saqarTvelos teqnikuri universiteti

leontina galdava

statikuri cikluri datvirTebis da betonis asakis gavlena arsebuli gravitaciuli kaSxlebis simtkiceze

disertacia doqtoris akademiuri xarisxis mosapoveblad

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დისერტაციის გაცნობა შეიძლება
სტუ-ს ბიბლიოთეკასა და სტუ-ს ვებ-გვერდზე

სადისერტაციო საბჭოს
სწავლული მდივანი: პროფესორი დ. ტაბატაძე

sarCevi

naSromSi wardgenili cxrilebis nusxa:

naSromSi wardgenili naxazebis nusxa:

Sesavali

maRali betonis kaSxlebis faqtiuri istoria daiwyo huveris (yofili vlisboulderis) TaRovan-gravitaciuli kaSxlis agebiT, romlis simaRle aris 221 m. am TaRovan-gravitaciuli kaSxlis mSenebloba md. koloradoze (aSS) daiwyo 1932, xolo dasrulda 1936 wels. amis Semdeg msoflioSi sxvadasxva tipis aTasobiT betonis kaSxali aigo, maT Soris saqarTveloSic. miuxedavad didi gamocdilebisa, inJinrebisTvis dResac aris Riad darCenili sakiTxebi, romlebic am kaSxlebis muSaobas ukavSirdeba da moiTxovs gadawyvetas. amiT iqneba miRweuli is, rom SesaZlebeli gaxdeba maTi sruli saeqspluatacio potencialis dadgena.

kompiuteruli teqnologiebis swrafma ganviTarebam me-20 saukunis 60-iani wlebidan gamoiwvia betonis kaSxlebis simtkicis angariSebisadmi midgomebSi Tvisobrivi naxtomi. win wamoiwia da TandaTanobiT dominanturi poziciebi daiWira maTematikis ricxviTma, meTodebma, rogorebic aris sasazRvro elementebis meTodi da sasruli elementebis meTodi. es ukanaskneli dRes warmoadgens ZiriTad da, faqtiurad, erTaderT zust da saimedo sangariSo meTods.

miuxedavad imisa, rom sasruli elementebis meTodi efuZvneba variaciul midgomas, misi udidesi upiratesoba aris is, rom misi saSualebiT SesaZlebelia gaangariSdes kaSxali, misi fuZe da wyalsacavi, rogorc erTiani sistema. am meTodisTvis ar aris problema masalis araerTgvarovneba, anizotropuloba, agebis Tanmimdevrobis gaTvaliswineba, fizikuri arawrfivoba, bzarwarmoqmna, filtracia moculobiTi formulireba da sxv.

kaSxlebis sasruli elementebiT angariSebis pionerebi iyvnen prof. Oo. zinkeviCi, prof. r. klafi, prof. e. uilsoni, prof. liam fini da sxv. maTi Rvawli udidesia kaSxlebis analizis dRevandeli maRali donis miRwevaSi. saqarTveloSi aRniSnulma meTodma kaSxlebis angariSebSi fexi moikida 70-ani wlebidan (a. mowoneliZe, m. yalabegiSvili, b.abulaZe).

sadisertacio naSromi exeba arsebuli da “gadaRlili” betonis gravitaciuli kaSxlebis daZabul-deformirebuli mdgomareobis angariSs ori mniSvnelovani faqtoris – masalis (betonis) asakisa da neli statikuri cikluri datvirTvebis gaTvaliswinebiT. am ukanasknelSi igulisxmeba wyalsacavis avseba-daclis ciklebi, romelTa raodenobac regulirebis saxezea damokidebuli. am faqtorebis gaTvaliswineba saSualebas iZleva dadgindes nagebobis simtkicis resursebi.

naSromi warmodgenilia 131 gverdze da Sedgeba Sesavlis, oTxi Tavis, daskvnebisa da citirebuli literaturis siisgan. teqstSi CarTulia 76 naxazi da 18 cxrili.

1. gravitaciuli kaSxlebis daZabul-deformirebuli mdgomareobis saangariSo meTodebis retrospeqtuli mimoxilva

1.1. klasikuri analizuri meTodebi

betonis kaSxlebis daZabul-deformirebuli mdgomareobis yvelaze adreuli analizuri saangariSo meTodi efuZvneba daSvebas, romlis Tanaxmadac kaSxali warmodgens kldovan fuZeSi xistad Camagrebul Zels, romelic ganicdis ori saxis deformacias brtyeli amocanis farglebSi: gaWimva-kumSvis da Runvis. es meTodi CvenSi cnobilia sami dasaxelebiT: masalaTa gamZleobis meTodi, araTanabari kumSvis meTodi da elementaruli meTodi [1]. inglisurenovan literaturaSi mas moixsenieben rogorc gravitaciul meTods.

am meTodis mixedviT ganixileba kaSxlis horizontaluri kveTebi (nax. 1.1) da iangariSeba vertikaluri normaluri Zabvebi σ_y sadawneo da udawneo waxnagebze Semdegi gamosaxulebidan:

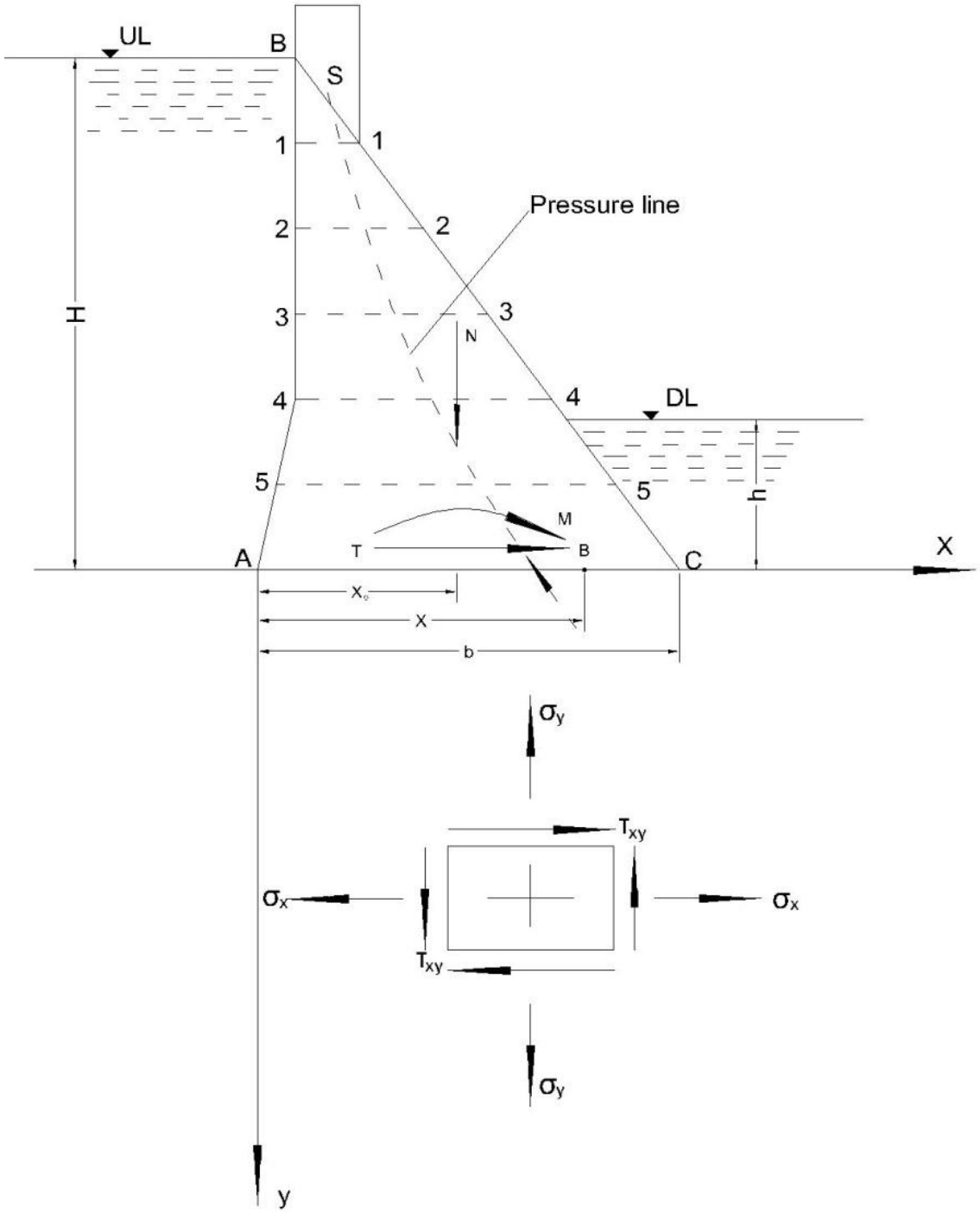
$$\sigma_y = \frac{N}{F} \mp \frac{M}{W} \qquad (1.1)$$

sadac N aris gansaxilveli kveTis zemoT moqmedi yvela vertikaluri Zalis jami; F - gansaxilveli kveTis farTobi ($F = b*1$, b – seqciis sigane); M - gansaxilveli kveTis zemoT moqmedi yvela Zalis mRunavi momentebis jami kveTis simZimis centris mimarT; W – kveTis winaRobis momenti ($W=\frac{b^2}{6}$).

σ_y Zabvis gansazRvris Semdeg iangariSeba horizontaluri normaluri Zabva σ_x da mxebi τ Zabvebi gansaxilveli wertilis doneze elementaruli prizmis amoWrisa da misi wonasworobis pirobebis ganxilvis Sedegad. amis Semdeg cnobili formulebiT iangariSeba mTavari Zabvebi da maTi mimarTulebebi igive wertilebSi.

aRsaniSnavia is, rom aRwerili meTodi dRemde warmatebiT gamoiyeneba dabali kaSxlebis gaangariSebisa. am meTods aqvs Seddegi uaryofiTi mxareebi:

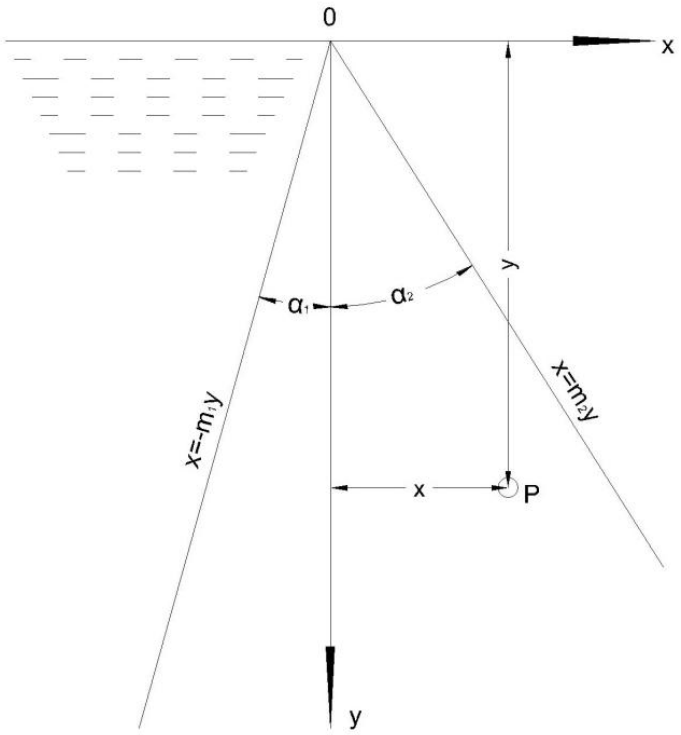
1. mas ar SeuZlia nagebobis daZabul-deformirebul mdgomareobaze fuZis gavlenis mxedvelobaSi miReba. es gavlena ki mniSvnelovania fuZidan daaxloebiT 1/3 – 1/4 ¼ simaRleze;



nax. 1.1: araTanabari kumSvis meTodiT gravitaciuli kaSxlis saangariSo sqema.

2. mas ar SeuZlia Zabvebis gansazRvra kaSxlis tanSi. igulisxmeba, rom Zabvebi masSi nawildeba swori xazis kanoniT.

elementaruli meTodis paralelurad damuSavda e.w. drekadobis Teoriis meTodi, romelic amocanas ganixilavs brtyeli deformaciis farglebSi [1]. nagebobaze moqmedebs sakuTari wona da hidrostatikuri dawneva. ganixileba usasrulo sigrZis samkuTxa profile (nax. 1.2). Zabvebi gamoisaxeba rogorc koordinatebis wrfivi funqciebi Semdegi saxiT:



nax. 1.2: drekadobis Teoriis meTodiT gravitaciuli kaSxlis saangariSo sqema.

$$\begin{aligned} \sigma_x &= a_1 x + b_1 y \\ \sigma_y &= a_2 x + b_2 y \\ \tau &= a_3 x + b_3 y \end{aligned} \qquad (1.2)$$

a da *b* koeficientebi ganisazRvrebian sasazRvro pirobebidan kaSxlis waxnagebze (wonasworobis pirobebi). isini arian funqciebi betonisa da wylis moculobiTi wonebis, agreTve sadawneo da udawneo waxnagebis daxrebis γ, γ_1, m_1 da m_2:

$$(\sigma_x, \sigma_y, \tau) = f(\gamma, \gamma_1, m_1, m_2) \tag{1.3}$$

Zabvis komponentebis gansazRvris Semdeg gaiangariSeba mTavari Zabvebi da maTi mimarTulebebi gansaxilveli kveTis nebismier wertilSi.

1.2. sakontaqto amocanebi - koWuri meTodi da naxevrad analizuri meTodi

klasikuri analizuri meTodebi ver iTvaliswineben fuZis gavlenas kaSxlis daZabul-deformirebul mdgomareobaze. koWuri meTodi, romelic miekuTvneba e.w. sakontaqto amocanebis klass, garkveulwilad asworebs am xarvezs da iZleva SesaZleblobas ganisazRvros gadaadgilebebi, deformaciebi da Zabvebi kaSxlisa da kldovani fuZis sakontaqto zedapirze [2].

koWuri meTodis mixedviT pirvel etapze gaiangariSeba fuZeSi xistad Camagrebuli samkuTxa profilis mqone kaSxali. ixsneba kaSxlis gaRunuli RerZis diferencialuri gantoleba

$$\frac{E_c * I(y)}{1-\nu_c^2} * \frac{d^2u}{dy^2} = -M(y), \tag{1.4}$$

sadac E_c da ν_c Sesabamisad, kaSxlis masalis (betoni) drekadobis moduli da puasonis koeficientia; $I(y)$ - kaSxlis gansaxilveli horizontaluri kveTis inerciis momenti, misi simZimis centrze gamavali RerZis mimarT; $M(y)$ - mRunavi momenti kaSxlis sakuTari wonisa da hidrostatikuri wnevisagan kveTis simZimis centris mimarT; u – kaSxlis kveTebis simZimis centrebis horizontaluri gadaadgilebebi.

zemod moyvanili diferencialuri gantolebidan ganisazRvreba $\frac{d^2u}{dy^2}$

Semdeg ZabvaTa wrfivi ganawilebis kanonidan gamomdinare ganisazRvreba Zabvis komponentebi. viciT ra ZabvaTa komponentebis mniSvnelobani, fardobiTi deformaciebisaTvis hukis ganzogadoebuli kanonis da koSis gantolebebis gamoyenebiT vpoulobT kaSxlis RerZis wertilebis gadaadgilebaTa komponentebs U_d da V_d .

angariSebis meore etapze sakontaqto zedapirze saZiebeli σ_y da τ reaqtiuli Zabvebi ganisazRvreba wonasworobisa da agreTve im pirobebidan, romlebic gamoisaxebian igiveobebiT:

$$\begin{aligned} U_d &\equiv U_f \\ V_d &\equiv V_f \end{aligned} \tag{1.5}$$

sadac U_f da V_f Sesabamisad, fuZis zedapiris wertilebis horizontaluri da vertikaluri gadaadgilebebia, romlebic Caiwereba [3]-Si moyvanili klasikuri naxevarsibrtyis amocanis formiT da Cebisevis polinomebis gamoyenebiT [2]. gamosaxulebidan (1.5) da wonasworobis pirobebidan ganisazRvrebian ucnobi koeficientebi.

gvecodineba ra koeficientTa mniSvnelobebi, σ_y da τ kontaqturi Zabvebi ganisazRvreba Semdegi formulebiT:

$$\sigma_y = \frac{1}{\sqrt{1-x_1^2}}\left[A_0 + A_1 x_1 + A_2\left(2x_1^2 - 1\right)\right] \tag{1.6}$$

$$\tau = \frac{1}{\sqrt{1-x_1^2}}\left[B_0 + B_1 x_1 + B_2\left(2x_1^2 - 1\right)\right] \tag{1.7}$$

sadac A_0, A_1, A_2, B_0, B_1 da B_2 gamosaxulebidan (1.5) da wonasworobis pirobebidan gansazRvruli koeficientebia.

sakontaqto amocanebis klass SeiZleba mivakuTvnoT e.w. naxevradanalizuri meTodic [4]. am meTodis arsi imaSi mdgomareobs, rom saangariSo sqemidan “kaSxali-fuZe” vardeba fuZe da misi gavlena kaSxlis daZabul-deformirebul mdgomareobaze icvleba garkveuli kanoniT ganawilebuli ZabvebiT, romlebic kaSxlis ZirSi miiReba rogorc sasazRvro pirobebi da kaSxali iangariSeba sasruli elementebis meTodiT. amocana or etapad ixsneba. pirvel etapze koWuri meTodiT iangariSeba normaluri Zabvebi sakontaqto zedapirze, xolo meore etapze iangariSeba uSualod kaSxali sasruli elementebis meTodiT.

1.3. sasruli elementebis meTodiT gravitaciuli kaSxlebis simtkiceze angariSi horizontaluri SreebiT TandaTanobiTi agebis gaTvaliswinebiT

sasruli elementebis meTodis erT-erTi umniSvnelovanisi upiratesoba gamoixateba imaSi, rom iteraciuli ciklebis saSualebiT SesaZlebelia masalebis meqanikuri maxasiaTeblebis cvlilebebis gaTvaliswineba daZabul-deformirebuli mdgomareobis mixedviT. faqtiurad, am SemTxvevaSi, saangariSo sistema ganixileba rogorc arawrfivi drekadi are. sem-is am upiratesobaze dayrdnobiT SesaZlebelia kaSxali gaangariSebuli iqnas misi TandaTanobiT, horizontalur Sreebad agebis, anu mSeneblobis grafikis da procesis mxedvelobaSi miRebiT [5]. angariSebisadmi aseTi midgoma saSualebas iZleva gaTvaliswinebuli iqnas agebis realuri procesi da misi gavlena dasrulebuli kaSxlis Camoyalibebul daZabul-deformirebul mdgomareobaze. garda amisa, es midgoma gansakuTrebiT mniSvnelovania datkepnilbetoniani kaSxlebis gaangariSebisas, radgan is srulad Seesabameba am tipis kaSxlebis fenobrivd datkepvnis sqemas.

am meTodis realizebisTvis aucilebelia betonis kumSvis $\sigma - \varepsilon$ diagramis arseboba da misi warmodgena wrfivad texili mrudis saxiT TiToeuli texilisaTvis (monakveTisTvis) drekadobis modulis E_i ($i = 1,2,3,\ldots k$) mudmivi mniSvnelobis miniWebiT (nax. 1.3).

zemodTqmulidan gamomdinare E_i–is cvlileba SeiZleba warmodgenili iqna Semdegi xarisxobrivi damokidebulebiT:

$$E_i = E_{in}\left(\frac{\sigma_0}{\sigma_i}\right)^{n_i} \tag{1.8}$$

sadac:

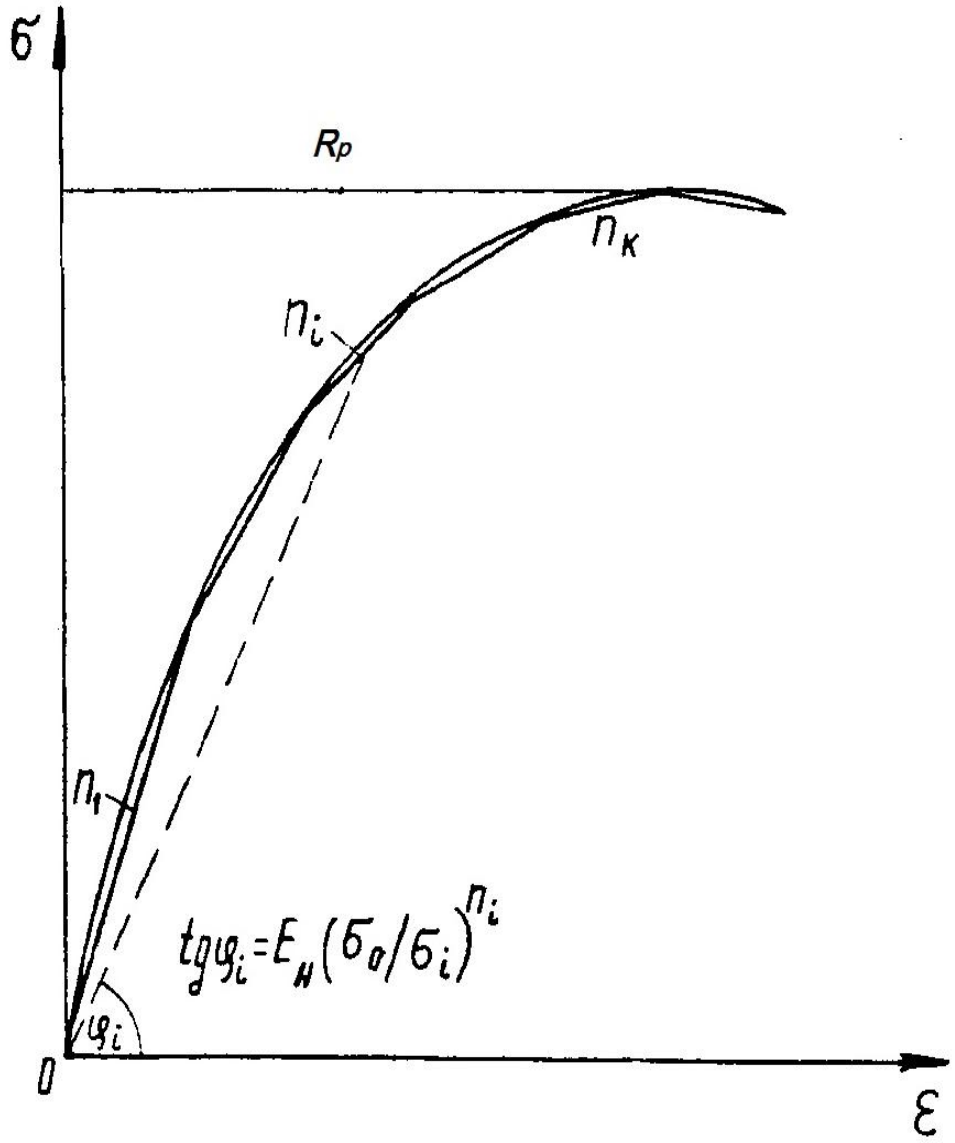
E_{in} - sawyisi drekadobis moduli

$\sigma_0 = 1$ mpa - formaluri sidide

σ_i - maqsimaluri mkumSavi mTavari Zabva, romelic Seesabameba *i* –uri monakvwTis centrs

n_i - *i*–uri monakveTis simrudis maxasiaTebeli $(0 \angle n_i \angle 1)$.

wrfivad texili diagramis interpolireba $S(x)$ splain-funqciis saSualebiT [6] Zalian mosaxerexebelia sasrulelementian sqemaSi iteraciuli angariSebisas [7].



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nax. 1.3: betonis kumSvis pirobiTi diagramis warmodgena wrfivad texili mrudis saxiT.

gravitaciuli kaSxlebis daZabul-deformirebuli mdgomareobis angariSis meTodika pirdapir aris dakavSirebuli amocanis fizikurad arawrfiv formulirebasTan, rac gulisxmobs miRebuli Sedegebis superpozicias (pirdapir dajamebas).

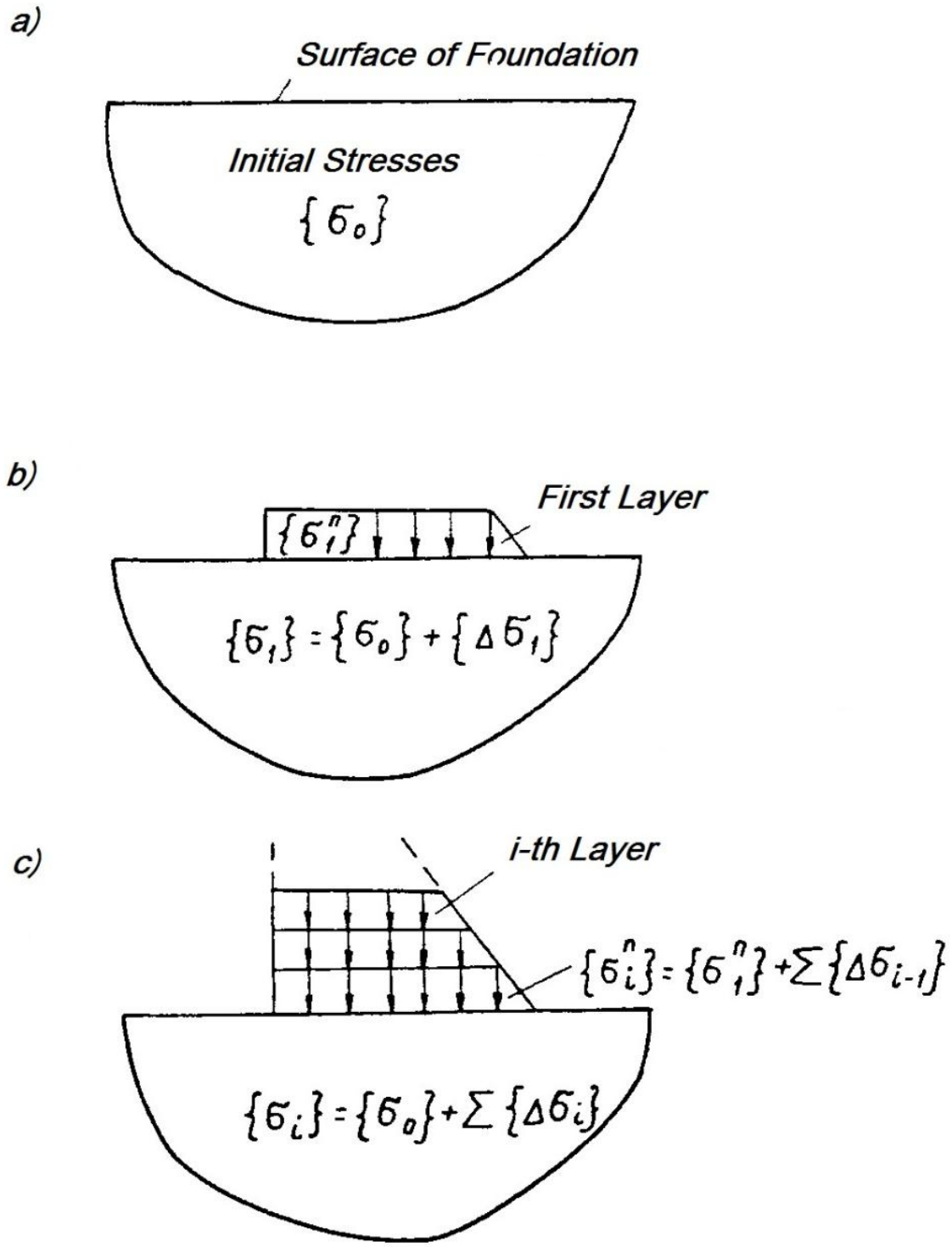
angariSebis saangariSo sqema mocemulia nax. 1.4-ze, xolo maTi Tanmimdevroba ki aseTia. betonis pirveli fenis dadebamde, kldovan fuZeSi ukve Camoyalibebulia istoriuli daZabul-deformirebuli mdgomareoba (nax. 1.4a). es mdgomareoba SeiZleba gamoisaxos $\{\sigma_0\}$ matrica-veqtoris saSualebiT. pirveli fenis dadebis Semdeg (nax. 1.4b), fuZeSi Camoyalibdeba $\{\Delta\sigma_1\}$ Zabvebi. meore fenis pirvelze dadebis Semdeg, analogiurad moxdeba Zabvebis gadanawileba, rogorc es moxda pirveli fenis dadebis Semdeg da a.S. bolo fenis dadebis Semdeg Camoyalibdeba sistema "kaSxali – fuZis" saboloo daZabul-deformirebuli mdgomareoba. swored kuburi splain-funqciiT interpolirebuli betonis kumSvis diagram zustad miesadageba zemod aRweril saangariSo sqemas. misi saSualebiT angariSebis yvela etapze zustdeba sixistis ganzogadoebuli matrica, romelic sasruli elementebis meTodis ganmsazRvreli wevria.

rasakvirvelia yoveli axali fenis dadebis Semdeg saangariSo sqemis kvanZebis koordinatebi icvleba Semdegi kanonzomierebiT:

$$\begin{aligned} x_i &= x_{i-1} + \Delta x_{i-1} \\ y_i &= y_{i-1} + \Delta y_{i-1} \end{aligned} \tag{1.9}$$

sadac x_i, y_i - kvanZebis koordinatebi kaSxlis agebis *i*–ur etapze;

$$\begin{aligned} \Delta x_{i-1} &= u_{i-1} \\ \Delta y_{i-1} &= v_{i-1} \end{aligned} \tag{1.10}$$



nax. 1.4: gravitaciuli kaSxlis saangariSo sqema fenobrivad agebis mxedvelobaSi miRebiT.

sadac $I u_{i-1}, v_{i-1}$ aris kvanZebis gadaadgilebebi sasruli elementebis gantolebis amoxsnis Sedegad mSeneblobis (i-1) etapze. angariSebis sawyis etapze

$$\Delta x_{i-1} = \Delta y_{i-1} = 0$$

zemodmoyvanili sqemis mixedviT miRebuli Sedegebi SeiZleba gaanalizdes pirveli jgufis zRvruli mdgomareobis meTodiT.

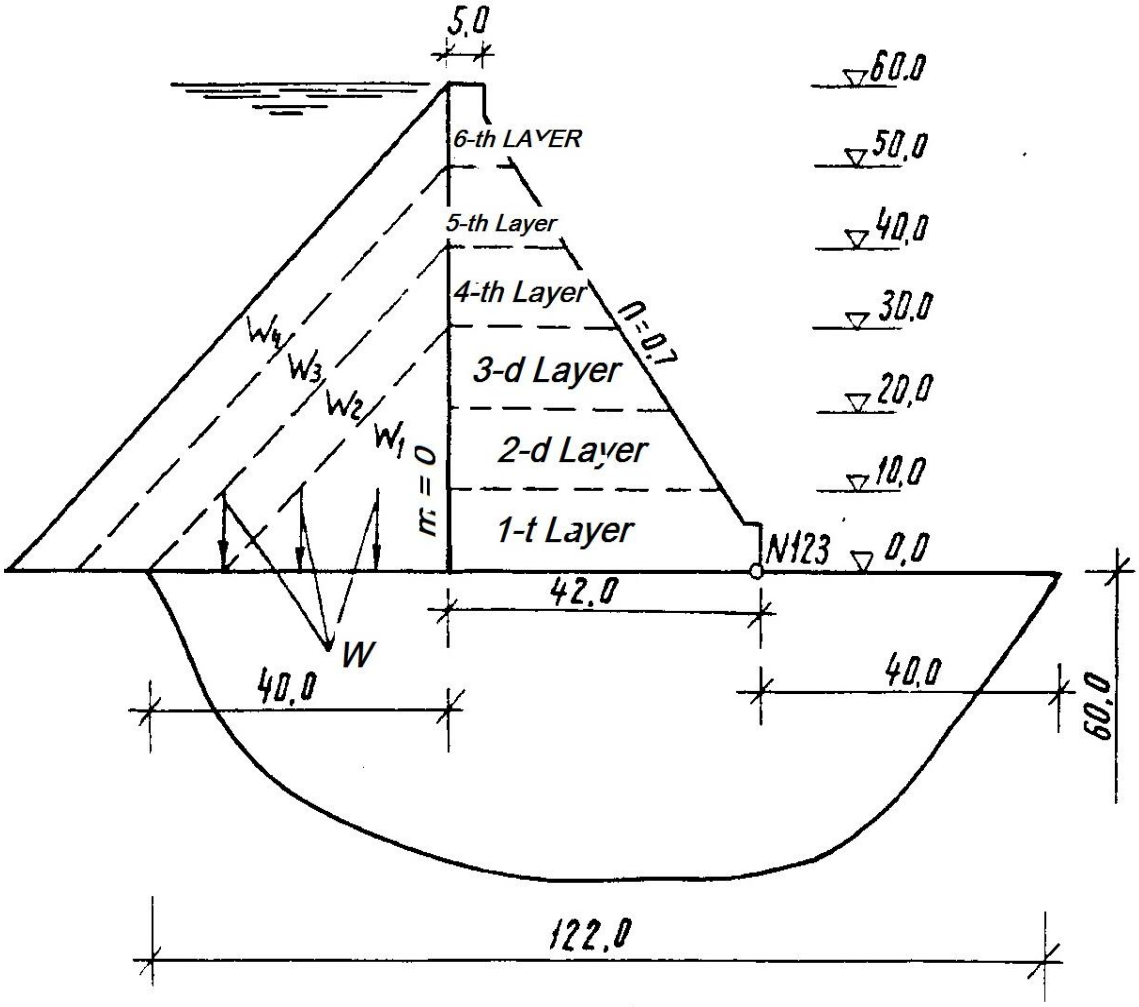
qvemoT moyvanilia sistema "pirobiTi gravitaciuli kaSxali – erTgvarovani kldovani fuZis" aRniSnuli midgomiT gaangariSebis Sedegebi.

sangariSo sqema dayofili aris 411 samkuTxovan elementad, romlebic SeerTebulia 243 kvanZSi. saangariSo sqema mocemulia nax. 1.5 – ze.

sistemis meqanikuri maxasiaTeblebi Semdegia: fuZis drekadobis moduli $E_f = 8250$ mpa, puasonis koeficienti $\nu_f = 0.18$. betonis sawyisi drekadobis moduli $E_{in.c} = 25000$ mpa, puasonis koeficienti $\nu_c = 0.17$.

CaiTvala, rom kaSxali Sendeba eqvs fenad. ganxiluli iqna Zalovani faqtorebis zemoqmedebis sami SemTxveva:

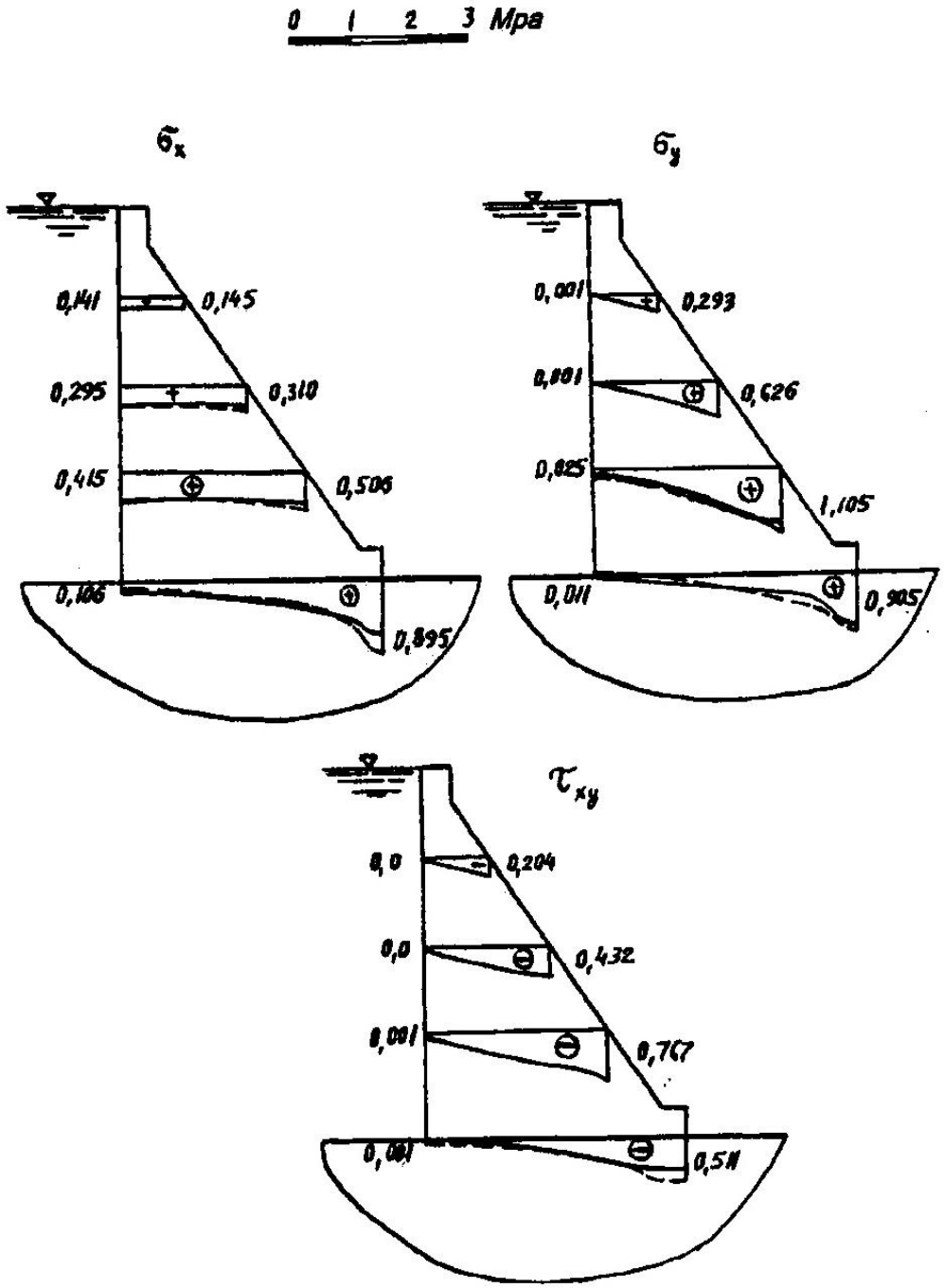
1. kaSxalze moqmedebs fenebis dadebis Sedegad TandaTanobiT zrdadi sakuTari wona;
2. kaSxalze moqmedebs fenebis dadebis Sedegad TandaTanobiT zrdadi sakuTari wona hidrostatikuri dawneva sadawneo waxnagze kaSxlis simaRlis naxevridan;
3. kaSxalze moqmedebs fenebis dadebis Sedegad TandaTanobiT zrdadi sakuTari wona, hidrostatikuri dawneva sadawneo waxnagze kaSxlis simaRlis naxevridan da vertikaluri hidrostatikuri dawneva wyalsacavis fuZeze.



nax. 1.5: sistema "pirobiTi gravitaciuli kaSxali – erTgvarovani kldovani fuZis" sangariSo sqema fenobrivi agebis mxedvelobaSi miRebiT.

nax. 1.6 – ze mocemulia mocemulia σ_x, σ_y da τ Zabvebis ganawilebis epiurebi dasrulebuli mSeneblobis SemTxvevaSi, rodesac kaSxalze moqmedebs mxolod sakuTari wona da hidrostatikuri dawneva sadawneo waxnagze.

nax. 1.7. – ze mocemulia σ_y Zabvebis ganawilebis epiurebi horizontalur kveTebSi mesame sangariSo SemTxvevis dros



nax. 1.6: Zabvebis ganawilebis epiurebi horizontalur kveTebSi.

———— agebis Tanmimdevrobis gauTvaliswineblad;
---------- agebis Tanmimdevrobis gaTvaliswinebiT.

damatebiT moqmedebs vertikaluri hidrostatikuri wneva wyalsacavis fuZeze.

rogorc Sedegebis analizma gviCvena, wyalsacavis fuZeze vertikaluri hidrostatikuri dawneva garkveulwilad amsubuqebs sadawneo waxnagis muSaobis pirobebs da praqtikulad gamoricxavs gamWimavi Zabvebis warmoSobas, maSin rodesac udawneo waxnagze ikveTeba mkumSavi Zabvebis Semcirebis tendencia.

cnobilia, rom kaSxlis simtkicis Sesafaseblad gamoiyeneba e.w. usafrTxoebis ganzogadoebuli koeficienti K_g^r. is warmoadgens rRveviswina Zalovani faqtoris (magaliTad, mTavari Zabva) N_f fardobas dasaSveb Zalovan faqtorTan $[N]$.

$$K_g^r = \frac{N_{m.f.}}{[N]} \tag{1.11}$$

es gamosaxuleba srulad ver aRwers kaSxlis saimedobas. ufro mizanSewonilia Semdegi formulis gamoyeneba:

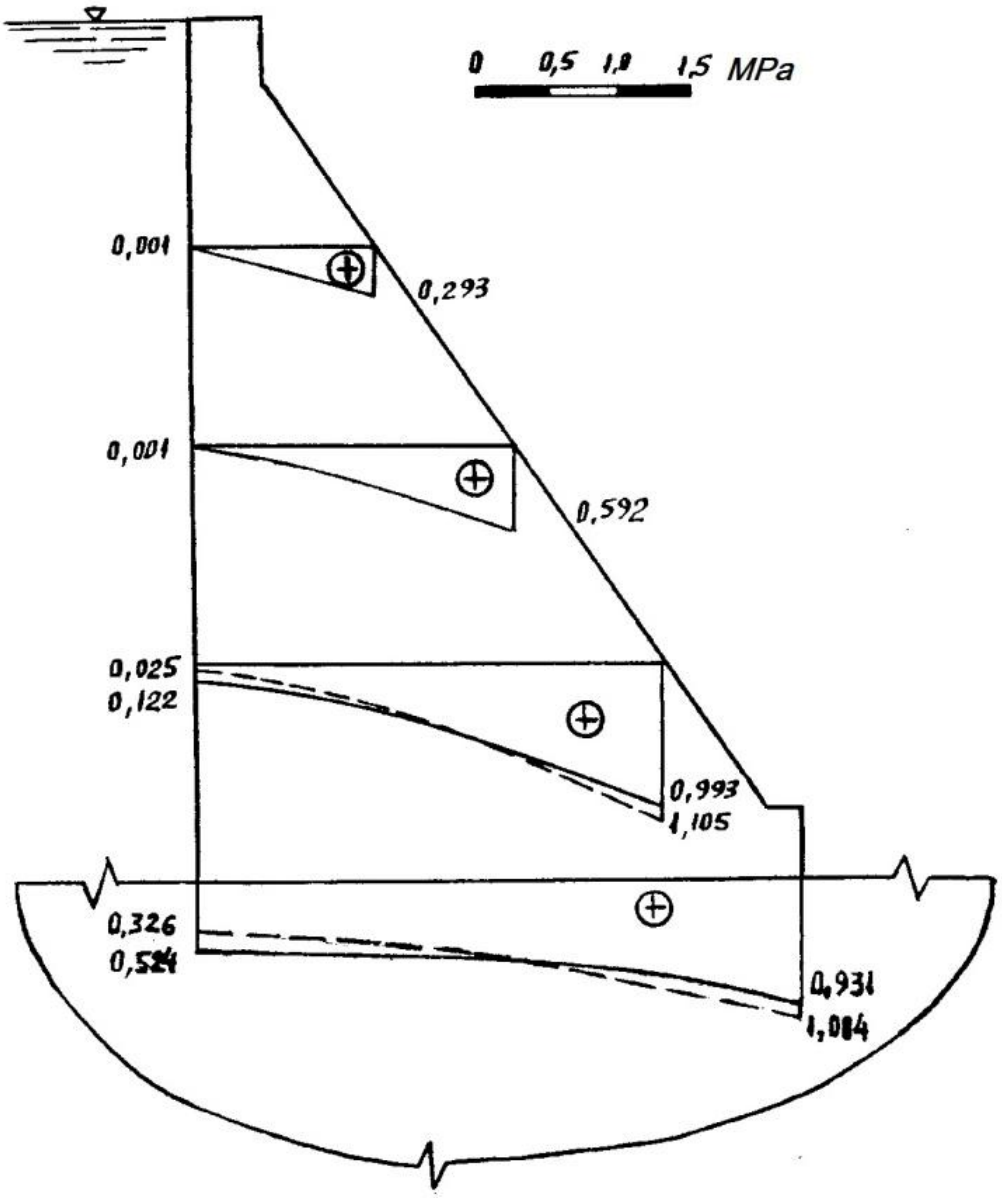
$$\sigma_{1av}^p = \frac{\Sigma\sigma_1^p}{n_1} \tag{1.12}$$

sadac:

$\Sigma\sigma_1^p$ - saangariSo sqemaSi Semavali kaSxlis yvela sakvanZo weryilSi mTavari mkumSavi Zabvebis jami;

n_1 - im kvanZebis raodenoba, sadac mxolod mkumSavi σ_1^p Zabvebia dafiqsirebuli.

kaSxlis saproeqto variantis angariSis Semdeg iangariSeba misi ufro ekonomikuri (Seviwroebuli) profilebi manmade, sanam σ_1 ar gautoldeba R_p - s. am SemTxvevaSi iangariSeba mTavari mkumSavi Zabvebis saSualo mniSvneloba:



nax. 1.7: σ_y ***Zabvebis ganawilebis epiurebi horizontalur kveTebSi.***

——— wyalsacais fskerze vertikaluri hidrostatikuri dawnevis gaTvaliswinebiT;

---------- am dawnevis gauTvaliswineblad.

$$\sigma_{1av} = \frac{\Sigma\sigma_1}{n_2} \tag{1.13}$$

sadac $\Sigma\sigma_1$ - kaSxlis ekonomikur profilSi mTavari mkumSavi Zabvebis jami;

n_2 - im kvanZebis raodenoba, romlebSic fiqsirdeba σ_1 mkumSavi Zabvebi.

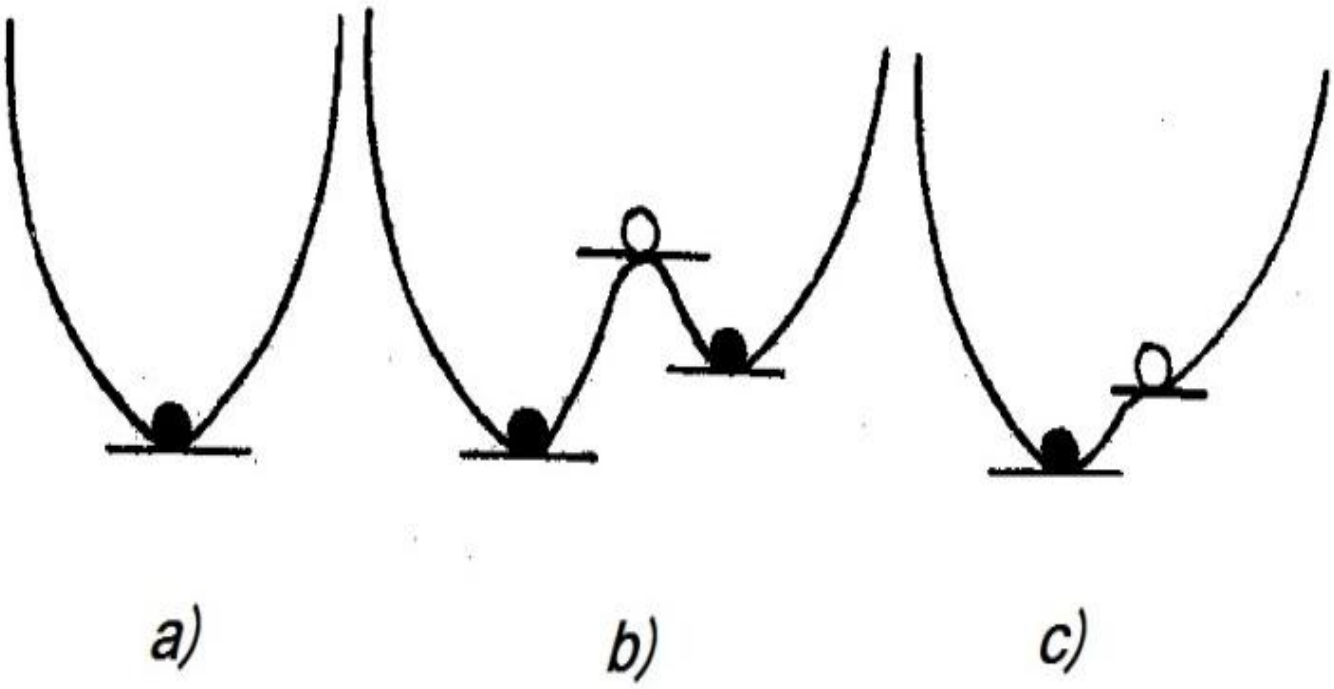
gvaqvs ra σ_{1av} da σ_1^p mniSvnelobebi, usafrTxoebis koeficienti SeiZleba gangariSdes Semdegi gamosaxulebidan:

$$K_l = \frac{\sigma_{1av}}{\sigma_1^p} \tag{1.14}$$

1.4. gravitaciuli kaSxlebis mdgradobis da simtkicis analizi katastrofebis Teoriis poziciebidan

tradiciuli, deterministuli midgomis Tanaxmad, imisaTvis, rom nagebobebSi davinaxoT mimdinare procesebi, saWiroa pirveli an meore rigis diferencialuri gantolebebis sistemebis amoxsna. miuxedavad amisa, daZabul-deformirebuli mdgomareobis cvlilebebis dinamikuri procesebi xSirad naxtomiseburad viTardeba. naxtomebi ki xdeba erTi Tvisobrivi mdgomareobidan meoreSi gadasvlis dros. magaliTad, kaSxlis mdgradi mdgomareobidan mdgradobis dakargva, stabiluri daZabuli mdgomareobidan rRvevis fazaSi gadasvla da a.S. Tvisobrivi mdgomareobis am uecar cvlilebebs kargad aRwers maTematikuri modelirebis erT-erTi saintereso forma – katastrofebis Teoria. misi arsi SeiZleba mokled Semdegnairad avxsnaT nax. 1.8-is mixedviT.

am naxazidan Cans, rom sistemis stabiluri wonasworoba Seesabameva raRac $V(x)$ funqciis minimumebs, xolo arastabiluri wonasworoba - $V(x)$ funqciis maqsimumebs. swored am ukanaskneli darRvevis SemTxvevaSi xdeba e.w. “katastrofa”, anu erTi Tvisobrivi mdgomareobidan meoreSi gadasvla.

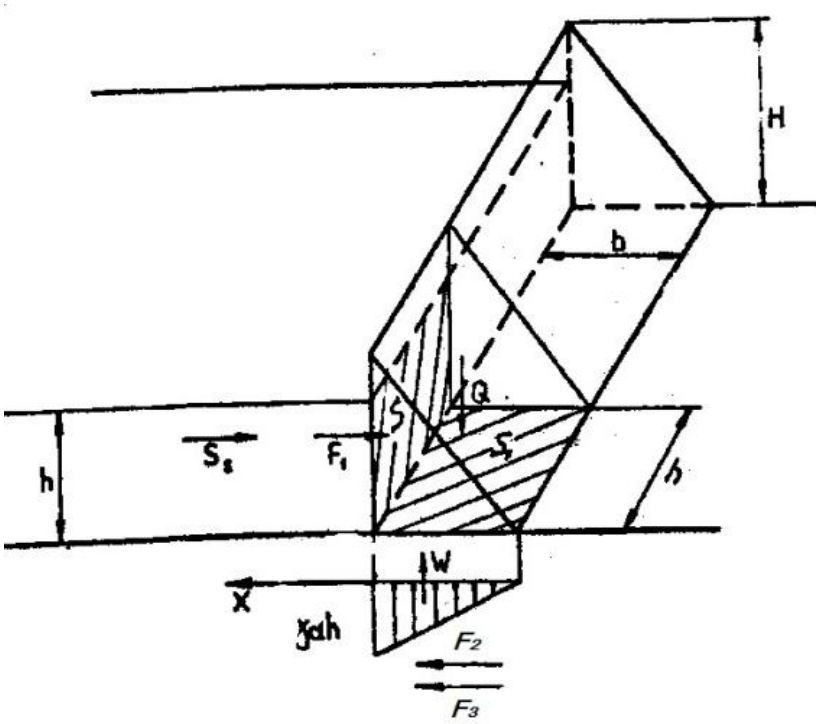


nax. 1.8: sistemis stabiluri wonasworobis sqema.

gravitaciuli kaSxlebis mdgradobis analizi katastrofebis Teoriaze dayrdnobiT, mocemulia [8]-Si.

ganvixiloT gravitaciuli kaSxlis mdgradoba hidrostatikuri dawnevisa da seismuri zemoqmedebis SemTxvevaSi. davuSvaT ori SesaZlo versia aRniSnuli problebis amosaxsnelad.

pirvel versiaSi davuSvaT, rom unda SevarCioT kaSxlis ori parametric: sigane fuZeSi (*b*) da simaRle (*H*), romlebmac unda uzrunvelyon kaSxlis mdgradoba avsebuli wyalsacavis SemTxvevaSi seismuri zemoqmedebis dros. am SemTxvevaSi mdgradobis dakargvad unda CavTvaloT wyalsacavSi wylis *h* siRrmis naxtomisebri cvlileba. davuSvaT *h* aris fuZis siganis nawili (nax. 1.9)



nax. 1.9: kaSxlis rRvevis sqema naxtomisebri sqema wylis h siRrmis naxtomisebri cvlilebisas.

hidrostatikuri wnevis intensivoba aris

$$P(h) = \gamma h, \tag{1.15}$$

sadac γ aris wylis moculobiTi wona.

hidrostatikuri dawneva sadawneo waxnagis garkveul *S* farTze aris:

$$F_1 = \frac{2}{3}\gamma h^3 \tag{1.16}$$

SeWidulobis Zala aris:

$$F_2 = cS_p = cbh \tag{1.17}$$

xaxunis Zala:

$$F_3 = f(Q - W) \tag{1.18}$$

sadac *Q* aris kaSxlis wona

$$Q = \gamma_1 V = 0.5\gamma_1 bHh \tag{1.19}$$

γ_1 aris betonis xvedriTi wona, W - filtraciuli dawneva kaSxlis fuZeze

$$W = 0.5\gamma\alpha bh^2 \tag{1.20}$$

V aris kaSxlis nawilis moculoba (h siganis farglebSi); α - filtraciuli wnevis Semamcirebeli koeficienti. aqedan gamomdinare, xaxunis Zala toli iqneba:

$$F_3 = f(0.5\gamma_1 bHh - 0.5\gamma\alpha bh^2) \tag{1.21}$$

pirveli miaxloebiT, seismomedegobis statikuri Teoriis mixedviT, seismuri Zalis sidide gamoisaxeba Semdegnairad:

$$S_s = K_s Q \tag{1.22}$$

sadac K_s aris seismurobis koeficienti.

sistemis potencialuri energiis kritikuli wertilebis zedapiris gantoleba Caiwereba Semdegnairad:

$$F_1 - (F_2 + F_3) + S_s = 0 \tag{1.23}$$

an Semdegnairad:

$$h^3 + \frac{3}{4} f\alpha bh^2 - \frac{3}{4}\frac{2c + f\gamma_1 H}{\gamma} bh + \frac{3}{2}\frac{k_s Q}{\gamma} = 0 \tag{1.24}$$

davuSvaT, rom

$$P_1 = \frac{3}{4} f\alpha b; \qquad P_2 = -\frac{3}{4}\frac{2c + f\gamma_1 H}{\gamma} b \quad \text{da} \quad P_3 = \frac{3}{4}\frac{k_s Q}{\gamma}$$

maSin gantoleba (1.24) miiRebs Semdeg formas:

$$h^3 + P_1 h^2 + P_2 h + P_3 = 0 \qquad (1.25)$$

es gantoleba ar aris mdgradi $P_1 h^2$ wevris gamo.

gamoviyenoT axali koordinatTa sistema da davuSvaT, rom $h = y - \frac{P_1}{3}$. maSin gantoleba (1.25)-s eqneba Semdegi saxe:

$$y^3 + (P_2 - \frac{1}{3}P_1^2)y + (P_3 - \frac{P_1 P_2}{3} + \frac{2}{27}P_1^3) = 0 \qquad (1.26)$$

CavsvaT

$$c_1 = P_2 - \frac{1}{3}P_1^2 \qquad \text{da} \qquad c_2 = (P_1 - \frac{PP_2}{3} + \frac{2}{27}P_1^3),$$

maSin gantoleba (1.26) miiRebs Semdeg formas:

$$y^3 + c_1 y + c_2 = 0 \qquad (1.27)$$

es gantoleba mdgradia da amitom katastrofebis jgufis gantoleba iqneba:

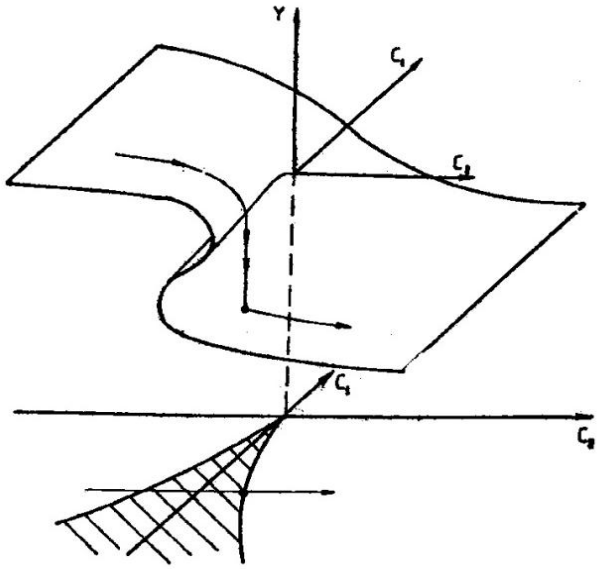
$$4c_1^3 + 27c_2^2 = 0 \qquad (1.28)$$

radganac c_2 Seicavs P_3-s mudmiv mniSvnelobas, seismuri datvirTvebis cvalebadoba iwvevs mxolod c_2-is cvalebadobas. Tu es cvlileba iseTia, rom fazis traeqtoria kveTs daStrixul farTs (nax. 1.10) Signidan gareT, moxdeba naxtomi sistemaSi, romelic Seesabameba c_2-is cvlilebas zemodan qveda (nulovan) doneze, e.i. moxdeba kaSxlis Zvra fuZeSi.

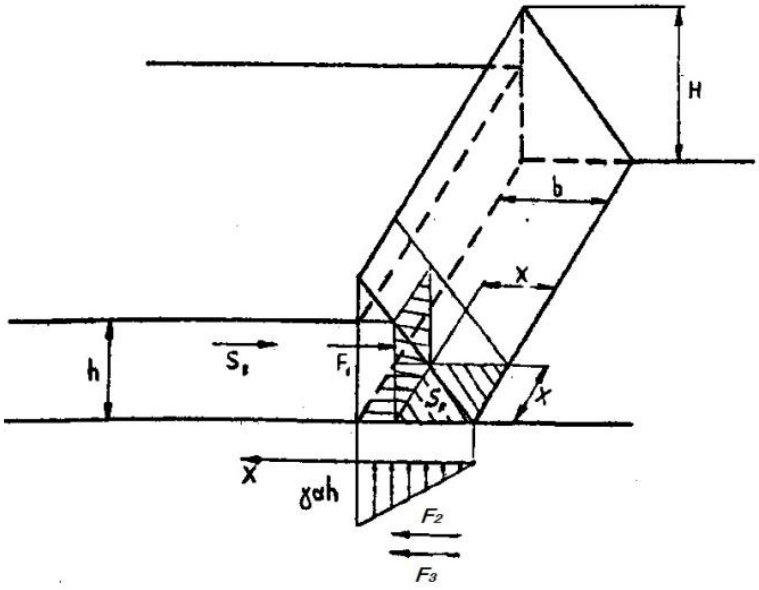
meore versiaSi daSvebulia, rom wylis siRrme *h* aris kontrolirebadi parametric. *H* da *b* aris mudmivi sidideebi. amocanis amoxsnis mizania davadginoT *h* –is da seismuri Zalis ra sidideebis dros gaCndeba bzari fuZeSi.

vuSvebT, rom pirveli bzari gaCena Seesabameba *x* sidideebis naxtoms zemodan qveda (nulovan) doneze.

davuSvaT, rom bzaris sigane tolia (*b-x)* –is (nax. 1.11)



nax. 1.10: naxtomis sqema sistemaSi – fazis traeqtoria kveTs daStrixul farTs.



nax. 1.11: bzaris gaCenis sqema kaSxlis fuZeSi.

davuSvaT, rom wylis siRrme aris *h* da $x*x$ - kaSxlis fuZis farTobis nawili. hidrostatikuri dawneva sadawneo waxnagze tolia:

$$F_1 = \frac{1}{2}\gamma h^2 x \tag{1.29}$$

SeWidulobis Zala aris:

$$F_2 = cx^2 \tag{1.30}$$

filtraciuli dawneva tolia:

$$W(x) = \int_0^x \frac{\gamma\alpha h}{b} x * 2x dx = \frac{2}{3}\frac{\gamma\alpha h}{b} x^3 \tag{1.31}$$

kaSxlis wona *h* –is farglebSi tolia:

$$Q = \frac{1}{2}\gamma_1 h x^2 \tag{1.32}$$

xaxunis Zala tolia:

$$F_3 = f(Q - W) = \frac{1}{2} f\gamma_1 h x^2 - \frac{2}{3}\frac{\gamma\alpha h}{b} f x^3 \tag{1.33}$$

seismuri zalis sidide ganisazRvreba (1.22) gamosaxulebidan. aqedan gamomdinare, kritikuli wertilebis potenciuri energiis zedapiris gantoleba aqvs Semdegi forma:

$$F_1 - (F_2 + F_3) + S_s = 0 \tag{1.34}$$

an

$$x^3 - \frac{3(2c + f\gamma_1 h)b}{4\gamma\alpha h f} x^2 + \frac{3}{4}\frac{bh}{\alpha f} x + \frac{3}{2}\frac{bk_s Q}{\gamma\alpha h f} = 0 \tag{1.35}$$

davuSvaT, rom

$$P_1 = -\frac{3(2c + f\gamma_1 h)b}{4\gamma\alpha hf}; P_2 = \frac{3}{4}\frac{bh}{\alpha f} \qquad \text{da} \quad P_3 = \frac{3}{2}\frac{bk_s Q}{\gamma\alpha hf} = 0$$

maSin (1.26) gantolebas eqneba Semdegi saxe:

$$x^3 + P_1 x^2 + P_2 x + P_3 = 0 \tag{1.36}$$

gadavweroT (1.36) gamosaxuleba axal sakoordinato sistemaSi:

$$y^3 + (P_2 - \frac{1}{3}P_1^2)y + (P_3 + \frac{P_1 P_2}{3} + \frac{2}{27}P_1^3) = 0 \tag{1.37}$$

davuSvaT, rom

$$c_1 = P_2 - \frac{1}{3}P_1^2 \qquad \text{da} \qquad c_2 = P_3 - \frac{P_1 P_2}{3} + \frac{2}{27}P_1^3$$

maSin gantoleba (1.37) miiRebs Semdeg formas:

$$y^3 + c_1 y + c_2 = 0 \tag{1.38}$$

am zedapiris proeqcia an katastrofebis kompleqtis gantoleba iqneba:

$$4c_1^3 + 27c_2^2 = 0 \tag{1.39}$$

am SemTxvevaSi SegviZlia ganvsazRroT $k_s Q$ da *h*-is is mniSvnelobebi, romlis drosac kaSxals mouva avaria.

katastrofebis Teoriis damaxasiaTebelia is, rom ar aris saWiro gantolebebis amoxsna. aucilebelia mxolod partametrebis cvlilebebis diapazonis dadgena.

2. arsebuli betonis kaSxlebis kompleqsuri retrospeqtuli statikuri analizis meTodika

arsebuli da didi xnis eqspluataciaSi myofi betonis kaSxlebis daZabul-deformirebuli mdgomareobis zusti angariSisas mxedvelobaSi unda iqnas miRebuli misi eqsploataciis istoria. qvemoT moyvanilia eqsploataciaSi myofi Zveli gravitaciuli kaSxalebis kompleqsuri retrospeqtuli angariSis meTodika, romelSic aris mcdeloba maqsimalurad daaxlovos kaSxlisa da misi masalis modelebi eqsploataciis realur pirobebTan. SemoTavazebuli meTodika Sedgeba Semdegi etapebisgan:

a) betonis arawrfivi drekadi rRvevis ganmsazRvreli modelis SerCeva brtyeli deformaciis pirobebisaTvis;
b) sakontaqto zonis ganmsazRvreli modelis SerCeva;
g) cocvadobis deformaciebis angariSi bolcman-volteras wrfivi STamomavlobiTi cocvadobis Teoriisa da modificirebuli arawrfivi drekadi rRvevis modelis bazaze;

d) kaSxalis tanSi bzaris gaCenisa da gavrcelebis analizi diskretulbzarebiani modelisa da betonis rRvevis kriteriumis gamoyenebiT;

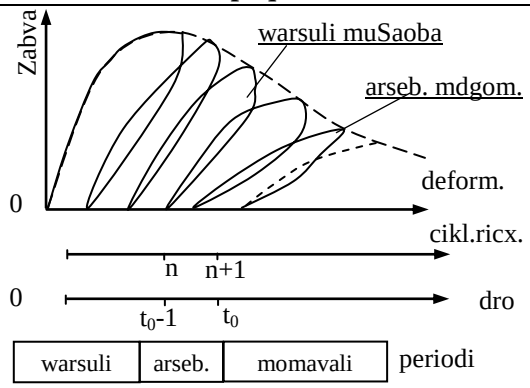
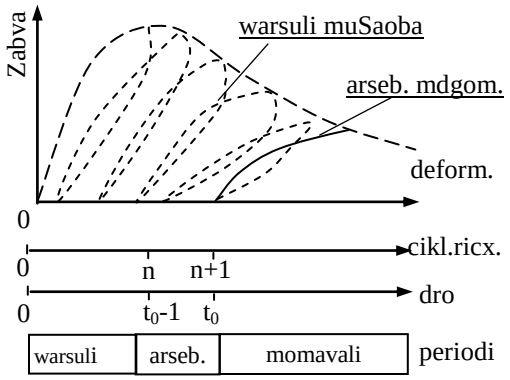
e) kaSxalis arsebuli mdgomareobis angariSi retrospeqtuli analizis Sedegad nagebobisa da masalis modificirebuli modelis gaTvaliswinebiT (mag. bzaris gaCena);

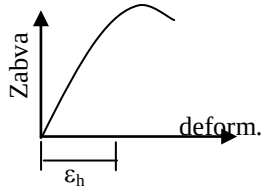
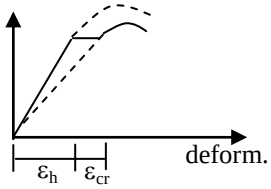
am meTodikis ZiriTadi principebi aRwerilia [9]-Si. qvemoT moyvanilia meTodikis arsi. am meTodikis principebs eyrdnoba Cvens mier damuSavebuli sakiTxebi - statikuri cikluri datvirTvebis da betonis asakis gavlena kaSxlis simtkiceze, romlebic Semdeg TavebSia ganxiluli.

2.1. meTodikis realizebis TanmimdevrobaA

meTodikis realizebis Tanmimdevroba mocemulia cxril 2.1 - Si

cxrili 2.1: meTodikis realizebis Tanmimdevroba.

<table>
<tr><td rowspan="2">deformaciis saxeoba</td><td>retrospeqtuli analizi</td><td>arsebuli mdgomareobis analizi</td></tr>
<tr><td> 
</td><td> 
</td></tr>
<tr><td>analizis etapi</td><td>analizis etapi</td></tr>
</table>

betoni brtyeli deformaciis pirobebSi	**<u>1. etapi R-1</u>**[1] **sawyisi monac.:** betonis da interfeisebis sixiste da simtkice **analizis meTodi:** betonis arawrf. drekadi rRvevis modeli**.** rRvevis modeli interfeisisaTvis  **Sedegi:** kaSxlis sawyisi ddm - $(\sigma,\varepsilon)_{Initial}$.	5. etapi P-2[2] **sawyisi monac.:** betonis modificirebuli sixiste da simtkice (etapidan R-4); kaSxlis modificirebuli ddm - $(\sigma, \varepsilon)_{Modified}$ (etapidan P-1). **analizis meTodi:** cocvadobis ε_{cr} def-is analizi modif-li bolcman-volteras TeoriiT. modif-li arawrf. drekadi rRvevis modeli kaSxlis betonisTvis. **Sedegi:** betonis modificirebuli sixiste da simtkice; kaSxlis modificirebuli ddm - $(\sigma, \varepsilon)_{Modified}$.
cocvadobis deformacia	2. etapi R-2[1] **sawyisi monac.:** betonis sawyisi sixiste da simtkice (etapidan R-1); kaSxlis sawyisi ddm - $(\sigma,\varepsilon)_{Initial}$. (etapidan R-1). **analizis meTodi:** cocvadobis ε_{cr} def-is analizi modif-li bolcman-volteras TeoriiT. modif-li arawrf. drekadi rRvevis modeli kaSxlis betonisTvis.  **Sedegi:** betonis modificirebuli sixiste da simtkice; kaSxlis modificirebuli ddm - $(\sigma, \varepsilon)_{Modified}$.	6. etapi P-3[2] **sawyisi monac.:** betonis modificirebuli sixiste da simtkice (etapidan P-2); kaSxlis modificirebuli ddm - $(\sigma, \varepsilon)_{Modified}$ (etapidan P-2). **analizis meTodi:** kaSxlis rRvevis kriter. brty. def-is pirobebSi; interfeisis rRvevis kriter. diskretuli rRvevis modeli; forovani wnevebis momateba bzarebSi. **Sedegi:** bzaris gaCena da gavrceleba betonSi da/an interfeisSi; kaSxlis modificirebuli ddm - $(\sigma, \varepsilon)_{Modified}$.
bzaris warmoqmna da gavrceleba	3. etapi R-3[1] **sawyisi monac.:** betonis modificirebuli sixiste da simtkice (etapidan R-2); kaSxlis modificirebuli ddm $(\sigma, \varepsilon)_{Modified}$ (etapidan R-2). **analizis meTodi:** kaSxlis rRvevis kriter. brty. def-is pirobebSi; interfeisis rRvevis kriter. diskretuli rRvevis modeli; forovani wnevebis momateba bzarebSi. **Sedegi:** bzaris gaCena da gavrceleba betonSi da/an interfeisSi; kaSxlis modificirebuli ddm - $(\sigma, \varepsilon)_{Modified}$.	
[1] **<u>R</u>** = retrospeqtuli analizi; [2] **<u>P</u>** = arsebuli mdgomareobis analizi;		

2.1.1. etapi R-1: betonis modeli brtyeli deformaciis amocanebisaTvis

gravitaciuli kaSxlis muSaobis Sefaseba unda moxdes brtyel deformaciaTa amocanebis farglebSi.

Cvens mier warmodgenili kaSxlis konstituciuri modeli eyrdnoba hipodrekad (arawrfivi drekadi rRveva) formulirebas. es modeli kargad aRwers mimdevrobiTad Seuqcevad Zabva-deformaciis damokidebulebas.

am midgomis mTavari upiratesoba gamoixateba imaSi, rom is martivad miesadageba ricxviT analizs da analizisTvis aucilebeli monacemebi Tavisuflad SeiZleba miviRoT betonis nimuSis erTRerZa kumSvaze gamocdidan. aRniSnul models SeuZlia gaiTvaliswinos Zabva-deformaciebis damokidebuleba pikur Zabvebamdec ki, anu gaiTvaliswinos plastikuri moculobiTi zrda kumSvis dros (dilatansia), romelic damaxasiaTebelia betonisTvis rRvevis wina etapze.

konstituciuri modeli iyenebs betonis rRvevis kriteriumebs brtyeli deformaciebis da brtyeli daZabuli mdgomareobis amocanebisTvis.

SemoTavazebuli modeli betonis orRerZovan Zabva-deformaciebis damokidebulebas ცვლის erTRerZa Zabva-deformaciebis damokidebulebebiთ. am midgomis mixedviT deformaciis nazrdis sidide TiToeuli mTavari mimarTulebisaTvis iangariSeba mTavari Zabvis nazrdis mixedviT imave mimarTulebiT.

- *betonis erTRerZa muSaoba*

betonis, rogorc samSeneblo masalis, muSaoba uSualod aris damokidebuli mis arsebul daZabul mdgomareobaze. amis umartivesi magaliTia betonis erTRerZa muSaoba. rac ufro zogadi xdeba ZabviTi mdgomareoba (orRerZa an samRerZa), masalis moqmedeba ufro rTuldeba. miuxedavad amisa, betonis erTRerZa muSaoba SeiZleba gamoyenebuli iqnas ufro rTuli modelebis safuZvlad, romlebic aRweren nagebobis ufro rTul muSaobas.

radganac betonis muSaoba damokidebulia mraval faqtorze (rogorebicaa komponentebis proporcia, Semavseblebis maxasiaTeblebi, modebuli datvirTvis saxeze da a.S.), Zalian rTulia moinaxos erTi gansakuTrebuli analizuri damokidebuleba, romelic

aRwerda Zabva-deformaciebis mrudebs, romelic zustad aRwerda yvela tipis betonis muSaobas. miuxedavad amisa, qvemoT moyvanili gamosaxulebas SeuZlioa sakmaod zustad aRweros zogadad betonis Zabva-deformaciebis mrudebi.

$$\frac{\sigma}{\sigma_c} = \frac{\frac{E_0}{E_c}\frac{\varepsilon}{\varepsilon_c}}{1+\left(\frac{E_0}{E_c}-2\right)\frac{\varepsilon}{\varepsilon_c}+\left(\frac{\varepsilon}{\varepsilon_c}\right)^2} \qquad (2.1)$$

sadac:

E_0 aris betonis sawyisi drekadobis moduli;

E_c - betonis mkveTi drekadobis moduli pikuri Zabvis dros;

σ_c da ε_c – Sesabamisad, maqsimaluri mkumSavi Zabva da Sesabamisi deformacia.

imisaTvis, rom dadgindes drekadobis mxebi moduli Zabva-deformaciebis mrudis nebismier wertilSi, mosaxerxebelia e.w. arawrfivobis β indeqsis gamoyeneba, romelic aRwers Zabva-deformaciebis mrudis im wertils, romelic Seesabamiseba betonis maqsimalur mkumSav Zabvas da iangariSeba rogorc:

$$\beta = \frac{\sigma}{\sigma_c} \qquad (2.2)$$

avRniSnoT $A= E_0/E_c$ da miviRoT mxedvelobaSi is, rom $\varepsilon_c=\sigma_c/E_c$ da $\varepsilon=\sigma/E_s$ (sadac E_s aris betonis mkveTi drekadobis moduli σ Zabvis dros). E_s – is gamosaxuleba Caiwereba Semdegnairad:

$$E_s = E_c(A_1 + \sqrt{A_1^2 - \beta^2}) \qquad (2.3)$$

sadac

$$A_1 = \frac{A - \beta(A-2)}{2} \qquad (2.4)$$

SeiZleba vaCvenoT, rom Zabva-deformaciebis mrudis nebismier wertilSi mxeb E_t da mkveT E_s drekadobis modulebs Soris marTebulia Semdegi damokidebuleba:

$$E_t = \frac{E_s^2}{E_s - \frac{\partial E_s}{\partial \sigma}\sigma} \tag{2.5}$$

gantolebebi (2.2) - (2.4) gamosaxuleba (2.5) – Tan erTad gamoiyeneba drekadobis mxebi modulis Semdegi gamosaxulebis miRebisaTvis:

$$E_t = \frac{2E_s(\frac{E_s}{E_c} - A_1)}{A} \tag{2.6}$$

- *betonis orRerZa muSaoba*

SemdgomSi, gantoleba (2.1) gamoyenebuli iqneba betonis muSaobis aRwerisas orRerZa ZabviT mdgomareobaSi. kerZod, drekadi, erTgvarovani da orTotropuli masalisTvis, Zabva-deformaciebis damokidebuleba diferencialur formaSi, mTavari Zabvebis gamoyenebiT, miiRebs Semdeg saxes:

$$\begin{Bmatrix} d\varepsilon_1 \\ d\varepsilon_2 \end{Bmatrix} = \begin{bmatrix} \frac{1}{E_{t1}} & -\frac{\nu_t}{\sqrt{E_{t1}E_{t2}}} \\ -\frac{\nu_t}{\sqrt{E_{t1}E_{t2}}} & \frac{1}{E_{t2}} \end{bmatrix} \begin{Bmatrix} d\sigma_1 \\ d\sigma_2 \end{Bmatrix} \tag{2.7}$$

sadac

ν_t aris puasonis koeficienti:

$$\nu_t = \sqrt{\nu_{t1}\nu_{t2}} \tag{2.8}$$

imisaTvis, rom ganvsazRroT drekadobis mxebi modulebi E_{t1} da E_{t2} mTavari Zabvebis mimarTulebebiT, β paramatri, romelic Seesabameba erTRerZa kumSvas, unda ganzogaddes orRerZa daZabul mdgomareobisTvis β_i *(i=1,2)*:

$$\beta_i = \frac{\sigma_i}{\sigma_{ci}} \tag{2.9}$$

sadac indeqsi *i* aRniSnavs σ_1 da σ_2 mTavari Zabvebis mimarTulebebs da zRvrul σ_{ic} Zabvebs. amis garda, (2.6) damokidebuleba SeiZleba modificirdes drekadobis mxebi modulis E_{ti} (*i=1,2*) gansasazRvravad mTavari Zabvebis mimarTulebebiT:

$$E_{ti} = \frac{2E_{si}(\frac{E_{si}}{E_{ci}} - A_{1i})}{A_i} \tag{2.10}$$

sadac

$$E_{si} = E_{ci}(A_{1i} + \sqrt{A_{1i}^2 - \beta_i^2}) \tag{2.11}$$

$$A_{1i} = \frac{A_i - \beta_i(A_i - 2)}{2} \tag{2.12}$$

$$A_i = \frac{E_{0i}}{E_{ci}} \tag{2.13}$$

$$E_{ci} = \frac{\sigma_{ci}}{\varepsilon_{ci}} \tag{2.14}$$

amis Semdeg, (2.10) – (2.14) gantolebebis parametrebi gaiangariSeba betonis daZabuli mdgomareobis Semdegi formebisaTvis: kumSva – kumSva (CC) , gaWimva – kumSva (TC) da gaWimva – gaWimva (TT). maqsimaluri mkumSavi Zabvebis mniSvnelobebi gaiangariSeba [8] – s mixedviT.

- *betonis konstituciuri kanonis modificireba brtyeli deformaciis amocanebisTvis*

Tu gaviTvaliswinebT imas, rom brtyeli deformaciis pirobebSi betonis gamocdis monacemebi praqtikurad ar arsebobs, zogierTi iyenebs betonis samRerZa gamocdis monacemebs da dahyavs is orRerZa kumSvaze [10]. Cven viyenebT rRvevis oTxparametrian kriteriums, romelic Semdegnairad gamoisaxeba [11]:

$$a\frac{J_{2p}}{\sigma_c^2}-b\frac{\sqrt{J_{2p}}}{\sigma_c}-c\frac{\sigma_{1p}}{\sigma_c}-d\frac{I_{1p}}{\sigma_c}-1=0 \tag{2.15}$$

sadac

$$I_{1p}=\sigma_{1p}+\sigma_{2p}+\sigma_{3p} \tag{2.16}$$

$$J_{2p}=\frac{1}{6}\left[\left(\sigma_{1p}-\sigma_{2p}\right)^2+\left(\sigma_{2p}-\sigma_{3p}\right)^2+\left(\sigma_{3p}-\sigma_{1p}\right)^2\right] \tag{2.17}$$

am gamosaxulebebSi $\sigma_{1p}\geq\sigma_{2p}\geq\sigma_{3p}$ arian pikuri mdgomareobis Sesabamisi mTavari Zabvebi, σ_c - betonis erTRerZa simtkice kumSvaze da *a, b, c, d* parametrebi, romlebic ganisazRvrebian eqsperimentalurad.

arawrfivobis indeqsi, romelic zemod aris aRwerili, miyvanilia moculobiTi amocanebis klasebisTvis Semdegi formiT:

$$\beta=\frac{\sigma_i}{\sigma_{ip}}\quad (i=1,2,3) \tag{2.18}$$

sadac σ_{ip} ($i=1,2,3$) aris pikuri Zabvis veqtoris Sesabamisi komponentebi.

zogadi damokidebuleba mkveTi Zabva-deformaciebis damokidebulebebis transversalurad izotropuli (orTotropuli) masalebisaTvis mTavar ZabvebSi Caiwereba Semdegnairad [12]:

$$\begin{Bmatrix}\varepsilon_1\\ \varepsilon_2\\ \varepsilon_3\end{Bmatrix}=\begin{bmatrix}\frac{1}{E_1} & \frac{-\nu_2}{E_2} & \frac{-\nu_1}{E_1}\\ \frac{-\nu_2}{E_2} & \frac{1}{E_2} & \frac{-\nu_2}{E_2}\\ \frac{-\nu_1}{E_1} & \frac{-\nu_2}{E_2} & \frac{1}{E_1}\end{bmatrix}\begin{Bmatrix}\sigma_1\\ \sigma_2\\ \sigma_3\end{Bmatrix} \tag{2.19}$$

brtyeli deformaciebis amocanebisTvis am gamosaxulebaSi $\varepsilon_3=0$. am SemTxvevaSi (2.19) gantolebis diferencialuri forma aRwers mxeb Zabva-deformaciebis damokidebulebas brtyeli deformaciebisTvis. am SemTxvevaSi CaiTvleba, rom masalis meqanikuri maxasiaTeblebi E_i da ν_i ($i=1,2$) Cainacvlebian Sesabamisi E_{ti} and ν_{ti} (i=1,2) mniSvnelobebiT. gantoleba (2.18)-dan ganisazRvreba σ_{ip} [13]:

$$\sigma_{ip}=\frac{\sigma_i}{\beta}\quad (i=1,2,3) \tag{2.20}$$

Tu CavsvavT (2.20) gamosaxulebas (2.15)-Si miviRebT:

$$a\frac{J_2}{\beta^2\sigma_c^2}-b\frac{\sqrt{J_2}}{\beta\sigma_c}-c\frac{\sigma_1}{\beta\sigma_c}-d\frac{I_1}{\beta\sigma_c}-1=0 \tag{2.21}$$

saidanac SeiZleba miviRoT Semdegi gamosaxuleba β-s gansazRvrisaTvis:

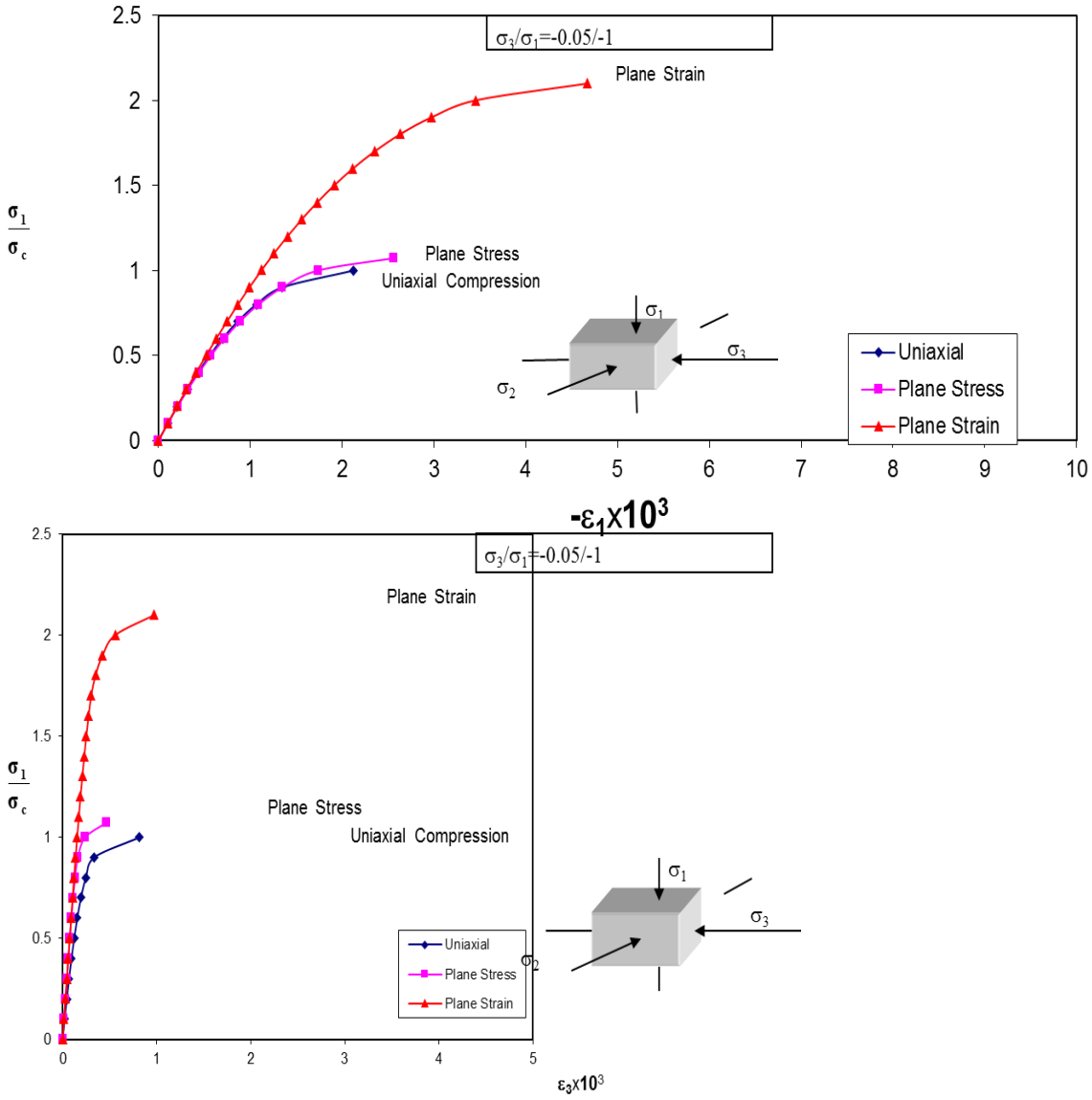
$$\beta^2+\frac{b\sqrt{J_2}+c\sigma_1+dI_1}{\sigma_c}-a\frac{J_2}{\sigma_c^2}=0 \tag{2.21}$$

- *analizis Sedegebi*

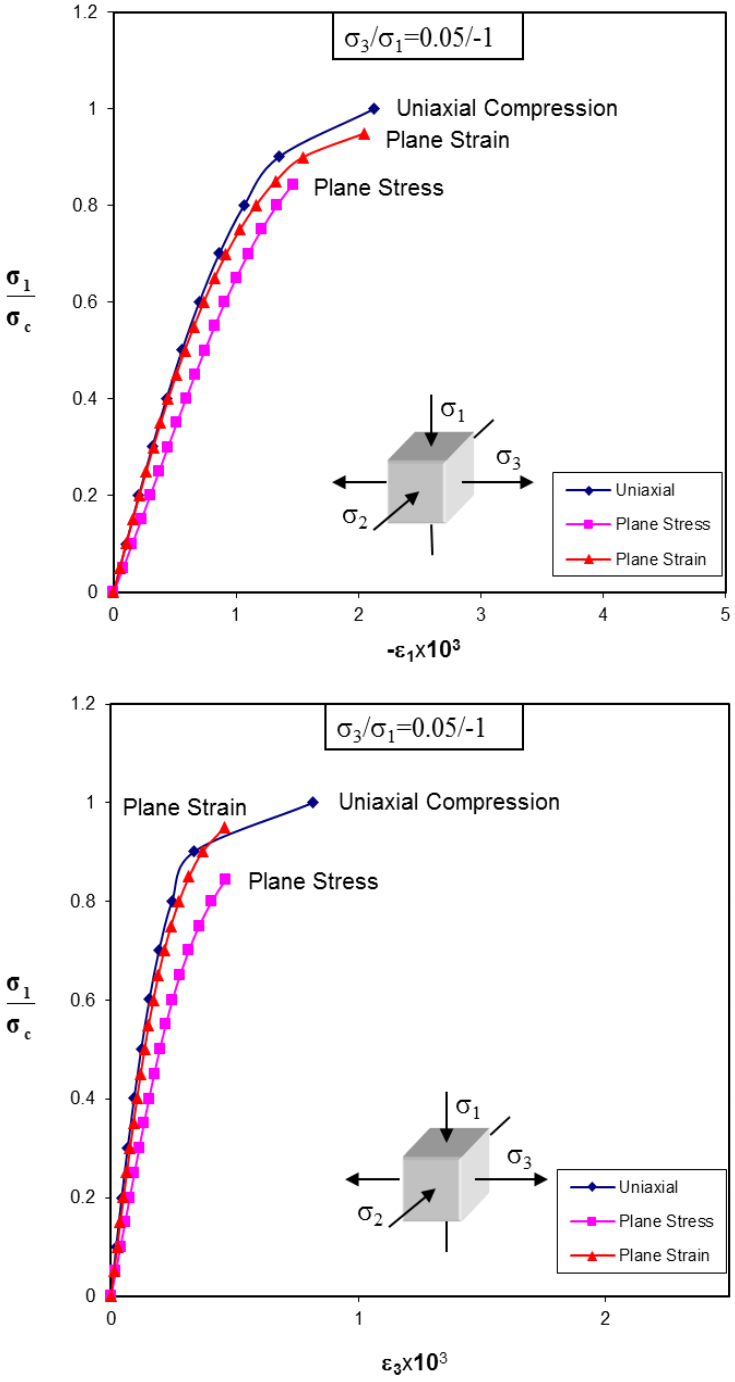
analizi daiwyo Zabvebis kumSva-kumSvis formiT, rodesac $\alpha=\sigma_3/\sigma_1=0.05$ (nax. 2.1). am naxazidan Cans, rom betonis Zabva-deformaciis mrudi brtyeli deformaciis

SemTxvevaSi Zalian axlosaa erTRerZian kumSvis diagramasTan, Tumca simtkice kumSvaze mniSvnelovnad izrdeba brtyeli deformaciis SemTxvevaSi, maSinac ki rodesac α-s mniSvneloba dabalia. kerZod, simtkice kumSvaze TiTqmis orjer metia erTRerZa kumSvis Sesabamis simtkiceze kumSvaze. α-s mniSvnelobis gazrdis Sedegad $\alpha=0.10$ da $\alpha=0.15$, sidideemde simtkice kumSvaze mniSvnelovnad izrdeba. analizis dros Cven ufro metad ar gagvizrdia α-s mniSvneloba, radgan gravitaciuli kaSxlebisTvis is imyofeba 0 – 0,2 –is farglebSi ($0.00 \leq \alpha \leq 0.20$).

ufro mniSvnelovani aRmoCnda gaWimva-kumSvis forma, radgan aseTi zonebi SeiZleba gaCndes gravitaciuli kaSxlis sadawneo waxnagze. nax. 2.2 – dan Cans, rom, rodesac $\alpha=-0.05$, betonis simtkice kumSvaze brtyeli deformaciis pirobebSi ufro maRalia, vidre brtyeli daZabuli mdgomareobis dros, Tumca ufro naklebia vidre erTRerZa kumSvis SemTxvevaSi. Semdegma kvlevebma aCvena, rom betonis simtkice kumSvaze brtyeli deformaciis pirobebSi mcirdeba α-s mniSvnelobis gazrdiT. magaliTad, rodesac $\alpha=-0.10$, betonis simtkice kumSvaze brtyeli deformaciis pirobebSi TiTqmis



nax. 2.1: **erTRerZa kumSvis, brtyeli daZabuli da brtyeli deformaciebis pirobebSi miRebuli Sedegebis urTierTSedareba gaWimva-kumSvis farglebSi, rodesac** $\alpha=\sigma_3/\sigma_1= 0.05$ **.**



nax. 2.2: **erTRerZa kumSvis, brtyeli daZabuli da brtyeli deformaciebis pirobebSi miRebuli Sedegebis urTierTSedareba gaWimva-kumSvis farglebSi, rodesac $\alpha=\sigma_3/\sigma_1=-0.05$.**

tolia analogiuri sidideze brtyeli daZabuli mdgomareobis dros. rodesac $\alpha=-0.15$, betonis simtkice kumSvaze brtyeli deformaciis pirobebSi naklebia analogiuri sidideze brtyeli daZabuli mdgomareobis dros.

analizidan gamomdinare dgindeba, rom brtyeli deformacia auaresebs betonis muSaobas gaWimva-kumSvis zonaSi gravitaciuli kaSxlis sadawneo waxnagis siaxloves, sadac mosalodnelia gamWimavi bzarebis warmoSoba da gavrceleba kaSxlis tanSi. aqedan gamomdinare, aucilebelia gravitaciuli kaSxlebis angariSi brtyeli deformaciebis pirobebSi, raTa moxdes bzaris SesaZlo warmoSobis swori gansazRvra.

2.1.2. etapi R-1: konstituciuri modeli interfeisebisaTvis (sakontaqto zedapirebisaTvis)

fuZis gavlenas Seswavlas kaSxlis daZabul-deformirebul mdgomareobaze didi praqtikuli mniSvneloba aqvs, radganac es gavlena vrceldeba fuZidan kaSxlis simaRlis TiTqmis erT mesamedze. klasikur sasruli elementebis angariSSi fuZe da kaSxali erTian saangariSo sistemaSi ganixileba. es modeli arc ise zustad aRwers im procesebs, romlebic sakontaqto zedapirze xdeba, anu ar xdeba sakontaqto zedapirze urTierTmimarT gadaadgilebebis dafiqsireba, radgan es kontaqti xistad Camagrebuli sqemis tolfasia. am problemis gadasaWrelad saWiroa damodelirdes uSualod interfeisi. amisaTvis gamoiyeneba specialuri sakontaqto elementebi, romlebic analogiuri elementebi SeiZleba gamoyenebuli iqnas ara marto kaSxlisa da fuZis sakontaqto zedapirze, aramed kaSxlis dasxmul fenebs Soris kontaqtis dasamodelireblad.

zogadad, interfeisis muSaoba misi mosazRvre masalebis Tvisebebzea damokidebuli. interfeisis muSaoba arawrfivia, amitom aucilebelia iseTi modelis damuSaveba, romelic am arawrfivobas aRwers.

konstituciuri damokidebuleba interfeisebisebisaTvis efuZneba hipodrekad (arawrfivi drekadi rRveva) models. am midgomis saSualebiT SesaZlebelia Zvris cdebidan miRebuli mxebi Zabvebis – fardobiTi gadaadgilebebis mrudis simulireba pikur mxeb Zabvebamdec ki, romlis drosac warmoiSoba dilatansiis efeqti kvanZebs Soris.

interfeisis elementebis arawrfivi damokidebuleba SeiZleba Caiweros diferencialuri formiT:

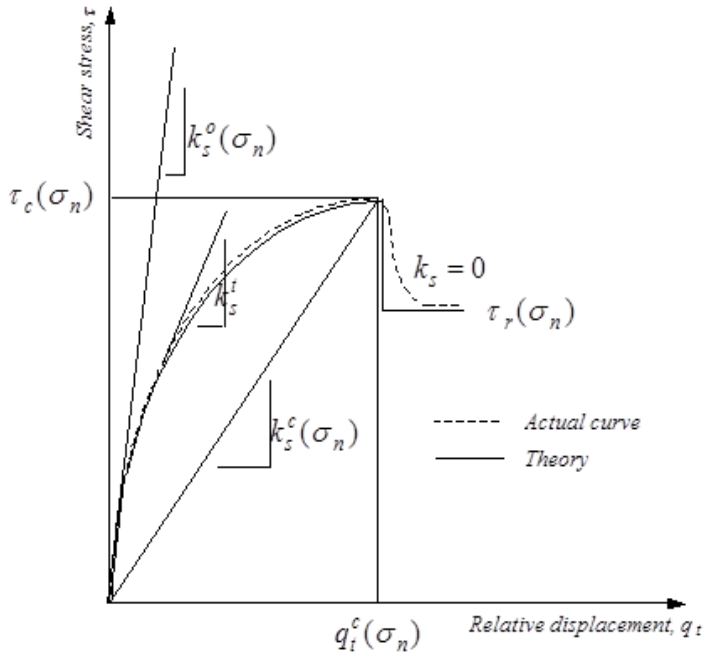
$$\begin{bmatrix} \partial\sigma_t \\ \partial\sigma_n \end{bmatrix} = \begin{bmatrix} k_s^t & 0 \\ 0 & k_n^t \end{bmatrix} \begin{bmatrix} \partial q_t \\ \partial q_n \end{bmatrix} \tag{2.22}$$

sadac k_s^t da k_n^t aris interfeisis sixistis matricis mZvreli da normaluri komponentebi da maTi mniSvnelobebi zogadad damokidebulia arsebul ZabviT mdgomareobaze.

qvemoT moyvanilia Zvris Zabva-deformaciebis da normaluri Zabva-deformaciebis konstituciuri damokidebulebebi.

- *mxebi Zabva-deformaciebis modeli*

betonsa da kldes Soris Zvraze tipuri cdis Sedegebi mocemulia nax. 2.3 - ze. Zvris moduli ZabviTi mdgomareobis nebismier safexurze (τ, σ_n) Caiwereba Semdegnairad:



nax. 2.3: mxebi Zabva-deformaciebis modeli interfeisisaTvis.

$$k_s^t = \frac{2k_s^s\left(\frac{k_s^s}{k_s^c} - A_1\right)}{A} \tag{2.23}$$

sadac:

$$k_s^s = k_s^c(A_1 + \sqrt{A_1^2 - \beta^2}) \tag{2.24}$$

$$k_s^c = \frac{k_s^0}{A} \tag{2.25}$$

$$A_1 = \frac{A - \beta(A-2)}{2} \tag{2.26}$$

am gantolebebSi Semavali mxebi Zabvis parametri β_τ analogiuria arawrfivobis β parametris da is Semdegnairad Caiwereba:

$$\beta_\tau = \frac{\tau}{\tau_c} \tag{2.27}$$

sadac τ_c aris interfeisis simtkice Zvraze. modelis ucnobi sidideebi, romlebic unda ganisazRvron, arian: Zvris sixistis sawyisi koeficienti k_s^0, interfeisis simtkice Zvraze τ_c da uganzomilebo parametric *A*, romelic erTmaneTTan akavSirebs sawyis Zvris sixistes da Zvris sixistis mkveT mniSvnelobas rRvevis momentSi. yvela es parametri damokidebulia normal Zabvebze da SeiZleba ganzogadnen interfeisSi normaluri Zabvebis mniSvnelobebTan SesabamisobaSi, rogorc qvemoT aris aRwerili.

Zvraze sixistis sawyisi koeficientis ganzogadeba. rogorc zemod iyo naxsenebi, Zvris sixistis sawyisi k_s^0 koeficientis mniSvneloba damokidebulia interfeisSi normaluri σ_n Zabvis mniSvnelobaze. karjanis (indoeTi) gravitaciuli kaSxlis fuZeSi arsebuli bzaris analizis safuZvelze, avtorebma gamoiyenes modeli, romelic Semdegnairad asaxavs k_s^0 – is da σ_n -is urTierTkavSirs [14]:

$$k_s^0 = K\gamma_w \left(\frac{\sigma_n}{P_a}\right)^n \tag{2.28}$$

sadac:

K aris sixistis uganzomilebo maCvenebeli;

γ_w - wylis xvedriTi wona;

P_a - atmosferuli wneva;

n - Zvraze sixistis maCvenebeli.

unda aRiniSnos, rom (2.28) gantoleba ar aris marTebuli im SemTxvevaSi, rodesac normaluri Zabva nulis tolia (σ_n=0). miuxedavad imisa, rom es gantoleba vargisia grunti-nagebobis urTierTobebis amocanebSi, is ver aRwers srulad kldesa da betons Soris, agreTve betonis or fenas Soris kontaqtebs. imisaTvis, rom gantolebis es nakli daiZlios, saWiroa (2.28) gantolebis modificireba Semdegi martivi gziT. davumatoT gantolebis

marjvena mxares interfeisSi Zvris sixistis sawyisi mniSvneloba, romelic Seesabameba nulovan normalur Zabvas, e.i.:

$$k_s^0 = \left(k_s^0\right)^{\sigma_n=0} + a\left(\frac{\sigma_n}{P_a}\right)^n \tag{2.29}$$

sadac: $a=K\gamma_w$ aris sixistis parametri (gamosaxuli igive ganzomilebaSi, rac k_s^0).

zemodmoyvanili saxiT gantoleba (2.29) gamoyenebuli iqna [15]-Si betonisa da kldis interfeisis muSaobis Sesaswavlad.

$\left(k_s^0\right)^{\sigma_n=0}$ -is mniSvnelobis dasadgenad sakmarisia Zvraze klasikuri cda nulovani normaluri Zabvebis SemTxvevaSi. parametri a SeiZleba advilad ganisazRvros mxebi Zabvebi-fardobiTi gadaadgilebebis mrudebidan, romlebic agebulia interfeisSi normaluri Zabvebis sxvadasxva mniSvnelobebis dros. xSirad miiReba, rom sawyisi Zvris mniSvneloba wrfivad aris damokidebuli normaluri Zabvis mniSvnelobebze, anu n=1.

interfeisis Zvraze simtkicis ganzogadeba. τ_c mxebi Zabvis pikuri mniSvneloba aris agreTve interfeisSi normaluri Zabvis funqcia nax. 2.3. mori-kulonis kriteriumis mixedviT is ganisazRvreba Semdegnairad:

$$\tau_c = c + \sigma_n \tan\phi \tag{2.30}$$

sadac:

c aris SeWiduloba;

ϕ - Sinagani xaxunis kuTxe (es parametrebi SeiZleba agreTve ganisazRvros uSualod Zvris cdebidan).

mas Semdeg, rac miRweuli iqneba Zvraze simtkicis zRvruli mniSvneloba, moxdeba rRveva Zvraze da k_s –is mniSvneloba miuaxlovdeba nuls. miuxedavad amisa, interfeisSi rCeba simtkicis garkveuli done nax. 2.3.

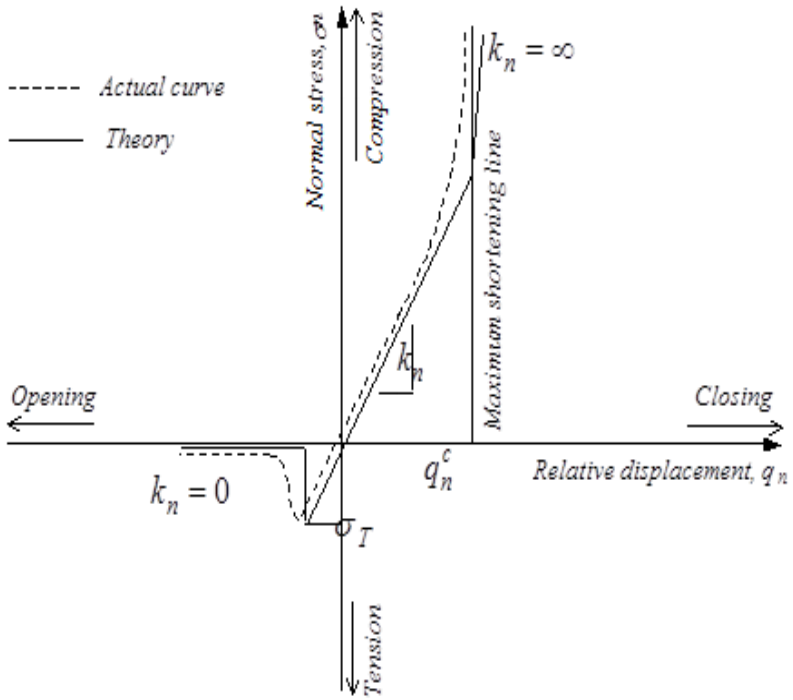
- *normaluri Zabva-deformaciebis modeli*

normaluri Zabva-deformaciebis modeli mocemuli nax. 2.4-ze. zogadad, normaluri Zabva-deformaciebis damokidebuleba arawrfivia (daStrixuli zona nax. 2. –ze). miuxedavad amisa, uSveben, rom es damokidebuleba zRvrul mkumSav da gamWimav rRvevebs Soris

aris wrfivi, e.i. normaluri sixiste iTvleba mudmiv sidided: k_n=*const* [16].

daSvebulia, rom interfeisebs kaSxalsa da fuZes Soris, agreTve kaSxlis dagebul fenebs Soris, SeuZlia miiRon garkveuli sididis gamWimavi Zabvebi. magaliTad, Upper Stillwater-is datkepnilbetoniani gravitaciuli kaSxali daproeqtebuli iyo 1,24 mpa sididis minimalur simtkiceze gaWimvaze betonis fenebs Soris [17].

gamWimavi Zabva gavlenas axdens interfeisis wertilebis urTierT fardobiT gadaadgilebebze, rodesac simtkice gaWimvaze interfeisSi miaRwevs Tavis zRvrul mniSvnelobas, e.i. rodesac $|\sigma_n| \geq |\sigma_n^t|$. amis Semdeg interfeiss aRar SeuZlia winaaRmdegoba gauwios gamWimav Zabvebs da is gaixsneba, e.i. Zabvebi daecema nulamde. Zvraze da normaluri sixistis koeficientebis sawyisi



nax. 2.4: normaluri Zabva-fardobiTi gadaadgilebis modeli interfeisisaTvis.

mniSvnelobebi uaxlovdeba nuls. Zabvebi gadanawildeba gauxsnel kontaqtebSi. igive principi vrceldeba kumSvis zonebSic nax. 2.4.

- *analizis Sedegebi*

interfeisis zemod aRwerili modelis bazaze miRebuli Sedegebi Sedarebuli iqna naturaSi Zvraze Catarebuli cdebis Sedegebs [15] betonsa da kldes Soris. Teoriuli da eqsperimentuli Sedegebis Sedarebis Sedegad dadginda, rom am or mruds Soris garkveuli sxvaoba gamowveuli iyo interfeisSi Zvraze simtkicis Teoriul da realur sidideebs Soris sxvaobiT. miuxedavad amisa, SeiZleba davaskvnaT, rom (2.23 – 2.26) gamosaxulebebi kargad aRweren mxebi Zabvebi-fardobiTi gadaadgilebebis realur (natural) mruds. analizis Semdeg etapebze moxda Teoriuli mrudebisTvis A parametris cvladi mniSvnelobebis aReba.

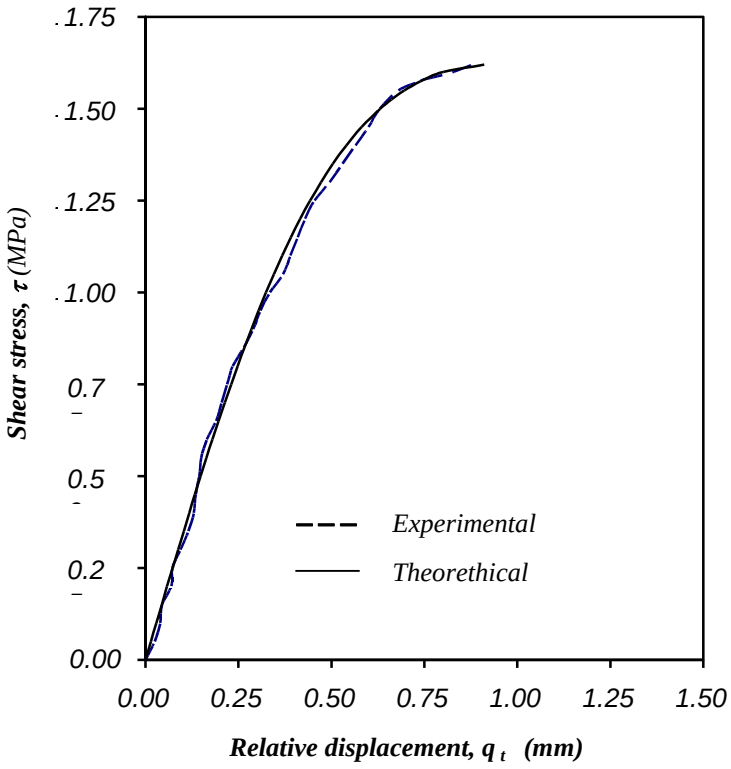
garkveuli sxvaoba Teoriul da eqsperimentul mrudebs Soris, romelic gamowveuli iyo Zvraze simtkicis Teoriul da realur sidideebs Soris sxvaobiT, dafiqsirda im SemTxvevisTvis, rodesac $\sigma_n = 3.08$ kg/sm^2 da $\sigma_n = 8.01$ kg/sm^2, maSin, rodesac sakmaod kargi korelacia dafiqsirda im SemTxvevisTvis, rodesac $\sigma_n = 11.89$ kg/sm^2 (nax. 2.5)

2.1.3. etapi R-2: cocvadobis deformaciebis angariSi

rogorc gviCvenebs betonis kaSxlebze mravalwliani naturuli dakvirvebebis, aseve laboratoruli eqsperimentebis Sedegebi, betonis cocvadobis Tvisebas da daRlilobas mniSvnelovani gavlena aqvs TviT nagebobis daZabul-deformirebul mdgomareobaze. imisaTvis, rom saangariSo meTodikaSi gaTvaliswinebuli iqnas betonis cocvadobis procesi, saWiroa vicodeT saangariSo sistemis (kaSxali – fuZe) sawyisi daZabul-deformirebuli mdgomareoba da masalis sawyisi meqanikuri maxasiaTeblebi.

angariSebi tardeba sam etapad:

- etapi 1 – iangariSeba sistema “kaSxali – fuZis” sawyisi daZabul-deformirebul mdgomareoba;
- etapi 2 – sistema “kaSxali – fuZe” iangariSeba im periodisTvis, rodesac kaSxalis betonis simtkice miaRwevs Tavis pikur mniSvnelobas. es, umravles SemTxvevaSi, xdeba betonis Casxmidan 8-10 wlis Semdeg [18, 19]. miRebulia, rom am droisaTvis betonSi cocvadobis procesi damTavrebulia. Tu kaSxlis tanSi warmoiSoba bzarebi, saWiroa angariSebi



$\sigma_n = 11.89\ kg/sm^2$
$\boldsymbol{c} = 3.1\ kg/sm^2$
$\tan\phi = 1.1$
$k_{so} = 230.0\ kg/cm^3$
$a = 10.0\ kg/sm^3$
$n = 1$
$P_a = 1.033\ kg/cm^2$

$$A = \frac{1}{3}\left(\frac{\sigma_n}{c + \sigma_n \tan\phi}\right)^2 + \frac{2}{3}\left(\frac{\sigma_n}{c + \sigma_n \tan\phi}\right) + \frac{4}{3}$$

nax. 2.5: aRwerili meTodiT miRebuli Sedegebis Sedareba [15]-Si moyvanil eqsperimentul monacemebTan betonsa da kldes Soris interfeisisaTvis A parametris sxvadasxva mniSvnelobebisTvis.

Catardes bzarwarmoqmnisa da cocvadobis procesis mxedvelobaSi miRebiT;

- etapi 3 – iangariSeba sistemis arsebuli (an momavali) daZabul-deformirebuli mdgomareoba. betonis meqanikuri maxasiaTeblebi zustdeba [20] datvirTva-gantvirTvis n ciklebis da eqspluataciis t periodis gaTvaliswinebiT. im SemTxvevaSi Tu aRmoCnda bzarebi, maSin CaiTvleba, rom cocvadobis procesi grZeldeba bzaris wveroebSi.

betonSi cocvadobis procesis aRsawerad gamoiyeneba bolcman-volteras wrfivi memkvidreobiTi Teoria. am Teoriis mixedviT, cocvadobis daZabul-deformirebuli mdgomareobis gantolebis yvelaze zogadi forma erTganzomilebiani amocanebisaTvis SeiZleba Caiweros Semdegnairad [21]:

$$\varepsilon(t) = \frac{\sigma(t)}{E(t)} + \int_0^t \frac{K(t)}{E(t)}\sigma(t)dt \qquad (2.31)$$

sadac:

$\varepsilon(t)$ - jamuri (drekadi da cocvadobis) deformacia drois t momentisaTvis;

$K(t)$ - cocvadobis funqcia, romelic damokidebulia datvirTvis asakze da t droze;

$E(t)$ - betonis drekadobis moduli, romelic damokidebulia datvirTvis asakze da icvleba t drosTan erTad;

$\sigma(t)$ - Zabva drois t momentisaTvis;

cocvadobis funqcia SeiZleba gaangariSdes Semdegi gantolebis saSualebiT:

$$K(t) = \delta_2 e^{\delta_1 t} \tag{2.32}$$

am gantolebaSi δ_1 da δ_2 koeficientebi gansazRvraven cocvadobis procesis xarisxs da miiRebian eqsperimentuli gziT. magaliTad, δ_1 miiReba, rogorc betonis fardobiTi Semoklebis siCqare rogorc drois funqcia.

- *analizis Sedegebi*

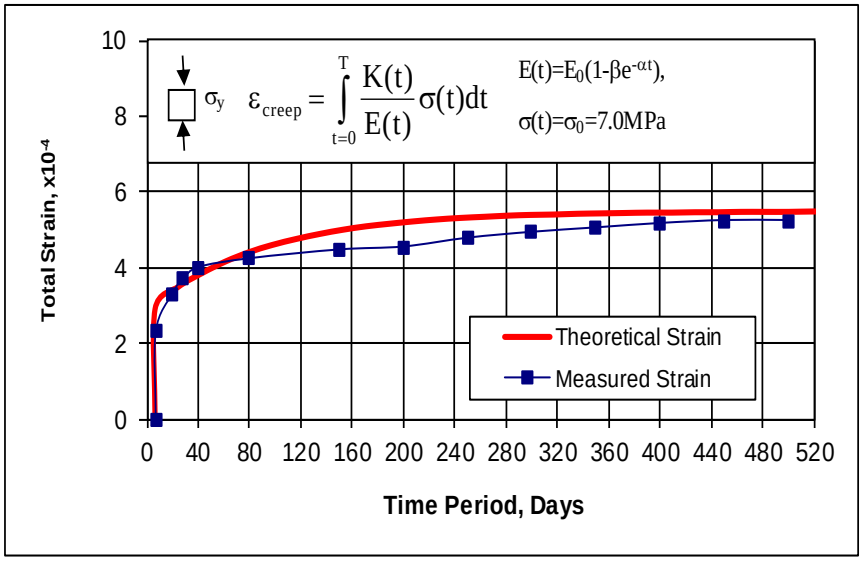
imisaTvis, rom cocvadobis sruli procesi zustad iqnas aRwerili, saWiroa ganisazRvros:

a) cocvadobis *K(t)* funqcia;
b) δ_1 da δ_2 koeficientebi, romlebic gamoiyeneba *K(t)* funqciis saangariSod da damokidebulni arian im droze, romlis ganmavlobaSic xdeba coxcvadobis procesze dakvirveba;
g) drekadobis moduli *E(t);*
c) $\sigma(t)$ Zabvebi *t* drois nebismier monakveTSi;
h) cocvadobis aRdgena datvirTvis moxsnis Semdeg;
i) cocvadobis procesi cikluri datvirTvebis dros.

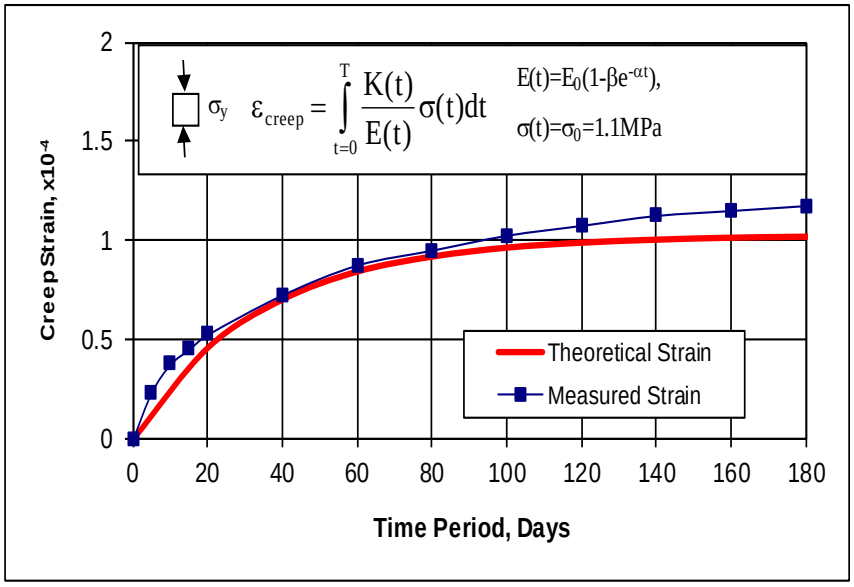
cocvadobis process sagrZnobi gavlena aqvs betonis Zabva-deformaciebis mrudze, romelzec, Tavis mxriv, damokidebulia kaSxalSi daZabul-deformirebuli mdgomareoba.

nax. 2.6 - ze mocemulia drekadi da cocvadobisgan gamowveuli jamuri deformaciebi [22]. eqsperimentaluri mrudi miRebulia 7 dRis nimuSis gamocdis Sedegad. Tavdapirvelad, angariSebSi miRebuli iqna drekadobis *E* modulis mudmivi mniSvneloba, magram ufro zusti Sedegebi miiReba, roca gamiviyenebT *E(t)* –s cvlad mniSvnelobebs, damokidebuls *t* droze.

nax. 2.7 -ze mocemulia cocvadobis deformacia, romelic miRebulia 28 dRis asakis betonis nimuSis gamocdis Sedegad.



nax. 2.6: cocvadobis deformaciebis angariSi σ(t) = 7,0 mpa-is dros.



nax. 2.7: cocvadobis deformaciebis angariSi σ(t) = 1,1 mpa-is dros.

unda aRiniSnos, rom Teoriuli modelis mixedviT cocvadobis procasi stabilirdeba daxloebiT 180 – 540 dReSi (0,5 – 1,5 weli). eqsperimentebi ki aCveneben, rom es procesi ufro didxans grZeldeba. amitom saWiroa Semdgomi kvlevebi, raTa moxdes Teoriuli da eqsperimentuli Sedegebis kargi korelacia.

2.1.4. etapi R-3: bzaris warmoSobis da gavrcelebis analizi

rRvevis meqanikis amocanebis modelirebis mTavari problema aris bzaris wveroSi gaCenili usasrulo sididis Zabva [23]. es xdeba imitom, rom Zabvis/deformaciis $r^{-1/2}$ xarisxis singularoba (r aris bzaris wverodan) Cndeba bzaris wveros siaxloves. amis gamo, sasruli elementebis Zalian xSiri badis gamoyenebac ki ar iZleva sasurvel sizustes. xSirad iyeneben specialur bzaris wveros elementebs problemis mosaxsnelad. amis alternatuli midgomaa, Seicvalos aseTi elementi modificirebuli izoparametruli kvadratuli sasrulo elementebiT [24, 25] da izoparametruli kvadratuli sasazRvro elementebiT [26, 27] garkveuli kvanZebis adgilis Secvlis gziT. aseTi elementebis gamoyeneba aRar xdis aucilebels SemoviyvanoT saangariSo sqemaSi bzaris wveros elementebi da es amartivebs Zabvis intensivobis faqtoris gamoTvlas bzaris wverosTan. garda amisa, aRar aris aucilebeli Zalian xSiri badis Seqmna bzarwarmoqmnis zonaSi zusti amonaxsnis misaRebad.

rRvevis meqanikis Teoriebi gulisxmobs, rom bzaris wverosTan Zabvebi aris usasrulo da isini xasiaTdebian Zabvis intensiobis faqtoriT K. rodesac aRwevs kritikul mniSvnelobas (romelic cnobilia rogorc K_c an rRvevis siblante), Cndeba katastrofuli bzari an swrafi rRveva. rRvevis siblante K_c aris masalis meqanikuri maxasiaTebeli, romelic ar aris damokidebuli nagebobis geometriaze an datvirTvis saxeobaze. Zabvis intensiobis faqtori ar aris Zabva TavisTavad. is zomavs imas, Tu ramdenad axlos aris bzari Tavis kritikul sigrZesTan, rodesac is iwyebs warmoSobas nagebobaSi.

cnobilia rRvevis sami klasikuri forma, romlebic efuZneba bzaris gverdebis fardobiT moZraobas: (1) bzaris gaxsnis forma (forma I); (2) bzaris dacurebis forma (forma II) da (3) bzaris gaxsnis forma (forma III). am samidan pirveli ori misaRebia gravitaciuli kaSxlebisaTvis, Tumca forma I aris yvelaze mniSvnelovani, radganac umravles SemTxvevebSi gravitaciuli kaSxlebis tanSi bzarebi Cndeba gamWimavi Zabvebis zonaSi (magaliTad, kaSxlis interfeisebTan da kaSxalsa da fuZes Soris kontaqtSi.

naSrom [28]-Si moyvanilia gamosaxulebebis mTeli seria Zabvebisa da gadaadgilebebisaTvis bzaris wverTan. Zabvis intensiobis faqtori K iangariSeba Zabvis da gadaadgilebis eqstrapolirebis Semdegi meTodebiT.

a) gadaadgilebis eqstrapolirebis meTodi (brtyeli ZabviTi mdgomareoba):

$$K_I = \frac{E\sqrt{2\pi}}{4(1-\nu^2)}\left(\frac{u_2}{\sqrt{r}}\right)_{r\to 0} \tag{3.33}$$

K_I –s zusti mniSvnelobis miRebis magivrad r=0 – Tan, aigeba K_I –s mniSvnelobebis da r manZilebs Soris damokidebuleba (3.33) – is mixedviT da gamoiyeneba swori xazis eqstrapolireba K_I –is misaRebad bzaris wverTan (r=0).

b) Zabvis eqstrapolirebis meTodi (brtyeli deformacia):

$$K_I = \sqrt{2\pi}\left(\frac{\sigma_{22}}{\sqrt{r}}\right)_{r\to 0} \tag{3.34}$$

rogorc wina SemTxvevaSi, aigeba K_I –s mniSvnelobebis da r manZilebs Soris damokidebuleba (3.34) – is mixedviT da gamoiyeneba swori xazis eqstrapolireba K_I –is misaRebad bzaris wverTan (r=0).

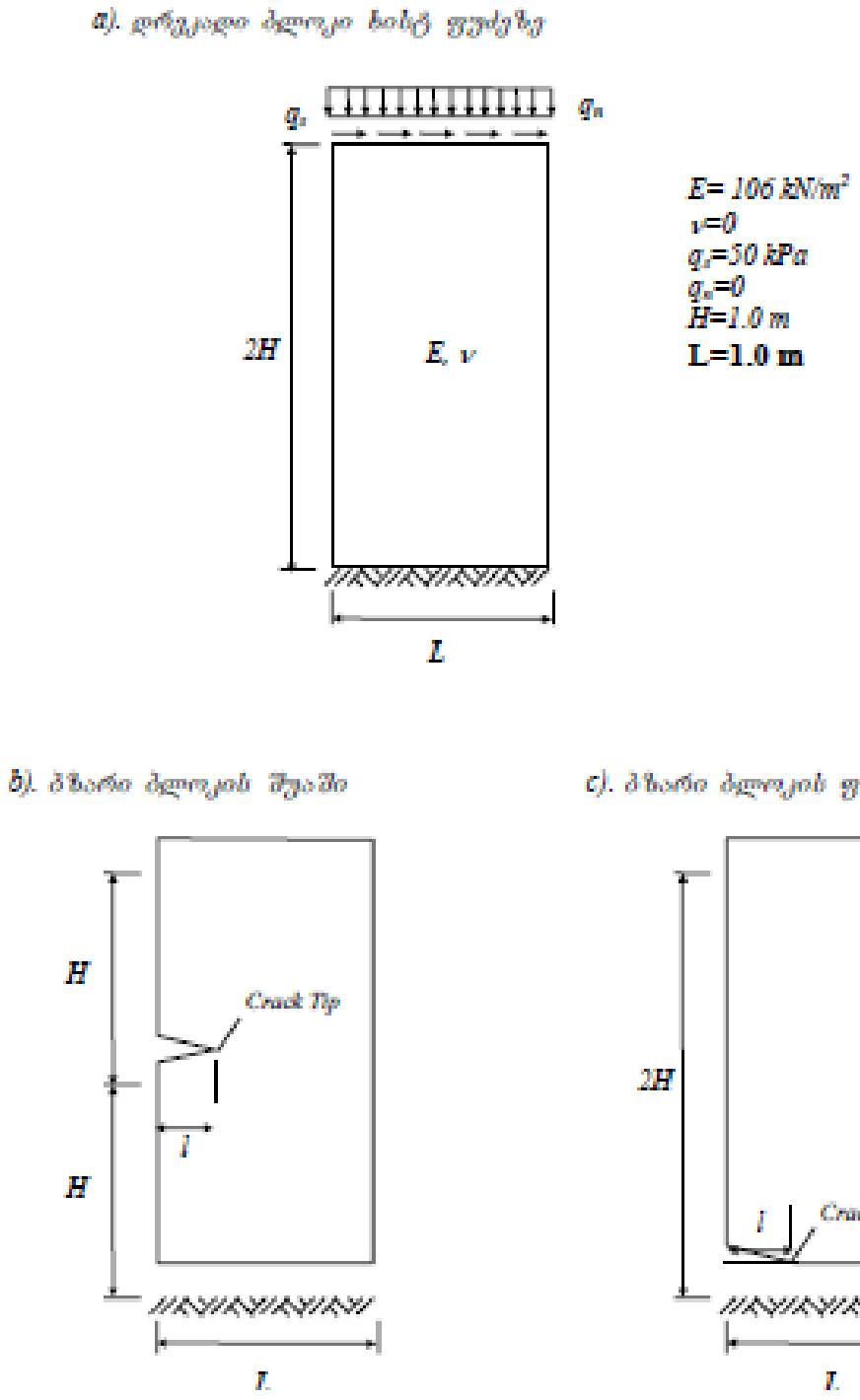
- *analizis Sedegebi – parametruli kvlevebi Zabvis intensiobis faqtorebis saangariSod*

parametruli kvlevebis erTi ZiriTadi mizani iyo dadgeniliyo interfeisebis izoparametruli kvadratuli singularuli sasruli elementebis da kvadratuli singularuli sasazRvro elementebis ricxviTi mdgradoba da saimedooba bzaris wverTan. meore mizani iyo kvadratuli singularuli sasruli elementebis da kvadratuli singularuli sasazRvro elementebis optimaluri zomebis dadgena bzaris wveros siaxlovesTan.

analizi Cautarda drekad bloks, romelzec modebuli aris Tanabradganawilebuli mxebi datvirTva zeda waxnagze. angariSebis dros gamoyenebuli blokis geometria, masalis meqanikuri Tvisebebi da modebuli Zalebi naCvenebia nax. 2,8a ze.

Catarda daaxloebiT 400 kompiuteruli gamoTvla sxvadasxva SemTxvevebisTvis. gamoyenebuli sxvadasxva sasruli elementebis – sasazRvro elementebis meTodi. angariSebi Catarda blokSi arsebuli bzaris sxvadasxva zomebisTvis. bzari ganTavsebuli iqna rogorc blokis SuaSi, aseve mis ZirSi (nax. 2,8 b da nax. 2,8 c).

angariSebi daiwyo drekad blokSi bzaris centrSi ganTavsebiT. Zabvis intensivobis faqtori K_I gaangariSebuli iqna 8-kvanZiani kvadratuli singularuli sasruli elementebis da 8-kvanZiani kvadratuli singularuli sasazRvro elementebis gamoyenebiT.

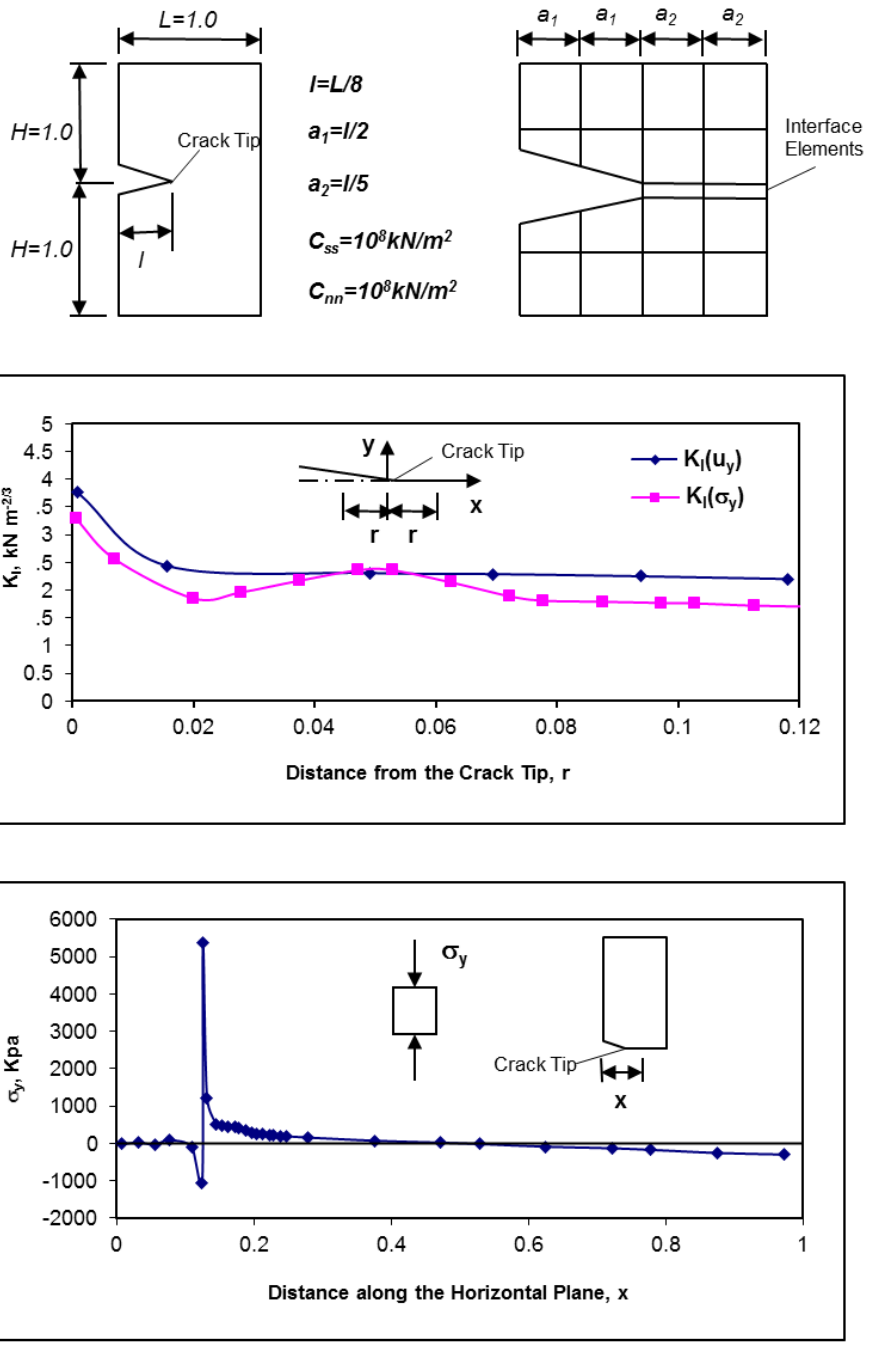


nax. 2.8: bzari drekad blokSi.

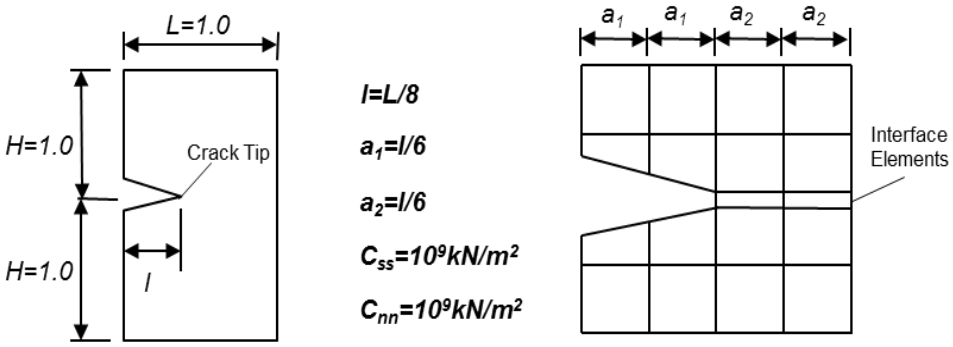
singularuli elementebi ganTavsebuli iqna bzaris gaswvriv misi wveros orive mxares. bzaris axlos gamoyenebuli iqna xSiri bade, gansakuTrebulad ufro patara zomis elementebi ganTavsda bzaris wveros garSemo. rogorc sawyisi mniSvneloba, interfeisis elementebisTvis normaluri da mxebi sixistis koeficientebi aRebuli iqna $C_{nn}=C_{ss}=10^8$ kn/m^3.

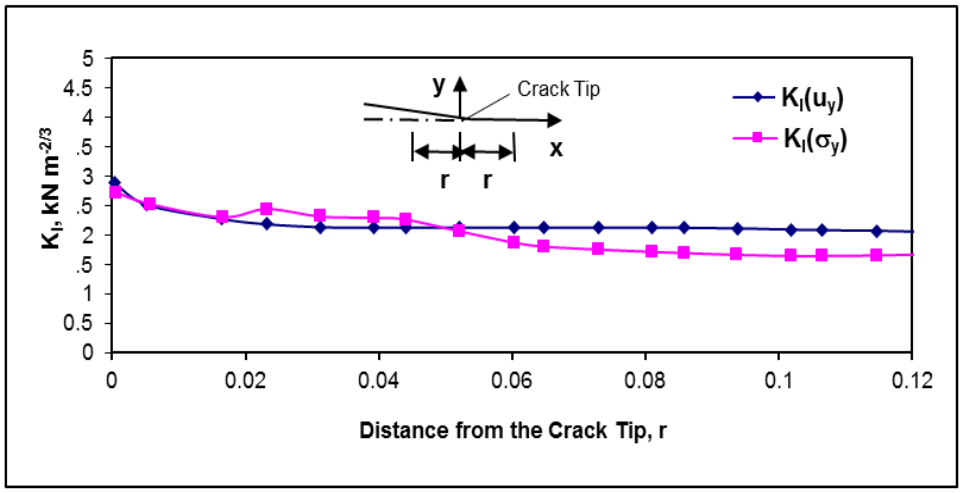
Tavdapirvelad CaiTvala, rom bzaris sigrZe toli iyo $l=L/8$, sadac L aris blokis sigane. angariSebi daiwyo im daSvebiT, rom $a_1 = a_2 = l/2$ da momdevno angariSebSi is mcirdeboda $l/5$- de (nax. 2.9 da 2.10). Zabvis intensivobis faqtori K_I -s mniSvnelobebi gaangariSebuli iqna orive, gadaadgilebis da Zabvis eqsrapolirebis meTodebiT. unda aRiniSnis, rom Tavdapirvelad K_I -s mniSvnelobebi, romlebic miRebuli iqna normaluri u_y gadaadgilebebis gamoyenebiT, miyvanili iqna im mniSvnelobebamde, romlebic miRebuli iqna normaluri σ_y Zabvebis gamoyenebiT. miuxedavad amisa, rodesac a_2-is mniSvneloba toli iyo $l/5$–is, K_I -s mniSvnelobebi, miRebulebi ori alternatuli meTodiT, gansxvavdebodnen erTmaneTisagan (nax. 2.9. amis mizezi SeiZleba iyos interfeisis elementebis normaluri da mxebi sixistis koeficientebis mniSvnelobebi, romlebic aRebuli iqna $C_{nn}=C_{ss}=10^8$ kn/m^3–is toli. es mniSvnelobebi aRebuli iqna naSromi [28]-dan. magaliTad, dadgenili iqna, rom interfeisis elementebi ricxobrivad mdgradia, rodesac normaluri da mxebi sixistis koeficientebis mniSvnelobebi tolia $C_{nn}=C_{ss}=10^8$ kn/m^3 –is, rodesac bzari ganTavsebulia blokis SuaSi. miuxedavad amisa, Zabvis maRali mniSvnelobebi Cndeba bzaris wveros siaxloves, magram es SeiZleba ar iyos realuri. amis gamo, angariSebis Semdeg etapebze gadawyda gazrdiliyo C_{nn} da C_{ss} -s mniSvnelobebi 10^9 kn/m^3 -de.

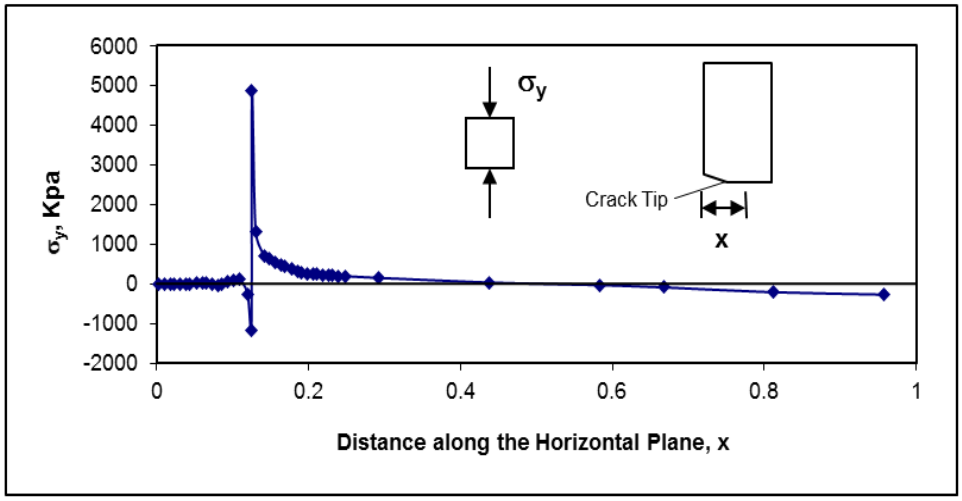
Zabvis intensivobis faqtori K_I -s mniSvnelobebi, romlebic gaangariSebuli iqna orive, gadaadgilebis da Zabvis



nax. 2.9: Zabvis intensivobis K_I faqtoris gaangariSeba.







nax. 2.10: Zabvis intensivobis K_I faqtoris gaangariSeba.

eqstrapolirebis meTodebiT, dauaxlovdnen erTmaneTs rodesac $C_{nn}=C_{ss}=10^9$ kn/m^3.

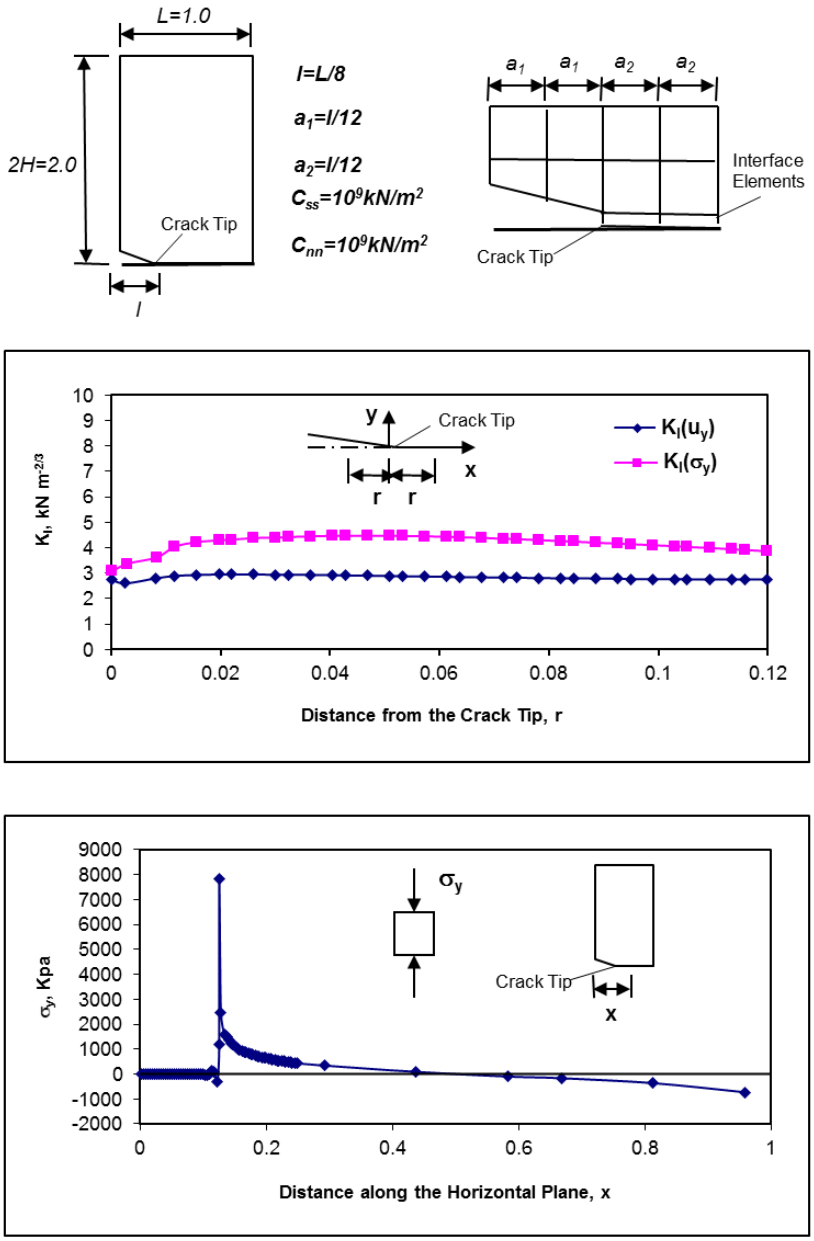
es Sedegebi kargad emTxveva im Sedegebs, romlebic miRebulia 8-kvanZiani izoparametruli kvadratuli singularuli sasruli elementebis gamoyenebisas.

aqedan gamomdinare, SeiZleba gakeTdes daskvna, rom interfeisis izoparametruli kvadratuli singularuli sasruli elementebi SeiZleba warmatebiT iqnas gamoyenebuli drekad sxeulebSi bzarebis gaCenisa da gavrcelebis damodelirebis amocanebSi.

angariSebis Semdeg etapze bzari ganTavsda drekadi blokis fuZeSi. interfeisis elementebisTvis normaluri da mxebi sixistis koeficientebi aRebuli iqna $C_{nn}=C_{ss}=10^9$ kn/m^3. daSvebuli iqna, rom bzaris sigrZe aris $l=L/8$, sadac L aris blokis sigane. angariSebi daiwyo $a_1 = a_2 = l/2$ –is SemTxvevisTvis da angariSebis Semdgom safexurebze sasruli elementebis bade xSirdeboda $a_1 = a_2 = l/3, l/4, l/5, l/6, l/8, l/10$ da $l/12$ -is mixedviT (nax. 2.11). Zabvis intensivobis faqtori K_I -s mniSvnelobebi gaangariSebuli iqna orive, gadaadgilebis da Zabvis eqstrapolirebis meTodebiT.

miuxedavad imisa, rom bzaris wverosTan sakmaod maRali sixSiris madea, K_I -is mniSvnelobebi, romlebic miRebulia normaluri u_y gadaadgilebebis saSualebiT, aCvenebs nakleb gabnevas, vidre is mniSvnelobebi, romlebic miRebulia vertikaluri σ_y Zabvebis saSualebiT. bzaris wverosTan sasruli elementebis badis sixSiris TandaTanobiTi gazrdis Semdeg, Zabvis intensivobis faqtori K_I -s mniSvnelobebi uaxlovdeba gadaadgilebis da Zabvis eqsrapolirebis meTodebiT miRebul analogiur mniSvnelobebs (nax. 2.11).

unda aRiniSnos, rom sasruli elementebis badis sixSiris aucilebeli xarisxi, romelic saWiroa maRali sizustis Sedegebis



nax. 2.11: Zabvis intensivobis K_I faqtoris gaangariSeba.

misaRebad, ufro maRalia, vidre im SemTxvevisTvis, rodesac bzari ganTavsebulia blokis SuaSi. es gamowveulia Zabvis ufro maRali mniSvnelobiT blokis fuZeSi.

SeiZleba davaskvnaT, rom gadaadgilebis eqstrapolirebis meTodi ufro uxeSi badis SemTxvevaSic ki iZleva K_I –is ufro misaReb sidideebs, vidre Zabvis eqstrapolirebis meTodi. miuxedavad amisa, rodesac bzari ganTavsebulia blokis fuZeSi, badis sixSiris aucilebeli xarisxi gacilebiT maRalia, vidre im SemTxvevaSi, rodesac bzari blokis SuaSia. es Sedegebi kargad emTxveva imaT, romlebic miRebulia rvakvanZiani izoparametruli kvadratuli singularuli sasruli elementebis gamoyenebiT. aqedan SeiZleba davaskvnaT, rom interfeisis izoparametruli kvadratuli singularuli sasruli elementebi warmatebiT SeiZleba gamoyenebuli iqnan drekadi sxeulis fuZeSi bzaris warmoSobisa da gavrcelebis amocanis modelirebaSi.

3. neli statikuri cikluri datvirTvebis da betonis asakis gavlena arsebuli gravitaciuli kaSxlis daZabul-deformirebul mdgomareobaze

garda ZiriTadi SeTanwyobisa da SesaZlo gansakuTrebuli SeTanwyobis Zalebisa, arsebuli kaSxlebis DdaZabul-deformirebul mdgomareobaze SesamCnev gavlenas axdens nagebobis asaki da hidrostatikuri dawnevis sididis perioduli cvlileba nagebobis

eqspluataciis istoriis ganmavlobaSi. am ukanasknelSi igulisxmeba wyalsacavis regulirebis grafiki, romlis mixedviTac wyalsacavi garkveuli periodulobiT ivseba da icleba. bunebrivia es problema dgas maregulirebeli wyalsacavebis SemTxvevaSi. hidrostatikuri dawnevis cvlilebis gavlena kaSxlebis muSaobaze miT ufro SesamCnevia, rac ufro maRalia kaSxali.

arsebuli problema pirvelad ganxiluli iqna [30, 31] – Si. Cvens mier moxda am Teoriis morgeba konkretuli nagebobiTvis. faqtiurad am naSromSi pirvelad aris mcdeloba dayvanili iqnas Teoriuli mosazrebebi praqtikul gamoyenebamde. garda amisa, Setanili iqna garkveuli koreqtivebi procesis ganmsazRvrel gantolebaSi, masSi Semavali zogierTi koeficientis dazustebis mxriv.

qvemoT moyvanilia brtyeli deformaciis pirobebSi betonis ganmsazRvreli modelis modificirebis sqema, romlis Sedegad SesaZlebelia gaTvaliswinebuli iqnas neli statikuri cikluri datvirTvebis da betonis asakis (eijingi) gavlena gravitaciuli kaSxlis daZabul-deformirebul mdgomareobaze. yuradReba ZiriTadaT gamaxvilebulia betonis meqanikuri maxasiaTeblebis mniSvnelobebis damokidebulebaze zemod aRniSnul procesebze.

es midgoma saSualebas iZleva mxedvelobaSi miviRoT betonis simtkicis Semcirebis efeqti (daRliloba) cikluri datvirTvebis dros, agreTve asakis efeqti betonis simtkiceze. konkretulad, betonis simtkice erTRerZa kumSvis dros σ_c gantolebebSi 2.2, 2.9 da 2.18, SeiZleba Seicvalos betonis simtkiciT, romelic modificirebulia datvirTva-gantvirTvis n ciklebisa da kaSxlis eqspluataciis t periodis gaTvaliswinebiT:

$$\sigma_c = \sigma_c(n, t) \tag{3.1}$$

fardobiTi ε_c deformaciis mniSvneloba, romelic Seesabameba betonis maqsimalur normalur mkumSav Zabvas, SeiZleba modificirdes datvirTva-gantvirTvis n ciklebisa da kaSxlis eqspluataciis periodis t Sesabamisad:

$$\varepsilon_c = \varepsilon_c(n, t) \tag{3.2}$$

cnobilia agreTve, rom cikluri datvirTva iwvevs betonis sixistis Semcirebas. amave dros, droTa ganmavlobaSi drekadobis moduli izrdeba. es ori efeqti miiReba mxedvelobaSi SemoTavazebul midgomaSi betonis sawyisi drekadobis modulis modificirebiT datvirTva-gantvirTvis n ciklebis kaSxlis eqspluataciis periodis t Sesabamisad:

$$E_0 = E_0\,(n,\,t) \tag{3.3}$$

cikluri datvirTvebi. cikluri datvirTva iwvevs nagebobis mniSvnelovan arawrfiv muSaobas da masalis meqanikuri maxasiaTeblebis sagrZnob cvlilebas. Sedegad vRebulobT imas, rom datvirTva-gantvirTvis (wyalsacavis avseba-dacla) ciklebis ricxvis gazrdis Sedegad sagrZnoblas mcirdeba betonis meqanikuri maxasieTebeli – drekadobis moduli.

naSromSi veyrdnobiT im empirikul damokidebulebebs, romlebic miRebuli iyo eqsperimentuli kvlevebis Sedegad da gamoqveynebulia [32]–Si. eqsperimentebi Catarda enguris TaRovani kaSxlidan amoRebul betonis nimuSebze, romlebic periodulad itvirTeboda-ganitvirTeboda neli cikluri mkumSavi datvirTvebiT. cdebis Sedegebis interpolirebis Semdeg, Sedga qvemod moyvanili damokidebulebebi, romlebic aRweren betonis maxasiaTeblebis gauaresebis process datvirTva-gantvirTvis ciklebTan damokidebulebaSi.

$$\begin{aligned}\sigma_c(n) &= (1 - a_\sigma^n \lg n)\sigma_c \\ E_0(n) &= (1 - a_E^n \lg n)E_0 \\ \varepsilon_c(n) &= (1 - a_\varepsilon^n \lg n)\varepsilon_c\end{aligned} \tag{3.4}$$

sadac a_σ^n, a_E^n da a_ε^n parametrebi aRweren betonis maxasiaTeblebis gauaresebis process cikluri datvirTvebis dros. n aris datvirTva-gantvirTvis ciklebis raodenoba, romelic Seesabameba kaSxlis eqspluataciis periodSi wyalsacavis avseba-daclis ciklebis raodenobas.

gamokvlevebma dagvanaxa, rom zemod moyvanili parametrebis mniSvnelobebi SeiZleba icvlebodes garkveul farglebSi betonis sxvadasxva klasisaTvis da maTi konkretuli mniSvnelobebi SeiZleba miRebuli iqnas mxolod betonis nimuSebis ciklur datvirTvebze gamocdis Sedegad. konkretulad, xsenebuli parametrebis mniSvnelobebi icvleba Semdeg diapazonebSi:

$$\begin{aligned} 0{,}05 \le a_{\sigma}^{n} \le 0{,}25 \\ 0{,}10 \le a_{E}^{n} \le 0{,}30 \\ 0{,}10 \le a_{\varepsilon}^{n} \le 0{,}30 \end{aligned} \qquad (3.5)$$

am naSromSi gamoyenebilia [32]-Si moyvanili konkretuli ricxviTio mniSvnelobebi. sainteresoa aRiniSnos, rom masalis parametrebis gauaresebis maCvenebeli da betonis simtkice pirdapir damokidebulia ZabviT mdgomareobaze, e.i. betonis nimuSis datvirTvis sidideze. magaliTad, betonis nimuSis drekadobis modulis mniSvneloba Semcirda 51,5% -iT (39780-dan 19300 mpa-de) 150 datvirTva-gantvirTvis ciklis modebis Semdeg, rodesac modebuli Zalisgan gamowveuli Zabva toli iyo $0.2\sigma_c$ –is, sadac σ_c aris betonis simtkice erTRerZa kumSvis dros.

rodesac modebuli Zalisgan gamowveuli Zabva toli iyo $0.5\sigma_c$ –is betonis nimuSis drekadobis modulis mniSvneloba Semcirda 29,3% -iT (33390-dan 23620 mpa-de) 150 datvirTva-gantvirTvis ciklis modebis Semdeg da rodesac modebuli Zalisgan gamowveuli Zabva toli iyo $0.8\sigma_c$ –is betonis nimuSis drekadobis modulis mniSvneloba Semcirda 20,9% -iT (28390-dan 22500 mpa-de) igive raodenobis datvirTva-gantvirTvis ciklis modebis Semdeg.

naSromSi Cven gamoviyeneT zemod moyvanili koeficientebis gasaSualoebuli mniSvnelobebi, romlebis kargad aRweren nagebobis realur muSaobas cikluri datvirTvebis dros.

aqve unda aRiniSnos, rom masalis maxasiaTeblebis da betonis simtkicis gauaresebis xarisxi statikuri cikluri datvirTvebis dros damokidebulia agreTve gamosacdeli betonis nimuSis asakze. magaliTad, 28 dRis asakis betonis nimuSis drekadobis modulis mniSvneloba Semcirda 51,5%-iT (39780-dan 19300 mpa-de) 150 datvirTva-gantvirTvis

ciklis modebis Semdeg da rodesac modebuli Zalisgan gamowveuli Zabva toli iyo $0.2\sigma_c$ – is. amave dros, 365 dRis (1 weliwadi) asakis betonis nimuSis drekadobis modulis mniSvneloba Semcirda 49,0%-iT (39830-dan 21750 mpa-de) 150 datvirTva-gantvirTvis ciklis modebis Semdeg da rodesac modebuli Zalisgan gamowveuli Zabva toli iyo $0.2\sigma_c$ – is. 1825 dRis (5 weliwadi) asakis betonis nimuSis drekadobis modulis mniSvneloba Semcirda 42,0%-iT (42460-dan 20310 mpa-de) igive raodenobis datvirTva-gantvirTvis ciklis modebis Semdeg da rodesac modebuli Zalisgan gamowveuli Zabva toli iyo $0.2\sigma_c$ – is. es monacemebi miuTiTebs sxvaoba ar aris mniSvnelovani da praqtikuli miznebisaTvis es SeiZleba ignorirebuli iyos.

masalis asaki (eijingi). analogiuri midgoma iqna gamoyenebuli betonis asakis gavlenis Sesaswavlad gravitaciuli kaSxlis daZabul-deformirebul mdgomareobaze. betonis meqanikuri maxasiaTeblebis droSi cvlilebis dasadgenad kvlav gamoyenebuli iqna logariTmuli funqcia. es damokidebulebebi SeiZleba Semdegnairad Caiweros:

$$\begin{aligned} \sigma_c(t) &= (1 + a_\sigma^t \lg t)\sigma_c \\ E_0(t) &= (1 + a_E^t \lg t)E_0 \\ \varepsilon_c(t) &= (1 + a_\varepsilon^t \lg t)\varepsilon_c \end{aligned} \tag{3.6}$$

sadac a_σ^t, a_E^t da a_ε^t parametrebi aRweren betonis maxasiaTeblebis cvlilebis process betonis asakTan damokidebulebaSi. t aris wlebis raodenoba, romelic Seesabameba kaSxlis eqspluataciis periods.

gamokvlevebma dagvanaxa, rom zemod moyvanili parametrebis mniSvnelobebi SeiZleba icvlebodes garkveul farglebSi betonis sxvadasxva klasisaTvis da maTi konkretuli mniSvnelobebi SeiZleba miRebuli iqnas mxolod arsebuli nagebobidan sxvadasxva asakis betonis nimuSebis gamocdis Sedegad. konkretulad, xsenebuli parametrebis mniSvnelobebi icvleba Semdeg diapazonebSi:

$$\begin{aligned} 0{,}05 \le a_\sigma^t &\le 0{,}15 \\ 0{,}05 \le a_E^t &\le 0{,}15 \\ 0{,}05 \le a_\varepsilon^t &\le 0{,}10 \end{aligned} \tag{3.7}$$

parametrebis aRnisnuli mniSvnelobebi mocemulia [32]-Si da isini miRebulia enguris kaSxlidan sxvadaxva periodSi amoRebuli nimuSebis gamocdas. kargad Cans, rom $a_{\sigma}^{t}, a_{E}^{t}$ da a_{ε}^{t} parametrebis mniSvnelobebi zogadad naklebia $a_{\sigma}^{n}, a_{E}^{n}$ da a_{ε}^{n} - mniSvnelobebze. es miuTiTebs imaze, rom asakis gavlena betonis Zabva-deformaciebis mrudze naklebia, vidre cikluri datvirTvebis. miuxedavad amisa, aRsaniSnavia, rom SesaZlebelia arsebobdes eqspluataciis wlebis da ciklebis raodenobis sxvadasxva kombinaciebi. magaliTad, eqspluataciis periodSi wyalsacavi icleba da ivseba weliwadSi erTxel, maSin ciklebis raodenoba emTxveva eqspluataciis wlebis raodenobas (n=t), magram, Tu cikli weliwadSi orjer xdeba, maSin ciklebis raodenoba eqsoluataciis wlebze orjer metia (n=2t).

betonis zemod moyvanili meqanikuri maxasiaTeblebi CarTuli arian (2.1) konstituciur gantolebaSi, raTa Seswavlili iqnad betonis gadaRla cikluri datvirTvebisa da asakis gavlenis Sedegad.

- *analizis Sedegebi*

analizebSi betonis asakis efeqti Seswavlili iqna ciklur zemoqmedebebTan erTad. analizis mizani iyo dadgeniliyo, Tu rogor icvleboda betonis meqanikuri maxasiaTeblebi betonis asakTan da nel statikur ciklur datvirTvebTan erTad da ra gavlenas axdens isini betonis Zabva-deformaciebis mrudze brtyeli deformaciis da brtyeli daZabuli mdgomareobis farglebSi. analizebi Catarda kumSva-kumSvisa da kumSva-gaWimvis datvirTvebisaTvis. gaWimva-gaWimvis variantisaTvis daSvebulia, rom is aRwers wrfivad process da simtkice gaWimvaze icvleba kumSvaze simtkicis proporciulad.

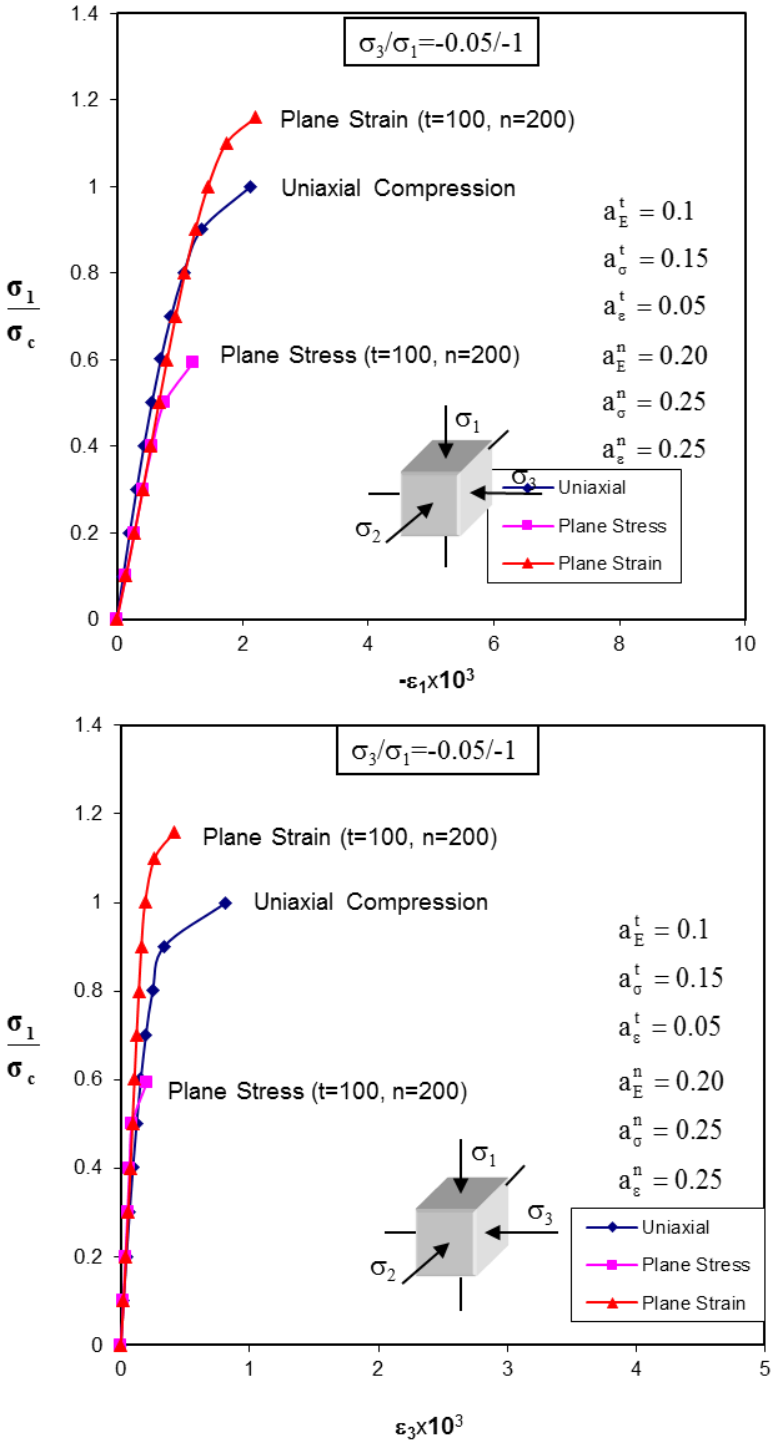
jamSi Catarda 200-de kompiuteruli angariSebi α-s sxvadasxva mniSvnelobebisaTvis (α aris minimaluri mTavari mimarTulebis dros Zabvis mniSvnelobis fardoba da maqsimaluri mTavari mimarTulebis dros arsebul ZabvasTan), rodesac t=0, 10, 25, 50 da 100, agreTve rodesac n = t da n = 2t.

nax. 3.1 – 3.4 –ze mocemulia analizis Sedegebi datvirTvis sxvadasxva formebis dros. zogadad ricxviTma angariSebma AaCvena, rom masalis meqanikuri maxasiaTeblebis mniSvnelovani Semcireba xdeba ukve maSin, rodesac n=10.

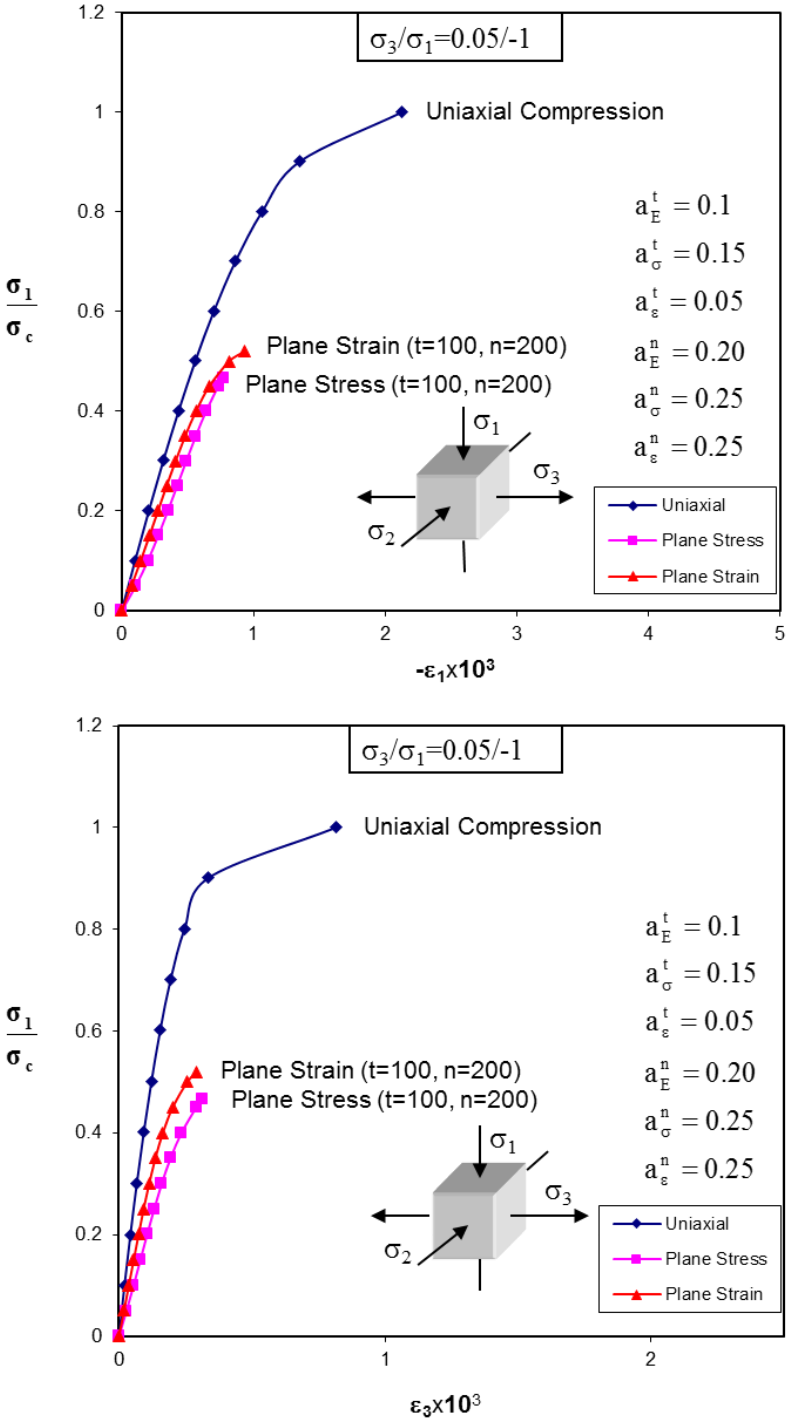
zogadi daskvna SeiZleba gakeTdes Semdegnairi: betonis meqanikuri maxasiaTeblebis gauaresebis xarisxi izrdeba datvirTva-gantvirTvis n ciklebis gazrdasTan erTad. betonis asaks aqvs garkveuli dadebiTi efeqti betonis meqanikuri maxasiaTeblebze, magram maTi gauaresebis xarisxi orive xsenebuli faqtoris erToblivi moqmedebis dros kvlav rCeba mniSvnelovani. magaliTad, rodesac $\alpha = -0{,}15$, $t=100$ and $n=200$, nimuSi irRveva da Cndeba bzari brtyeli deformaciis mdgomareobis SemTxvevaSi, rodesac mkumSavi Zabva utoldeba erTRerZa kumSvis dros betonis simtkicis daaxloebiT 20%-s.

3.1. etapi R-4: cikluri datvirTvebisa da betonis asakis gavlena interfeisebze

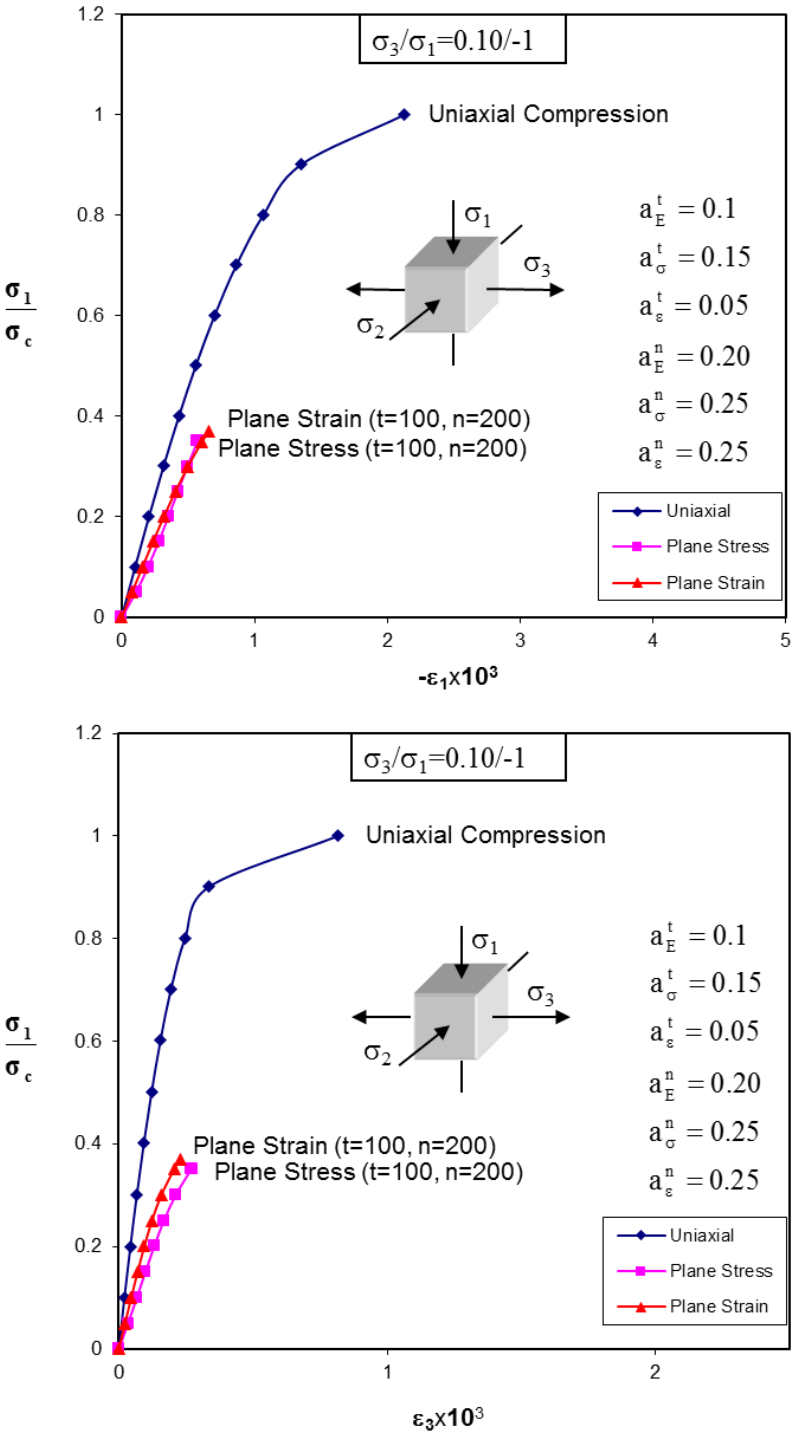
Zvris cdebidan, romlebic iTvaliswineben agreTve statikur ciklur datvirTvebs, mxebi Zabvebi-fardobiTi gadaadgilebebis mrudebis miReba sakmaod rTulia. amitom veyrdnobiT wina paragrafSi moyvanil cikluri datvirTvebisa da betonis asakis gavlenis ricxviT Sefasebebs uSualod kaSxlis tanSi. SeiZleba davaskvnaT, rom datvirTva-gantvirTvis ciklebis did raodenoba Seamcirebs interfeisebis simtkices.



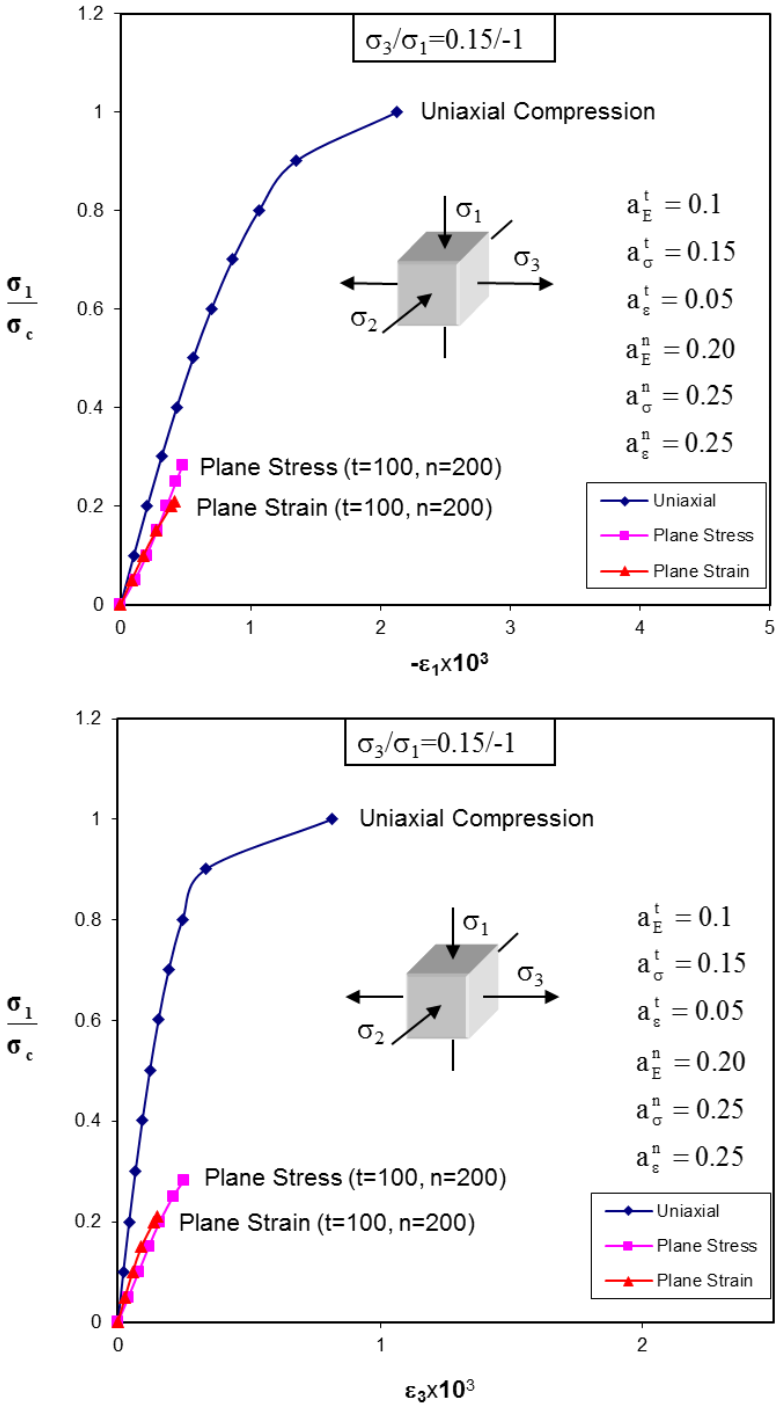
nax. 3.1: betonis erTRerZa kumSvis cdis, brtyeli daZabuli da brtyeli deformaciebis Sedegebis Sedareba (kumSva-kumSva) n ciklebisa t asakis mxedvelobaSi mixedviT, rodesac α=0,05.



nax. 3.2: betonis erTRerZa kumSvis cdis, brtyeli daZabuli da brtyeli deformaciebis Sedegebis Sedareba (gaWimva-kumSva) n ciklebisa t asakis mxedvelobaSi mixedviT, rodesac α= - 0,05.



nax. 3.3: betonis erTRerZa kumSvis cdis, brtyeli daZabuli da brtyeli deformaciebis Sedegebis Sedareba (gaWimva-kumSva) n ciklebisa t asakis mxedvelobaSi mixedviT, rodesac α= - 0,10.



nax. 3.4: betonis erTRerZa kumSvis cdis, brtyeli daZabuli da brtyeli deformaciebis Sedegebis Sedareba (gaWimva-kumSva) n ciklebisa t asakis mxedvelobaSi mixedviT, rodesac α= - 0,15.

cikluri datvirTvis gavlena k_s^0 Zvris simtkiceze SeiZleba gaTvaliswinebuli iqnas sawyisi Zvris sixistis modifikaciis gziT $\left(k_s^0\right)^{\sigma_n=0}$ nulovani normaluri ZabvasTan

damokidebulebaSi. wina paragrafis analogiurad, SeiZleba gamoviyenoT Semdegi empirikuli damokidebuleba nulovan normalur ZabvasTan asocirebuli $\left(k_s^0\right)^{\sigma_n=0}$ sawyisi Zvris sixistis sididis vardnis dasadgenad. datvirTva-gantvirTvis n ciklebTan damokidebulebiT xsenebuli damokidebuleba Caiwereba Semdegnairad:

$$\left(k_s^0\right)^{\sigma_n=0} = (1 - a_k^n \lg n)\left(k_s^0\right)^{\sigma_n=0} \tag{3.8}$$

sadac:

a_k^n - parametri, romelic aRwers nulovan normalur ZabvasTan asocirebuli sawyisi Zvris sixistis sididis vardnas statikuri cikluri datvirTebis dros;

n - kaSxlis eqspluataciis Sesabamisi datvirTva-gantvirTvis ciklebis raodenoba.

statikuri cikluri datvirTebis Sedegad interfeisebSi Zvris simtkicis vardna SeiZleba gaTvaliswinebuli iqnas *c* SeWidulobis sididis modificirebiT (2.30) gamosaxulebaSi. Zvris simtkicis vardna datvirTva-gantvirTvis n ciklebTan damokidebulebSi SeiZleba ganisazRvros Semdegi empirikuli damokidebulebidan:

$$\tau_c = c(1 - a_\tau^n \lg n) + \sigma_n \tan\phi \tag{3.9}$$

sadac:

a_τ^n - parametri, romelic aRwers SeWidulobis sididis vardnas statikuri cikluri datvirTebis dros;

zemod naxsenebi koeficientebi icvleba Semdeg farglebSi:

$$\begin{aligned} 0{,}10 \le a_\tau^n \le 0{,}25 \\ 0{,}15 \le a_k^n \le 0{,}30 \end{aligned} \tag{3.10}$$

betonis asaki gaTvaliswinebuli iqna analogiuri gziT. kerZod, nulovan normalur ZabvasTan asocirebuli sawyisi Zvris sixistis sididis vardnis ganisazRvreba Semdegi gamosaxulebiT:

$$\left(k_s^0\right)^{\sigma_n=0} = (1+a_k^t \lg t)\left(k_s^0\right)^{\sigma_n=0} \tag{3.11}$$

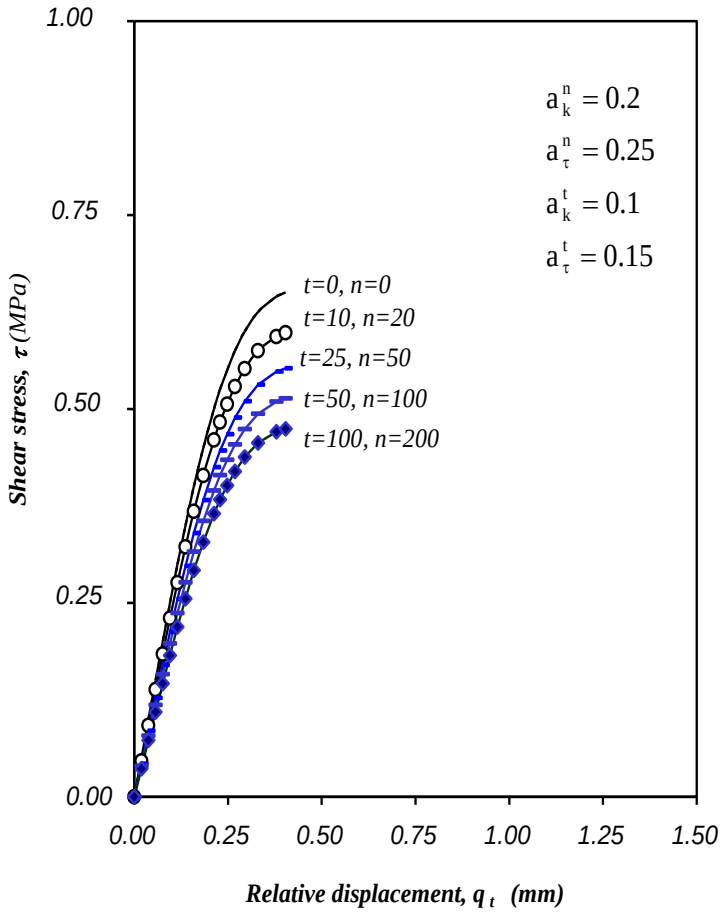
interfeisebSi Zvris simtkiceze asakis gavlena ganisazRvreba Semdegi formuliT:

$$\tau_c = c(1+a_\tau^t \lg t) + \sigma_n \tan\phi \tag{3.12}$$

Sesabamisi koeficientebis mniSvnelobebi icvleba Semdeg farglebSi:

$$\begin{aligned} 0{,}05 \le a_\tau^t \le 0{,}15 \\ 0{,}10 \le a_k^t \le 0{,}20 \end{aligned} \tag{3.13}$$

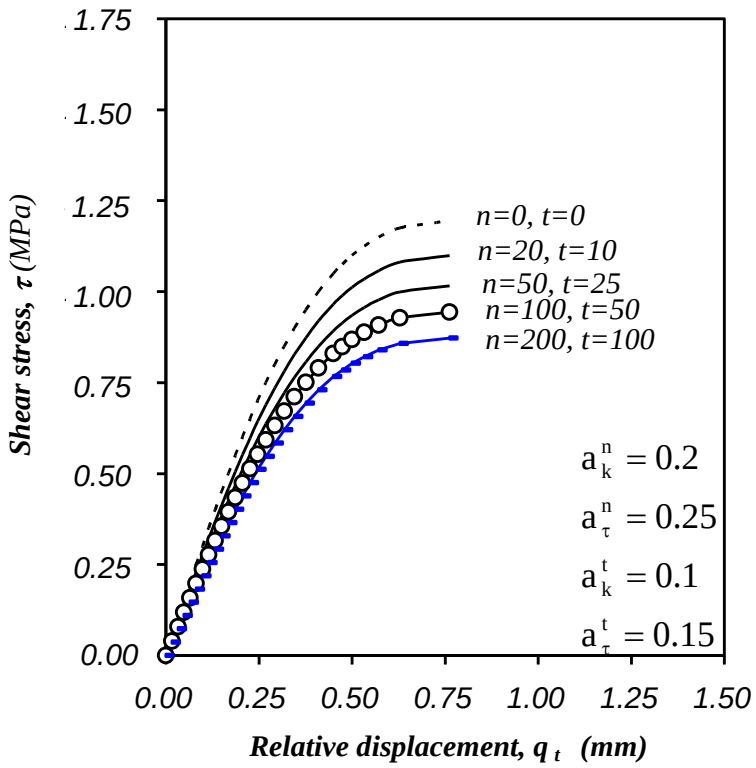
angariSebis ramodenime Sedegi mocemulia nax. 3.5 – 3.6-ze. isini cikluri datvirTvebis da betonis asakis gavlenas interfeisSi mxebi Zabva-fardobiTi gadaadgilebebis mrudebze. cxadad Cans, rom cikluri datvirTvebi iwveven sakontaqto kavSirebis masalis maxasiaTeblebis mniSvnelovan vardnas. aqedan gamomdinare, sadac SesaZlebelia, unda mimdinareobdes monitoring, raTa misi masalebi gamoyenebuli iqnas zemod moyvanili parametrebis modificirebisaTvis arsebul mdgomareobasTan Sesabamisad.



σ_n =3.08 kg/sm^2
c =3.1 kg/sm^2
tanϕ =1.1
k_{so} =230.0 kg/cm^3
a=10.0 kg/sm^3
n=1
P_a =1.033 kg/cm^2

$$A = \frac{1}{3}\left(\frac{\sigma_n}{c+\sigma_n \tan\phi}\right)^2 + \frac{2}{3}\left(\frac{\sigma_n}{c+\sigma_n \tan\phi}\right) + \frac{4}{3}$$

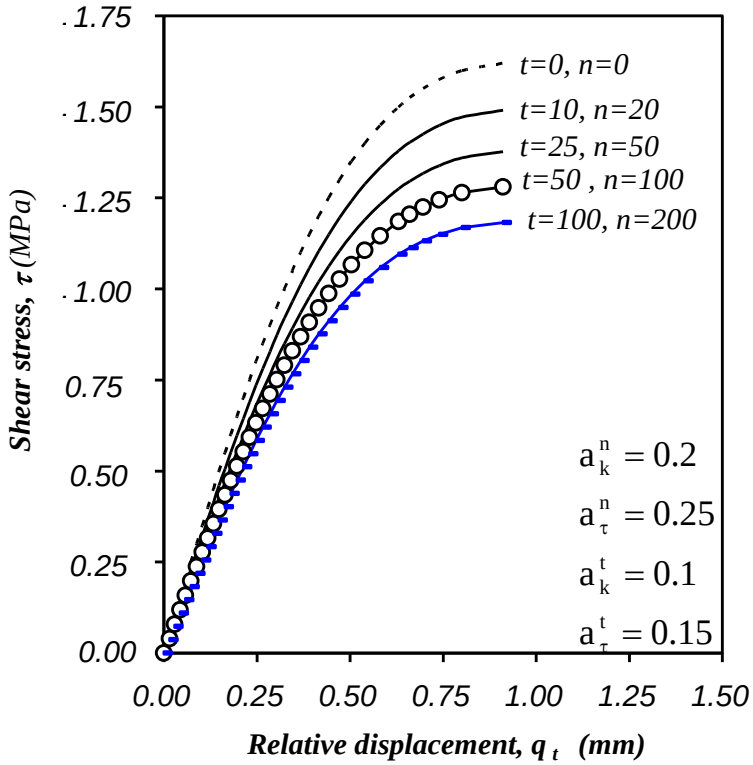
nax. 3.5: betonsa da kldes Soris interfeisSi mxebi Zabva-fardobiTi gadaadgilebis mrudebi cvalebadi A parametris SemTxvevebSi n datvirTva-gantvirTvis ciklebis raodenobasTan da t betonis asakTan kavSirSi.



σ_n =8.01 kg/sm^2
c =3.1 kg/sm^2
tanϕ =1.1
k_{so} =230.0 kg/cm^3
a=10.0 kg/sm^3
n=1
P_a =1.033 ka/cm^2

$$A = \frac{1}{3}\left(\frac{\sigma_n}{c + \sigma_n \tan\phi}\right)^2 + \frac{2}{3}\left(\frac{\sigma_n}{c + \sigma_n \tan\phi}\right) + \frac{4}{3}$$

nax. 3.6: betonsa da kldes Soris interfeisSi mxebi Zabva-fardobiTigadaadgilebis mrudebi cvalebadi A parametris SemTxvevebSi n datvirTva-gantvirTvis ciklebis raodenobasTan da t betonis asakTan kavSirSi.



σ_n =11.89 kg/sm^2
c =3.1 kg/sm^2
tanϕ =1.1
k_{so} =230.0 kg/cm^3
a=10.0 kg/sm^3
n=1
P_a =1.033 kg/cm^2

$$A=\frac{1}{3}\left(\frac{\sigma_n}{c+\sigma_n\tan\phi}\right)^2+\frac{2}{3}\left(\frac{\sigma_n}{c+\sigma_n\tan\phi}\right)+\frac{4}{3}$$

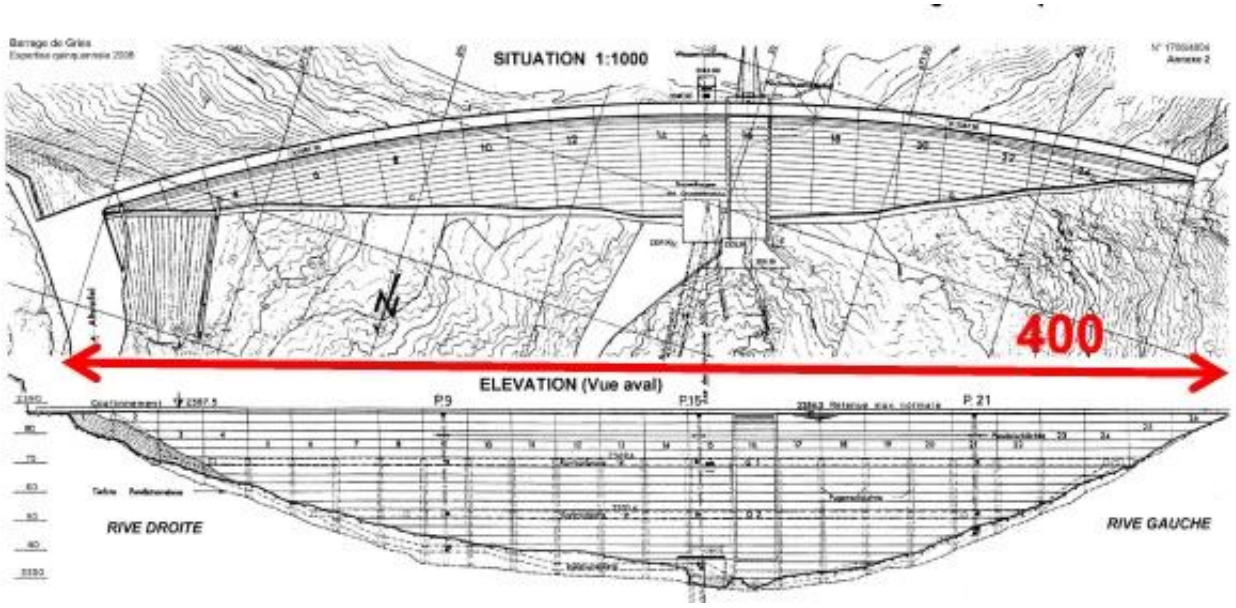
nax. 3.7: betonsa da kldes Soris interfeisSi mxebi Zabva-fardobiTigadaadgilebis mrudebi cvalebadi A parametris SemTxvevebSi n datvirTva-gantvirTvis ciklebis raodenobasTan da t betonis asakTan kavSirSi.

4. statikuri cikluri datvirTebis da betonis asakis gavlena greisis gravitaciuli kaSxlis daZabul-deformirebul mdgomareobaze

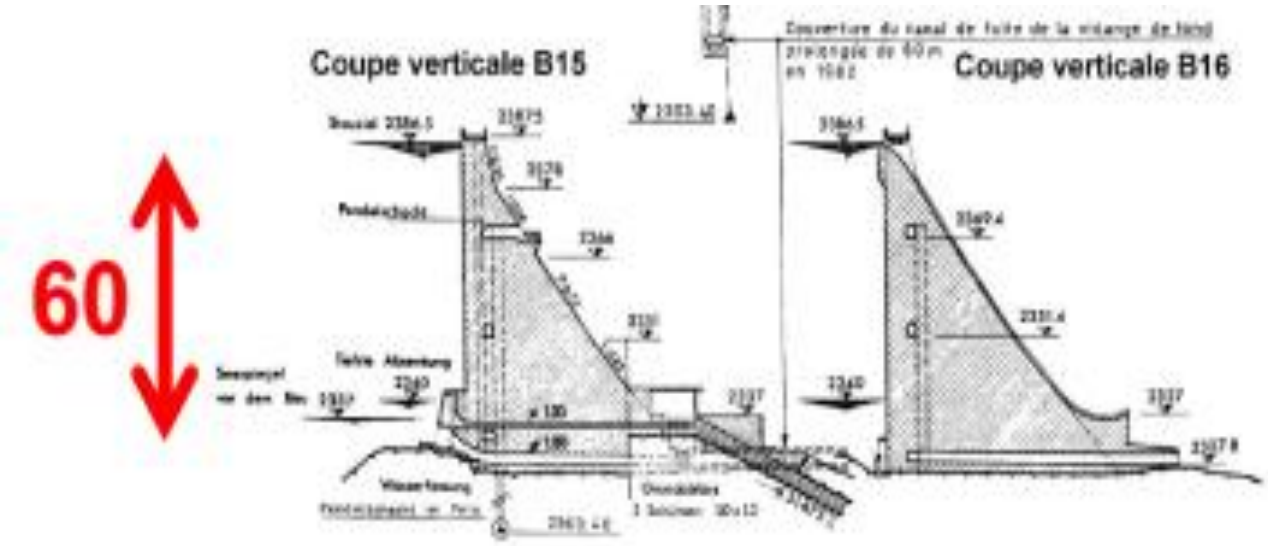
4.1. sawyisi monacemebi

zemod aRwerili meTodika aprobirebuli iqna 60 m simaRlis greisis (Greis) gravitaciuli kaSxlis saangariSod, romelic mdebareobs valaisis (Valais) kantonSi (Sveicaria). is eqspluataciaSi Sevida 1965 wels da dRemde qmnis energetikuli daniSnulebis wyalsacavs[1]. kaSxlis adgilmdebareoba da zogierTi geometriuli parametric mocemulia nax. 4.1, 4.2 da 4.3-ze.

nax. 4.1: greisis kaSxali da misi adgilmdebareoba.



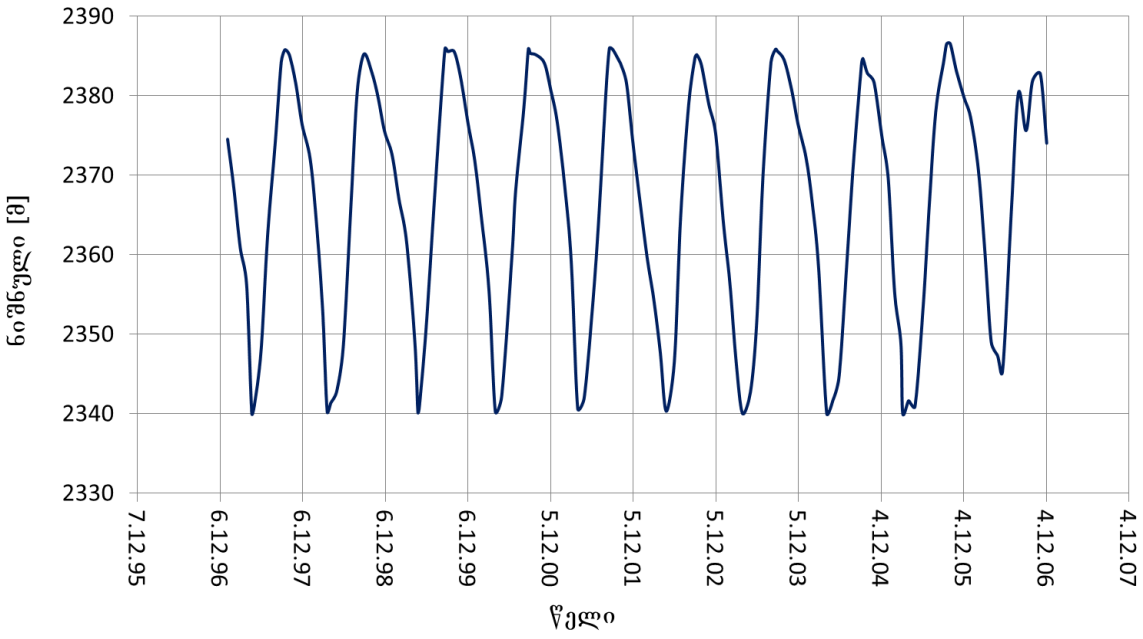
nax. 4.2: greisis kaSxali (gegma da xedi qveda biefidan).



nax. 4.3: greisis kaSxlis centraluri (B15 da B16 blokebi) ganivi Wrilebi.

wyalsacavi ZiriTadaT ikvebeba greisis myinvaris dnobiT. myinvari mdebareobs Sveicariisa da italiis sazRvarze da misi sigrZe daaxloebiT 5 km-ia, xolo farTobi - 5.26 km^2 (2008 wlis monacemebis Tanaxmad). amasTanave, sainteresoa is faqtic, rom rezervuaris sruli Sevsebis dros, normaluri Setborvis done (nSd) aRwevs 2386 metr niSnuls, romelic yvelaze maRalia SveicariaSi arsebul wyalsacavebs Soris.

greisis kaSxali qmnis sezonuri regulirebis energetikul wyalsacavs, romlis sruli moculoba Seadgens 18.6 mln. m^3, xolo sarkis zedapiris farTobi – 0.5 km^2. wyalsacavis avseba-dacla xdeba weliwadSi erTxel. am ciklebis tipuri grafiki mocemulia nax. 4.4 –ze.

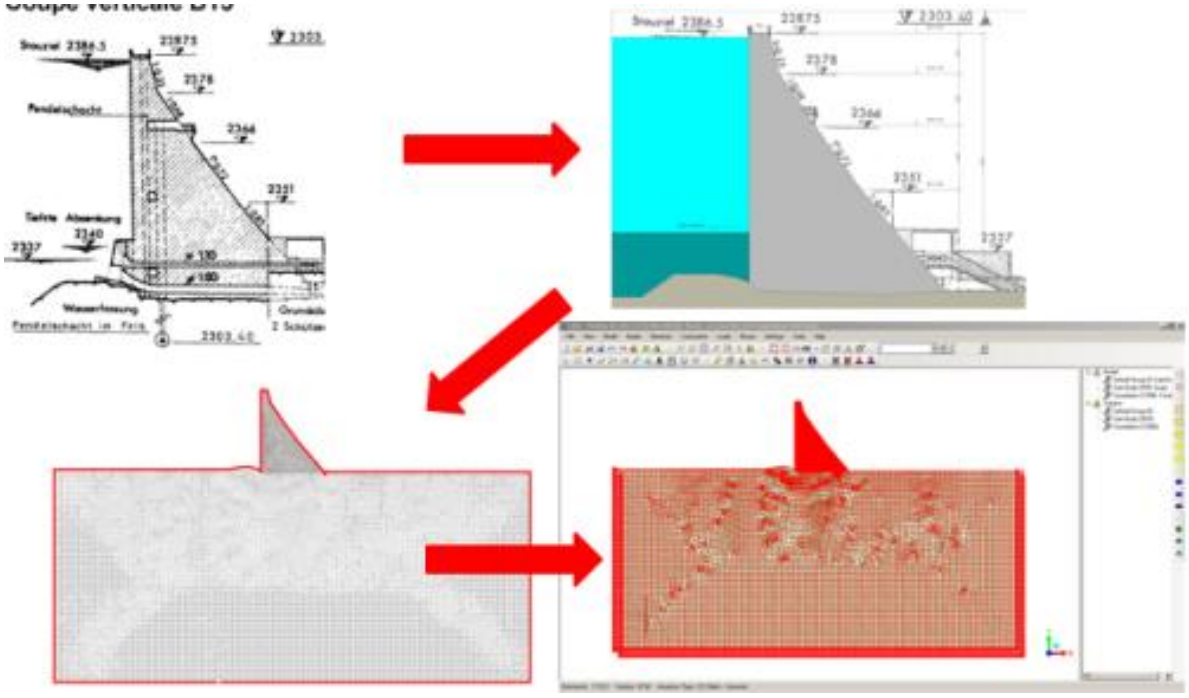


nax. 4.4: greisis kaSxlis wyalsacavis avseba-daclis grafiki (1996-2006 wlebi).

kaSxals aqvs vertikaluri sadawneo waxnagi, xolo udawneo waxnagis daxra icvleba 0,68-dan 0,85-is farglebSi, kaSxlis zeda nawilis daxra (zRvis donidan ∇ 2387,5 –sa da ∇ 2378,0 m-s Soris) tolia 0,25-is. kaSxlis betonis sawyisi drekadobis moduli E_i =20000 mpa ($2*0^6$ t/m^2), puasonis koeficienti – $\nu = 0{,}2$ da simkvrive – $\gamma = 2{,}55$ t/m^3. kaSxali agebulia erTgvarovan kldovan fuZeze. misi drekadobis moduli E_f = 10000 mpa ($1*10^6$ t/m^2), puasonis koeficienti – $\nu_f = 0{,}2$ simkvrive – $\gamma_f = 2.55$ t/m^3.

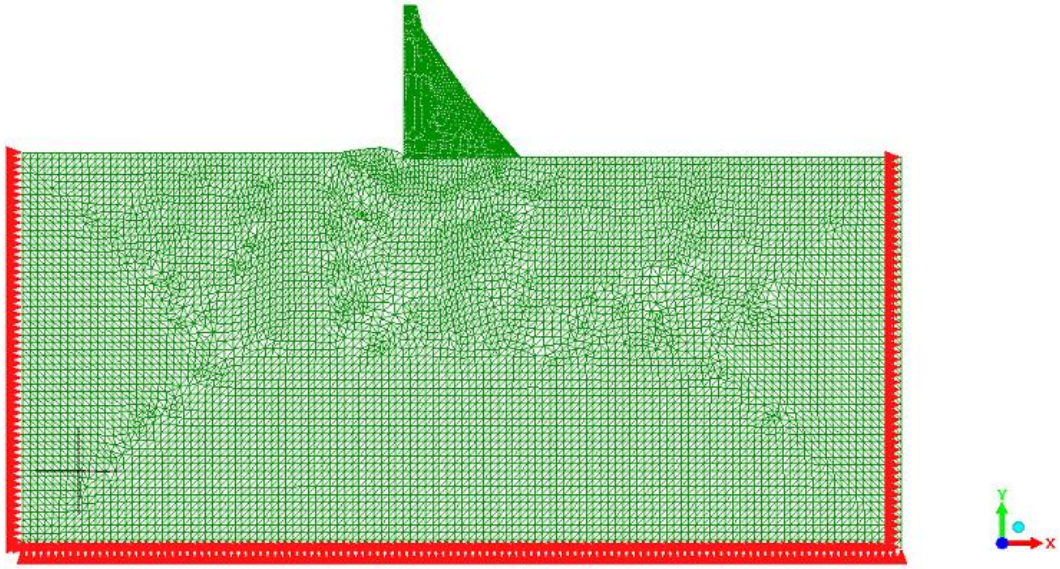
saangariSod gamoyenebuli iqna programa LISA 8.0.0. saangariSo sistemis “greisis kaSxali – fuZe” badis samkuTxa elementebis raodenoba aris 17022, xolo kvanZebis – 8790.

SerCeuli iqna blok B15-is ganivi kveTi, romlis transformacia sasruli elementebis saangariSo sqemad mocemulia nax. 4.5-ze.



nax. 4.5: blok B15-is da misi fuZis sangariSo sqemad SerCevis Tanmimdevroba.

nax. 4.6-ze mocemulia TviT saangariSo sistemis sasrulelementovani sqema.



nax. 4.6: sasruli elementebis meTodiT sangariSo sistema "greisis kaSxali – fuZe".

nax. 4.7-ze mocemulia saangariSo sistemidan amoRebuli fragmenti – TviT kaSxali da fuZis nawili.

statikuri cikluri datvirTebisa da betonis asakis gavlenis Sesaswavlad Tavdapirvelad saWiroa sistemis daZabul deformirebuli mdgomareobis angariSi kaSxlis betonis sawyisi (saproeqto) meqanikuri maxasiaTeblebis gamoyenebiT.

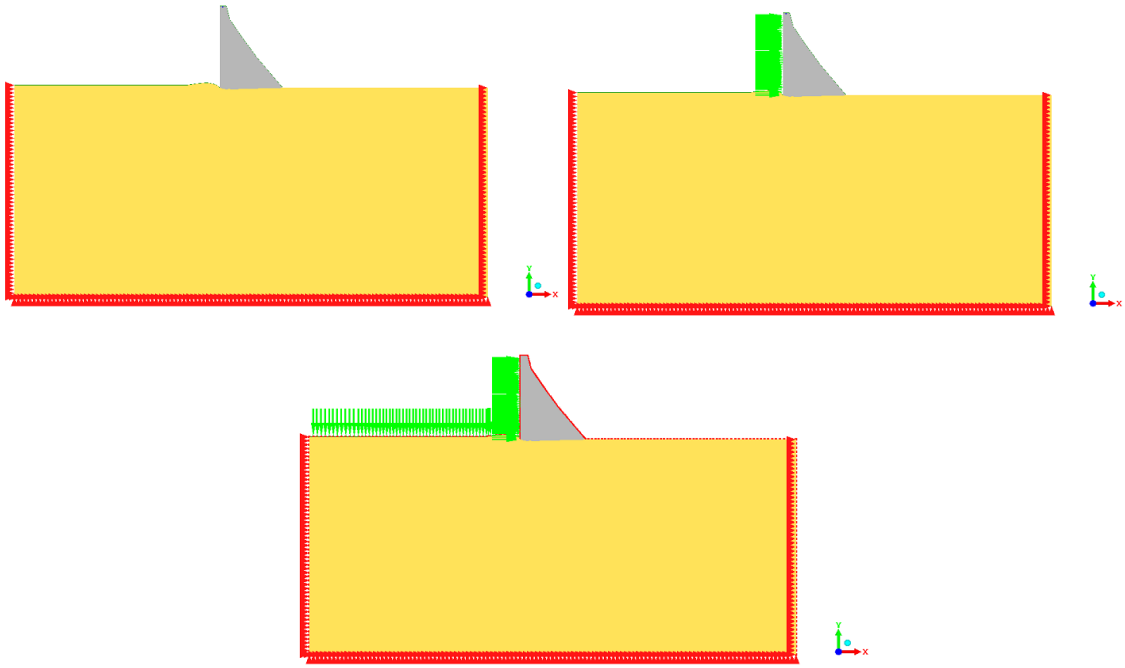
realizebuli iqna Semdegi saangariSo sqemebi, rodesac sistemaze moqmedebs:

1. mxolod kaSxlis sakuTari wona;
2. sakuTariwona da hidrostatikuri dawneva kaSxlis sadawneo waxnagze;
3. sakuTariwona, hidrostatikuri dawneva kaSxlis sadawneo waxnagze da vertikaluri hidrostatikuri dawneva wyalsacavis fuZeze;
4. sakuTari wona, hidrostatikuri dawneva kaSxlis sadawneo waxnagze da vertikaluri hidrostatikuri dawneva wyalsacavis fuZeze betonis modificirebuli meqanikuri maxasiaTebelis (drekadobis moduli) mxedvelobaSi miRebiT, romelic iTvaliswinebs cikluri datvirTvebis gavlenas betonis Tvisebebze;
5. sakuTari wona, hidrostatikuri dawneva kaSxlis sadawneo waxnagze da vertikaluri hidrostatikuri dawneva wyalsacavis fuZeze betonis modificirebuli meqanikuri

maxasiaTebelis (drekadobis moduli) mxedvelobaSi miRebiT, romelic iTvaliswinebs kaSxlis gavlenas betonis Tvisebebze;

yvela am SemTxvevisaTvis gaangariSebuli iqna gadaadgilebebi, fardobiTi deformaciebi, Zabvis komponentebi, mTavari Zabvebi da maTi mimarTulebebi rogorc badis elementebSi, aseve kvanZebSi.

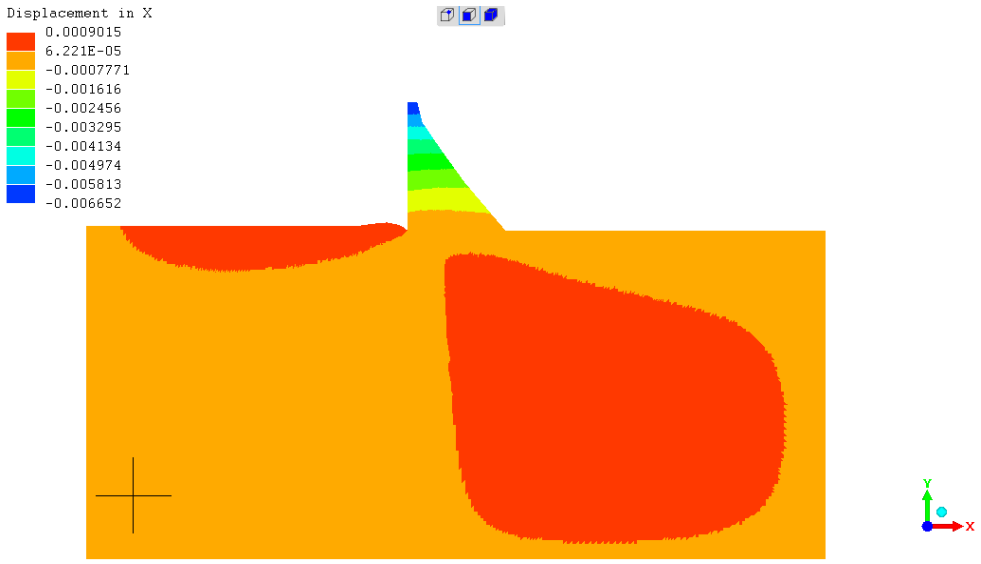
nax. 4.7-ze mocemulia am saangariSo SemTxvevebis ZiriTadi sqemebi



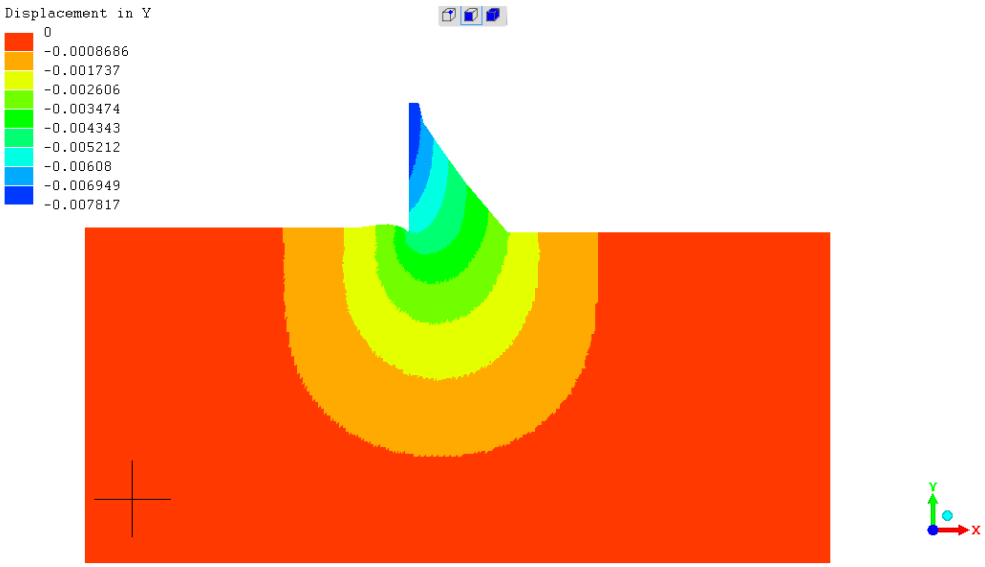
nax. 4.7: saangariSo SemTxvevebis ZiriTadi sqemebi.

4.2. sistemaze moqmedebs mxolod kaSxlis sakuTari wona (samSeneblo SemTxveva)

nax. 4.8 da 4.9-ze mocemulia sistemaSi horizontaluri *u* da vertikaluri *v* gadaadgilebebis izoubnebi.



nax. 4.8: sistemis horizontaluri u (X RerZis mimarTulebiT) gadaadgilebebis izoubnebi.

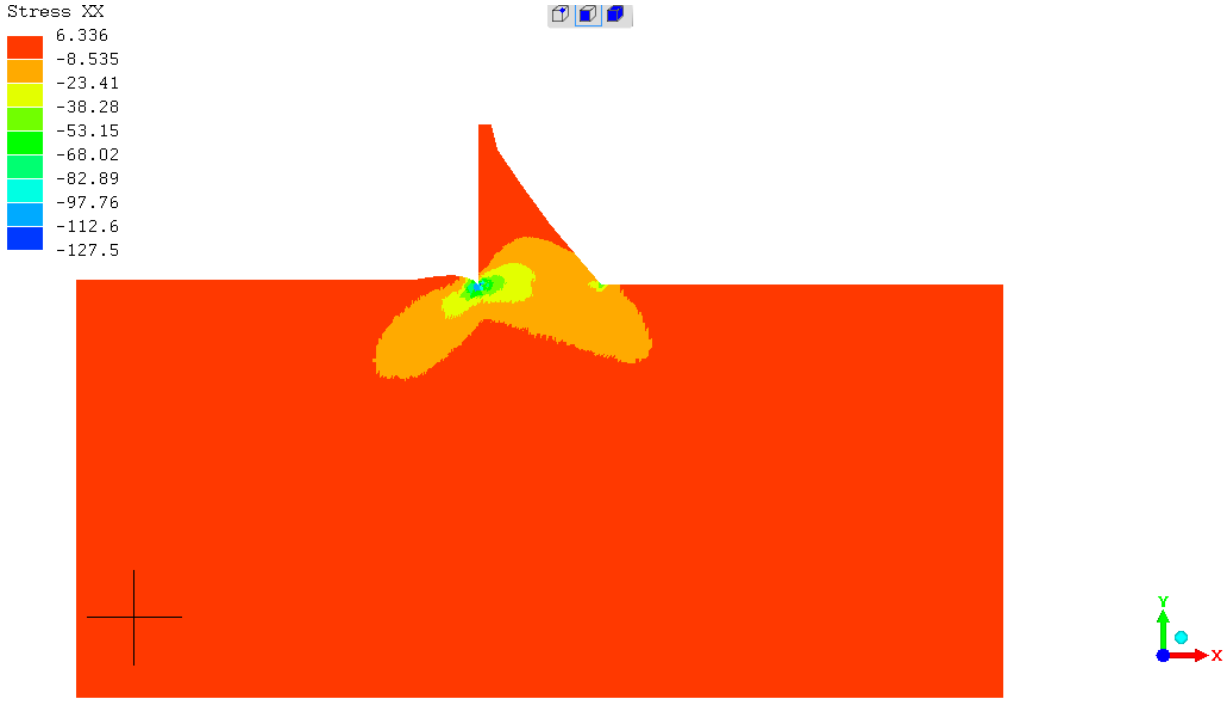


nax. 4.9: sistemis vertikaluri v (Y RerZis mimarTulebiT) gadaadgilebebis izoubnebi.

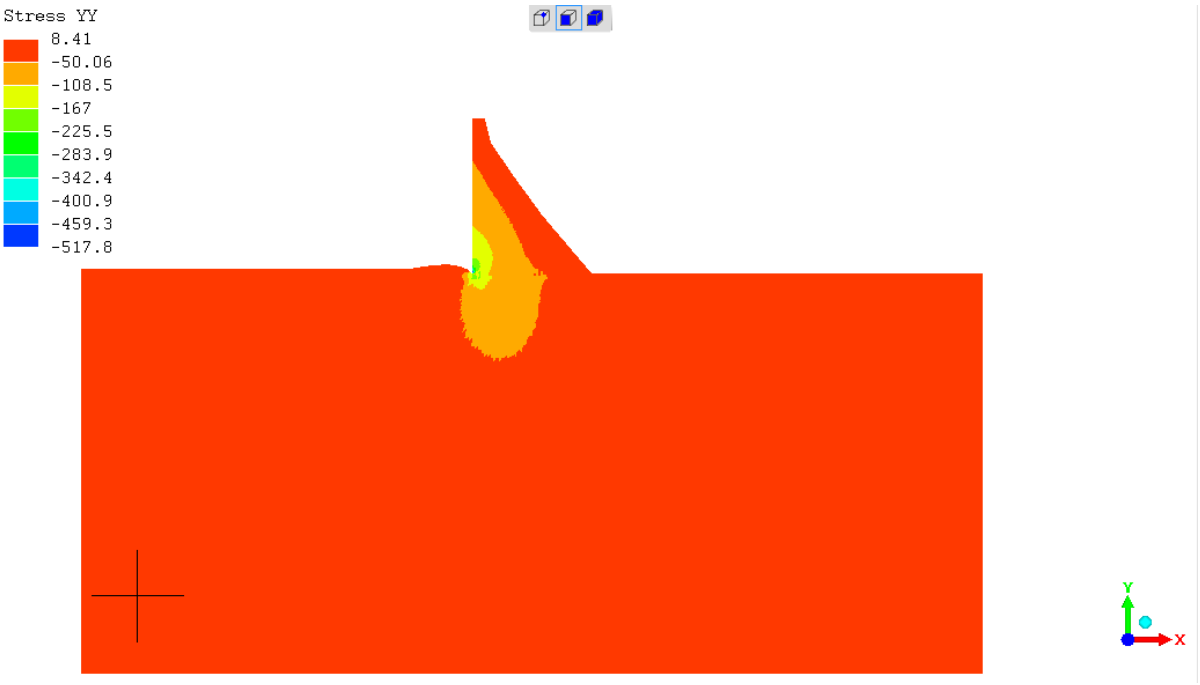
Sedegebidan Cans, rom maqsimaluri horizontaluri gadaadgilebebi (-0,665 sm) fiqsirdeba kaSxlis Txemis zonaSi (muqi lurji feri)

da meTodurad mcirdeba fuZisaken. aRsaniSnavia is, rom gadaxris veqtori mimarTulia zeda biefisaken. analogiuri situaciaa vertikaluri gadaadgilebebis mxrivac. maqsimaluri vertikaluri gadaadgilebebi (-0,782 sm) aRiniSneba kaSxlis Txemis zonaSi da vrceldeba sadawneo waxnagis TiTqmis Suamde (muqi lurji feri). yuradRebas iqcevs vertikaluri gadaadgilebis suraTi fuZeSi. misi suraTi kargad emTxveva businesskis klasikuri amocanis (vertikaluri Seyursuli Zala naxevarsibrtyis zedapirze) Tvisobriv Sedegs, rac miuTiTebs Cveni sangariSo sqemis sizusteze.

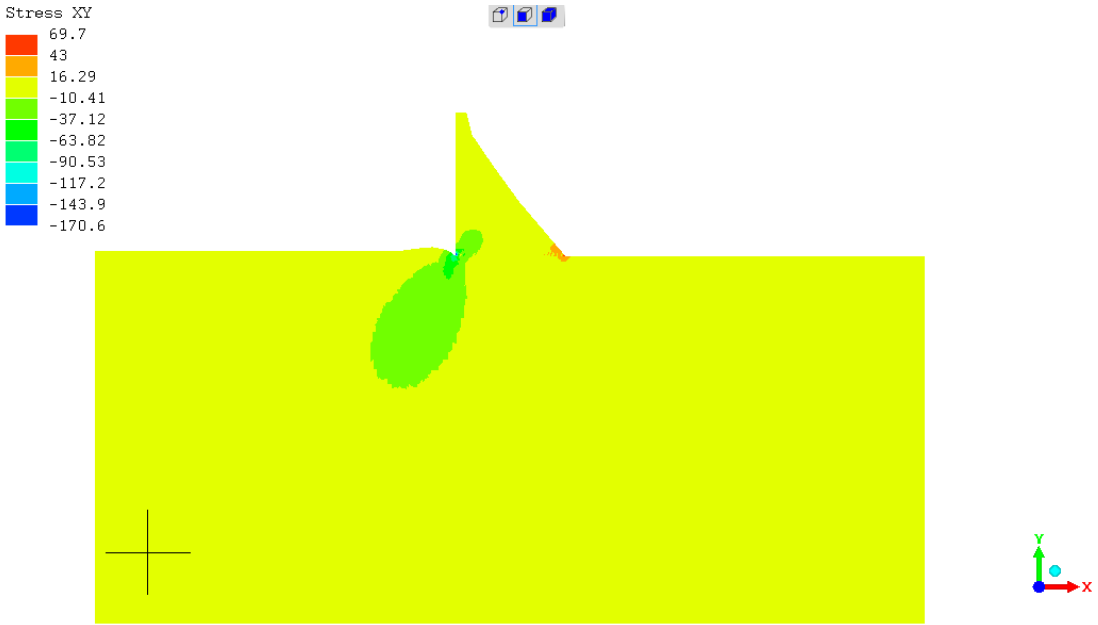
nax. 4.10, 4.11, 4.12 da 4.13-ze mocemulia sistemaSi horizontaluri normaluri σ_x, vertikaluri normaluri σ_y, mxebi τ da maqsimaluri mTavari σ_1 Zabvebis izoubnebi.



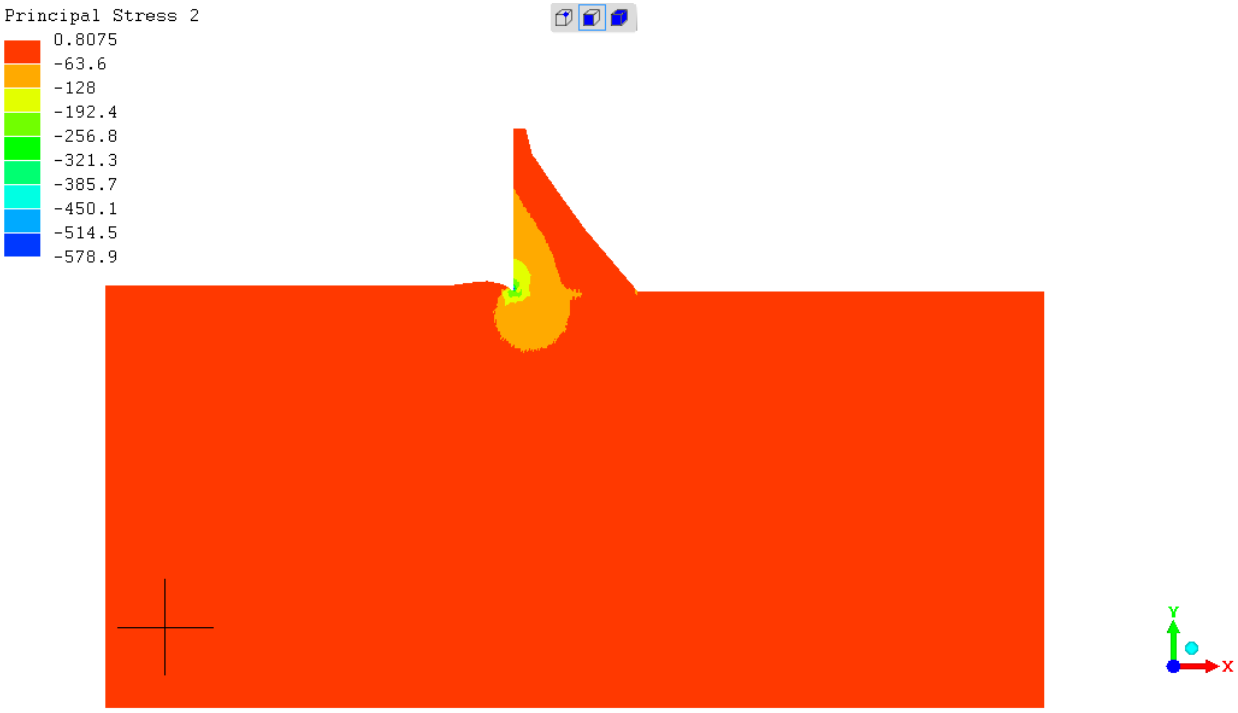
nax. 4.10: horizontaluri normaluri σ_x Zabvebis izoubnebi.



nax. 4.11: vertikaluri normaluri σ_y Zabvebis izoubnebi.



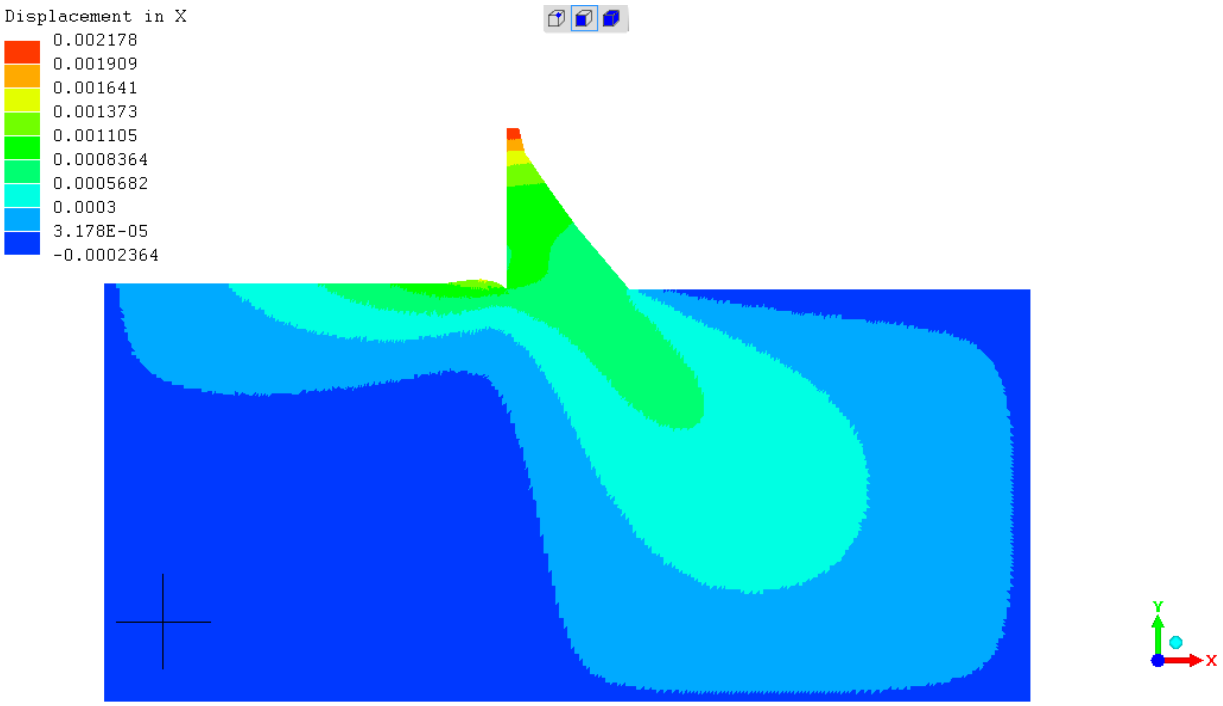
nax. 4.12: mxebi τ Zabvebis izoubnebi.



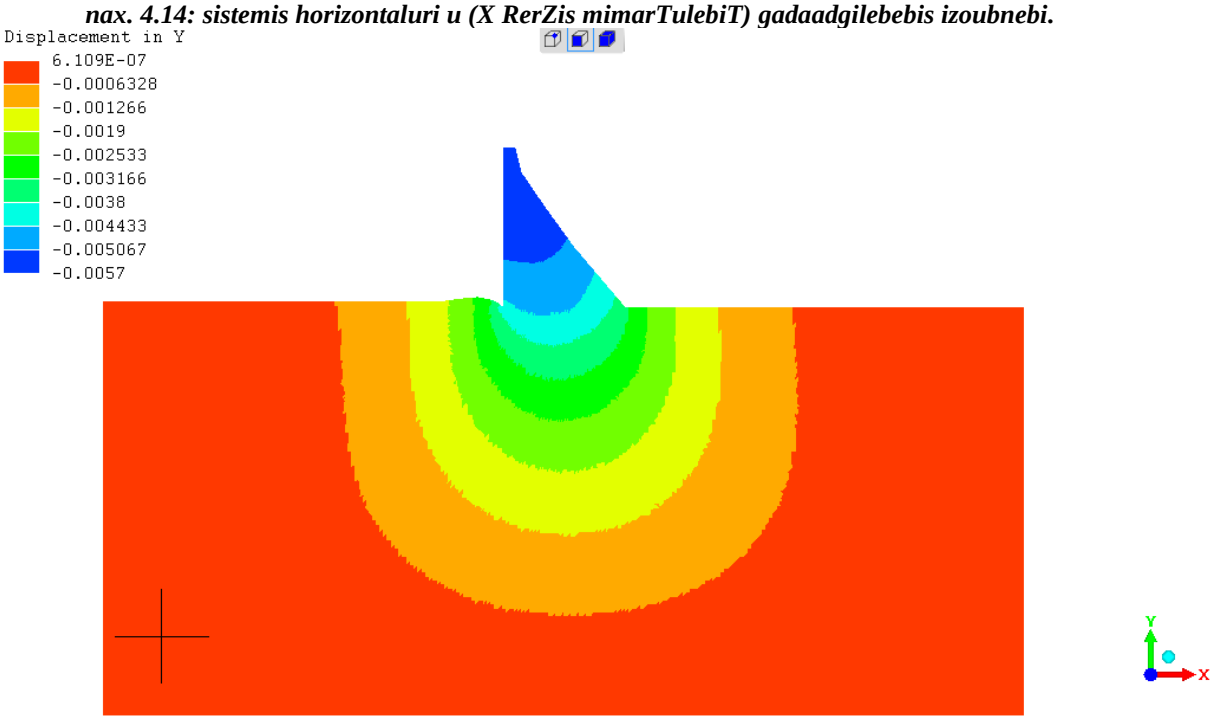
nax. 4.13: maqsimaluri mTavari σ_1 ***Zabvebis izoubnebi.***

4.3. sistemaze moqmedebs kaSxlis sakuTari wona da hidrostatikuri dawneva sadawneo waxnagze (saeqspluatacio SemTxveva)

saangariSo sqema mocemulia nax. 4.7 –ze. nax. 4.14 da 4.15 mocemulia saangariSo sistemaSi horizontaluri u da vertikaluri v gadaadgilebebis izoubnebi.



nax. 4.14: sistemis horizontaluri u (X RerZis mimarTulebiT) gadaadgilebebis izoubnebi.

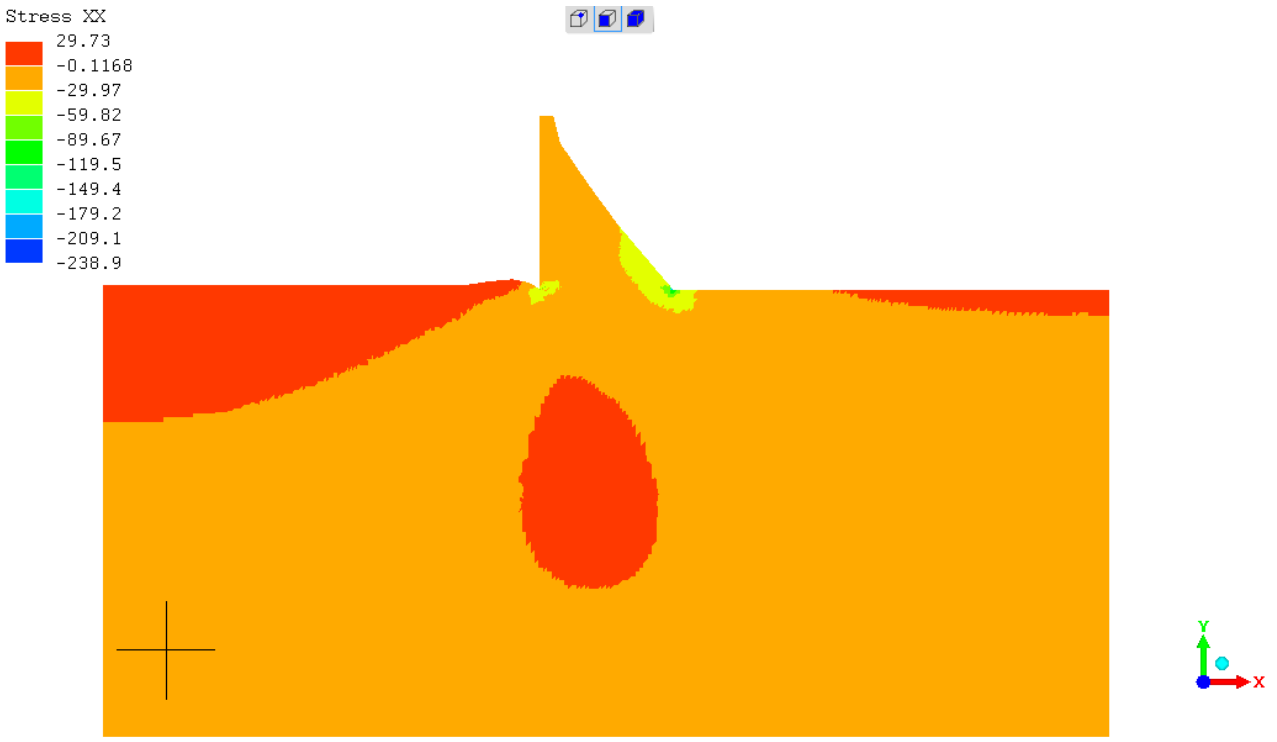


nax. 4.15: sistemis vertikaluri v (Y RerZis mimarTulebiT) gadaadgilebebis izoubnebi.

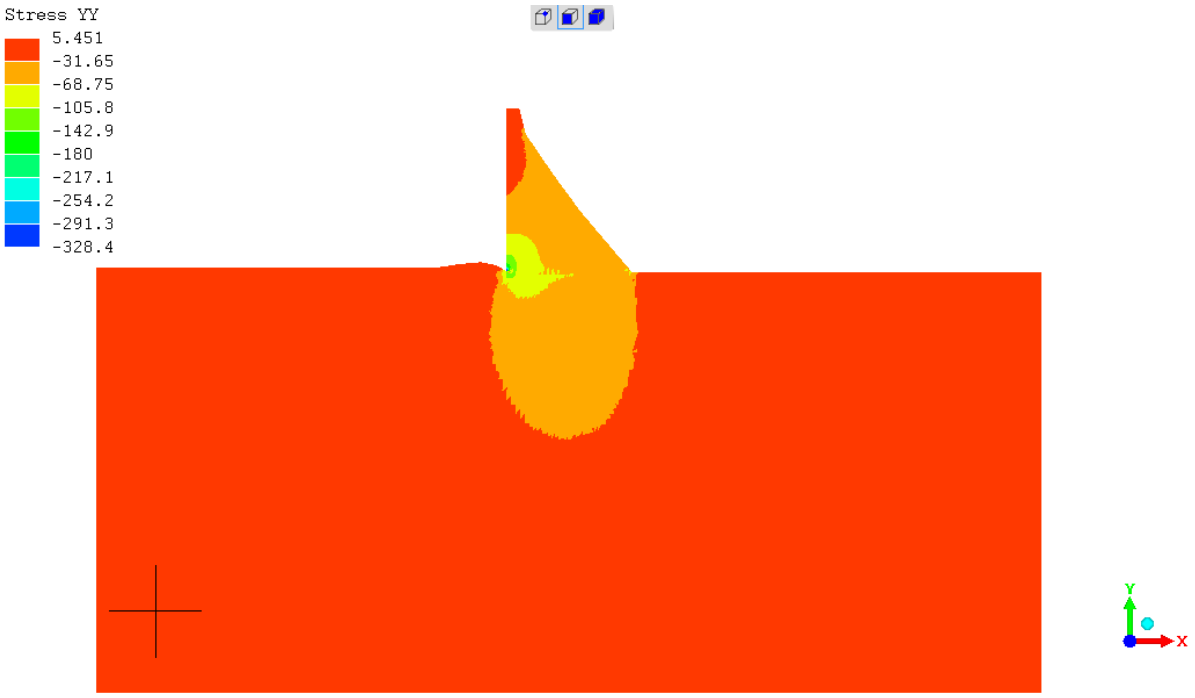
Sedegebidan Cans, rom maqsimaluri horizontaluri gadaadgilebebi (-0,2178 sm) fiqsirdeba kaSxlis Txemis zonaSi (narinjisferi)

da meTodurad mcirdeba fuZisaken. aRsaniSnavia is, rom gadaxris veqtori mimarTulia zeda biefisaken. analogiuri situaciaa vertikaluri gadaadgilebebis mxrivac. maqsimaluri vertikaluri gadaadgilebebi (-0,57 sm) aRiniSneba kaSxlis Txemis zonaSi da vrceldeba kaSxlis tanis zeda 2/3-ze (muqi lurji feri).

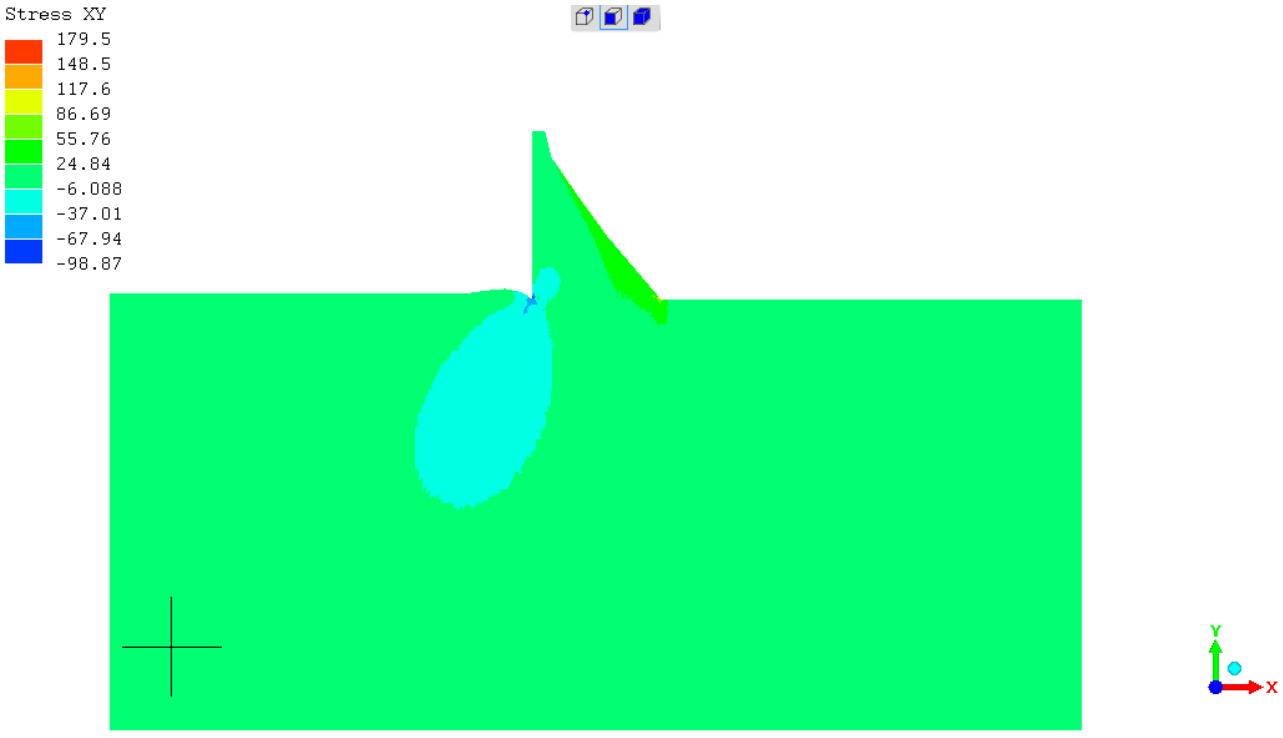
nax. 4.16, 4.17, 4.18 da 4.19-ze mocemulia sistemaSi horizontaluri normaluri σ_x, vertikaluri normaluri σ_y, mxebi τ da maqsimaluri mTavari σ_1 Zabvebis izoubnebi.



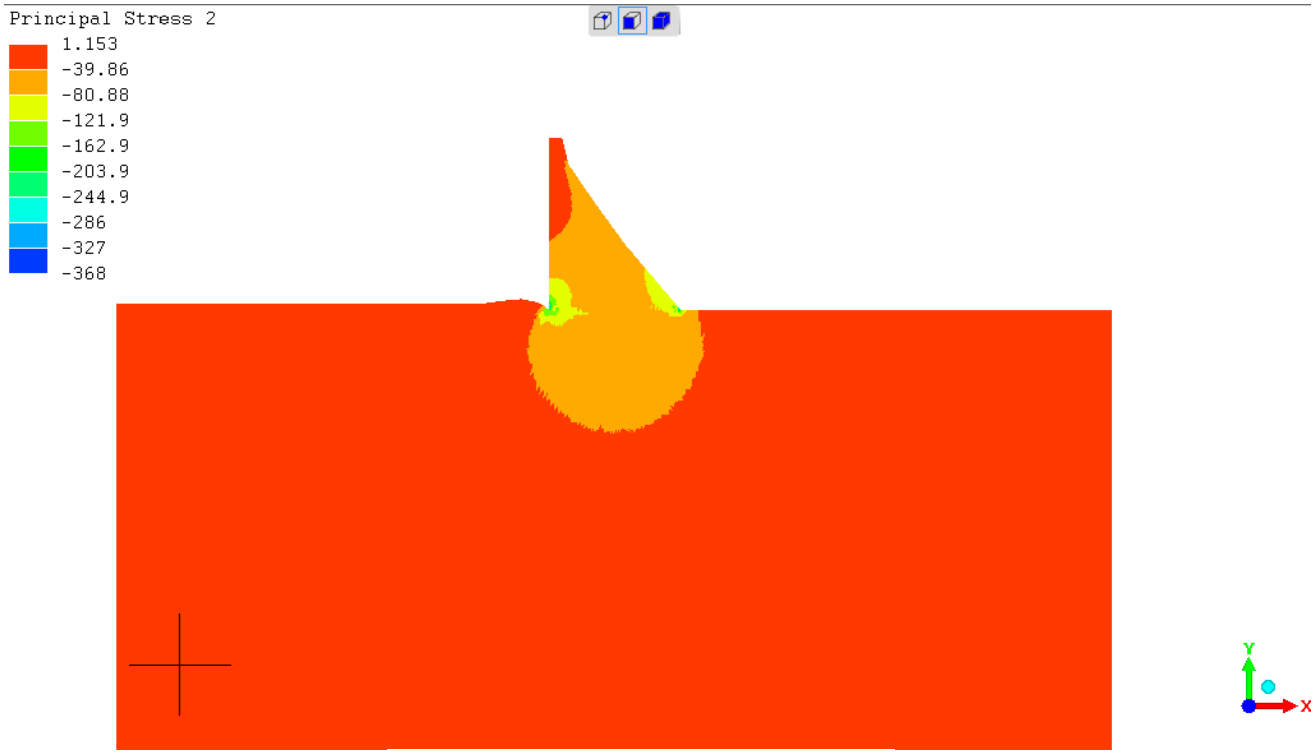
nax. 4.16: horizontaluri normaluri σ_x Zabvebis izoubnebi.



nax. 4.17: vertikaluri normaluri σ_y Zabvebis izoubnebi.



nax. 4.18: mxebi τ Zabvebis izoubnebi.



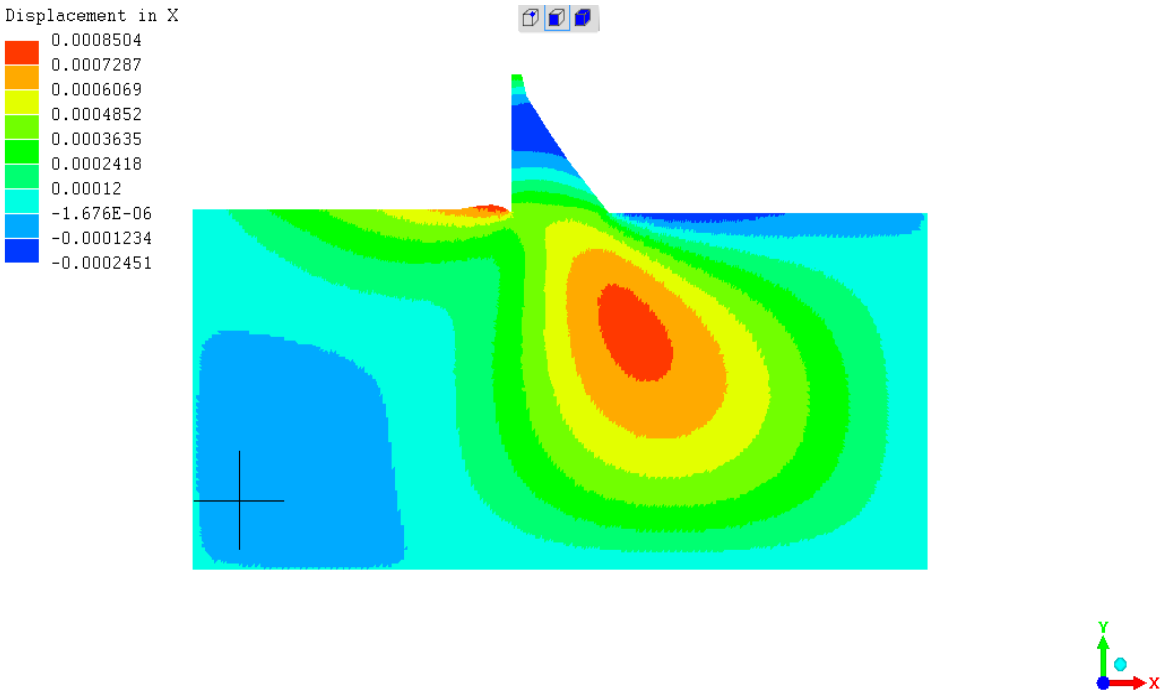
nax. 4.19: maqsimaluri mTavari σ_1 Zabvebis izoubnebi.

4.4. sistemaze moqmedebs kaSxlis sakuTari wona, hidrostatikuri dawneva sadawneo waxnagze da vertikaluri hidrostatikuri dawneva wyalsacavis fskerze

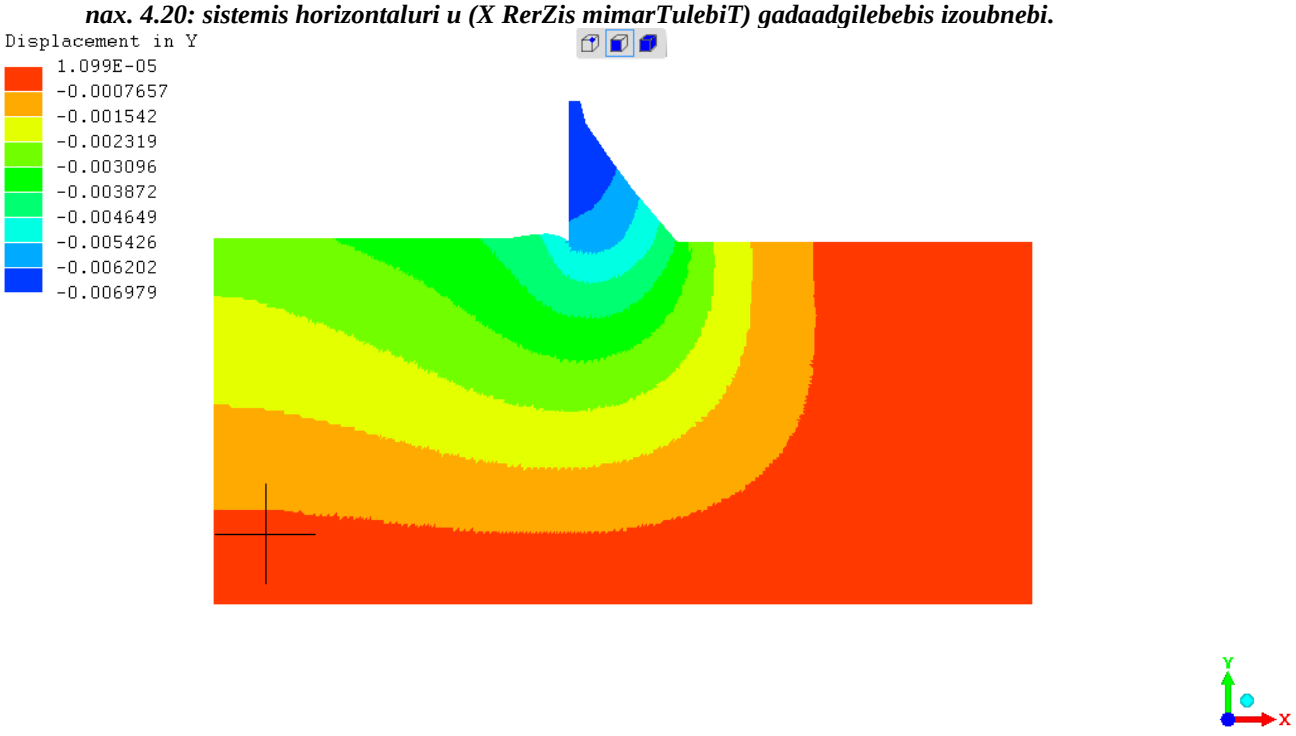
garda sakuTari wonisa da hidrostatikuri dawnevisa kaSxlis sadawneo waxnagze, sistema gaangariSebuli iqna damatebiT datvirTvaze – vertikalur hidrostatikur datvirTvaze wyalsacavis fskerze. datvirTvis am komponents sasruli elementebis sqemaSi naklebi yuradReoba eqceoda da, amis gamo, gadawyda Segveswavla am ukanasknelis realuri gavlena kaSxlis daZabul-deformirebul mdgomareobaze.

saangariSo sqema mocemulia nax. 4.7 –ze.

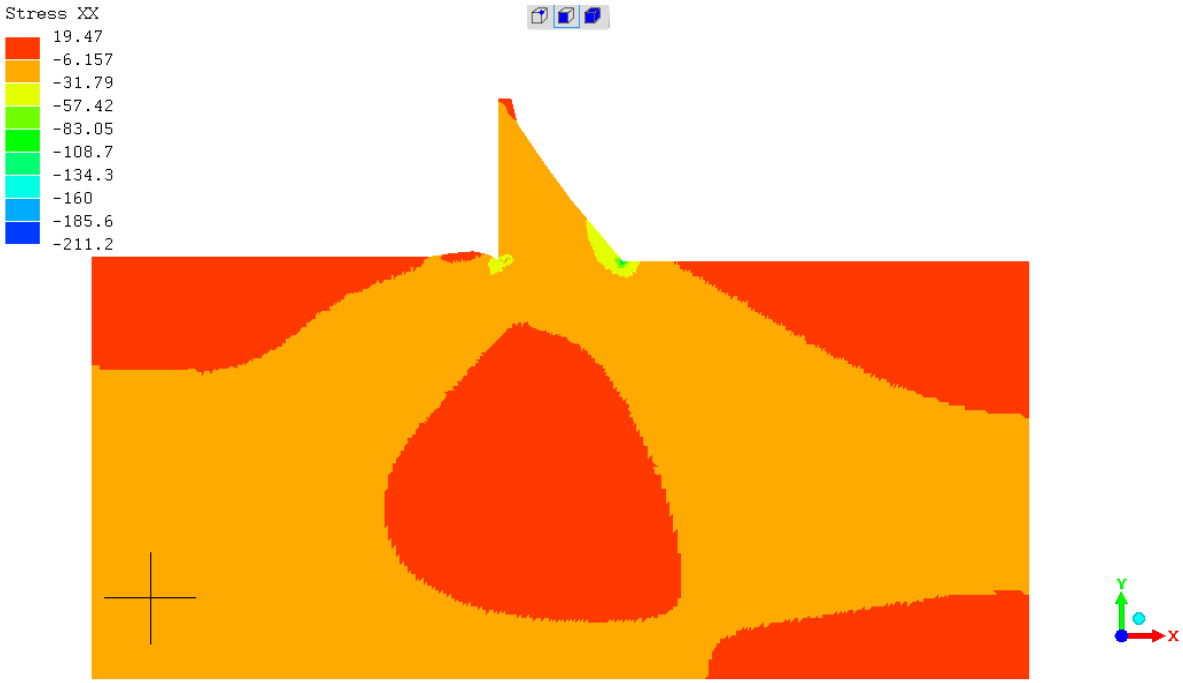
gaanalizebis mizniT qvemoT moyvanilia gadaadgilebebisa da Zabvebis izoubnebis zogierTi naxazebi.



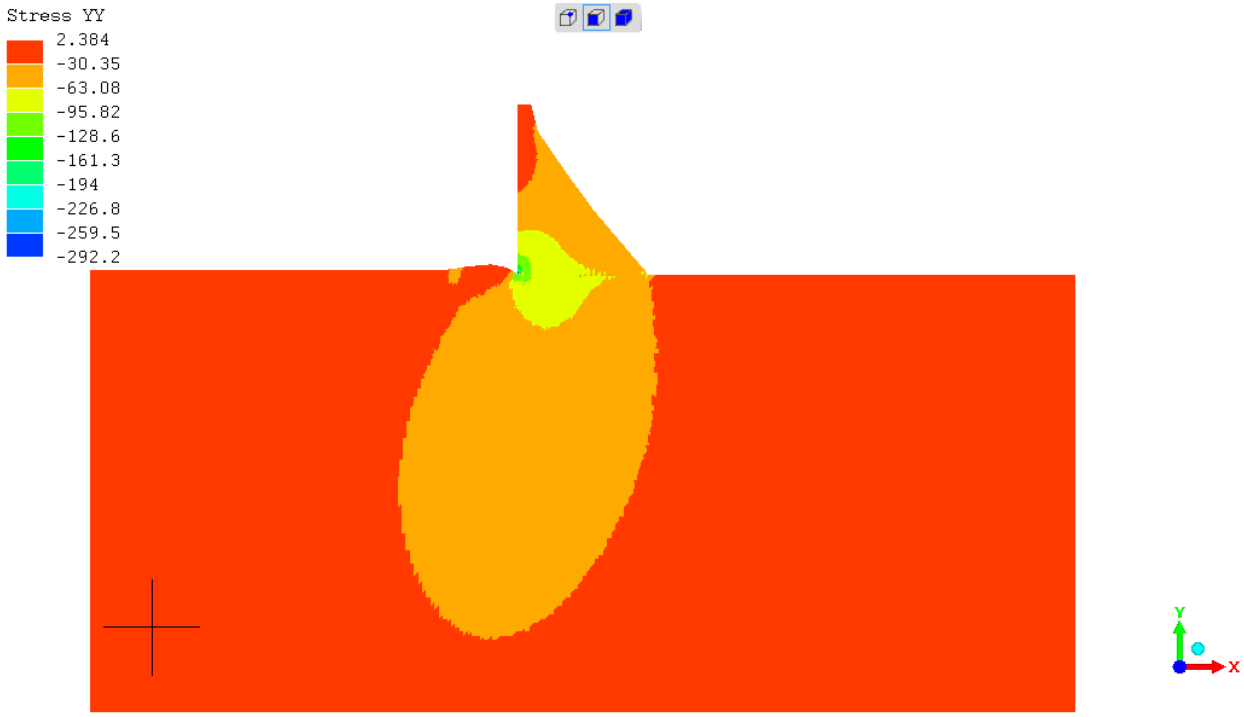
nax. 4.20: sistemis horizontaluri u (X RerZis mimarTulebiT) gadaadgilebebis izoubnebi.



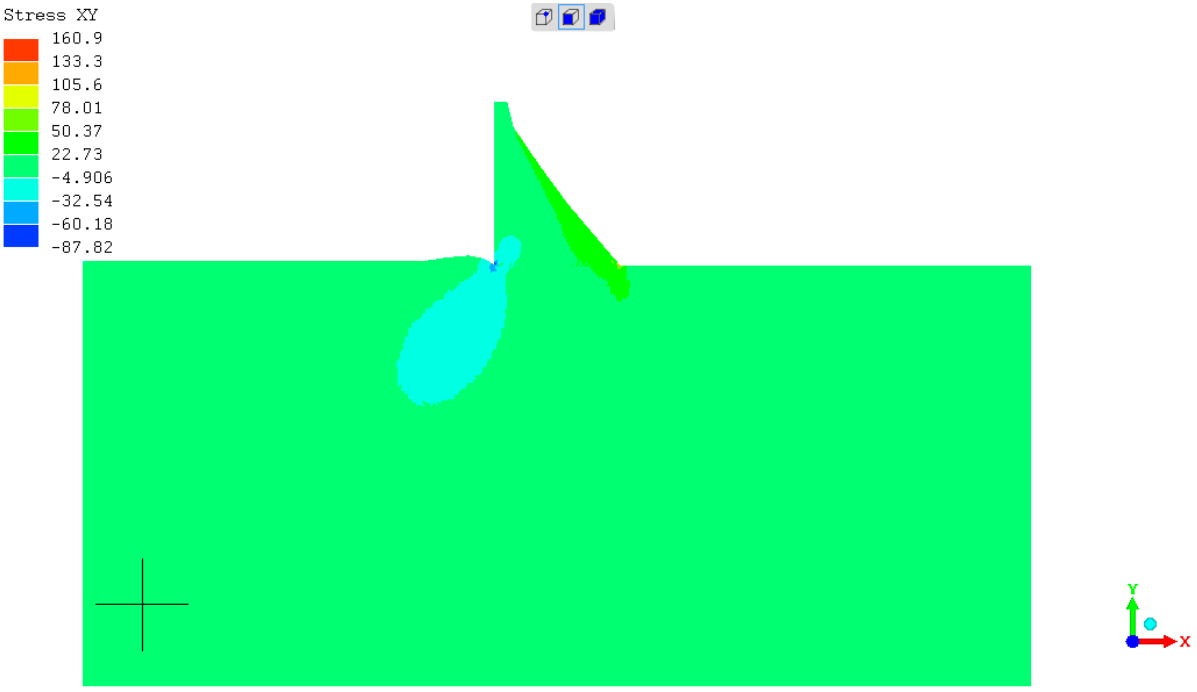
nax. 4.21: sistemis vertikaluri v (Y RerZis mimarTulebiT) gadaadgilebebis izoubnebi.



nax. 4.22: horizontaluri normaluri σ_x Zabvebis izoubnebi.



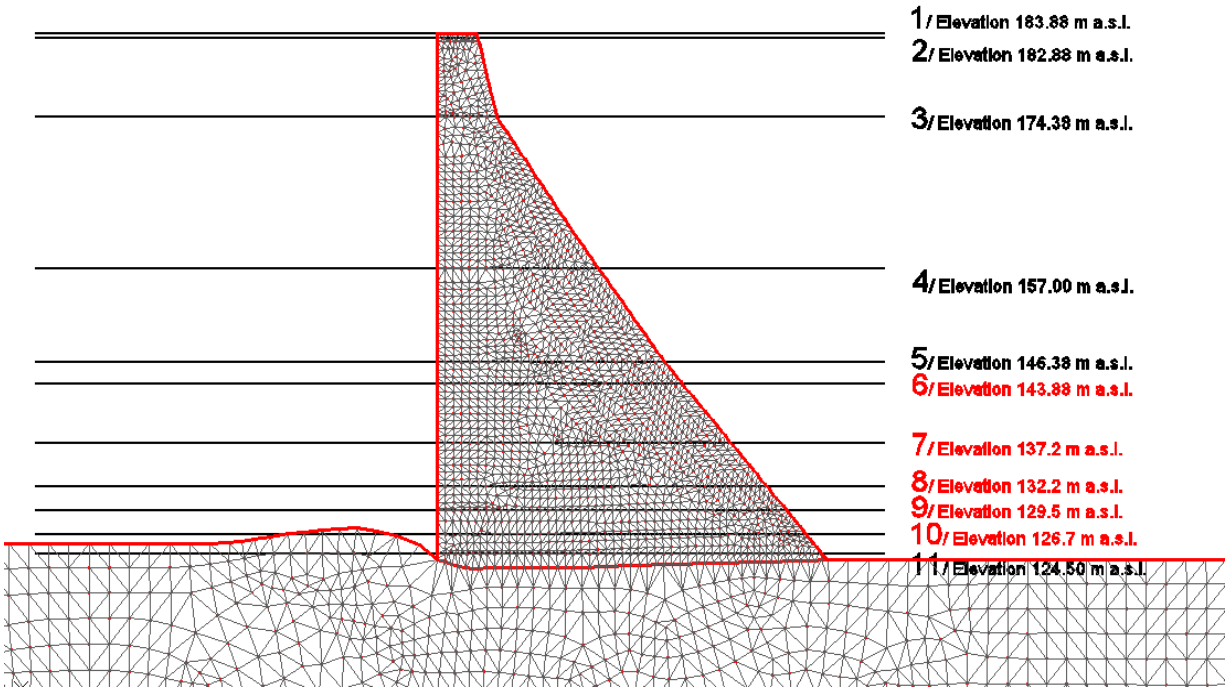
nax. 4.23: vertikaluri normaluri σ_y Zabvebis izoubnebi.



nax. 4.24: mxebi τ Zabvebis izoubnebi.

garda sistemis daZabuli-deformirebuli mdgomareobis zogadi suraTisa, Cvens konkretulo interess warmoadgens, Tu ra gavlena aqvs hidrostatikis vertikalur mdgenels uSualod kaSxlis mdgomareobaze. qvemoT moyvanilia am sakiTxis analizi ufro dawvrilebiT.

nax. 4.25-ze mocemulia saangariSo sistemidan amoRebuli fragmenti – TviT kaSxali da fuZis nawili.



nax. 4.25: sistemis "greisis kaSxali – fuZe – wyalsacavi" saangariSo sqema sasruli elementebis meTodiT (fragmenti).

amocanis amoxsnis Sedegad miRebuli vrceli informaciidan moviyvanT mxolod nawils, romelic gvaZlevs saSualebas gamovitanoT daskvnebi wyalsacavis fuZeze zemoqmedebis gavlenis Sesaxeb uSualod kaSxlis daZabul-deformirebul mdgomareobaze.

SerCeuli iqna aTi ganivi kveTi da erTi Txemis sibrtye, romlebSic gakeTda Sedegebis analizi. bunebrivia, sistemis yvelaze kritikuli da sapasuxismgebo aris kaSxalsa da fuZes Soris sakontaqto kveTi (kveTi #11).

cxr. 4.1 – is zeda fragmentSi mocemulia kveTis nomeri da mdebareoba zRvis donidan, xolo qveda, ZiriTad, nawilSi - kvanZebis numeracia, koordinatebi, agreTve σ_y Zabvebi kvanZebSi Semdegi saangariSo SemTxvevebisaTvis:

- saangariSo sistemaze moqmedebs mxolod sakuTari wona da hidrostatikuri dawneva kaSxlis sadawneo waxnagze da
- sistemaze moqmedebs sakuTari wona, hidrostatikuri dawneva sadawneo waxnagze da hidrostatikuri dawneva wyalsacavis fskerze.

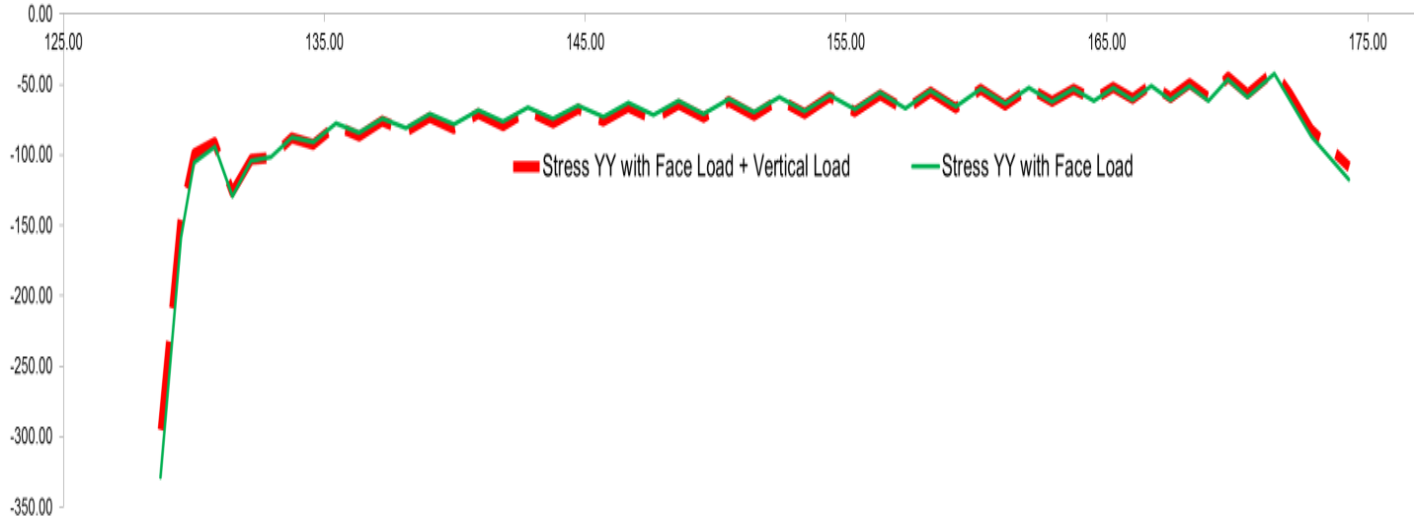
kvanZi #7080 aris kaSxlis sadawneo waxnagisa da fuZis zedapiris kveTis wertili, xolo kvanZi #7359 - udawneo waxnagisa da fuZis zedapiris kveTis wertili, cxrilSi moyvanili sxva wertilebis nomrebi maT Soris aris ganlagebuli.

Zabvebis grafikuli gamosaxulebebi (epiurebi) mocemulia nax. 4.26 - ze. Sedegebis analizi gviCvenebs rom vertikalur hidrostatikur dawnevas wyalsacavis fskerze aqvs SesamCnevi gavlena kaSxlis waxnagebze Zabvebis mniSvnelobebze, Tumca kaSxlis tanSi es gavlena umniSvneloa. miRebuli Sedegebis nawili gamoqveynebulia [33]-Si.

cxrili 4.1:

Alignment	11
Elevation	124.5

Point	7080	7310	7391	7312	7311	7388	7383	7382	7325	7324	7326	7348	7328	7327	7329	7358	7331	7330	7332	7359
X	128.72	129.50	130.00	130.80	131.47	132.19	132.96	133.75	134.58	135.44	136.33	137.23	138.13	139.04	139.96	140.90	141.85	142.80	143.77	144.73
Y	124.50	124.50	124.50	124.50	124.50	124.50	124.50	124.50	124.50	124.50	124.50	124.50	124.50	124.50	124.50	124.50	124.50	124.50	124.50	124.50
Stress YY with Face Load	-328.62	-158.74	-105.57	-93.91	-129.03	-104.36	-101.60	-87.21	-90.78	-77.29	-83.95	-73.92	-80.51	-70.81	-78.05	-67.97	-75.96	-65.98	-74.26	-64.61
Stress YY with Face Load + Vertical Load	-295.33	-144.52	-98.85	-91.13	-126.10	-102.86	-101.75	-87.87	-92.32	-78.93	-86.26	-76.14	-83.26	-73.33	-81.03	-70.60	-79.01	-68.63	-77.29	-67.21
	111.27%	109.84%	106.80%	103.05%	102.32%	101.46%	99.85%	99.25%	98.32%	97.93%	97.32%	97.09%	96.69%	96.57%	96.32%	96.28%	96.13%	96.14%	96.08%	96.13%



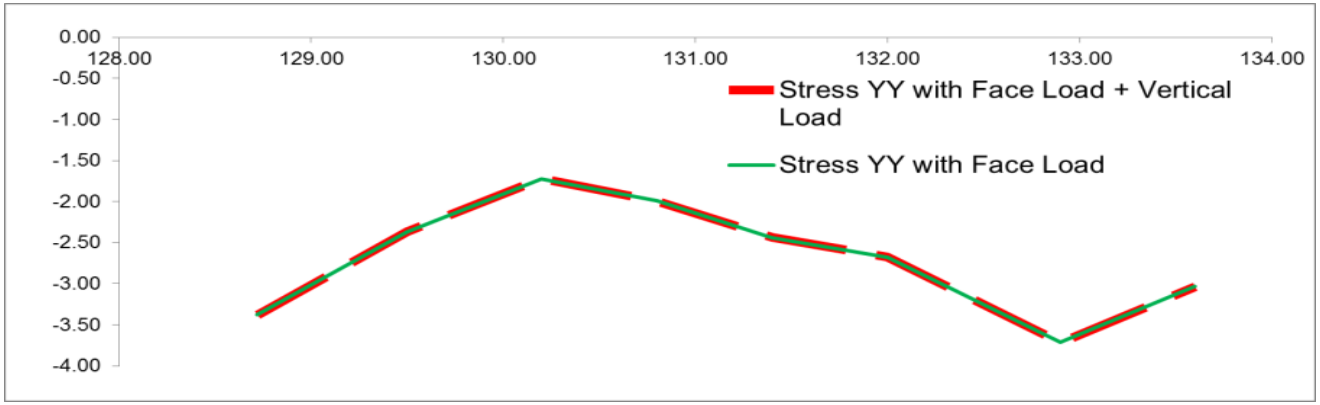
nax. 4.26: σ_y Zabvebi sakontaqto kveTSi (7080 – 7359). wiTeli da wyvetili texili xazi - σ_y Zabvebi meore SemTxvevisaTvis – yvela Zalis erToblivi moqmedeba; mwvane texili xazi - σ_y Zabvebi pirveli SemTxvevisaTvis – mxolod sakuTari wona hidrostatikuri dawneva sadawneo waxnagze.

kaSxlis daZabul-deformirebuli mdgomareobis sruli suraTis warmosadgenad (4.2 – 4.19) cxrilebSi da (4.27 – 4.35) naxazebze moyvanilia analogiuri monacemebi kaSxlis 2-2, 3-3, 4-4, 5-5, 6-6, 7-7, 8-8, 9-9 da 10-10 horizontalur kveTebSi (nax. 4.25).

cxrili 4.2:

Aligm	2
Elevation	182.88

Point	6943	7171	7392	7587	7403	7404	7376	7152
X	128.72	129.50	130.20	130.80	131.40	132.00	132.90	133.60
Y	182.88	182.88	182.88	182.88	182.88	182.88	182.88	182.88
Stress YY with Face Load	-3.38	-2.37	-1.72	-1.99	-2.44	-2.68	-3.71	-3.03
Stress YY with Face Load + Vertical Load	-3.38	-2.37	-1.72	-1.99	-2.44	-2.68	-3.71	-3.03
	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

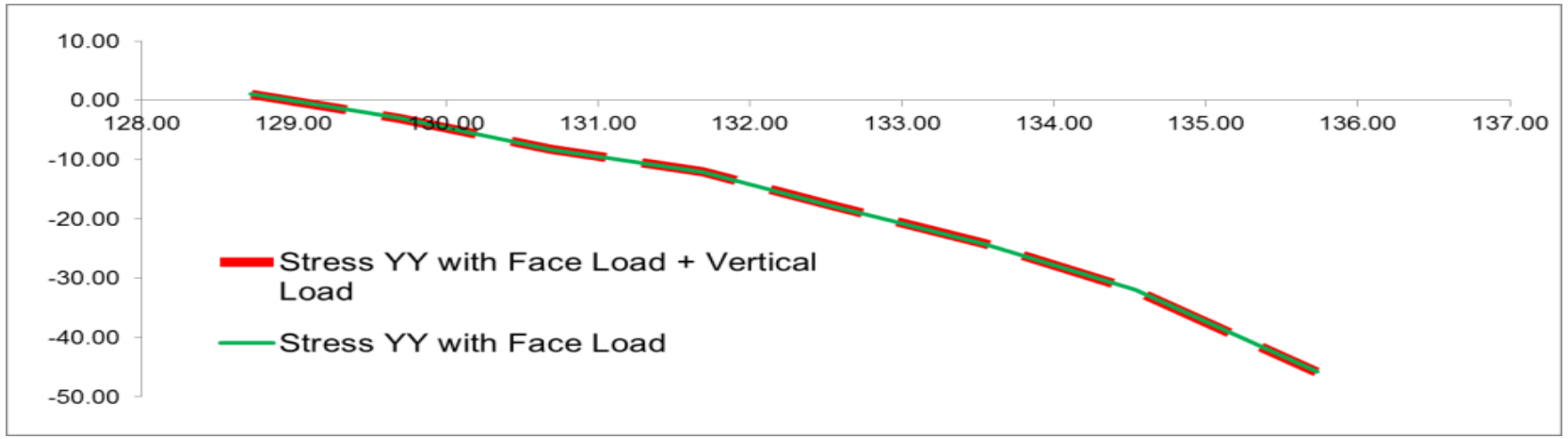


nax. 4.27: σ_y Zabvebi 2-2 kveTSi (6943 – 7152). wiTeli da wyvetili texili xazi - σ_y Zabvebi meore SemTxvevisaTvis – yvela Zalis erToblivi moqmedeba; mwvane texili xazi - σ_y Zabvebi pirveli SemTxvevisaTvis – mxolod sakuTari wona hidrostatikuri dawneva sadawneo waxnagze.

cxrili 4.3:

Number	3
Elevation	174.38

Point	6962	7189	7419	7789	7792	7411	7184	6955
X	128.72	129.69	130.69	131.69	132.53	133.54	134.53	135.73
Y	174.38	174.38	174.38	174.38	174.38	174.38	174.38	174.38
Stress YY with Face Load	1.02	-3.04	-8.28	-12.06	-17.70	-24.21	-32.00	-45.78
Stress YY with Face Load + Vertical Load	1.02	-3.04	-8.28	-12.06	-17.70	-24.21	-32.00	-45.78
	99.98%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

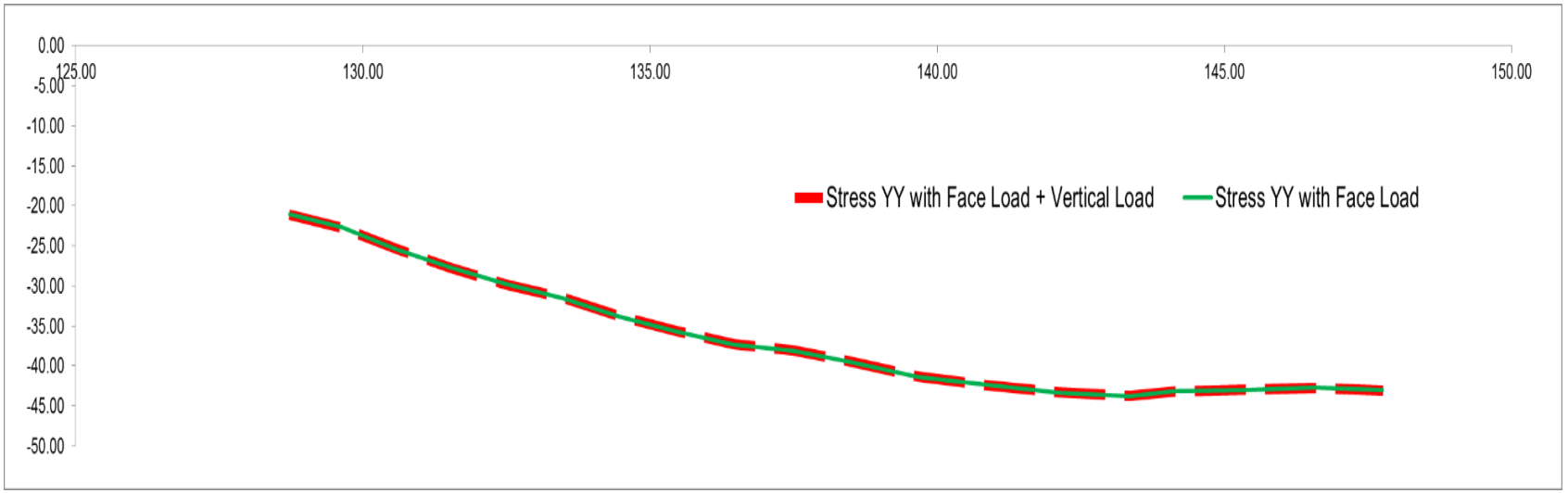


nax. 4.28: σ_y Zabvebi 3-3 kveTSi (6962 – 6955). wiTeli da wyvetili texili xazi - σ_y Zabvebi meore SemTxvevisaTvis – yvela Zalis erToblivi moqmedeba; mwvane texili xazi - σ_y Zabvebi pirveli SemTxvevisaTvis – mxolod sakuTari wona hidrostatikuri dawneva sadawneo waxnagze.

cxrili 4.4:

Aligm	4
Elevation	157

Point	7001	7230	7467	7674	7674	7873	8043	8182	8307	8467	8531	8403	8275	8147	8091	7928	7669	7460	7233	7003
X	128.72	129.64	130.58	131.54	131.54	132.51	133.49	134.47	135.46	136.46	137.49	138.43	139.66	140.88	142.11	143.35	144.15	145.37	146.57	147.76
Y	157.00	157.00	157.00	157.00	157.00	157.00	157.00	157.00	157.00	157.00	157.00	157.00	157.00	157.00	157.00	157.00	157.00	157.00	157.00	157.00
Stress YY with Face Load	-21.04	-22.71	-25.38	-27.72	-27.72	-29.85	-31.51	-33.86	-35.67	-37.30	-38.06	-39.39	-41.37	-42.41	-43.30	-43.76	-43.16	-42.98	-42.75	-43.07
Stress YY with Face Load + Vertical Load	-21.10	-22.76	-25.41	-27.73	-27.73	-29.84	-31.49	-33.84	-35.65	-37.27	-38.04	-39.37	-41.36	-42.40	-43.30	-43.77	-43.16	-42.99	-42.77	-43.10
	99.71%	99.80%	99.90%	99.97%	99.97%	100.02%	100.05%	100.07%	100.07%	100.07%	100.07%	100.06%	100.04%	100.02%	100.01%	99.99%	99.99%	99.97%	99.95%	99.92%

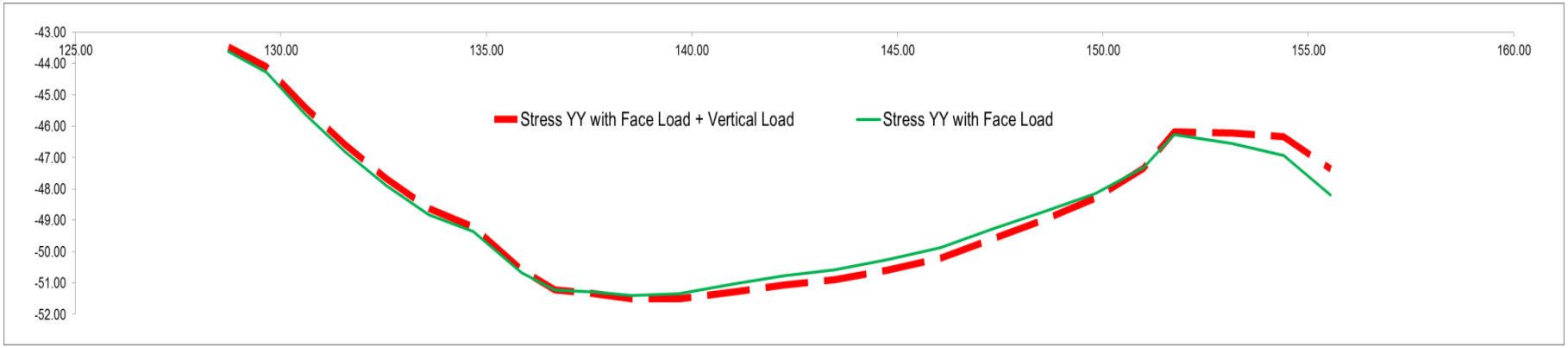


nax. 4.29: σ_y ***Zabvebi 4-4 kveTSi (7001 – 7003). wiTeli da wyvetili texili xazi -*** σ_y ***Zabvebi meore SemTxvevisaTvis – yvela Zalis erToblivi moqmedeba; mwvane texili xazi -*** σ_y ***Zabvebi pirveli SemTxvevisaTvis – mxolod sakuTari wona hidrostatikuri dawneva sadawneo waxnagze.***

cxrili 4.5:

Alignment	5
Elevation	146.38

Point	7016	7245	7475	7683	7971	8061	8138	8309	8498	8588	8640	8704	8749	8716	8647	8576	8461	8282	8187	8062	7895	7706	7478	7246	7017
X	128.72	129.65	130.59	131.56	132.56	133.60	134.69	135.86	136.67	137.59	138.55	139.69	141.08	142.24	143.48	144.77	146.05	147.31	148.56	149.81	150.99	151.73	153.15	154.40	155.54
Y	146.38	146.38	146.38	146.38	146.38	146.38	146.38	146.38	146.38	146.38	146.38	146.38	146.38	146.38	146.38	146.38	146.38	146.38	146.38	146.38	146.38	146.38	146.38	146.38	146.38
Stress YY with Face Load	-43.62	-44.29	-45.63	-46.82	-47.90	-48.82	-49.36	-50.68	-51.23	-51.29	-51.41	-51.35	-51.03	-50.77	-50.57	-50.25	-49.87	-49.28	-48.73	-48.16	-47.31	-46.26	-46.55	-46.94	-48.20
Stress YY with Face Load + Vertical Load	-43.47	-44.11	-45.40	-46.59	-47.67	-48.62	-49.22	-50.59	-51.21	-51.33	-51.51	-51.52	-51.28	-51.07	-50.90	-50.59	-50.21	-49.59	-48.98	-48.30	-47.34	-46.19	-46.22	-46.33	-47.37
	100.35%	100.42%	100.49%	100.51%	100.48%	100.40%	100.30%	100.17%	100.02%	99.93%	99.81%	99.67%	99.51%	99.42%	99.36%	99.32%	99.33%	99.37%	99.50%	99.70%	99.94%	100.16%	100.72%	101.32%	101.75%

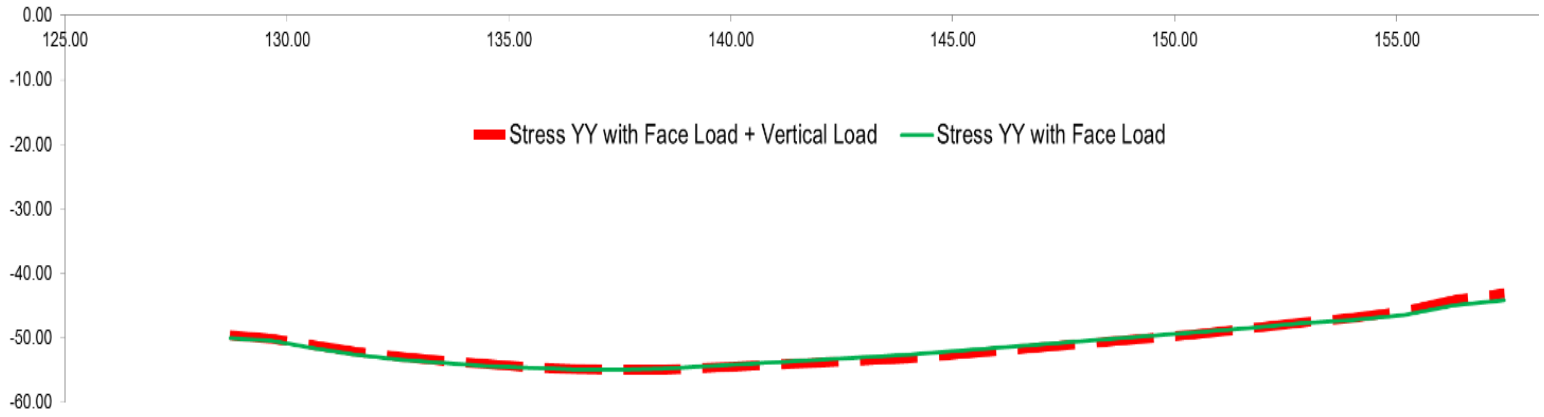


nax. 4.30: σ_y Zabvebi 5-5 kveTSi (7016 – 7017). wiTeli da wyvetili texili xazi - σ_y Zabvebi meore SemTxvevisaTvis – yvela Zalis erToblivi moqmedeba; mwvane texili xazi - σ_y Zabvebi pirveli SemTxvevisaTvis – mxolod sakuTari wona hidrostatikuri dawneva sadawneo waxnagze.

cxrili 4.6:

Aligm	6
Elevation	~ 143.88

Point	7034	7264	7597	7644	7843	8013	8162	8290	8399	8557	8619	8703	8264	8128	7967	7722	7510	7273	7043
X	128.72	129.65	130.60	131.55	132.54	133.54	134.56	135.55	136.53	137.51	138.47	144.00	150.43	151.62	152.80	153.98	155.16	156.31	157.43
Y	143.88	143.88	143.88	143.89	143.91	143.92	143.93	143.91	143.88	143.86	143.86	143.95	143.77	143.91	144.01	144.10	144.16	144.17	144.16
Stress YY with Face Load	-50.00	-50.50	-51.63	-52.58	-53.34	-53.93	-54.39	-54.70	-54.86	-54.90	-54.80	-52.60	-49.19	-48.47	-47.81	-47.25	-46.45	-45.01	-44.22
Stress YY with Face Load + Vertical Load	-49.60	-50.08	-51.19	-52.14	-52.95	-53.60	-54.15	-54.55	-54.82	-54.96	-54.97	-53.13	-49.49	-48.59	-47.73	-46.93	-45.84	-44.08	-43.07
	100.80%	100.84%	100.87%	100.84%	100.75%	100.62%	100.45%	100.26%	100.07%	99.88%	99.70%	99.00%	99.41%	99.75%	100.17%	100.70%	101.33%	102.09%	102.65%

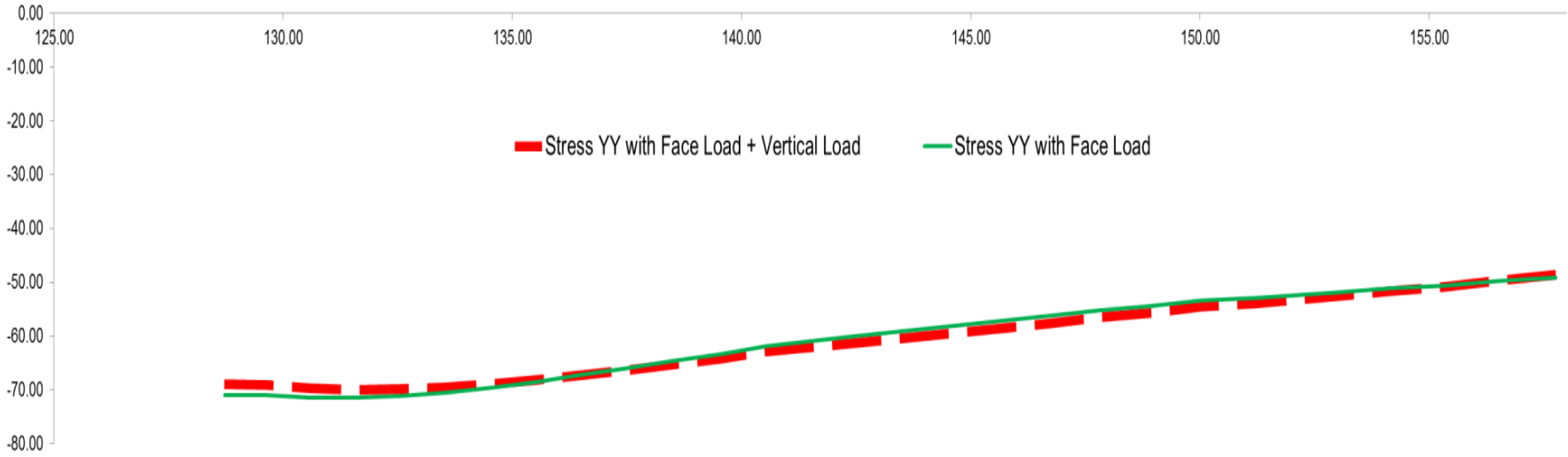


nax. 4.31: σ_y Zabvebi 6-6 kveTSi (7034 – 7043). wiTeli da wyvetili texili xazi - σ_y Zabvebi meore SemTxvevisaTvis – yvela Zalis erToblivi moqmedeba; mwvane texili xazi - σ_y Zabvebi pirveli SemTxvevisaTvis – mxolod sakuTari wona hidrostatikuri dawneva sadawneo waxnagze.

cxrili 4.7:

Alignm	7
Elevation	~ 137.2

Point	7062	7291	7513	7724	7891	8060	8211	8331	8445	8506	8591	8668	8722	7109	7115	8790	8734	8690	8606	8509	8453	8371	8217	8033
X	128.72	129.65	130.60	131.57	132.54	133.53	134.52	135.51	136.50	137.50	138.50	139.53	140.54	142.43	146.68	147.83	148.89	150.04	151.22	153.04	154.17	155.32	156.55	157.77
Y	137.20	137.21	137.20	137.19	137.18	137.17	137.16	137.15	137.14	137.15	137.18	137.23	137.20	137.20	136.91	136.91	136.90	136.94	136.91	136.51	136.58	136.62	136.70	136.78
Stress YY with Face Load	-70.97	-71.01	-71.46	-71.52	-71.19	-70.52	-69.61	-68.51	-67.28	-65.99	-64.70	-63.45	-61.89	-60.10	-56.29	-55.23	-54.43	-53.37	-52.92	-51.84	-51.19	-50.65	-49.79	-49.12
Stress YY with Face Load + Vertical Load	-69.00	-69.14	-69.71	-69.99	-69.93	-69.59	-69.00	-68.23	-67.31	-66.31	-65.26	-64.22	-62.85	-61.29	-57.67	-56.57	-55.67	-54.49	-53.87	-52.57	-51.68	-50.86	-49.70	-48.68
	102.85%	102.71%	102.50%	102.18%	101.79%	101.35%	100.89%	100.42%	99.95%	99.53%	99.15%	98.80%	98.46%	98.06%	97.61%	97.64%	97.76%	97.94%	98.23%	98.60%	99.05%	99.57%	100.17%	100.90%

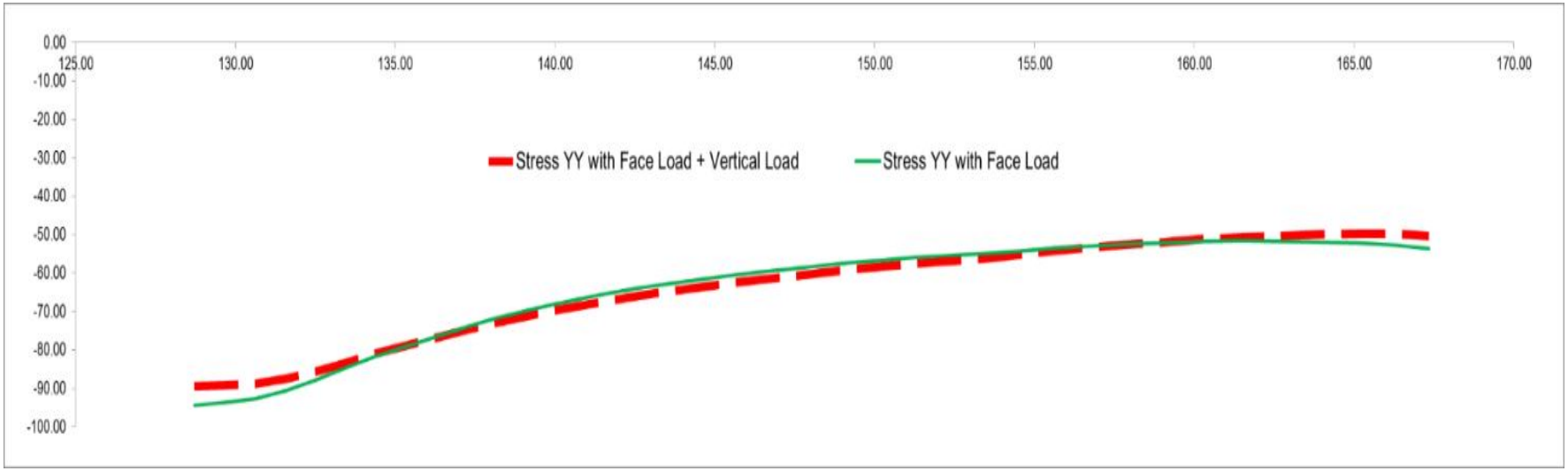


nax. 4.32: σ_y Zabvebi 7-7 kveTSi (7062 – 8033). wiTeli da wyvetili texili xazi - σ_y Zabvebi meore SemTxvevisaTvis – yvela Zalis erToblivi moqmedeba; mwvane texili xazi - σ_y Zabvebi pirveli SemTxvevisaTvis – mxolod sakuTari wona hidrostatikuri dawneva sadawneo waxnagze.

cxrili 4.8:

Alignment	8
Elevation	~ 132.2

Point	7167	7390	7537	7702	7818	8059	8194	8537	8578	8541	8540	8500	8499	8559	8558	8587	8525	8524	8582	8581	8572	8539	8521	8520	8423	8328	8203	8018	7925	7726	7522	7296	7066
X	128.72	129.67	130.62	131.58	132.53	133.48	134.43	137.40	138.18	139.02	139.89	140.78	141.69	142.63	143.58	145.46	146.40	147.34	149.24	150.22	151.25	153.68	154.65	155.69	157.82	159.02	160.27	161.49	162.71	163.92	165.10	166.24	167.35
Y	132.20	132.20	132.21	132.23	132.25	132.27	132.30	132.07	131.95	131.89	131.86	131.86	131.89	131.91	131.94	132.00	132.03	132.06	132.15	132.23	132.36	132.41	132.40	132.25	132.28	132.23	132.29	132.35	132.40	132.46	132.50	132.51	132.49
Stress YY with Face Load	-94.45	-93.76	-92.72	-90.58	-87.77	-84.62	-81.48	-73.61	-71.65	-69.92	-68.23	-66.67	-65.21	-63.86	-62.67	-60.63	-59.74	-58.91	-57.34	-56.62	-55.96	-54.82	-54.18	-53.42	-52.52	-52.09	-51.72	-51.64	-51.74	-51.91	-52.22	-52.67	-53.55
Stress YY with Face Load + Vertical Load	-89.46	-89.23	-88.88	-87.57	-85.60	-83.26	-80.82	-74.52	-72.91	-71.42	-69.93	-68.53	-67.17	-65.91	-64.75	-62.70	-61.77	-60.88	-59.13	-58.29	-57.47	-55.97	-55.13	-54.11	-52.69	-51.99	-51.18	-50.67	-50.32	-50.01	-49.82	-49.77	-50.28
	105.58%	105.07%	104.32%	103.45%	102.53%	101.64%	100.82%	98.77%	98.27%	97.89%	97.56%	97.29%	97.07%	96.90%	96.79%	96.69%	96.71%	96.76%	96.97%	97.14%	97.37%	97.94%	98.29%	98.72%	99.68%	100.19%	101.06%	101.91%	102.83%	103.80%	104.80%	105.83%	106.50%

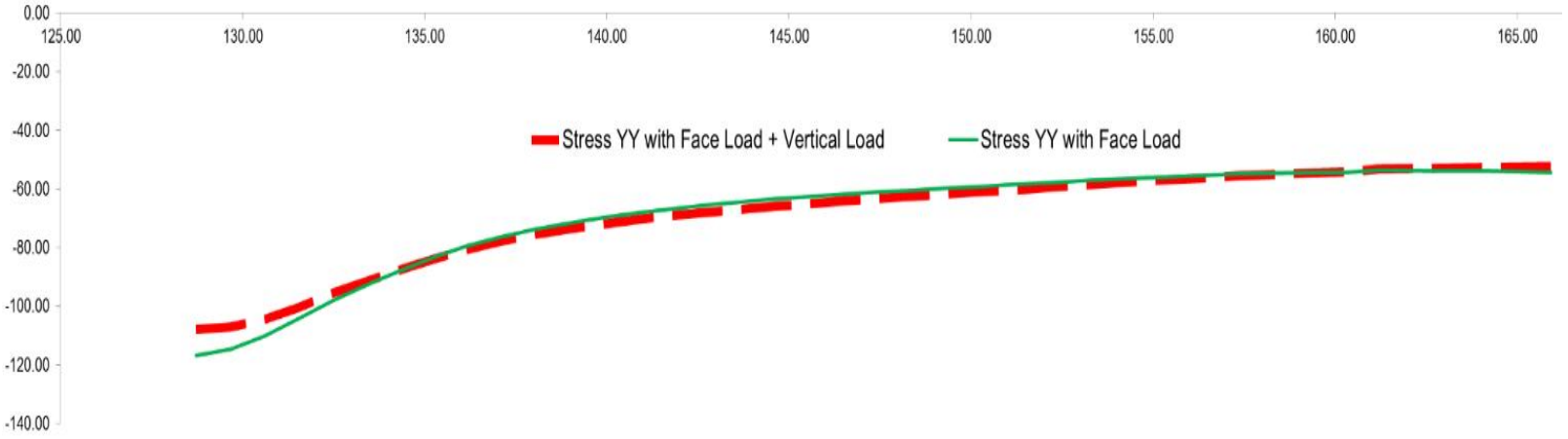


nax. 4.33: σ_y Zabvebi 7-7 kveTSi (7167 – 7066). wiTeli da wyvetili texili xazi - σ_y Zabvebi meore SemTxvevisaTvis – yvela Zalis erToblivi moqmedeba; mwvane texili xazi - σ_y Zabvebi pirveli SemTxvevisaTvis – mxolod sakuTari wona hidrostatikuri dawneva sadawneo waxnagze.

cxrili 4.9:

Alignment	9
Elevation	~ 129.5

Point	7154	7378	7548	7758	7816	8088	8172	8205	8204	8219	8218	8265	8266	8237	8177	8176	8179	8247	8169	8168	8192	8220
X	128.72	129.67	130.61	131.53	132.50	133.62	134.55	135.37	136.19	137.07	138.03	138.97	139.90	140.82	141.76	142.70	143.66	144.61	145.56	146.50	147.45	148.40
Y	129.50	129.50	129.50	129.50	129.50	129.50	129.50	129.50	129.50	129.50	129.50	129.50	129.50	129.50	129.50	129.50	129.50	129.50	129.50	129.50	129.50	129.50
Stress YY with Face Load	-116.72	-114.69	-110.29	-104.41	-97.95	-91.52	-86.74	-82.79	-79.46	-76.50	-73.76	-71.59	-69.80	-68.19	-66.83	-65.58	-64.52	-63.51	-62.65	-61.79	-61.11	-60.36
Stress YY with Face Load + Vertical Load	-107.95	-107.20	-104.59	-100.41	-95.53	-90.60	-86.54	-83.36	-80.50	-77.92	-75.54	-73.61	-71.98	-70.50	-69.22	-68.00	-66.95	-65.93	-65.04	-64.12	-63.36	-62.53
	108.13%	106.99%	105.45%	103.99%	102.53%	101.01%	100.23%	99.32%	98.71%	98.17%	97.65%	97.26%	96.96%	96.73%	96.56%	96.44%	96.36%	96.33%	96.33%	96.37%	96.44%	96.54%

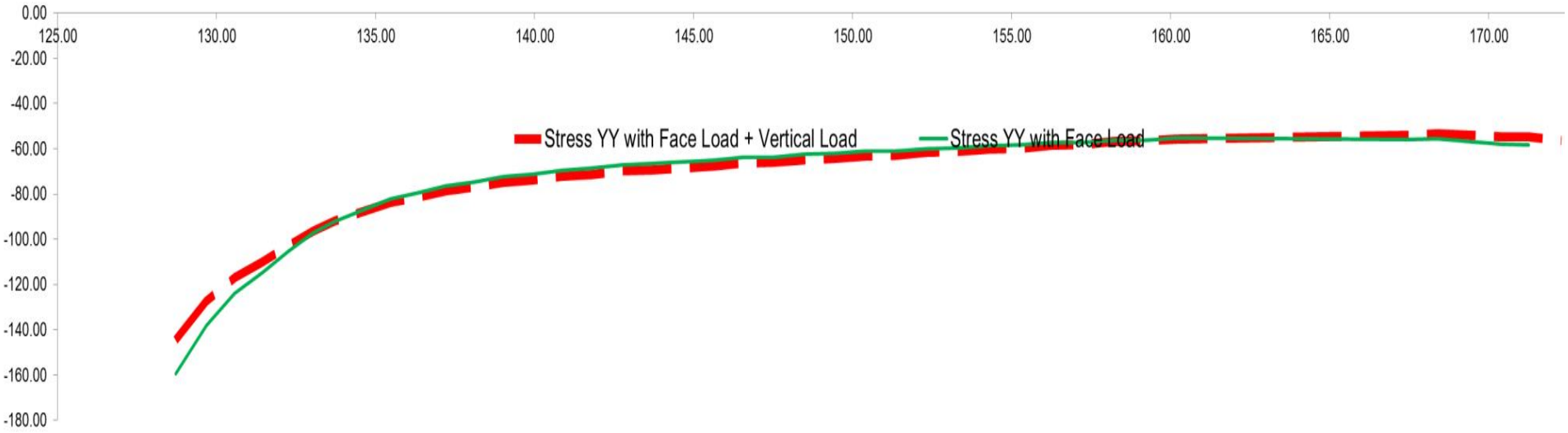


nax. 4.34:. σ_y Zabvebi 7-7 kveTSi (7154 – 8220). wiTeli da wyvetili texili xazi - σ_y Zabvebi meore SemTxvevisaTvis – yvela Zalis erToblivi moqmedeba; mwvane texili xazi - σ_y Zabvebi pirveli SemTxvevisaTvis – mxolod sakuTari wona hidrostatikuri dawneva sadawneo waxnagze.

cxrili 4.10:

Aligm	10
Elevation	~ 128.77

Point	7078	7306	7538	7626	7893	7979	7974	7806	7898	7950	7954	7946	7918	7811	7810	7923	7813	7941
X	128.72	129.67	130.58	131.44	132.26	133.04	133.72	135.47	136.34	137.21	138.11	139.02	139.94	140.86	141.80	142.75	143.70	145.61
Y	126.70	126.72	126.68	126.72	126.73	126.70	126.66	126.87	126.85	126.86	126.87	126.88	126.89	126.90	126.92	126.94	126.96	127.01
Stress YY with Face Load	-159.40	-138.14	-123.87	-114.59	-105.27	-97.15	-91.98	-82.37	-79.48	-76.50	-74.67	-72.47	-71.24	-69.47	-68.65	-67.17	-66.64	-65.01
Stress YY with Face Load + Vertical Load	-144.42	-127.63	-117.02	-110.06	-102.92	-96.27	-92.10	-83.67	-81.21	-78.53	-76.94	-74.89	-73.80	-72.09	-71.32	-69.85	-69.31	-67.60
	110.37%	108.23%	105.86%	104.12%	102.29%	100.92%	99.86%	98.46%	97.87%	97.42%	97.05%	96.76%	96.53%	96.37%	96.25%	96.18%	96.14%	96.17%



nax. 4.35: σ_y Zabvebi 10-10 kveTSi (7154 – 8220). wiTeli da wyvetili texili xazi - σ_y Zabvebi meore SemTxvevisaTvis – yvela Zalis erToblivi moqmedeba; mwvane texili xazi - σ_y Zabvebi pirveli SemTxvevisaTvis – mxolod sakuTari wona hidrostatikuri dawneva sadawneo waxnagze.

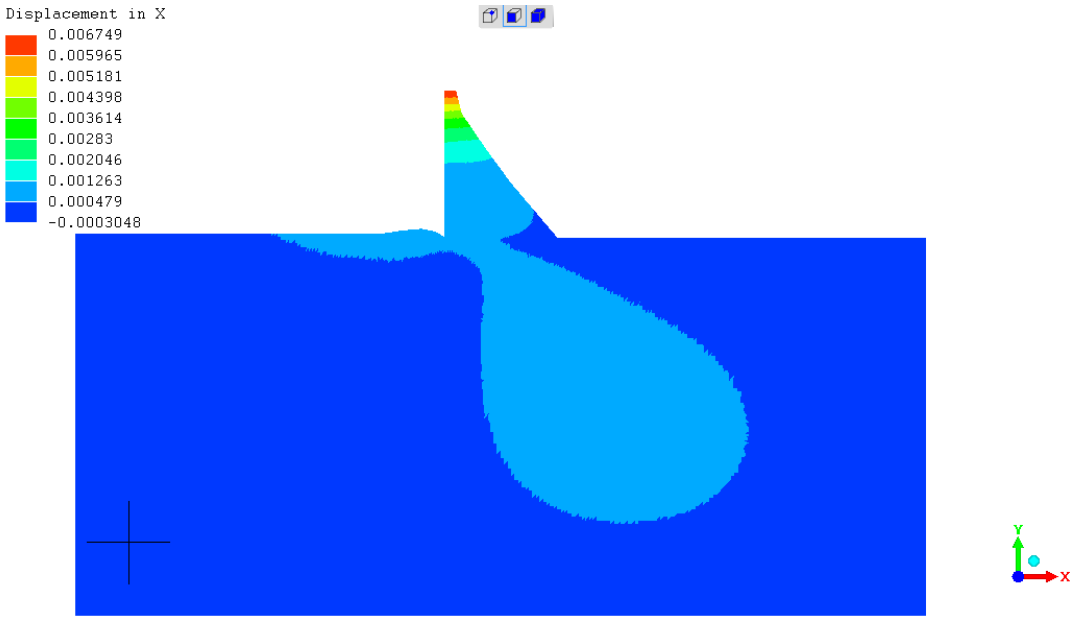
4.5. statikuri cikluri datvirTebis da betonis asakis gavlena greisis kaSxlis daZabul-deformirebul mdgomareobaze

Cvens xelT arsebuli monacemebiT greisis kaSxali eqspluataciaSia 48 weliwadi. vinaidan misi wyalsacavi sezonuri regulirebisaa, dacla-avsebis cikli n = 48.

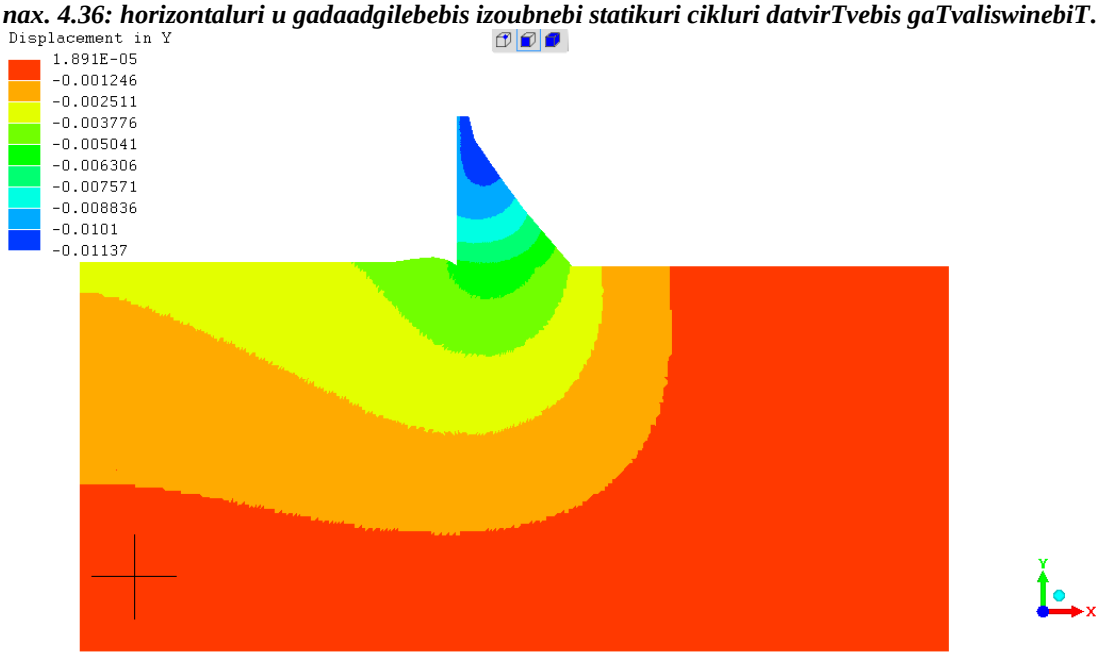
mesame TavSi aRwerili meTodikis gamoyeneba sistemis "greisis kaSxali – fuZe" moxda Semdegi TanmimdevrobiT.

1. Tavdapirvelad gaangariSebuli iqna greisis kaSxlis saproeqto varianti kldovan fuZesTan erTad. kaSxlis aRebuli iqna sawyisi (saproeqto) betonis drekadobis moduli E_0. kaSxalze moqmedebs misi sakuTari wona da hidrostatikuri dawneva rogorc sadawneo waxnagze, aseve wyalsacavis fskerze. gaangariSebuli iqna gadaadgilebi, deformaciebi, Zabvis komponentebi, mTavari Zabvebi da maTi mimarTulebebe rogorc badis elementebSi, aseve kvanZebSi;
2. miRebuli maqsimaluri Zabvebi gaanalizebuli iqna (3.4), (3.5), (3.6) da (3.7) gamosaxulebebis saSualebiT. avseba-daclis ciklebis raodenoba n = 48 da eqspluataciis wlebis raodenoba t=48 weliwadi. analizis Sedegad dadginda (3.4 da 3.5 pirobebi), rom drekadobis modulis mniSvneloba davarda $E_{n=48}$ = 0,4*10^6 t/m^2-de cikluri datvirTvebis Sedegad. rac Seexeba asaks, misi gavlena betonis drekadobis modulze dadebiTia (3.6 da 3.7 pirobebi). drekadobis moduli gaizarda da gaxda - $E_{t=48}$ = 2,7*10^6 t/m^2
3. sistema "greisis kaSxali-fuZe" gaangariSebuli iqna meore sangariSo etapze miRebuli drekadobis modulis modificirebuli mniSvnelobis gaTvaliswinebiT.

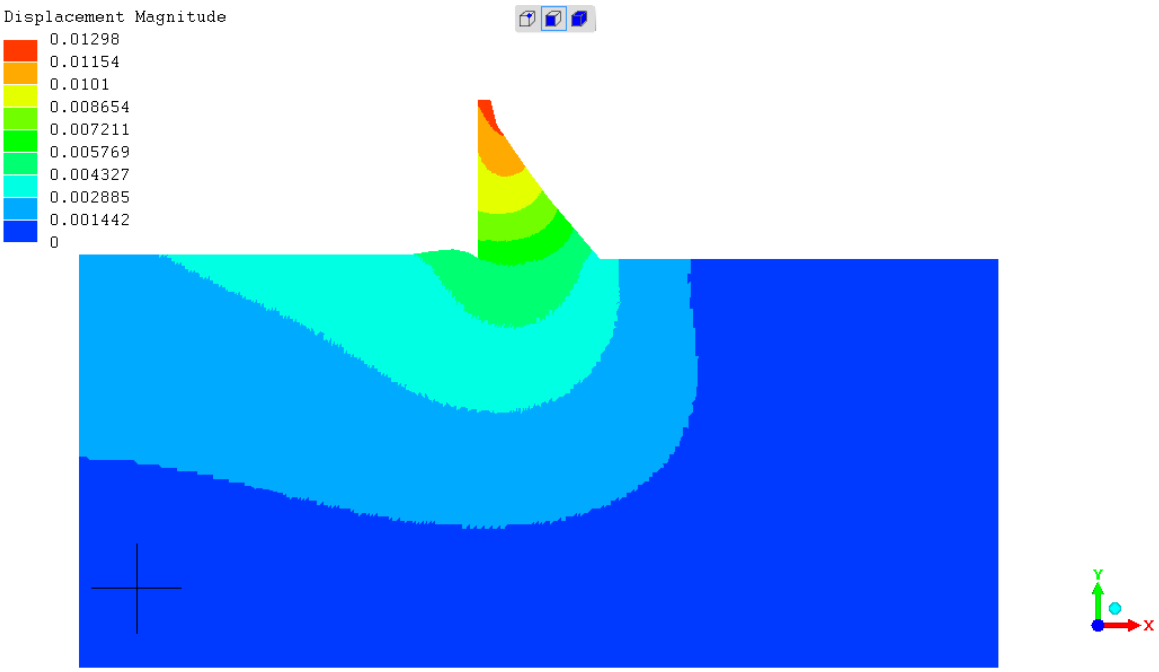
nax. 4.36 – 4.40 –ze moyvanilia gaangariSebis zogierTi Sedegi neli statikuri ciklebis gaTvaliswinebiT, rodesac n = 48.



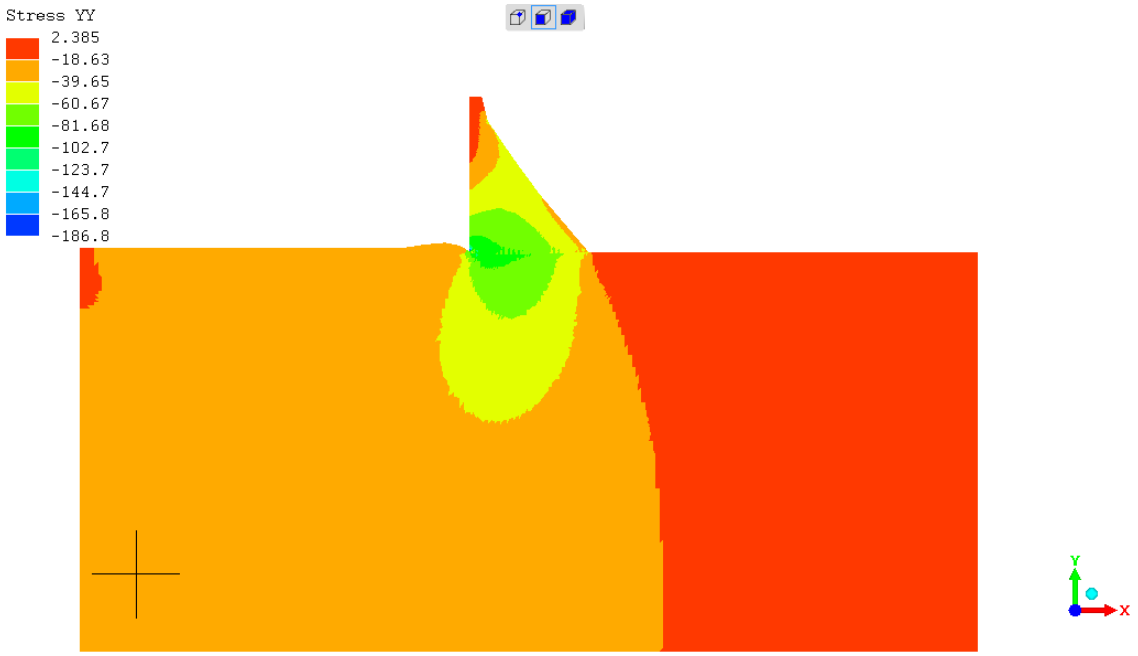
nax. 4.36: horizonTaluri u gadaadgilebebis izoubnebi statikuri cikluri datvirTvebis gaTvaliswinebiT.



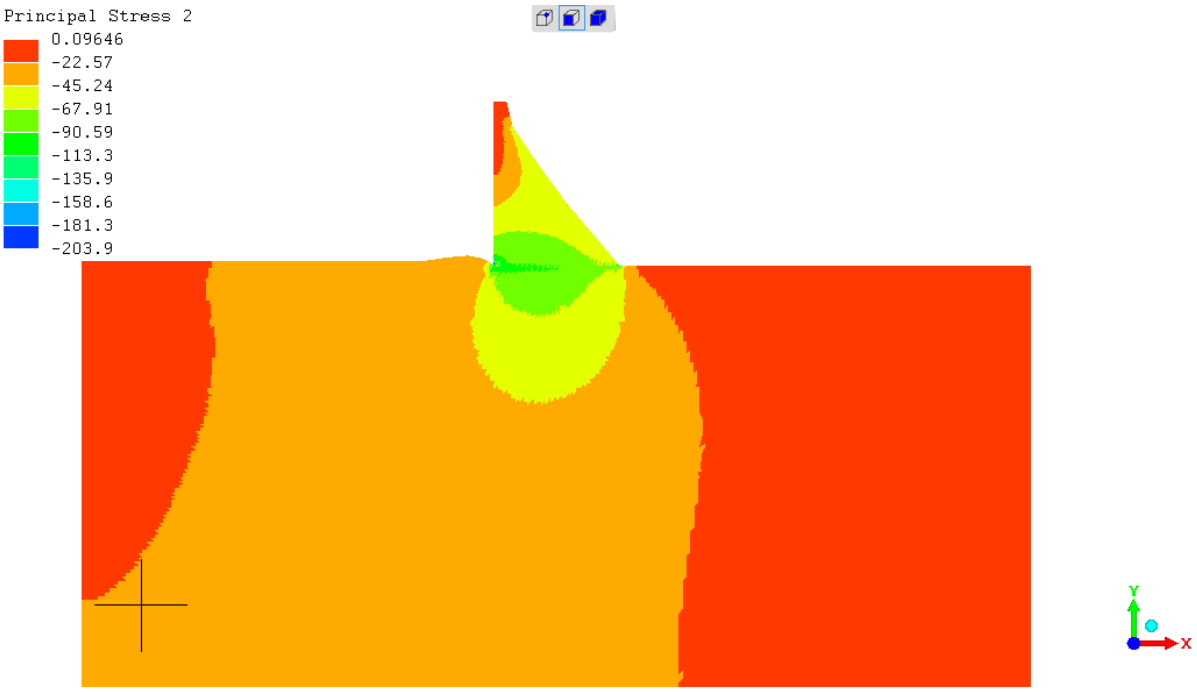
nax. 4.37: vertikaluri v gadaadgilebebis izoubnebi statikuri cikluri datvirTvebis gaTvaliswinebiT.



nax. 4.38: gadaadgilebebis magnitudebis izoubnebi statikuri cikluri datvirTvebis gaTvaliswinebiT.



nax. 4.39: Zabvebis izoubnebi statikuri cikluri datvirTvebis gaTvaliswinebiT.



nax. 4.40: maqsimaluri mTavari Zabvebis izoubnebi statikuri cikluri datvirTvebis gaTvaliswinebiT.

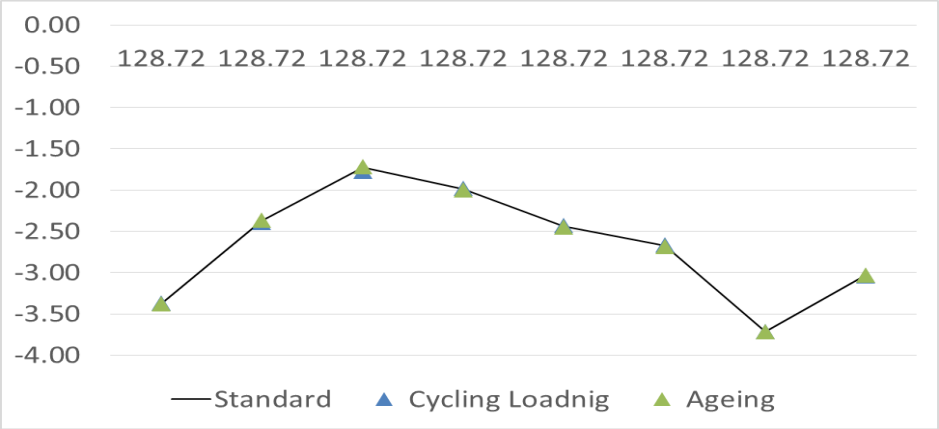
cxrilebSi 4.11 – 4.19 da nax. 4.41 – 4.49-ze moyvanilia kaSxlis tanis zogierT horizontalur kveTSi (nax. 4.25) vertikaluri normaluri Zabvebis mniSvnelobebi da epiurebi im saangariSo SemTxvevisTvis, rodesac sistemaze moqmedebs kaSxlis sakuTari wona, hidrostatikuri dawneva sadawneo waxnagze da vertikaluri hidrostatikuri dawneva wyalsacavis fskerze. Sedarebulia sami sxvadasxva SemTxveva:

- standartuli anu saproeqto varianti - (angariSebSi figurirebs betonis sawyisi drekadobis moduli);
- neli statikuri cikluri datvirTvebis gaTvaliswinebiT (n = 48);
- betonis asakis gaTvaliswinebiT (t=48).

Sedegebi naTlad gvaCveneben yvela zemod CamoTvlili faqtoris gavlenis xarisxs kaSxlis daZabul deformirebul mdgomareobaze. zogadad SeiZleba iTqvas, rom cikluri datvirTvebi kaSxlis daZabul deformirebul mdgomareobaze uaryofiT gavlenas axdenen, maSin, rodesac betonis asaki piriqiT, aumjobesebs mis meqanikur maxasiaTeblebs. gavlenis ZiriTadi aspeqtebi gaSuqebulia daskvnebSi.

cxrili 4.11:

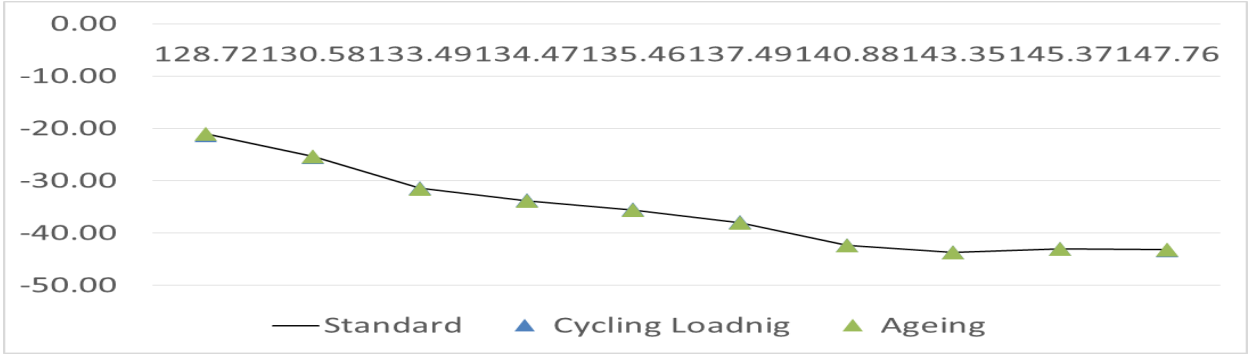
Aligm	2							
Elevation	182.88							
Point	6943	7171	7392	7587	7403	7404	7376	7152
X	128.72	128.72	128.72	128.72	128.72	128.72	128.72	128.72
Standard	-3.38	-2.37	-1.72	-1.99	-2.44	-2.68	-3.71	-3.03
Cycling Loadnig	-3.36	-2.39	-1.78	-1.98	-2.43	-2.67	-3.71	-3.04
Ageing	-3.38	-2.36	-1.71	-2.00	-2.45	-2.68	-3.71	-3.03



nax. 4.41: vertikaluri normaluri σ_y Zabvebis epiurebi me-2 kveTSi rodesac sistemaze moqmedebs kaSxlis sakuTari wona, hidrostatikuri wneva sadawneo waxnagze da vertikaluri hidrostatikuri dawneva wyalsacavis fskerze (uwyveti xazi – saproeqto variant, cisferi samkuTxedi – cikluri datvirTvebis gaTvaliswinebiT, mwvane samkuTxedi – asakis gaTvaliswinebiT).

cxrili 4.12:

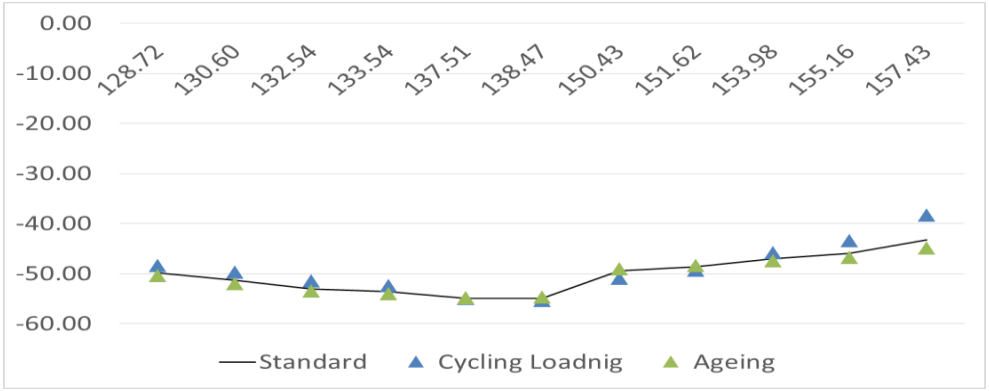
Aligm	4									
Elevation	157									
Point	7001	7467	8043	8182	8307	8531	8147	7928	7460	7003
X	128.72	130.58	133.49	134.47	135.46	137.49	140.88	143.35	145.37	147.76
Standard	-21.11	-25.42	-31.50	-33.84	-35.65	-38.03	-42.39	-43.76	-43.00	-43.13
Cycling Loadnig	-21.34	-25.51	-31.44	-33.76	-35.55	-37.93	-42.35	-43.78	-43.05	-43.26
Ageing	-21.05	-25.40	-31.52	-33.87	-35.67	-38.05	-42.39	-43.75	-42.99	-43.12



nax. 4.42: vertikaluri normaluri σ_y ***Zabvebis epiurebi me-4 kveTSi rodesac sistemaze moqmedebs kaSxlis sakuTari wona, hidrostatikuri wneva sadawneo waxnagze da vertikaluri hidrostatikuri dawneva wyalsacavis fskerze (uwyveti xazi – saproeqto variant, cisferi samkuTxedi – cikluri datvirTvebis gaTvaliswinebiT, mwvane samkuTxedi – asakis gaTvaliswinebiT).***

cxrili 4.13:

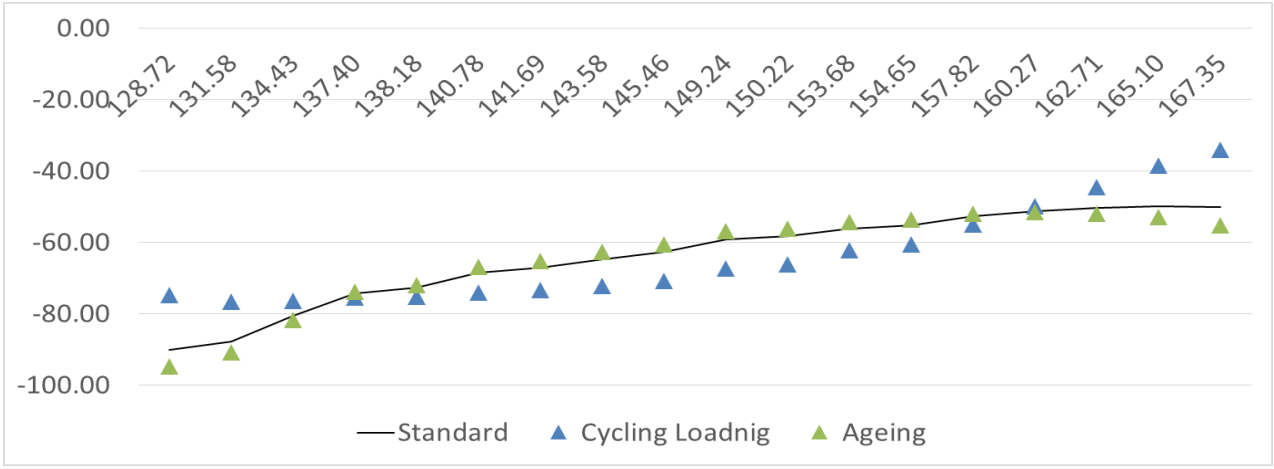
Aligm	6										
Elevation	~143.88										
Point	7034	7597	7843	8013	8557	8619	8264	8128	7722	7510	7043
X	128.72	130.60	132.54	133.54	137.51	138.47	150.43	151.62	153.98	155.16	157.43
Standard	-49.81	-51.34	-53.03	-53.65	-54.90	-54.88	-49.46	-48.60	-47.01	-45.97	-43.28
Cycling Loadnig	-48.33	-49.68	-51.50	-52.34	-54.99	-55.36	-50.86	-49.30	-45.77	-43.45	-38.29
Ageing	-50.40	-51.92	-53.52	-54.05	-54.82	-54.68	-49.03	-48.39	-47.42	-46.79	-44.89



nax. 4.43: vertikaluri normaluri σ_y ***Zabvebis epiurebi me-6 kveTSi rodesac sistemaze moqmedebs kaSxlis sakuTari wona, hidrostatikuri wneva sadawneo waxnagze da vertikaluri hidrostatikuri dawneva wyalsacavis fskerze (uwyveti xazi – saproeqto variant, cisferi samkuTxedi – cikluri datvirTvebis gaTvaliswinebiT, mwvane samkuTxedi – asakis gaTvaliswinebiT).***

cxrili 4.14:

Aligm	8																	
Elevation	~132.2																	
Point	7167	7702	8194	8537	8578	8500	8499	8558	8587	8582	8581	8539	8521	8423	8203	7925	7522	7066
X	128.72	131.58	134.43	137.40	138.18	140.78	141.69	143.58	145.46	149.24	150.22	153.68	154.65	157.82	160.27	162.71	165.10	167.35
Standard	-90.18	-87.68	-80.66	-74.28	-72.69	-68.38	-67.05	-64.67	-62.66	-59.16	-58.33	-56.06	-55.21	-52.78	-51.24	-50.35	-49.79	-50.19
Cycling Loadnig	-74.76	-76.73	-76.43	-75.49	-75.32	-74.00	-73.41	-72.13	-70.76	-67.29	-66.18	-62.28	-60.64	-54.89	-49.92	-44.45	-38.59	-34.03
Ageing	-94.88	-90.76	-81.70	-73.82	-71.86	-66.80	-65.29	-62.64	-60.48	-56.95	-56.19	-54.32	-53.68	-52.08	-51.47	-51.91	-53.01	-55.16



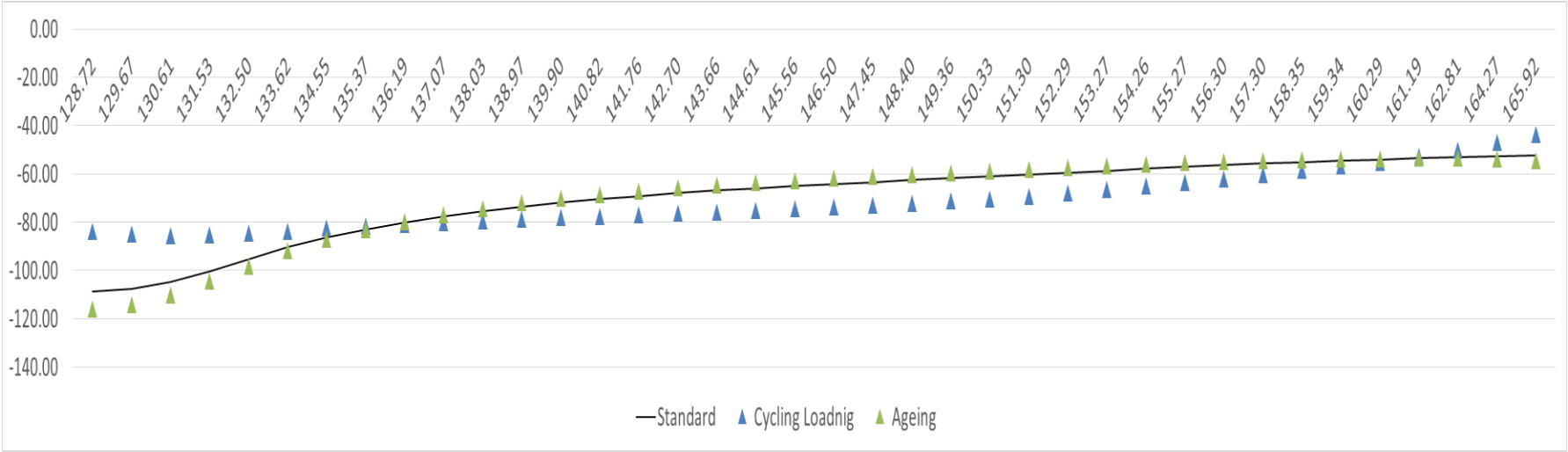
nax. 4.44: vertikaluri normaluri σ_y ***Zabvebis epiurebi me-8 kveTSi rodesac sistemaze moqmedebs kaSxlis sakuTari wona, hidrostatikuri wneva sadawneo waxnagze da vertikaluri hidrostatikuri dawneva wyalsacavis fskerze (uwyveti xazi – saproeqto variant, cisferi samkuTxedi – cikluri datvirTvebis gaTvaliswinebiT, mwvane samkuTxedi – asakis gaTvaliswinebiT).***

cxrili 4.15:

Aligm	9
Elevation	~129.5

Point	7154	7378	7548	7758	7816	8088	8172	8205	8204	8219	8218	8265	8266	8237	8177	8176	8179	8247	8169	8168
X	128.72	129.67	130.61	131.53	132.50	133.62	134.55	135.37	136.19	137.07	138.03	138.97	139.90	140.82	141.76	142.70	143.66	144.61	145.56	146.50
Standard	-108.77	-107.67	-104.70	-100.30	-95.30	-90.31	-86.24	-83.06	-80.25	-77.72	-75.37	-73.47	-71.89	-70.43	-69.18	-67.99	-66.97	-65.96	-65.09	-64.19
Cycling Loadnig	-83.75	-84.88	-85.51	-85.13	-84.38	-83.80	-82.28	-81.74	-80.86	-80.11	-79.38	-78.71	-78.13	-77.49	-76.92	-76.27	-75.69	-75.01	-74.37	-73.63
Ageing	-116.07	-114.18	-109.99	-104.34	-98.09	-91.82	-87.08	-83.19	-79.90	-76.95	-74.21	-72.02	-70.20	-68.56	-67.15	-65.84	-64.72	-63.64	-62.71	-61.77

8192	8220	8228	8209	8208	8213	8243	8242	8246	8234	8233	8158	8157	8216	8394	8255	8089	7912
147.45	148.40	149.36	150.33	151.30	152.29	153.27	154.26	155.27	156.30	157.30	158.35	159.34	160.29	161.19	162.81	164.27	165.92
-63.45	-62.63	-61.89	-61.09	-60.36	-59.50	-58.69	-57.86	-57.10	-56.41	-55.70	-55.05	-54.65	-54.29	-53.30	-52.97	-52.53	-52.26
-72.96	-72.12	-71.27	-70.24	-69.19	-67.90	-66.58	-65.09	-63.57	-61.97	-60.26	-58.42	-56.82	-55.26	-52.74	-50.24	-46.99	-43.51
-61.01	-60.19	-59.47	-58.71	-58.05	-57.28	-56.59	-55.91	-55.31	-54.84	-54.37	-54.02	-53.93	-53.87	-53.26	-53.47	-53.84	-54.47



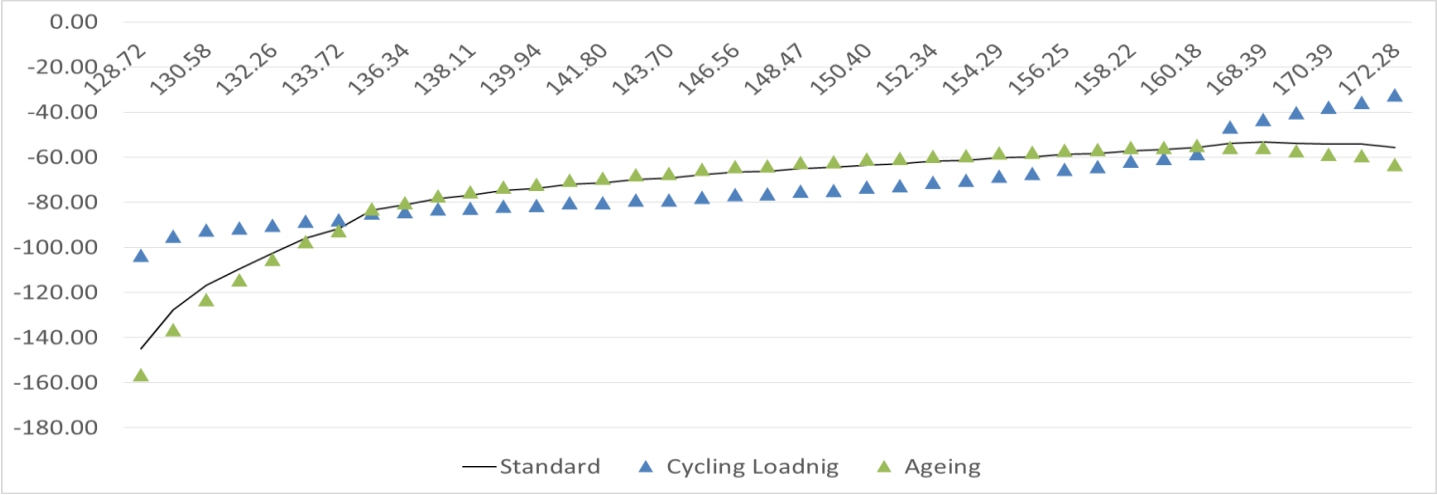
nax. 4.45: vertikaluri normaluri σ_y Zabvebis epiurebi me-9 kveTSi rodesac sistemaze moqmedebs kaSxlis sakuTari wona, hidrostatikuri wneva sadawneo waxnagze da vertikaluri hidrostatikuri dawneva wyalsacavis fskerze (uwyveti xazi – saproeqto variant, cisferi samkuTxedi – cikluri datvirTvebis gaTvaliswinebiT, mwvane samkuTxedi – asakis gaTvaliswinebiT).

cxrili 4.16:

Aligm	10
Elevation	-128.77

Point	7078	7306	7538	7626	7893	7979	7974	7806	7898	7950	7954	7946	7918	7811	7810	7923	7813	7941	7823	7822	7862
X	128.72	129.67	130.58	131.44	132.26	133.04	133.72	135.47	136.34	137.21	138.11	139.02	139.94	140.86	141.80	142.75	143.70	145.61	146.56	147.51	148.47
Y	126.70	126.72	126.68	126.72	126.73	126.70	126.66	126.87	126.85	126.86	126.87	126.88	126.89	126.90	126.92	126.94	126.96	127.01	127.03	127.06	127.10
Stress YY with Face Load	-159.41	-138.13	-123.85	-114.57	-105.25	-97.14	-91.96	-82.36	-79.47	-76.50	-74.66	-72.47	-71.25	-69.47	-68.65	-67.18	-66.64	-65.02	-63.91	-63.61	-62.48
Stress YY with Face Load + Vertical Load	-237.74	-209.77	-188.86	-173.70	-157.48	-142.97	-132.69	-113.85	-107.16	-100.57	-95.55	-90.24	-86.24	-81.74	-78.42	-74.48	-71.65	-65.71	-62.59	-60.37	-57.42
	67.05%	65.85%	65.58%	65.96%	66.83%	67.94%	69.31%	72.34%	74.16%	76.06%	78.14%	80.30%	82.61%	84.99%	87.55%	90.20%	93.02%	98.94%	102.10%	105.37%	108.83%

7861	7900	7899	7931	7930	7938	7933	7932	7949	7948	7937	7922	7760	7611	7622	7491	7370	7134
149.43	150.40	151.37	152.34	153.31	154.29	155.26	156.25	157.24	158.22	159.20	160.18	167.49	168.39	169.50	170.39	171.25	172.28
127.13	127.17	127.20	127.23	127.27	127.30	127.34	127.37	127.40	127.43	127.45	127.48	126.67	126.70	126.72	126.67	126.58	126.68
-62.20	-61.14	-60.92	-59.87	-59.64	-58.61	-58.39	-57.40	-57.25	-56.25	-56.14	-55.39	-55.86	-55.70	-56.96	-57.95	-58.41	-60.84
-55.34	-52.65	-50.76	-48.23	-46.47	-44.10	-42.44	-40.20	-38.66	-36.57	-35.23	-33.50	-27.30	-25.77	-24.82	-24.10	-23.66	-23.05
112.39%	116.14%	120.02%	124.14%	128.35%	132.90%	137.60%	142.78%	148.07%	153.81%	159.35%	165.36%	204.60%	216.18%	229.45%	240.45%	246.83%	264.01%



nax. 4.46: vertikaluri normaluri σ_y Zabvebis epiurebi me-10 kveTSi rodesac sistemaze moqmedebs kaSxlis sakuTari wona, hidrostatikuri wneva sadawneo waxnagze da vertikaluri hidrostatikuri dawneva wyalsacavis fskerze (uwyveti xazi – saproeqto variant, cisferi samkuTxedi – cikluri datvirTvebis gaTvaliswinebiT, mwvane samkuTxedi – asakis gaTvaliswinebiT).

cxrili 4.17:

Aligm	11
Elevation	124.5

Point	7080	7310	7391	7312	7311	7388	7383	7382	7325	7324	7326	7348	7328	7327	7329	7358	7331	7330	7332	7359	7334	7333
X	128.72	129.50	130.00	130.80	131.47	132.19	132.96	133.75	134.58	135.44	136.33	137.23	138.13	139.04	139.96	140.90	141.85	142.80	143.77	144.73	145.69	146.65
Standard	-292.22	-143.05	-98.23	-90.99	-125.86	-102.69	-101.77	-87.87	-92.38	-78.99	-86.38	-76.25	-83.42	-73.47	-81.22	-70.78	-79.23	-68.82	-77.53	-67.43	-76.07	-65.90
Cycling Loadnig	-186.77	-95.90	-73.99	-79.17	-113.29	-94.09	-97.39	-86.98	-95.10	-82.57	-91.69	-81.85	-90.65	-80.55	-89.84	-78.85	-88.88	-77.68	-87.99	-76.66	-86.57	-75.34
Ageing	-320.08	-155.50	-104.64	-93.66	-127.87	-104.00	-102.45	-87.78	-91.57	-78.02	-85.10	-74.89	-81.73	-71.80	-79.23	-68.89	-77.01	-66.76	-75.13	-65.28	-73.64	-63.69

7335	7360	7337	7336	7338	7361	7340	7339	7341	7362	7343	7342	7344	7363	7350	7349	7351	7352	7346	7345	7347	7389	7173	7172	7174
147.62	148.58	149.54	150.51	151.47	152.44	153.41	154.37	155.34	156.31	157.28	158.24	159.21	160.17	161.11	162.02	162.90	163.72	164.50	165.25	165.98	166.71	167.44	168.17	168.90
-74.72	-64.04	-73.41	-62.33	-72.18	-60.72	-70.97	-59.09	-69.64	-57.29	-68.07	-55.37	-66.53	-53.33	-64.45	-52.56	-62.10	-53.04	-60.87	-51.78	-60.02	-50.21	-59.25	-49.42	-59.36
-85.75	-73.62	-84.41	-71.68	-82.83	-69.46	-80.75	-66.94	-78.34	-64.04	-75.45	-60.72	-71.97	-56.97	-67.77	-54.54	-63.41	-53.41	-60.44	-50.57	-57.61	-47.16	-54.48	-44.11	-51.82
-72.15	-61.78	-70.83	-60.12	-69.66	-58.63	-68.63	-57.19	-67.51	-55.63	-66.23	-54.00	-65.09	-52.33	-63.46	-51.93	-61.57	-52.76	-60.75	-51.88	-60.34	-50.75	-60.16	-50.51	-60.98

nax. 4.47: vertikaluri normaluri σ_y Zabvebis epiurebi me-11 kveTSi rodesac sistemaze moqmedebs kaSxlis sakuTari wona, hidrostatikuri wneva sadawneo waxnagze da vertikaluri hidrostatikuri dawneva wyalsacavis fskerze (uwyveti xazi – saproeqto variant, cisferi samkuTxedi – cikluri datvirTvebis gaTvaliswinebiT, mwvane samkuTxedi – asakis gaTvaliswinebiT).

daskvnebi

1. didi xnis ganmavlobaSi eqspluataciaSi myofi betonis kaSxlebis arsebuli daZabul-deformirebuli mdgomareobis angariSisas aucilebelia miRebuli iqnas mxedvelobaSi misi eqsploataciis istoria.
2. eqspluataciis istoris gaTvaliswinebisas unda Catardes:

   a) betonis arawrfivi drekadi rRvevis ganmsazRvreli modelis SerCeva brtyeli deformaciis pirobebisaTvis;

   b) sakontaqto zonis ganmsazRvreli modelis SerCeva;

   g) cocvadobis deformaciebis angariSi;

   d) kaSxalis tanSi bzaris gaCenisa da gavrcelebis analizi;

   e) wyalsacavis avseba-daclis ciklebis raodenobis gavlenis analizi betonis meqanikur maxasiaTeblebze, kerZod mis drekadobis modulze;

   v) betonis asakis gavlenis analizi betonis meqanikur maxasiaTeblebze, kerZod mis drekadobis modulze;
3. neli statikuri cikluri datvirTva (wyalsacavis avseba-daclis ciklebi) iwvevs gravitaciuli kaSxlis betonis meqanikuri maxasiaTeblebis sagrZnob cvlilebas, kerZod ciklebis ricxvis gazrdis Sedegad sagrZnoblad mcirdeba betonis meqanikuri maxasieTebeli – drekadobis moduli.
4. drekadobis modulis gauaresebis maCvenebeli da betonis simtkice pirdapir damokidebulia ZabviT mdgomareobaze. magaliTad, betonis drekadobis modulis mniSvneloba mcirdeba 51,5% -iT (39780-dan 19300 mpa-de) 150 datvirTva-gantvirTvis ciklis modebis Semdeg, rodesac modebuli Zalisgan gamowveuli Zabva tolia $0.2\sigma_c$ –is, sadac σ_c aris betonis simtkice erTRerZa kumSvis dros. rodesac modebuli Zalisgan gamowveuli Zabva tolia $0.5\sigma_c$ –is, drekadobis modulis mniSvneloba mcirdeba 29,3% -iT (33390-dan 23620 mpa-de) 150 datvirTva-gantvirTvis ciklis modebis Semdeg. rodesac modebuli Zalisgan gamowveuli Zabva tolia $0.8\sigma_c$ –is, drekadobis modulis mniSvneloba mcirdeba 20,9% -iT (28390-dan 22500 mpa-de) 150 datvirTva-gantvirTvis ciklis modebis Semdeg;
5. masalis maxasiaTeblebis da betonis simtkicis gauaresebis xarisxi statikuri cikluri datvirTvebis dros damokidebulia agreTve gamosacdeli betonis nimuSis asakze. magaliTad, 28 dRis asakis betonis nimuSis drekadobis modulis mniSvneloba mcirdeba 51,5%-iT (39780-dan 19300 mpa-de) 150 datvirTva-gantvirTvis ciklis modebis Semdeg da rodesac modebuli Zalisgan gamowveuli Zabva tolia $0.2\sigma_c$ –is. amave dros, 365 dRis (1 weliwadi) asakis betonis nimuSis

drekadobis modulis mniSvneloba mcirdeba 49,0%-iT (39830-dan 21750 mpa-de) 150 datvirTva-gantvirTvis ciklis modebis Semdeg da rodesac modebuli Zalisgan gamowveuli Zabva tolia $0.2\sigma_c$ –is. 1825 dRis (5 weliwadi) asakis betonis nimuSis drekadobis modulis mniSvneloba mcirdeba 42,0%-iT (42460-dan 20310 mpa-de) igive raodenobis datvirTva-gantvirTvis ciklis modebis Semdeg da rodesac modebuli Zalisgan gamowveuli Zabva tolia $0.2\sigma_c$ –is.

6. neli statikuri cikluri datvirTva iwvevs interfeisebis (kaSxlisa da fuZis sakontaqto sibrtye, betonis fenebs Soris sakontaqto sibrtyeebi) masalis maxasiaTeblis (Zvris moduli) mniSvnelovan vardnas;
7. griesis gravitaciuli kaSxlis (Sveicaria) magaliTze Seswavlili iqna wyalsacavis fskerze vertikaluri hidrostatikuri Zalis gavlena kaSxlis daZabul-deformirebul mdgomareobaze. Sedegebis analizi gviCvenebs rom vertikalur hidrostatikur dawnevas wyalsacavis fskerze aqvs SesamCnevi gavlena kaSxlis waxnagebze Zabvebis mniSvnelobebze sakontaqto zedapirTan axlos. zemod es gavlena mcirdeba. uSualod kaSxlis tanSi zogadad es gavlena umniSvneloa;
8. griesis kaSxlis angariSis Sedegebi aCvenebs, rom statikuri cikluri datvirTva (Cvens SemTxvevaSi 48 cikli) mniSvnelovnad cvlis kaSxlis daZabul deformirebul mdgomareobas interfeisis zonaSi. zogadad es gavlena vrceldeba daaxloebiT interfeisidan zemod kaSxlis 1/4¼ simaRleze. zogadad SeiZleba iTqvas, rom cikluri datvirTvebi kaSxlis daZabul deformirebul mdgomareobaze uaryofiT gavlenas axdenen, maSin, rodesac betonis asaki piriqiT, aumjobesebs mis meqanikur maxasiaTeblebs.

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