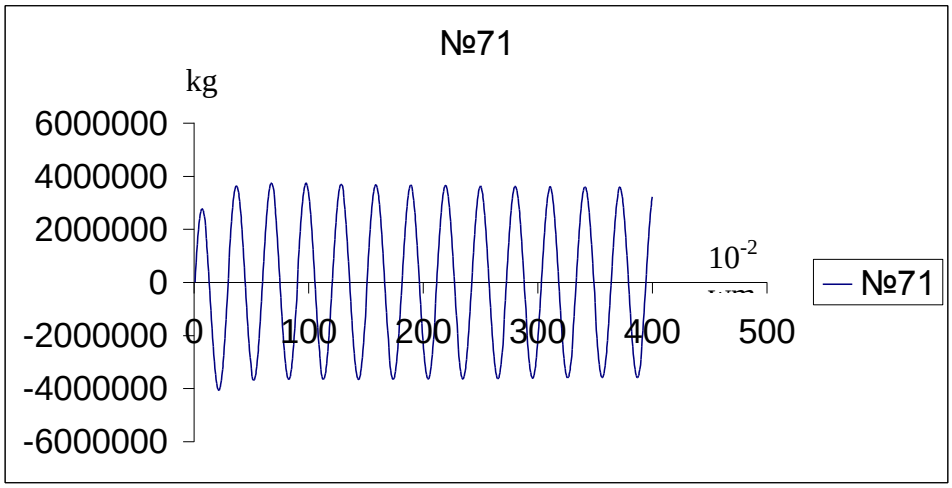
a=25
β=2

nax. 3.13 gruntis impulsuri gadaadgileba



a=25
β=2

nax. 3.14 drekadi oscilatoris gadaadgilebebi



a=25
β=2

nax. 3.15 Zalebi drekad oscilatorSi

erTjeradi dartymisas Tu ukve gvaqvs Tavisufali rxeva, maSin amas ara aqvs mniSvneloba, radgan jamuri Zalebi mcirea da ver aRwevs zRvrul mniSvnelobas.

ganmeorebiTi dartymisas ki gavlena iqneboda mniSvnelovani radgan rogorc gadaadgilebebi aseve Zalebi gamodis gacilebiT meti vidre erTjeradi drekadi rxevisas. nax. (3.16 – 3.20).

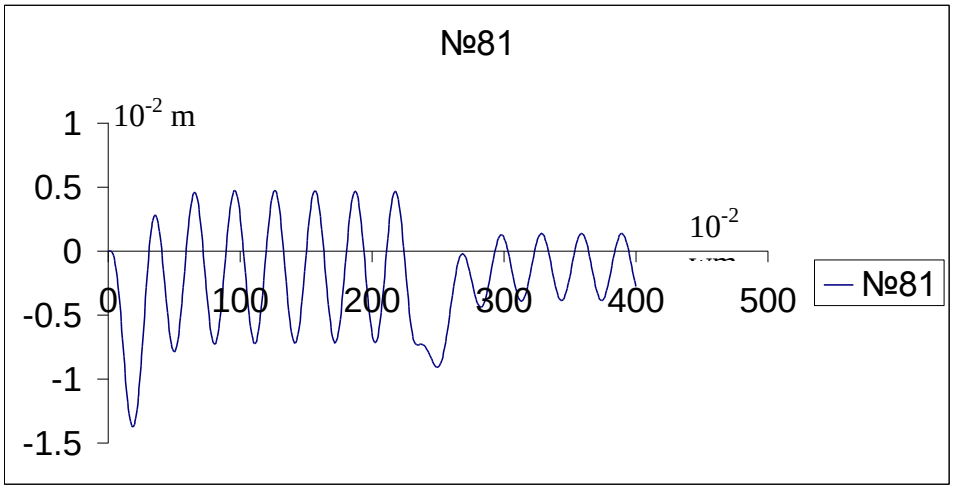
es programa SeiZleba gamoyenebuli iyos dempferebis gavlenis Sesaswavlad. Cveulebriv dempferebs iyeneben saZirkvlis doneze, e.i Reros qveda boloze, radgan iTvleba, rom Rerosa da masas Soris aRZruli Zala Reros farglebSi mudmivia, amitom dempferze imoqmedebs igive Zala rac zeviT gvaqvs. roca Zala miaRwevs dempferisTvis mocemul zRvrul mniSvnelobas demferi imuSavebs rogorc plastikuri sxeuli fizikur kanonze horizontalur ubniT. Tu gvecodineba dempferis Zvris deformacia da Sesabamisad horizontaluri gaadaadgileba, maSin Cven SegveZleba gamovTvaloT Reros qveda boloze miniWebuli gadaadgileba, rac toli iqneba uSualod gruntis gadaadgilebisa da dempferis zeda Sris gadaadgilebis algebruli jamisa. am gadaadgilebas mivaniWebT sistemas, romelic mTlianad muSaobs drekad mdgomareobaSi. gansazRvras moiTxovs mxolod dempferis deformacia. plastikuri sxeulis ganmartebaSi vkiTxulobT [62], roca deformaciis siCqare ar udris nuls masala iqceva rogorc blanti siTxe gansazRvruli gantolebiT $S = \mu \times f(d)$, sadac S Zabvis tenzoris deviatoria, f ki deformaciaTa siCqaris tenzoris d tenzoruli funqciaa..... $\mu = \eta \times I_2$ sadac η siblantis koeficientia, I_2 ki Zvris deformaciis siCqareTa meore invariantia [63].

$$I_2 = \frac{1}{6}\left[(\xi_x - \xi_y)^2 + (\xi_y - \xi_z)^2 + (\xi_z - \xi_x)^2 + \frac{3}{2}(\eta_{xy}^2 + \eta_{yz}^2 + \eta_{zx}^2)\right]$$

Cven SemTxvevaSi gvaqvs mxolod $\eta_{xy} = \frac{df_{xy}}{dt}$ da τ_{xy}

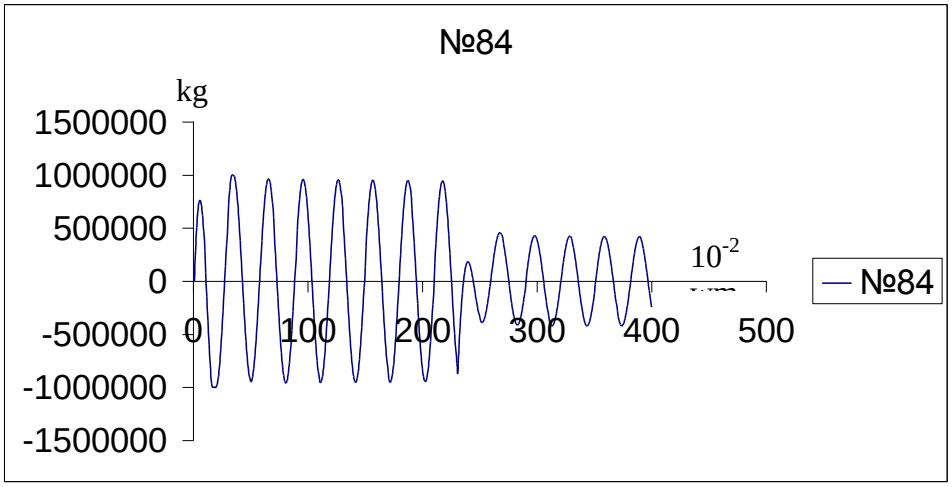
e.i $I_2 = \frac{1}{4}\left(\frac{d\gamma}{dt}\right)^2$, … $\mu = \frac{\eta}{4}\left(\frac{d\gamma}{dt}\right)^2$. Cveulebriv iReben, rom $f(d) = d$, horizontalur ubanze ki $\tau_{xy} = \tau_s$ e.i $\tau_s = \frac{\eta}{4}\left(\frac{dy}{dt}\right)^2$, sadac t_s drois moments aRniSnavs, roca Zala utoldeba zRvrul mniSvnelobas da drekadidan gadavdivarT plastikur ubanze. Tu dempferis simaRles avRniSnavT l_d maSin gadaadgileba toli iqneba $\sqrt[3]{\frac{4\tau_s}{\eta}}(t - t_s) \times l_d$, xolo Reros boloze gadaadgileba iqneba $ate^{-\beta t} - \sqrt[3]{\frac{4\tau_s}{4}}(t - t_s)l_d$.

Sesrulebuli iyo gamoTvlebi roca $\tau_s = 1000$ kg\sm^2, $\eta = 7{,}8$kg/wmsm^2, l_d =40sm, S_{zR} =10^6 kg-s. maqsimaluri gadaadgileba gamovida 2,5 sm, Zalebi ki cxadia ar aRemateboda 10^6 kg. es dempferi rom ar gvqonoda gadaadgileba iqneboda odnav mcire 2.45 sm. magram Zalebi gadaaWarbebdnen 1,5 10^6 kg-s.



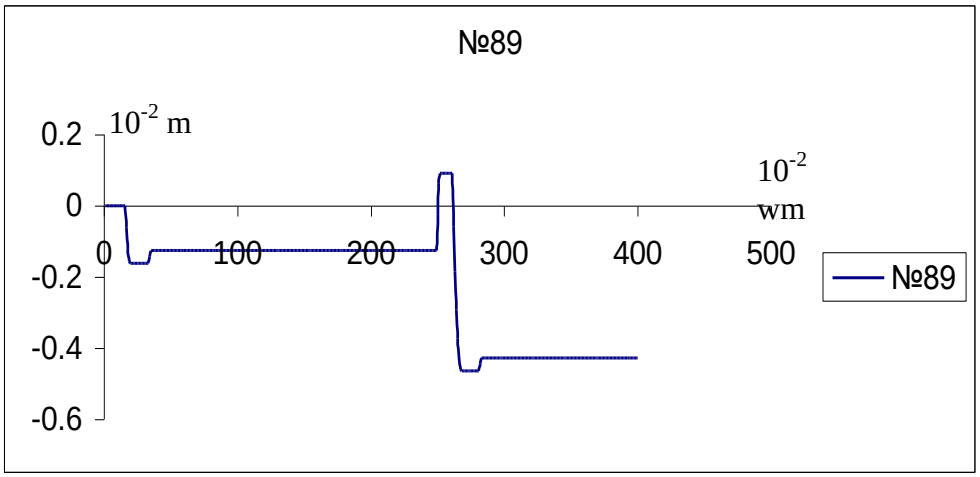
a=10
β=5

nax. 3.16 gadaadgilebebi ganmeorebiTi impulsisas



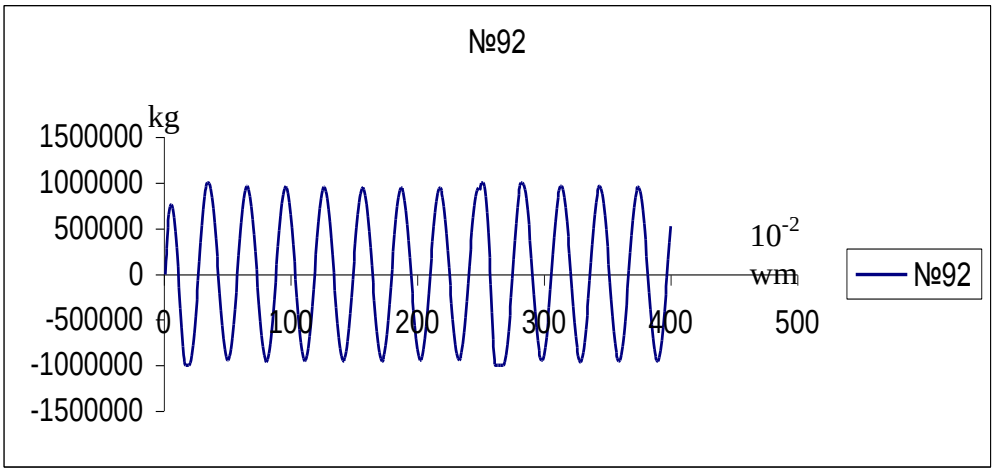
a=10
β=5

nax. 3.17 Zalebi ganmeorebiTi impulsisas



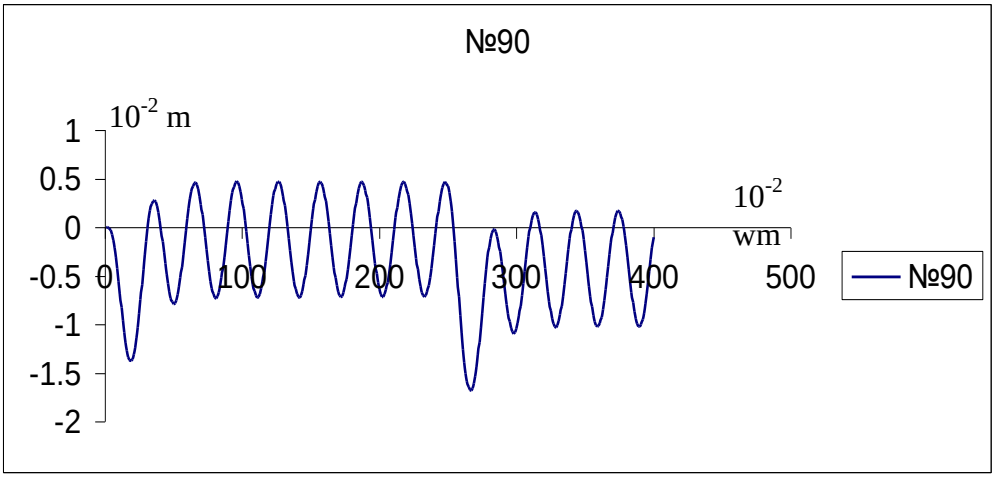
a=10
β=5

nax. 3.18 plastikuri gadaadgilebebi ganmeorebiTi impulsisas



a=10
β=5

nax. 3.19 Zalebi ganmeorebiTi impulsisas



a=10
β=5

nax. 3.20 gadaadgilebebi ganmeorebiTi impulsisas

3.4 oscilatoris arawrfivi rxevebis Seswavla, roca liTonis Rero muSaobs prandtlis sqemis mixedviT, mxolod Runvaze

ganvixiloT oscilatoris arawrfivi rxeva, rodesac Rero muSaobs mxolod Runvaze. dilei algoriTmis Sesabamisad, roca Seyursul masaze moqmedebs Zala P, drois pirveli bijisTvis ucnobi S Zalis gamoTvlisaTvis uwyvetobis pirobas eqneba saxe:

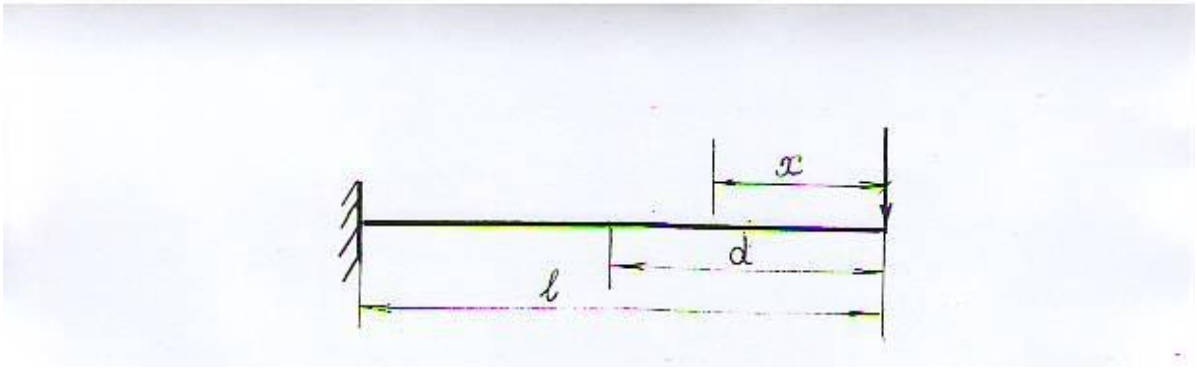
$$\frac{\Delta t^2}{2m} S_1 + \delta = \frac{p\Delta t^2}{2m} \qquad (8)$$

sadac δ gamosaxavs konsolis bolos gadaadgilebas S_1 Zalis qmedebiT. Tu Rero mTlianad drekad mdgomareobaSia, maSin cxadia $\delta = \frac{S_1 l^3}{3EI}$. im SemTxvevisaTvis, roca Reros garkveuli ubani gadasulia drekad-plastikur mdgomareobaSi saWiroa analogiuri damokidebulebis dadgena Zalasa da gadaadgilebas Soris. amisaTvis ganvixiloT konsoluri koWis drekad-plastikuri Runvis amocana [64].

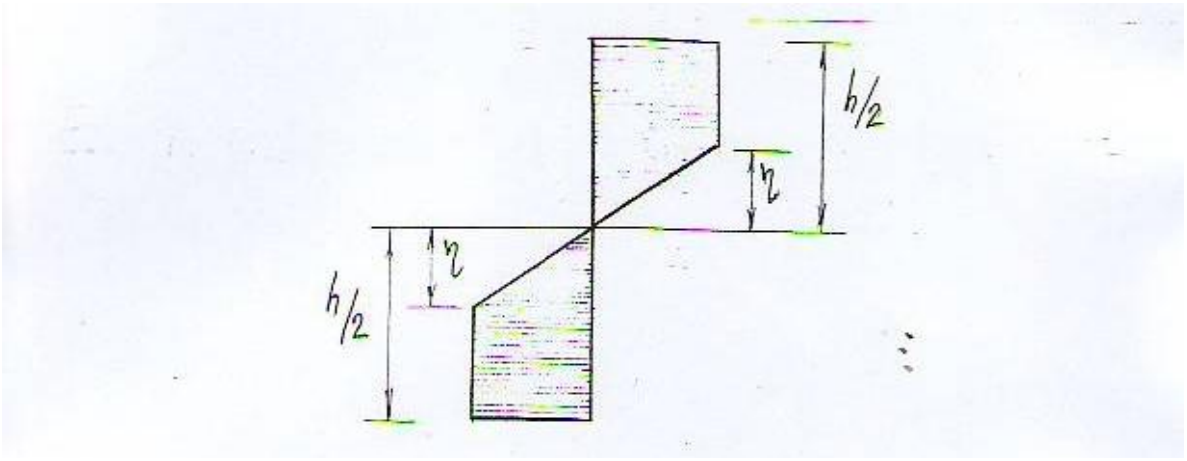
koWis sigrZis mixedviT gveqneba ori are: drekadi ($0 \le x \le d$) da drekad-plastikuri ($d \le x \le l$) (nax. 3.21). davamyaroT damokidebuleba mRunav momentsa da simrudes Soris drekad-plastikuri ubnisaTvis. rogorc cnobilia, kveTSi romlis simaRlis mixedviT gvaqvs drekadi da plastikuri ubnebi Siga Zalebis momenti (nax. 3.22) tolia:

$$M_x = \sigma_d \cdot b\left(\frac{h^2}{4} - \frac{\eta^2}{3}\right)$$

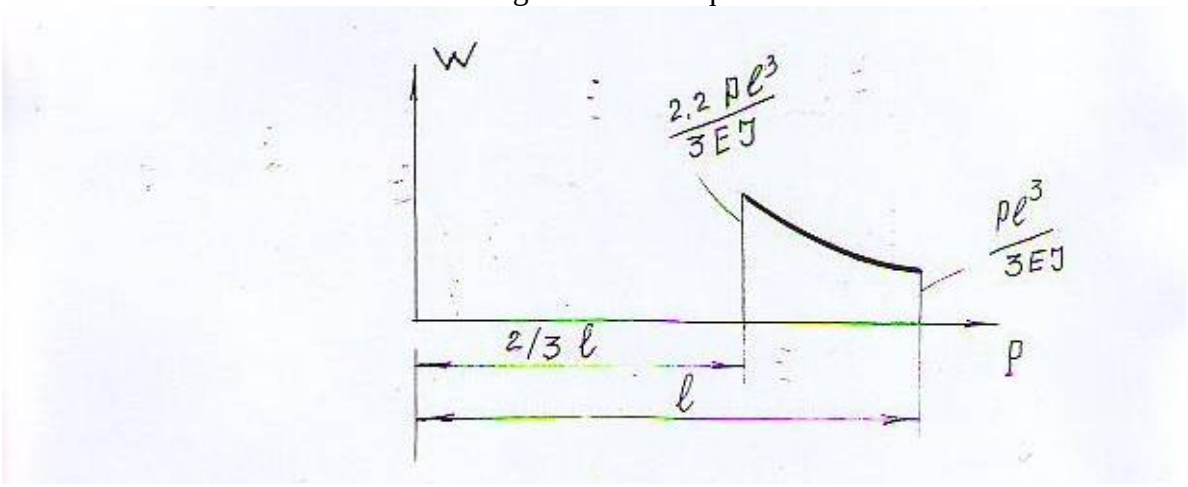
sadac $\eta = \rho\varepsilon_d = \rho\frac{\sigma_d}{E}$, xolo b koWis siganea, σ_d - denadobis zRvari, ε_d - Sesabamisi deformaciaa.



3.21. saangariSo sqema



3.22 Zabvebis ganawileba sisqis mixedviT



3.23 Zala-gadaadgilebis damokidebuleba

maSasadame simrude $\frac{1}{\rho}=\frac{\sigma_{\text{d}}}{\sqrt{3}Eh}\cdot\frac{1}{\left(1-\frac{M_x}{M_{\text{z}}}\right)^{1\backslash 2}}$, sadac $M_{\text{z}}=\sigma_{\text{d}}\frac{bh^2}{4}$. imis

gaTvaliswinebiT, rom $\frac{1}{\rho}\approx W''(x)$ da $M_x=P\cdot x$ gveqneba:

$$W''(x)=\frac{\sigma_{\text{d}}}{\sqrt{3}Eh}\cdot\frac{1}{\left(1-\frac{P\,x}{M_{\text{z}}}\right)^{1\backslash 2}}$$

igive damokidebuleba SeiZleba Caiweros im garemoebis gaTvaliswinebiT, rom drekadi da drekad-plastikuri areebis sazRvarze e.i. kveTSi $x=d$, romlis ganapira boWkoebi gadasulia plastikur mdgomareobaSi, koWis ganivi kveTis marTkuTxa moxazulobis Sesabamisad mRunavi momenti Seadgens zRruli momentis mniSvnelobis $\frac{2}{3}$ -s.

Aamrigad $Pd=\frac{2}{3}M_{\text{zR}}$ e.i. (9)

$$W''(x) = \frac{\sqrt{2}\sigma_d}{EEh} \cdot \frac{1}{\left(\frac{3}{2} - \frac{x}{d}\right)^{1\backslash 2}}$$

integrebiT vRebulobT:

$$W'(x) = -\frac{2\sqrt{2}\sigma_d}{EEh} \cdot \left(\frac{3}{2} - \frac{x}{d}\right)^{1/2} + C_1$$

da

$$W(x) = \frac{2\sqrt{2}\sigma_d d^2}{3Eh} \cdot \left(\frac{3}{2} - \frac{x}{d}\right)^{3/2} + C_1 x + C_2$$

sadac C_1 da C_2 saintegro mudmivebia. maTi gansazRvris mizniT viyenebT koWis Camagrebis pirobebs: $W(l) = W'(l) = 0$. Sesabamisad

$$C_1 = -\frac{2\sqrt{2}\sigma_d}{EEh} \cdot \left(\frac{3}{2} - \frac{l}{d}\right)^{1/2}$$

$$C_2 = -\frac{4\sqrt{2}\sigma_d d^2}{3Eh} \cdot \left(\frac{3}{2} - \frac{l}{d}\right)^{3/2} - \frac{2\sqrt{2}\sigma_d dl}{Eh}\left(\frac{3}{2} - \frac{l}{d}\right)^{1/2}$$

maTi gaTvaliwinebiT gveqneba:

$$W'(x) = \frac{2\sqrt{2}\sigma_d d}{EEh}\left[\left(\frac{3}{2} - \frac{l}{d}\right)^{1/2} - \left(\frac{3}{2} - \frac{x}{d}\right)^{1/2}\right]$$

$$W(x) = \frac{4\sqrt{2}\sigma_d d^2}{3Eh} \cdot \left[\left(\frac{3}{2} - \frac{x}{d}\right)^{3/2} - \left(\frac{3}{2} - \frac{l}{d}\right)^{3/2}\right] - \frac{2\sqrt{2}\sigma_d dl}{Eh}\left[\left(\frac{3}{2} - \frac{l}{d}\right)^{1/2} \cdot (l - x)\right] \quad (10)$$

drekadi ubnisaTvis $(0 \le x \le d)$ gveqneba:

$$W''(x) = \frac{Px}{EI}$$

an radganac $\frac{P}{EI} = \frac{2}{3}\frac{M_{zR}}{d} : \frac{4}{3}\frac{Ebh^3}{12} = \frac{2\sigma_d}{EEdh}$, $W''(x) = \frac{2\sigma_d \cdot x}{EEdh}$ Sesabamisad

$$W'(x) = \frac{\sigma_d \cdot x^2}{EEdh} + D_1$$

$$W(x) = \frac{\sigma_d \cdot x^3}{E3Edh} + D_1 x + D_2$$

D_1, D_2 saintegro mudmivebis dasadgenad drekadi da drekad-plastikuri areebis sazRvarze gvaqvs CaRunvisa da mobrunebis kuTxeebis uwyvetobis piroba. maTi gaTvaliswinebiT gveqneba

$$D_1 = \frac{\sigma_d \cdot d}{Eh} \cdot \left[-3 + 2\sqrt{2}\sqrt{\frac{3}{2} - \frac{l}{d}} \right]$$

$$D_2 = \frac{\sigma_d \cdot d^2}{Eh} \cdot \frac{10 - 2\sqrt{2}\sqrt{\frac{3}{2} - \frac{l}{d}} \cdot \left(3 + \frac{l}{d} \right)}{3} \qquad (11)$$

imisaTvis, rom miviRoT damokidebuleba Zalasa da konsolis bolos gadaadgilebas Soris unda aviRoT drekadi ubnis Sesabamisi gadaadgileba roca x=0, gveqneba $W(0)=D_2$. maSasadame miviReT damokidebuleba W(0) da d –s Soris an rac igivea P –s Soris. Tu avagebT am damokidebulebebs mas eqneba saxe (nax. 3.23) miRebuli mrudi SeiZleba warmodgenil iqnes drekad mdgomareobaSi damokidebulebis msgavsad koeficientebiT $K_1 W = \frac{K_1 P l^3}{3EI}$, sadac K_1 iqneba gansxvavebuli mrudis TiToeuli wertilisaTvis. igi ganisazRvreba agebuli mrudis safuZvelze. Tu Sualeds 2/3 l -dan l-mde davyofT mcire nawilebad (mag. aTas nawilad) Cven gveqneba K_1 aTasi sruliad gansxvavebuli mniSvneloba da SegviZlia visargebloT K-is Semcveli formuliT. magram drois yoveli bijisTvis CvenTvis ucnobia ra manZilze gavrcelda drekad-plastikuri ubani e.i. ras udris K_1. amis dasadgenad viqceviT Semdegnairad: danayofis yoveli wertilisaTvis viTvliT Zalis mniSvnelobas (9) formulis safuZvelze da dilei-algoriTmis Sesabamisi formuliT, sadac Sedis Sesabamisi K_1. romeli wertilisTvisac am ori Zalis mniSvneloba daemTxveva erTmaneTs moTxovnili sizustiT im wertilamde iqneba gavrcelebuli drekad-plastikuri zona da iqneba Sesabamisi K_1 da Zalac.

Camoyalibebuli algoriTmi samarTliania im SemTxvevebisaTvis roca drekad-plastikuri zona ar scildeba $x = \frac{2}{3} l$ -s e.i. roca CamagrebaSi warmoiqmneba plastikuri saxsari.

am algoriTmis safuZvelze Sesrulebulia gamoTvlebi roca: 4 m sigrZis da 20X40 sm ganivi kveTis konsolis boloze moTavsebul Seyursul m masaze moqmedebs P P Zala. Ddenadobis zRvari $S_{dn} = 2000$ kg\sm^2, $E = 2 \cdot 10^6$.

algoriTmisa da programis Semowmebis mizniT, jer Sesrulebuli iyo gamoTvlebi drekadi Reros SemTxvevaSi, roca $m = 15$ xolo P icvleba. (nax. 3.24) warmodgenilia gadaadgilebis epiurebi. rogorc mosalodneli iyo rxevis amplitudebi icvleba Zalis sididis

proporciulad roca $P = 10000$ $A_{\max} = 1{,}98$; roca $P = 11000$ $A_{\max} = 2{,}19$ da roca $P = 12000$ $A_{\max} = 2{,}39$.

nax. 3.25-ze moyvanilia gadaadgilebebi mudmivi datvirTvisa da sxvadasxva masebisaTvis. rogorc grafikidan Cans masis zrdasTan erTad izrdeba gadaadgilebebis rxevebis periodi, xolo amplitudebi rCeba ucvleli.

analogiur movlenas aqvs adgili Zalvebis SemTxvevaSic, nax. 3.26-ze moyvanilia P datvirTvis sididis cvlilebisas mudmivi masis dros Zalvebis cvlilebis suraTi. am SemTxvevaSi mudmivi masis dros rxevis periodi erTi da igivea, xolo amplitudebi izrdeba. mag. roca $P = 10000$ $AF_{\max} = 19952{,}23$; roca $P = 11000$ $AF_{\max} = 2194$ da roca $P = 12000$ $AF_{\max} = 2394{,}27$.

nax. 3.27-ze mocemulia erTi da igive datvirTvisa da sxvadasxva masebis SemTxveva: masis zrda iwvevs Zalvebis rxevis periodis gazrdas, xolo amplituda rCeba mudmivi.

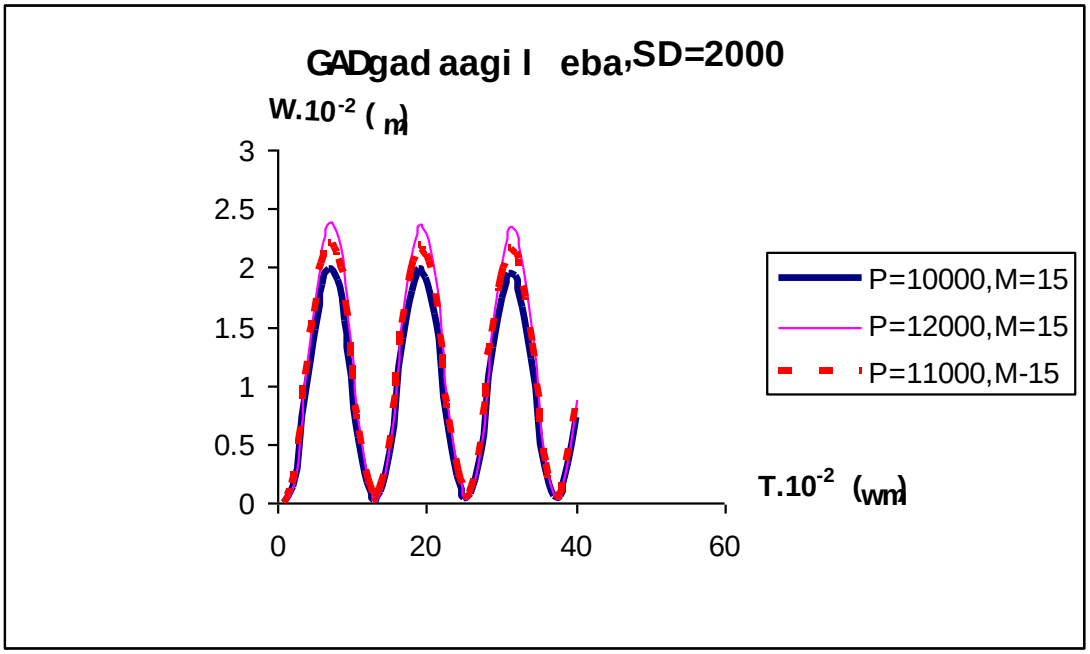
nax. 3.28-ze warmodgenilia gadaadgilebebis epiurebi iseTi datvirTvebis SemTxvevaSi, rodesac gansaxilav koWSi Cndeba plastikuri deformaciebi. roca $P = 12500$jer kidev Rero drekad stadiaSia, xolo roca $P = 13500$ gvaqvs drekad-plastikuri stadiis dasawyisi.

Nnax. 3.29-ze warmodgenilia mudmivi masis dros P datvirTvis cvlilebisas gaangariSebiT miRebuli gadaadgilebebis grafikebi. grafikebidan Cans, rom periodi erTi da igivea, xolo amplitudebi izrdeba datvirTvebis zrdasTan erTad. rac Seexeba plastikur ares: igi vrceldeba Camagrebidan 4-sm-ze, roca $P = 13500$; 16 sm-ze, roca $P = 14000$ da 41 sm-ze roca $P = 15000$.

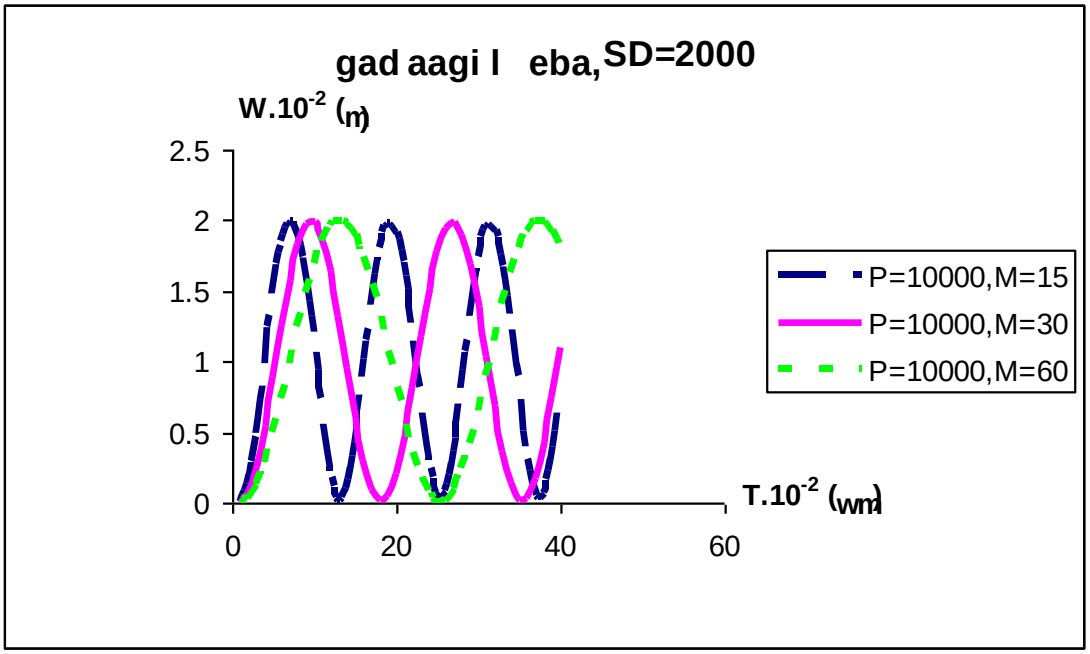
nax. 3.30-ze moyvanilia gadaadgilebebis epiurebi mudmivi datvirTvisa da sxvadasxva masebis SemTxvevaSi. aqac periodi izrdeba masebis zrdasTan erTad: roca $P = 15000$ da m=15. plastikuri zona vrceldeba Camagrebidan 41 sm-ze, xolo roca $P = 15000$ da m=30 29.9 sm-ze, xolo rodesac $P = 20000$ da m=15 plastikuri
zona vrceldeba 114.3 sm-ze, m=30-s SemTxvevaSi ki 107.76 sm-ze.

aqedan SeiZleba davaskvnaT, rom masis gazrdiT plastikurobis gavrcelebis zona mcirdeba.

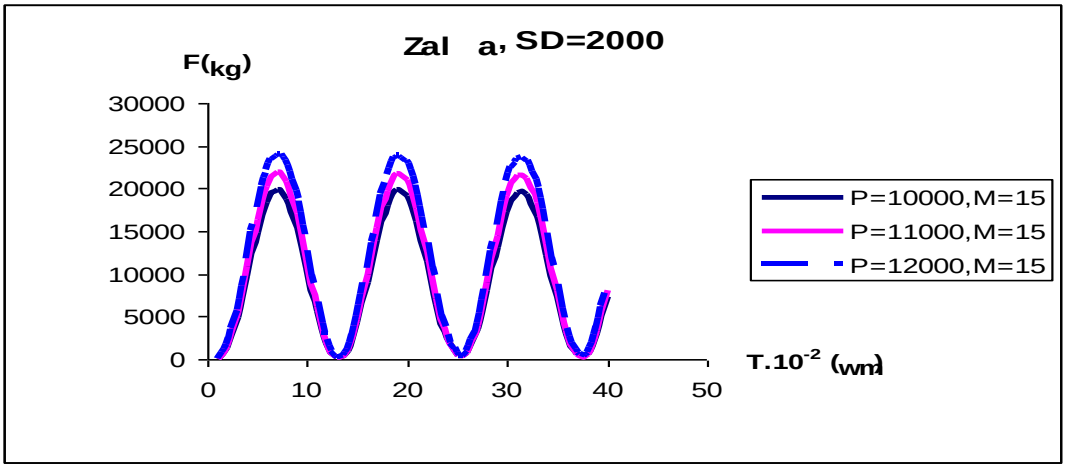
nax. 3.31-ze moyvanilia erTi da igive datvirTvebis dros masebis cvlilebisas Zalvebis grafiki. am SemTxvevaSic masebis zrdasTan erTad izrdeba periodi.



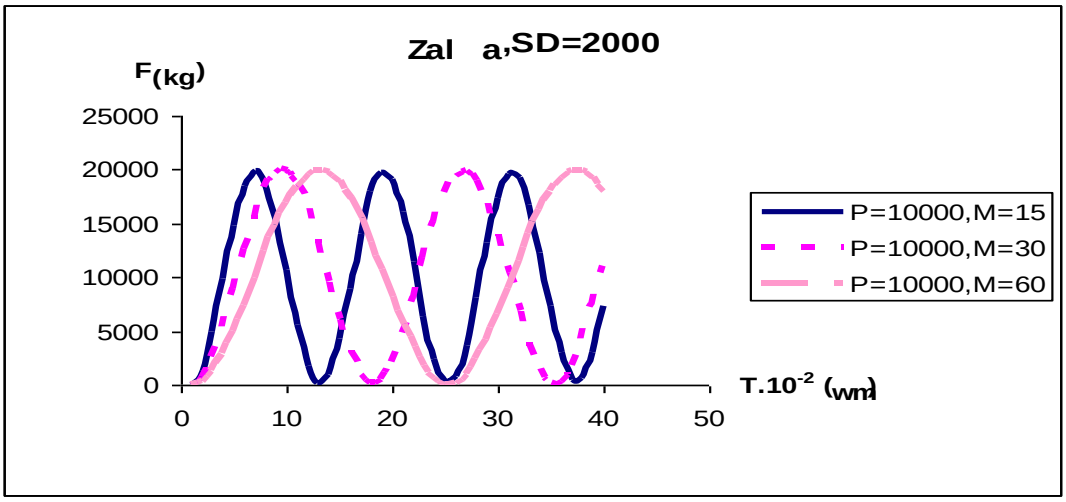
nax. 3.24 gadaadgilebebi Zalis sxvadasxva mniSvnelobisaTvis



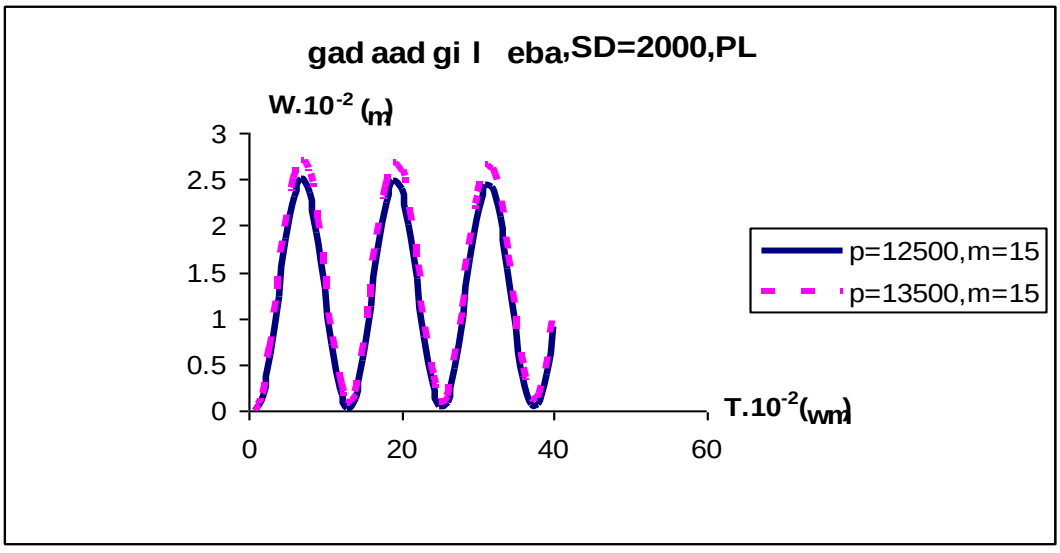
nax. 3.25 gadaadgilebebi masis sxvadasxva mniSvnelobisaTvis



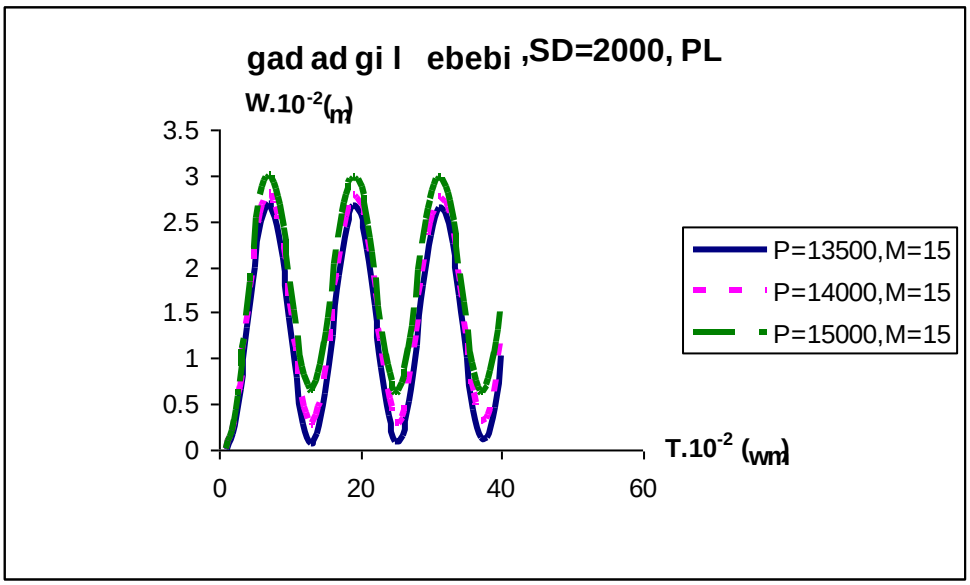
nax. 3.26 Zalebi mudmivi masisa da sxvadasxva datvirTvisas



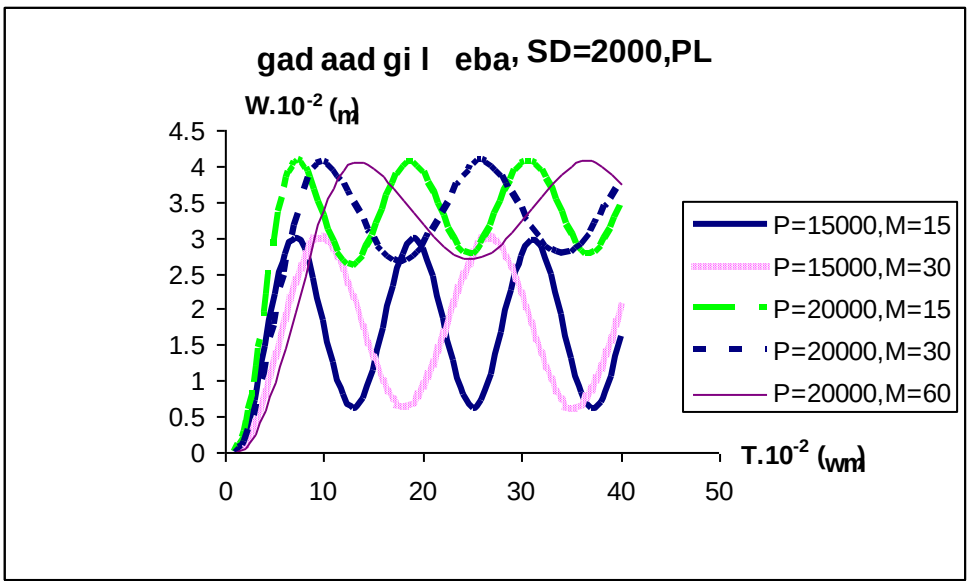
nax. 3.27 Zalebi sxvadasxva masebisa da erTidaigive datvirTvisaTvis



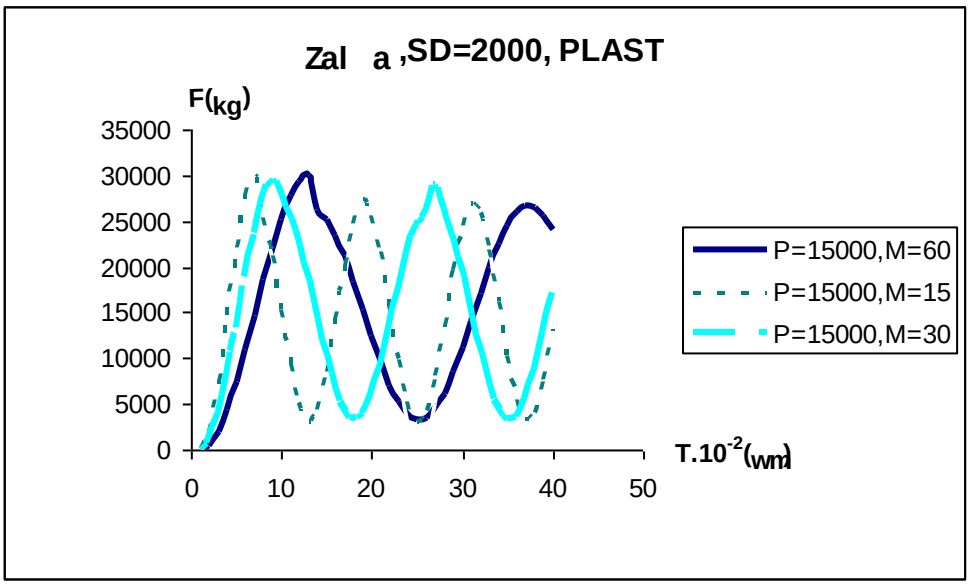
nax. 3.28 gadaadgilebebi plastikurobis warmoqmnis momentisaTvis



nax. 3.29 drekad-plastikuri gadaadgilebebi mudmivi masisa da sxvadasxva datvirTvisaTvis



nax. 3.30 drekad-plastikuri gadaadgilebebi mudmivi datvirTvisas da sxvadasxva masisTvis



nax. 3.31 Zalebi gadaadgilebebi mudmivi datvirTvisas da sxvadasxva masisTvis

3.5 ori Seyursuli masis arawrfivi rxevebis Seswavla, roca damakavSirebeli Reroebi muSaoben mxolod Zvraze

ganvixiloT ori Seyursuli masis rxeva, romlebic erTmaneTTan da gruntTan dakavSirebuli arian deformadi ReroebiT. vigulisxmoT rom es ukanasknelni muSaoben mxolod Zvraze prandtlis sqemis Sesabamisad. aqac vigulisxmoT, rom grunti ganicdis impulsur gadaadgilebas, ris Sedegadac masebi ganicdian inerciis Zalebisa da ReroebTan urTierTqmedebis Zalebis gavlenas. dilei-algoriTmis meTodis Sesabamisad saangariSo sqemas eqneba saxe nax. 3.32 aqac erTmasiani SemTxvevis analogiurad S_1 da S_2 Zalebi warmovadginoT TiToeuli Δt drois monakveTSi mudmiv Zalebis jamebis saxiT:

$$S_1 = \sum_{i=1}^{i=I} S_{1i}\ ,\ S_2 = \sum_{i=1}^{i=I} S_{2i} \qquad (12)$$

pirveli masis gadaadgilebisaTvis, erTmasiani SemTxvevis analogiurad gveqneba:

$$Y = \sum_{i=1}^{i=I} S_{1i} \frac{\left(t_I - t_{i-1}\right)^2}{2m_1}. \qquad (13)$$

m_2 masis moZraobis gantolebas eqneba saxe:

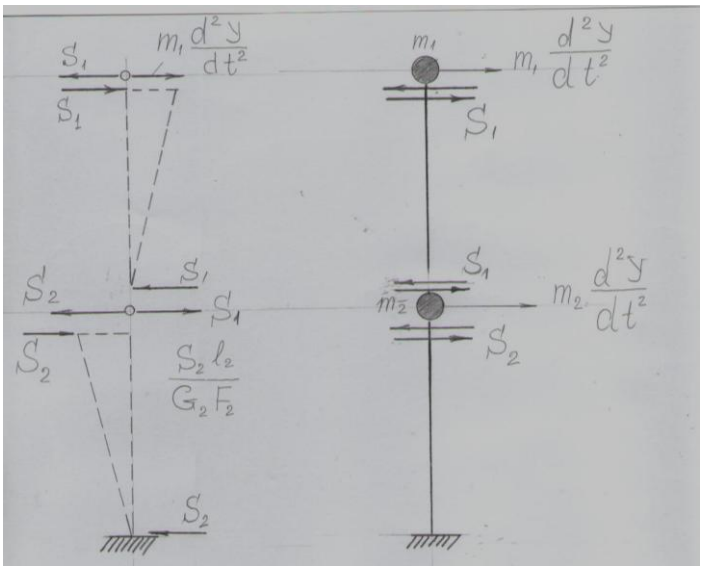
$$m_2 \frac{d^2 Y_2}{dt^2} + S_1 - S_2 = 0 \qquad (14)$$

Tu gaviTvaliswinebT (12)-s da gavaintegrebT (14)-s nulovani sawyisi pirobebiT miviRebT (13)-is analogiur gamosaxulebas:

$$Y_2 = -\sum_{i=1}^{i=I} S_{1i} \frac{\left(t_I - t_{i-1}\right)^2}{2m_2} + \sum_{i=1}^{i=I} S_{2i} \frac{\left(t_I - t_{i-1}\right)^2}{2m_2} \qquad (15)$$

moviyvanoT gadaadgilebebis uwyvetobis pirobebi.

(nax. 3.33)-is mixedviT Δt droSi S_1 Zalis qmedebiT m_1 masa gadaadgildeba sididiT $\frac{\Delta t_2}{2m_1} S_{11}$, rac miiReba (13)-dan, roca $I = 1$. analogiurad m_2 masa gadaadgildeba sididiT $S_2 \frac{\Delta t^2}{2m_2} - S_{11} \frac{\Delta t^2}{2m_2}$.



nax. 3.32 ormasiani sistemis saangariSo sqema

am gadaadgilebebis Sedegad m_1 da m_2 masebs Soris manZilis gegmili gadaadgilebis mimarTulebaze toli iqneba.

$$\left(\frac{\Delta t^2}{2m_1} + \frac{\Delta t^2}{2m_2}\right) S_{11} - \frac{\Delta t^2}{2m_2} S_{21} \qquad (16)$$

uwyvetobis pirobidan gamomdinare es manZili toli unda iyos pirveli Reros S_1 Zalis qmedebiT gamowveuli Zvris deformaciis. rac Caiwereba Semdegnairad

$$\left(\frac{\Delta t^2}{2m_1} + \frac{\Delta t^2}{2m_2} + \frac{l}{GF}\right) S_{11} - \frac{\Delta t^2}{2m_2} S_{21} = 0 \qquad (17)$$

analogiurad vmsjelobT meore masisa da gruntis gadaadgilebebis mimarTac. marTlac, gruntisa YFYF da m_2 masis gadaadgilebebs Soris sxvaoba unda toli iyos meore Reros Zvris deformaciiT gamowveuli gadaadgilebis:

$$-\frac{\Delta t^2}{2m_2}S_{11}+\left(\frac{\Delta t^2}{2m_2}+\frac{l}{GF}\right)S_{21}=YF \qquad (18)$$

(17), (18) gantolebaTa sistemidan ganisazRvreba S_{11} da S_{21} mniSvnelobebi drois pirveli bijisaTvis.

drois Semdegi bijisaTvis e.i roca $I=2$ sistemas eZleva saxe:

$$\left(\frac{(2\Delta t)^2}{2m_1}+\frac{(2\Delta t)^2}{2m_2}+\frac{l}{GF}\right)S_{11}+\left(\frac{\Delta t^2}{2m_1}+\frac{\Delta t^2}{2m_2}+\frac{l}{GF}\right)S_{12}-\frac{(2\Delta t)^2}{2m_2}S_{21}-\frac{(\Delta t)^2}{2m_2}S_{22}=0$$

$$-\frac{(2\Delta t)^2}{2m_2}S_{11}-\frac{\Delta t^2}{2m_2}S_{12}+\left(\frac{(2\Delta t)^2}{2m_2}+\frac{l}{GF}\right)S_{21}+\left(\frac{\Delta t^2}{2m_2}+\frac{l}{GF}\right)S_{22}=YF \qquad (19)$$

xolo nebismieri I bijisaTvis gveqneba:

$$\left(\frac{\Delta t^2}{2m_1}+\frac{\Delta t^2}{2m_2}+\frac{l}{GF}\right)S_{1I}-\frac{(\Delta t)^2}{2m_2}S_{2I}=-\sum_{i=1}^{i=I-1}S_{1i}\left(\left(\frac{1}{2m_1}+\frac{1}{2m_2}\right)(I-i+1)^2\Delta t^2+\frac{l}{GF}\right)S_{1i}+\sum_{i=1}^{i=I-1}\frac{(I-i+1)^2\Delta t^2}{2m_2}S_{2i}$$

(20)

$$-\frac{\Delta t^2}{2m_2}S_{1I}+\left(\frac{\Delta t^2}{2m_2}+\frac{l}{GF}\right)S_{2I}=YF\sum_{i=1}^{I-1}\frac{(I-i+1)^2\Delta t^2}{2m_2}S_{1i}+\sum_{i=1}^{i=I-1}\left(\frac{(I-i+1)^2\Delta t^2}{2m_2}+\frac{l}{GF}\right)S_{2i}$$

(20) sistemis amonaxseni Caiwereba Semdegnairad:

$$S_{1I}=\frac{tl_2(1)\cdot Dlm(n)+tm_2(1)\cdot Tlm(n)}{tl_1(1)\cdot tl_2(1)-tm_2(1)^2},$$

$$S_{2I}=\frac{tl_1(1)\cdot Tlm(n)+tm_2(1)\cdot Dlm(n)}{tl_1(1)\cdot tl_2(1)-tm_2(1)^2} \qquad (21)$$

sadac

$$tl_1(n)=\frac{(n\times\Delta t)^2}{2m_1}+\frac{(n\times\Delta t)^2}{2m_2}+\frac{l_1}{GF},\quad tl_2(n)=\frac{(n\Delta t)^2}{2m_2}+\frac{l}{GF},$$

$$Dlm(n)=tm_2(n)\cdot S_{21}+tm_2(n-1)S_{22}+....+tm_2(2)S_{2,n-1}-tl_1(n)S_{11}-tl_1(n-1)S_{12}-....-tl_1(2)S_{1,n-1}$$

$$Tlm(n)=YF(n)+tm_2(n)S_{11}+tm_2(n-1)S_{12}+....+tm_2(2)S_{1,n-1}-tl_2(n)S_{21}-tl_2(n-1)S_{22}-....-tl_2(2)S_{2,n-1}$$

$$tm_2(n)=\frac{(n\Delta t)^2}{2m_2},\quad tm_1(n)=\frac{(n\Delta t)^2}{2m_1}$$

moyvanili amonaxsnebi samarTliania drekadi rxevebis SemTxvevaSi. plastikuri deformaciebis arsebobis SemTxvevaSi daemateba: pirvel gantolebaSi pirveli Reros, xolo meore gantolebaSi meore Reros plastikuri gadaadgileba.Tu romelime ReroSi Zala gadaaWarbebs zRvrul mniSvnelobas, iq Zalis nazrdi iqneba nulis toli. sistemidan ganisazRvreba plastikuri gadaadgileba da meore ReroSi Zalis nazrdis axali mniSvneloba.

maSasadame uwyvetobis piroba Caiwereba Semdegnairad:

$$tl_1(1)S_{1n} - tm_2(1)S_{2n} = Dlm(n) - \sum_{i=1}^{n-1} PL1(i) - PL1(n)$$

$$-tm_2(1)S_{1n} + tl_2(1)S_{2n} = Tlm(n) - \sum_{i=1}^{n-1} PL2(i) - PL2(n) \qquad (22)$$

sadac jamebi warmoadgenen gansazRvrul bijamde dagrovil plastikuri gadaadgilebebis algebrul jamebs. Tu orive ReroSi Zalebis mniSvnelobebi naklebia zRvrulze maSin $PL1(I)$ da $PL2(I)$ nulis tolia da gveqneba

$$S_{1n} = \frac{tl_2(1)\cdot\left[DLm(n) - \sum Pl1(i)\right] + tm_2(1)\left[Tlm(n) - \sum PL2(i)\right]}{tl_1(1)\cdot tl_2(1) - tm_2(1)^2} \qquad (23)$$

$$S_{2n} = \frac{tl_1(1)[TLm(n) - \sum PL2(i)] + tm_2(1)[DLm(n) - \sum PL1(i)}{tl_1(1)\cdot tl_2(1) - tm_2(1)^2}$$

exla vTqvaT pirvel ReroSi Zalis mniSvnelobam gadaaWarba zRruls maSin $S_{1n} = 0$ da $tl(1)S_{1n}$–is adgilas dagvrCeba mxolod $PL1(n)$, romelic formalurad Secvlis $\frac{l}{GF}S_{1n}$ drekad gadaadgilebas, radgan meore ReroSi Zala naklebia zRvrulze $Pl2(n) = 0$ da (22) miiRebs saxes:

$$tl_1(1)\frac{PL_1(n)}{tl_1(1)} - Tm_2(1)\cdot S_{2n} = DLm(n) - \sum Pl1(i)$$

$$0\cdot\frac{PL1(n)}{tl_1(1)} + tl_2(1)\cdot S_{2n} = TLm(n) - \sum PL2(i)$$

misi amoxsna ki mogvcems

$$PL1(n) = \frac{[DLm(n) - \sum PL1(1)]tl_2(1) + [TLm(n) - \sum PL2(i)]tm_2(1)}{tl_2(1)} \qquad (24)$$

$$S_{2n} = \frac{TLm(n) - \sum PL2(i)}{tl_2(1)}$$

Aanalogiurad gveqneba im SemTxvevaSi roca meore ReroSi gadaaWarbebs Zala zRvrul mniSvnelobas. maSin $PL1(n) = 0$ $S_{2n} = 0$

$$S_{1n} = \frac{DLm(n) - \sum PL1(i)}{tl_1(1)}, \qquad (25)$$

$$PL2(n) = \frac{[TLm(n) - \sum PL2(i)]tl_1(1) + tm_2(1)[DLm(n) - \sum PL1(i)]}{tl_1(1)}$$

im SemTxvevaSi Tu orive ReroSi Zala metia zRvrulze maSin $S_{1n} = 0,\ S_{2n} = 0$ da

$$PL1(n) = Dlm(n) - \sum PL1(i), \qquad (26)$$

$$PL2(n) = tlm(n) - \sum PL2(i)$$

SemdgomSi programis kompaqturad Caweris mizniT $DLm(n)$ da $TLm(n)$-s mivceT Semdegi saxe:

$$DLm(n) = S_{22} - S_{21} - \frac{l_1}{G_1F_1}S01,$$

$$TLm(n) = YF(n) + S_{23} - S_{22} - \frac{l_2}{G_2F_2}S02$$

sadac $S01$ da $S02$ pirvel da meore ReroSi Zalebis zRvruli mniSvnelobebia,

$$S_{21} = S_{24} - S_{23,}$$

$$S_{22} = tm_2(n)S_{21} + tm_2(n-1)S_{22} + ... + tm_2(2)S_{2,n-1},$$

$$S_{23} = tm_2(n)S_{11} + tm_2(n-1)S_{12} + ... + tm_2(2)S_{1,n-1}, \qquad (27)$$

$$S_{24} = tm_1(n)S_{11} + tm_1(n-1)S_{12} + ... + tm_1(2)S_{1,n-1}.$$

demferebis arsebobis SemTxvevaSi gansxvavebulad Caiwereba uwyvetobis pirobebi (17), (18), (19) da (20).

saZirkvlis doneze moTavsebul demferis dros (18)-Si gaTvaliswinebuli unda iyos drekadi Zvris deformaciasTan erTad is plastikuri gadaadgileba romelsac ganicdis demferi, roca Zala aRemateba zRvrul mniSvnelobas. es gadaadgileba toli iqneba $\frac{S02}{ABS(S02)} \cdot V\Delta tl_{2\rho}$ sadac V plastikuri gadaadgilebis siCqarea $l_{2\rho}$ ki dempferis simaRle. Tu dempferi gvaqvs zeda Reros ZirSi maSin analogiuri wevri daemateba (17) gantolebasac, ris Sedegadac sistema drois pirveli bijisTvis miiRebs saxes:

$$tl_1(1)\cdot S_{11} - tm_2(1)S_{21} = -\frac{S01}{ABS(S01)}V\cdot\Delta t\cdot l_{1p} \qquad (28)$$

$$-tm_2(1)S_{11} + tl_2(1)S_{21} = YF - \frac{S02}{ABS(S02)}\cdot V\cdot\Delta t\cdot l_{2p}$$

nebismieri I bijisTvis (20) marjvena mxares daemateba Sesabamisi wevrebi $-\frac{S01}{ABS(S01)}\cdot V\cdot j\Delta t\cdot l_{1p}$ da $-\frac{S02}{ABS(S02)}\cdot V\cdot j\Delta t\cdot l_{2p}$ sadac j aRniSnavs drois Δt bijis raodenobas, romlis drosac Zalebi aRematebian dempferebis zRvrul sidideebs. analogiuri cvlileba Seva sistemis amonaxsenSic (21) sadac $Dlm(n)$ da $Tlm(n)$ gamosaxulebebSi Seva moyvanili Sesakrebebi.

aq igulisxmeba, rom demferebis arsebobisas Reroebi muSaoben drekad stadiaSi. Tu es ase ar aris maSin cxadia mivmarTavT (22) da (23) damokidebulebas $Dlm(n)$ da $Tlm(n)$ gamosaxulebebis saTanado cvlilebiT.

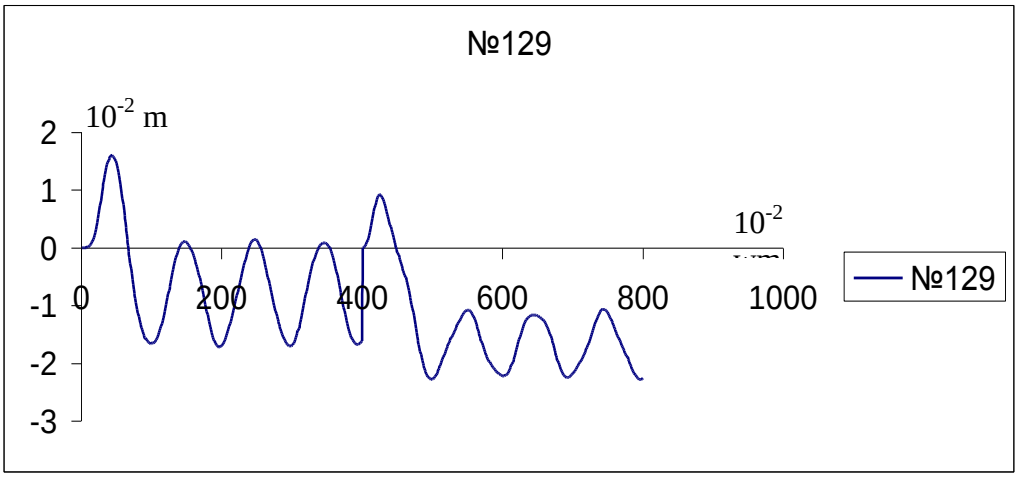
3.6 ori masis SemTxvevaSi Sesrulebuli gamoTvlebis Sedegebi

gamoTvlebi Sesrulebulia roca $M1 = M2 = 15000\text{kg}$, $a = 50\,\text{sm/wm}$, $\beta = 8.$ impulsis moqmedebis ganmavlobaSi pirveli masis maqsimaluri gadaadgileba tolia daaxloebiT 1,6 sm . Semdeg rxeva sruldeba plastikuri gadaadgilebis 0,8 sm mimarT amplitudiT 0.83sm. meore masis maqsimaluri gadaadgileba sawyis momentSi tolia 0.94 sm, xolo rxeva xdeba plastikuri gadaadgilebis 1.7-is mimarT amplitudiT 0.6 sm (nax. 3.33). Tu am mniSvnelobas SevadarebT drekad rxevas vnaxavT, rom pirveli masis maqsimaluri gadaadgileba tolia 4 sm, meore masisa ki 2,8sm (nax 3.34,3.35). rogorc vxedavT plastikuri deformaciebis gaTvaliswinebiT rogorc gadaadgilebis absolituri mniSvnelobebi, aseve rxevis amplitudebi mcirdeba. kidev ufro mniSvnelovania gavlena Zalebis mniSvnelobaze. plastikuri deformaciebis gaTvaliswinebisas pirvel ReroSi Zala aRwevs maqsimalur mniSvnelobas 10^6 erTxel, meore ReroSi ki samjer. drekadi rxevisas pirvel ReroSi Zala oTxjer aRwevs sidides, romlebic samjer da metad aRematebian zRvrul mniSvnelobas. meore ReroSi Zalebis mniSvneloba oTxjer da metad metia zRvrul mniSvnelobaze (nax. 3.36).

Ggamokvleulia masebis sidideTa cvlilebis gavlena rxevis procesze. Tu meore masas SevamcirebT samjer pirveli masis maqsimaluri gadaadgileba impulsis moqmedebis procesSi iqneba TiTqmis igive. rac Seexeba Semdgom rxevas, is sruldeba plastikuri gadaadgilebis 0.28 sm mimarT amplitudiT 1 sm.Mmeore masis maqsimaluri gadaadgileba impulsis

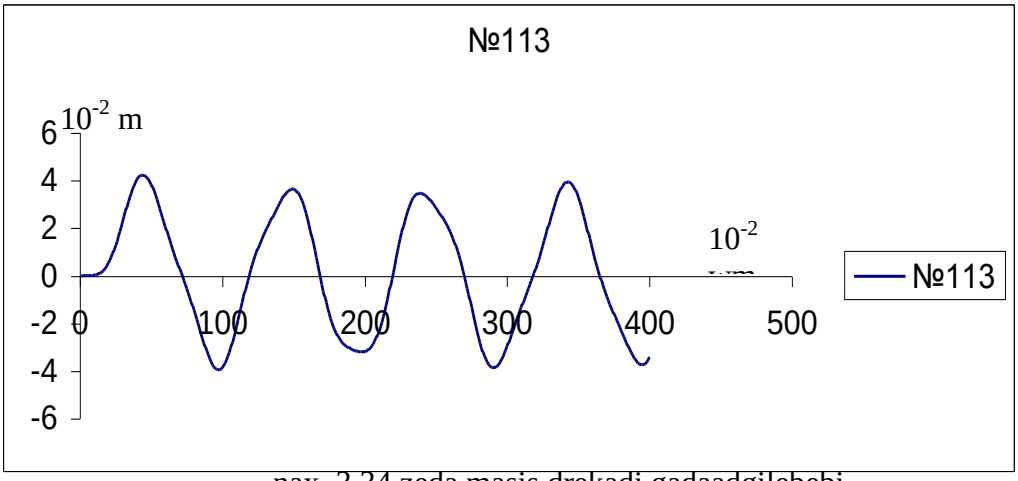
moqmedebis procesSi 1.25 sm. Semdgomi rxeva ki sruldeba plastikuri gadaadgilebis 0.82 sm-is mimarT amplitudiT 0.55 sm (nax. 3.37). rac Seexeba Zalebs pirvel ReroSi Zala aRwevs zRvrul mniSvnelobas TiTojer rogorc dadebiTi ise uaryofiTi niSniT, meore ReroSi ki oTxjer dadebiTi niSniT, erTxel ki uaryofiTiT.

drekadi rxevis SemTxvevaSi impulsis moqmedebis periodSi gvaqvs^: maqsimaluri amplituda pirveli masisTvis 3,5 sm meoresTvis 3,1 sm.



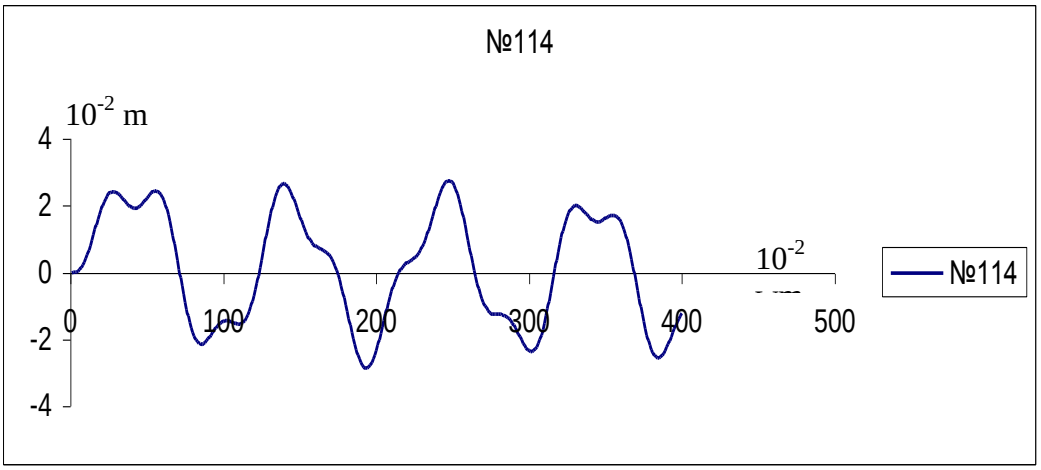
a=25
β=8

nax. 3.33 drekad-plastikuri sistemis gadaadgilebebi



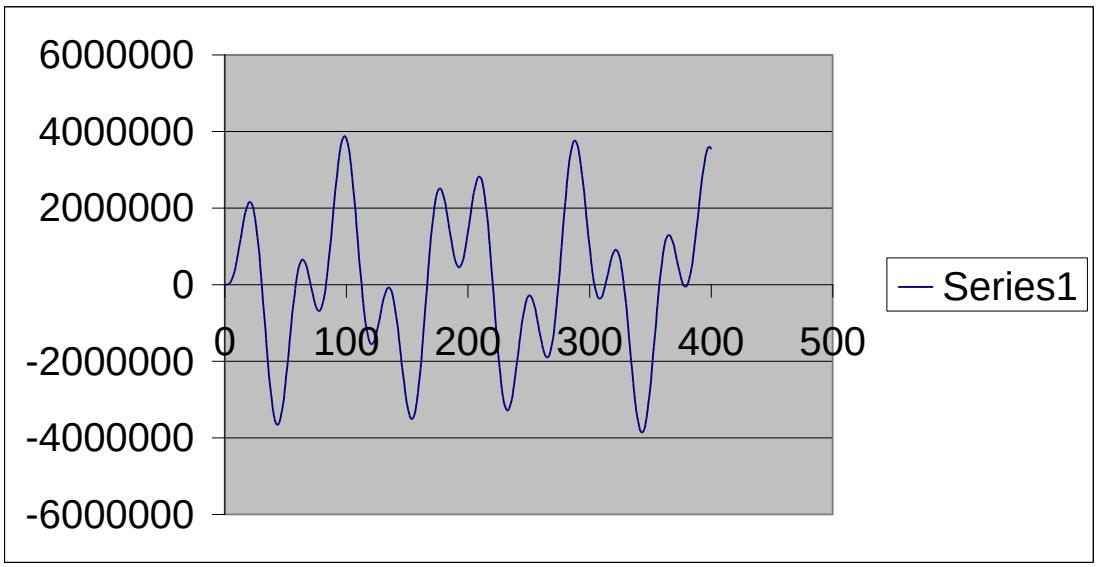
a=25
β=8

nax. 3.34 zeda masis drekadi gadaadgilebebi

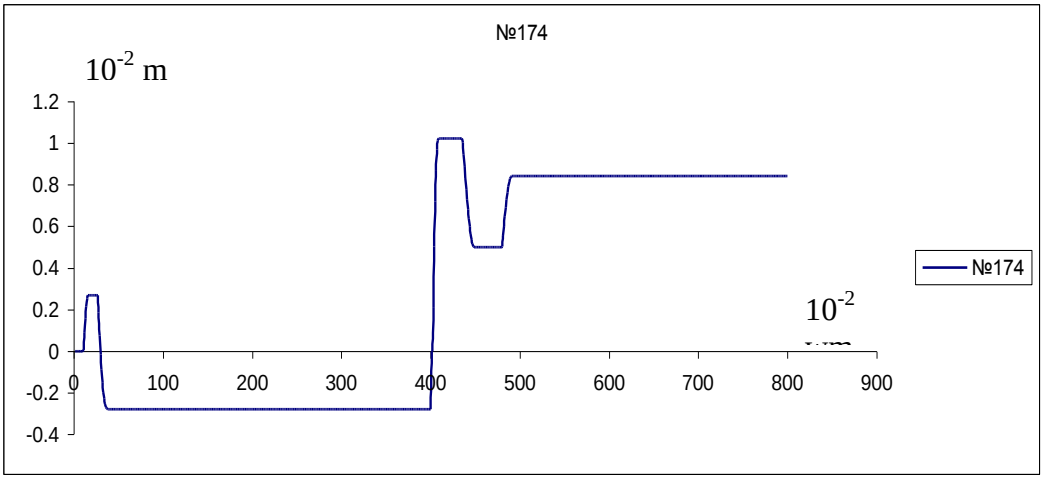


a=25
β=8

nax. 3.35 zeda masis drekadi gadaadgilebebi

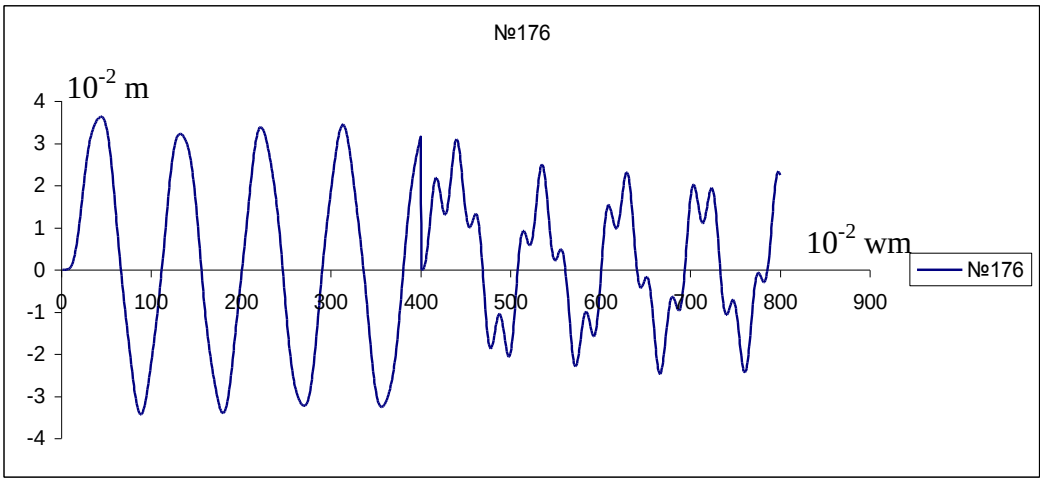


nax. 3.36 Zalebi drekad sistemaSi



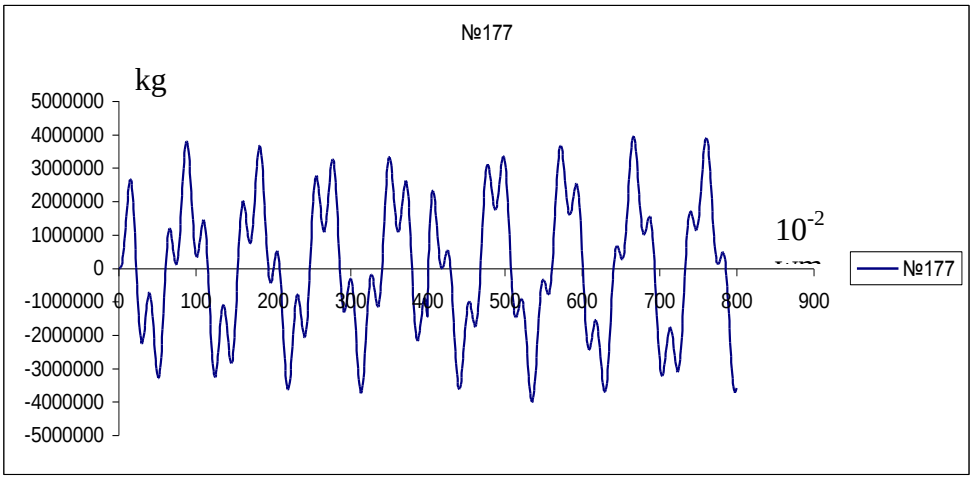
a=25
β=8

nax. 3.37 plastikuri gadaadgilebebi



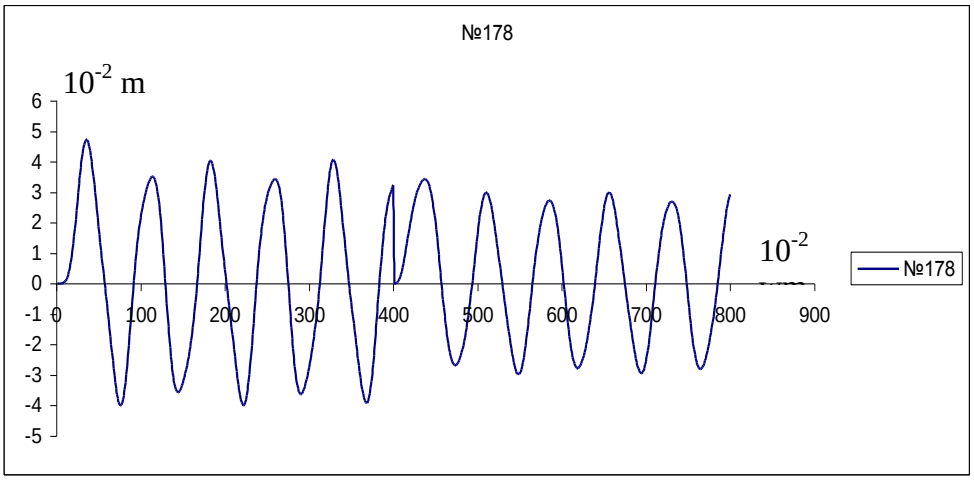
a=25
β=8

nax. 3.38. drekadi gadaadgilebebi



a=25
β=8

nax. 3.39 Zalebi drekad sistemaSi



a=25
β=8

nax. 3.40 drekadi gadaadgilebebi

Semdgomi rxeva xdeba pirveli masis amplitudiT 3,2 sm, meore masisTvis 2,4 sm (nax. 3.38). rac Seexeba Zalebs, maTi maqsimaluri mniSvnelobebi icvleba $3{,}8\cdot10^{6}$–dan $3{,}1\cdot10^{6}$–mde pirveli masisTvis da $4\cdot10^{6}$ -dan $3{,}1\cdot10^{6}$ -mde meore masisTvis (nax. 3.39).

im SemTxvevaSi Tu pirvel masas SevamcirebT samjer maSin impulsis moqmedebis procesSi gadaadgileba aRwevs pirveli masisaTvis 4.7 sm-s, meore masisaTvis ki 3.3 sm-s (nax. 3.40). Semdegi rxevisas pirveli masis maqsimaluri amplitudaa 4 sm, meore masis ki 3 sm. arsebiTia gavlena Zalebis mniSvnelobaze, radgan pirvel ReroSi Zalebi odnav aRemateba $2\cdot10^{6}$–s, meore ReroSi ki $4{,}3\cdot10^{6}$ -is tolia.

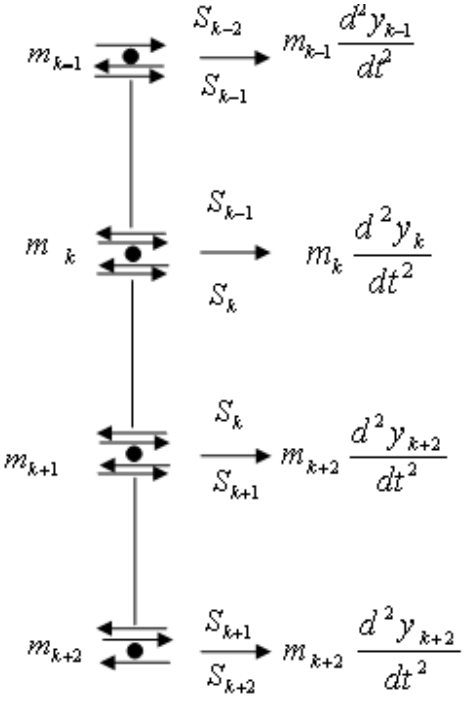
miRebuli Sedegebis Sedarebidan Cans, rom roca meore masas vamcirebT samjer gadaadgileba impulsis moqmedebis dros mcirdeba daaxloebiT pirveli masisTvis $\approx 2{,}25$-jer, meore masisTvis $\approx 2{,}4$–jer. Semdgomi rxeva ki sruldeba pirveli masis samjer da ufro metad

Semcirebuli amplitudiT, meore masis ki oTxjer da ufro metad Semcirebuli amplitudiT. Zalebi ki pirvel ReroSi mcirdeba TiTqmis oTxjer, meoreSi ki TiTqmis xuTjer.

pirveli masis samjer Semcirebis SemTxvevaSi impulsis moqmedebis dros maqsimaluri amplituda mcirdeba 3 -jer pirveli masisTvis da 2-jer meore masisTvis. SemdgomSi rxeva xdeba pirveli masis daaxloebiT oTxjer Semcirebuli amplitudiT, meore masisa ki xuTjer Semcirebuli amplitudiT. Zalebi pirvel ReroSi mcirdeba daaxloebiT orjer, meoreSi ki oTxjer.

3.7 erT RerZze ganlagebuli mravali masis arawrfivi rxevebi

ganvixiloT erT RerZze ganlagebuli mravali masis rxeva. aviRoT romelime m_k masa.



nax. 3.41 saangariSo sqema

misi moZraobis diferencialuri gantoleba iqneba

$$m_k \frac{d^2 y_k}{dt^2} + S_{k-1} - S_k = 0$$

Tu TiToeul Zalas warmovadgenT jamis saxiT

$$S_k = \sum_{i=1}^{I-1} S_{k,i}$$

da gavaintegrebT nulovani sawyisi pirobebiT, gveqneba

$$y_k = -\sum_{i=1}^{I} \frac{(t_I - t_{j-1})^2}{2m_k} S_{k-1,i} + \sum_{i=1}^{I} \frac{(t_I - t_{j-1})^2}{2m_k} S_{k,i}$$

uwyvetobis piroba m_k da m_{k+1} masebs Soris pirveli Δt monakveTisaTvis Caiwereba Semdegnairad:

$$-S_{k-1,1}\frac{\Delta t^2}{2m_k} + \left(\frac{\Delta t^2}{2m_k} + \frac{\Delta t^2}{2m_{k+1}} + \frac{l}{GF}\right)S_{k,1} - S_{k+1,1}\frac{\Delta t^2}{2m_{k+1}} = 0$$

meore bijisaTvis gveqneba:

$$-S_{k-1,2}\frac{\Delta t^2}{2m_k} - S_{k-1,1}\frac{(2\Delta t)^2}{2m_k} + \left(\frac{\Delta t^2}{2m_k} + \frac{\Delta t^2}{2m_{k+1}} + \frac{l}{GF}\right)S_{k,2} + \left[\frac{(2\Delta t)^2}{2m_k} + \frac{(2\Delta t)^2}{2m_{k+1}} + \frac{l}{GF}\right]S_{k,1} -$$

$$-S_{k+1,2}\frac{\Delta t^2}{2m_{k+1}} - S_{k+1,1}\frac{(2\Delta t)^2}{2m_{k+1}} = 0$$

nebismieri I bijisaTvis:

$$-S_{k-1,I}\frac{\Delta t^2}{2m_k}-\sum_{i=1}^{I-1}S_{k-1,i}\frac{(t_I-t_{i-1})^2}{2m_k}+S_{k,I}\left[\Delta t^2\left(\frac{1}{2m_k}+\frac{1}{2m_{k+1}}\right)+\frac{l}{GF}\right]+$$

$$+\sum_{i=1}^{I-1}S_{k,I}\left[(t_I-t_{i-1})^2\left(\frac{1}{2m_k}+\frac{1}{2m_{k+1}}\right)+\frac{l}{GF}\right]-S_{k+1,I}\frac{\Delta t^2}{2m_{k+1}}-\sum_{i=1}^{I-1}S_{k+1,i}\frac{(t_I-t_{i-1})^2}{2m_{k+1}}=0$$

es gamosaxuleba samarTliania, Tu Rero drekadia. magram Tu plastikurSia daemateba $\Delta_{k,\text{pl}}=\Delta_{k,I}+\sum_{i=1}^{I-1}\Delta_{k,i}$.

Tu mas davumatebT da marcxena mxareSi gadavitanT mxolod $S_{k,I}$ da $\Delta_{k,I}$ Semcvel wevrebs, gveqneba:

$$S_{k,I}\left[\Delta t^2\left(\frac{1}{2m_k}+\frac{1}{2m_{k+1}}\right)+\frac{l}{GF}\right]+\Delta_{k,I}=\sum_{i=1}^{I}S_{k-1,I}\frac{(t_I-t_{i-1})^2}{2m_k}-$$

$$-\sum_{i=1}^{I-1}S_{k,I}\left[(t_I-t_{i-1})^2\left(\frac{1}{2m_k}+\frac{1}{2m_{k+1}}\right)+\frac{l}{GF}\right]+\sum_{i=1}^{I-1}S_{k+1,i}\frac{(t_I-t_{i-1})^2}{2m_{k+1}}-\sum_{i=1}^{I-1}\Delta_{k,i}$$

wina paragrafSi gamoyenebuli aRniSvnebis gaTvaliswinebiT, gveqneba:

$$S_{k,I}\left[tm_k(1)+tm_{k+1}(1)+FL\right]+\Delta_{k,I}=S_{k-1,1}tm_k(I)+S_{k-1,2}tm_k(I-1)+\ldots+S_{k-1,I}tm_k(1)-$$
$$-S_{k,1}\left[tm_k(I)+tm_{k+1}(I)+FL\right]-S_{k,2}\left[tm_k(I-1)+tm_{k+1}(I-1)+FL\right]-\ldots-$$
$$-S_{k,I-1}\left[tm_k(2)+tm_{k+1}(2)+FL\right]+S_{k+1,1}tm_k(I)+S_{k+1,2}tm_{k+1}(I-1)+\ldots+$$
$$+S_{k+1,I}tm_{k+1}(1)-\sum_{i=1}^{I-1}\Delta_{k,i}$$

Caweris gamartivebis mizniT SemoviRoT Semdegi aRniSvnebi:

$$k4=k+1$$
$$k3=k-1$$
$$S01(k)=\sum_{i=1}^{I-1}S_{k,i}$$
$$S02(k)=\frac{\sum_{i=1}^{I-1}\left[I\cdot DT-(i-1)\cdot DT\right]^2\cdot Sk3(i)}{2M(k)}$$
$$S03(k)=\frac{\sum_{i=1}^{I-1}\left[I\cdot DT-(i-1)\cdot DT\right]^2\cdot Sk(i)}{2M(k)}$$
$$S04(k)=\frac{\sum_{i=1}^{I-1}\left[I\cdot DT-(i-1)\cdot DT\right]^2\cdot Sk(i)}{2M(k4)}$$
$$S05(k)=\frac{\sum_{i=1}^{I-1}\left[I\cdot DT-(i-1)\cdot DT\right]^2\cdot Sk4(i)}{2M(k4)}$$

e.i. roca k Reroze momqmedi Zvris Zala naklebia mis zRvrul mniSvnelobaze, maSin:

$$S_{k,I} = \frac{Dlm(k)}{tl_k(1)}$$

da Tu metia

$$\Delta_{k,I} = Dlm(k)$$

sadac

$$Dlm(k) = S02(k) - S03(k) - S04(k) - S01(k) \cdot FL + S05(k) - \sum_{i=1}^{I-1} \Delta_{k,i}$$

$$tl_k(1) = tm_k(1) + tm_{k+1}(1) + FL$$

moyvanili uwyvetobis pirobebi samarTliania yvela RerosaTvis, garda pirveli da bolo Reroebisa. pirveli RerosaTvis gantolebaSi ar Seva $S02(k)$, xolo bolo gantolebaSi $S04(k)$ da $S05(k)$. amave dros bolo gantolebas daemateba gruntis gadaadgileba YF. Seicvleba $tl_k(1)$-is gamosaxuleba masSi ar Seva $tm_{k+1}(1)$. e.i. gveqneba:

$$S_{n,I} = \frac{S02(n) - S03(n) - S01(n) \cdot FL - \sum_{i=1}^{I-1} \Delta_{n,i}}{\frac{\Delta t^2}{2m_n} + \frac{l}{GP}}$$

es, roca Rero drekad mdgomareobaSia, xolo Tu Rero plastikurSia, maSin plastikuri gadaadgileba $\Delta_{n,I}$ toli iqneba mxolod mricxvelis.

miRebuli gantolebaTa sistema ixsneba mimdevrobiTi miaxloebis xerxiT. TiToeuli gantolebidan marcxena mxareSi gadmogvaqvs $S_{k,I}$ da $\Delta_{k,I}$. drois TiToeuli DT bijisaTvis marjvena mxareSi saZiebel sidideebs vaniWebT raRac (nulovan) mniSvnelobebs, viTvliT axal mniSvnelobebs da vadasturebT wina miaxloebis mniSvnelobebs, roca sxvaoba aRmoCndeba moTxovnil sizusteze naklebi, gadavdivarT drois Semdeg bijze. amave dros drois yoveli bijisaTvis TiToeul ReroSi mowmdeba, xom ar aWarbebs miRebuli Zala mis zRvrul mniSvnelobas. Tu aWarbebs, maSin Zalis nazrdi aiReba nulis tolad da gamoiTvleba plastikuri gadaadgileba zemoT moyvanili formulebiT.

3.8 mravali masis SemTxvevaSi gamoTvlebis Sedegebi da maTi analizi

gamoTvlebi Sesrulebulia wina paragrafSi ganxiluli konkretuli zomebis SemTxvevaSi im gansxvavebiT, rom aRebulia xuTsarTuliani nageboba. zemoqmedeba isev impulsuri gadaadgilebaa, roca $\alpha=50$ da $\beta=8$.

xuTive ReroSi dafiqsirda plastikuri gadadgilebebi. zeda pirvel da meore ReroSi TiTqmis Tanabari sididis ≈0.37 sm (nax. 3.42). Semdeg or ReroSi naklebi, Sesabamisad 0.11 da 0.14 sm, qveda mexuTe ReroSi ki maqsimumi 1.62 sm. masebis gadaadgilebis aseTi ganawileba ganpirobebulia albaT plastikuri gadaadgilebebiT da gansakuTrebiT pirveli Reros maqsimaluri gadaadgilebiT. masebis maqsimaluri gadadgilebebi qveda sam ReroSi TiTqmis Tanabaria ≈2.3 sm (nax. 3.43). zevidan meore ReroSi cota naklebi ≈1.93 sm da kidev ufro naklebi zeda pirvel ReroSi ≈1.8 sm. yvela es sidide gruntis gadaadgilebis sawinaaRmdego mimarTulebiTaa. xolo dadebiTi mimarTulebiT gadaadgilebebi zevidan, meoredan mexuTes CaTvliT daaxloebiT 0.8 sm-ia. xolo zevidan pirvelSi TiTqmis 1.5 sm. es gasagebicaa, radgan impulsis moqmedebis periodSi Reroebma miiRo uaryofiTi plastikuri gadaadgileba (garda qvedasi), romlebic warmoadgenen narCen gadaadgilebebs da ikribebian Semdgomi rxevis Sedegad gadadgilebebTan. qveda Rerom miiRo dadebiT plastikuri gadaadgileba, romelic Semdgom kidev ufro gaizarda. rac Seexeba Zalebs isini Seesabamebian gadaadgilebebs. mkumSavi Zalebi oTxive ReroSi aRematebian zRvruls, gamWimavi ki gacilebiT naklebia masze ≈700000kg. mxolod qveda ReroSi gvaqvs orive niSnis Zalebi zRvrulze meti maTgan ki gansakuTrebiT gamWimavi, romelic orjer drois sxvadasxva momentisaTvis aWarbebs zRvruls.

miRebul Sdegebs Tu SvadarebT drekad rxevebs davrwmundebiT, rom rogorc Zalebi, aseve gadaadgilebebi drekad-plastikuri rxevis SemTxvevaSi gacilebiT naklebia drekadi rxevis Sesabamis mniSvnelobebTan SedarebiT (nax. 3.44). Tanac suraTi Tvisobrivad gansxvavdeba. mag. gadaadgilebebi maqsimaluri gvaqvs zeda ReroSi da is orjer da metad aRemateba drekad-plastikuri rxevisas maqsimalur gadaadgilebas. rac Seexeba Zalebs zevidan pirvel da meore ReroSi Zalebis maqsimaluri mniSvneloba samjer metia zRvrulze, mesame da meoTxeSi ornaxevarjer, mexuTeSi ki kvlav samjer (nax. 3.45).

ganxiluli iyo igive konstruqciisaTvis ganmeorebiT impulsuri zemoqmedebis gavlena pirveli impulsis dawyebidan ori wamis Semdeg (impulsi moqmedebs 1 wamis ganmavlobaSi) (nax. 3.46). zemoqmedebam gamoiwvia zeda pirvel ReroSi plastikuri gadaadgilebis zrda 90%-iT (nax. 3.47). meore da mesame ReroSi umniSvnelod, meoTxeSi gaizarda 5-jer, mexuTeSi, e.i. qveda ReroSi orjer. rac Seexeba gadaadgilebebs (nax. 3.48),

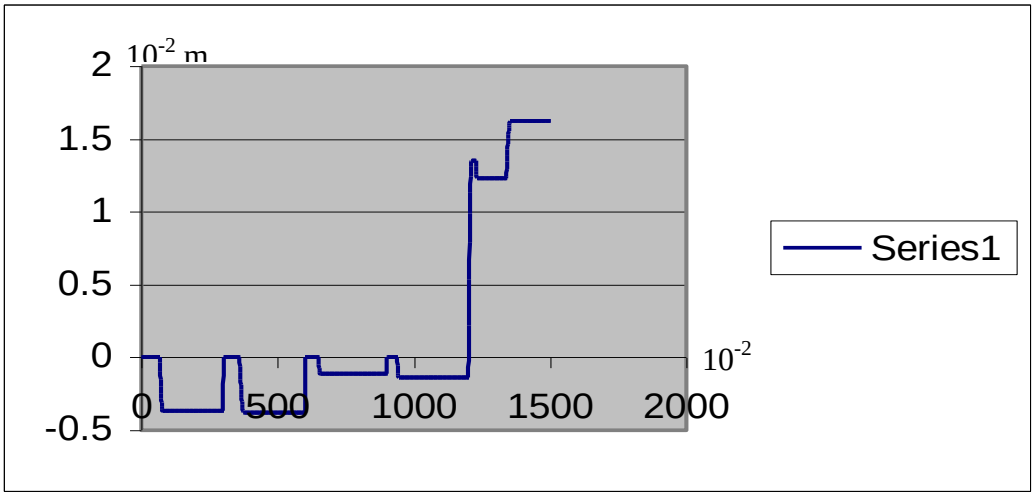
isini gaizarda, magram ar gadauWarbebiaT maqsimalur mniSvnelobebisTvis garda qveda Rerosi, sadac gadaadgileba gaizarda samjer da ufro metad. Sesabamisi suraTi gvaqvs ZalebSic (nax. 3.49). yvela ReroSi Zalebis mniSvnelobani aWarbeben zRvrul mniSvnelobas.

ganmeorebiT impulsuri zemoqmedebis gavlena gaTvaliswinebuli iyo sruli drekadi rxevisas. ganmeorebiTma zemoqmedebam erTnaxevarjer gazarda pirveli zemoqmedebiT gamowveuli maqsimaluri gadaadgileba (nax. 3.50). Tu SevadarebT drekad-plastikurs, maSin gaizarda oTxjer. es exeba zeda pirvel masas. zevidan meore masis drekadi gadadgileba gaizarda TiTqmis orjer, drekad-plastikuri ki 2.5-jer. mesame da meoTxe masis drekadi gadaadgilebebi gaizarda daaxloebiT 1.5-jer, drekad-plastikurTan SedarebiT ki TiTqmis ar Secvlila. rac Seexeba qveda masas, misi drekadi gadaadgileba darCa igive drekad plastikurTan SedarebiT ki Semcirda 1.5-jer. rac Seexeba Zalebs, zeda or ReroSi Zalebi ar gazrdila, mesameSi gaizarda TiTqmis orjer, meoTxeSi 1.5-jer, mexuTeSi ki umniSvnelod (nax. 3.51).

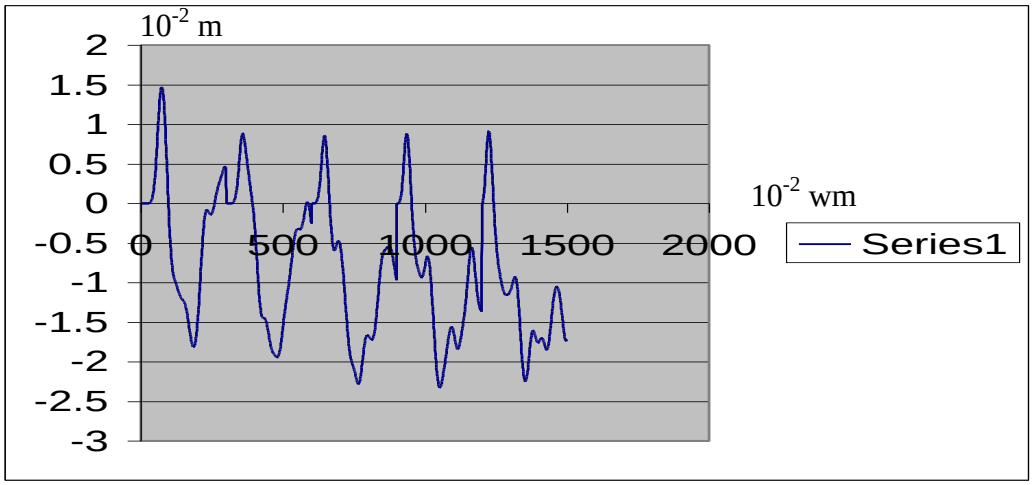
igive zemoqmedebaze gaangariSebuli iyo TeqvsmetsarTuliani nageboba. Seyursuli masebis sidideebi iyo iseTive, rogorc xuTsarTulianis SemTxvevaSi. rac Seexeba kveTis farTobebs, isini icvlebodnen.

SevadaroT TeqvsmetsarTuliani mudmivkveTiani Reroebis mqone ori Senobis Zalebi da gadaadgilebebi kveTis farTobis ori mniSvnelobisa da erTidaigive zemoqmedebis pirobebSi. ganxiluli iyo SemTxvevebi, roca kveTis farTobi tolia 890 sm^2 da 1053 sm^2 (es Seesabameba Sesabamisad Svelerebis #22 da @#24a) drekadi rxevebis SemTxvevaSi (nax. 3.52). maqsimaluri gadadgilebi orive SemTxvevaSi gvqonda zeda boloze 4.0 da 4.17 sm Sesabamisad. gadaadgilebebi mcirdeba qveda sarTulebisaTvis da Sesabamisad mcirdeba sxvaobac, rac TiTqmis aRara gvaqvs pirveli sarTulisaTvis. aRsaniSnavia, rom masebis gadaadgilebis epiurebi orive SemTxvevaSi erTnairia da TiToeul SemTxvevaSi sxvadasxvaa imis mixedviT, Tu romeli masa gvaqvs. zeda pirveli ori masisaTvis gvaqvs TiTo naxevari talRa erTi impulsis moqmedebis periodSi, meore ki niSniT gansxvavebuli, impulsis moqmedebis Sewyvetis Semdeg. qveda masebisaTvis es naxevari talRebi icvlian formebs, Suaze iyofian da TandaTan scildebian erTmaneTs (nax. 3.53, 3.54). maqsimaluri gadaadgilebebi daaxloebiT erTnairia 2.3 sm-s farglebSi. Tu SevadarebT Zalebs aqac meti kveTis farTobis SemTxvevaSi gvaqvs meti Zala ≈15%-iT. absolutur sididT Zala aRwevs maqsimums ($\approx 3.5 \cdot 10^6$ kg) zevidan meore RerosTvis, Semdeg mcirdeba da daaxloebiT Tanabaria ($\approx 2.3 \cdot 10^6$ kg) danarCeni ReroebisaTvis garda qveda pirveli ori Rerosi, sadac kvlav aRwevs maqsimums sul qveda Rerosas ($\approx 3.6 \cdot 10^6$ kg).

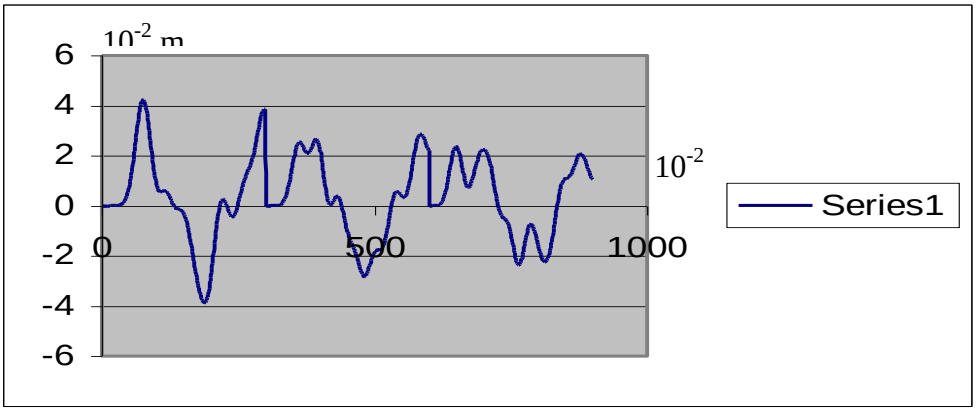
Tu am or SemTxvevas SevadarebT erTmaneTs drekad-plastikuri muSaobis gaTvaliswinebiT, vnaxavT, rom plastikuri gadaadgilebebis ganawilebis suraTi zustad erTnairia, mxolod meti kveTis farTobis SemTxvevaSi gvaqvs odnav meti plastikuri gadadgileba. aRsaniSnavia isic, rom zemodan meore ReroSi (nax. 3.55) plastikuri gadadgileba gacilebiT metia danarCeni Reroebis plastikur gadaadgilebebze, garda qveda pirveli Rerosi, sadac es gadaadgileba rigiT metia (≈1.6 sm) danarCenebze.



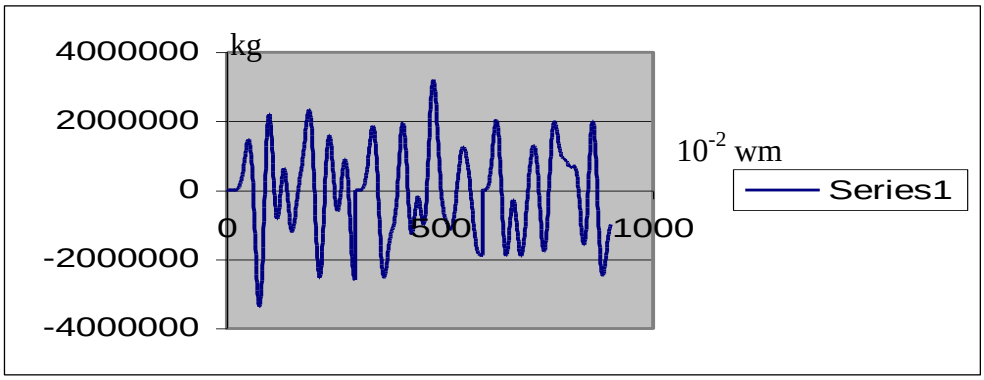
nax. 3.42 plastikuri gadaadgilebebi ReroebSi



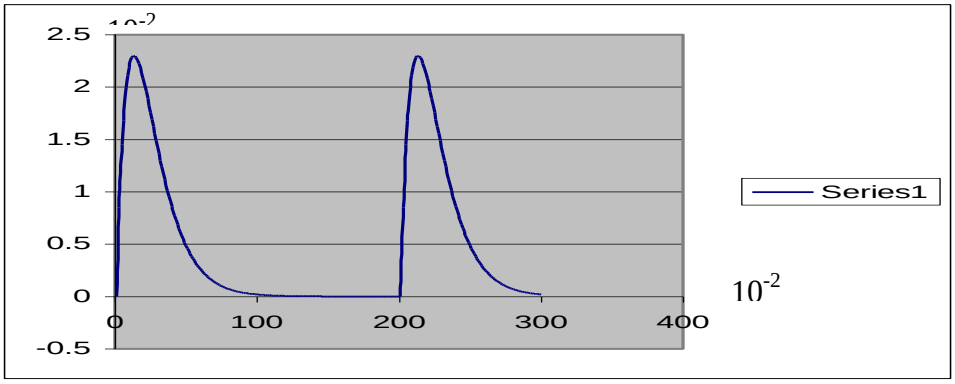
nax. 3.43 masebis gadaadgilebebi



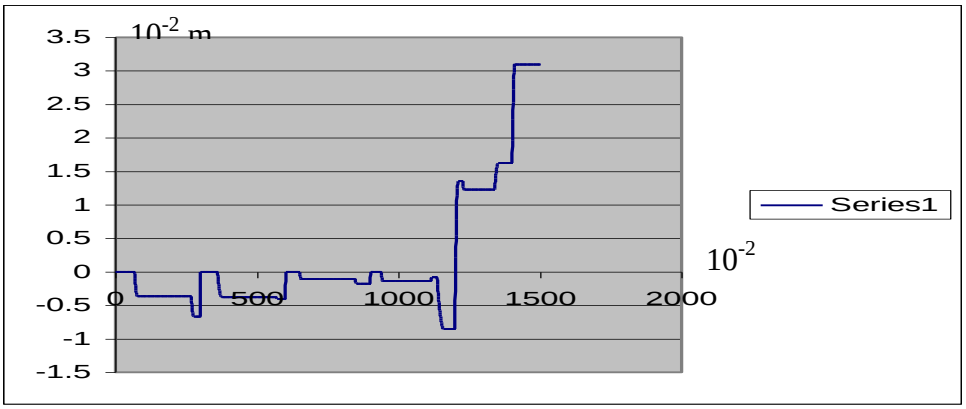
nax. 3.44 gadaadgilebebi drekadi rxevisas



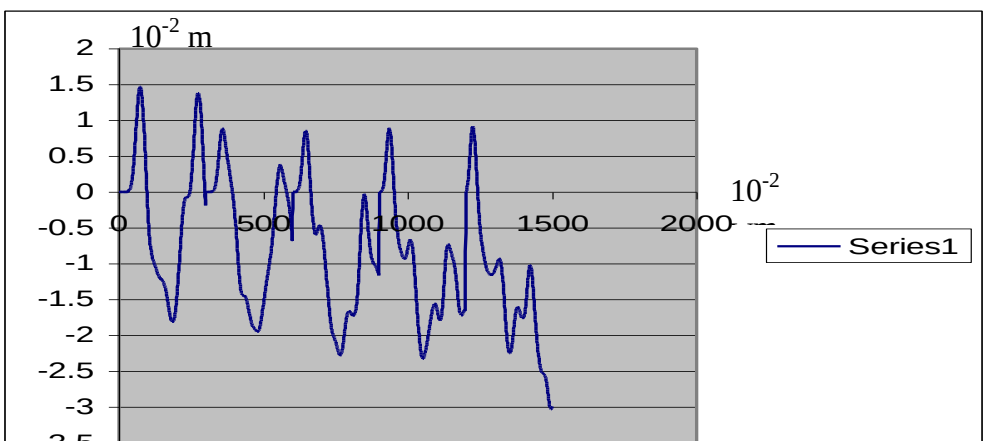
nax. 3.45 Zalebi drekadi rxevisas



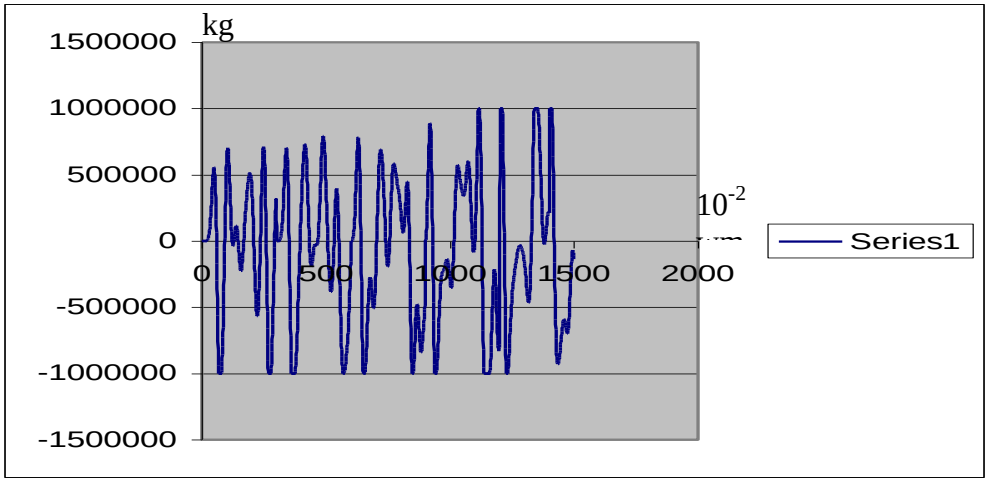
nax. 3.46 ganmeorebiTi impulsi



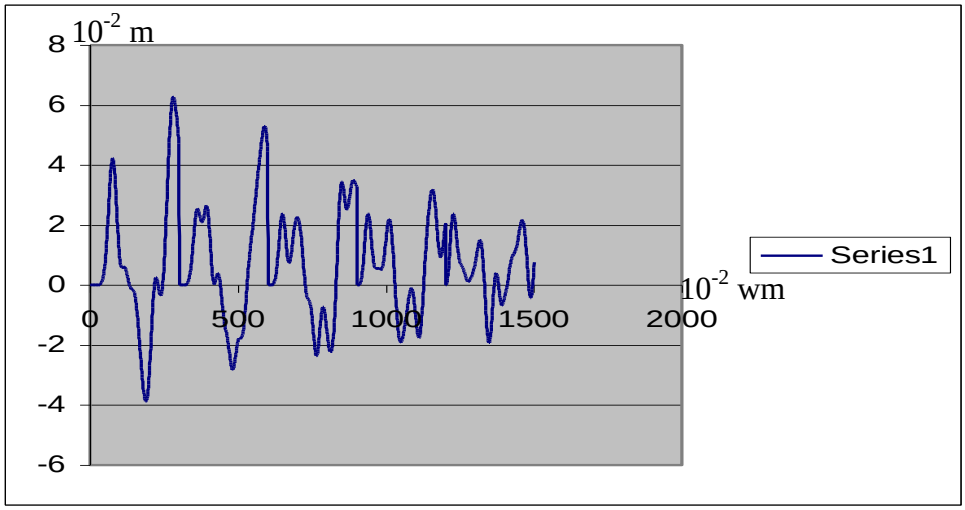
nax. 3.47 plastikuri gadaadgilebebi ganmeorebiTi impulsisas



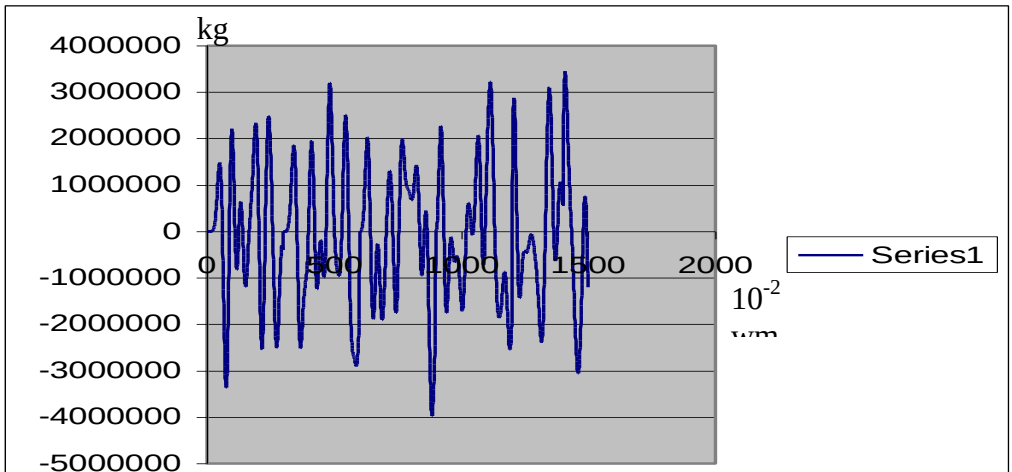
nax. 3.48 gadaadgilebebi ganmeorebiTi impulsisas



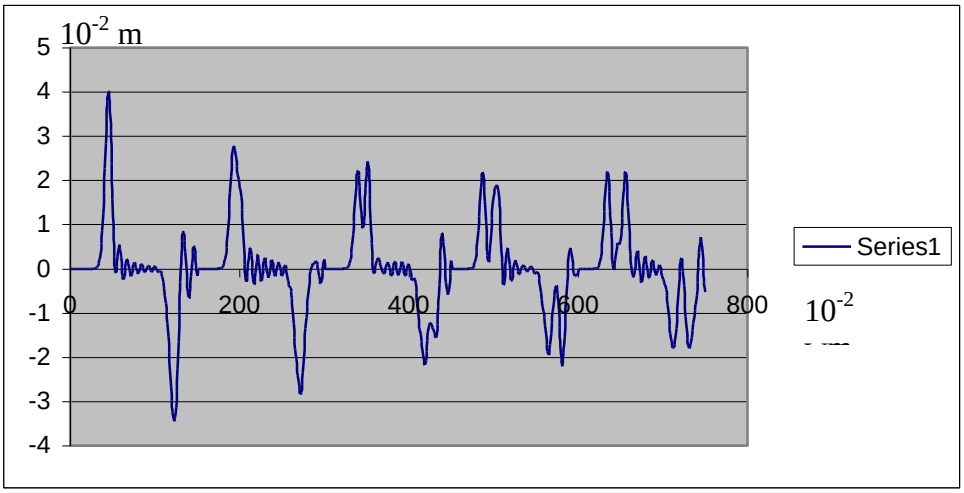
nax. 3.49 Zalebi ganmeorebiTi impulsisas



nax. 3.50 drekadi gadaadgilebebi ganmeorebiTi impulsisas



nax. 3.51 Zalebi ganmeorebiTi impulsisas



nax. 3.52 TeqvsmetsarTulianis zeda xuTi sarTulis gadaadgilebebi

rac Seexeba masebis gadaadgilebebs, aqac epiurebi orive SemTxvevaSi formiT erTnairia. maqsimaluri gadaadgileba impulsis moqmedebis periodSi gvaqvs zeda pirveli masisTvis 1.5 sm meti farTobisas, 1.3 sm – naklebi. es kanonzomiereba SenarCunebulia mTeli gansaxilveli SualedisaTvis 6 wm. absoluturi sididiT maqsimaluri gadaadgilebebi gvaqvs mas Semdeg, rac impulsi Sewyvets moqmedebas. impulsis moqmedebis procesSi maqsimaluri gadadgilebebi mcirdeba ≈0.8 sm-mde, bolo xuTi masisTvis ki TiTqmis Tanabaria ≈1.0 sm (nax. 3.56). amisgan gansxvavebiT gadaadgilebebi impulsis Sewyvetis Semdeg niSniT uaryofiTia, TandaTanobiT izrdeba da -1.7 sm-dan aRwevs -2.5 sm-mde. rac Seexeba gadaadgilebis epiuris formas, drekadi rxevisagan gansxvavebiT, yvela masisTvis mas aqvs TiTqmis erTnairi forma dadebiTi naxevartalRuri da cota ufro rTuli uaryofiTi gadaadgilebebis saxiT.

Zalebis SemTxvevaSi gvaqvs daaxloebiT igive Tanafardobebi. meti farTobis SemTxvevaSi Zalebi metia. amave dros Zalebi aRweven TavianT maqsimalur mniSvnelobas impulsis moqmedebis momentSi an misi dasasrulisaTvis. es principi darRveulia qveda pirvel ReroSi, sadac maqsimums Zala aRwevs impulsis moqmedebis dasrulebis Semdeg (nax. 3.58).

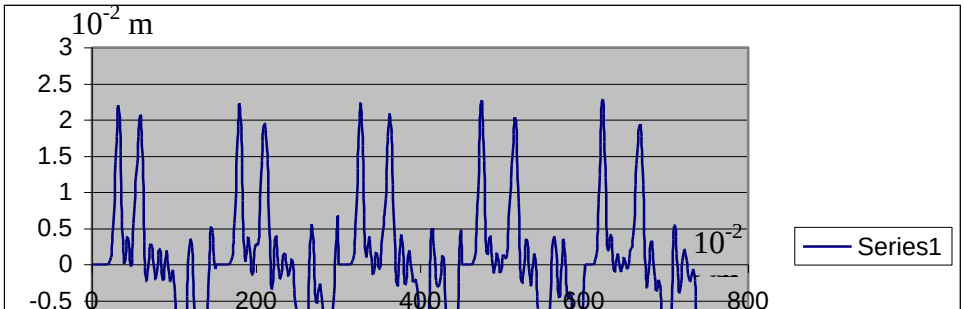
aqve unda aRiniSnos is garemoeba, rom impulsis moqmedebis gavlena zeda Reroebisa da masebisaTvis vrceldeba garkveuli drois Semdeg, rac saWiroa talRis gavrcelebisaTvis da rac kargad Cans, rogorc gadaadgilebebis, aseve Zalebis epiurebze.

exla vnaxoT ra gavlenas axdens gadaadgilebebisa da Zalebis mniSvnelobaze kveTis farTobis cvlileba sarTulebis mixedviT. ganxiluli iyo SemTxveva, roca kveTis farTobi mudmivia oTx-oTxi sarTulis farglebSi da icleba wrfivTan miaxloebuli kanoniT, izrdeba zevidan qveviT. mudmivi kveTi F=890 sm^2 ganawilebuli iyo aRniSnuli kanoniT, rogorc gadaadgilebebi aseve Zalebi gamovida ufro meti, vidre mudmivi kveTis SemTxvevaSi gvqonda. rac kidev erTxel miuTiTebs im faqtze, rom rac ufro xistia konstruqcia, miT ufro naklebad xdeba reaqciis Caqroba.

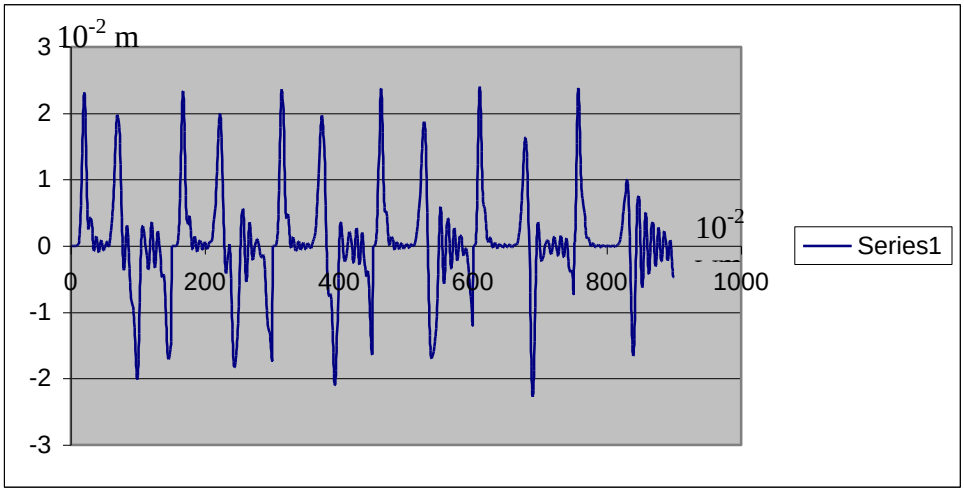
exla ganvixiloT SemTxveva, roca kveTis farTobebi oTx-oTx sarTulze mudmivia, magram icvleba kvadratuli parabolis kanoniT da is SevadaroT mudmivi kveTis SemTxvevas, roca F(I)=1053 sm^2. plastikuri gadaadgilebebi cvladi kveTis SemTxvevaSi yvelgan gamovida meti, vidre mudmivi kveTis SemTxvevaSi, garda qveda pirveli sarTulisa, sadac iyo meti: 1.6 sm nacvlad 1.2 sm-sa. amave dros cvladis SemTxvevaSi yoveli oTxi erTnairi kveTis sarTulebze zemodan meore sarTulze plastikuri gadaadgileba iyo meti danarCen samze (cxadia garda qveda pirveli oTxeulisa) 348. (nax. 3.57). mudmivi kveTis SemTxvevaSi plastikuri gadaadgileba izrdeba qevidan qveviT mdovreT, garda zemodan meore da qvemo pirveli sarTulisa (nax. 3.55).

SevadaroT cvladi kveTis Senobis rxevebi analogiur Senobis rxevebTan, romlis pirveli sarTuli SedarebiT moqnilia F=1000 sm^2 nacvlad 1296 sm^2-sa. plastikuri gadadgilebebi yvela sarTulze, garda qveda pirvelisa metia moqnil pirvel sarTulTan SedarebiT, pirvelze ki piriqiT gvaqvs 1.25 sm da 1.6 sm. rac Seexeba masebis gadaadgilebebs, maTi epiurebi moxazulobiT erTnairia, magram gansxvavebulia dadebiTi da uaryofiTi niSnis gadaadgilebebi. dadebiTi niSnis gadaadgilebebi yvelgan naklebia moqnili pirveli sarTulis SemTxvevaSi da isini icvleba 1.25 sm-dan 0.8 sm-s Soris, uaryofiTi ki metia. maTi sidideebi icvleba -1.22 sm-dan -2.4 sm-mde. aRsaniSnavia isic, rom maqsimaluri dadebiTi gadaadgileba moqnili sarTulis SemTxvevaSi gvaqvs impulsis moqmedebis bolo momentisaTvis (0.85 wm), xolo Cveulebrivis dros impulsis moqmedebis Sewyvetidan 1.6 wm-s Semdeg.

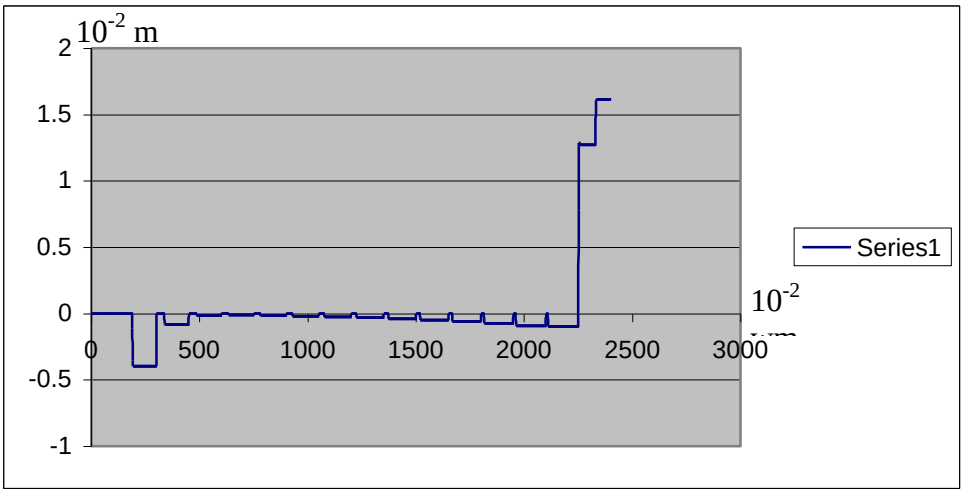
rac Seexeba Zalebs, maTi sidideebi zeda 9 sarTulis SemTxvevaSi axloa erTmaneTTan (dadebiTi mniSvnelobani odnav naklebia moqnil sarTulTan SedarebiT). zevidan meaTe sarTulidan dawyebuli moqnil sarTulianSi Zalebi naklebia Cveulebrivze da Tanac mniSvnelovnad: qveda pirvel or sarTulze gvaqvs $1.6 \cdot 10^6$ da $1.25 \cdot 10^6$ kg. ase, rom moqnili pirveli sarTuli mniSvnelovnad amcirebs Zalebis mniSvnelobas qveda sarTulebSi.



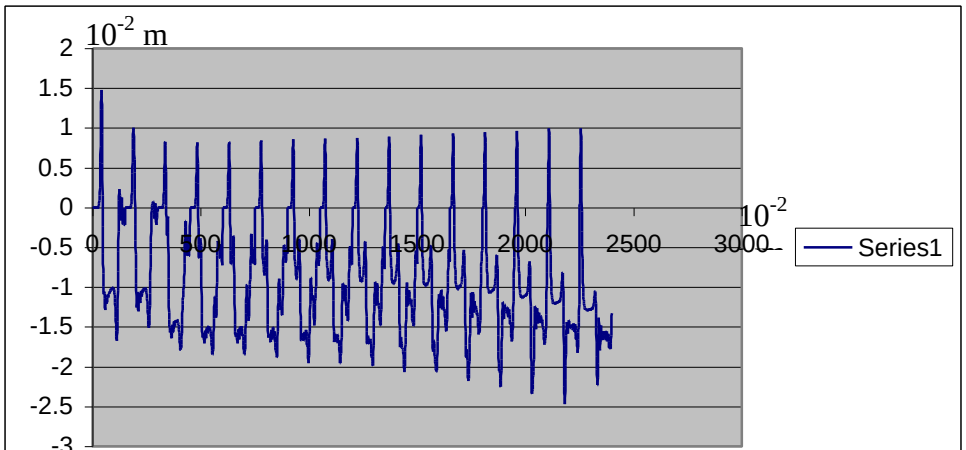
nax. 3.53 TeqvsmetsarTulianis zevidan me-6-me-10 sarTulebis gadaadgilebebi



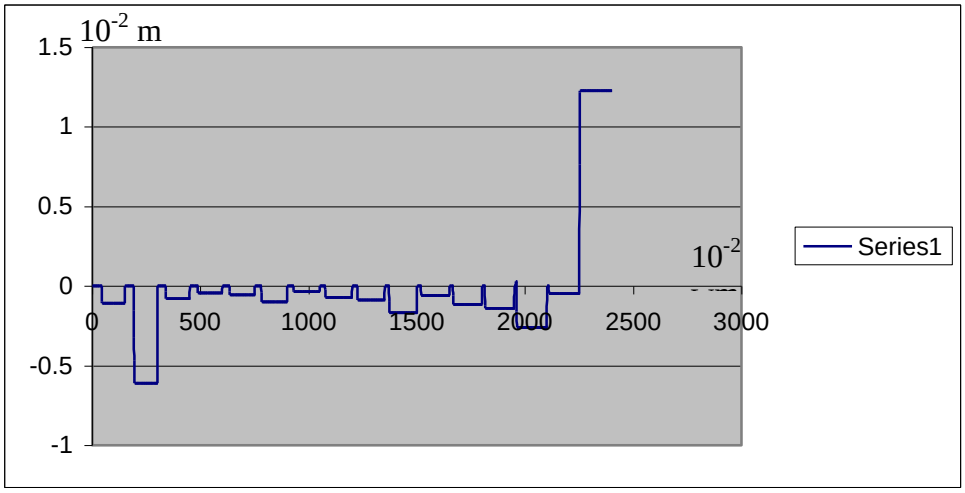
nax. 3.54 TeqvsmetsarTulianis zevidan me-11-me-16 sarTulebis gadaadgilebebi



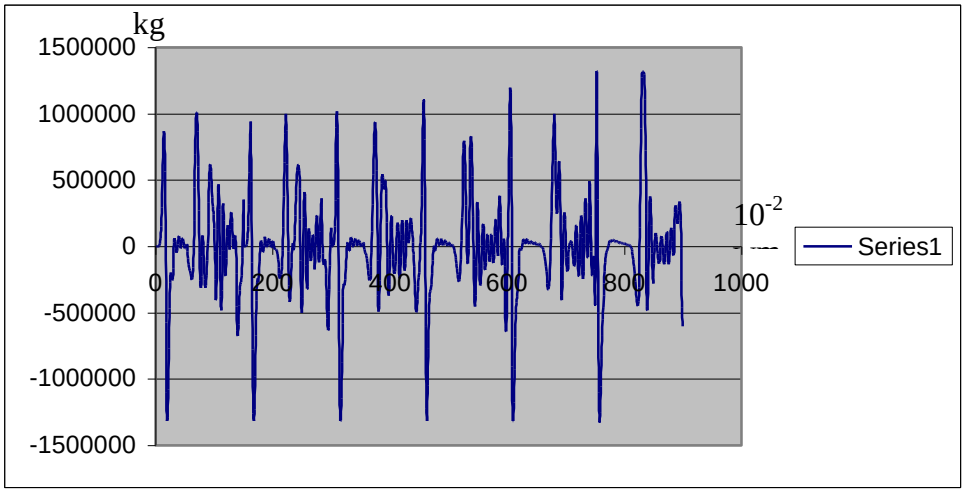
nax. 3.55 plastikuri gadaadgilebebi mudmivi sixistis SemTxvevaSi



nax. 3.56 gadaadgilebebis ganawilebis suraTi



nax. 3.57 gadaadgilebebi cvladi sixistis SemTxvevaSi



nax. 3.58 Zalebi qveda eqvs ReroSi

daskvnebi

1. impulsis moqmedebis SemTxvevaSi drekad-plastikuri sistemis gadaadgilebebi naklebia drekadi rxevisas gadaadgilebebTan SedarebiT.
2. drekad-plastikuri sistemis SemTxvevaSi impulsis moqmedebis damTavrebis Semdeg rxeva xdeba narCeni plastikuri gadaadgilebis mimarT.

3. impulsis moqmedebis SemTxvevaSi erTi da igive aCqareba SeiZleba gamowveuli iyos sxvadasxva saxis siCqariT, rasac Seesabameba gadaadgilebisa da Zalebis mniSvnelobani. aqedan gamomdinare teqtonikuri rRvevis mimdebare teritoriaze, sadac zemoqmedebas aqvs impulsis xasiaTi, seismuri daraionebis zonad mizanSewonilia aRebuli iyos ara aCqareba, aramed siCqare.
4. ganmeorebiTi dartymis SemTxvevaSi, imisgan damokidebulebiT, Tu rxevis ra momentSi xdeba ganmeorebiTi dartyma, Sedegi iqneba sxvadasxva. masalis fizikuri kanonidan gamomdinare Zala ar SeiZleba aRematebodes zRvrul mniSvnelobas, SemcirebiT ki SeiZleba mniSvnelovnad Semcirdes. gadaadgilebis SemTxvevaSi ki, romlebic ar aris SezRuduli, SeiZleba isini mniSvnelovnad gaizardos.
5. damuSavebuli algoriTmi da programa SeiZleba gamoyenebuli iqnes dempferis gavlenis Sesaswavlad. Tu dempferad gamoviyenebT dabali denadobis zRvris mqone masalas, maSin nagebobas gadaecema ara uSualod gruntis gadaadgileba, aramed misi algebruli jami dempferis zeda Sris gadadgilebasTan. ganxilul SemTxvevaSi dempferis gamoyenebam mniSvnelovnad Seamcira nagebobaSi rogorc Zalebi, aseve gadadgilebebi.
6. ormasiani sistemis SemTxvevaSi qveda masis samjer Semcirebam TiTqmis ar Secvala zeda masis maqsimaluri gadadgileba., samagierod Seamcira plastikuri gadaadgileba TiTqmis samjer, romlis mimarTac grZeldeba rxeva. qveda masis gadadgileba gaizarda ≈30%-iT, plastikuri gadaadgileba ki TiTqmis ganaxevrda. zeda masis samjer Semcirebis SemTxvevaSi, gadaadgileba izrdeba TiTqmis samjer orive masisaTvis.

   drekadi rxevis SemTxvevaSi masebis cvlileba iwvevs arsebiTad gansxvavebul Sedegebs. qveda masis Semcirebisas samjer, gadaadgileba mcirdeba zeda masisTvis ≈2.2jer, meore masisa ≈2.4-jer. Semdgomi rxeva sruldeba zeda masis samjer da ufro metad Semcirebuli amplitudiT, qveda masis ki oTxjer Semcirebuli amplitudiT. Zalebi zeda ReroSi mcirdeba 4-jer, qvedaSi 6-jer.

   zeda masis samjer SemcirebiT impulsis moqmedebis dros maqsimaluri amplituda mcirdeba samjer zeda masisTvis da 2-jer qveda masisTvis. Semdgomi rxeva xdeba pirveli masis oTxjer Semcirebuli amplitudiT, meore masis ki xuTjer Semcirebuli amplitudiT. Zalebi zeda ReroSi mcirdeba daaxloebiT orjer, qvedaSi oTxjer.
7. xuTsarTuliani nagebobis SemTxvevaSi, roca α=50 da β=8 xuTive ReroSi gvaqvs plastikuri gadaadgilebebi. maqsimaluria gadaadgileba qveda ReroSi (1.62 sm),

zeda orSi gacilebiT naklebi (0.37 sm) da kidev ufro naklebi zevidan mesame da meoTxeSi (0.11 da 0.14 sm). maqsimaluri gadaadgilebebi qveda sam ReroSi TiTqmis Tanabaria (2.3 sm), cota naklebi zeda or ReroSi (1.9 da 1.8 sm).

am sidideTa Sedareba drekad rxevebTan gvaZlevs principulad gansxvavebul Sedegebs. maqsimaluri gadaadgilebebi gvaqvs zeda or ReroSi da isini orjer aRemateba drekad-plastikur gadaadgilebebs.

8. ganmeorebiT zamoqmedebis gavlena gacilebiT mniSvnelovania drekad rxevebze drekad-plastikur rxevebTan SedarebiT.
9. igive zemoqmedebaze gamokvleuli iyo TeqvsmetsarTuliani nageboba Reroebis sixisteebis ganawilebis sxvadasxva SemTxvevaSi. roca sixiste mudmivia yvelgan, mudmivia oTx-oTx sarTulze da icvleba simaRlis mixedviT wrfivad da paraboluri kanoniT. impulsis moqmedebis procesSi gadaadgileba aRmoCnda meti meti sixistis mqone nagebobebis SemTxvevaSi.
10. dilei-algoriTmis safuZvelze amoxsnilia oscilatoris rxevis drekad-plastikuri amocana, roca Rero muSaobs mxolod Runvaze. Zala-gadaadgilebis damokidebuleba miRebulia statikuri amocanidan konsolis drekad-plastikuri Runvis Sesaxeb. gamoTvlebis Sedegad miRebulia rxevisas drekad-plastikuri ubnebis gavrcelebis suraTi. naCvenebia, rom Seyursuli masis zrda iwvevs plastikuri ubnebis gavrcelebis aris Semcirebas da rxevis periodis zrdas.

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