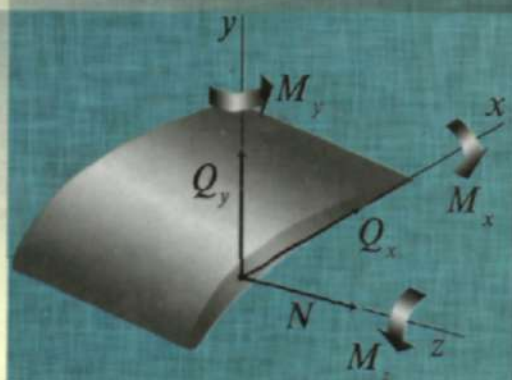
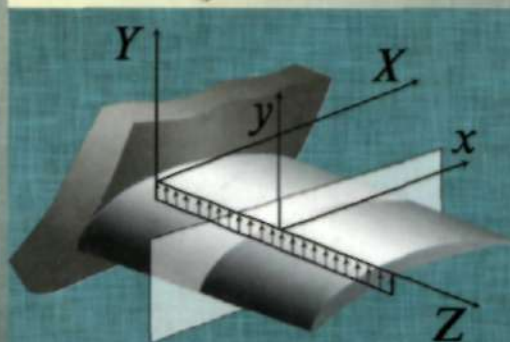


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S. Hasanov, A. Nabiyeu

# Materiallar qarshiligidan masalalar yechish



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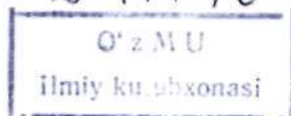
**O'ZBEKISTON RESPUBLIKASI OLIY VA O'RTA  
MAXSUS TA'LIM VAZIRLIGI**

**S.M. Hasanov, A.N. Nabiyeu**

**MATERIALLAR QARSHILIGIDAN  
MASALALAR YECHISH**

*O'zbekiston Respublikasi Oliy va o'rta  
maxsus ta'lim vazirligi tomonidan  
oliy texnika ta'lim muassasalari talabalari uchun  
o'quv qo'llanma sifatida tavsiya etilgan*

B 11176



**TOSHKENT  
"O'ZBEKISTON"  
2006**

**Taqrizchilar:** texnika fanlari doktori, professor *M. Ergashov*,  
fizika-matematika fanlari nomzodi, dotsent *K. Adilov*.

«Materiallar qarshiligidan masalalar yechish» o'quv qo'llanmasi O'zbekiston Respublikasi Oliy va o'rta maxsus ta'lim vazirligi oliy ta'lim muassasalarining sanoat, transport va qurilish sohalari uchun tasdiqlangan amaldagi o'quv dasturlariga muvofiq yozilgan.

O'quv qo'llanmada materiallar qarshiligi fanining asosiy mavzulariga oid masalalar yechimi hamda talabalar bajarishi lozim bo'lgan hisob-grafika ishlari variantlari keltirilgan. Bundan tashqari, oliy o'quv yurtlari talabalari o'rtasida «Materiallar qarshiligi» fanidan o'tkazib kelingan Respublika olimpiadalarida taqdim etilgan bir turkum masalalar yechimi ham keltirilgan.

Qo'llanma oliy texnika ta'lim muassasalarining talabalari uchun mo'ljallangan. Undan aspirantlar, muhandis-texnik xodimlar va o'rta maxsus, kasb-hunar ta'lim tizimining o'qituvchilari ham foydalanishlari mumkin.

**Hasanov S.M.**

**X 30** Materiallar qarshiligidan masalalar yechish: Oliy texnika o'quv yurtlari talabalari uchun o'quv qo'llanma/ S.M. Hasanov, A.N. Nabiyeu – T.: O'zbekiston, 2006. 288 b.

ББК 30.121я7

№ 418-2006

## SO'ZBOSHI

Kadrlar tayyorlash Milliy dasturining ikkinchi – sifat bosqichi talablari doirasida Oliy va o'rta maxsus ta'lim muassasalarida amaliy mashg'ulotlarga ajratilgan o'quv yuklamalari hajmini mumkin qadar ko'paytirishga alohida e'tibor qaratilgan.

Hozirgi paytda «Materiallar qarshiligi» fanidan masalalar to'plami hamda misol va masalalar yechish bo'yicha Oliy texnika o'quv yurtlari talabalariga mo'ljallangan o'zbek tilidagi uslubiy ko'rsatmalar, qo'llanmalar, darsliklar yetarli emas. Shu bois mazkur o'quv qo'llanmada «Materiallar qarshiligi» fanida eng ko'p uchraydigan masalalarning yechimlari berilgan.

Ushbu kitobga mualliflarning ko'p yillar davomida Toshkent Politehnika instituti (Toshkent Davlat Texnika Universiteti) va Toshkent Davlat aviatsiya institutlarida o'qigan ma'ruza matnlari va o'tkazgan amaliy mashg'ulotlari, yozgan uslubiy qo'llanmalari va foydalangan qo'lyozmalari asos qilib olingan.

O'quv qo'llanma oliy texnika ta'lim muassasalarida sanoatning mashinasozlik, samolyotsozlik, avtomobilsozlik, metallurgiya hamda transport va qurilish sohalariga bo'yicha o'qiyotgan talabalarga mo'ljallangan. Undan mazkur ta'lim muassasalarining aspirantlari va kasb-hunar kollejlarning texnik mexanika fani o'qituvchilari ham foydalanishlari mumkin.

Mazkur o'quv qo'llanma texnika fanlari nomzodi dotsent S.M.Hasanovning umumiy tahriri asosida yozilgan bo'lib, uning I, II, IV, VI, VIII, X, XI, XII, XIV boblarini dotsent S.M.Hasanov, III, V, IX, XIII boblarini esa texnika fanlari nomzodi dotsent A.N.Nabiyeu yozgan.

Shuni ta'kidlash lozimki, materiallar qarshiligi fanidan misol-masalalar yechish va hisob-grafika ishlarini bajarish bo'yicha rus va o'zbek tillarida chop etilgan ba'zi o'quv adabiyotlaridan muhandislik amaliyotida ko'p uchraydigan ayrim tipik masalalar ushbu kitobga deyarli o'zgarishsiz tanlab olindi. Mualliflar bunday yondashuvni, eng avvalo, o'quv adabiyotlarining yangi avlodi hozircha taqchil bo'lgan davrda mavjud adabiyotlardan ham unumli foydalanishga talabalarni undashga asos bo'ladi, deb hisoblaydilar.

XIV bobni yozishda Toshkent arxitektura va qurilish instituti professor-o'qituvchilarining turli yillarda «Materiallar qarshiligi» fanidan talabalar o'rtasida o'tkazilgan Respublika olimpiadalariga taklif qilgan masalalaridan foydalanilgan. Bu bobdan asosan professor-o'qituvchilar foydalanishini nazarda tutib, undagi masalalar tahlili qisqa holda berildi. Ba'zi boblarning oxirida talabalar uchun keltirilgan topshiriqlarni tuzishda Y.F. Vinokurov va boshqalarning o'quv qo'llanmalaridan [13] foydalanildi.

Mualliflar qo'lyozmani nashrga tayyorlashda bergan foydali maslahatlari uchun dotsent F.S. To'raxodjayevga samimiy minnatdorchilik bildiradilar.

Qo'llanmaning mazmuni va sifatini boyitishga qaratilgan barcha tanqidiy fikr-mulohazalar uchun kitobxonlarga oldindan minnatdorchilik bildirgan holda, ularni quyidagi manzilga yuborishlarini iltimos qilamiz: 700077, Toshkent shahri, Buyuk Ipak Yo'li ko'chasi, 38.



## Materiallar qarshiligidagi qo'llaniladigan asosiy belgilashlar va ularning o'lchov birliklari:

- $A$  – ko'ndalang kesim yuzasi,  $m^2$ ;  
 $F$  – kuch,  $kN$ ;  
 $E$  – cho'zilish va siqilishdagi elastiklik moduli,  $MPa$ ;  
 $G$  – siljishdagi elastiklik moduli,  $MPa$ ;  
 $I$  – kesimning inersiya momenti,  $m^4$ ;  
 $I_x, I_y$  – o'qlarga nisbatan inersiya momenti,  $m^4$ ;  
 $I_{xy}$  – markazdan qochma inersiya momenti,  $m^4$ ;  
 $I_p$  – polyar inersiya momenti,  $m^4$ ;  
 $M$  – eguvchi moment,  $kN \cdot m$ ;  
 $N$  – bo'ylama kuch,  $kN$ ;  
 $Q$  – ko'ndalang kuch,  $kN$ ;  
 $S$  – kesimning statik momenti,  $m^3$ ;  
 $i$  – kesimning inersiya radiusi,  $M$ ;  
 $m$  – to'plangan moment, juft kuch,  $kN \cdot m$ ;  
 $q$  – taralgan kuch intensivligi,  $kN/m$ ;  
 $\alpha$  – materialning temperatura ta'sirida chiziqli kengayish koeffitsiyenti,  $1/grad$ ;  
 $\gamma$  – solishtirma og'irlik,  $kN/m^3$ ;  
 $\Delta, \delta$  – chiziqli ko'chish,  $mm$ ;  
 $\varepsilon$  – nisbiy deformatsiya;  
 $\theta$  – ko'ndalang kesimning aylanish burchagi,  $rad$ ;  
 $\lambda$  – sterjenning egiluvchanligi;  
 $\mu$  – Puasson koeffitsiyenti;  
 $\sigma$  – normal kuchlanish,  $MPa$ ;  
 $\tau$  – urinma kuchlanish,  $MPa$ .

### Karrali yoki ulushli birliklar

| Qo'shimcha   | Giga   | Mega   | Kilo   | Gekto  | Deka | Detsi     | Santi     | Milli     | Mikro     | Nano      |
|--------------|--------|--------|--------|--------|------|-----------|-----------|-----------|-----------|-----------|
| Belgilash    | G      | M      | k      | g      | Da   | d         | s         | m         | mk        | n         |
| Ko'paytuvchi | $10^9$ | $10^6$ | $10^3$ | $10^2$ | 10   | $10^{-1}$ | $10^{-2}$ | $10^{-3}$ | $10^{-6}$ | $10^{-9}$ |

## Mexanik qiymatlarning xalqaro o'lchov birliklar sistemasidagi (SI) o'lchov birliklari

| Qiymatlar         |                | O'lchov birliklari (SI) |                           |                                                                                |
|-------------------|----------------|-------------------------|---------------------------|--------------------------------------------------------------------------------|
| Nomi              | Belgilash      | Nomi                    | Belgilash                 | Birliklar nisbati                                                              |
| Kuch              | $F, Q, N$      | Nyuton                  | N                         | $10 \text{ N} = 1 \text{ kg} \cdot \text{kuch}$                                |
| Kuchlanish        | $\sigma, \tau$ | Paskal                  | Pa                        | $1 \text{ Pa} = 1 \text{ N/m}^2$                                               |
| Elastiklik moduli | $E, G$         | Paskal                  | Pa                        | $1 \text{ MPa} = 10 \text{ kg} \cdot \text{kuch/sm}^2$                         |
| Kuch momenti      | $M$            | Nyuton-metr             | $\text{N} \cdot \text{m}$ | $1 \text{ N} \cdot \text{m} = 0,1 \text{ kg} \cdot \text{kuch} \cdot \text{M}$ |
| Taralgan kuch     | $q$            | Nyuton taqsim metr      | $\text{N/m}$              | $1 \text{ N/m} = 0,1 \text{ kg} \cdot \text{kuch} \cdot \text{M}$              |

## I BOB

## CHO'ZILISH VA SIQILISH

## 1.1- §. Asosiy mulohazalar

- Berilgan sterjenlarning ko'ndalang kesimlarida faqatgina bitta bo'ylama kuch  $N$ , ta'sir ko'rsatsa, u holda cho'zilish yoki siqilish deformatsiyasi sodir bo'ladi.
- Kuch sterjenni cho'zsa, bo'ylama kuch ishorasi musbat, siqsa – manfiy olinadi.
- Sterjenning ixtiyoriy ko'ndalang kesimida hosil bo'ladigan normal kuchlanish quyidagiga teng bo'ladi:

$$\sigma = \frac{N}{A} \quad (1.1)$$

Bu yerda,  $N$  – bo'ylama kuch;  $A$  – kesim yuzasi.

- Cho'zilish va siqilishda sterjen mustahkamlik sharti quyidagiga teng:

$$\sigma_{\max} = \frac{N_{\max}}{A} \leq [\sigma]. \quad (1.2)$$

Bu yerda,  $[\sigma]$  – ruxsat etilgan normal kuchlanish.

- Cho'zilishda sterjen uzunligi ortadi, siqilishda esa kamayadi:

$$\Delta l = l - l_1.$$

Bu yerda,  $\Delta l$  – bo'ylama deformatsiya;

$l$  – sterjenning dastlabki uzunligi;

$l_1$  – sterjenning deformatsiyadan keyingi uzunligi.

- Nisbiy bo'ylama deformatsiya quyidagiga teng:

$$\varepsilon = \Delta l / l. \quad (1.3)$$

- Cho'zilishda sterjen ko'ndalang kesimi kamayadi, siqilishda esa ko'payadi:

$$\Delta b = b_1 - b.$$

Bu yerda,  $\Delta b$  – absolut qisqarish;

$b$  – kesimning oldingi o'lchami;

$b_1$  – kesimning deformatsiyadan keyingi o'lchami.

- Nisbiy ko'ndalang deformatsiya quyidagiga teng:

$$\varepsilon_q = \frac{\Delta b}{b}. \quad (1.4)$$

➤ Cho'zilish va siqilishda Guk qonuni quyidagiga teng:

$$\sigma = E \cdot \varepsilon; \quad (1.5)$$

$$\Delta l = \frac{N \cdot l}{EA}. \quad (1.6)$$

Bu yerda,  $E$  – materialning elastiklik moduli.

➤ Puasson koeffitsiyenti quyidagiga teng:

$$\mu = \frac{\varepsilon_q}{\varepsilon}. \quad (1.7)$$

## 1.2- §. Cho'zilish va siqilishdagi statik aniq masalalar

### 1- masala

Ko'ndalang kesim yuzasi  $A = 0.8 \cdot 10^{-4} \text{ m}^2$  va uzunligi  $l = 1 \text{ m}$  bo'lgan po'lat sterjenning  $F = 10000 \text{ N}$  cho'zuvchi kuchdan hosil bo'lgan absolut uzayishini aniqlang.

#### Yechish:

Sterjen materiali uchun  $E = 2 \cdot 10^3 \text{ N/m}^2$  ekanligini e'tiborga olib, (1.6) ifodadan absolut uzayishni topamiz:

$$\Delta l = \frac{Fl}{EA} = \frac{10000 \cdot 1}{2 \cdot 10^3 \cdot 0.8 \cdot 10^{-4}} = 0.625 \cdot 10^{-3} \text{ m}.$$

### 2- masala

Ko'ndalang kesimi kvadrat shaklidagi po'lat brus tashqi kuch ta'siridan bo'ylama yo'nalishda  $\Delta l = 3.2 \cdot 10^{-5} \text{ m}$  ga uzayib, ko'ndalang yo'nalishda  $\Delta h = 0.03 \cdot 10^{-5} \text{ m}$  ga siqilgan. Agar brusning bo'ylama o'lchami (uzunligi)  $l = 30 \cdot 10^{-2} \text{ m}$  va ko'ndalang o'lchami  $h = 1 \cdot 10^{-2} \text{ m}$  bo'lsa, Puasson koeffitsiyenti nechaga teng?

#### Yechish:

(1.7) ifodadan foydalanib, Puasson koeffitsiyentini aniqlaymiz:

$$\mu = \frac{\Delta h}{\Delta l} \cdot \frac{l}{h} = \frac{0.03 \cdot 10^{-5}}{3.2 \cdot 10^{-5}} \cdot \frac{30 \cdot 10^{-2}}{1 \cdot 10^{-2}} = 0.28.$$

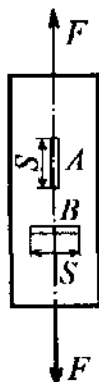
### 3- masala

Elastiklik moduli  $E_r$  va Puasson koeffitsiyenti  $\mu$  larning tajribaviy qiymatlarini aniqlash uchun po'lat materialdan yasalgan tekis namuna cho'zilishga sinalgan (1.1- shakl). Namuna ning deformatsiyasi bo'ylama va ko'ndalang yo'nalishlarda o'rnatilgan  $A$  va  $B$  richagli tenzo-

metrlar yordamida o'lchangan. Tenzometrlar bir xil bazali ( $S_A = S_B = 20 \text{ mm}$ ) bo'lib, ularning kattalashtirishi mos ravishda  $k_A = 950$  va  $k_B = 1190$  ga teng.

Namunaning kesim yuzasi  $A_0 = 1 \cdot 10^2 \text{ mm}^2$  ga teng. Tajriba natijalari 1.1-jadvalda keltirilgan.

1.1-jadval



1.1-shakl

| Namunaning yuklanishi, $F, \text{kN}$ | Tenzometrlarning ko'rsatishi, mm |       |
|---------------------------------------|----------------------------------|-------|
|                                       | $n_A$                            | $n_B$ |
| 2                                     | 4,5                              | 36,0  |
| 12                                    | 14,5                             | 32,5  |
| 22                                    | 24,0                             | 30,0  |
| 32                                    | 34,5                             | 25,5  |

**Yechish:**

Namunani cho'zuvchi kuch ortirmasining o'rtacha qiymati

$$\Delta F = \frac{(12 - 2) + (22 - 12) + (32 - 22)}{3} = 10 \text{ kN ga teng.}$$

$\Delta F$  ga mos keluvchi tenzometr ko'rsatishi ortirmasining o'rtacha qiymatlarini hisoblaymiz:

$$\Delta n_A = \frac{(14,5 - 4) + (24 - 14,5) + (34,5 - 24)}{3} = 10 \text{ mm;}$$

$$\Delta n_B = \frac{|(32,5 - 36) + (30 - 32,5) + (25,5 - 30)|}{3} = 3,5 \text{ mm.}$$

Absolut uzayishning o'rtacha qiymati:

$$\Delta S_A = \frac{10}{950} = 1,05 \cdot 10^{-2} \text{ mm; } \Delta S_B = \frac{3,5}{1190} = 2,9 \cdot 10^{-3} \text{ mm.}$$

Shunday qilib,

$$E_T = \frac{\Delta F \cdot S_A}{A_0 \cdot \Delta S_A} = 1,9 \cdot 10^5 \text{ MPa; } \mu_T = \frac{\epsilon_B}{\epsilon_A} = \frac{\Delta S_B \cdot S_A}{\Delta S_A \cdot S_B} = 0,28.$$



## 4- masala

Uzunligi va diametri ma'lum bo'lgan pog'onali po'lat sterjen chizmada ko'rsatilgandek,  $F_1=30$  kN,  $F_2=65$  kN,  $F_3=170$  kN bo'ylama kuchlar bilan yuklangan. Sterjenning xususiy og'irligini e'tiborga olmay, bo'ylama kuch va normal kuchlanish epyuralari qurilsin hamda sterjen uchining ko'chishi aniqlansin.

Bunda,  $d=2$  sm;  $l_1=20$  sm;  $l_2=30$  sm;  $l_3=20$  sm.

## Yechish:

Sterjenni o'ng tomondan boshlab uchta oraliq (uchastka)ga ajratamiz. Kesish usulini qo'llab, avvalo har bir uchastka uchun bo'ylama kuch  $N$  va normal kuchlanish  $\sigma$  larni aniqlaymiz.

Oraliq: I.2- shakl (b) da ko'rsatilgan sterjen bo'lagining muvozanat tenglamasini tuzamiz:

$$\sum Z_i = F_1 - N_1 = 0;$$

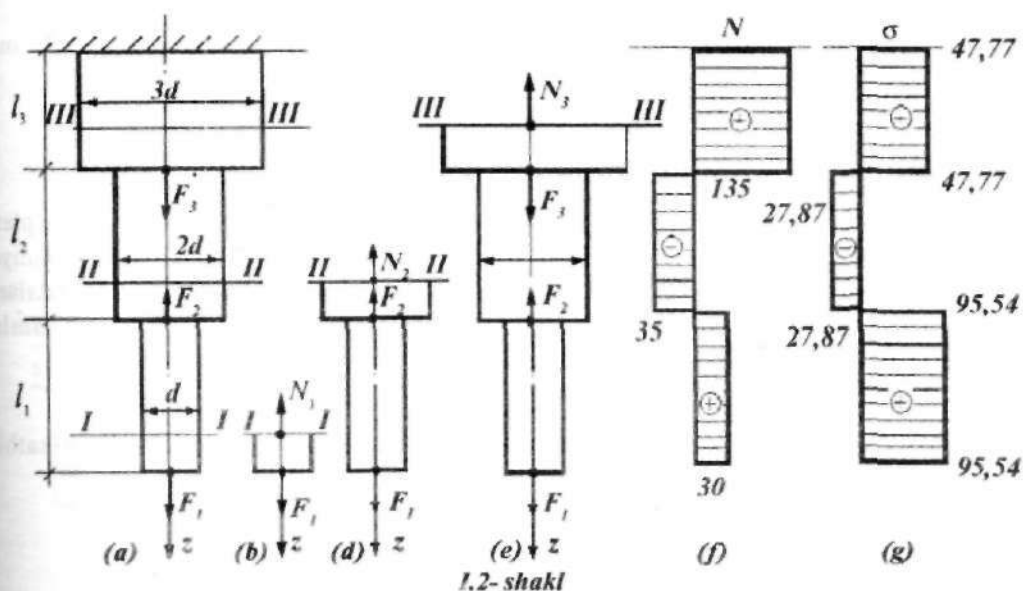
bundan,  $N_1 = F_1$  yoki  $N_1 = 30$  kN.

(1.5) ifodaga ko'ra, normal kuchlanish

$$\sigma_1 = \frac{N_1}{A_1}$$

ga teng, bu yerda,  $A_1 = \pi d^2/4 \approx 3,14 \text{ sm}^2 = 3,14 \cdot 10^{-4} \text{ m}^2$ .

$$\text{Demak, } \sigma_1 = \frac{30 \cdot 10^3}{3,14 \cdot 10^{-4}} = 95,54 \cdot 10^6 \frac{\text{N}}{\text{m}^2} = 95,54 \text{ MPa.}$$



II oraliq: I.2- shakl (d) chizmada tasvirlangan bo'lakcha uchun:

$$\sum Z_i = F_1 - F_2 - N_2 = 0.$$

Bundan,  $N_2 = F_1 - F_2 = -35 \text{ kN}$ ;

$$\sigma_2 = \frac{N_2}{A_2} = \frac{-35 \cdot 10^3}{\frac{\pi(2d)^2}{4} \cdot 10^{-4}} = -27,87 \text{ MPa}.$$

III oraliq: I.2- shakl (e) chizmadan foydalanib, quyidagilarni hisoblaymiz:

$$\sum Z_i = F_1 - F_2 + F_3 - N_3 = 0.$$

Bundan,  $N_3 = F_1 + F_3 - F_2 = 135 \text{ kN}$ .

$$\sigma_3 = \frac{N_3}{A_3} \quad \text{yoki} \quad \sigma_3 = \frac{135 \cdot 10^3}{\frac{\pi(3d)^2}{4} \cdot 10^{-4}} = 47,77 \text{ MPa}.$$

I.2- shakl (f) va (g) larda, mos ravishda, bo'ylama kuch va normal kuchlanishlarning epyuralari ko'rsatilgan.

Sterjen uchidagi kesimning ko'chishini topishda (I.6) ifodadan foydalanamiz:

$$\Delta l = \frac{1}{E} \cdot \sum_{i=1}^3 \frac{N_i l_i}{A_i};$$

bu yerda,  $E = 2 \cdot 10^{11} \text{ N/m}^2$  yoki

$$\Delta l = \frac{1}{E} \left( \frac{30 \cdot 10^3 \cdot 20 \cdot 10^{-2}}{3,14 \cdot 10^{-4}} - \frac{35 \cdot 10^3 \cdot 30 \cdot 10^{-2}}{12,56 \cdot 10^{-4}} + \frac{135 \cdot 10^3 \cdot 20 \cdot 10^{-2}}{28,56 \cdot 10^{-4}} \right) \approx 0,10 \cdot 10^{-3} \text{ m}.$$

Demak, sterjen 0,101 mm ga uzayar ekan.

### 5- masala

Pastki uchi tayanchga qistirib mahkamlangan po'lat sterjenga  $F = 80 \text{ kN}$  ga teng to'plan-gan kuch hamda  $q(z) = ql/z$  ( $q = 40 \text{ N/m}$  bo'lib, tayanch kesimga qo'yilgan) qonuniyat bo'yicha o'zgaruvchi tekis taralgan yuk ta'sir etmoqda (I.3- shakl, a). Sterjenning ko'ndalang kesim yuzasi  $A = 15 \text{ sm}^2 = 15 \cdot 10^{-4} \text{ m}^2$  ga teng. Bo'ylama kuch va ko'ndalang kesimlar ko'chishining epyuralari qurilsin.

### Yechish:

Sterjenni yuqori uchidan boshlab ikkita oraliqqa ajratamiz va kesish usulini tatbiq etamiz.

I oraliq:  $0 \leq z_1 \leq 3 \text{ m}$

$$N(z_1) = - \int_0^{z_1} \frac{q}{l} z dz = - \frac{q z_1^2}{2l} = -4 z_1^2,$$

bunda:

$$z_1 = 0, \quad N(0) = 0;$$

$$z_1 = 2, \quad N(2) = -16 \text{ kN};$$

$$z_1 = 3, \quad N(3) = -36 \text{ kN}.$$

II oraliq:  $3 \text{ m} \leq z_2 \leq 5 \text{ m}$

$$N(z_2) = F - \int_0^{z_2} \frac{q}{l} z dz = F - \frac{qz_2^2}{2l} \quad \text{yoki} \quad N(z_2) = 80 - 4z_2^2;$$

bunda:

$$z_2 = 3, \quad N(3) = 80 - 36 = 44 \text{ kN};$$

$$z_2 = 4,472, \quad N(4,472) = 0;$$

$$z_2 = 5, \quad N(5) = -20 \text{ kN}.$$

I.3- shakl (e) da bo'ylama kuch epyurasi qurilgan.

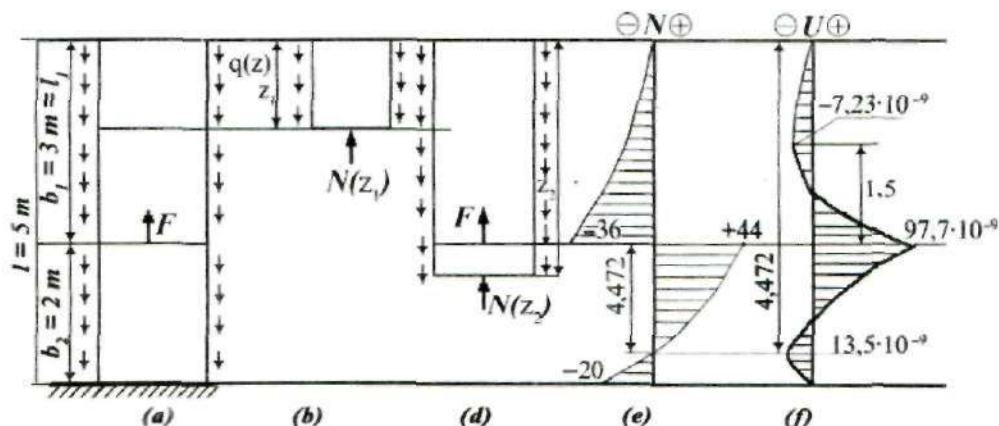
Tayanch kesimda ko'chish nolga teng. II oraliqda yotuvchi  $z$  kesimlarning ko'chishi quyidagicha aniqlanadi:

$$U(z_2) = \int_{z_2}^5 \frac{N(z) dz}{EA} = \int_{z_2}^5 \frac{(80 - 4z^2) dz}{EA} = \frac{1}{EA} (233,33 - 80z_2 + \frac{4}{3}z_2^3);$$

$$\text{bu yerda, } EA = 15 \cdot 10^{-4} \cdot 2 \cdot 10^{11} = 3 \cdot 10^8 \frac{\text{N}}{\text{m}^2} \cdot \text{m}^2 = 3 \cdot 10^8 \text{ N}.$$

Eng katta ko'chishni topamiz:

$$\frac{dU(z_2)}{dz_2} = -80 + 4z_2^2 = 0, \quad \text{bundan, } z_2 \approx 4,472 \text{ m}.$$



I.3- shakl

Demak,  $z_2 = 5 \text{ m}$  da  $U(5) = 0$ ;

$$z_2 = 4,472 \text{ m da } U(4,472) = -\frac{4,0644}{EA} = -13,548 \text{ m} \cdot 10^{-9} \text{ m};$$

$$z_2 = 3 \text{ m da } U(3) = \frac{29,33}{EA} = 97,77 \cdot 10^{-9}.$$

I oraliq uchun ko'chishning ifodasini yozamiz:

$$U(z_1) = U(3) + \int_{z_1}^3 \frac{N(z) dz}{EA} = 97,77 \cdot 10^{-9} - \int_{z_1}^3 \frac{4z^2 dz}{EA} = -22,23 \cdot 10^{-9} + \frac{4}{3} \cdot \frac{z_1^3}{EA}.$$

$$z_1 = 0 \quad \text{bo'lsa,} \quad U(0);$$

$$z_1 = 1,5 \text{ m} \quad \text{bo'lsa,} \quad U(1,5) = -7,23 \cdot 10^{-9} \text{ m};$$

$$z_1 = 3 \text{ m} \quad \text{bo'lsa,} \quad U(3) = 97,77 \cdot 10^{-9} \text{ m}.$$

Yuqorida hosil qilingan qiymatlar asosida ko'chish epyurasini quramiz (1.3- shakl, f).

### 6- masala

Ichki va tashqi diametrlarining nisbati mos ravishda:  $d:D = 4:5$  munosabatda bo'lgan  $l=0,3 \text{ m}$  uzunlikdagi cho'yan ustun  $F=150 \cdot 10^4 \text{ N}$  kuchni ko'tarib turadi (1.4- shakl). Ichki ( $d$ ), tashqi ( $D$ ) diametrlar hamda ustunning to'la qisqarishi aniqlansin. Cho'yaning siqilishdagi ruxsat etilgan kuchlanishi  $\sigma_{adm} = 100 \text{ MPa}$ , elastiklik moduli  $E=0,8 \cdot 10^5 \text{ MPa}$  ma'lum deb hisoblansin.

### Yechish:

Ustunning barcha ko'ndalang kesimlarida  $N=F$  siquvchi bo'ylama kuchlar vujudga kelishi o'z-o'zidan ravshan. Ustunning ichi kavak bo'lganligi sababli, uning yuzasi

$$A = \frac{\pi}{4} (D^2 - d^2)$$

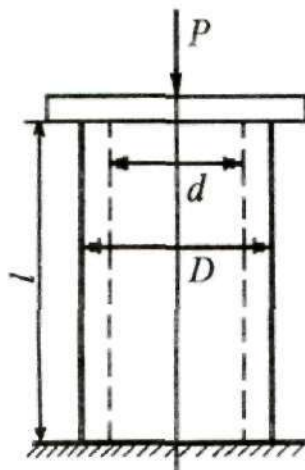
ga teng. Buni e'tiborga olib, quyidagini hosil qilish mumkin:

$$\frac{\pi}{4} (D^2 - d^2) \geq \frac{N}{\sigma_{adm}} \quad \text{yoki} \quad \frac{\pi}{4} \left[ D^2 - \left( \frac{4D}{5} \right)^2 \right] \geq \frac{F}{\sigma_{adm}};$$

bundan,

$$D \geq \sqrt{\frac{100F}{2\pi\sigma_{adm}}} = \sqrt{\frac{100 \cdot 150 \cdot 10^4}{9 \cdot 3,14 \cdot 100 \cdot 10^6}} = 0,23 \text{ m}.$$

$D = 25 \text{ sm}$  deb qabul qilamiz, u holda ustunning ichki diametri  $d = 4D/5 = 20 \text{ sm}$  ga teng bo'ladi. (1.6) ifodaga ko'ra,



1.4- shakl

$$\Delta l = \frac{Fl}{EA} = \frac{150 \cdot 10^4 \cdot 0,3}{0,8 \cdot 10^{11} \cdot \frac{\pi}{4} [(0,25)^2 - (0,2)^2]} \approx 0,318 \cdot 10^{-3} \text{ m.}$$

Demak, ustun  $\Delta l = 0,318 \text{ mm}$  ga qisqarar ekan.

### 7- masala

Sharnirlar vositasida ulangan po'lat sterjenlar ko'tara oladigan eng katta yuk aniqlansin (1.5- shakl). Sterjen diametri  $d = 2 \text{ sm}$ , materialning cho'zilishdagi ruxsat etilgan kuchlanishi  $\sigma_{adm} = 140 \text{ MPa}$ ,  $\alpha = \beta = 60^\circ$ .

### Yechish:

Cho'zilish va siqilishdagi mustahkamlik shartidan har bir sterjenda paydo bo'luvchi bo'ylama kuchni aniqlaymiz:

$$N \geq A \cdot \sigma_{adm} = \frac{\pi}{4} (2 \cdot 10^{-2})^2 \cdot 140 \cdot 10^3 = 43,96 \text{ kN};$$

$$N_1 = N_2 = N.$$

Endi S tugunning muvozanatini tekshiramiz (1.5- shakl, b):

$$\sum Y_i = -Q + 2N \cdot \cos 60^\circ = 0.$$

$$\text{Bundan, } Q = 2 \cdot 43,96 \cdot 0,5 = 43,96 \text{ kN.}$$

### 8- masala

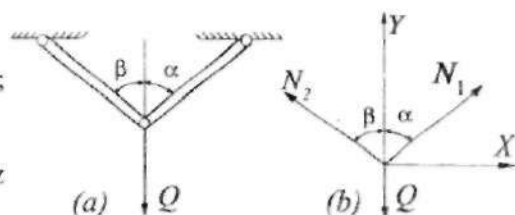
Ikki pog'onali cho'yan brus ko'tara oladigan kuchning ruxsat etilgan qiymati aniqlansin (1.6- shakl, a).

Brus materialining cho'zilishdagi va siqilishdagi ruxsat etilgan kuchlanishlari mos ravishda  $\sigma_{adm}^+ = 40 \text{ mPa}$  va  $\sigma_{adm}^- = 10 \text{ mPa}$ .

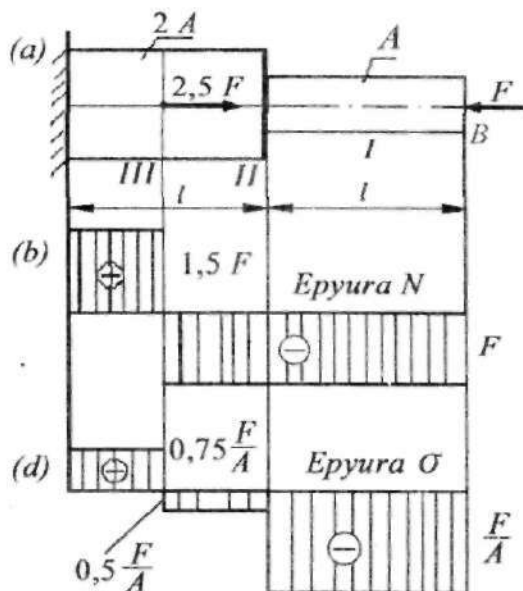
### Yechish:

Kesish usulini qo'llab, brusning uchala uchastkasi (oralig'i) uchun ham bo'ylama kuch  $N$  (1.6- shakl, b) va normal kuchlanish  $\sigma$  (1.6- shakl, d) larning epyuralarini ko'ramiz.

Normal kuchlanish epyurasidan ko'rinib turibdiki, eng katta cho'zuvchi kuchlanish



1.5- shakl



1.6- shakl

III oraliqda va eng katta siquvchi kuchlanish I oraliqda paydo bo'lar ekan. Shuning uchun mustahkamlik shartlari quyidagicha yoziladi:

$$\frac{F}{A} \leq \sigma_{adm}^-; \quad 0,75 \frac{F}{A} \leq \sigma_{adm}^+.$$

Bulardan,

$$F^I = F \leq A \cdot \sigma_{adm}^- = 10^{-3} \cdot 120 = 120 \text{ kN}; \quad F^{II} = A \cdot \sigma_{adm}^-;$$

$$F^{III} = \frac{A \cdot \sigma_{adm}^+}{0,75} = \frac{10^{-3} \cdot 40}{0,75} = 53,4 \text{ kN}.$$

Kuchning ruxsat etilgan qiymati  $F_{adm} = F^{III} = 53,4 \text{ kN}$  ga teng.

### 9- masala

Bug' silindrlining qopqog'i silindrga 8 ta bolt bilan biriktirilgan. Silindrlarning ichki diametri  $D = 50 \cdot 10^{-2} \text{ m}$ , boltlar uchun ruxsat etilgan kuchlanish  $\sigma_{adm} = 50 \text{ MPa}$  va silindrdagi bug'ning bosimi  $P = 6 \text{ atm}$  ( $1 \text{ atm} = 9,81 \cdot 10^4 \text{ N/m}^2 = 9,81 \cdot 10^{-2} \text{ MPa}$ ).

#### Yechish:

Avval 8 ta boltning cho'zuvchi  $F$  kuchni topamiz:

$$F = P \cdot \frac{\pi D^2}{4} = 6 \cdot 9,81 \cdot 10^4 \cdot \frac{3,14(50 \cdot 10^{-2})^2}{4} = 115,51 \text{ kN}.$$

Bu kuchni 8 ta bolt qabul qilganligi uchun hisob tenglamasi quyidagicha bo'ladi:

$$F \leq 8 \cdot \sigma_{adm} \cdot \frac{\pi d^2}{4};$$

bundan,  $d = 1,92 \cdot 10^{-2} \text{ m}$ .

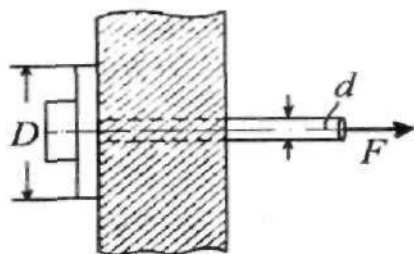
### 10- masala

Diametri  $d = 30 \cdot 10^{-3} \text{ m}$  bo'lgan tortqi  $F$  kuch bilan cho'zilganda, unda kuchlanish paydo bo'ladi (I.7- shakl). Tortqiga kiygizilgan shaybaning devorga ko'rsatadigan bosimi  $q = 1,5 \text{ MPa}$  dan oshib ketmasligi uchun shayba diametri qancha bo'lishi kerak?

#### Yechish:

Oldin cho'zuvchi kuch  $F$  ni aniqlaymiz:

$$F = \sigma \cdot \frac{\pi d^2}{4} = 80 \cdot 10^3 \cdot \frac{3,14(30 \cdot 10^{-3})^2}{4} = 56,4 \text{ kN}.$$



I.7- shakl

$$\text{Mustahkamlik shartini } F \leq q \frac{\pi(D^2 - d^2)}{4}$$

ko'rinishda yozib, undan shaybaning diametrini aniqlaymiz:  $D = 4,7 \cdot 10^{-1} \text{ m} = 470 \text{ mm}$ .

### 11- masala

Po'lat sterjen tashqi kuchlar bilan yuklangan (1.8- shakl, a). Tashqi kuchlarning bajargan ishi deformatsiyaning potensial energiyasiga tengligini isbotlang.

#### Yechish:

Kesish usulini qo'llab, har bir oraliq uchun bo'ylama kuch  $N$  va ko'chish  $\Delta l$  larning epyuralarini ko'ramiz (1.8- shakl, d). (Epyuralarni mustaqil qurish o'quvchilarga havola qilinadi).

Tashqi kuchlarning bajargan ishini hisoblashda  $w_0 = F \cdot \Delta l / 2$  ifodadan foydalanamiz, shuning uchun

$$w = w_k + w_{zp} =$$

$$= \frac{1}{2} F \cdot \frac{5Fa}{3EA} + \frac{1}{2} (-2F) \cdot \frac{(-2F)a}{3EA} = \frac{9}{6} \cdot \frac{F^2 a^2}{EA}$$

Deformatsiyaning potensial energiyasini aniqlashda esa

$$U_0 = \frac{N^2 l}{2EA}$$

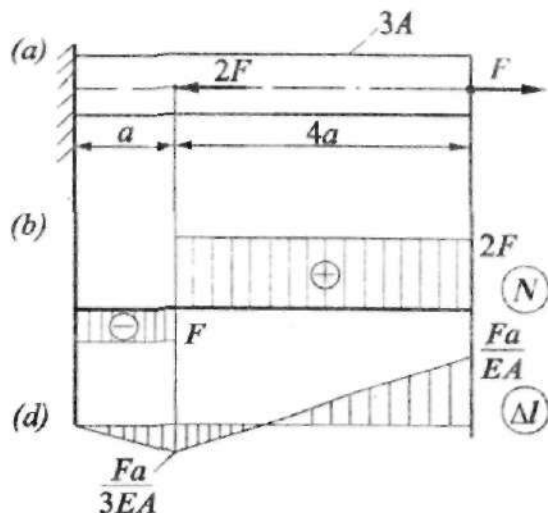
ifoda ishlatiladi. Demak,

$$U = U_I + U_{II} = \frac{F^2 \cdot 5a}{6EA} + \frac{(-2F)^2 a}{6EA} = \frac{9}{6} \cdot \frac{F^2 a^2}{EA}$$

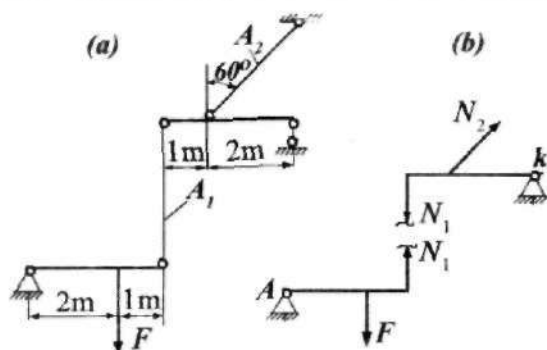
Shunga ko'ra,  $W = U = \frac{3}{2} \cdot \frac{F^2 a^2}{EA}$  ga teng ekan.

### 12- masala

1.9- shakl (a)da tasvirlangan 1- va 2- tortqilarning diametri aniqlansin. Tortqi materiali uchun ruxsat etilgan kuchlanish  $\sigma_{adm} = 160 \text{ MPa}$ , tashqi kuch esa  $F = 900 \text{ kN}$  ga teng.



1.8- shakl



1.9-shakl

**Yechish:**

Tortqilarni fikran tekisliklar bilan kesib, ichki zo'riqish – bo'ylama kuchlarni chizmada tasvirlaymiz (1.9- shakl, b). Statika-ning muvozanat tenglamalarini tuzamiz:

$$\Sigma M_{A_2} = F \cdot 2 - N_1 \cdot 3 = 0;$$

$$\Sigma M_{k_1} = N_2 \cdot 2 \cdot \cos 60^\circ - N_1 \cdot 3 = 0.$$

Bulardan,  $N_1 = 600 \text{ kN}$ ;  $N_2 = 1800 \text{ kN}$ .

Mustahkamlik shartidan foydalanib, har bir tortqining zaruriy ko'ndalang kesim yuzasini hisoblaymiz:

$$A_1 \geq \frac{N_1}{\sigma_{adm}} = \frac{600 \cdot 10^3}{160 \cdot 10^6} = 3,75 \cdot 10^{-3} \text{ m}^2;$$

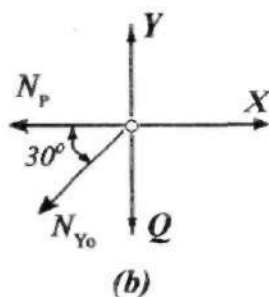
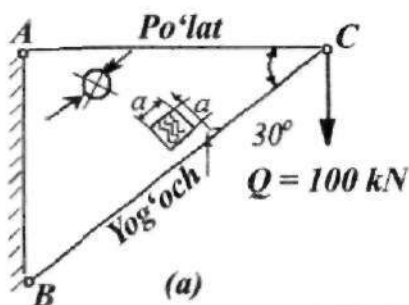
$$A_2 \geq \frac{N_2}{\sigma_{adm}} = \frac{1800 \cdot 10^3}{160 \cdot 10^6} = 11,25 \cdot 10^{-3} \text{ m}^2.$$

Endi tortqilarning kerakli diametrlarini aniqlaymiz:

$$d_1 = \sqrt{\frac{4A_1}{\pi}} = 69,11 \cdot 10^{-3} \text{ m}; \quad d_2 = \sqrt{\frac{4A_2}{\pi}} = 119,7 \cdot 10^{-3} \text{ m}.$$

**13- masala**

Kronshteyn ABC ga  $Q = 100 \text{ kN}$  yuk sharnir vositasida osilgan (1.10- shakl, a). Po'lat tortqi AC va yog'och tirgak BC larning zaruriy ko'ndalang kesim o'lchamlari aniqlansin. Po'lat materiali uchun ruxsat etilgan kuchlanish  $\sigma_{adm}^p = 140 \text{ MPa}$ , yog'och uchun esa  $\sigma_{adm}^{Yo} = 10 \text{ MPa}$  ga teng.



1.10- shakl



**Yechish:**

Kesish usulidan foydalanib,  $C$  tugunning muvozanatini tekshiramiz (I.10- shakl, b):

$$\sum x_i = -N_p - N_{y0} \cdot \cos 30^\circ = 0;$$

$$\sum y_i = Q + N_{y0} \cdot \cos 60^\circ = 0.$$

Bulardan,  $N_{y0} = -200$  kN (tirgak siqiladi);  $N_p = 173,2$  kN (tortqi cho'ziladi).

Tortqi kesimining zaruriy diametri:

$$d \geq \sqrt{\frac{4 N_p}{\pi \sigma_{adm}}} = \sqrt{\frac{4 \cdot 173,2 \cdot 10^3}{3,14 \cdot 140 \cdot 10^6}} = 3,97 \cdot 10^{-2} \text{ m}.$$

Tirgak kesimining zaruriy o'lchami:

$$a \geq \sqrt{\frac{N_{y0}}{\sigma_{adm}}} = \sqrt{\frac{200 \cdot 10^3}{10 \cdot 10^6}} = 14,14 \cdot 10^{-2} \text{ m}.$$

**14- masala**

I.11- shaklda tasvirlangan sterjenlar sistemasi  $C$  tugunining vertikal ko'chishi aniqlansin. Sterjenlarning bikrligi  $EA$ , osib qo'yilgan yuk  $Q$  va  $L$  masofa ma'lum deb hisoblansin.

**Yechish:**

Tashqi kuchning bajargan ishi quyidagiga teng:

$$W = \frac{1}{2} Q \cdot \lambda_c;$$

bu yerda,  $\lambda_c$  —  $C$  tugunining vertikal ko'chishi bo'lib, uning qiymati hozircha noma'lum.

Sterjenlar deformatsiyasining potentsial energiyasi

$$U = \frac{N_1^2 l_{CB}}{2EA} + \frac{N_2^2 l_{CD}}{2 \cdot 2EA}$$

ko'rinishda ifodalanadi.

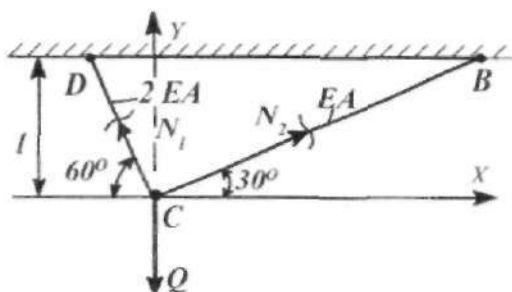
$C$  tugun uchun muvozanat tenglamalarini yozamiz:

$$\sum X_i = N_2 \cos 30^\circ - N_1 \cos 60^\circ = 0;$$

$$\sum Y_i = N_1 \cos 30^\circ + N_2 \cos 60^\circ - Q = 0.$$

Bulardan,  $N_1 = \frac{\sqrt{3}}{2} Q$ ;  $N_2 = \frac{1}{2} Q$ .

Chizmadan  $l_{CB} = 2l$ ,  $l_{CD} = 2\sqrt{3}l$  ekanligi ma'lum.



I.11- shakl

Energiyaning saqlanish qonuniga asoslanib, quyidagi tenglamani (ifodani) yozib olamiz:

$$\frac{1}{2} Q \cdot \lambda_c = \frac{\left(\frac{\sqrt{3}}{2} Q\right)^2 \cdot 2l}{2EA} + \frac{\left(\frac{Q}{2}\right)^2 \cdot 2\sqrt{3}l}{4EA}.$$

Bundan,  $\lambda_c = 1,933 \frac{Ql}{EA}$ .

### 1.3- §. Sterjenning xususiy og'irligidan hosil bo'ladigan kuchlanish va deformatsiya

Sterjenning xususiy og'irligidan hosil bo'ladigan kuchlanish, agarda uning ko'ndalang kesimi o'zgarmas bo'lsa, uning materiali va uzunligiga bog'liq bo'ladi. Hosil bo'lgan umumiy kuchlanish esa tashqi kuchlar va xususiy og'irlikdan hosil bo'lgan kuchlanishlar yig'indisiga teng bo'ladi.

Sterjenning xususiy og'irligidan hosil bo'ladigan deformatsiya ham uning uzunligi bo'ylab og'zaruvchan bo'ladi.

Uzunligi  $l$  ga teng bo'lgan sterjenning tashqi  $F$  kuch va xususiy og'irligidan hosil bo'ladigan absolut uzayishi quyidagiga teng bo'ladi:

$$\Delta l = \frac{F \cdot l}{EA} + \frac{G \cdot l}{2EA}.$$

Bu yerda,  $G = \gamma \cdot l \cdot A$ .

#### 15- masala

Pog'onali betondan qilingan kolonna ( $\gamma = 25 \text{ kN/m}^3$ ,  $E = 27 \text{ GPa}$ )  $F_1$ ,  $F_2$  va o'zining xususiy og'irligi ta'sirida bo'lsin. Quyidagilarni aniqlash talab qilinadi:

- 1) kolonnaning mustahkamligini tekshirish;
- 2) har bir uchastkadagi kolonna ko'ndalang kesimining ( $A_1$ ,  $A_2$ ,  $A_3$ ) mo'tadil qiymatini aniqlash;
- 3) I-I kesimning ko'chishini aniqlash.

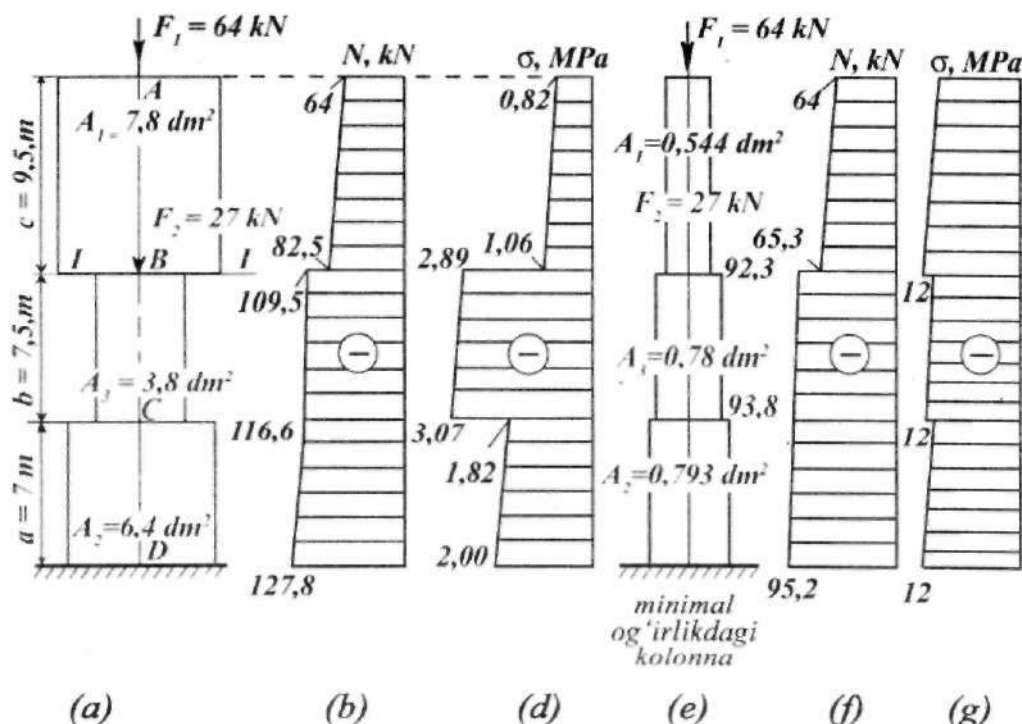
#### Yechish:

Kolonnaning har bir bo'lagi og'irligini aniqlaymiz ( $G = g \cdot A \cdot l$ ):

$$G_1 = 25000 \cdot 7,8 \cdot 10^{-2} \cdot 9,5 = 18,5 \cdot 10^3 \text{ N} = 18,5 \text{ kN};$$

$$G_2 = 25000 \cdot 6,4 \cdot 10^{-2} \cdot 7 = 11,2 \text{ kN};$$

$$G_3 = 25000 \cdot 3,8 \cdot 10^{-2} \cdot 7,5 = 7,1 \text{ kN}.$$



I.12- shakl

Uchastkalardagi bo'ylama kuch qiymatlarini aniqlaymiz:

$$\begin{aligned}
 N_I &= -F_1 - \gamma \cdot A_1 \cdot z_1; & 0 \leq z_1 \leq c. \\
 N_{I_{z_1=0}} &= -F_1 = -64\text{ kN}; & N_{I_{z_1=c}} &= -64 - 18,5 = -82,5\text{ kN}. \\
 N_{II} &= F_1 - F_2 - G_1 - \gamma \cdot A_3 \cdot z_2; & 0 \leq z_2 \leq b. \\
 N_{II_{z_2=0}} &= -109,5\text{ kN}; & N_{II_{z_2=b}} &= -64 - 27 - 18,5 - 7,1 = -116,6\text{ kN}. \\
 N_{III} &= -F_1 - F_2 - G_1 - G_3 - \gamma A_2 \cdot z_3; & 0 \leq z_3 \leq a. \\
 N_{III_{z_3=0}} &= -116,6\text{ kN}; & N_{III_{z_3=a}} &= -116,6 - 11,2 = -127,8\text{ kN}.
 \end{aligned}$$

Topilgan qiymatlar bo'yicha bo'ylama kuch epyuralarini quramiz (I.12- shakl, b).

Kesimlarda hosil bo'ladigan normal kuchlanishlar qiymatini  $\sigma = N/A$  ifoda yordamida aniqlab uning epyurasini quramiz (I.12- shakl, d).

Bu epyuradan ko'rinib turibdiki, eng katta normal kuchlanish ikkinchi uchastkaning oxirgi kesimida hosil bo'lar ekan. Ya'ni,

$$\sigma_{\max} = 3,07\text{ MPa} < [\sigma] = 12\text{ MPa}.$$

Og'irligi eng kam miqdorga teng bo'lgan (mo'tadil) kolonnaning o'lchamlarini  $\sigma_{\max} = [\sigma]$  dan foydalangan holda aniqlaymiz. Yechimni kolonnaning yuqori qismidan boshlaymiz.

$$\frac{N_{1\max}}{A_1} = \frac{F_1 + \gamma \cdot A_1 \cdot c}{A_1} \geq [\sigma].$$

$$\text{Bunda, } A_1 \geq \frac{F_1}{[\sigma] - \gamma \cdot c} = \frac{64000}{12 \cdot 10^6 - 25000 \cdot 9,5} = 5,44 \cdot 10^{-3} \text{ m}^2 = 0,544 \text{ dm}^2.$$

U holda, I uchastkaning mo'tadil og'irligi quyidagiga teng bo'ladi:

$$G_1 = 25000 \cdot 0,544 \cdot 10^{-2} \cdot 9,5 = 1,3 \text{ kN}.$$

Xuddi shuningdek,

$$A_3 = \frac{F_1 + F_2 + G_1}{R - \gamma \cdot b} = 0,781 \text{ dm}^2; \quad G_3 = 1,5 \text{ kN}.$$

$$A_2 = \frac{F_1 + F_2 + G_1 \cdot G_3}{R - \gamma \cdot a} = 0,793 \text{ dm}^2; \quad G_2 = 1,4 \text{ kN}.$$

I-I kesimning ko'chishi quyidagiga teng bo'ladi:

$$\Delta_{1-1} = \Delta I_a + \Delta I_b.$$

$$\text{Unda, } \Delta I_a = \frac{(F_1 + F_2 + G_1 + G_3 + \frac{G_2}{2})a}{EA} \text{ qiymatlarni o'rniga qo'ysak, } \Delta I_a = 3,09 \text{ mm}.$$

$$\Delta I_b = \frac{(F_1 + F_2 + G_1 + \frac{G_3}{2})b}{EA_3}; \text{ bu yerda } \Delta I_b = 3,31 \text{ mm}.$$

U holda,  $\Delta_{1-1} = 3,09 + 3,31 = 6,4 \text{ mm}$  (pastga qarab ko'chadi).

### 16- masala

$F$  kuch hamda o'zining xususiy og'irligi ta'sirida bo'lgan po'lat sterjen uchun bo'ylama kuch epyurasi hamda I-I kesimning ko'chishi aniqlansin (I.13- shakl, a).

Berilgan:  $a = 3 \text{ m}$ ;  $b = 2 \text{ m}$ ;  $c = 1,5 \text{ m}$ ;  $A = 10 \text{ sm}^2$ ;  $F = 1 \text{ kN}$ ;  $E = 2 \cdot 10^5 \text{ MPa}$ . Sterjenning solishtirma og'irligi:  $\gamma = 7,8 \text{ kN/m}^3 = 7,8 \cdot 10^4 \text{ N/m}^3$ .

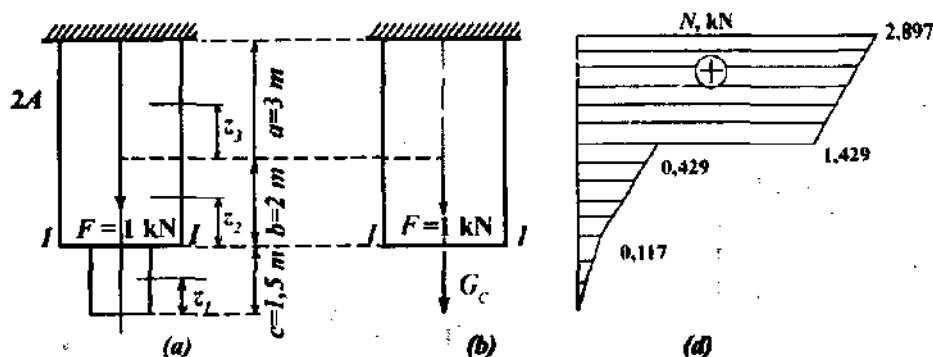
### Yechish:

Uchastkalarining xususiy og'irligini aniqlaymiz:

$$G_c = \gamma \cdot A \cdot c = 7,8 \cdot 10^4 \cdot 10 \cdot 10^{-4} \cdot 1,5 = 117 \text{ N} = 0,117 \text{ kN};$$

$$G_b = \gamma \cdot 2A \cdot b = 7,8 \cdot 10^4 \cdot 2 \cdot 10 \cdot 10^{-4} \cdot 2 = 312 \text{ N} = 0,312 \text{ kN};$$

$$G_a = \gamma \cdot 2A \cdot a = 7,8 \cdot 10^4 \cdot 2 \cdot 10 \cdot 10^{-4} \cdot 3 = 468 \text{ N} = 0,468 \text{ kN}.$$



1.13- shakl

Uchastkalardagi bo'ylama kuch qiymatlarini aniqlaymiz:

$$\begin{aligned}
 N_I &= \gamma \cdot A \cdot z_1; & 0 \leq z_1 \leq c; \\
 z_1 = 0 \text{ da } N_I &= 0; & z_1 = c \text{ da } N_I = 0,117 \text{ kN}; \\
 N_{II} &= G_c + \gamma \cdot 2A \cdot z_2; & 0 \leq z_2 \leq b; \\
 z_2 = 0 \text{ da } N_{II} &= 0,117 \text{ kN}; & z_2 = b \text{ da } N_{II} = 0,429 \text{ kN}; \\
 N_{III} &= G_c + G_b + F + \gamma \cdot 2A \cdot z_3; & 0 \leq z_3 \leq a; \\
 z_3 = 0 \text{ da } N_{III} &= 1,429 \text{ kN}; & z_3 = a \text{ da } N_{III} = 2,897 \text{ kN}.
 \end{aligned}$$

Topilgan qiymatlar bo'yicha bo'ylama kuch epyurasini quramiz (1.13- shakl, d).

I-I kesimning ko'chishini aniqlashda birinchi uchastkaning xususiy og'irligi  $G_c$  bo'lganda, uni to'plangan kuch sifatida ko'rsak, berilgan sterjenni 1.13- shakl (b) ko'rinishiga keltirish mumkin. Unda,

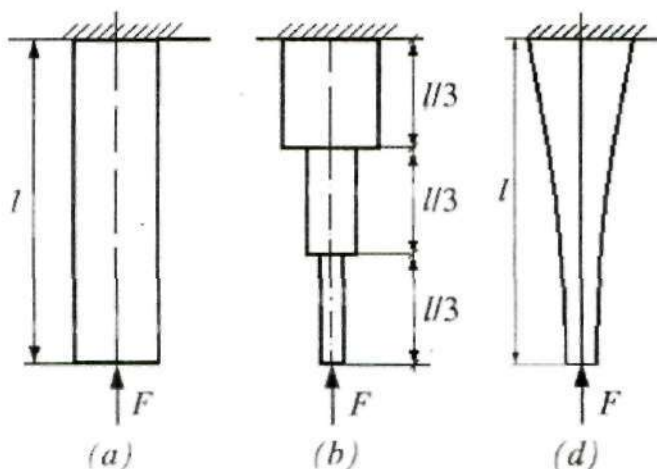
$$\begin{aligned}
 \Delta_{I-I} &= \Delta_{a+b} = \frac{G_c(a+b)}{E \cdot 2A} + \frac{P \cdot a}{E \cdot 2A} + \frac{\gamma(a+b)^2}{2E} = \\
 &= \frac{117 \cdot (3+2)}{2 \cdot 10^{11} \cdot 2 \cdot 10 \cdot 10^{-4}} + \frac{1 \cdot 10^3 \cdot 3}{2 \cdot 10^{11} \cdot 2 \cdot 10 \cdot 10^{-4}} + \frac{78 \cdot 10^3 (3+2)^2}{2 \cdot 2 \cdot 10^{11}} = \\
 &= (1,46 + 7,5 + 4,88) \cdot 10^{-6} \text{ m} = 13,84 \cdot 10^{-3} \text{ mm}.
 \end{aligned}$$

Ko'chish pastga qarab bo'ladi.

### 17- masala

1.14- shaklda ko'rsatilgan o'zgarmas kesimli, pog'onali va teng qarshilikli bruslarga  $F = 4 \text{ MN}$  (400 t) markaziy siquvchi kuch qo'yilgan. Har bir brusning uzunligi  $l = 42 \text{ m}$  bo'lib, uning materiali uchun quyidagilar ma'lum:  $\sigma_{adm} = 12 \text{ MPa}$ ,  $\gamma = 22,0 \text{ kN/m}^3$ .

Bruslarning og'irliklari solishtirilsin.



1.14- shakl

**Yechish:**

a) o'zgarmas kesimli brus.

Bu brusning yuzasini hisoblaymiz:

$$A_1 = \frac{F}{\sigma_{adm} - \gamma l} = \frac{4 \cdot 10^6}{1,2 \cdot 10^6 - 2,2 \cdot 10^4 \cdot 42} = 14,5 \text{ m}^2.$$

Bрусning hajmi esa  $V_1 = A_1 l = 603 \text{ m}^3$  ga teng. Shunga ko'ra, uning og'irligi

$$G_1 = \gamma V_1 = 13398 \text{ kN} = 13398 \cdot 10^3 \text{ N} = 13,398 \text{ MN}$$

bo'lar ekan.

b) pog'onali brus.

Navbat bilan pastki, o'rta va yuqori pog'onalarining ko'ndalang kesim yuzasini aniqlaymiz:

$$A_2^p = \frac{F}{\sigma_{adm} - \gamma \cdot \frac{l}{3}} = \frac{4 \cdot 10^6}{1,2 \cdot 10^6 - 14 \cdot 2,2 \cdot 10^4} = 4,48 \text{ m}^2;$$

$$A_2^o = \frac{F}{\sigma_{adm} \left(1 - \frac{\gamma l}{3 \sigma_{adm}}\right)^2} = \frac{4 \cdot 10^6}{1,2 \cdot 10^6 \left(1 - \frac{14 \cdot 2,2 \cdot 10^4}{1,2 \cdot 10^6}\right)^2} = 6,03 \text{ m}^2;$$

$$A_3^{yu} = \frac{F}{\sigma_{adm} \left(1 - \frac{\gamma l}{3 \sigma_{adm}}\right)^2} = 8,12 \text{ m}^2.$$

Pog'onali brusning og'irligini hisoblaymiz:

$$G_2 = \gamma \sum_1^3 A_i l_i = \gamma (A_2^{yu} + A_2^{o'} + A_2^o) \cdot \frac{l}{3} = 5738040 \text{ N} = 5,74 \text{ MN}.$$

d) teng qarshilikli brus.

Teng qarshilikli brus uchidagi kesimning yuzasi quyidagiga teng bo'ladi:

$$A_3^o = \frac{F}{\sigma_{adm}} = \frac{4 \cdot 10^6}{1,2 \cdot 10^6} = 3,33 \text{ m}^2.$$

Ixtiyoriy kesimning yuzasi:  $A_3(z) = A_3^o \cdot l^{\frac{\gamma z}{\sigma_{adm}}}$

Brusning og'irligi:

$$G_3 = \gamma \int_0^l A(z) dz = \gamma A_3^o \int_0^l l^{\frac{\gamma z}{\sigma_{adm}}} \cdot dz = F \left( l^{\frac{\gamma l}{\sigma_{adm}}} - 1 \right) = 4 \cdot 10^6 \left( l^{\frac{2,2 \cdot 10^4 \cdot 42}{1,2 \cdot 10^6}} - 1 \right) =$$

$$= 4,639 \cdot 10^6 \text{ N} = 4,639 \text{ MN}.$$

Bruslarning og'irliklarini o'zaro taqqoslaymiz:

$$G_1 : G_2 : G_3 = 13,358 : 5,74 : 4,639 = 2,89 : 1,24 : 1.$$

Demak, teng qarshilikli brusning og'irligi pog'onali brusning og'irligidan taxminan 20%, o'zgarmas kesimli brus og'irligidan esa 65% yengil ekan.

## 1.4- §. Cho'zilish va siqilishda statik noaniq masalalar

Cho'zilish va siqilish deformatsiyasiga oid masalalarni yechayotganda, sterjenlarning tayanchlarida hosil bo'luvchi reaksiya kuchlarini yoki ularning ko'ndalang kesimlaridagi zo'riqish kuchlarini statikaning muvozanat tenglamalari yordamida aniqlash mumkin bo'lmasa, bunday masalalarga cho'zilish va siqilishdagi statik noaniq masalalar deyiladi.

Bunday masalalarni yechish quyidagi tartibda amalga oshiriladi:

- bog'lanishlar reaksiya kuchlari bilan almashtiriladi;
- mumkin bo'lgan statika tenglamalari tuziladi;
- masalaning statik noaniqlik darajasi aniqlanadi:  $S = m - n$ ;

bu yerda,  $S$  - masalaning statik noaniqlik darajasi;

$m$  - noma'lum reaksiya kuchlari soni;

$n$  - tuzilishi mumkin bo'lgan statika tenglamalari soni;

- masalaning mahkamlanish shartidan foydalanib, ortiqcha deformatsiya tenglamasi tuziladi;

- statika tenglamalari bilan ortiqcha deformatsiya tenglamalari birgalikda yechilib, masala statik aniq masalaga aylantiriladi.

Harorat o'zgarishi natijasida sterjenlarda hosil bo'ladigan kuchlanishlarni aniqlashda ham yuqorida keltirilgan tartib saqlanib qoladi, lekin sterjenlar uzunligi o'zgarishini hisoblayotganda haroratning ta'siri e'tiborga olinadi. Harorat o'zgarishi natijasida sterjenlar uzunligining o'zgarishi quyidagi ifoda bilan aniqlanadi:

$$\Delta l = l \alpha \cdot \Delta t.$$

Bu yerda,  $l$  – sterjenning uzunligi;

$\alpha$  – sterjen materialining o'rtacha chiziqli kengayishi;

$\Delta t$  – haroratning o'zgarish qiymati.

Ba'zi hollarda konstruksiya qismlarini tayyorlash jarayonida texnologik xatolarga yo'l qo'yilib, ularning ayrimlari keragidan uzunroq yoki qisqaroq qilib yasaladi. Agar konstruksiya statik aniq bo'lsa, yig'ilgan (montaj)dan keyin uning sterjenlarida qo'shimcha zo'riqish kuchlari paydo bo'ladi. Lekin statik noaniq konstruksiyalarning sterjenlaridan birontasi loyihadagi o'lchamlari bo'yicha tayyorlanmasa, montajdan keyin mazkur sterjendagina emas, balki u bilan bog'langan boshqa sterjenlarda ham qo'shimcha zo'riqishlar hosil bo'ladi. Bunday masalalarni yechish uchun qo'shimcha deformatsiya tenglamalari tuzilayotganda sterjenlarni tayyorlashdagi xatoliklar natijasida hosil bo'ladigan deformatsiyalar ham e'tiborga olinadi.

### 18- masala

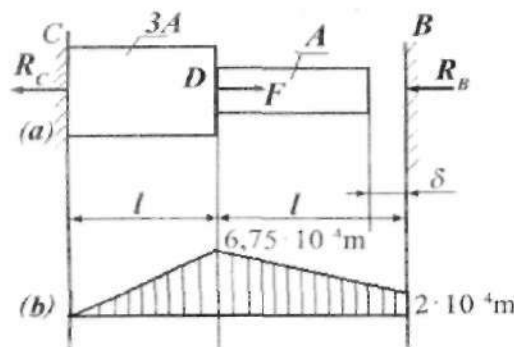
Chap uchi bilan mahkamlangan prizmatik po'lat sterjenning o'ng uchi  $B$  tayanchga  $\delta = 2 \cdot 10^{-4}$  m yetmaydi (I.15- shakl,  $a$ ). Sterjen  $F = 250$  kN kuch bilan yuklangan, ko'ndalang kesimlarda paydo bo'luvchi ko'chish epyuralari qurilsin.

Quyidagilar ma'lum deb hisoblansin:  $E = 2 \cdot 10^5$  MPa,  $A = 20 \cdot 10^{-4}$  m,  $l = 4$  m.

### Yechish:

Faraz qilaylik,  $B$  tayanch olib tashlangan bo'lsin, u holda  $F$  kuch ta'siridan sterjenning o'ng uchi  $\delta_b = \Delta l_F = \frac{F \cdot l}{E \cdot 3A} = 8,33 \cdot 10^{-4}$  m ga ko'chadi.

$\delta_b > \delta$  bo'lganligi sababli,  $\delta$  oraliq yopilib, masala statik noaniq holatga o'tadi.



I.15- shakl

I.15- shakl ( $a$ ) dan foydalanib, masalaning statik tomonini tahlil qilamiz:

$$\sum z_i = R_C - F - R_B = 0.$$

Bitta muvozanat tenglamasi tarkibida ikkita ( $R_B$ ,  $R_C$ ) noma'lum ishtirok etmoqda: masala bir marta statik noaniq hisoblanadi.

Bu masalani yechish uchun yana bitta qo'shimcha tenglama zarur.

Kuchlar ta'sirining bir-biriga xalal bermaslik prinsipiga asoslanib, qo'shimcha deformatsiya tenglamasini tuzamiz:



$$\Delta l_F + \Delta l_{R_B} = \delta \quad \text{yoki} \quad \frac{F \cdot l}{E \cdot 3A} - \frac{R_B \cdot l}{E \cdot A} - \frac{R_B \cdot l}{E \cdot 3A} - \delta = 0.$$

Bundan,  $R_B = 47,5 \cdot 10^3 \text{ N} = 47,5 \text{ kN}$ .

Demak,  $R_C = R_B - F$  yoki  $R_C = -202,5 \text{ kN}$ .

Ko'chishlarni hisoblaymiz:

$$\delta_C = 0; \quad \delta_D = \delta_C + \frac{202,5 \cdot 10^3 \cdot 4}{3 \cdot 2 \cdot 10^{11} \cdot 20 \cdot 10^{-4}} = 6,75 \cdot 10^{-4} \text{ m};$$

$$\delta_B = \delta_D + \frac{(-47,5 \cdot 10^3) \cdot 4}{2 \cdot 10^{11} \cdot 20 \cdot 10^{-4}} = 2 \cdot 10^{-4} \text{ m} \quad \text{yoki} \quad \delta_B = \delta.$$

Bu qiymatlar yordamida ko'chish epyurasi quriladi (I.15- shakl, b).

### 19- masala

Ikki tomonidan mahkamlangan sterjenga  $F_1, F_2$  kuchlar ta'sir etayotgan bo'lsin.

Berilgan:  $A_1 = 2A_2$ ;  $E_p = 2,1 \cdot 10^5 \text{ MPa}$ ;  $[\sigma]_p = 210 \text{ MPa}$ ;  $E_{al} = 7 \cdot 10^4 \text{ MPa}$ ;  $[\sigma]_{al} = 150 \text{ MPa}$ ;  $a = 0,4 \text{ m}$ ;  $b = 0,8 \text{ m}$ ;  $c = 1,4 \text{ m}$  (I.16- shakl, a).

#### Yechish:

Mumkin bo'lgan statika tenglamalarini tuzamiz:

$$\Sigma Z = 0; \quad R_1 + R_2 - F_1 - F_2 = 0.$$

Masalaning statik noaniqlik darajasini aniqlaymiz:  $S = m - n = 2 - 1 = 1$ . Demak, masala bir marta statik noaniq, masalani qo'shimcha deformatsiya tenglamasiz yechish mumkin emas.

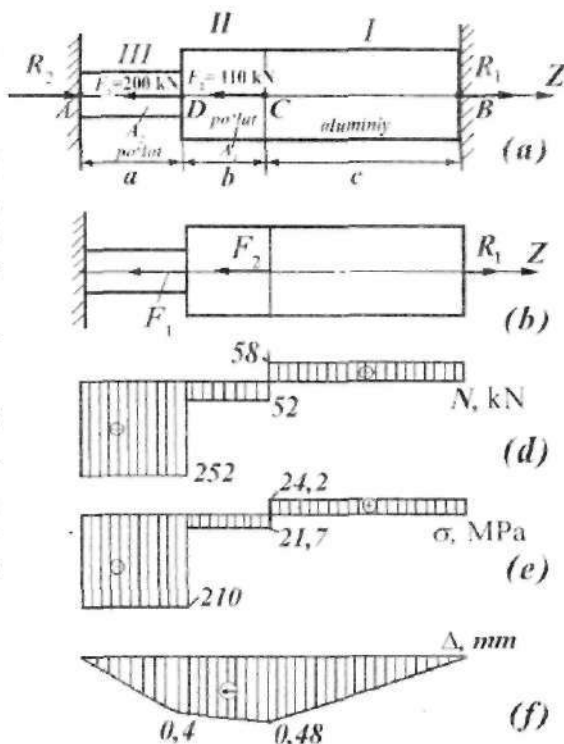
Qo'shimcha tenglama quyidagi ko'rinishga ega bo'ladi:

$$\Delta l = \Delta l_a + \Delta l_b + \Delta l_c = 0. \quad (a)$$

Sterjenning o'ng tomonidagi bog'lanishni tashlab yuborib, uning ta'sirini  $R_1$  orqali ifodalaymiz (I.16- shakl, b). Shunda har bir uchastkada hosil bo'ladigan absolut uzayishlar teng bo'ladi:

$$\Delta l_a = \frac{(-F_1 - F_2 + R_1) \cdot 0,4}{E_p \cdot A_2};$$

$$\Delta l_b = \frac{(-F_2 + R_1) \cdot 0,8}{E_p \cdot A_1}; \quad \Delta l_c = \frac{R_1 \cdot 1,4}{E_{al} \cdot A_1}.$$



I.16- shakl

Bu qiymatlarni (a) ga qo'ysak:

$$\frac{(-F_1 - F_2 + R_1) \cdot 0,4}{E_p \cdot A_2} + \frac{(-F_2 + R_1) \cdot 0,8}{E_p \cdot A_1} + \frac{R_1 \cdot 1,4}{E_{al} \cdot A_1} = 0.$$

Bu yerda,  $A_1 = 2A_2$ ;  $E_p = 3E_{al}$  ekanligini e'tiborga olsak:

$$\frac{(-310 + R_1) \cdot 0,4}{3E_{al} \cdot A_2} + \frac{(-110 + R_1) \cdot 0,8}{3E_{al} \cdot 2A_2} + \frac{1,4 \cdot R_1}{E_{al} \cdot 2A_2} = 0.$$

Bu tenglamadan  $R_1 = 58$  kN ga teng ekanligi aniqlanadi.

Shunday qilib, masala statik aniq masalaga aylandi. Bu masala uchun bo'ylama kuch epyurasi I.16- shakl (d) da keltirilgan.

Sterjenning ko'ndalang kesim yuzasini aniqlaymiz:

$$A_2 \geq \frac{N_a}{[\sigma]_p} = \frac{252000}{210 \cdot 10^6} = 12 \cdot 10^{-4} \text{ m}^2. \text{ Unda, } A_1 = 24 \cdot 10^{-4} \text{ m}^2.$$

Har bir uchastka uchun  $\sigma = N/A$  ifodadan kesimlarda bo'ladigan normal kuchlanish qiymatlarini aniqlaymiz va uning epyurasini ko'ramiz (I.16- shakl, e)

Sterjenning absolut deformatsiyasi epyurasini ko'rish uchun uning C va D kesimlari deformatsiyasini aniqlash kifoyadir, chunki A va B kesimlarda  $\Delta_A$  va  $\Delta_B$  lar nolga teng.

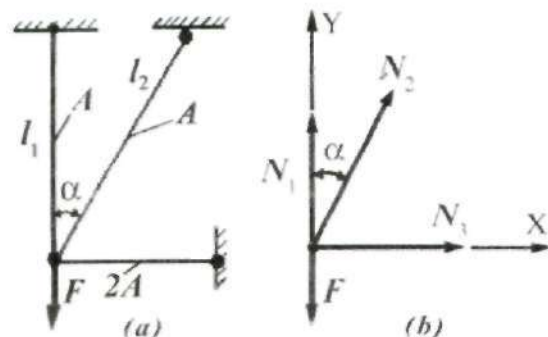
$$\Delta l_c = \frac{N_1 \cdot c}{E_{al} \cdot A_1} = \frac{58000 \cdot 1,4}{7 \cdot 10^{10} \cdot 24 \cdot 10^{-4}} = 0,48 \text{ mm (cho'zilyapti);}$$

$$\Delta l_a = \frac{N_3 \cdot a}{E_p \cdot A_2} = \frac{-252000 \cdot 1,4}{2,1 \cdot 10^{11} \cdot 12 \cdot 10^{-4}} = -0,4 \text{ mm (qisqarayapti).}$$

Topilgan qiymatlar bo'yicha  $\Delta$  epyurasini quramiz (I.16- shakl, f).

## 20- masala

Energetik usul yordamida I.17- shakl (a) da tasvirlangan sterjenlar tizimidagi ichki zo'ri-



I.17- shakl

qishlar aniqlansin. Sterjenlar bir xil materialdan yasalgan bo'lib, quyidagi ma'lumotlar ma'lum:  $F$ ;  $l$ ;  $A$ ;  $\alpha = 30^\circ$ ;  $l_1 = l$ ;  $l_2 = 1,548 l$ ;  $l_3 = 0,5774 l$ .

### Yechish:

C tugunni fikran ajratib (I.17- shakl, b), uchta noma'lum bo'ylama kuchlar mavjudligiga ishonch hosil qilish mumkin. Ma'lumki, bir nuqta (tugun)da kesuvchi kuchlar tizimi ikkita muvozanat tenglamasini tuzishga imkon beradi:

$$\sum X_i = N_3 + N_2 \cdot \sin \alpha = 0; \quad \sum Y_i = N_1 + N_2 \cdot \cos \alpha - F = 0.$$

Demak, masala bir marta statik noaniq ekan.

Deformatsiyaning potensial energiyasini aniqlash ifodasini yozamiz:

$$U = \sum_{i=1}^3 \frac{N_i^2 l_i}{2EA} = \frac{N_1^2 l_1}{2EA} + \frac{N_2^2 l_2}{2EA} + \frac{N_3^2 l_3}{2E \cdot 2A}.$$

Endi deformatsiyaning potensial energiyasini funksiya  $U = U(N_2)$  shaklida yozib olamiz:

$$U(N_2) = \frac{(F - N_2 \cos \alpha)^2 l}{2EA} + \frac{N_2^2 \cdot 1,1547l}{2EA} + \frac{(-N_2 \cdot \sin \alpha)^2 \cdot 0,5774l}{4EA}$$

yoki 
$$U(N_2) = \frac{l}{2EA} [(F - N_2 \cos \alpha)^2 + 1,1547 N_2^2 + 0,0723 N_2^2].$$

Deformatsiya potensial energiyasining minimallik shartiga ko'ra:

$$\frac{dU}{dN_2} = 0 \quad \text{yoki} \quad \frac{l}{2EA} [2(F - N_2 \cos \alpha)(-\cos \alpha) + 2,3094 N_2 + 0,1446 N_2] = 0;$$

bundan,  $N_2 = 0,439 F$ . Shu sababli,  $N_1 = 0,6198 F$ ,  $N_3 = -0,2195 F$ .

Demak, 1- va 2- sterjenlar cho'zilishga, 3- sterjen esa siqilishga qarshilik ko'rsatar ekan.

## 21- masala

Tekis taralgan  $q$  kuch bilan yuklangan absolut bikr brus  $CD$  ni uchta sterjen yordamida shipga osish zarur (1.18- shakl, a). Ammo, 3- sterjen loyihadagi o'lchamga qaraganda  $\Delta$  miqdorga qisqaroq qilib yasalgan. Sterjenlar bir xil materialdan yasalgan bo'lib, turlicha bikrliklarga ega. Montaj kuchlanishlari va tashqi kuchdan bo'lgan kuchlanishlar aniqlansin.

## Yechish:

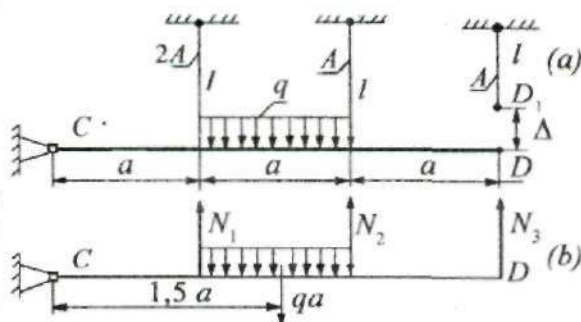
Konstruksiyanı yig'ish uchun  $D$  va  $D_1$  nuqtalarga miqdor jihatdan teng, lekin qarama-qarshi yo'nalishlardagi bo'yлама kuchni qo'yish zarur (1.18- shakl, b).

$CD$  brusning muvozanatini tekshiramiz:

$$\begin{aligned} \sum M_{C_1} &= 0, \\ qa \cdot 1,5a - N_1 \cdot a - N_2 \cdot 2a - N_3 \cdot 3a &= 0 \\ \text{yoki } N_1 + 2N_2 + 3N_3 - 1,5qa &= 0. \end{aligned}$$

Bitta tenglamada uchta ( $N_1$ ,  $N_2$ ,  $N_3$ ) noma'lum bor: masala ikki marta statik noaniqdir.

Deformatsiyaning potensial energiyasini aniqlaymiz:



1.18- shakl

$$U = \frac{1}{2E} \sum_{i=1}^3 \frac{N_i^2 l_i}{A_i} \quad \text{yoki}$$

$$U = \frac{1}{2E} \left( \frac{N_1^2 l}{2A} + \frac{N_2^2 l}{A} + \frac{N_3^2 l}{A} \right) = \frac{l}{2EA} (0,5 N_1^2 + N_2^2 + N_3^2).$$

Muvozanat tenglamasini nazarda tutib, deformatsiyaning potensial energiyasini

$$U(N_2, N_3) = \frac{l}{2EA} [0,5(-2N_2 - 3N_3 + 1,5qa)^2 + N_2^2 + N_3^2]$$

tarzida ifodalaymiz.

Oxirgi ifodadan navbat bilan  $N_2$  va  $N_3$  bo'yicha xususiy hosila olib, quyidagi algebraik tenglamalar tizimiga ega bo'lamiz:

$$\left. \begin{aligned} \frac{\partial u}{\partial N_2} &= \frac{l}{2EA} [(-2) \cdot (-2N_2 - 3N_3 + 1,5qa) + 2N_2] = \Delta \\ \frac{\partial u}{\partial N_3} &= \frac{l}{2EA} [-3(-2N_2 - 3N_3 + 1,5qa) + 2N_3] = \Delta \end{aligned} \right\}$$

Bu tenglamalarni birgalikda yechib, quyidagi ichki zo'riqlashlarni aniqlaymiz:

$$N_2 = 0,2 qa - 0,4 \frac{EA\Delta}{l}; \quad N_3 = 0,3 qa + 0,4 \frac{EA\Delta}{l}.$$

1-sterjendagi zo'riqlash esa quyidagicha bo'ladi:

$$N_1 = 0,2 qa - 0,4 \frac{EA\Delta}{l}.$$

Har bir sterjendagi normal kuchlanishlarni topamiz:

$$\sigma_1 = 0,1 \frac{qa}{A} - 0,2 \frac{EA}{l}; \quad \sigma_2 = 0,2 \frac{qa}{A} - 0,4 \frac{EA}{l}; \quad \sigma_3 = 0,3 \frac{qa}{A} + 0,4 \frac{EA}{l}.$$

Xususiy hollar:

a)  $\Delta = 0$  bo'lsin, ya'ni 3-sterjen ham loyiha bo'yicha tayyorlangan bo'lsin. Bu holda montaj kuchlanishlari nolga teng bo'lib, sterjenlarda faqatgina tashqi kuchlardan kuchlanishlar paydo bo'ladi:

$$\sigma'_1 = 0,1 \frac{qa}{A}; \quad \sigma'_2 = 0,2 \frac{qa}{A}; \quad \sigma'_3 = 0,3 \frac{qa}{A}.$$

b)  $q = 0$  bo'lsin. Bu holda sterjenlarda quyidagi montaj kuchlanishlari yuzaga keladi:

$$\sigma''_1 = -0,2 \frac{EA}{l}; \quad \sigma''_2 = -0,4 \frac{EA}{l}; \quad \sigma''_3 = 0,4 \frac{EA}{l}.$$

## 22- masala

$F = 1,4$  MN kuch bilan yuklangan temir beton kolonnadagi (1.19- shakl) beton va temir armaturada bo'ladigan normal kuchlanish qiymati aniqlansin.

Berilgan:  $A_{arm} = 10 \text{ sm}^2$ ; po'lat va beton elastiklik modullari orasidagi bog'lanish:  $E_p : E_b = 15$ .

## Yechish:

$F$  kuch ta'sirida beton va po'lat armaturada bo'ladigan reaksiya kuchlari har xil bo'ladi. Shuning uchun masala bir marta statik noaniqdir. Unda,

$$R_p + R_b = F. \quad (a)$$

Ularda bo'ladigan absolut qisqarish deformatsiyasi quyidagiga teng bo'ladi:

$$\Delta l_b = \Delta l_p \text{ yoki } \frac{R_b \cdot l}{E_b \cdot A_b} = \frac{R_p \cdot l}{E_p \cdot A_p};$$

$$\text{unda } R_p = R_b \cdot \frac{E_p \cdot A_p}{E_b \cdot A_b}$$

Bu qiymatni (a) ga qo'yib, quyidagini hosil qilamiz:

$$R_b = \frac{F}{1 + \frac{E_p \cdot A_p}{E_b \cdot A_b}};$$

$$\text{agarda } A_b = 30 \cdot 30 - 10 = 890 \text{ sm}^2 \text{ bo'lsa, u holda: } R_b = \frac{1,4}{1 + 15 \cdot \frac{10}{890}} = 1,2 \text{ MN.}$$

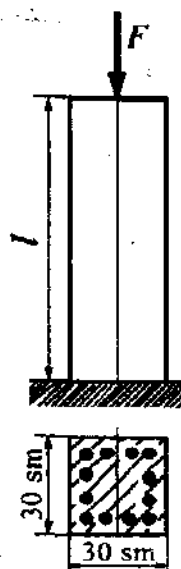
Po'lat armatura hosil bo'ladigan reaksiya kuchi  $R_p = 1,4 - 1,2 = 0,2$  MN ga teng bo'ladi.

Unda kolonnaning ko'ndalang kesimida bo'ladigan normal kuchlanish (xususiyl og'irlikni hisobga olmaganda) quyidagiga teng bo'ladi:

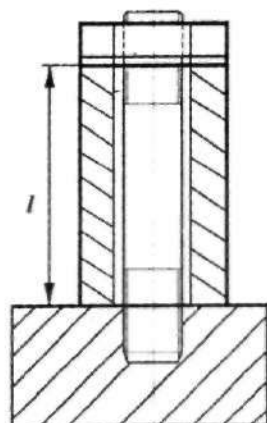
$$\sigma_p = \frac{R_p}{A_p} = \frac{-0,2 \cdot 10^6}{10 \cdot 10^{-4}} = -200 \text{ MPa}; \quad \sigma_b = \frac{R_b}{A_b} = \frac{-1,2 \cdot 10^6}{890 \cdot 10^{-4}} = -13,5 \text{ MPa.}$$

## 23- masala

Po'lat shpilka misdan yasalgan trubka (quvur)ning orasidan o'tkazilgan (1.20- shakl, a). Shpilka rezbasining qadami  $t = 2,5$  mm. Agar gaykani burab, 1/5 ga aylantirilsa, shpilka va trubka kesimlarida qancha kuchlanish sodir bo'ladi?



1.19- shakl



(a)

I.20- shakl



(b)

**Yechish:**

Gayka buralganda shpilka cho'zilib, trubka siqiladi. Kesish usulini qo'llab, quyidagi muvozanat tenglamasiga ega bo'lamiz (I.20- shakl, b):

$$\sum Z = 0; N_p - N_M = 0 \text{ yoki}$$

$$N_p = N_M = N;$$

bu yerda,  $N_p$  – shpilkani cho'zuvchi kuch;  $N_M$  – trubkani (quvurni) siquvchi kuch. Demak, masala bir marta statik noaniq ekan.

Qo'shimcha tenglama  $\Delta l \cdot M + \Delta l \cdot P = \frac{l}{5}$  ko'rinishda ifodalanadi.

$$\text{Guk qonuniga asosan } \frac{Nl}{E_p A_p} + \frac{Nl}{E_M A_M} = \frac{l}{5} \cdot l.$$

$E_p = 2 E_M = 2 \cdot 10^5 \text{ MPa}$  ekanligini e'tiborga olib, oxirgi ifodadan ichki zo'riqishni topamiz:

$$N = \frac{2l E_M A_M A_p}{5(A_M + 2 A_p) \cdot l}.$$

Shpilka va trubkaning kesim yuzalarini hisoblagandan so'ng, ifoda bo'yicha kuchlanishlarni osongina topish mumkin:  $\sigma_p = 120,4 \text{ MPa}$ ,  $\sigma_M = -65 \text{ MPa}$ .

**24- masala**

Bir xil materialdan yasalgan va bir xil ko'ndalang kesimga ega sterjenlar I.21- shakl (a) da ko'rsatilgandek mahkamlangan. I- sterjen berilgan uzunligiga nisbatan  $\Delta$ -qiymatga qisqaroq qilib yasalgan. Sterjenlarni yig'ish (montaj qilish) natijasida bo'ladigan boshlang'ich kuchlanishni aniqlash kerak. Berilgan:  $\Delta = 4 \text{ mm}$ ;  $l = 4 \text{ m}$ ;  $E = 2 \cdot 10^5 \text{ MPa}$ ;  $\alpha = 45^\circ$ .

**Yechish:**

Shakldan ko'rinib turibdiki, sterjenlar sistemasini yig'ishda uchta sterjenni ham cho'zishga to'g'ri keladi (shaklda punktir chiziqlar bilan ko'rsatilgan). C' bog'lanishni kesib (I.21- shakl, b), unga ta'sir etayotgan kuchlardan muvozanat tenglamasini tuzamiz ( $\alpha$  burchak o'zgarishini e'tiborga olmagan holda):

$$\sum X = 0; N_3 \cdot \sin \alpha - N_2 \cdot \sin \alpha = 0; \quad (a)$$

bu yerda,  $N_2 = N_3$ .

$$\sum Y = 0; N_1 - N_2 \cdot \cos \alpha - N_3 \cdot \cos \alpha = 0. \quad (b)$$

Demak, masala bir marta statik noaniqdir.



Qo'shimcha deformatsiya tenglamasi quyidagiga teng bo'ladi:

$$\Delta = \Delta l_1 + \delta_c, \text{ bu yerda, } \delta_c = \frac{\Delta l_2}{\cos \alpha}; \text{ unda } \Delta = \Delta l_1 + \frac{\Delta l_2}{\cos \alpha}.$$

Guk qonunini qo'llagan holda quyidagini hosil qilamiz:

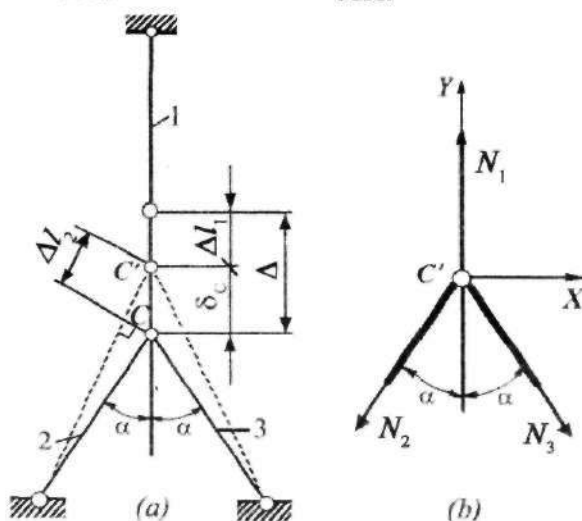
$$\Delta = \frac{N_1 l}{EA} + \frac{N_2 \cdot l}{EA \cdot \cos \alpha}. \quad (d)$$

Bu yerda, 1- sterjen uzunligi (a), (b) va (d) tenglamalarni birgalikda yechib, sterjenlarda bo'ladigan zo'riqish kuchlarini aniqlaymiz:

$$N_1 = \frac{2\Delta EA \cdot \cos^2 \alpha}{(1 + 2\cos^2 \alpha)};$$

$$N_2 = N_3 = \frac{\Delta EA \cdot \cos \alpha}{(1 + 2\cos^2 \alpha)l}.$$

Sterjenlarda bo'ladigan normal kuchlanishlarni  $\sigma = N/A$  ifoda yordamida aniqlaymiz:



1.21- shakl

$$\sigma_1 = \frac{2\Delta E \cos^2 \alpha}{(1 + 2\cos^2 \alpha)l} = \frac{2 \cdot 4 \cdot 10^{-4} \cdot 2 \cdot 10^5 \left(\frac{\sqrt{2}}{2}\right)^2}{\left[1 + 2\left(\frac{\sqrt{2}}{2}\right)^2\right] \cdot 4} = 100 \text{ MPa};$$

$$\sigma_2 = \sigma_3 = \frac{\Delta E \cos \alpha}{(1 + 2\cos^2 \alpha)l} = \frac{4 \cdot 10^{-4} \cdot 2 \cdot 10^5 \cdot \frac{\sqrt{2}}{2}}{\left[1 + 2\left(\frac{\sqrt{2}}{2}\right)^2\right] \cdot 4} = 70,7 \text{ MPa}.$$

## 25- masala

Po'lat materialdan yasalgan sterjenlar 1.22- shakl (a) da ko'rsatilgandek yig'ilgan. O'rtadagi sterjen  $\Delta t^0$  sovutilganda, har bir sterjenda yuzaga keladigan ichki zo'riqishlarni aniqlang. Masalani yechishda energetik usul tavsiya qilinadi. Sterjenlarning moyillik koeffitsiyentlari  $\beta_1 = \beta_3$  va  $\beta_2$  lar ma'lum deb hisoblansin.

**Yechish:**

Agar o'rtacha sterjenning pastki uchi  $A$  tugunga ulanmaganda, u haroratning  $\Delta t^0$  ga pasayishidan  $\Delta L_2(t) = \alpha \cdot 2h \cdot \Delta t^0$  miqdorga qisqargan bo'lardi. Ammo yon tomonlardagi sterjenlarning qarshiligi tufayli o'rtadagi sterjen  $\Delta L_2(t)$  dan kichik qiymatga qisqaradi. Umuman, o'rtadagi sterjenda cho'zuvchi, yon tomondagi sterjenda esa siquvchi bo'ylama kuchlar paydo bo'ladi (I.22- shakl).

$A$  tugunning muvozanatini tekshirib, quyidagi ikkita tenglamaga ega bo'lamiz:

$$\begin{aligned} \sum X_i &= N_1 \sin \varphi - N_3 \sin \varphi = 0 & \text{yoki} & \quad N_1 = N_3; \\ \sum Y_i &= N_2 - N_1 \cos \varphi - N_3 \cos \varphi = 0 & \text{yoki} & \quad N_2 = 2N_1 \cos \varphi. \end{aligned}$$

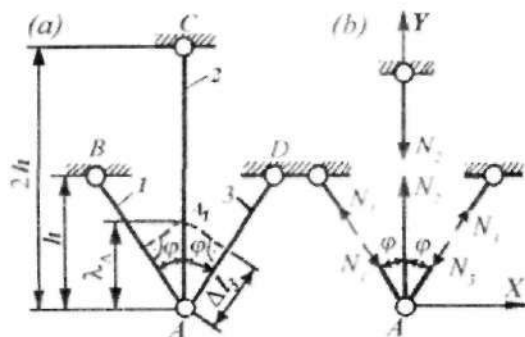
Demak, masala bir marta statik noaniq ekan.

Berilgan sistema uchun deformatsiyaning potentsial energiyasini yozib olamiz:

$$U = \frac{1}{2} \sum_{i=1}^3 N_i^2 \beta_i + 2L_2 \Delta t^0 N_2 \quad \text{yoki} \quad U = \frac{1}{2} N_1^2 \beta_1 + \frac{1}{2} N_3^2 \beta_3 + \frac{1}{2} N_2^2 \beta_2 + \alpha \cdot 2h \Delta t^0 \cdot N_2.$$

Statika tenglamalarini nazarda tutib, quyidagiga ega bo'lamiz:

$$U(N_1) = \beta_1 N_1^2 + 2\cos^2 \varphi \cdot \beta_2 N_1^2 + 4\alpha h \Delta t^0 \cos \varphi \cdot N_1.$$



I.22- shakl

$$\frac{\partial U}{\partial N_1} = 0 \quad \text{shartdan foydalanib, yon tomondagi sterjenlarda paydo bo'luvchi ichki zo'riqlashlarni aniqlaymiz:}$$

$$N_1 = N_3 = \frac{2\alpha h \Delta t^0 \cos \varphi}{\beta_1 + 2\cos^2 \varphi \cdot \beta_2}.$$

O'rtadagi sterjenda esa

$$N_2 = \frac{4\alpha h \Delta t^0 \cos^2 \varphi}{\beta_1 + 2\cos^2 \varphi \cdot \beta_2}$$

ichki zo'riqlash yuzaga keladi.

**26- masala**

Ikkala uchi bilan mahkamlangan po'lat sterjen notekis qizdirilmoqda (I.23- shakl). Harorat  $\Delta t(z) = \Delta t^0 \cdot z/l$  qonuniyat bo'yicha o'zgarimoqda. Sterjen kesimlarida haroratning o'zgarishi tufayli bo'lgan kuchlanish aniqlansin.

**Yechish:**

Haroratning o'zgarishi ikkala tayanchda ham reaksiya paydo qiladi:

$$\sum Z_i = -R_C + R_B = 0.$$



Demak, masala bir marta statik noaniq ekan. Kesish usulidan (1.23- shakl, b) foydalanib,  $N = -R_c$  ekanligi aniqlanadi.

Unda:

$$U = \int_0^l \frac{(-R_c)^2 dz}{2EA} + \alpha \int_0^l (-R_c) \frac{\Delta t_0}{l} z dz =$$

$$= \frac{R_c^2 l}{2EA} - \frac{\alpha}{2} R_c \Delta t_0 l.$$

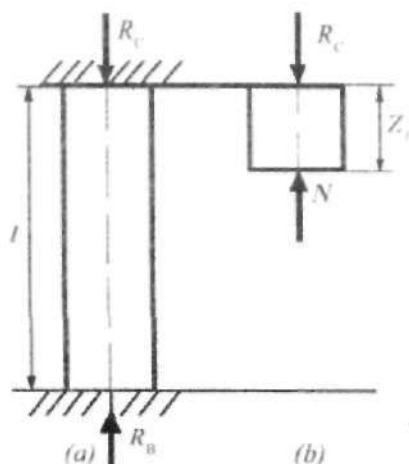
Udan  $R_c$  bo'yicha hosila olib, uni nolga tenglaymiz:

$$\frac{R_c l}{EA} - \frac{1}{2} \alpha \Delta t_0 l = 0;$$

bundan,  $R_c = 0,5 \alpha EA \cdot \Delta t_0$ .

B tayanchdagi reaksiya ham  $0,5 \alpha EA \cdot \Delta t_0$  ga tengdir.

Demak, harorat kesimda  $\sigma_1 = N/A$  yoki  $\sigma_1 = 0,5 \alpha E \cdot \Delta t_0$  ga teng siquvchi kuchlanishni hosil qilar ekan.



1.23- shakl

## 27- masala

Uzunligi  $l = 12$  m, qalinligi  $h = 40 \cdot 10^{-2}$  m bo'lgan temir-beton ko'prigi plitasi C tayanchga  $\Delta = 0,3 \cdot 10^{-2}$  m oraliq bilan o'rnatilgan (1.24- shakl). Temir-betonning chiziqli kengayish koef-fitsiyenti  $\alpha = 0,00001$ , elastiklik moduli esa  $E = 2 \cdot 10^4$  MPa.  $\Delta t^0 = 30^\circ \text{C}$  ga oshirilganda plitada hosil bo'luvchi kuchlanish hisoblansin.

### Yechish:

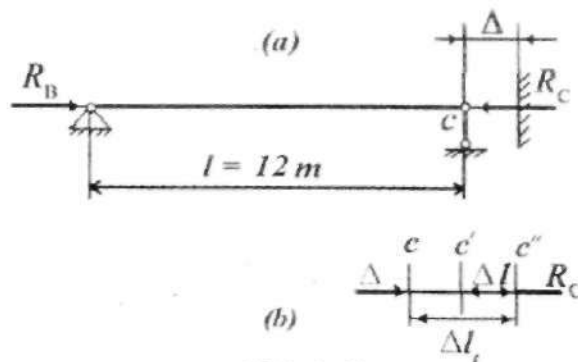
Agar B tayanch xalaqit bermaganda, oshuvidan  $\Delta$  plita oraliqni yopib:

$$\Delta t_1 = \alpha l \cdot \Delta t = 0,00001 \cdot 12 \cdot 30 = 0,36 \cdot 10^{-2} \text{ m}$$

miqdorga erkin uzaygan bo'lar edi.

Bundan chiqdi, tayanchlarda bir xil, ammo yo'nalishlari qarama-qarshi bo'lgan  $R_B$  va  $R_C$  reaksiyalar, kesimlarda esa  $N = R_B = -R_C$  zo'riqishlar vujudga kelar ekan. Bu reaksiyalarni yoki zo'riqishlarni aniqlash uchun muvozanat tenglamasi-sining o'zi yetarli emas, chunki masala statik noaniq. Shu sababli yana bitta qo'shimcha tenglama tuzish zarur.

Masalaning mohiyatidan kelib chiqib deformatsiya tenglamasini tuzamiz:



1.24- shakl

$$\Delta t = \Delta \quad \text{yoki} \quad \Delta l_t - \Delta l_{rc} - \Delta = 0.$$

Guk qonunini e'tiborga olib, oxirgi ifodadan zo'riqishni aniqlaymiz:

$$N = \frac{EA}{l} (\Delta - \alpha \Delta t^0).$$

Demak, plitaning eni  $b = 1$  m uzunlikdagi qismiga

$$N = \frac{2 \cdot 10^{10} \cdot 1 \cdot 40 \cdot 10^{-2}}{12} (0.3 \cdot 10^{-2} - 0.36 \cdot 10^{-2}) = -400 \text{ kN}$$

ichki zo'riqish to'g'ri kelar ekan.

$$\text{Plitadagi kuchlanishni hisoblaymiz: } \sigma = \frac{N}{A} = -1,0 \text{ MPa.}$$

### 28- masala

1.25- shaklda ko'rsatilgan sterjen biki tekislikka chap uchi bilan mustahkamlangan, sterjenning o'ng uchi ikkinchi biki tekislikka  $\Delta = 0,03$  mm ga yetmaydi.

Sterjenni  $30^\circ$  ga qizdirilsa (egilish deformatsiyasi e'tiborga olinmay), uning qismlaridagi kuchlanishlar aniqlansin.

**Berilgan:**  $E_M = 1 \cdot 10^6 \text{ kg/sm}^2$ ;  $E_p = 2 \cdot 10^6 \text{ kg/sm}^2$ ;  $\alpha_p = 165 \cdot 10^{-7}$ ;  $\alpha_M = 125 \cdot 10^{-7}$ ;  $a = 1,5$  m;  $b = 1$  m;  $A = 100 \text{ sm}^2$ .

### Yechish:

1. Temperatura ta'siridan hosil bo'ladigan sterjenning absolut uzayishini hisoblaymiz:

$$\Delta l_t = \alpha_p \cdot a \cdot \Delta t + \alpha_M \cdot b \cdot \Delta t = 165 \cdot 10^{-7} \cdot 1,5 \cdot 300 + 125 \cdot 10^{-7} \cdot 30 \cdot 1 = 0,112 \text{ sm} \quad (a)$$

$\Delta t > \Delta$  demak masala statik noaniq.

2. Reaksiya kuchlarini  $R_A$  va  $R_B$  orqali ifodalasak, unda statika tenglamasi quyidagiga teng bo'ladi:  $\Sigma Z = 0$ ;  $R_A - R_B = 0$ . Bu yerdan:

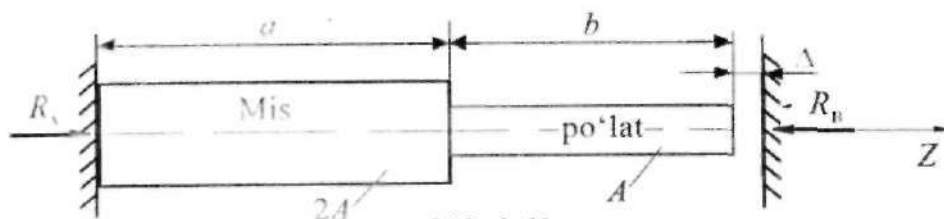
$$R_A = R_B = R. \quad (b)$$

3. Qo'shimcha (deformatsiya) tenglamani tuzamiz:

$$\Delta l_{rc} = \Delta l_t - \Delta. \quad (d)$$

Bu yerda:

$$\Delta l_{rc} = \frac{R \cdot a}{E_M \cdot A_M} + \frac{R \cdot b}{E_p \cdot A_p} = R \left( \frac{150}{1 \cdot 10^6 \cdot 200} + \frac{100}{2 \cdot 10^6 \cdot 100} \right) = 1,25 R \cdot 10^{-6} \text{ sm.} \quad (e)$$



1.25- shakl

(a), (b), (e) larni (d) ga qo'yib, quyidagini hosil qilamiz:  $1,25 R \cdot 10^6 = 0,112 - 0,003 = 0,109$ .  
Bunda:

$$R = \frac{0,109 \cdot 10^6}{1,25} = 87000 \text{ kg} = 87 \text{ t.}$$

4. Sterjenlardagi kuchlanishlarni aniqlaymiz:

$$\sigma_M = -\frac{R}{A_M} = -\frac{87000}{200} = -435 \text{ kg/sm}^2;$$

$$\sigma_p = -\frac{R}{A_p} = -\frac{87000}{100} = -870 \text{ kg/sm}^2.$$

## 1.5- §. Cho'zilish va siqilishga doir topshiriqlar

### 1- topshiriq

Markaziy bo'lgan cho'zilish va siqilishdagi statik aniq masalalar.

**Berilgan:** Po'latdan yasalgan pog'onali sterjenga bo'ylama  $F_l$  kuchlar ta'sir etmoqda.  
Ruxsat etilgan normal kuchlanish  $[\sigma] = 210 \text{ MPa}$ .

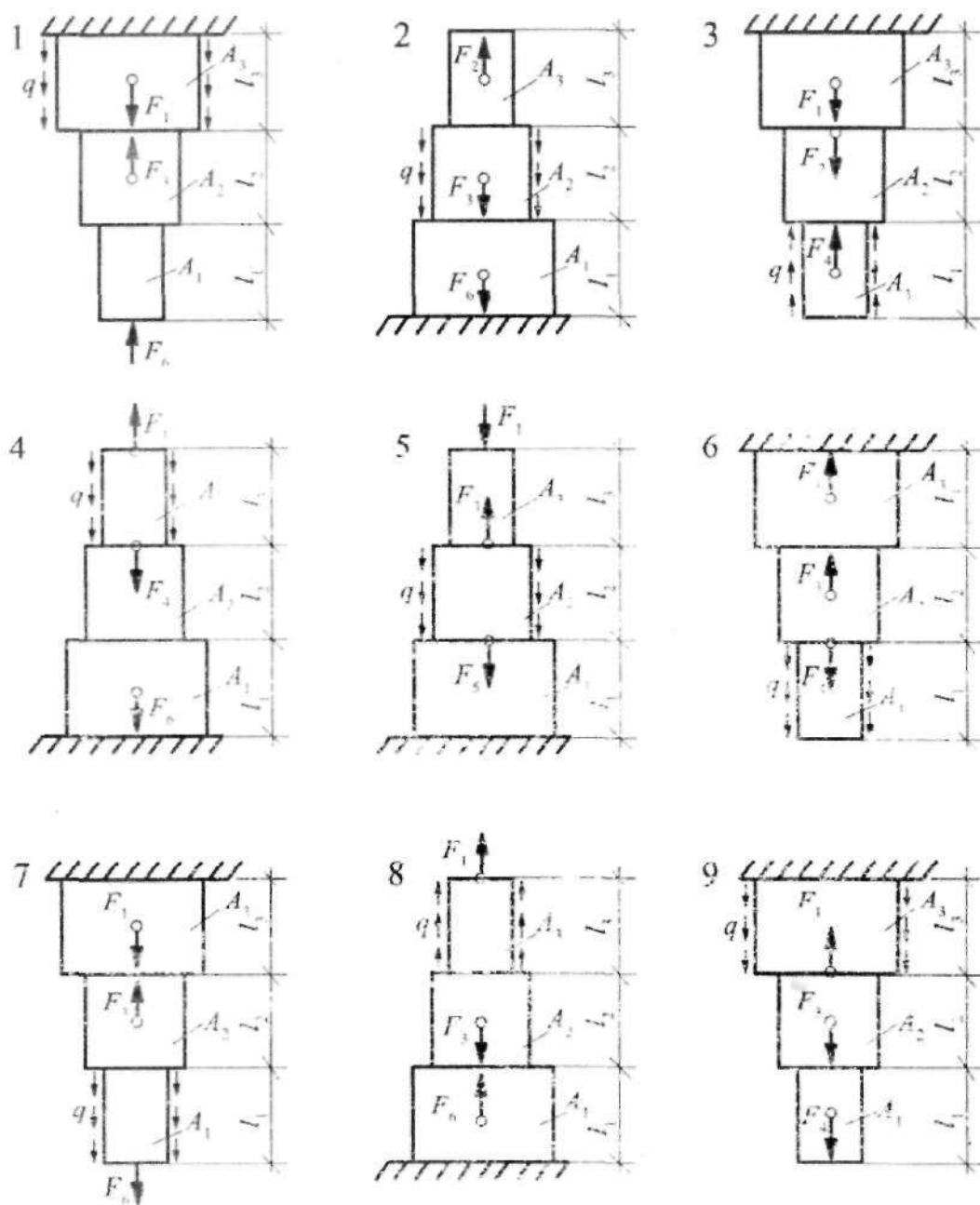
**Topish kerak:**

- 1) bo'ylama kuch, normal kuchlanish va deformatsiya epyuralari qurilsin;
- 2) sterjenning mustahkamligi tekshirilsin.

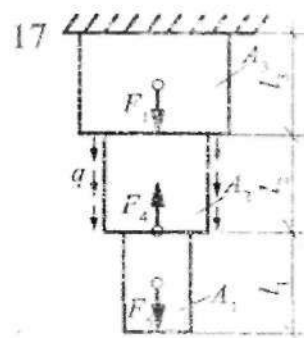
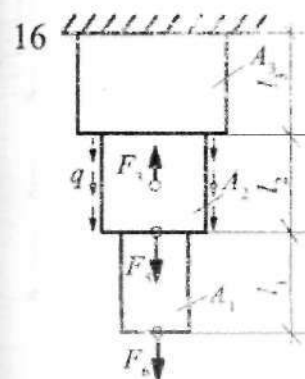
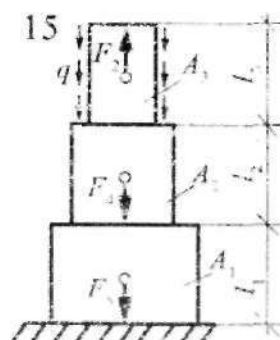
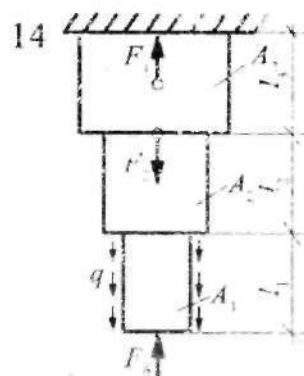
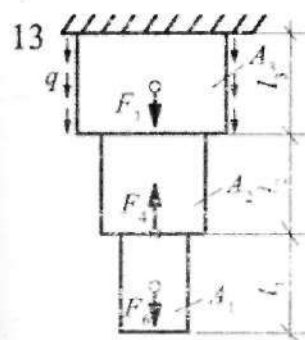
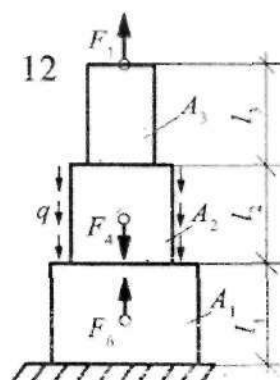
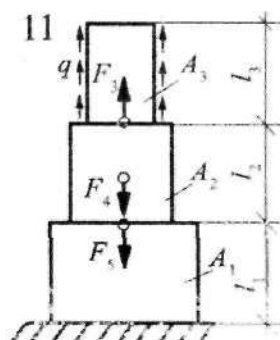
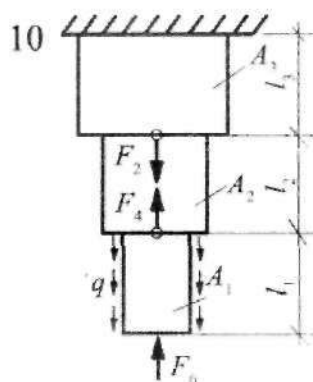
Kerakli ma'lumotlar I.2- jadvalda, hisoblash sxemalari esa I.26- shaklda keltirilgan.

I.2- jadval

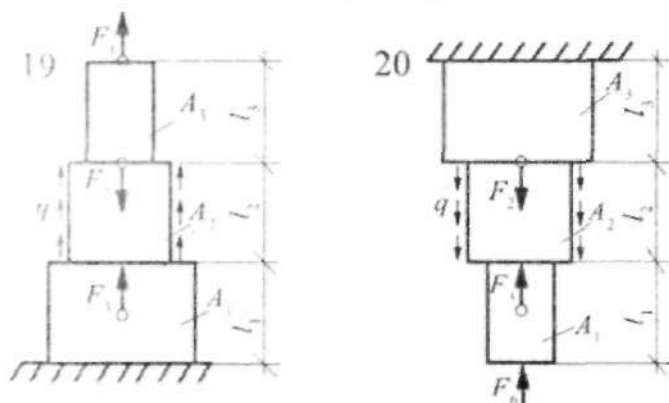
| №  | Uchastka uzunligi, sm |       |       | Ko'ndalang kesim yuzasi, sm <sup>2</sup> |       |       | Tashqi kuchlar, kN |       |       |       |       |       | Taralgan kuch, kN/sm |
|----|-----------------------|-------|-------|------------------------------------------|-------|-------|--------------------|-------|-------|-------|-------|-------|----------------------|
|    | $l_1$                 | $l_2$ | $l_3$ | $A_1$                                    | $A_2$ | $A_3$ | $F_1$              | $F_2$ | $F_3$ | $F_4$ | $F_5$ | $F_6$ | q                    |
| 1  | 40                    | 80    | 50    | 8                                        | 4     | 6     | 60                 | 180   | 160   | 140   | 100   | 80    | 30                   |
| 2  | 50                    | 46    | 70    | 10                                       | 4     | 4     | 120                | 80    | 200   | 160   | 120   | 60    | 40                   |
| 3  | 80                    | 40    | 30    | 14                                       | 4     | 8     | 80                 | 140   | 160   | 60    | 60    | 80    | 20                   |
| 4  | 42                    | 60    | 80    | 12                                       | 8     | 6     | 100                | 140   | 100   | 120   | 40    | 60    | 35                   |
| 5  | 52                    | 42    | 62    | 12                                       | 16    | 8     | 60                 | 120   | 160   | 80    | 100   | 40    | 25                   |
| 6  | 78                    | 50    | 60    | 8                                        | 4     | 16    | 120                | 80    | 140   | 100   | 60    | 120   | 45                   |
| 7  | 30                    | 80    | 42    | 10                                       | 12    | 6     | 80                 | 100   | 120   | 80    | 60    | 80    | 50                   |
| 8  | 42                    | 62    | 50    | 6                                        | 12    | 4     | 120                | 140   | 100   | 60    | 80    | 60    | 50                   |
| 9  | 60                    | 30    | 48    | 10                                       | 4     | 8     | 140                | 80    | 60    | 100   | 120   | 40    | 65                   |
| 10 | 70                    | 50    | 690   | 6                                        | 8     | 4     | 100                | 120   | 100   | 140   | 40    | 80    | 70                   |



I.26- shakl (davomi)



I.26- shakl (davomi)



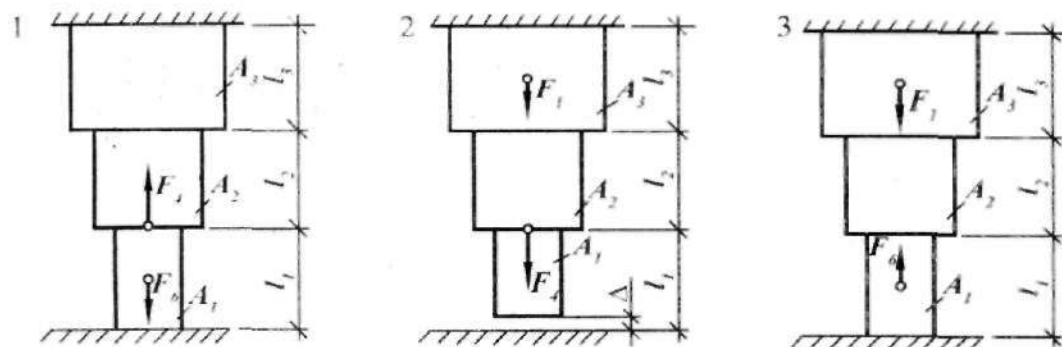
## 2- topshiriq

Markaziy bo'lgan cho'zilish va siqilishdagi statik noaniq masalalar.

**Berilgan:** Po'latdan yasalgan pog'onali sterjenga bo'yлама  $F_1$  kuchlar ta'sir etmoqda. Ruxsat etilgan normal kuchlanish  $[\sigma] = 210 \text{ MPa}$ . Oraliq masofa  $\Delta = 0,1 \text{ mm}$ .

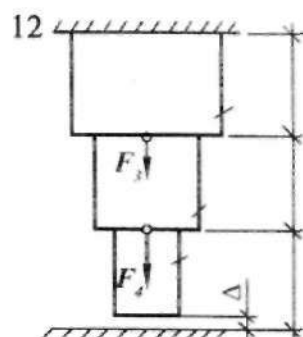
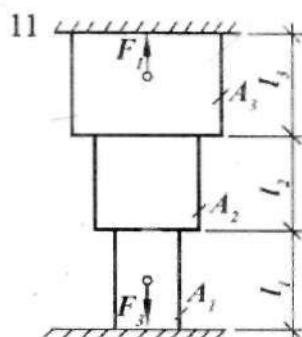
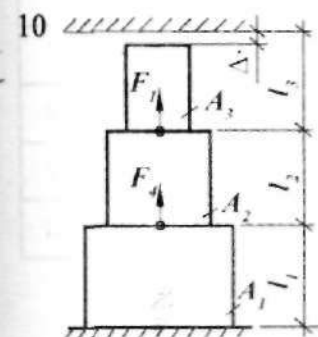
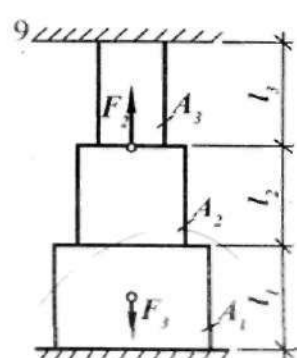
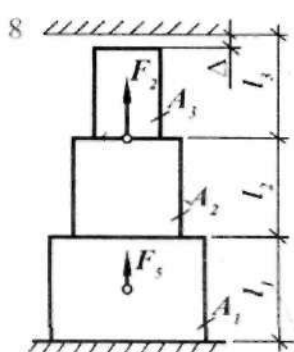
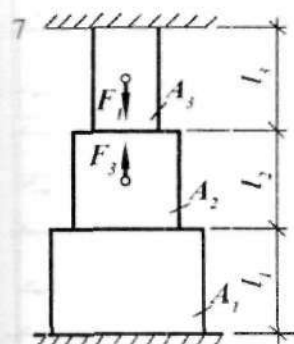
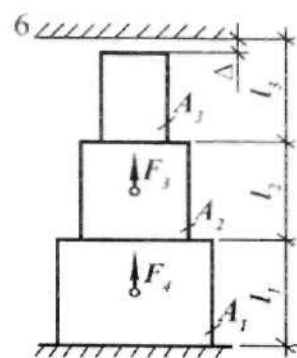
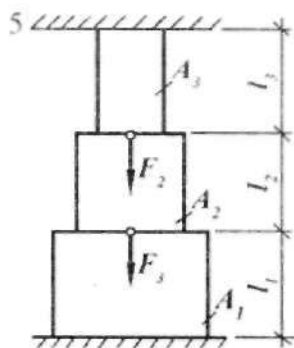
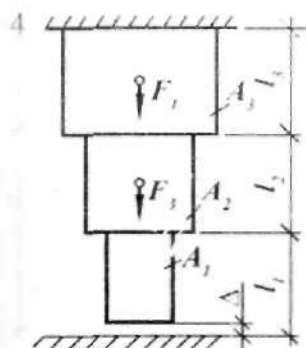
**Topish kerak:**

- 1) tayanch reaksiya kuchlari aniqlansin;
  - 2) bo'yлама kuch, normal kuchlanish va deformatsiya epyuralari qurilsin;
  - 3) sterjenning mustahkamligi tekshirilsin.
- Kerakli ma'lumotlar I.2- jadvalda, hisoblash sxemalari I.27- shaklda keltirilgan.

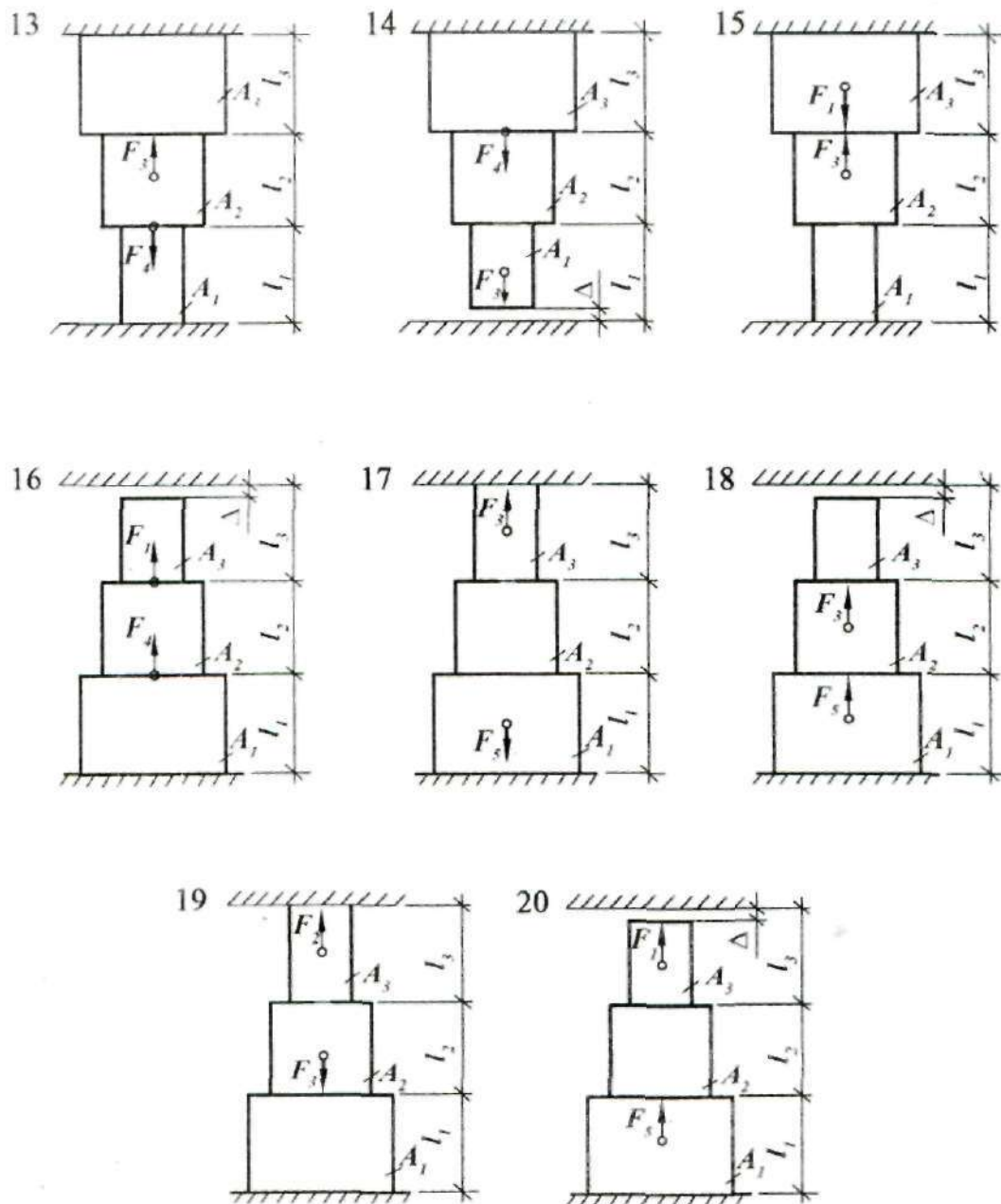


I.27- shakl

I.27- shakl (davomi)



1.27- shakl (davomi)





## 3- topshiriq

Absolut qattiq balka po'lat tortqilar yordamida mahkamlangan. Unga to'plangan kuch  $F$ , va taralgan kuch  $q$  lar ta'sir etmoqda.

Tortqi uchun ruxsat etilgan normal kuchlanish  $[\sigma] = 210$  MPa ga teng.

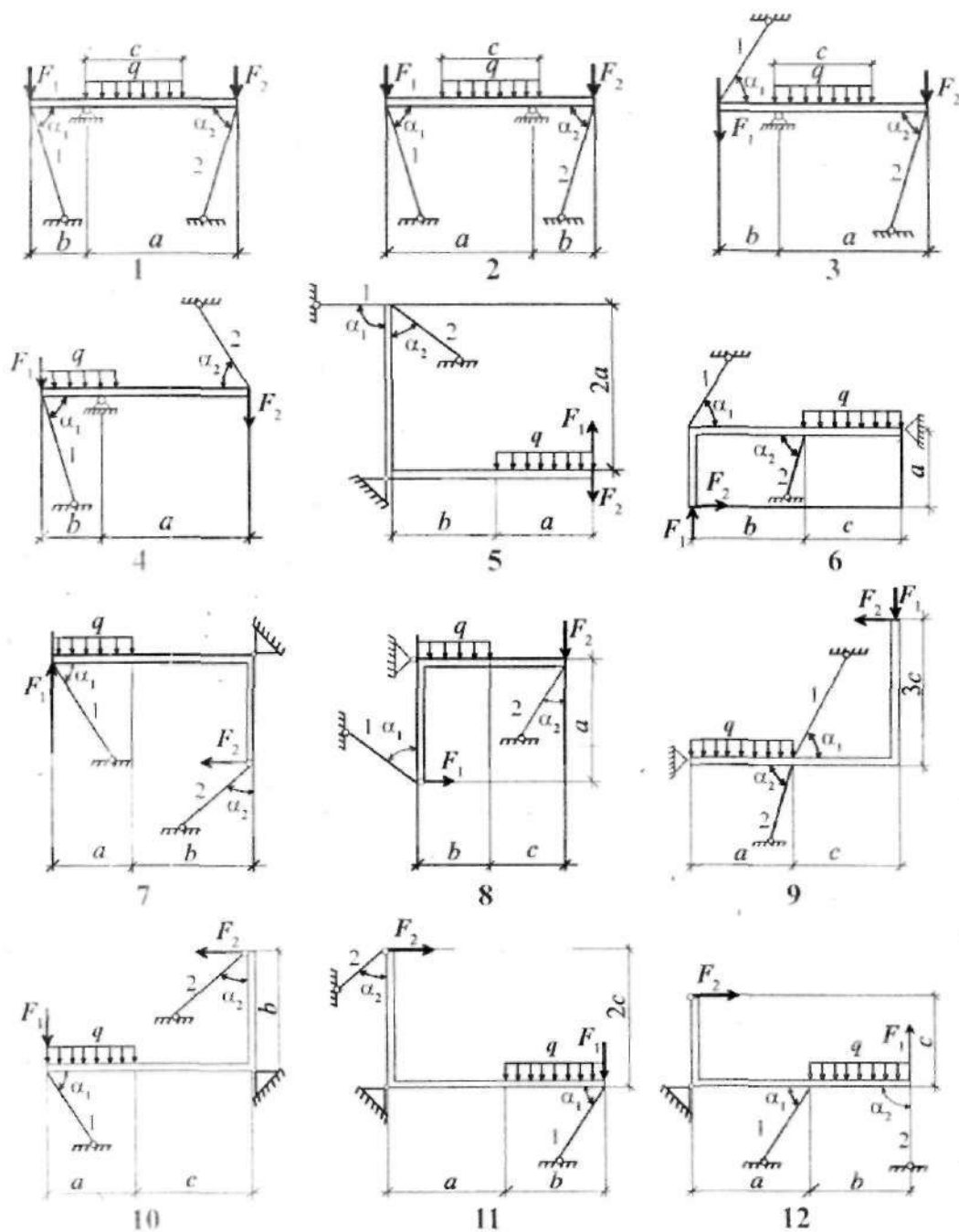
**Topish kerak:**

- 1) tortqilardagi bo'ylama kuch va kuchlanishlar topilsin;
- 2) tortqilardagi eng katta zo'riqish kuchi bo'yicha mustahkamlik shartiga binoan, eng katta ta'sir kuchi aniqlansin.

Kerakli ma'lumotlar I.3- jadvalda, hisoblash sxemalari I.28- shaklda keltirilgan.

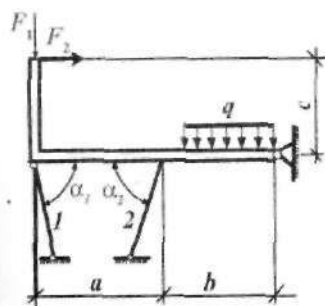
I.3- jadval

| №  | Tashqi kuchlar |       |      | Uchastka uzunligi, m |     |     |       |       | Ko'ndalang kesim yuzasi, m <sup>2</sup> |       | Burchak, grad |            |
|----|----------------|-------|------|----------------------|-----|-----|-------|-------|-----------------------------------------|-------|---------------|------------|
|    | KN             | KN    | KN/m |                      |     |     |       |       |                                         |       |               |            |
|    | $F_1$          | $F_2$ | $q$  | $a$                  | $b$ | $c$ | $l_1$ | $l_2$ | $A_1$                                   | $A_2$ | $\alpha_1$    | $\alpha_2$ |
| 1  | -              | 50    | -    | 5.4                  | 2.6 | 0.8 | 1.0   | 1.2   | 6                                       | 12    | 90            | 45         |
| 2  | 30             | -     | -    | 4.8                  | 2.8 | 1.2 | 1.4   | 1.0   | 8                                       | 10    | 45            | 90         |
| 3  | 12             | -     | -    | 4.6                  | 2.4 | 1.4 | 1.0   | 1.4   | 6                                       | 8     | 90            | 30         |
| 4  | -              | -     | 10   | 4.4                  | 2.8 | 0.6 | 1.2   | 1.4   | 6                                       | 6     | 60            | 90         |
| 5  | -              | 25    | -    | 4.8                  | 2.6 | 1.4 | 1.4   | 1.6   | 10                                      | 8     | 90            | 120        |
| 6  | -              | 20    | -    | 4.6                  | 2.6 | 1.0 | 1.2   | 1.4   | 6                                       | 10    | 135           | 90         |
| 7  | 50             | -     | -    | 5.2                  | 2.4 | 0.8 | 1.4   | 1.0   | 8                                       | 12    | 90            | 135        |
| 8  | -              | -     | 12   | 4.8                  | 3.2 | 1.4 | 1.6   | 1.2   | 6                                       | 6     | 60            | 90         |
| 9  | -              | -     | 10   | 4.8                  | 2.6 | 1.2 | 1.0   | 1.2   | 8                                       | 8     | 90            | 45         |
| 10 | -              | 40    | -    | 4.6                  | 2.4 | 1.0 | 1.2   | 1.0   | 1.2                                     | 8     | 45            | 90         |

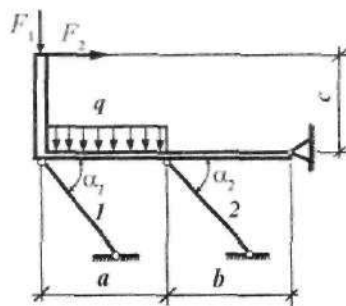


1.28- shakl

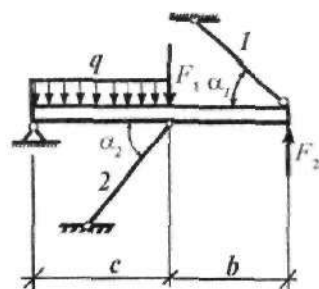
I.28- shakl (davomi)



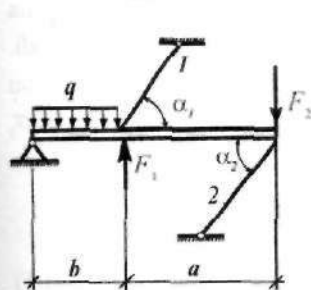
13



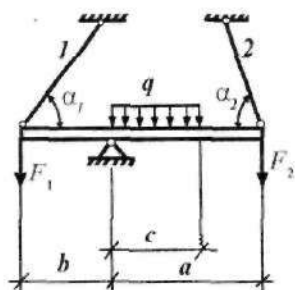
14



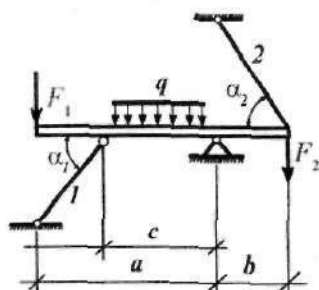
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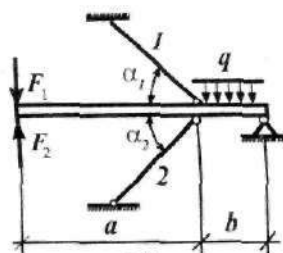
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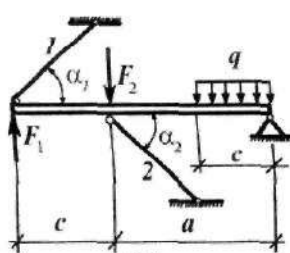
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## II BOB

# NUQTADAGI KUCHLANISH VA DEFORMATSIYALANISH HOLATLARI

## 2.1- §. Asosiy mulohazalar

- Nuqtadagi kuchlanish holati deb, mazkur nuqta orqali o'tkaziladigan barcha yuzachalarda paydo bo'ladigan normal va urinma kuchlanishlarning to'plamiga aytiladi.
- Urinma kuchlanishlar ta'sir ko'rsatmaydigan yuzalarga bosh yuzalar deyiladi; bu yuzadagi normal kuchlanishlarga esa bosh kuchlanishlar deyiladi. Ular  $\sigma_1$ ;  $\sigma_2$ ;  $\sigma_3$  orqali belgilanib, quyidagi munosabatda bo'ladi:  $\sigma_1 > \sigma_2 > \sigma_3$ .
- Kuchlanish holatlari chiziqli, tekis va fazoviy bo'ladi.
- Chiziqli kuchlanish holatida qiya kesimlardagi kuchlanishlar quyidagilarga teng:

$$\sigma_\alpha = \cos^2 \alpha; \quad (II.1)$$

$$\tau_\alpha = \frac{\sigma_1}{2} \sin 2\alpha. \quad (II.2)$$

- Tekis kuchlanish holatida qiya kesimlarda hosil bo'ladigan kuchlanishlar quyidagilarga teng:

$$\sigma_\alpha = \sigma_x \cdot \sin^2 \alpha + \sigma_y \cdot \cos^2 \alpha - \tau_{xy} \cdot \sin 2\alpha; \quad (II.3)$$

$$\tau_\alpha = \frac{(\sigma_y - \sigma_x)}{2} \sin 2\alpha + \tau_{xy} \cdot \cos 2\alpha. \quad (II.4)$$

- Istalgan ikkita o'zaro perpendikular yuzalardagi urinma kuchlanishlar miqdor jihatdan bir-biriga teng, lekin yo'nalishlari qarama-qarshi bo'ladi:

$$\tau_{xy} = \tau_{yx}$$

- Tekis kuchlanish holatida normal va urinma kuchlanishlarning ekstremal qiymatlari quyidagilarga teng:

$$\sigma_{\max/\min} = \frac{\sigma_x + \sigma_y}{2} \pm \frac{1}{2} \sqrt{(\sigma_x - \sigma_y)^2 + 4\tau_{xy}^2}; \quad (II.5)$$

$$\tau_{\max/\min} = \pm \frac{1}{2} \sqrt{(\sigma_x - \sigma_y)^2 + 4\tau_{xy}^2}. \quad (II.6)$$

- Bosh yuzalarning holati quyidagicha aniqlanadi:

$$\operatorname{tg} 2\alpha_0 = \frac{2\tau_{xy}}{\sigma_x - \sigma_y} \quad (II.7)$$

- Fazoviy kuchlanish holatida umumlashgan Guk qonuni quyidagicha ifodalanadi:

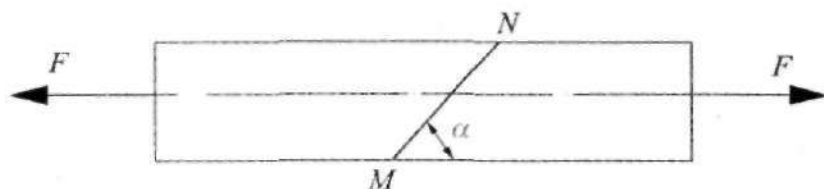
$$\left. \begin{aligned} \varepsilon_1 &= \frac{1}{E} [\sigma_1 - \mu(\sigma_2 + \sigma_3)] \\ \varepsilon_2 &= \frac{1}{E} [\sigma_2 - \mu(\sigma_1 + \sigma_3)] \\ \varepsilon_3 &= \frac{1}{E} [\sigma_3 - \mu(\sigma_1 + \sigma_2)] \end{aligned} \right\}; \quad (II.8)$$

bu yerda,  $\varepsilon_1$ ;  $\varepsilon_2$ ;  $\varepsilon_3$  – nisbiy deformatsiyalar.

## 2.2- §. Nuqtadagi kuchlanish va deformatsiyalanish holatlariga doir masalalar

### 29- masala

O'zaro qarama-qarshi yo'nalgan ikkita kuch bilan doiraviy sterjenning  $MN$  qiya kesimida hosil bo'ladigan kuchlanishlarni hisoblang (II.1- shakl). Qaysi og'ma yuzalarda urinma kuchlanishlar ekstremal qiymatga ega bo'ladi? Quyidagilar ma'lum:  $F = 300 \text{ kN}$ ,  $d = 8 \cdot 10^{-2} \text{ m}$ ,  $\alpha = 30^\circ$ .



II.1- shakl

### Yechish:

Dastlab sterjen o'qiga nisbatan tik o'tkazilgan kesmadagi kuchlanishni aniqlaymiz:

$$\sigma_0 = \frac{4F}{\pi d^2} = \frac{4 \cdot 300}{3,14 (8 \cdot 10^{-2})^2} = 5,97 \cdot 10^4 \text{ kN/m}^2 = 59,7 \text{ MPa}.$$

(II.1) va (II.2) formulalar yordamida qiya kesimlardagi kuchlanishlar hisoblanadi:

$$\sigma_\alpha = \sigma_0 \cos^2 \alpha = 4,48 \cdot 10^4 \text{ kN/m}^2 = 44,8 \text{ MPa};$$

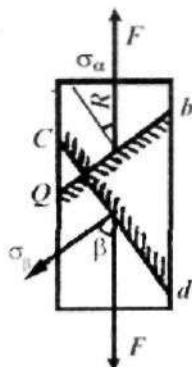
$$\tau_\alpha = 0,5 \sigma_0 \sin 2\alpha = 2,58 \cdot 10^4 \text{ kN/m}^2 = 25,8 \text{ MPa}.$$

Oxirgi formuladan ko'rinib turibdiki,  $\sin 2\alpha + 1$  yoki 1 larni qabul qilgandagina, urinma kuchlanish, mos ravishda, o'zining eng katta yoki eng kichik qiymatlariga erishadi, xolos. Shunga ko'ra, sterjen o'qiga  $45^\circ$  va  $135^\circ$  burchaklarda qiyalangan yuzalarda urinma kuchlanishlar ekstremal qiymatlarga erishar ekan:

$$\begin{aligned}\tau_{\alpha=45}(\max) &= 0,5 \sigma_0 = 2,985 \cdot 10^4 \text{ kN/m}^2; \\ \tau_{\alpha=135}(\min) &= -0,5 \sigma_0 = -2,985 \cdot 10^4 \text{ kN/m}^2.\end{aligned}$$

### 30- masala

O'zaro tik joylashgan va og'ma yuzachalardagi normal kuchlanishlarni  $\sigma_\alpha = \sigma_\beta/3 = 30 \text{ MPa}$  ga teng bo'lgan, ko'ndalang kesimi kvadrat ( $a = 16 \cdot 10^{-2} \text{ m}$ ) namunani cho'zuvchi kuchning qiymati topilsin (II.2- shakl). Namunaning bo'ylama o'qi bilan og'ma yuza normali orasidagi burchaklar aniqlansin.



II.2- shakl

#### Yechish:

Ko'ndalang kesimdagi normal kuchlanish  $\sigma_0$  ni og'ma yuzachalardagi kuchlanishlar orqali ifodalaymiz:

$$\sigma_\alpha = \sigma_0 \cos^2 \alpha; \quad \sigma_\beta = \sigma_0 \cos^2 \beta = \sigma_0 \sin^2 \alpha;$$

bu yerda,  $\beta = -(90 - \alpha)$ .

Hadlab qo'shamiz:  $\sigma_\alpha + \sigma_\beta = \sigma_0$ . Bundan,  $\sigma_0 = 120 \text{ MPa}$ .

Namunani cho'zuvchi kuch:

$$F = \sigma_0 \cdot 2a^2 = 2 \cdot 120 \cdot 10^3 (16 \cdot 10^{-2})^2 = 384 \text{ kN}.$$

Yuqoridagi ifodalardan:

$$\operatorname{tg}^2 \alpha = \sigma_\beta / \sigma_\alpha = 3; \quad \alpha = 60^\circ; \quad \beta = -(90 - \alpha) = -30^\circ.$$

### 31- masala

II.3- shakl (a)da tasvirlangan tekis kuchlanish holati uchun normal va urinma kuchlanishlarning ekstremal qiymatlari hamda ular ta'sir etuvchi yuzachalarning holatlarini aniqlash talab etiladi. Kuchlanishlar MPa larda berilgan.

#### Yechish:

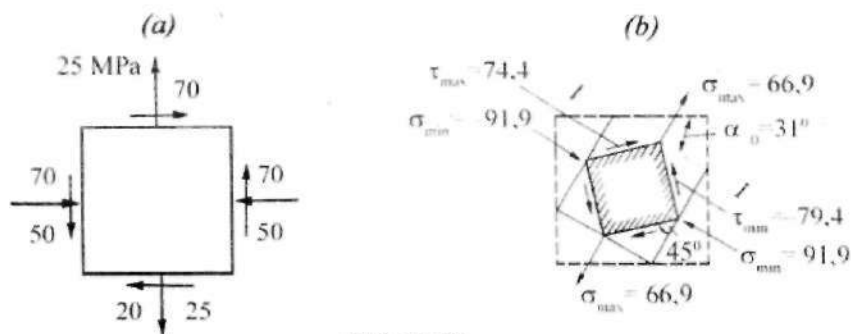
Quyidagi formula bo'yicha ekstremal normal kuchlanishlar aniqlanadi:

$$\sigma_{\max/\min} = \frac{\sigma_x + \sigma_y}{2} \pm \frac{1}{2} \sqrt{(\sigma_x - \sigma_y)^2 + 4\tau_{xy}^2} = 0,5 \left[ (-50 + 25) \pm \sqrt{(-50 + 25)^2 + 4 \cdot (70)^2} \right] = -12,5 \pm 79,4.$$

Shunday qilib,  $\sigma_{\max} = 66,9 \text{ MPa}$ ;  $\sigma_{\min} = -91,9 \text{ MPa}$ .

(II.6) formula yordamida ekstremal urinma kuchlanishlar topiladi:

$$\tau_{\max/\min} = \pm \frac{1}{2} \sqrt{(\sigma_x - \sigma_y)^2 + 4\tau_{xy}^2} = \pm 0,5 \sqrt{(-50 + 25)^2 + 4 \cdot (70)^2} = \pm 79,4.$$



11.3- shakl

Demak,  $\tau_{\max} = 79,4$  MPa;  $\tau_{\min} = -79,4$  MPa.

Bosh yuzachalarning holatini aniqlashda (II.7) formula ishlatiladi:

$$\operatorname{tg} 2\alpha_0 = 2 \cdot 70 / (-50 - 25) = -1,866 \Rightarrow 2\alpha_0 = \arctg(-1,866) \cong 62^\circ \Rightarrow \alpha_0 = 31^\circ.$$

$\sigma_{\max}$  bosh kuchlanish ta'sir etadigan bosh yuzaning holatini chizmada tasvirlash uchun gorizontaal yuzani (chunki bu yuzadagi normal kuchlanishning algebraik qiymati vertikal yuzadagi normal kuchlanishdan katta)  $\alpha_0$  burchakka buramiz;  $\alpha_0$  ning yo'nalishini tanlashda shunga e'tibor berish kerakki, buralayotgan yuzachadagi (bizning misolimizda gorizontaal yuzacha) urinma kuchlanish element yuzining markaziga nisbatan aylantirishga intilsin. Shu qoidaga amal qilib,  $\sigma_{\max}$  ning yo'nalishi doimo  $\tau_{xy}$  va  $\tau_{yx}$  larning yo'nalish (strelka) lari uchrashadigan koordinata o'qlarining ikkita choragi orqali o'tishiga ishonch hosil qilish mumkin (II.3- shakl, b).

II.3- shakl (b) da  $\tau_{\max}$  lar ta'sir etadigan siljish yuzalari ham ko'rsatilgan.

### 32- masala

Berilgan kuchlanish tenzoriga ko'ra kuchlanish holati aniqlansin (kuchlanishlar MPa lar-da berilgan).

$$\text{a) } \begin{vmatrix} 50 & 50 & 50 \\ 50 & 50 & 50 \\ 50 & 50 & 50 \end{vmatrix} \quad \text{b) } \begin{vmatrix} 0 & 40 & 60 \\ 40 & 0 & 50 \\ 60 & 50 & 0 \end{vmatrix}$$

### Yechish:

Kuchlanish tenzorining invariantlarini hisoblaymiz:

$$\text{a) } S_1 = 50 + 50 + 50 = 150 \text{ MPa};$$

$$S_2 = 50 \cdot 50 + 50 \cdot 50 + 50 \cdot 50 - 50^2 - 50^2 - 50^2 = 0;$$

$$S_3 = 50 \cdot 50 \cdot 50 - 50 \cdot 50^2 - 50 \cdot 50^2 - 50 \cdot 50^2 + 2 \cdot 50 \cdot 50 \cdot 50 = 0.$$

Demak,  $S_1 = 150$  MPa;  $S_2 = S_3 = 0$  chiziqli kuchlanish holati.

$$b) S_1 = 0;$$

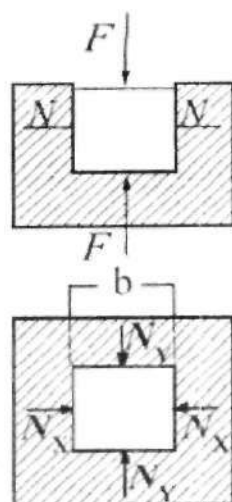
$$S_2 = -40^2 - 60^2 - 50^2 = -7700 \text{ MPa} \neq 0;$$

$$S_3 = 2 \cdot 40 \cdot 60 = 24 \cdot 10^4 \text{ MPa} \neq 0.$$

Bu hajmiy kuchlanish holatiga to'g'ri keladi, chunki  $\theta = 0$  ga teng.

### 33- masala

Mis materialidan yasalgan elementar kubik «deformatsiyanmaydigan» detal o'yig'iga tirqishsiz erkin o'rnatilgan bo'lib,  $F = 400 \text{ kN}$  kuch bilan markaziy siqilgan (II.4- shakl). Kubik hajmining nisbiy o'zgarishi hamda deformatsiyaning solishtirma potensial energiyasi aniqlansin. Quyidagilar ma'lum deb hisoblansin:  $E = 1 \cdot 10^5 \text{ MPa}$ ,  $\mu = 0,34$ ,  $b = 10 \cdot 10^{-2} \text{ m}$ .



II.4- shakl

### Yechish:

Detal yetarlicha bikr bo'lganligi tufayli, quyidagi ikkita ko'ndalang nisbiy deformatsiyalar nolga teng bo'ladi:

$$\left. \begin{aligned} \varepsilon_x &= -\frac{\sigma_x}{E} + \mu \frac{\sigma_y}{E} + \mu \frac{\sigma_z}{E} = 0 \\ \varepsilon_y &= -\frac{\sigma_y}{E} + \mu \frac{\sigma_x}{E} + \mu \frac{\sigma_z}{E} = 0 \end{aligned} \right\} \quad (a)$$

$$\text{bu yerda, } \sigma_x = \frac{N_x}{b^2}; \quad \sigma_y = \frac{N_y}{b^2}; \quad \sigma_z = \frac{F}{b^2} \quad (b)$$

Deformatsiya tenglamasidan  $\sigma_x = \sigma_y = \frac{\mu}{(1-\mu)} \cdot \sigma_z$  ekanligi kelib chiqadi. (b) ifodani e'tiborga olib, kubik devorlariga ta'sir etuvchi reaksiyalarni hisoblaymiz:

$$N_x = N_y = \frac{\mu}{1-\mu} \cdot F = 206,1 \text{ kN}.$$

Demak, kubikdagi bosh kuchlanishlar quyidagicha bo'lar ekan:

$$\sigma_1 = \sigma_x = -\frac{N_x}{b^2} = -20,61 \text{ MPa};$$

$$\sigma_2 = \sigma_y = -\frac{N_y}{b^2} = -20,61 \text{ MPa};$$

$$\sigma_3 = \sigma_z = -\frac{F}{b^2} = -40 \text{ MPa}.$$

Kubik hajmining nisbiy o'zgarishini hisoblaymiz:

$$\theta = \frac{1-2\mu}{E} (\sigma_1 + \sigma_2 + \sigma_3) = -25,99 \cdot 10^{-5}.$$



Hajmning o'zgarishidan hosil bo'lgan solishtirma potensial energiya quyidagiga teng bo'ladi:

$$a_h = \frac{1-2\mu}{6E} (\sigma_1 + \sigma_2 + \sigma_3)^2 = 351,82 \cdot 10^{-5} \cdot 10^3 \frac{\text{kN} \cdot \text{m}}{\text{m}^3} = 3,5182 \frac{\text{kN} \cdot \text{m}}{\text{m}^3}$$

Endi shaklning o'zgarishidan hosil bo'lgan solishtirma potensial energiyani aniqlaymiz:

$$\begin{aligned} a_{sh} &= \frac{1+\mu}{6E} [(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2] = \\ &= \frac{1+0,34}{6 \cdot 1 \cdot 10^5} [(-20,61 + 40)^2 + (-40 + 20,61)^2] = 1,6793 \frac{\text{kN} \cdot \text{m}}{\text{m}^3} \end{aligned}$$

Shunday qilib, kubikning to'la solishtirma potensial energiyasi  $a = a_h + a_{sh} = 5,1975 \text{ kN} \cdot \text{m/m}^3$  ga teng ekan.

### 34- masala

Berilgan nuqtadagi tekis kuchlanganlik holati uchun analitik va grafik usullarda quyidagilar aniqlansin (II.5 shakl, a):

- 1) ixtiyoriy yuzachadagi ( $\alpha = 40^\circ$ ) kuchlanish;
- 2)  $\sigma_{\max}$  va  $\sigma_{\min}$  bosh kuchlanishlar;
- 3) bosh yuzalarning holati;
- 4) urinma kuchlanishlarning ekstremal qiymatlari.

### Yechish:

#### 1. Analitik usul.

Ixtiyoriy yuzachadagi kuchlanishlarni ( $\alpha = 40^\circ$ ) quyidagi formula yordamida aniqlaymiz (II.5- shakl, b):

$$\begin{aligned} \sigma_{x_1} &= \sigma_x \cdot \cos^2 \alpha + \sigma_y \cdot \sin^2 \alpha - \tau_y \cdot \sin 2\alpha = \\ &= 40 \cos^2 40^\circ + (-20) \cdot \sin^2 40^\circ - (-30) \cdot \sin 80^\circ = 44,8 \text{ MPa}; \\ \tau_{y_1} &= \frac{\sigma_x - \sigma_y}{2} \sin 2\alpha + \tau_y \cdot \cos 2\alpha = \frac{40 - (-20)}{2} \sin 80^\circ = 24,3 \text{ MPa} \end{aligned}$$

Bosh kuchlanishlar quyidagiga teng bo'ladi:

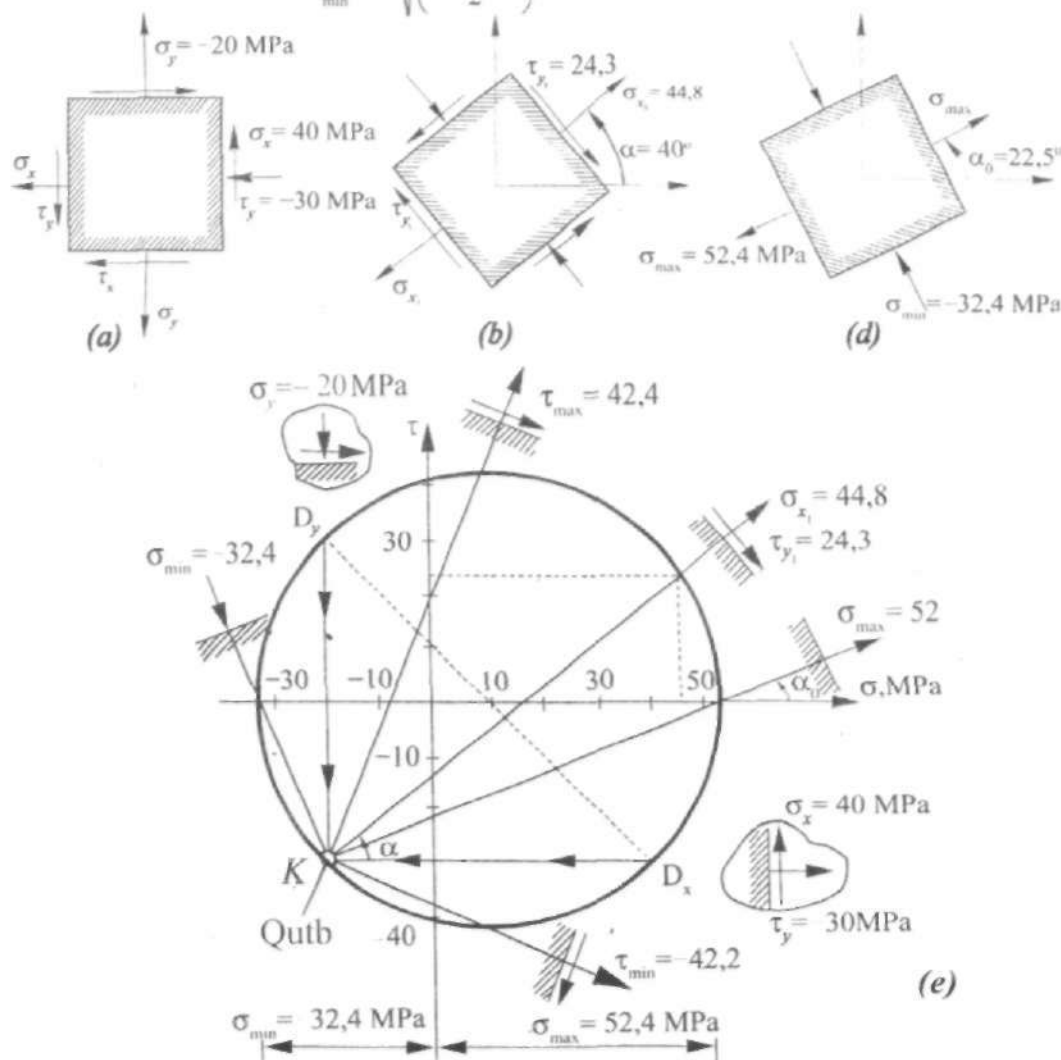
$$\begin{aligned} \sigma_{\max/\min} &= \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_y^2} = \\ &= \frac{40 + (-20)}{2} \pm \sqrt{\left[\frac{40 - (-20)}{2}\right]^2 + (-30)^2} = 10 \pm 42,4 \text{ MPa}. \\ \sigma_{\max} &= 52,4 \text{ MPa}; \quad \sigma_{\min} = -32,4 \text{ MPa}. \end{aligned}$$

Endi bosh yuzalarning holatini aniqlaymiz ( II.5- shakl, d):

$$\operatorname{tg} \alpha_0 = -\frac{\tau_y}{\sigma_{\max} - \tau_y} = -\frac{(-30)}{52,4 - (-20)} = 0,414; \alpha_0 = 22,5^\circ.$$

Ekstremal urinma kuchlanish esa quyidagiga teng bo'ladi:

$$\tau_{\max \min} = \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_y^2} = \pm 42,4 \text{ MPa}.$$



II.5- shakl

## II. Grafik usul (Mor aylanasi yordamida)

1) Masshtab asosida  $X$  o'qi yo'nalishi bo'ylab  $\sigma$  va  $Y$  o'qi yo'nalishi bo'ylab  $\tau$  qiymatlarini qo'yamiz (II.5- shakl, e).

2)  $D_x (\sigma_x; \tau_x)$  va  $D_y (\sigma_y; \tau_y)$  nuqtalarni berilgan koordinatalari bo'yicha II.5- shakl, (e) ga qo'yamiz. Bu yerda,  $\sigma_x = 40$ ,  $\tau_x = -30$ ;  $\sigma_y = -20$  va  $\tau_y = -30$  ga tengdir.

3)  $D_x$  va  $D_y$  nuqtalardan o'tgan to'g'ri chiziqlarning gorizontaal  $\sigma$  o'qi bilan kesishidan hosil bo'lgan nuqta Mor doirasining markazidir.

4)  $D_x$  nuqtadan gorizontaal hamda  $D_y$  nuqtadan vertikal o'qlarga parallel chiziqlar o'tkazamiz. Bunda ularning kesishgan nuqtasi doiraning qutbini ( $K$  nuqta) hosil qiladi.

5)  $K$  nuqtadan (qutbdan) bizni qiziqtirayotgan tekislikka o'tkazilgan normalga parallel to'g'ri chiziq o'tkazib, Mor doirasi yordamida kerakli qiymatlarni aniqlaymiz ( II.5- shakl, e).

## 2.3- §. Nuqtadagi kuchlanish va deformatsiyaning holatlari bo'yicha topshiriq

### 4- topshiriq

Nuqtadagi tekis kuchlanganlik holati.

**Berilgan:** elastik deformatsiyanuvchi jismning (II.6- shakl) xavfli nuqtasidan ajratib olingan to'g'ri to'rtburchakning qirralariga normal va urinma kuchlanishlar ta'sir etmoqda. Jism po'latdan yasalgan bo'lib, ruxsat etilgan normal kuchlanish  $[\sigma] = 210$  MPa ga teng.

### Topish kerak:

1) bosh kuchlanishlarning qiymati va yo'nalishi analitik usulda hamda Mor aylanasi yordamida aniqlansin;

2) shaklda bosh yuzalarning holati va bosh kuchlanishlarning yo'nalishi ko'rsatilsin;

3) eng katta urinma kuchlanishning qiymati aniqlansin;

4) mustahkamlik nazariyalaridan birini qo'llab, jism materialining shu nuqtadagi mustahkamligi tekshirilsin;

5)  $X, Y, Z$  o'qlari bo'yicha elementning nisbiy chiziqli deformatsiyasi topilsin;

6) elementning nisbiy hajmiy deformatsiyasi topilsin.

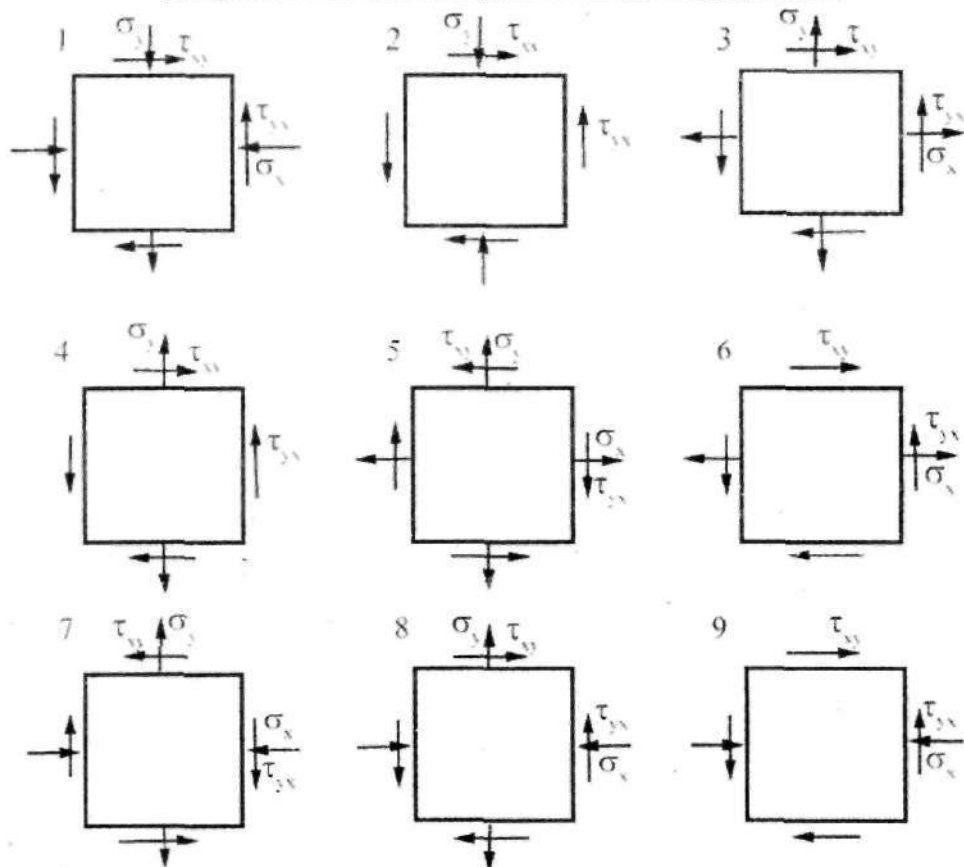
Hisoblash uchun qiymatlar II.1- jadvalda, chizmalar esa II.6- shaklda keltirilgan.

II.1- jadval

| No | $\sigma_x$ , MPa | $\sigma_y$ , MPa | $\sigma_{xy}$ , MPa |
|----|------------------|------------------|---------------------|
| 1  | 40               | 130              | 40                  |
| 2  | 70               | 70               | 80                  |
| 3  | 30               | 120              | 40                  |

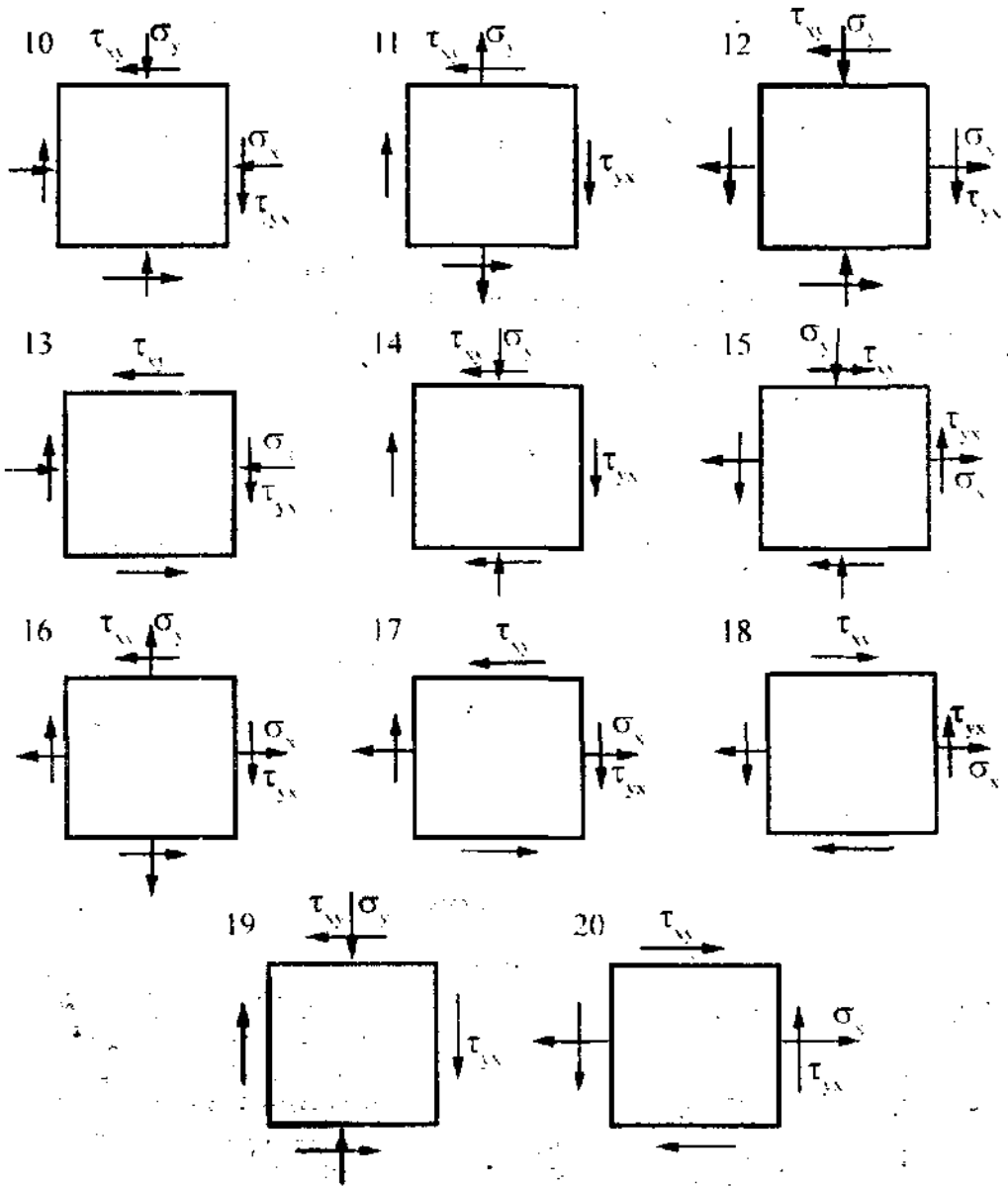
II.1- jadval (davomi)

| №  | $\sigma_x$ , MPa | $\sigma_y$ , MPa | $\sigma_{xy}$ , MPa |
|----|------------------|------------------|---------------------|
| 4  | 80               | 50               | 70                  |
| 5  | 90               | 40               | 60                  |
| 6  | 40               | 140              | 40                  |
| 7  | 50               | 120              | 60                  |
| 8  | 110              | 30               | 70                  |
| 9  | 60               | 40               | 60                  |
| 10 | 90               | 40               | 60                  |



II.6-shakl

II.6- shakl (davomi)



## III BOB

## SILJISH

## 3.1- §. Asosiy mulohazalar

- Elastik sterjendan ma'lum qiyalikdagi tekisliklar yordamida ajratib olingan elementar kubning tomonlariga faqat urinma kuchlanishlar ta'sir qilsa, u holda kubning bunday tekis kuchlanish holatiga sof siljish deyiladi.
- Faqat urinma kuchlanishlar paydo bo'ladigan yuzalar sof siljish yuzalari deyiladi.
- Siljishdagi Guk qonuni quyidagicha teng:

$$\tau = G \cdot \gamma; \quad (III.1)$$

bu yerda,  $\tau$  – urinma kuchlanish;

$G$  – siljishdagi elastiklik moduli va u quyidagicha ifodalanadi:

$$G = \frac{E}{2(1 + \mu)}; \quad (III.2)$$

$\gamma$  – nisbiy siljish burchagi va u quyidagicha ifodalanadi:

$$\gamma = \frac{\delta}{a}; \quad (III.3)$$

bu yerda,  $\delta$  – absolut siljish;

$a$  – elementning balandligi.

## 3.2- §. Siljishga doir masalalar

## 35- masala

Cho'zuvchi  $F$  kuch bilan yuklangan bolt qalpog'ining diametri  $D$  va balandligi  $h$  ni aniqlang (III.1- shakl). Quyidagi joiz kuchlanishlar ma'lum:

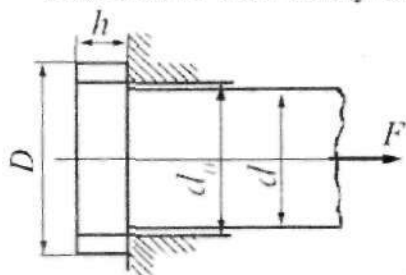
$\delta_{adm} = 140$  MPa (cho'zilishdagi);

$\tau_{adm} = 140$  MPa (kesilishdagi);

$\sigma'_{con} = 250$  MPa (ezilishdagi);

$d_0 = 3,4 \cdot 10^{-2}$  m;  $d = 3,2 \cdot 10^{-2}$ .

Material cho'zilish, kesilish va ezilishlarga bir xil qarshilik ko'rsatishi inobatda olingan holda, hisoblash olib borilsin.



III.1- shakl

**Yechish:**

Chizmadan koʻrinib turibdiki, boltning sterjen qismi choʻzilishga, bosh qismi kesilishga, devorga tegib turgan tayanch yuzasi esa ezilishga qarshilik koʻrsatadi.

a) sterjenning choʻzilishdagi mustahkamlik shartidan joiz kuchni aniqlaymiz:

$$F_{adm} = \sigma_{adm} \frac{\pi d^2}{4} = 140 \cdot 10^3 \frac{3,14(3,2 \cdot 10^{-2})^2}{4} = 112,6 \text{ kN}.$$

b) ezilishdagi mustahkamlik shartidan tayanch yuzaning diametrini aniqlaymiz:

$$\frac{F}{A_{ez}} \leq \sigma'_{con};$$

bu yerda,  $A_{ez} = \frac{\pi(D^2 - d_0^2)}{4}$ ;  $F = F_{adm}$  (masalaning shartiga koʻra).

$$\text{Bundan, } D \geq \sqrt{\frac{4F_{adm}}{\pi\sigma'_{con}} + d_0^2} = \sqrt{\frac{4 \cdot 112,6}{3,14 \cdot 250 \cdot 10^3} + (3,14 \cdot 10^{-2})^2} = 4,17 \cdot 10^{-2} \text{ m};$$

$D = 4,2 \cdot 10^{-2} \text{ m}$  deb qabul qilamiz.

d) kesilishga mustahkamlik shartini yozamiz:  $\frac{F}{A_{kes}} \leq \tau_{adm}$ ;

bu yerda,  $A_{kes} = \pi d_0 \cdot h$ ;  $F = F_{adm}$  (masalaning shartiga asosan).

Demak,  $h \geq \frac{F_{adm}}{\pi d_0 \tau_{adm}} = \frac{112,6}{3,14 \cdot 3,4 \cdot 10^{-2} \cdot 100 \cdot 10^3} = 1,055 \cdot 10^{-2} \text{ m}$ ;  $h = 1,1 \cdot 10^{-2} \text{ m}$  deb qabul qilinadi.

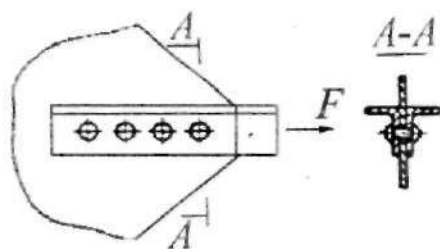
**36- masala**

Ikkita  $90 \times 56 \times 8$  li burchaklikdan iborat ferma raskosini  $\delta = 1,2 \cdot 10^{-2} \text{ m}$  qalinlikdagi kosinkaga biriktirish uchun diametri  $d = 2,3 \cdot 10^{-2} \text{ m}$  li parchin mixdan nechta zarur (III.2- shakl)? Raskosdagi choʻzuvchi kuch  $F = 300 \text{ kN}$  boʻlib, uning materiali uchun  $\sigma'_{con} = 280 \text{ MPa}$ ,  $\tau_{adm} = 100 \text{ MPa}$  ga teng.

**Yechish:**

Birikmada ikki kesilishli parchin mix ishlatilganligi sababli, uning kesilmaslik sharti

$$\tau_{kes} = \frac{F}{2n \cdot \frac{\pi d^2}{4}} \leq \tau_{adm} \quad \text{koʻrinishda yoziladi.}$$



III.2- shakl

Bunda, 
$$n \geq \frac{N}{2 \cdot \frac{\pi d^2}{4} \cdot \tau_{adm}} = \frac{300 \cdot 10^{-3}}{2 \cdot \frac{3,14 (2,3 \cdot 10^{-2})^2}{4} \cdot 100} = 3,6.$$

Ezilmaslik sharti esa quyidagicha: 
$$\sigma_{ez} = \frac{F}{n \cdot \delta d} \leq \sigma'_{con}.$$

Bunda, 
$$n \geq \frac{F}{\delta d \sigma'_{con}} = \frac{300 \cdot 10^{-3}}{1,2 \cdot 2,3 \cdot 10^{-4} \cdot 280} = 3,9.$$

Demak, birikmaga  $n = 4$  ta parchin mix yetarli ekan.

### 37- masala

III.3- shaklda tasvirlangan birikmadagi boltning diametrini aniqlash talab etiladi. List (polosa)ning qalinligi  $\delta = 2 \cdot 10^{-2}$  m bo'lib, uni cho'zuvchi kuch  $F = 200$  kN ga teng. Bolt materiali uchun joiz kuchlanishlar ma'lum:  $[\sigma]_{ez} = 200$  MPa,  $[\tau]_{kes} = 80$  MPa.

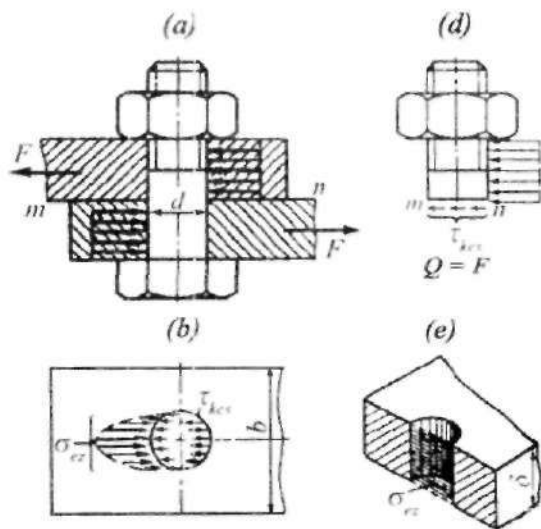
#### Yechish:

Bolt bir kesilishli bo'lganligi sababli kesilishdagi mustahkamlik shartini

$$\frac{F}{\frac{\pi d^2}{4}} \leq [\tau]_{kes}$$

ko'rinishida yozib, undan boltning diametrini topamiz:

$$d \geq \sqrt{\frac{4F}{\pi \cdot [\tau]_{kes}}} = \sqrt{\frac{4 \cdot 200 \cdot 10^3}{3,14 \cdot 80 \cdot 10^6}} = 5,6 \cdot 10^{-2} \text{ m} \approx 6 \cdot 10^{-2} \text{ m}.$$



III.3- shakl

Ezilishdagi mustahkamlik sharti  $\frac{F}{\delta d} \leq [\sigma]_{ez}$  dan diametrni aniqlaymiz (III.3- shakl, e):

$$d \geq \frac{F}{\delta \cdot [\sigma]_{ez}} = \frac{200 \cdot 10^3}{2 \cdot 10^{-2} \cdot 200 \cdot 10^6} = 5 \cdot 10^{-2} \text{ m}.$$

Shunday qilib,  $d = 6 \cdot 10^{-2}$  m qabul qilinadi.



**38- masala**

Cho'zuvchi kuch  $F = 40$  kN bo'lganda tortqining qalpog'ida hosil bo'luvchi kesuvchi kuchlanishning qiymatini aniqlang. Boltning diametri  $d = 2 \cdot 10^{-2}$  m, qalpog'ning qalinligi esa  $S = 2,4 \cdot 10^{-2}$  m ga teng (III.4- shakl).

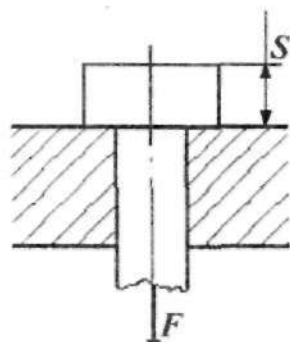
**Yechish:**

Shartli kesilish yuzasini hisoblaymiz:

$$A_{kes} = \pi ds = 3,14 \cdot 2,4 \cdot 10^{-2} = 15,072 \cdot 10^{-4} \text{ m}^2.$$

Tortqining qalpog'idagi ezuvchi kuchlanish quyidagiga teng:

$$\sigma_{kes} = \frac{F}{A_{kes}} = \frac{40}{15,072 \cdot 10^{-4}} = 0,26 \cdot 10^3 \frac{\text{kN}}{\text{m}^2} = 0,26 \text{ MPa}.$$



III.4- shakl

**39- masala**

Qalinligi  $\delta = 1,4 \cdot 10^{-2}$  m bo'lgan po'lat listda (III.5- shakl)  $d = 1,4 \cdot 10^{-2}$  m li teshik o'yish uchun puansonga qanday  $F$  kuch qo'yilishi kerak? List materialining kesilishiga qarshilik qiluvchi mustahkamlik chegarasi  $\tau_b = 360$  MPa ga teng.

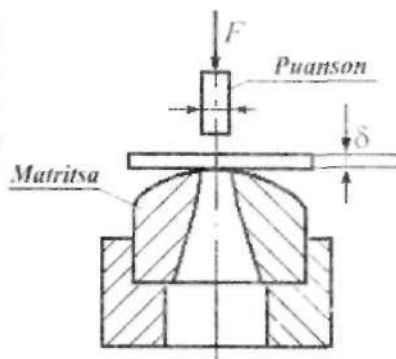
**Yechish:**

Listga teshik o'yishda puanson kesgan yuza:

$$A_{kes} = \pi d \delta = 3,14 \cdot 1,4 \cdot 10^{-2} \cdot 1,2 \cdot 10^{-2} = 5,28 \cdot 10^{-4} \text{ m}^2.$$

Teshik o'yish uchun zarur bo'lgan kuch esa quyidagicha topiladi:

$$F = \tau_b \cdot A_{kes} = 360 \cdot 10^3 \cdot 5,28 \cdot 10^{-4} = 190,08 \text{ kN}.$$



III.5- shakl

**3.3- §. Siljish deformatsiyasi bo'yicha topshiriq****5- topshiriq**

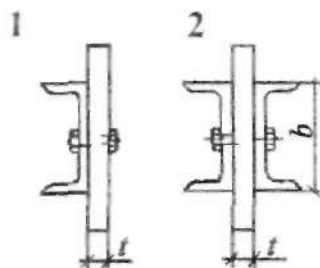
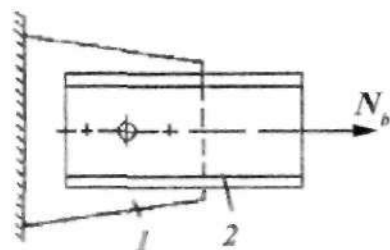
To'g'ri to'rtburchak va prokat profillardan tashkil topgan (III.6- shakl) kesimning (simmetrik) quyidagi qiymatlari aniqlansin:

- 1) kesimning og'irlik markazi;
- 2) bosh markaziy inersiya momentlari;
- 3) kesim masshtabda chizilib, kerakli o'qlar va o'lchamlar ko'rsatilsin.

Hisoblash uchun qiymatlar III.1- jadvalda, kesim chizmalari III.6- shaklda keltirilgan.

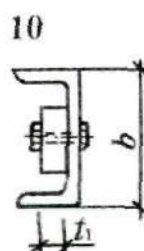
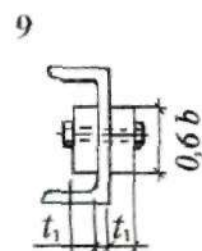
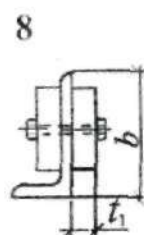
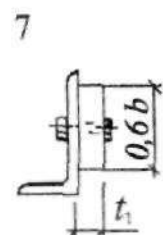
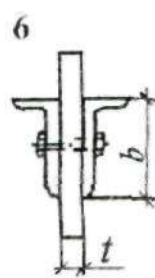
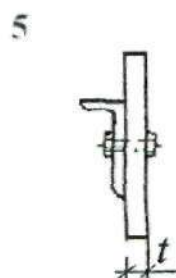
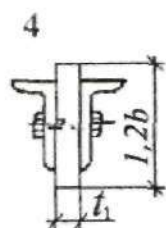
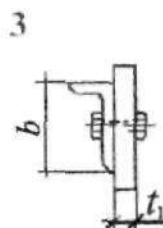
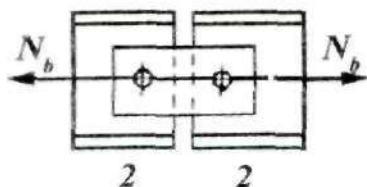
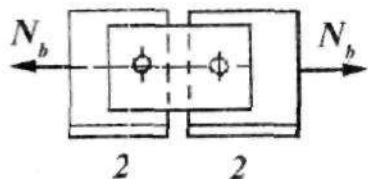
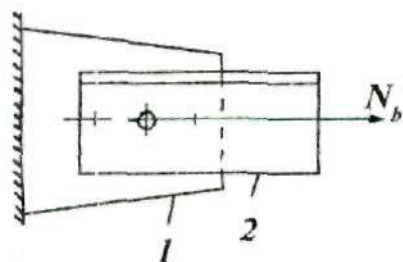
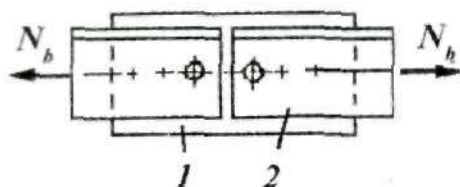
III.1- jadval

| №  | O'lchamlar |     |                               |                                | Nomer                   |                        |
|----|------------|-----|-------------------------------|--------------------------------|-------------------------|------------------------|
|    | List, sm   |     | Burchaklik, mm                |                                | Qo'shtavr<br>(GOST -72) | Shvellar<br>(GOST -72) |
|    | h          | b   | Teng yonli<br>(GOST 8509 -72) | Teng yonsiz<br>(GOST 8510 -72) |                         |                        |
| 1  | 16         | 1.8 | 80x80x8                       | -                              | 18a                     | 22                     |
| 2  | 16         | 2.2 | 80x80x7                       | -                              | 18                      | 20a                    |
| 3  | 16         | 1.4 | 80x80x6                       | -                              | 16                      | 22                     |
| 4  | 18         | 2.0 | -                             | 100x63x6                       | 20                      | 22a                    |
| 5  | 18         | 2.4 | -                             | 110x70x7                       | 18a                     | 22                     |
| 6  | 18         | 1.6 | -                             | 90x56x6                        | 18                      | 22a                    |
| 7  | 20         | 2.2 | 110x70x7                      | -                              | 20a                     | 24                     |
| 8  | 20         | 2.4 | -                             | 110x70x7                       | 18a                     | 22                     |
| 9  | 20         | 1.8 | 100x100x8                     | -                              | 18a                     | 20                     |
| 10 | 22         | 2.4 | -                             | 125x80x12                      | 22                      | 24a                    |



III.6- shakl

III.6- shakl (davomi)



## IV BOB

## TEKIS SHAKLLARNING GEOMETRIK TAVSIFNOMALARI

## 4.1- §. Asosiy mulohazalar

Ko'rib o'tganimizdek, markaziy cho'zilish yoki siqilish deformatsiyasida brusning ko'ndalang kesim yuzi mustahkamlik va bikrlikni tavsiflovchi asosiy miqdor ekan.

Ammo buralish, egilish, murakkab deformatsiya, bo'ylama egilish (siqilgan sterjenlarning ustuvorligi) va dinamik yuklarning ta'sirlarini o'rganish jarayonida ko'ndalang kesim yuza tekis shakllarning geometrik tavsifnomasi bo'la olmaydi.

Shuning uchun bu deformatsiya turlarini o'rganishda tekis shakllarning quyidagi geometrik tavsifnomalarini ham bilish muhimdir:

- tekis shakllarning o'qqa nisbatan statik momentlari;
- tekis shakllarning inersiya momentlari;
- tekis shakllarning markazdan qochirma inersiya momentlari;
- tekis shakllarning qarshilik momentlari.

## 4.2- §. Tekis shakllarning inersiya momentlari

## 1. Tekis shakllarning o'qqa nisbatan statik momentlari

Kesimning  $X$  va  $Y$  o'qlariga nisbatan statik momentlari (IV.1- shakl) quyidagiga teng:

$$S_x = \int_{(A)} y \cdot dA; \quad (IV.1)$$

$$S_y = \int_{(A)} x \cdot dA. \quad (IV.2)$$

Bunda tekis shakllarning og'irlik markazi koordinatalari quyidagilarga teng bo'ladi:

$$x_c = \frac{S_y}{A}; \quad (IV.3)$$

$$y_c = \frac{S_x}{A}. \quad (IV.4)$$

## 2. Tekis shakllarning inersiya momentlari

Ixtiyoriy tekis shaklning o'qli yoki ekvatorial inersiya momenti deb, miqdor jihatdan quyidagi integralga teng bo'lgan geometrik tavsifnomaga aytiladi:

$$a) X \text{ o'qiga nisbatan } J_x = \int_{(A)} y^2 dA; \quad (IV.5)$$

$$b) Y \text{ o'qiga nisbatan } J_y = \int_{(A)} x^2 dA. \quad (IV.6)$$

Tekis shaklning qutb inersiya momenti deb, quyidagi integral bilan aniqlanuvchi geometrik tavsifnomaga aytiladi:

$$J_p = \int_{(A)} \rho^2 dA; \quad (IV.7)$$

bunda,  $\rho$  – elementar,  $dA$  – yuzachadan qutb nuqtasi – 0 gacha bo'lgan masofa.

Tekis shakllarning o'qli (ekvatorial) va qutb inersiya momentlari faqat musbat kattaliklardir.

## 3. Tekis shakllarning markazdan qochirma inersiya momentlari

Tekis shaklning markazidan qochirma inersiya momenti deb quyidagi integralga teng bo'lgan geometrik tavsifnomaga aytiladi:

$$J_{xy} = \int_{(A)} xy dA. \quad (IV.8)$$

Bittasi yoki ikkalasi ham tekis shaklning simmetriya o'qlari hisoblanuvchi o'qlarga nisbatan markazdan qochirma inersiya momentlari nolga teng bo'ladi. Bundan tashqari,  $XY$  ko'paytma musbat yoki manfiy qiymatlarga ham ega bo'lishi mumkin.

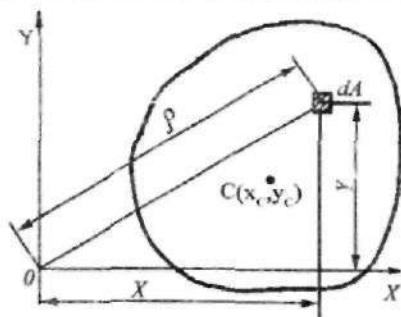
## 4. Tekis shakllarning qarshilik momentlari

Tekis shaklning o'qli qarshilik momenti deb biror o'qqa nisbatan olingan inersiya momentining shu o'qdan mazkur shaklda joylashgan eng uzoqdagi nuqtagacha bo'lgan masofaga nisbati bilan o'lchanadigan kattalikka aytiladi (IV.2- shakl):

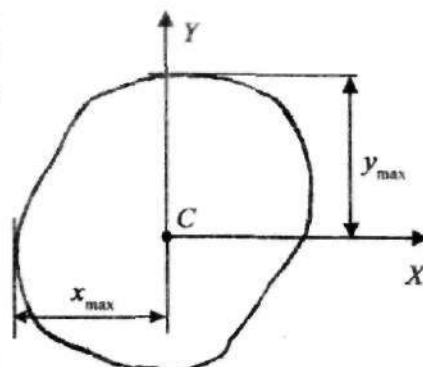
$$X \text{ o'qiga nisbatan } W_x = \frac{S_x}{y_{\max}};$$

$$Y \text{ o'qiga nisbatan } W_y = \frac{S_y}{x_{\max}}.$$

Tekis shaklning qutb qarshilik momenti deb qutb inersiya momentining qutb nuqtasidan mazkur shaklda



IV.1- shakl



IV.2- shakl

joylashgan eng uzoqdagi nuqttagacha bo'lgan masofaga nisbati bilan o'lchanadigan kattalikka aytiladi:

$$W_p = \frac{S_p}{\rho_{\max}}$$

### 5. Oddiy tekis shakllarning inersiya momentlarini hisoblash

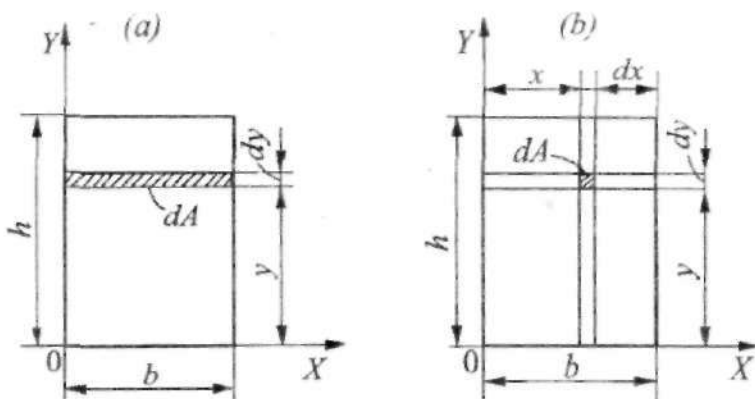
a) *to'g'ri to'rtburchak*. Asosi  $b$  va balandligi  $h$  bo'lgan to'g'ri to'rtburchakning asosidan o'tuvchi  $X$  o'qqa nisbatan inersiya momentini hisoblaymiz (IV.3- shakl). Buning uchun  $X$  o'qidan ixtiyoriy  $Y$  masofada yuzasi  $dA = b dy$  ga teng bo'lgan cheksiz yupqa qatlam ajratib olamiz. Inersiya momentining ta'rifiga asosan:

$$J_x = \int_{(A)} y^2 dA = \int_{(A)} y^2 b dy$$

Oxirgi ifodani integrallashda uning  $0$  dan  $h$  gacha o'zgarishini e'tiborga olamiz:

$$J_x = \int_0^h y b dy = \frac{bh^3}{3}$$

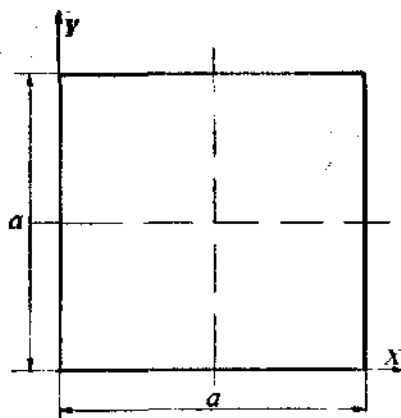
Xuddi shu tartibda vertikal  $Y$  o'qqa nisbatan inersiya momentini aniqlab, uning  $J_y = \frac{hb^3}{3}$  ekanligiga ishonch hosil qilish mumkin.



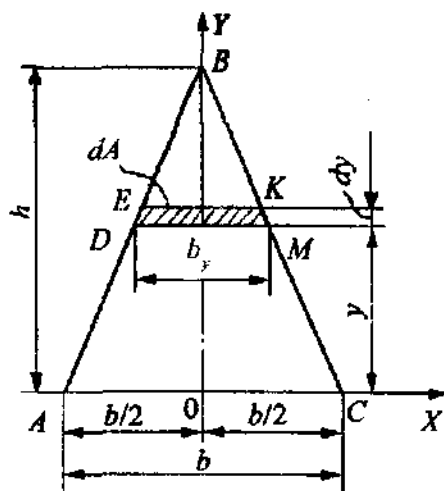
IV.3-shakl

b) *kvadrat*. (IV.5) va (IV.6) formulalarga asosan, tomonlari  $b = h = a$  bo'lgan kvadrat uchun o'qli inersiya momentlari quyidagicha bo'ladi (IV.4- shakl):

$$J_x = J_y = \frac{a^4}{3}$$



IV.4-shakl



IV.5-shakl

d) *uchburchak*. Asosi  $b$  va balandligi  $h$  ga teng bo'lgan ixtiyoriy uchburchakning asosidan o'tuvchi  $X$  o'qqa nisbatan inersiya momentini hisoblaymiz (IV.5- shakl). Uchburchakning asosidan ixtiyoriy  $y$  masofada qalinligi  $dy$  bo'lgan cheksiz yupqa  $DEKM$  trapetsiya ajratib olamiz. Agar trapetsiyaning yuzasini to'g'ri to'rtburchakning yuzasiga taxminan teng deb olsak, u holda,  $dA \approx b_y dy$  bo'ladi.

$ABC$  va  $DBM$  uchburchaklarning o'xshashligidan:

$$\frac{b_y}{b} = \frac{h-y}{h} \quad \text{yoki} \quad b_y = \frac{b}{h}(h-y)$$

munosabatni yozib olib, quyidagi formulani hosil qilamiz:

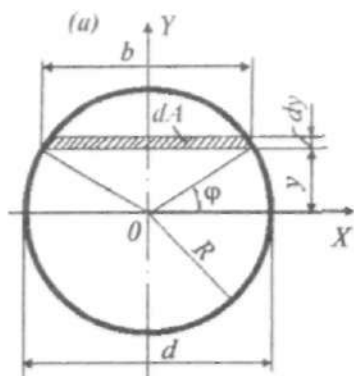
$$J_x = \int_{(A)} y^2 dA = \int_0^h y^2 \cdot \frac{b}{h}(h-y) dy = \frac{bh^3}{12}.$$

e) *doira*. Dastlab doiraning qutb inersiya momentini aniqlaymiz: buning uchun doira markazidan ixtiyoriy masofada yuzasi  $dA = 2\pi\rho d\rho$  bo'lgan cheksiz yupqa doira ajratib olamiz (IV.6- shakl).

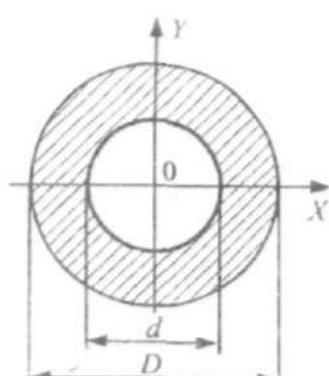
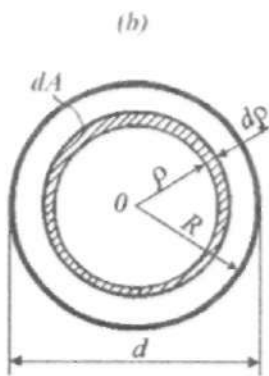
U holda,  $J_o = 2\pi \int_0^R \rho^3 d\rho = \frac{\pi R^4}{2} = \frac{\pi D^4}{32}$  bo'ladi.

(IV.7) formuladan foydalanib, doiraning ekvatorial inersiya momentlarini aniqlaymiz. Doira  $OX$  va  $OY$  o'qlarga nisbatan simmetrik shakl bo'lganligi uchun uning ekvatorial inersiya momentlari o'zaro teng bo'ladi:

$$J_x = J_y = 0,5J_o = \frac{\pi D^4}{64}.$$



IV.6- shakl



IV.7- shakl

f) *halqa*. IV.7- shaklda tasvirlangan halqa uchun inersiya momenti tashqi va ichki doiralarning qutb inersiya momentlari ayirmasiga teng bo'ladi:

$$J_p = \frac{\pi D^4}{32} - \frac{\pi d^4}{32} = \frac{\pi D^4}{32} (1 - c^4);$$

bu yerda,  $c = \frac{d}{D}$ .

Halqaning ekvatorial inersiya momentlari quyidagicha topiladi:

$$J_x = J_y = \frac{\pi D^4}{64} (1 - c^4).$$

g) *murakkab tekis shakllarning inersiya momentlari*. Murakkab tekis shakllarning inersiya momentlarini hisoblash aniq integralning quyidagi xossasiga asoslangan:

$$\int_{(A)} \int y^2 dA = \sum_{i=1}^n \left( \int_{A_i} y^2 dA = \int_{A_1} y^2 dA + \int_{A_2} y^2 dA + \dots + \int_{A_n} y^2 dA \right);$$

bundan,  $A = A_1 + A_2 + A_3 + \dots + A_n$ .

Bu integrallarning har biri tegishli qismning birorta  $x$  o'qiga nisbatan inersiya momentini ifodalaydi:

$$J_x = J_x^1 + J_x^2 + \dots + J_x^n.$$

Oxirgi ifoda murakkab tekis shaklning inersiya momenti uni tashkil etuvchi alohida qismlar inersiya momentlarining yig'indisiga teng, deyishga asos bo'ladi.

Bu qoida yordamida murakkab tekis shakllarning markazdan qochirma inersiya momentlarini ham aniqlash mumkin.

Murakkab ko'rinishdagi tekis shakllarning inersiya momentlarini osonroq aniqlash maqsadida uni, albatta, inersiya momentlari oldindan ma'lum bo'lgan bir necha oddiy: to'g'ri



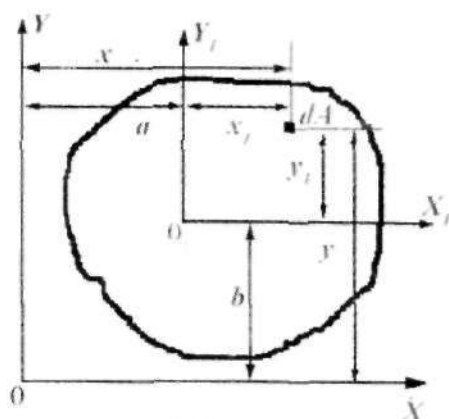
to'rtburchak, uchburchak, doira va shu kabi tekis shakllarga ajratish ma'qul.

h) o'qlarni parallel ko'chirganda inersiya momentlarining o'zgarishi. Tekis kesim yuzaning markaziy o'qlariga parallel bo'lgan ixtiyoriy o'qlarga nisbatan inersiya momentlari quyidagicha aniqlanadi (IV.8- shakl):

$$J_X = J_{X_c} + Fb^2; \quad (IV.9)$$

$$J_X = J_{X_1} + Fb^2; \quad J_Y = J_{Y_1} + Fa^2;$$

$$J_{XY} = J_{X_1Y_1} + Fab.$$



IV.8- shakl

Bu yerda,  $X_1$  va  $Y_1$  – markaziy o'qlar.

## 7. O'qlar burilganda inersiya momentlarining o'zgarishi

$$J_{X_1} = J_X \cos^2 \alpha + J_Y \sin^2 \alpha - J_{XY} \sin 2\alpha;$$

$$J_{Y_1} = J_X \sin^2 \alpha + J_Y \cos^2 \alpha + J_{XY} \sin 2\alpha;$$

$$J_{X_1Y_1} = \frac{1}{2} (J_X - J_Y) \cdot \sin 2\alpha + J_{XY} \cos 2\alpha.$$

Quyidagi formuladan bosh inersiya o'qlarining vaziyati aniqlanadi:

$$\operatorname{tg} 2\alpha_0 = \frac{-2J_{XY}}{J_X - J_Y}.$$

Bosh inersiya momentlari quyidagicha topiladi:

$$J_{\max}^{\min} = 0.5 \left[ (J_X + J_Y) \pm \sqrt{(J_X - J_Y)^2 + 4J_{XY}^2} \right]$$

### E'tibor bering!

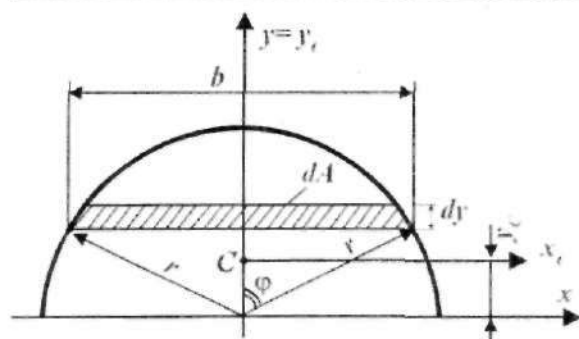
- Agarda kesim ikkita shakldan iborat bo'lsa, uning og'irlik markazi shu shakllar og'irlik markazini birlashtiruvchi to'g'ri chiziq ustida yotadi.
- Koordinata o'qlaridan biri simmetriya o'qi bo'lsa, unda  $Y$  va unga perpendikular yo'nalgan o'q bosh o'qlar bo'ladi.  $J_{XY}$  esa nolga teng bo'ladi.

1- ilovada eng ko'p uchraydigan kesim yuzalarining geometrik tavsifnomalari berilgan.

## 40- masala

IV.9- shaklda tasvirlangan yarim doira uchun quyidagilarni aniqlash talab etiladi:

- a) og'irlik markazi koordinatalari;
- b) bosh markaziy inersiya o'qlarining holati;



IV.9- shakl

d) bosh markaziy inersiya momentlarining qiymati:

$$W_x = \frac{S_x}{y_{\max}}$$

**Yechish:**

a) Berilgan tekis shakl vertikal o'qqa nisbatan simmetrik joylashganligi uchun, uning og'irlik markazi shu o'q ustida yotishi tabiiy. Shuning uchun og'irlik markazi koordinatasi hisoblangan  $y_c$  masofani aniqlash kifoya.

Shtrixlangan qatlamning yuzachasi  $dA \approx b \cdot dy = 2r \sin \varphi \cdot dy$  chizmadan  $y = r \cdot \cos \varphi$  ga teng. Yangi o'zgaruvchini kiritamiz:  $dy = -r \sin \varphi \cdot d\varphi$ .

U holda, kesimning  $x$  o'qiga nisbatan statik momenti quyidagiga teng bo'ladi:

$$\begin{aligned} S_x = \int_{(A)} y dA &= \int_{y=0}^{y=r} y \cdot 2r \cdot \sin \varphi \cdot dy = \int_{\varphi=\pi/2}^{\varphi=0} r \cdot \cos \varphi \cdot 2r \cdot \sin \varphi (-r \cdot \sin \varphi) d\varphi = \\ &= -2r^3 \int_{\varphi=\pi/2}^{\varphi=0} \sin^2 \varphi \cdot \cos \varphi d\varphi = \frac{2}{3} r^3. \end{aligned}$$

b) Demak,  $y_c = \frac{S_x}{A} = \frac{4r}{3\pi}$ .

Markaziy bosh inersiya o'qlaridan biri  $y_c$  simmetriya o'qi, ikkinchisi esa unga tik joylashgan  $x_c$  gorizontal o'qidir. Boshqacha qilib aytganda, tekis shakl bitta simmetriya o'qiga ega bo'lganligi uchun  $J_{x_c y_c} = 0$  bo'ladi; bundan chiqdi,  $\text{tg } \alpha_0 = 0$  yoki  $\alpha_0 = 0$ .

d) (IV.3) formulaga binoan:

$$J_x = J_{y_c} = 0,5 \frac{\pi d^4}{64} = \frac{\pi r^4}{8} \approx 0,393 \cdot r^4;$$

u holda,  $J_{x_c} = J_x - y_c^2 \cdot A = \frac{\pi r^4}{8} - \left(\frac{4r}{3\pi}\right)^2 \cdot \frac{1}{2} \pi r^2 \approx 0,111 r^4.$

Buni quyidagicha ifodalash ma'qul: tekis shaklning og'irlik markazidan o'tuvchi  $x_c$  va  $y_c$  o'qlar bosh markaziy inersiya o'qlari bo'la oladi, chunki tekis shakl bitta simmetriya o'qiga ega bo'lganligi uchun  $J_{x_c y_c} = 0$ ; bundan chiqdi,  $\text{tg } \alpha_0 = 0$  yoki  $\alpha_0 = 0$ .

#### 41- masala

IV.10- shaklda tasvirlangan kesim yuzaning  $X, Y$  o'qlariga nisbatan o'qli va markazdan qochma inersiya momentlari topilsin.

**Yechish:**

Chizmadan  $dA \approx b \cdot dy = \sqrt{r^2 - y^2} dy$  ekanligi ma'lum.

Yangi o'zgaruvchi kiritamiz:

$$y = r \cdot \sin \varphi; \quad dy = r \cdot \cos \varphi \, d\varphi.$$

Integral chegarasini 0 dan  $\pi/2$  gacha olib, quyidagilarni hisoblaymiz:

$$J_x = \int_{(A)} y^2 dA \quad \text{yoki}$$

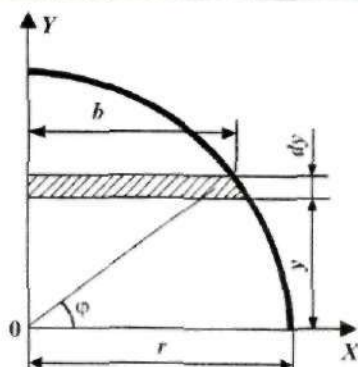
$$J_x = \int_0^{\pi/2} r^2 \sin^2 \varphi \sqrt{r^2 - r^2 \sin^2 \varphi} \cdot r \cos \varphi \, d\varphi = \frac{\pi \cdot r^4}{16}.$$

Xuddi shunga o'xshash:  $J_y = \frac{\pi \cdot r^4}{16}.$

Shtrixlangan qatlam uchun  $dJ_{xy}$  ni topishda quyidagi formuladan foydalanamiz:

$$dJ_{xy} = \frac{b}{2} \cdot y dA = \frac{r^4}{2} \cdot \cos^3 \varphi \cdot \sin \varphi \, d\varphi.$$

Bundan,  $J_{xy} = \frac{r^4}{2} \cdot \int_0^{\pi/2} \cos^3 \varphi \cdot \sin \varphi \, d\varphi = \frac{r^4}{8} = \frac{d^4}{128}.$



IV.10- shakl

**42- masala**

To'g'ri burchakli uchburchakning katetlariga parallel bo'lgan markaziy o'qlarga nisbatan markazdan qochma inersiya momenti topilsin (IV.11- shakl).

**Yechish:**

Berilgan tekis shakl uchun quyidagilar ma'lum:

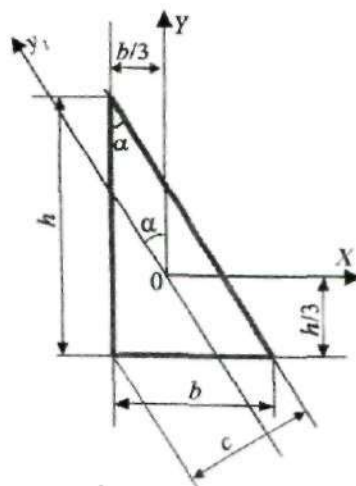
$$J_x = \frac{bh^3}{36}; \quad J_y = \frac{hb^3}{36}; \quad J_{y_1} = \frac{lc^3}{36};$$

bu yerda,  $c = \frac{bh}{l}$ , chunki  $A = \frac{bh}{2} = \frac{cl}{2}$ ;

u holda,  $J_{y_1} = J_y \cos^2 \alpha + J_x \sin^2 \alpha + J_{xy} \cos 2\alpha$ ;

bu yerda,  $\cos \alpha = \frac{b}{l}$ ;  $\sin \alpha = \frac{h}{l}$ .

Tegishli ixchamlashtirishdan so'ng  $J_{xy} = -\frac{b^2 h^2}{72}$  ekanligi kelib chiqadi.



IV.11- shakl

## 43- masala

IV.12- shaklda tasvirlangan 90x90x9 mm li teng yoqli burchaklik (GOST 8509-72) ning markaziy o'qlarga nisbatan markazdan qochma inersiya momentlari hisoblansin. Sortament jadvalidan quyidagi ma'lumotlar olingan:  $J_{\max} = J_{X_0} = 186 \text{ sm}^4$ ,  $J_{\min} = J_{Y_0} = 48,6 \text{ sm}^4$ .

## Yechish:

Quyidagi formula yordamida burchaklikning  $X_1$  va  $Y_1$  o'qlariga nisbatan markazdan qochma inersiya momentlarini aniqlaymiz:

$$J_{X_1 Y_1} = \frac{1}{2} (J_{X_0} - J_{Y_0}) \sin 2\alpha_0 + J_{X_0 Y_0} \cos 2\alpha_0.$$

$X_0$  shaklning simmetriya o'qi hamda  $X_0$  va  $Y_0$  lar markaziy bosh o'qlar bo'lganligi uchun  $J_{X_0 Y_0} = 0$  ga teng.  $X_0 = 45^\circ$ , chunki markazdan qochma inersiya momenti aniqlanishi kerak bo'lgan  $X$  va  $Y$  o'qlar markaziy bosh o'qlarga nisbatan soat strelkasi harakati bo'yicha burilgan.

$$\text{Shunday qilib, } J_{X_1 Y_1} = \frac{186 - 48,6}{2} \cdot (-1) = -68,7 \text{ sm}^4.$$

## 44- masala

To'g'ri burchakli to'rtburchak (20 x 2,75 sm) va burchaklikdan № 12,5/8 (125 x 8012) iborat kesim berilgan (IV.13- shakl). Kesimning bosh inersiya momenti ( $J_y$ ;  $J_x$ ) va bosh o'qlarning yo'nalishi aniqlansin.

## Yechish:

Sortament jadvalidan burchaklikning geometrik xarakteristikalarini aniqlaymiz:

$$A_2 = 23,36 \text{ sm}^2; X_0 = 2 \text{ sm}; Y_0 = 4,22 \text{ sm};$$

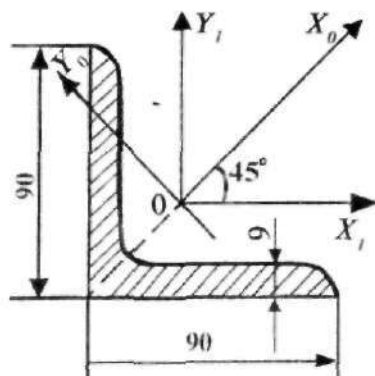
$$I_{X_2} = 364,79 \text{ sm}^4; I_{Y_2} = 116,84 \text{ sm}^4;$$

$$I_{X_2 Y_2} = 118 \text{ sm}^4.$$

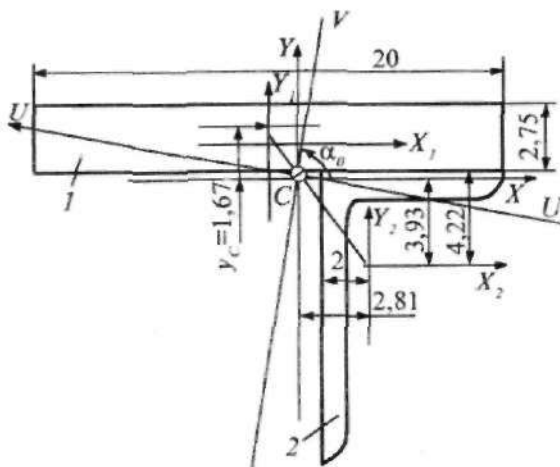
$X_1$  va  $Y_1$  o'qlarga nisbatan butun kesimning og'irlik markazini aniqlaymiz:

$$X_c = \frac{\sum A_i \cdot x_i}{\sum A_i} = \frac{A_1 \cdot x_1 + A_2 \cdot x_2}{A_1 + A_2};$$

$$Y_c = \frac{\sum A_i \cdot Y_i}{\sum A_i} = \frac{A_1 \cdot Y_1 + A_2 \cdot Y_2}{A_1 + A_2}.$$



IV.12- shakl



IV.13- shakl

Bu formulalarda  $X_1$  va  $Y_1$  lar nolga teng, chunki  $X_1$  va  $Y_1$  o'qlar to'g'ri burchakli to'rt-burchakning og'irlik markazidan o'tadi. Unda:

$$x_c = \frac{23,36 \cdot \left(\frac{20}{2} - 8 + 2\right)}{78,36} = 1,19 \text{ sm}; \quad y_c = \frac{-23,36 \cdot \left(\frac{275}{2} + 4,22\right)}{78,36} = -1,67 \text{ sm}.$$

Topilgan qiymatlarni shaklga qo'yib butun kesim uchun og'irlik markazni  $C$  nuqta orqali ifodalaymiz.  $C$  nuqtadan  $X$  va  $Y$  koordinata o'qlarini o'tkazamiz va ularga nisbatan inersiya momentlarini aniqlaymiz:

$$I_x = \frac{20 \cdot (2,75)^3}{12} + 1,67^2 \cdot 55 + 364,79 + 3,93^2 \cdot 23,36 = 913 \text{ sm}^4;$$

$$I_y = \frac{2,75 \cdot 20^3}{12} + 1,19^2 \cdot 55 + 116,84 + 2,81^2 \cdot 23,36 = 2213 \text{ sm}^4;$$

$$I_{xy} = 0 + (-1,19) \cdot 1,67 \cdot 55 + 118 + 2,81 \cdot (-3,93) \cdot 23,36 = -249 \text{ sm}^4.$$

Bosh inersiya momentlarini aniqlaymiz:

$$I_{u/v} = \frac{I_x + I_y}{2} \pm \sqrt{\left(\frac{I_x - I_y}{2}\right)^2 + I_{xy}^2} = \frac{913 + 2213}{2} \pm \sqrt{\left(\frac{913 - 2213}{2}\right)^2 + (-249)^2} = 1563 \pm 696 \text{ sm}^4.$$

Bu yerdan,  $I_u = 2259 \text{ sm}^4$ ;  $I_v = 867 \text{ sm}^4$ .

Bosh o'qlarning yo'nalishini quyidagi formula yordamida aniqlaymiz:

$$\operatorname{tg} \alpha_0 = -\frac{I_{xy}}{I_v - I_y} = -\frac{(-249)}{2259 - 2213} = 5,41;$$

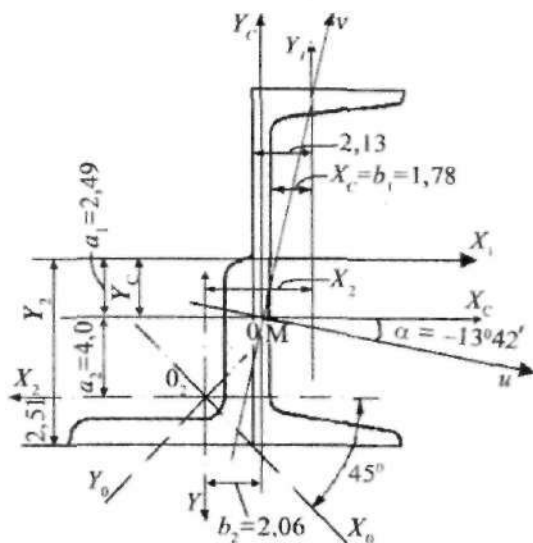
$$\alpha_0 = 79,5^\circ.$$

$\alpha_0$  burchak  $X$  o'qining musbat yo'nalishidan boshlab hisoblanadi.  $\alpha_0 > 0$  bo'lganda, burchak shaklda soat strelkasi harakatiga teskari yo'nalishda,  $\alpha_0 < 0$  bo'lganda esa, soat strelkasi harakati yo'nalishi bo'yicha olinadi.

#### 45- masala

IV.14- shaklda ko'rsatilgan 18a nomerli shveller hamda  $90 \times 90 \times 8$  o'lchamli teng yonli burchaklikdan iborat kesim uchun quyidagilar topsin:

1) og'irlik markazi;



IV.14- shakl

- 2) og'irlik markazidan o'tuvchi ixtiyoriy o'qlar sistemasi ( $X_c$ ,  $Y_c$ ) ga nisbatan inersiya momentlari va markazdan qochirma inersiya momenti;  
 3) markaziy bosh inersiya o'qlarining yo'nalishi;  
 4) bosh inersiya momentlari.

### Yechish:

GOST 8240-56 dan shvellerga tegishli, GOST 8509-57 dan teng yonli burchaklikka tegishli qiymatlarni ko'chirib yozamiz:

18a nomerli shveller o'lchamlari

$$h_1 = 180 \text{ mm}$$

$$b_1 = 74 \text{ mm}$$

$$d_1 = 5,1 \text{ mm}$$

$$A_1 = 22,2 \text{ sm}^2$$

$$J_{x_1} = 1190 \text{ sm}^4$$

$$J_{y_1} = 132 \text{ sm}^4$$

$$z_0 = 2,13 \text{ sm}$$

90x90x8 o'lchamli burchaklik

$$b_2 = 74 \text{ mm}$$

$$d_2 = 8 \text{ mm}$$

$$A_2 = 13,9 \text{ sm}^2$$

$$J_{x_2} = J_{y_2} = 106 \text{ sm}^4$$

$$J_{x_0} = J_{y_{\max}} = 168 \text{ sm}^4$$

$$J_{y_0} = J_{y_{\min}} = 43,8 \text{ sm}^4$$

$$z_0 = 2,51 \text{ sm}$$

1. Yordamchi o'qlarga nisbatan (yordamchi o'qlar sifatida shvellerning  $X_1$  va  $Y_1$  o'qlari tanlangan) murakkab shaklning og'irlik markazini topamiz:

$$Y_c = \frac{\sum S x_i}{\sum A} = \frac{A_1 \cdot Y_1 + A_2 \cdot Y_2}{A_1 + A_2} = \frac{0 + 13,9 \cdot [-(9 - 2,51)]}{22,2 + 14} = -2,49 \text{ sm};$$

$$X_c = \frac{\sum S y_i}{\sum A} = \frac{A_1 \cdot X_1 + A_2 \cdot X_2}{A_1 + A_2} = \frac{0 + 13,9 \cdot [-(2,13 + 2,51)]}{22,2 + 14} = -1,78 \text{ sm}.$$

Qabul qilingan masshtabda  $X_c$  va  $Y_c$  larni IV.14- shaklga qo'yib chiqamiz va murakkab shaklning og'irlik markazi 0 ni topamiz. U  $O_1$  va  $O_2$  nuqtalarini birlashtiruvchi to'g'ri chiziq ustida yotadi.

2. Topilgan markaziy o'qlarga nisbatan murakkab shaklning inersiya momentlari hamda markazdan qochirma inersiya momentini formulaga ko'ra hisoblaymiz:

$$J_{x_c} = J_{x_1} + A_1 \cdot a_1^2 + J_{x_2} + A_2 \cdot a_2^2 = 1190 + 22,2 \cdot 2,49^2 + 106 + 13,9 \cdot 4^2 = 1656,5 \text{ sm}^4;$$

$$J_{y_c} = J_{y_1} + A_1 \cdot b_1^2 + J_{y_2} + A_2 \cdot b_2^2 = 132 + 22,2 \cdot 1,78^2 + 106 + 13,9 \cdot 2,86^2 = 422,3 \text{ sm}^4.$$

Ko'p hollarda teng yonli burchaklikning markazdan qochirma inersiya momentini topishda xatolikka yo'l qo'yiladi. Murakkab shaklning  $X_c$ ,  $Y_c$  o'qlariga nisbatan markazdan qochirma inersiya momenti  $J_{x_c, y_c}$  ni topish uchun, avvalo, burchaklikning  $X_c$  va  $Y_c$  ga parallel bo'lgan markaziy o'qlari  $X_2$ ,  $Y_2$  ga nisbatan markazdan qochirma inersiya momentini topish zarur.

Burchakning  $X_2, Y_2$  o'qlarga nisbatan markazdan qochirma inersiya momenti quyidagicha topiladi:

$$J_{X_2Y_2} = \frac{J_{X_0} - J_{Y_0}}{2} \sin 2\alpha + J_{X_0Y_0} \cos 2\alpha.$$

$X_0, Y_0$  burchaklikning bosh inersiya o'qlari bo'lganidan,  $X_0, Y_0$  o'qlari bilan  $X_2, Y_2$  o'qlari orasidagi burchak  $\alpha = 45^\circ$ .

$$J_{X_2Y_2} = \frac{168 - 43,6}{2} \sin(2 \cdot 45^\circ) = 62,2 \text{ sm}^4.$$

$$J_{X_cY_c} = J_{X_lY_l} + A_1 \cdot a_1 \cdot b_1 + J_{X_2Y_2} + A_2 \cdot a_2 \cdot b_2 =$$

$$= 0 + 22,2 \cdot (+1,78) \cdot (+2,49) + 62,2 + 13,9 \cdot (-2,86) \cdot (-4) = 319,7 \text{ sm}^4.$$

Murakkab shakl bosh inersiya o'qlarining markaziy o'qlarga nisbatan og'ish burchagi  $\alpha$  ni quyidagicha topamiz:

$$\operatorname{tg} 2\alpha = -\frac{2J_{X_lY_l}}{J_{X_l} - J_{Y_l}} = -\frac{2 \cdot 319,7}{1656,5 - 422,3} = -0,518; 2\alpha = -27^\circ 24', \alpha = -13^\circ 42'.$$

Bosh inersiya momentlarini topamiz:

$$J_u = J_{X_c} \cos^2 \alpha + J_{Y_c} \sin^2 \alpha - J_{X_cY_c} \sin 2\alpha =$$

$$= 1656,5 \cdot (\cos(-13^\circ 42'))^2 + 422,3 \cdot (\sin(-13^\circ 42'))^2 - 319,7 \cdot \sin(-27^\circ 24') = 1735,7 \text{ sm}^4;$$

$$J_v = J_{X_c} \sin^2 \alpha + J_{Y_c} \cos^2 \alpha - J_{X_cY_c} \sin 2\alpha =$$

$$= 1656,5 \cdot (\sin(-13^\circ 42'))^2 + 422,3 \cdot (\cos(-13^\circ 42'))^2 - 319,7 \cdot \sin(-27^\circ 24') = 345,7 \text{ sm}^4.$$

### Tekshirish:

$$J_{X_c} + J_{Y_c} = 1656,5 + 422,3 = 2078,8 \text{ sm}^4; \quad J_u + J_v = 1735,7 + 345,7 = 2081,4 \text{ sm}^4.$$

Farqi  $(J_u + J_v) - (J_{X_c} + J_{Y_c}) = 2,6 \text{ sm}$ . Chiqqan xato ruxsat etiladigan chegarada.

$$J_{uv} = \frac{J_{X_c} - J_{Y_c}}{2} \sin 2\alpha + J_{X_cY_c} \cos 2\alpha =$$

$$= \frac{1656,5 - 422,3}{2} (-0,4602) + 319,7 \cdot 0,8879 = -284 + 284 = 0.$$

Bosh inersiya momentlarini quyidagi formuladan hisoblasa ham bo'ladi:

$$J_{\frac{u}{v}} = J_{\frac{\max}{\min}} = \frac{J_{X_c} + J_{Y_c}}{2} \pm \frac{1}{2} \sqrt{(J_{X_c} - J_{Y_c})^2 + 4J_{X_cY_c}^2} =$$

$$= \frac{1656,5 + 422,3}{2} \pm \frac{1}{2} \sqrt{(1656,5 - 422,3)^2 + 4 \cdot 319,7^2} = 1039,4 \pm 695.$$

$$J_u = J_{\max} = 1734,4 \text{ sm}^4; J_v = J_{\min} = 344,4 \text{ sm}^4; J_u + J_v = 2078,8 \text{ sm}^4.$$

Bu yerda ( $J_{x_c} + J_{y_c}$ ) bilan ( $J_u + J_v$ ) o'rtasida xatolik yo'q.

#### 4.3- §. Tekis shakllarning geometrik tavsifnomalari bo'yicha topshiriqlar

##### 6- topshiriq

To'g'ri to'rtburchak va prokat profilardan tashkil topgan kesimning (simmetrik) quyidagi qiymatlari aniqlansin:

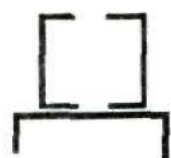
- 1) kesimning og'irlik markazi aniqlansin;
- 2) bosh markaziy inersiya momentlari aniqlansin;
- 3) kesim masshtabda chizilib, kerakli o'qlar va o'lchamlar ko'rsatilsin.

Hisoblash uchun qiymatlar IV.1- jadvalda, kesimlar IV.15- shaklda keltirilgan.

IV.1- jadval

| №  | O'lchamlar |     |                                |                                 | Nomer                    |                         |
|----|------------|-----|--------------------------------|---------------------------------|--------------------------|-------------------------|
|    | List, sm   |     | Burchaklik, mm                 |                                 | Qo'shtavr<br>(GOST - 72) | Shveller<br>(GOST - 72) |
|    | h          | b   | Teng yonli<br>(GOST 8509 - 72) | Teng yonsiz (GOST<br>8510 - 72) |                          |                         |
| 1  | 16         | 1.8 | 80x80x8                        | -                               | 18a                      | 22                      |
| 2  | 16         | 2.2 | 80x80x7                        | -                               | 18                       | 20a                     |
| 3  | 16         | 1.4 | 80x80x6                        | -                               | 16                       | 22                      |
| 4  | 18         | 2.0 | -                              | 100x63x6                        | 20                       | 22a                     |
| 5  | 18         | 2.4 | -                              | 110x70x7                        | 18a                      | 22                      |
| 6  | 18         | 1.6 | -                              | 90x56x6                         | 18                       | 22a                     |
| 7  | 20         | 2.2 | 110x70x7                       | -                               | 20a                      | 24                      |
| 8  | 20         | 2.4 | -                              | 110x70x7                        | 18a                      | 22                      |
| 9  | 20         | 1.8 | 100x100x8                      | -                               | 18a                      | 20                      |
| 10 | 22         | 2.4 |                                | 125x80x12                       | 22                       | 24a                     |





1



2



3



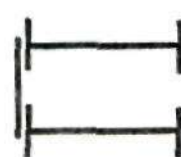
4



5



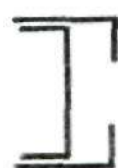
6



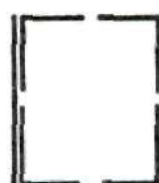
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14



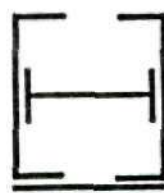
15



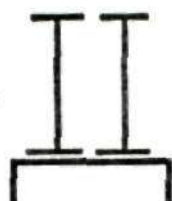
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17



18



19



20

## 7- topshiriq

To'g'ri to'rtburchak va prokat profilardan tashkil topgan kesimning (nosimmetrik) quyidagi qiymatlari aniqlansin:

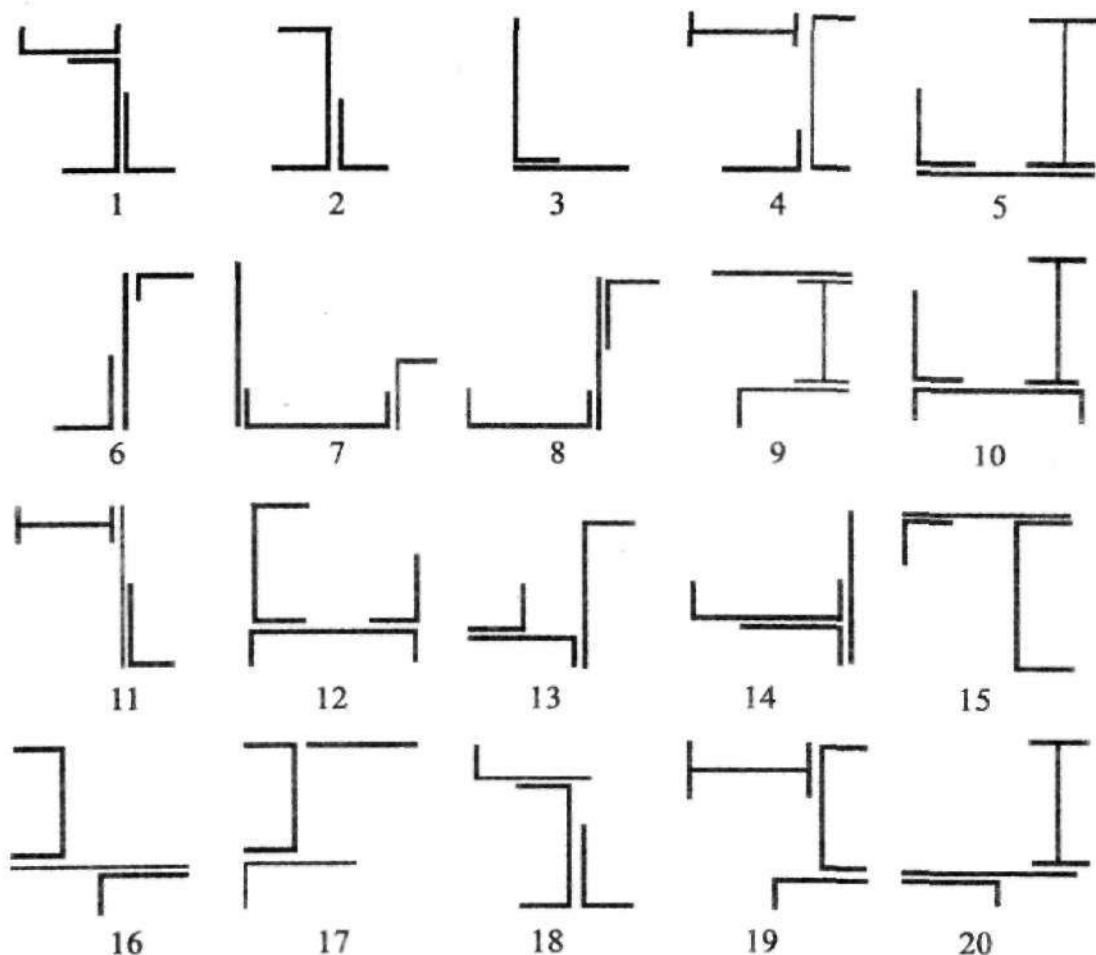
1) kesimning og'irlik markazi;  
2) markaziy o'qlarga nisbatan kesimning inersiya hamda markazdan qochirma inersiya momentlari;

3) bosh markaziy inersiya o'qlarining yo'nalishi;

4) bosh markaziy inersiya momentlarining qiymatlari;

5) kesim masshtabda chizilib, kerakli o'qlar va o'lchamlar ko'rsatilsin.

Hisoblash uchun qiymatlar IV.1- jadvalda, kesimlar IV.16- shaklda keltirilgan.



IV.16- shakl

## V BOB

## BURALISH

## 5.1- §. Asosiy mulohazalar

- Agarda kuchlanish holatidagi brusning ko'ndalang kesimlarida ichki kuchlardan faqat burovchi moment mavjud bo'lib, qolganlari nolga teng bo'lsa, u holda buralish deformatsiyasi sodir bo'ladi.
- Buralishga qarshilik ko'rsatuvchi doiraviy kesimli brusga val deyiladi. Valning og'irlik markazidan ixtiyoriy  $\rho$  masofada yotuvchi nuqtalarida hosil bo'ladigan urinma kuchlanish quyidagiga teng bo'ladi:

$$\tau_{\rho} = \frac{T_{\epsilon}}{J_{\rho}} \cdot \rho; \quad (V.1)$$

bu yerda,  $T_{\epsilon}$  – burovchi moment;  $J_{\rho}$  – polyar inersiya momenti.

- Eng katta urinma kuchlanish val ko'ndalang kesimining eng chekka nuqtalarida paydo bo'ladi:

$$\tau_{\max} = \frac{T_{\epsilon}}{W_{\rho}}; \quad (V.2)$$

bu yerda,  $W_{\rho}$  – polyar qarshilik momenti.

- Buralish burchagi quyidagi Guk qonuni bo'yicha aniqlanadi:

$$\varphi = \frac{T_{\epsilon} \cdot l}{G \cdot J_{\rho}}; \quad (V.3)$$

bu yerda,  $l$  – val uzunligi;  $G \cdot J_{\rho}$  – valning buralishdagi bikrligi;  $\varphi$  – radianda o'lchanadi.

- Nisbiy buralish burchagi quyidagiga teng:

$$\theta = \frac{\varphi}{l} = \frac{T_{\epsilon}}{G \cdot J_{\rho}}. \quad (V.4)$$

- Valni loyihalashdagi hisoblar ikki xil shart bo'yicha amalga oshiriladi:  
– mustahkamlik sharti bo'yicha:

$$\tau_{\max} = \frac{T_{\epsilon}^{\max}}{W_{\rho}} \leq \tau_{\text{adm}}; \quad (V.5)$$

– bikrlilik sharti bo'yicha

$$\theta_{\max} = \frac{T_e^{\max}}{G \cdot J_{\rho}} \leq \theta_{\text{adm}}^0. \quad (\text{V.6})$$

## 5.2- §. Buralishga doir masalalar

### 46- masala

Diametri  $d = 10 \cdot 10^{-2} \text{ m}$  ( $d = 10 \text{ sm} = 100 \text{ mm}$ ) bo'lgan yaxlit val  $n = 90$  aylanish/minut tezlik bilan aylanmoqda. Agar valning  $l = 2,5 \text{ m}$  uzunligi  $\varphi = 1,8^\circ$  ga burilsa, u qancha kilovatt quvvat uzatishi mumkin? Eng katta urinma kuchlanishning qiymati ham aniqlansin.

Valning materiali uchun  $G = 8 \cdot 10^4 \text{ MPa}$ .

### Yechish:

Ma'lumki, burovchi moment, quvvat va buralish burchaklari o'zaro quyidagi formulalar bilan bog'langan:

$$T_e = 9549 \frac{P_{\text{kvt}}}{n}; \quad \varphi^0 = \frac{180^\circ}{\pi} \cdot \frac{T_e l}{G J_{\rho}}.$$

Bularni solishtirib,  $9549 \frac{P_{\text{kvt}}}{n} = \frac{G J_{\rho}}{e} \cdot \frac{180^\circ}{\pi} \cdot \varphi^0$  ifodani hosil qilamiz.

Bundan quvvatni aniqlaymiz:  $P_{\text{kvt}} = \frac{G J_{\rho} n \pi \varphi^0}{9549 l \cdot 180^\circ}$  yoki

$$P_{\text{kvt}} = \frac{G \pi d^4 n}{32 \cdot 9549 l} \cdot \frac{\pi \varphi^0}{180^\circ} = \frac{8 \cdot 10^4 \cdot 10^6 (3,14)^2 (10 \cdot 10^{-2})^4 \cdot 90 \cdot 1,8}{32 \cdot 9549 \cdot 2,5 \cdot 180} = 92,23 \text{ kVt}.$$

Eng katta urinma kuchlanish kesimning tashqi chetida hosil bo'ladi:

$$\tau_{\max} = \frac{T_e}{W_s} = \frac{16 T_e}{\pi d^3} = \frac{16 \cdot 9549 \cdot 92,93}{3,14 (10 \cdot 10^{-2})^3 \cdot 90} = 50,24 \cdot 10^6 \frac{\text{N}}{\text{m}^2} = 50,24 \text{ MPa}.$$

### 47- masala

Kater motorining kuragini harakatga keltiruvchi yaxlit val dvigateldan 100 ot kuchiga teng quvvat olib, 180 aylanish/minut tezlik bilan aylanadi. Shu valning diametrini hisoblang.

Valning materiali uchun quyidagilar ma'lum:  $\tau_{\text{adm}} = 46 \text{ MPa}$ ,  $\theta_{\text{adm}}^0 = 0,25 \text{ grad/m}$ ,  $G = 8 \cdot 10^4 \text{ MPa}$ .

**Yechish:**

Dastlab, valga qo'yilgan burovchi momentni aniqlaymiz:

$$T_e = 7028,8 \frac{P_{0k}}{n} = 7028,8 \frac{100}{180} = 3904,89 \text{ N} \cdot \text{m}.$$

Valning diametrini aniqlash uchun uni mustahkamlik va bikrlikka tekshirib ko'rish lozim. (V.5) formuladan foydalanib, valning mustahkamlik shartini qanoatlantiruvchi zaruriy diametrini hisoblaymiz:

$$d_r = 1,72 \cdot \sqrt[3]{\frac{T_e}{\tau_{adm}}} = 1,72 \cdot \sqrt[3]{\frac{3904,89}{46 \cdot 10^6}} = 1,72 \cdot 4,395 \cdot 10^{-2} = 7,56 \cdot 10^{-2} \text{ m}.$$

Bikrlilik shartini qanoatlantiruvchi zaruriy diametrni aniqlaymiz:

$$d_\theta = 4,92 \cdot \sqrt[4]{\frac{T_e}{G \theta_{adm}^0}} = 4,92 \cdot \sqrt[4]{\frac{3904,89}{8 \cdot 10^4 \cdot 10^6 \cdot 0,25}} = 4,92 \cdot 2,102 \cdot 10^{-2} = 10,34 \cdot 10^{-2} \text{ m}.$$

Hisoblash natijasida hosil qilingan diametrlarning qiymatlarini yaxlitlaymiz:  $d_r = 76 \text{ mm}$ ;  $d_\theta = 104 \text{ mm}$ . Shunday qilib, valning diametri uchun uning katta qiymatini  $d_0 = 104 \text{ mm}$  deb qabul qilamiz.

**48- masala**

Uzunliklari o'zaro teng va bir xil materialdan yasalgan ikkita val bir xil mustahkamlikka ega. Ulardan biri yaxlit bo'lib, diametri  $d$  ga, ikkinchisining ichi g'ovak bo'lib, ichki va tashqi diametrlarining nisbati  $\alpha = d_2 : d_1 = 0,8$  ga teng. Ikkinchi val birinchisiga qaraganda qanchaga yengil?

**Yechish:**

Masalaning shartiga ko'ra, ikkala valning kesimida paydo bo'luvchi eng katta urinma kuchlanishlar bir xil qiymatga ega:

$$\tau_{max} = \frac{16 \cdot T_e^{max}}{\pi d^3} = \frac{16 \cdot T_e^{max}}{\pi d_1^3 (1 - \alpha^4)};$$

$$d_1 = \frac{1}{\sqrt[3]{1 - \alpha^4}} \cdot d = 1,19d; \quad d_2 = \frac{\alpha}{\sqrt[3]{1 - \alpha^4}} \cdot d = 0,954d.$$

Yaxlit val og'irligining ichi g'ovak val og'irligiga nisbatini aniqlaymiz:

$$\frac{\gamma l A_v}{\gamma l A_k} = \frac{\gamma l \frac{\pi d^2}{4}}{\gamma l \frac{\pi}{4} (d_1^2 - d_2^2)} = 1,98.$$

Shunday qilib, ichi g'ovak val yaxlit valdan taxminan 2 marta yengil ekan.

## 49- masala

Agar ichki va tashqi diametrlarining nisbati  $\alpha = d_2 : d_1 = 0,7$  bo'lgan g'ovak val bilan diametri  $d$  ga teng yaxlit vallarning ko'ndalang kesim yuzalari bir xil bo'lsa, qaysi val chidamli bo'ladi? Ikkala valning bikrligi solishtirilsin.

## Yechish:

Masalaning shartidan  $A = \frac{\pi d^2}{4} = \frac{\pi d_1^2}{4} (1 - \alpha^2)$  munosabatni yozib olamiz.

Bundan,  $d = \sqrt{1 - \alpha^2} d_1 = 0,714 d_1$  kelib chiqadi.

Ikkala valda ham eng katta urinma kuchlanish kesimdagi eng chekka nuqtalarda paydo bo'ladi:

$$\tau_{ya}^{\max} = \frac{16 T_c^{\max}}{\pi d^3};$$

$$\tau_g^{\max} = \frac{16 T_c^{\max}}{\pi d_1^3 (1 - \alpha^4)}.$$

Bundan chiqdi, g'ovak val yaxlit valga qaraganda

$$\frac{d_1^3 (1 - \alpha^4)}{d^3} = 2,088$$

marta mustahkamroq bo'lar ekan.

Vallarning bikrliklari quyidagi nisbatda bo'ladi:

$$\frac{d_1^4 (1 - \alpha^4)}{d^4} = 2,92.$$

Demak, yaxlit valning bikrligi g'ovak valning bikrligidan taxminan 3 marta katta ekan.

## 50- masala

Uzunligi  $l = 1,5$  m bo'lgan yaxlit valga dvigateldan quvvat oladigan bitta yetakchi va stanolarga aylanma harakat beradigan uchta yetaklanuvchi shkivlar o'rnatilgan (V.1- shakl, a). Yetaklanuvchi shkivlarning quvvati mos ravishda 25, 15 va 12 ot kuchiga teng. Val po'latdan yasalgan bo'lib, minutiga 200 marta aylanadi.

Ruxsat etilgan urinma kuchlanish  $\tau_{adm} = 35$  MPa, ruxsat etilgan nisbiy buralish burchagi  $\theta_{adm}^0 = 0,25$  grad/m, siljishdagi elastiklik moduli  $G = 8 \cdot 10^4$  MPa va hajmi og'irligi  $\gamma_{adm} = 7,85 \cdot 10^4$  N/m<sup>3</sup> lar ma'lum.

Yetakchi shkivning o'rni qaysi yetaklanuvchi shkiv o'rni bilan almashtirilganda, valni tayyorlash uchun eng kam material sarf qilinadi?

Podshipniklardagi ishqalanish kuchlari e'tiborga olinmasin.

**Yechish:**

Masalani yechish ikki bosqichda olib boriladi.

1. Dastlab, shkiylarning o'rmini almashtirmasdan, valni yasash uchun qancha material sarflanishini hisoblash lozim. Buning uchun quyidagi ishlar ketma-ket bajariladi:

a) burovchi momentlarning epyurasini qurish:

b) valni mustahkamlik va bikrlikka tekshirib, zarur diametrini aniqlash.

Valni va unga o'rnatilgan shkiylarni chizish oson bo'lishi uchun ularning fazoviy ko'rinishini tekislikda tasvirlaymiz (V.1- shakl, b). Yetaklanuvchi shkiylarga qo'yilgan burovchi momentlar quyidagi formula yordamida aniqlanadi:

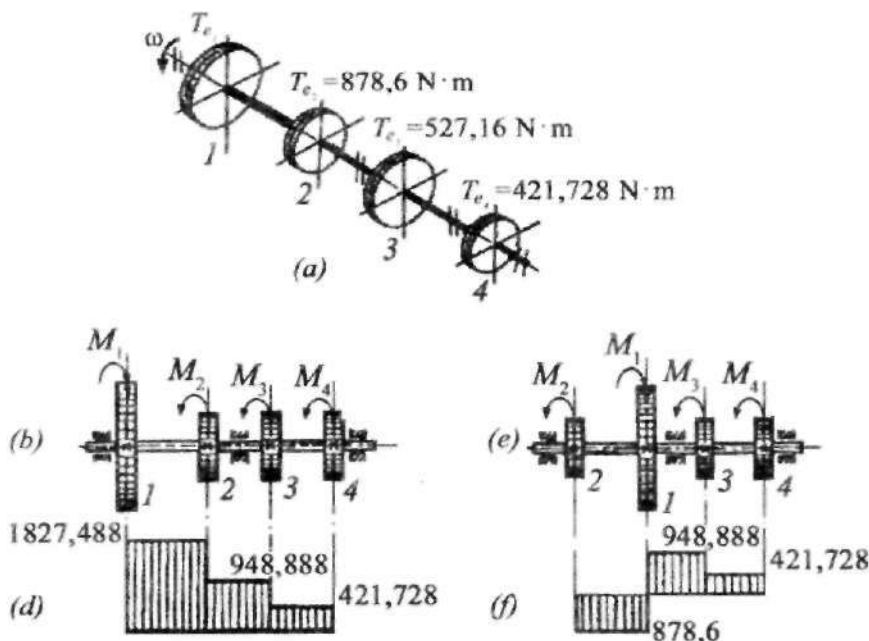
$$T_e = 7028,8 \cdot \frac{N_{ok}}{n};$$

bu yerda,  $N_{ok}$  – quvvat,  $n$  – aylanishlar soni.

$$\text{U holda, } T_{e_1} = 7028,8 \cdot \frac{25}{200} = 878,6 \text{ N} \cdot \text{m}; T_{e_2} = 7028,8 \cdot \frac{15}{200} = 527,16 \text{ N} \cdot \text{m};$$

$$T_{e_4} = 7028,8 \cdot \frac{12}{200} = 421,728 \text{ N} \cdot \text{m}.$$

Yetakchi shkiy uzatayotgan burovchi moment esa  $T_{e_l} = T_{e_2} + T_{e_3} + T_{e_4} = 1827,488 \text{ N} \cdot \text{m}$  ga teng bo'ladi.



V.1- shakl

Kesish usulini tatbiq etib, valga shkiqlar oralig'ida ta'sir etuvchi burovchi momentlarni aniqlaymiz:

$$\text{I-I kesimda: } T_e^I = \sum_{i=1}^n M_{z_i} = T_{e1} = 1827,488 \text{ N}\cdot\text{m};$$

$$\text{II-II kesimda: } T_e^{II} = T_{e1} - T_{e2} = 948,888 \text{ N}\cdot\text{m};$$

$$\text{III-III kesimda: } T_e^{III} = T_{e1} - T_{e2} - T_{e3} = 421,728 \text{ N}\cdot\text{m}.$$

V.1- shakl (a). Bu qiymatlar yordamida burovchi moment epyurasi quriladi (V.1- shakl, d); epyuradan ko'rinib turibdiki,  $T_e^{\max} = 1827,988 \text{ N}\cdot\text{m}$  ga teng ekan.

Valning mustahkamlik shartini qanoatlantiruvchi zaruriy diametrni aniqlaymiz:

$$d_r = 1,72 \cdot \sqrt[4]{\frac{T_e^{\max}}{\tau_{\text{adm}}}} = 1,72 \cdot \sqrt[4]{\frac{1827,488}{35 \cdot 10^6}} = 1,72 \cdot 3,7377 \cdot 10^{-2} = 6,4288 \cdot 10^{-2} \text{ m}.$$

Valning birlilik shartini qanoatlantiruvchi zaruriy diametr esa quyidagicha aniqlanadi:

$$d_\theta = 4,92 \cdot \sqrt[4]{\frac{T_e^{\max}}{G\theta_{\text{adm}}^0}} = 4,92 \cdot \sqrt[4]{\frac{1827,488}{8 \cdot 10^{10} \cdot 0,25}} = 4,92 \cdot 1,7386 \cdot 10^{-2} = 8,554 \cdot 10^{-2} \text{ m}.$$

Nihoyat, valning diametri uchun yaxlitlab olingan  $d_0 = 9 \cdot 10^{-2} \text{ m} = 90 \text{ mm}$  qiymat qabul qilinadi.

Bundan chiqdi, birinchi holatda valni tayyorlash uchun

$$Q' = \gamma \cdot l \cdot \frac{\pi d_0^2}{4} = 7,85 \cdot 10^4 \cdot 1,5 \cdot \frac{3,14}{4} (9 \cdot 10^{-2})^2 = 748,71 \text{ N}$$

og'irlikdagi material sarflanar ekan.

Yuqoridagi hisoblashlardan ko'rinib turibdiki, materialni tejash uchun burovchi momentning eng katta qiymati  $T_e^{\max}$  ni mumkin qadar kamaytirish zarur ekan. Bunga erishish uchun yetakchi shkiqlarni valga ratsional tartibda o'rnatish kifoya: yetakchi shkiq yetaklanuvchi shkiqlar orasiga shunday o'rnatilishi kerakki, iloji boricha yetakchi shkiqdan ikkala tomonga uzatilayotgan quvvatlarning yig'indisi teng bo'lsin.

1- va 2- shkiqlarning o'rinlarini almashtirib (V.1- shakl, e), yana oldingi tartibda hisoblashlarni davom ettiramiz (o'quvchilarning mustaqil bajarishi tavsiya etiladi).

Burovchi momentlarning epyurasi qurilgach (V.1- shakl, f), valning zaruriy diametrlarini aniqlaymiz:

$$d_r = 1,72 \cdot \sqrt[4]{\frac{948,888}{35 \cdot 10^6}} = 5,167 \cdot 10^{-2} \text{ m}; \quad d_\theta = 4,92 \cdot \sqrt[4]{\frac{948,888}{8 \cdot 10^{10} \cdot 0,25}} = 7,26 \cdot 10^{-2} \text{ m}.$$

Yaxlitlangan  $d_0 = 8 \cdot 10^{-2} \text{ m}$  o'lcham qabul qilinadi.

Demak, po'lat materialdan uzunligi  $l = 1,5 \text{ m}$  va diametri  $d_0 = 8 \cdot 10^{-2} \text{ m}$  bo'lgan valni yasash uchun



$$Q'' = 7,85 \cdot 10^4 \cdot 1,5 \frac{3,14 \cdot (8 \cdot 10^{-2})^2}{4} = 591,576 \text{ N}$$

material zarur ekan.

$$\text{Tejalgan materialni foizlarda hisoblaymiz: } \Delta Q = \frac{(748,71 - 591,576)}{748,71} \cdot 100\% = 21\%.$$

### 51- masala

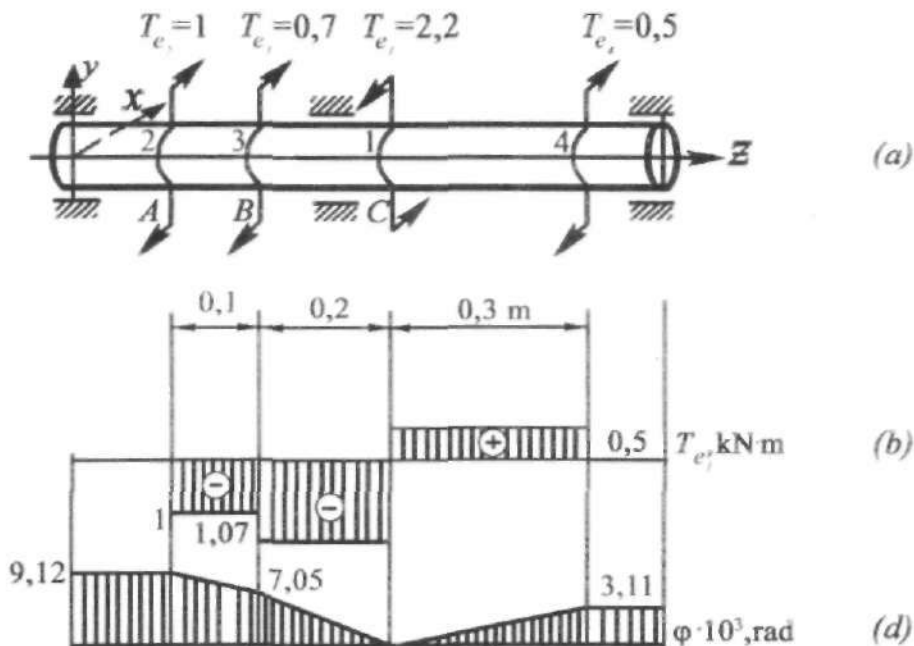
O'zgarmas burchak tezlik bilan aylanayotgan 1- shkiv qolgan 3 ta shkivni aylanma harakatga keltiradi (V.2- shakl). Bu shkivlarda hosil bo'lgan momentlar quyidagilarga teng:  $T_{e2} = 1 \text{ kN} \cdot \text{m}$ ;  $T_{e3} = 0,7 \text{ kN} \cdot \text{m}$ ;  $T_{e4} = 0,5 \text{ kN} \cdot \text{m}$ .

Ko'ndalang kesimi yaxlit hamda g'ovak ko'rinishdagi ( $d:D=0,8$ ) vallarning diametrlari aniqlansin ( $[\tau]_{\text{ovak}} = 80 \text{ MPa}$ ). Burovchi moment hamda buralish burchaklari epyuralari ko'rilsin. Bikrlik shartlari quyidagi tengliklar bo'yicha tekshirilsin:  $[\theta] = 3 \text{ grad/m}$ ;  $G = 8 \cdot 10^4 \text{ MPa}$ .

1- shkivdagi burovchi moment qiymatini aniqlaymiz:

$$\sum M_z = 0; \quad T_{e1} = T_{e2} + T_{e3} + T_{e4} = 2,2 \text{ kN} \cdot \text{m}$$

Valni uchta uchastkaga bo'lib, ulardagi eguvchi momentlarni aniqlaymiz (oldingi masaladagidek) va uning epyurasini quramiz (V.2- shakl, b). Demak, eng katta burovchi moment



V.2- shakl

$T_e^{\max} = 1,7 \text{ kN} \cdot \text{m}$  ga teng. Buralishdagi mustahkamlik shartiga binoan, val ko'ndalang kesimining qutb inersiya momentini aniqlaymiz:

$$W_p \geq \frac{T_e^{\max}}{[\tau]_{\text{q'rt}}} = \frac{1700}{80 \cdot 10^6} = 21,25 \cdot 10^{-6} \text{ m}^3 = 21,25 \text{ sm}^3.$$

Aylana ko'rinishdagi kesimning qarshilik momenti  $W_p = \pi \cdot D^3 / 16$  ekanligini e'tiborga olib, ko'ndalang kesim yaxlit bo'lgan valning diametrini aniqlaymiz:

$$D \geq \sqrt[3]{\frac{16 W_p}{\pi}} = \sqrt[3]{\frac{16 \cdot 21,25}{3,14}} = 4,77 \text{ sm}.$$

Kesimi g'ovak ko'rinishdagi vallar uchun:

$$W_p = \frac{\pi D^3}{16} \left[ 1 - \left( \frac{d}{D} \right)^4 \right] = \frac{3,14 D^3}{16} (1 - 0,8^4) = 0,116 D^3.$$

Shunga ko'ra, uning ichki va tashqi diametrlari:

$$D \geq \sqrt[3]{\frac{W_p}{0,116}} = \sqrt[3]{\frac{21,25}{0,116}} = 5,68 \text{ sm};$$

$$d = 0,8 \cdot 5,68 = 4,54 \text{ sm}$$

ga teng bo'ladi.

Yaxlit va g'ovak vallarning ko'ndalang kesim yuzalarini aniqlaymiz:

$$A_{\text{yaxlit}} = \frac{\pi D^2}{4} = \frac{3,14 \cdot 4,77^2}{4} = 17,9 \text{ sm}^2;$$

$$A_{\text{g'ovak}} = \frac{\pi \cdot D^2}{4} \left[ 1 - \left( \frac{d}{D} \right)^2 \right] = \frac{3,14 \cdot 5,68^2}{4} [1 - 0,8^2] = 9,12 \text{ sm}^2.$$

Bu qiymatlarni solishtirish shuni ko'rsatadiki, g'ovak valni qo'llaganda unga sarf bo'ladigan metall miqdori yaxlit valga nisbatan ikki baravar kam bo'lar ekan.

Keyingi hisoblarni g'ovak val uchun amalga oshiramiz.

Val ko'ndalang kesimi yuzalarining buralish burchaklarini 1-shkiv mahkamlangan kesim yuzasini qo'zg'almas deb hisoblab, shu kesimga nisbatan aniqlaymiz:

$$\varphi_{\text{CD}} = \frac{T_e^{\text{CD}} \cdot I_{\text{CD}}}{G \cdot I_p} = \frac{500 \cdot 0,3}{8 \cdot 10^{10} \cdot 60,3 \cdot 10^{-8}} = 3,11 \cdot 10^{-3} \text{ rad}.$$

Bu yerda,

$$I_p = \frac{\pi \cdot D^4}{32} \left[ 1 - \left( \frac{d}{D} \right)^4 \right] = \frac{3,14 \cdot 5,68^4}{32} [1 - 0,8^4] = 6,03 \text{ sm}^4;$$

$$\varphi_{\text{CB}} = \frac{T_e^{\text{BC}} \cdot I_{\text{BC}}}{G \cdot I_p} = \frac{1700 \cdot 0,2}{8 \cdot 10^{10} \cdot 60,3 \cdot 10^{-8}} = 7,05 \cdot 10^{-3} \text{ rad};$$

$$\varphi_{BA} = \frac{T_e^{AB} \cdot l_{AB}}{G \cdot I_p} = \frac{100 \cdot 0,1}{8 \cdot 10^{10} \cdot 60,3 \cdot 10^{-8}} = 2,07 \cdot 10^{-3} \text{ rad};$$

$$\varphi_{CA} = \varphi_{CB} + \varphi_{BA} = 7,05 \cdot 10^{-3} + 2,07 \cdot 10^{-3} = 9,12 \cdot 10^{-3} \text{ rad}.$$

Valning birlilik shartini tekshiramiz. Unda nisbiy buralish burchaklari:

$$\text{CD uchastkada } \theta_{CD} = \varphi_{CD}/l_{CD} = 3,11 \cdot 10^{-3}/0,3 = 0,0104 \text{ rad/m};$$

$$\text{CB uchastkada } \theta_{CB} = \varphi_{CB}/l_{CB} = 7,05 \cdot 10^{-3}/0,2 = 0,0353 \text{ rad/m};$$

$$\text{BA uchastkada } \theta_{BA} = \varphi_{BA}/l_{BA} = 2,07 \cdot 10^{-3}/0,1 = 0,0207 \text{ rad/m}$$

ga teng bo'ladi.

Topilgan qiymatlardan ko'rinib turibdiki, eng katta nisbiy buralish burchagi quyidagiga teng:

$$\theta_{\max} = \theta_{CB} = 0,0353 < [\theta] = 3 : 57,3 = 0,0524 \text{ rad/m}.$$

Bu yerda,  $1_{\text{rad}} = 57,3 \text{ grad}$ .

Demak, valning birligi qanoatlantirarli darajada ekan.

## 52- masala

Chap uchi bilan qistirib mahkamlangan, uchiga esa qo'zg'almas qilib biriktirilgan biki travers o'rnatilgan brusni tashqi moment burmoqda (V.3- shakl, a). Traversning aylanishini maxsus tayanch cheklaydi.

Berilgan brus uchun burovchi moment epyurasini qurish talab etiladi.

## Yechish:

Brusning o'ng uchini tayanchdan ozod qilib, B kesimning qanchaga aylanishini hisoblaymiz (V.3- shakl, b):

$$\varphi_{B_T} = \frac{T_e \cdot 2a}{G \frac{\pi d^4}{32} (1 - \alpha^4)} = \frac{T_e \cdot 2a}{G \frac{\pi d^4}{32} [1 - (0,7)^4]} = 26,8 \frac{T_e \cdot a}{G d^4}.$$

Bundan chiqdi, masala statik noaniq ekan, chunki brus  $T_e$  moment bilan yuklanganda oraliq yopilib, travers va tayanch orasidagi qiymati hozircha noma'lum bo'lgan  $T_{eX}$  juft kuch vujudga keladi (V.3- shakl, b).

Muvozanat tenglamasini tuzamiz:  $-T_{eA} + T_e - T_{eX} = 0$  yoki  $T_{eA} + T_{eX} = T_e$ .

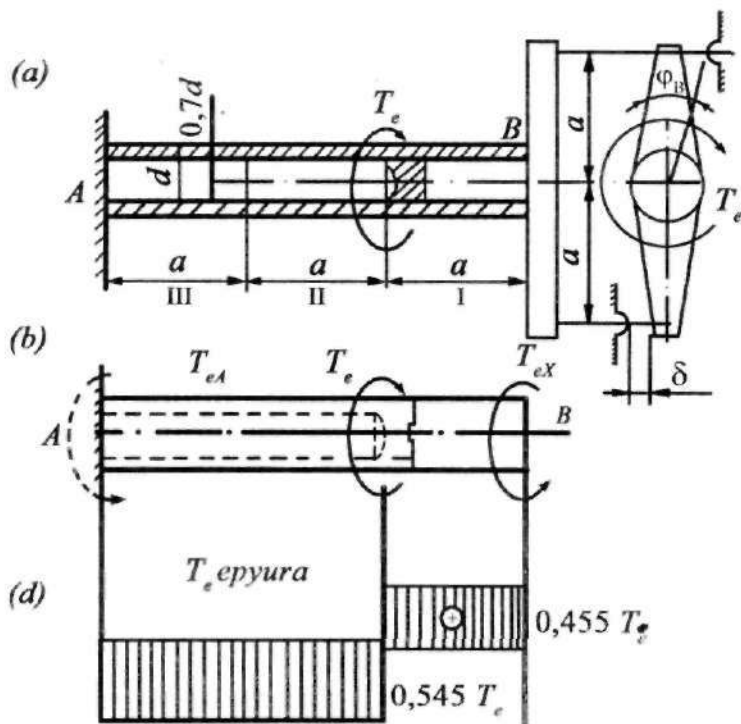
Kuchlar ta'sirining bir-biriga xalal bermaslik prinsipiga tayanib, qo'shimcha tenglama, ya'ni ko'chish tenglamasini tuzamiz:

$$\frac{T_e \cdot 2a}{G \frac{\pi d^4}{32} (1 - \alpha^4)} - \frac{T_{eX} \cdot 2a}{G \frac{\pi d^4}{32} (1 - \alpha^4)} - \frac{T_{eX} \cdot 2a}{G \frac{\pi d^4}{32}} = \frac{\delta}{a}.$$

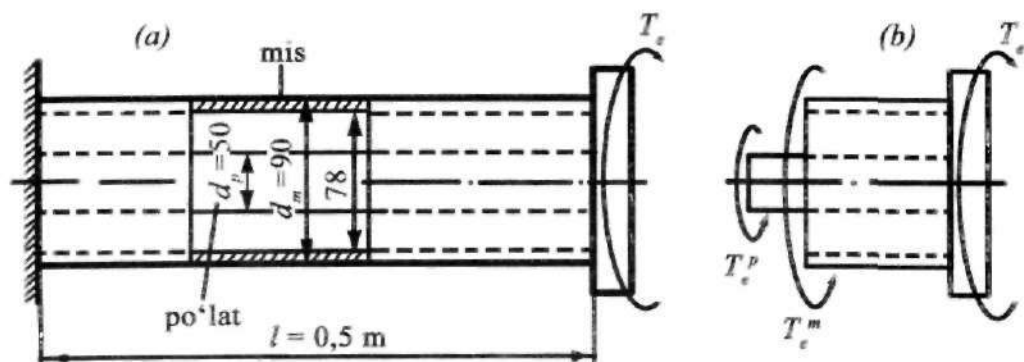
Tegishli soddalashtirishdan so'ng,  $T_{eX} = 0,455 \cdot T_e$  ekanligi kelib chiqadi.

Demak, qistirib mahkamlangan tayanchda  $T_{eA} = T_e - T_{eX} = 0,545 T_e$  ga teng bo'lgan burovchi moment hosil bo'lar ekan.

Kesish usulini qo'llab, burovchi moment epyurasini quramiz (V.3- shakl, d).



V.3- shakl



V.4- shakl

## 53- masala

Po'lat valik va mis trubka chap uchi bilan devorga qistirib mahkamlangan, o'ng uchiga esa biki disk biriktirilgan (V.4- shakl, a). Diskka  $T_e$  tashqi moment qo'yilgan.

$T_e$  momentning ruxsat etilgan qiymatini aniqlash talab etiladi.

Quyidagi ma'lumotlar berilgan:

po'lat uchun:  $\tau_{adm}^p = 100$  MPa;  $G_p = 8 \cdot 10^4$  MPa;

mis uchun:  $\tau_{adm}^m = 50$  MPa;  $G_m = 4 \cdot 10^4$  MPa.

## Yechish:

Kesish usulini tatbiq etib (V.4- shakl, b), quyidagi muvozanat tenglamasini tuzamiz:

$$T_e^p + T_e^m - T_e = 0;$$

bu yerda,  $T_e^p$  va  $T_e^m$  – tegishli po'lat valik va mis trubkalar qabul qiladigan burovchi momentlar.

Masala bir marta statik noaniq hisoblanadi. Shuning uchun qo'shimcha tenglama tuzish zarur.

Valik va trubkaning o'ng uchlariidagi kesimning buralish burchaklari teng, chunki disk ularga biki qilib mahkamlangan. Bu shartni quyidagicha yozamiz:

$$\varphi_p = \varphi_m \quad \text{yoki} \quad \frac{T_e^p l}{G_p J_p^p} = \frac{T_e^m l}{G_m J_p^m}.$$

Bu formulaga son qiymatlarini qo'yib,  $T_e^p = 0,302 T_e$ ;  $T_e^m = 0,698 T_e$  ekanligiga ishonch hosil qilamiz. Valikni mustahkamlikka tekshiramiz:

$$\tau_{max}^p = \frac{0,302 \cdot T_e}{W_{p_p}} \leq \tau_{adm}^p.$$

Bundan,

$$T_{adm}^p = T_e = \frac{1}{0,302} \cdot W_{p_p} \tau_{adm}^p = \frac{\frac{\pi}{16} \cdot 50^3 \cdot 100}{0,302} = 8 \text{ kN} \cdot \text{m};$$

trubkaning mustahkamlik shartidan esa,

$$T_{adm}^m = \frac{1}{0,698} \cdot W_{p_m} \tau_{adm}^m = \frac{\frac{\pi}{16} \cdot 90^3 \left[ 1 - \left( \frac{78}{90} \right)^4 \right] \cdot 50}{0,698} = 4,52 \text{ kN} \cdot \text{m}$$

kelib chiqadi.

Bundan chiqdi, tashqi momentning ruxsat etilgan miqdori bo'lib, mis trubkaning mustahkamligi bilan aniqlanadi. Agar konstruktsiya ruxsat etilgan momentga teng tashqi moment bilan yuklansa, u holda po'lat valik to'liq yuklanmaydi. Balki u ruxsat etilganiga nisbatan

$\frac{8-4,52}{8} \cdot 100\% = 43,5\%$  ga kam yuklanadi. Ammo bundan po'lat valikning diametrini kichiklashtirish mumkin ekan, degan xulosa kelib chiqmaydi. Chunki diametr o'zgarsa, tashqi moment qayta taqsimlanadi.

### 5.3- §. Buralishda valni mustahkamlikka va bikrlikka hisoblash bo'yicha topshiriqlar

#### 8- topshiriq

**Berilgan:** ko'ndalang kesimi aylanadan iborat bo'lgan po'lat val (V.5- shakl) tashqi burovchi momentlar bilan yuklangan. Val uchun ruxsat etilgan kuchlanish  $[\tau] = 130 \text{ MPa}$  ga teng.

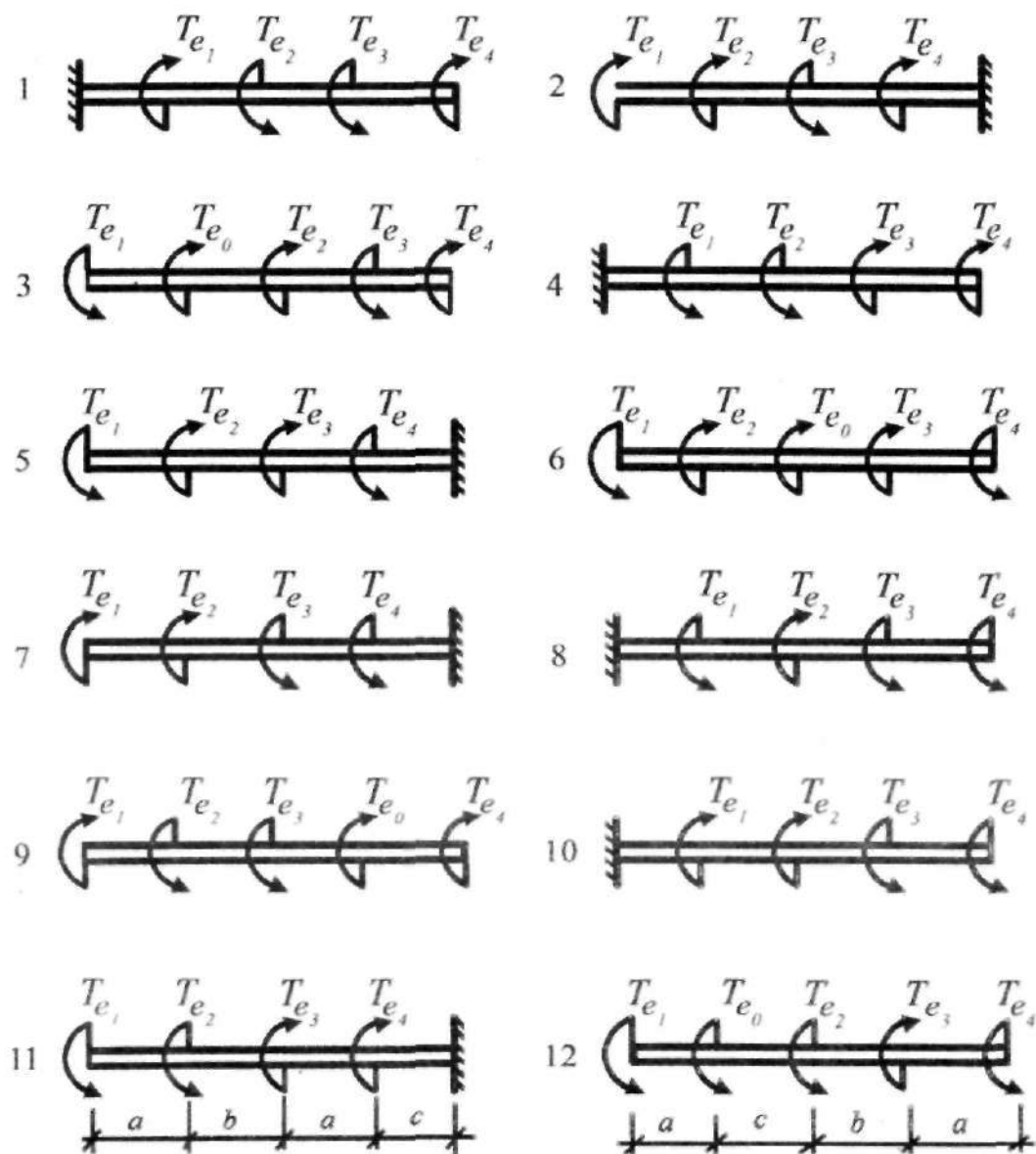
#### Topish kerak:

- 1) berilgan val uchun burovchi momentlar epyurasi qurilsin;
- 2) valning diametri mustahkamlik va bikrlilik shartiga binoan tanlansin;
- 3) valning aylanish burchagi epyurasi qurilsin;
- 4) eng katta nisbiy buralish burchagi aniqlansin.

Kerakli ma'lumotlar V.1- jadvalda, hisoblash sxemalari esa V.5- shaklda keltirilgan.

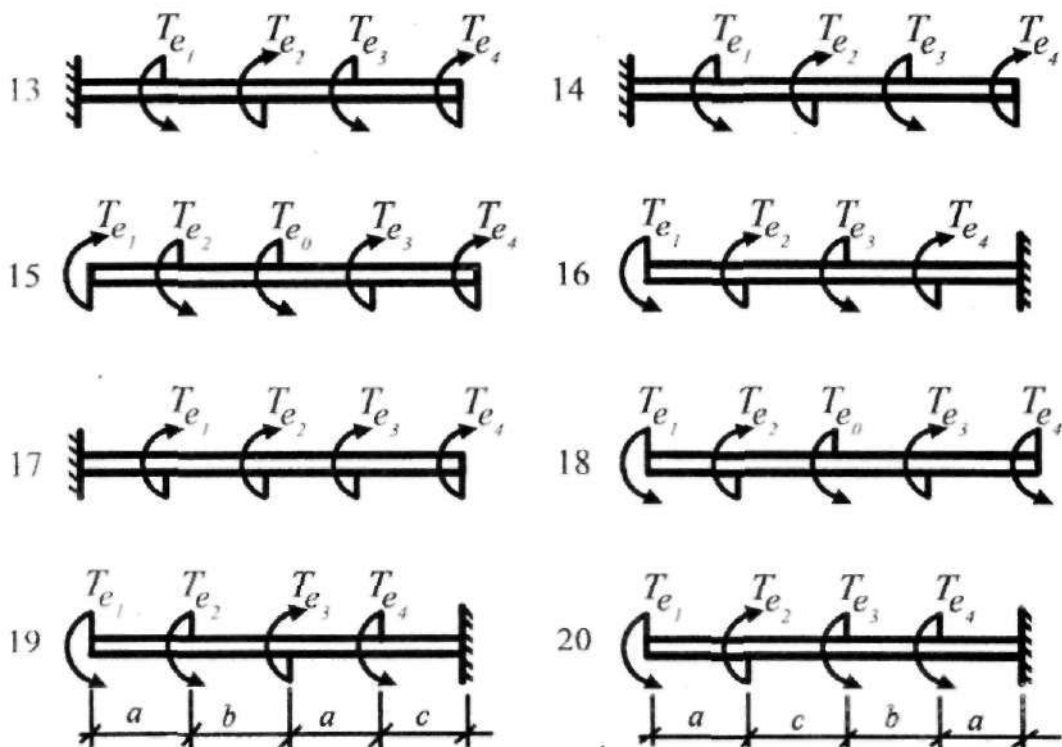
V.1- jadval

| №  | Uchastkalar uzunligi |          |          | Moment, kN · m |          |          |          | $\theta_{adm}$<br>grad/m |
|----|----------------------|----------|----------|----------------|----------|----------|----------|--------------------------|
|    | <i>a</i>             | <i>b</i> | <i>c</i> | $T_{b1}$       | $T_{b2}$ | $T_{b3}$ | $T_{b4}$ | <i>q</i>                 |
| 1  | 1,0                  | 0,8      | 1,7      | 28             | 14       | 23       | 6        | 3,0                      |
| 2  | 1,3                  | 0,8      | 1,4      | 5              | 22       | 10       | 26       | 3,0                      |
| 3  | 1,1                  | 1,7      | 0,4      | 10             | 17       | 9        | 28       | 2,0                      |
| 4  | 1,1                  | 1,9      | 0,6      | 7              | 24       | 11       | 21       | 1,4                      |
| 5  | 1,3                  | 0,8      | 1,4      | 5              | 22       | 10       | 26       | 3,0                      |
| 6  | 1,2                  | 1,0      | 0,9      | 33             | 8        | 25       | 8        | 1,5                      |
| 7  | 1,2                  | 1,1      | 0,8      | 14             | 10       | 24       | 12       | 2,4                      |
| 8  | 1,4                  | 0,5      | 1,1      | 27             | 12       | 22       | 6        | 2,6                      |
| 9  | 1,3                  | 0,8      | 1,1      | 5              | 18       | 8        | 25       | 1,0                      |
| 10 | 1,3                  | 0,6      | 1,5      | 19             | 11       | 10       | 22       | 1,8                      |



V.5- shakl

V.5- shakl (davomi)





## VI BOB

TO'G'RI EGILISHDA BALK VA RAMALAR UCHUN ICHKI KUCH  
FAKTORLARI EPYURALARINI QURISH

## 6.1- §. Epyura qurish qoidalari

Bruslarni mustahkamlik va birklikka hisoblashda ularning qaysi kesimlarida ichki kuchlar ekstremal (eng katta yoki eng kichik) qiymatlarga erishishini, aniqrog'i, ichki kuchlarning brus uzunligi bo'yicha o'zgarish qonuniyatini bilish muhimdir. Odatda, bu qonuniyatni analitik bog'lanishlar va ular yordamida quriladigan epyuralar orqali ifodalash mumkin.

Ichki kuchlarning brus uzunligi bo'yicha o'zgarish qonunini ko'rsatuvchi grafik yoki diagramma mazkur ichki kuchlarning epyuralari yoki, qisqacha, epyura deyiladi.

Demak, epyuralarni to'g'ri qurish muhim ahamiyatga ega ekan, chunki ular yordamida brusning xavfli kesimi tanlanadi hamda ichki kuchlarning hisobiy qiymatlari aniqlanadi.

Har bir ichki kuchning o'ziga aynan bitta tenglama mos keladi.

Epyuralarni qurishda quyidagi umumiy tartiblardan foydalanish tavsiya etiladi:

- 1) statikaning muvozanat tenglamalari yordamida tayanch reaksiya kuchlari aniqlanadi;
- 2) brusni tegishli «oraliq»larga ajratib, ma'lum tartibda *I*, *II*, *III*,... raqamlar bilan belgilanadi; oraliqning chegaralari quyidagilardan iborat bo'lishi mumkin (VI.1- shakl):

a) to'plangan kuchlar va juft kuchlar qo'yilgan kesimlar;

b) bitta qonuniyat bo'yicha o'zgaruvchi taqsimlangan kuchlarning boshlanish va oxirgi kesimlari;

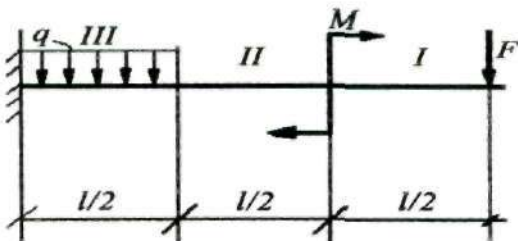
d) bruslarning siniq joylari;

- 3) kesish usulidan foydalanib, har bir oraliq uchun ichki kuchlarning analitik ifodalari yoziladi; bunda ichki kuchlarning ishoralariga alohida e'tibor berish zarur;

- 4) analitik ifodalar tarkibidagi o'zgaruvchi «*Z*»ga tegishli qiymatlar berib, har bir oraliqning o'ziga xos kesimlaridagi ichki kuchlarning miqdorlari – ordinatalari hisoblanadi;

5) ordinatalar aniq masshtab bilan brus o'qiga parallel qilib o'tkazilgan nol chizig'iga tik (perpendikular) qilib joylashtiriladi va epyura chiziladi; odatda, epyurada musbat qiymatlar nol chizig'ining yuqori, manfiy qiymatlar esa pastki qismiga joylashtiriladi;

- 6) epyura nol chizig'iga tik bo'lgan chiziqlar bilan shtrixlanadi.



VI.1- shakl

Egilgan to'sinlarning barcha kesimlarida ko'ndalang kuch  $Q$  va eguvchi moment  $M$  paydo bo'ladi. Shu sababli, to'sinning tayanchlari, tayanch reaksiyalarini aniqlash hamda turli xil to'sinlar uchun  $Q$  va  $M$  larning epyuralarini qurish tartiblarini mukammalroq bilish zarur.

Dastlab, egilishdagi ichki kuchlar uchun quyidagi qoidalarini bayon qilamiz:

– to'sindan ajratib olingan bo'lakchaga ta'sir etayotgan barcha kuchlar (tashqi kuchlar va tayanch reaksiyalari)ning to'sin o'qiga tik yo'nalgan o'qqa nisbatan olingan proyeksiyalar yig'indisi ko'ndalang kuch deyiladi hamda

$$Q_y(z) = \pm \sum Y_i \quad (a)$$

ko'rinishda aniqlanadi;

– to'sindan ajratib olingan bo'lakchaga ta'sir etayotgan barcha kuchlar (tashqi yuklar va tayanch reaksiyalari)dan qirqilgan kesim markaziga nisbatan olingan momentlarning algebraik yig'indisi eguvchi moment deyiladi hamda

$$M(z) = \pm \sum M_{oi} \quad (b)$$

ko'rinishdagi formula yordamida aniqlanadi.

$Q$  va  $M$  lar uchun ishoralar qoidasi quyidagicha:

– agar tashqi kuchlar (tashqi yuklar va tayanch reaksiyalari) vektori to'sindan ajratib olingan bo'lakchani qirqilgan kesim markaziga nisbatan soat strelkasi harakati yo'nalishi bo'yicha aylantirsa, ko'ndalang kuch musbat va, aksincha, soat strelkasi harakati yo'nalishiga teskari aylantirsa, manfiy ishorali qilib olinadi (VI.2- shakl);

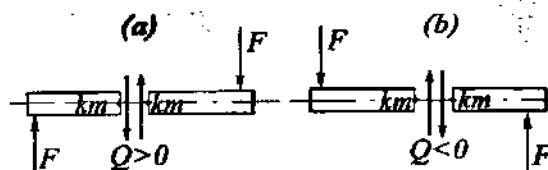
– agar kuchlar (tashqi yuklar va tayanch reaksiyalari) vektori to'sindan ajratib olingan bo'lakchani qirqilgan kesim markaziga nisbatan olingan momentlar to'sindan ajratib olingan bo'lakchani yuqori tolalarini siqsa, u holda eguvchi moment musbat va, aksincha, yuqori tolalarini cho'zsa, manfiy ishorali qilib tanlanadi (VI.3- shakl).

Eguvchi moment, kesuvchi kuch va yoyilgan kuch intensivligi orasida quyidagi differensial va integral munosabatlar mavjuddir:

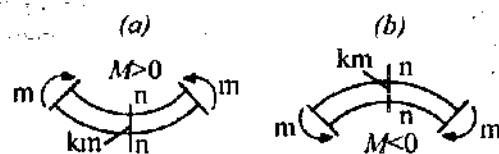
$$\frac{dM_x}{dz} = Q_y; \quad (VI.1)$$

$$\frac{d^2 M_x}{dz^2} = \frac{dQ_y(z)}{dz} = -q. \quad (VI.2)$$

Ya'ni:



VI.2- shakl



VI.3- shakl

- eguvchi momentdan  $Z$  absissa bo'yicha olingan hosila tekshirilayotgan kesimdagi ko'ndalang kuchga tengdir;
- eguvchi momentdan  $Z$  absissa bo'yicha olingan ikkinchi hosila yoyilgan yuk intensivligining teskari ishora bilan olingan qiymatiga tengdir.

Yuqorida keltirilgan differensial bog'lanishlardan, birinchidan, ko'ndalang kuch  $Q$  va eguvchi moment  $M$  larning epyuralarini qurishga, ikkinchidan esa qurilgan epyuralarning to'g'ri yoki noto'g'riligini tekshirishga imkon beruvchi quyidagi muhim xulosalar kelib chiqadi:

- yoyilgan yuk intensivligi bo'lmagan uchastkalarda  $Q$  ning epyurasi to'sin o'qiga parallel yo'nalgan to'g'ri chiziq,  $M$  ning epyurasi esa to'sin o'qiga og'ma yo'nalgan to'g'ri chiziq bilan chegaralangan bo'ladi;
- yoyilgan yuk intensivligi ta'sir etayotgan uchastkalarda  $Q$  ning epyurasi to'sin o'qiga og'ma to'g'ri chiziq,  $M$  ning epyurasi esa kvadratik parabola yoyi bilan chegaralangan bo'ladi;
- kesuvchi kuch nolga teng bo'lgan kesimda eguvchi moment ekstremal qiymatga erishadi;
- $Q > 0$  bo'lgan uchastkalarda chapdan o'ngga tomon  $M$  ning ordinatasi orta boshlaydi, ya'ni eguvchi momentning musbat qiymati oshadi, manfiy qiymati esa kamayadi;
- aksincha,  $Q_x < 0$  bo'lgan uchastkalarda esa  $M$  ning ordinatasi kamaya boshlaydi;
- to'plangan kuch qo'yilgan kesimlarda  $Q$  ning epyurasi shu kuch miqdori qadar sakraydi,  $M$  ning epyurasini chegaralovchi chiziq esa o'z yo'nalishini o'zgartiradi;
- juft kuch qo'yilgan kesimlarda  $Q$  ning epyurasida hech qanday o'zgarish bo'lmaydi,  $M$  ning epyurasida esa shu juft kuch miqdori qadar sakrash sodir bo'ladi;
- chetki sharnirli tayanchlarda kesuvchi kuch tayanch reaksiyalariga, eguvchi moment esa nolga teng bo'ladi (agar shu kesimlarga juft kuch qo'yilmagan bo'lsa);
- to'sin (konsol) ning erkin uchiga juft kuch qo'yilmagan bo'lsa, eguvchi moment shu kesimda nolga teng bo'ladi; agar konsol uchiga to'plangan kuch ham qo'yilmagan bo'lsa, shu kesimda kesuvchi kuch ham nolga teng bo'ladi;
- qistirib mahkamlangan tayanchda kesuvchi kuch shu tayanchning reaksiya kuchiga, eguvchi moment esa reaktiv momentiga teng bo'ladi.

## 6.2- §. To'sinlarning tayanch reaksiyalarini aniqlash

Umumiy holda tekislikdagi statik aniq tizim (to'sin, rama, arka, egri brus) larning tayanch reaksiyalari quyidagi uchta statikaning muvozanat tenglamalaridan topiladi:

$$\begin{array}{ll} \Sigma Z_i = 0 & \Sigma Z_i = 0; \\ \Sigma Y_i = 0 & \text{yoki} \quad \Sigma M_{A_i} = 0; \\ \Sigma M_{A_i} = 0 & \Sigma M_{B_i} = 0. \end{array} \quad (\text{VI.3})$$

Bu yerda,  $A$  va  $B$  harflari tayanchlarga tegishli nuqtani ifodalaydi.

Biz faqat to'sinning geometrik o'qiga tik yo'nalgan tashqi kuchlar ta'siri ostidagi egilishni o'rganish bilan chegaralanamiz, xolos. Shu sababli, bunday to'sinlarning tayanch reaksiyalarini aniqlash uchun  $\sum Z_i = 0$  tenglamani tuzishning zaruriyati qolmaydi, ya'ni tayanchning gorizontall tuzuvchisi  $N=0$  bo'ladi.

Konsolning tayanch reaksiyalarini aniqlash uchun esa quyidagi ikkita tenglamani tuzish tavsiya etiladi:

$$\sum Y_i = 0; \quad \sum M_{A_i} = 0.$$

Parallel kuchlar sistemasi ta'siri ostidagi ikki tayanchli oddiy va konsol uchli to'sinlarning tayanch reaksiyalarini aniqlash uchun esa  $A$  va  $B$  tayanchlarga nisbatan hamma kuchlardan olingan momentlar tenglamasidan foydalanish zarur:

$$\sum M_A(P_i) = 0; \quad \sum M_B(P_i) = 0;$$

keyin esa tayanch reaksiyalarning qiymatlari

$$\sum Y_i = 0$$

tenglama yordamida tekshirib ko'riladi.

#### 54- masala

Ikki uchi bilan sharnirli qo'zg'almas va qo'zg'aluvchi tayanchlarga tiralgan oddiy to'singa VI.4- shaklda ko'rsatilgandek, to'plangan va juft kuchlar ta'sir etmoqda. Mazkur to'sinning tayanch reaksiyalarini aniqlash talab etiladi.

#### Yechish:

To'sinning chap tayanchini  $R_A$  va o'ng tayanchini esa  $R_B$  reaksiyalar bilan almashtiramiz. Barcha kuchlardan  $A$  va  $B$  tayanchlarga nisbatan momentlar olib, berilgan masala uchun quyidagi ifodani tuzamiz:

$$\sum M_A(P_i) = 0 \quad \text{yoki} \quad 2ql \cdot 2l - ql \cdot (2l + 2l) - 3ql^2 - R_B \cdot 6l = 0;$$

$$\sum M_B(P_i) = 0 \quad \text{yoki} \quad R_A \cdot 6l - 2ql \cdot 4l + ql \cdot 2l - 3ql^2 = 0.$$

Oxirgi tenglamalardan noma'lum reaksiyalarni aniqlaymiz:

$$R_A = 3ql/2; \quad R_B = -ql/2.$$

Demak,  $R_B$  tayanch reaksiyasining haqiqiy yo'nalishi  $Y$  o'qiga teskari yo'nalgan ekan.

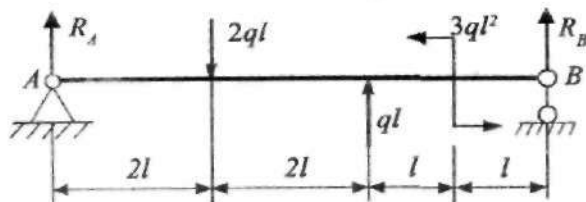
Quyidagi tenglamani tuzib,  $R_A$  va  $R_B$  larning qiymatlari to'g'ri topilganligiga ishonch hosil qilamiz:

$$R_A - 2ql + ql + R_B = 0$$

yoki

$$\frac{3ql}{2} - 2ql + ql - \frac{ql}{2} = 0;$$

$$0 = 0.$$

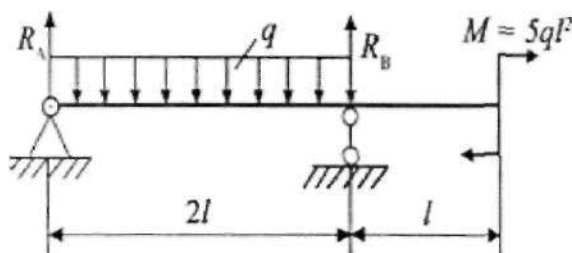


VI.4- shakl

**55- masala**

VI.5- shaklda tasvirlangan konsol uchli oddiy to'sin juft kuch va tekis taralgan yoyilgan kuch ta'sirida bo'lsin. To'sinning tayanch reaksiyalarini aniqlaymiz.

Quyidagilar ma'lum:  $q, M, l$ .



VI.5- shakl

**Yechish:**

To'sinning tayanchlarini  $R_A$  va  $R_B$  reaksiyalar bilan almashtiramiz.

Shuni eslatib o'tish lozimki, yoyilgan kuchlardan biror nuqtaga moment olish uchun, dastlab, ularning teng ta'sir etuvchisi aniqlanadi.

Statikaning muvozanat tenglamalarini tuzamiz:

$$\Sigma M_A = 0; \quad q \cdot 2l \cdot \frac{2l}{2} - R_B \cdot 2l + M = 0; \quad \text{bunda, } R_B = \frac{7ql}{2};$$

$$\Sigma M_B = 0; \quad R_A \cdot 2l - q \cdot 2l \cdot \frac{2l}{2} + M = 0; \quad \text{bunda, } R_A = -\frac{3ql}{2}.$$

Tekshiramiz:

$$\Sigma Y_i = 0; \quad R_A - q \cdot 2l + R_B = -\frac{3ql}{2} - 2ql + \frac{7ql}{2} = 0.$$

Oxirgi tenglama tayanch reaksiyalarining to'g'ri aniqlanganligini tasdiqlaydi.

**56- masala**

VI.6- shaklda tasvirlangan ramaning tayanch reaksiyalari topilsin.

Quyidagilar ma'lum:  $F = 5 \cdot 10^4 \text{ N}$ ;  $q = 2 \cdot 10^4 \text{ N/m}$ ;  $l = 1,2 \text{ m}$ .

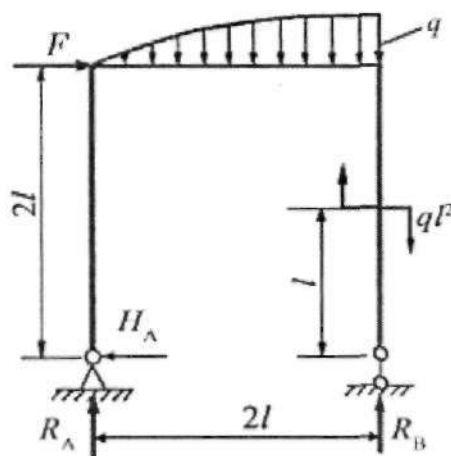
**Yechish:**

Ramaning sharnirli qo'zg'almas tayanchini  $H_A$  va  $R_A$ , sharnirlar qo'zg'aluvchi tayanchini esa  $R_B$  reaksiyalar bilan almashtiramiz.

Muvozanat tenglamalarini tuzamiz:

$$\Sigma Z_i = 0; \quad F - H_A = 0; \quad H_A = 5 \cdot 10^4 \text{ N};$$

$$\Sigma M_{A_i} = 0; \quad F \cdot 2l + \frac{2q \cdot 2l}{3} \cdot \frac{5 \cdot 2l}{8} + M - R_B \cdot 2l = 0; \quad R_B = 8,2 \cdot 10^4 \text{ kN};$$



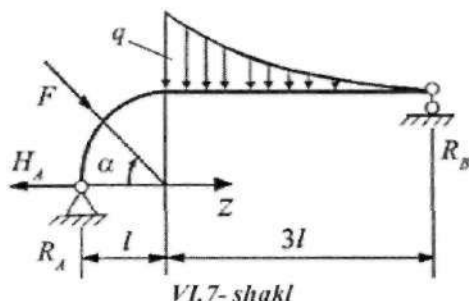
VI.6- shakl

$$\Sigma M_{B_1} = 0; \quad R_A \cdot 2l + F \cdot 2l - \frac{2q \cdot 2l}{3} \cdot \frac{3 \cdot 2l}{8} + M = 0; \quad R_A = -5 \cdot 10^4 \text{ kN}.$$

**Tekshirish:**

$$\Sigma Y_i = 0; \quad R_A + R_B - \frac{2q \cdot 2l}{3} = 0; \quad -5 \cdot 10^4 + 8,2 \cdot 10^4 - 3,2 \cdot 10^4 = 0.$$

Demak, tayanch reaksiyalari to'g'ri topilgan.



VI.7-shakl

### 57- masala

Egri brusga to'plangan va yoyilgan kuch ta'sir etmoqda (VI.7- shakl); A va B tayanchlardagi reaksiyalar aniqlansin.

Quyidagilar ma'lum:  $\alpha = 45^\circ$ ;  $q = 1 \cdot 10^4 \text{ N/m}$ ;  $F = 2 \cdot 10^4 \text{ N}$ ;  $l = 1 \text{ m}$ .

### Yechish:

Tayanchlarni tegishli nuqtalar bilan almashtirib, muvozanat tenglamalarini tuzamiz:

$$\Sigma Z_i = 0, \quad F \cdot \cos \alpha - H_A = 0;$$

$$\Sigma M_{A_1} = 0, \quad \sin \alpha (l - l \cos \alpha) + \frac{q \cdot 3l}{3} \cdot \frac{3l}{4} + l - R_B \cdot 4l + F \cdot \cos \alpha \cdot l \sin \alpha = 0;$$

$$\Sigma M_{B_1} = 0, \quad R_A \cdot 4l + H_A \cdot l - F \cdot \cos \alpha (l - l \sin \alpha) - F \cdot \cos \alpha (3l + l \cos \alpha) - \frac{q \cdot 3l}{3} \cdot \frac{3 \cdot 3l}{4} = 0.$$

Demak,  $H_A = 1,414 \cdot 10^4 \text{ N}$ ;  $R_A = 1,6205 \cdot 10^4 \text{ N}$  va  $R_B = 0,79 \cdot 10^4 \text{ N}$  ga teng ekan, bu qiymatlarning to'g'riligini tekshirish uchun  $\Sigma Y_i = 0$  tenglamani tuzamiz:

$$R_A - F \sin \alpha - \frac{q \cdot 3l}{3} + R_B = 0 \quad \text{yoki} \quad 2,41 \cdot 10^4 - 2,41 \cdot 10^4 = 0.$$

Demak, reaksiya kuchlari to'g'ri topilgan.

## 6.3- §. Tashqi kuchlar bilan yuklatilgan turli xil to'sinlar uchun ko'ndalang kuch va eguvchi moment epyuralarini qurish

### 58- masala

Ikki oraliqdan iborat konsol uchun ko'ndalang kuch va eguvchi moment epyuralarini quring (VI.8- shakl, a).

### Yechish:

Kesish usuliga muvofiq har bir oraliqni  $z$  masofada fikran qirqib, konsoldan ajratilgan bo'lakchani alohida chizib olamiz (VI.8- shakl, b, d). Kesim og'irlik markaziga navbat bilan  $Q^I(z_1)$ ,  $Q^{II}(z_2)$  ko'ndalang kuchlarni va  $M^I(z_1)$ ,  $M^{II}(z_2)$  eguvchi momentlarni qo'yamiz.

Konsoldan ajratib olingan bo'lakcha uchun ichki kuchlarning analitik ifodalarini tuzamiz:

I oraliq:  $0 \leq z_1 \leq l$

$$Q^I(z_1) = \pm \sum_{i=1}^1 Y_i = -F = \text{const};$$

$$M^I(z_1) = \pm \sum_{i=1}^1 M_{0_i} = -F \cdot z_1.$$

II oraliq:  $l \leq z_2 \leq 2l$

$$Q^{II}(z_2) = \pm \sum_{i=1}^2 Y_i = -F + 3F = 2F = \text{const};$$

$$M^{II}(z_2) = \pm \sum_{i=1}^2 M_{0_i} = -F \cdot z_2 + 3F(z_2 - l).$$

Hosil bo'lgan ifodalardan ko'rinib turibdiki, ikkala oraliqda ham ko'ndalang kuchlar  $Q^I(z_1) = \text{const}$ ;  $Q^{II}(z_2) = \text{const}$ ; eguvchi moment  $M^I(z_1)$ ,  $M^{II}(z_2)$  lar chiziqli qonuniyat bilan o'zgarar ekan.

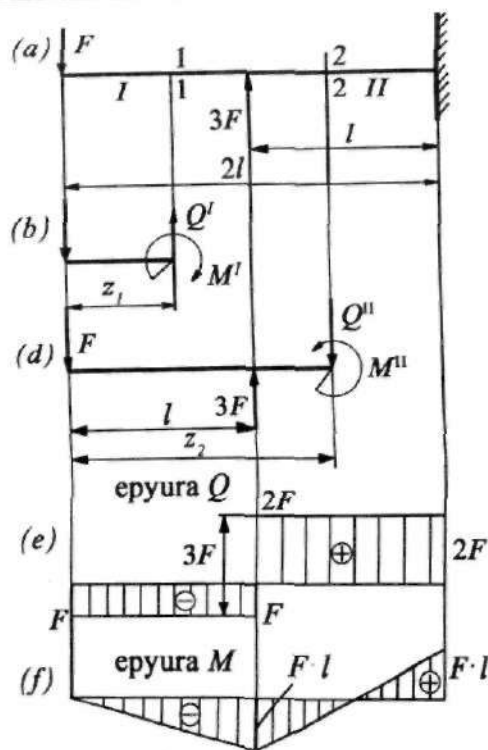
Har bir oraliq uchun quyidagi jadvalni tuzamiz.

| I oraliq |      |        | II oraliq |      |        |
|----------|------|--------|-----------|------|--------|
| $z_1$    | $Q$  | $M$    | $z_2$     | $Q$  | $M$    |
| 0        | $-F$ | 0      | 0         | $2F$ | $-F l$ |
| $l$      | $-F$ | $-F l$ | $2l$      | $2F$ | $F l$  |

Jadvaldagi qiymatlardan foydalanib, ichki kuchlarning miqdorlari – ordinatalarini aniq masshtab bilan konsol o'qiga parallel o'tkazilgan nol chizig'iga perpendikular qilib joylashtiramiz. Natijada, har bir oraliq uchun ko'ndalang kuch  $Q(z)$  va eguvchi moment  $M(z)$  larning epyuralari paydo bo'ladi (VI.8- shakl, e, f).

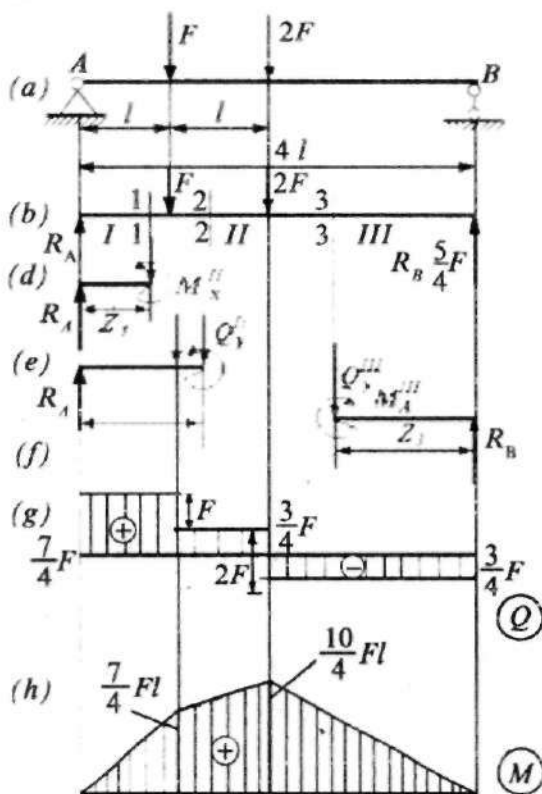
### 59- masala

Oddiy to'singa  $F$  va  $2F$  kuchlar ta'sir ko'rsatmoqda (VI.9- shakl, a). Ichki zo'riqishlarning epyuralarini qurish talab etiladi.



VI.8- shakl





VI.9- shakl

**Yechish:**

Dastlab  $A$  (qo'zg'almas sharnirli) va  $B$  (qo'zg'aluvchan sharnirli) tayanchlarda paydo bo'luvchi reaksiyalarni aniqlash zarur (VI.9- shakl, b).  $A$  tayanchdagi gorizontal tashkil etuvchi  $H_A = 0$  ga teng.

To'sinning muvozanatini tekshiramiz:

$$\sum_{i=1}^n M_A(F_i) = 0; Fl + 2F \cdot 2l - R_B \cdot 4l = 0;$$

$$\sum_{i=1}^n M_B(F_i) = 0; -2F \cdot 2l - F \cdot 3l + R_A \cdot 4l = 0$$

muvozanat tenglamalarini tayanch reaksiyalariga nisbatan yechsak,  $R_A = 7F/4$  va  $R_B = 5F/4$  lar kelib chiqadi. Bu qiymatlarning to'g'riligiga ishonch hosil qilish uchun

$$\sum_{i=1}^n Y_i = 0$$

tenglamani tuzamiz:

$$R_A - F - 2F + R_B = 0 \quad \text{yoki}$$

$$\frac{7F}{4} - F - 2F + \frac{5F}{4} = 0.$$

Oxirgi ifodaning chap tomoni ham nolga teng. Demak, tayanch reaksiyalari to'g'ri topilgan. Kesish usulidan foydalanib, uchala oraliq uchun ham to'sindan «bo'lakcha» ajratib olamiz va kesim og'irlik markaziga ko'ndalang kuch va eguvchi momentlarni joylashtiramiz (VI.9- shakl, d, e, f).

Har bir bo'lakcha uchun quyidagi analitik ifodalarni tuzamiz:

I oraliq:  $0 \leq z_1 \leq l$

$$Q_y^I(z_1) = \pm \sum_{i=1}^1 Y_i = R_A = \frac{7F}{4} = \text{const}; \quad M_x^I(z_1) = \pm \sum_{i=1}^1 M_{0i} = R_A \cdot z_1 = \frac{7F \cdot z_1}{4}.$$

II oraliq:  $l \leq z_2 \leq 2l$

$$Q_y^{II}(z_2) = \pm \sum_{i=1}^2 Y_i = R_A - F = \frac{3F}{4} = \text{const}; \quad M_x^{II}(z_2) = \pm \sum_{i=1}^2 M_{0i} = R_A \cdot z_2 - F(z_2 - l).$$



III oraliq: (o'ng tomon)  $0 \leq z_3 \leq 2l$ ;

$$Q_y^{III}(z_3) = \pm \sum_{i=1}^1 Y_i = -R_B = -\frac{5F}{4} = \text{const}; \quad M_x^{III}(z_3) = \pm \sum_{i=1}^1 M_{0_i} = R_B \cdot z_3 = \frac{5F}{4} \cdot z_3.$$

Quyidagi jadvalni tuzamiz.

| I oraliq |                 |                 | II oraliq |                |                 | III oraliq |                 |                  |
|----------|-----------------|-----------------|-----------|----------------|-----------------|------------|-----------------|------------------|
| $z_1$    | $Q$             | $M$             | $z_2$     | $Q$            | $M$             | $z_3$      | $Q$             | $M$              |
| 0        | $\frac{7Fl}{4}$ | 0               | 0         | $\frac{3F}{4}$ | $\frac{7Fl}{4}$ | 0          | $-\frac{5F}{4}$ | 0                |
| $l$      | $\frac{7Fl}{4}$ | $\frac{7Fl}{4}$ | $2l$      | $\frac{3F}{4}$ | $\frac{7Fl}{4}$ | $l$        | $-\frac{5F}{4}$ | $\frac{10Fl}{4}$ |

Jadvaldagi qiymatlar asosida qat'iy mashtab bilan ko'ndalang kuch va eguvchi moment epyuralarini quramiz (VI.9- shakl, g, h).

### 60- masala

Konsol uchli to'singa  $F$  va  $M = 3Fl$  tashqi kuch ta'sir etmoqda (VI.10- shakl, a). Ushbu to'sin uchun  $Q$  va  $M$  epyuralarini quring.

### Yechish:

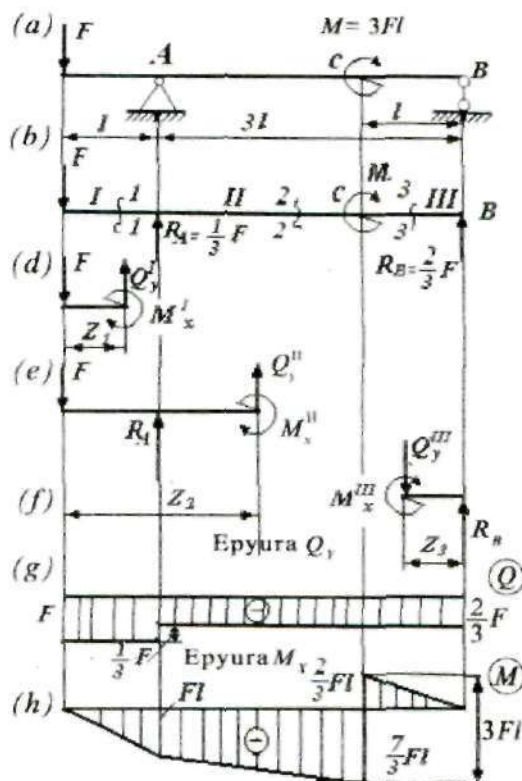
VI.10- shakl (b) dan foydalanib,  $A$  va  $B$  tayanchlardagi reaksiya kuchlarini aniqlaymiz.

$$\sum_{i=1}^n M_A(F_i) = 0; \quad Fl + M - R_B \cdot 3l = 0;$$

$$\sum_{i=1}^n M_B(F_i) = 0; \quad -F \cdot 4l + M + R_A \cdot 3l = 0$$

muvozanat tenglamalarini tayanch reaksiyalari-ga nisbatan yechsak,  $R_A = \frac{F}{3}$  va  $R_B = \frac{2F}{3}$  lar kelib chiqadi.

Endi  $R_A$  va  $R_B$  larning qiymatlarini tekshirib ko'ramiz:



VI.10- shakl

$$\sum_{i=1}^n Y_i = 0; \quad R_A - F + R_B = 0 \quad \text{yoki} \quad \frac{F}{3} - F + \frac{2F}{3} = 0.$$

Oxirgi tenglama chap tomonining nolga tengligi reaksiya kuchlarining to'g'ri aniqlanganligini tasdiqlaydi.

Oldingi masalalardagi kabi har bir oraliqni navbat bilan fikran qirqamiz (VI.10- shakl, d, e, f) hamda ichki zo'riqlashlarning analitik ifodalarini tuzamiz:

I oraliq:  $0 \leq z_1 \leq l$

$$Q_y^I(z_1) = \pm \sum_{i=1}^1 Y_i = -F = \text{const}; \quad M_x^I(z_1) = \pm \sum_{i=1}^1 M_{0_i} = -F \cdot z_1.$$

II oraliq:  $l \leq z_2 \leq 4l$

$$Q_y^{II}(z_2) = \pm \sum_{i=1}^2 Y_i = R_A - F = \frac{F}{3} - F = -\frac{2}{3}F = \text{const};$$

$$M_x^{II}(z_2) = \pm \sum_{i=1}^2 M_{0_i} = R_A(z_2 - l) - F \cdot z_2 = \frac{F \cdot (z_2 - l)}{3} - F \cdot z_2.$$

III oraliq: (o'ng tomon)  $0 \leq z_3 \leq l$

$$Q_y^{III}(z_3) = \pm \sum_{i=1}^1 Y_i = -R_B = -\frac{2}{3}F = \text{const}; \quad M_x^{III}(z_3) = \pm \sum_{i=1}^1 M_{0_i} = R_B \cdot z_3 = \frac{2}{3}F \cdot z_3.$$

Quyidagi jadvalni tuzamiz:

| I oraliq |      |     | II oraliq |       |        | III oraliq |       |       |
|----------|------|-----|-----------|-------|--------|------------|-------|-------|
| $z_1$    | Q    | M   | $z_2$     | Q     | M      | $z_3$      | Q     | M     |
| 0        | -F   | 0   | 0         | -2F/3 | -Fl    | 0          | -2F/3 | 0     |
| l        | -F/4 | -Fl | 4l        | -2F/3 | -7Fl/3 | l          | -2F/3 | 2Fl/3 |

VI.10- shakl (g), (h) larda jadvallardagi qiymatlar bo'yicha qurilgan ko'ndalang kuch  $Q$  va eguvchi moment  $M$  larning epyuralari tasvirlangan.

#### 61- masala

Qo'zg'almas va qo'zg'aluvchan tayanchlarda yotuvchi oddiy to'singa  $q = \text{const}$  yoyilgan kuch intensivligi ta'sir ko'rsatmoqda (VI.11- shakl, a).  $Q$  va  $M$  epyuralari qurilsin.

#### Yechish:

Har galgidek, masalani yechishni tayanch reaksiyalarni aniqlashdan boshlaymiz (VI.11- shakl, b). Buning uchun statikaning muvozanat tenglamalarini tuzish kifoya:

$$\sum_{i=1}^n M_A(F_i) = 0; \quad ql \cdot \frac{l}{2} - R_B \cdot 2l = 0;$$

$$\sum_{i=1}^n M_B(F_i) = 0; \quad -ql \cdot \left(\frac{l}{2} + l\right) + R_A \cdot 2l = 0.$$

Bulardan,  $R_A = \frac{3}{4}ql$  va  $R_B = \frac{1}{4}ql$  ekanligi ma'lum.

Tayanch reaksiyalarning qiymatlarini tekshirib ko'rish maqsadida

$$\sum_{i=1}^n Y_i = 0; \quad R_A - ql + R_B = 0$$

tenglamani tuzamiz.

$$\text{Demak, } \frac{3}{4}ql - ql + \frac{1}{4}ql = 0 \text{ yoki } 0 = 0.$$

Kesish usulini qo'llab, V.11-shakl (d, e) chizmalarni hosil qilamiz. Natijada,  $Q$  va  $M$  larning analitik ifodalari quyidagi ko'rinishda yoziladi:

I oraliq:  $0 \leq z_1 \leq l$

$$Q_y'(z_1) = \pm \sum_{i=1}^2 Y_i = R_A - qz_1 = \frac{3}{4}ql - qz_1; \quad M_x'(z_1) = \pm \sum_{i=1}^2 M_{0i} = R_A \cdot z_1 - qz_1 \cdot \frac{z_1}{2} = \frac{3ql \cdot z_1}{4} - \frac{qz_1^2}{2}$$

(bu yerda  $z_1/2$  - kuch yelkasi, ya'ni teng ta'sir etuvchi  $qz_1$  qo'yilgan nuqtadan I-I kesimning og'irlik markazigacha bo'lgan masofa).

II oraliq: (o'ng tomon)  $0 \leq z_2 \leq l$

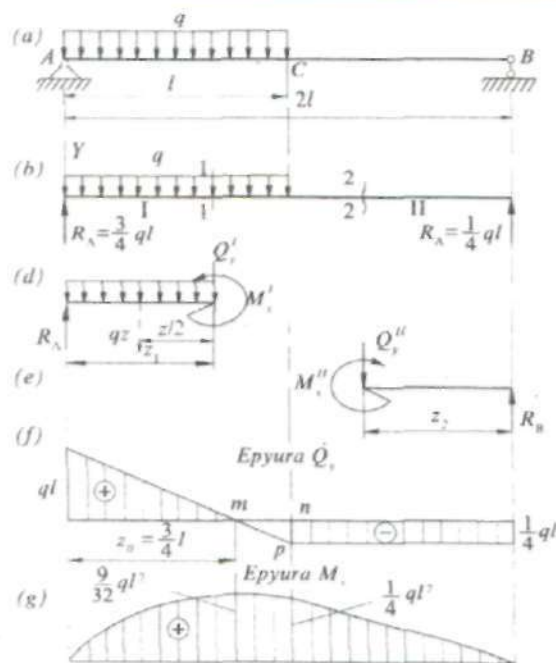
$$Q_y''(z_2) = \pm \sum_{i=1}^1 Y_i = -R_B = -\frac{1}{4}ql = \text{const}; \quad M_x''(z_2) = \pm \sum_{i=1}^1 M_{0i} = R_B \cdot z_2 = \frac{ql \cdot z_2}{4}$$

ifodaning birinchisi yordamida ko'ndalang kuch epyurasi quriladi:

$$z_1 = 0 \text{ da } Q_y'(0) = \frac{3}{4}ql;$$

$$z_2 = l \text{ da esa } Q_y''(0) = -\frac{1}{4}ql \text{ bo'ladi.}$$

Demak, I oraliqning boshlanishida ko'ndalang kuch musbat, oxirida esa manfiy qiymatga ega bo'lar ekan. Boshqacha aytganda,  $0 \leq z_1 \leq l$  oraliqda ko'ndalang kuch nolga teng bo'lgan kesim mavjud. Buni aniqlash uchun shu oraliqda ko'ndalang kuch tenglamasini nolga tenglab,



V.11-shakl

$z_1 = z_0$  ni aniqlaymiz:  $Q_y^I(z_1) = 0$  yoki  $\frac{3ql}{4} - qz_0 = 0$ . Bundan,  $z_0 = \frac{3l}{4}$  ekanligi kelib chiqadi.

$M_x^I(z_1)$  eguvchi momentning tenglamasi ikkinchi tartibli egri chiziq tenglamasidan iborat; shu sababli epyura qurish uchun eng kamida yana bitta nuqtadagi eguvchi moment qiymatini bilish shart.  $z_0 = 3l/4$  bo'lgan «o'ziga xos» kesimda eguvchi momentning qiymatini topamiz:

$$M_0 = \frac{3ql}{4} \cdot z_0 - \frac{q}{2} \cdot z_0^2 = \frac{3ql}{4} \cdot \frac{3l}{4} - \frac{q}{2} \cdot \left(\frac{3l}{4}\right)^2 = \frac{9ql^2}{32}.$$

*Eslatma:* materiallar qarshiligi to'la kursida ko'ndalang kuch nolga teng bo'lgan kesimda eguvchi moment ekstremal (max yoki min) qiymatga erishishi isbotlangan. Shu bois, biz tekshirayotgan hol uchun:

$$z_0 = \frac{3l}{4} \text{ da } M_0 = \frac{9ql^2}{32} \text{ bo'ladi.}$$

Odatdagidek, har bir oraliq uchun jadval tuzamiz:

| I oraliq       |                 |                    | II oraliq |                 |                  |
|----------------|-----------------|--------------------|-----------|-----------------|------------------|
| $z_1$          | $Q$             | $M$                | $z_2$     | $Q$             | $M$              |
| 0              | $\frac{3ql}{4}$ | 0                  | 0         | $-\frac{ql}{4}$ | 0                |
| $\frac{3l}{4}$ | 0               | $\frac{9ql^2}{32}$ |           |                 |                  |
| $l$            | $-\frac{ql}{4}$ | $\frac{ql^2}{4}$   | $l$       | $\frac{ql}{4}$  | $\frac{ql^2}{4}$ |

Jadvaldagi qiymatlar bo'yicha ma'lum masshtabda ko'ndalang kuch  $Q$  va eguvchi moment  $M$  larning epyuralarini quramiz (VI.11- shakl, f, g).

### 62- masala

Konsol uchli to'singa juft kuch va  $Q$  yoyilgan kuch ta'sir ko'rsatmoqda (VI.12- shakl, a). Shu to'sin uchun ko'ndalang kuch va eguvchi momentning epyurasi qurilsin. Quyidagilar ma'lum:  $q = 4 \cdot 10^4 \text{ N/m}$ ;  $M = 3 \cdot 10^4 \text{ N} \cdot \text{m}$ ;  $l = 1 \text{ m}$ .

### Yechish:

To'sinning tayanchlarini tayanch reaksiyalari bilan almashtiramiz:  $R_A$  va  $R_B$  larni aniqlash uchun esa statikaning muvozanat tenglamalarini tuzamiz:

$$\Sigma M_A = 0, \quad q \cdot \frac{3l}{2} \cdot 2 \cdot \frac{3l}{3} + M - R_B \cdot 3l = 0; \quad \text{bundan, } R_B = 5 \cdot 10^4 \text{ N};$$

$$\Sigma M_B = 0, R_A \cdot 3l - q \cdot \frac{3l}{2} \cdot \frac{3l}{3} + M = 0;$$

bundan,  $R_A = 1 \cdot 10^4$  N.

**Tekshirish:**

$$\Sigma Y_1 = 0, R_A - q \cdot \frac{3l}{2} + R_B = 0 \text{ yoki}$$

$$1 \cdot 10^4 - 1,5 \cdot 4 \cdot 10^4 \cdot 1 + 5 \cdot 10^4 = 0, 0 = 0.$$

Oxirgi tenglama tayanch reaksiyalarining to'g'ri topilganligini tasdiqlaydi.

To'sin o'qi bo'yicha  $Z$  ni yo'naltirib, oraliqni mos ravishda  $I$  va  $II$  raqamlari bilan belgilaymiz. Yana kesim usuliga murojaat etib, har bir oraliqni tegishlicha  $I-I$  va  $II-II$  tekisliklari bilan fikran qirqamiz.

Qirqimning ixtiyoriy tomonidan bo'lakchalar ajratib olib,  $Q$  va  $M$  larning tenglamalarini tuzamiz:

I oraliq: (chap tomon uchun)  $0 \leq z_1 \leq 3l$

$$Q(z_1) = R_A - q(z_1) \cdot \frac{z_1}{2}; \quad M(z_1) = R_A \cdot z_1 - q(z_1) \cdot \frac{z_1}{2} \cdot \frac{z_1}{3};$$

bu yerda,  $q(z_1)$  – ixtiyoriy  $z_1$  uzunlikka to'g'ri keluvchi yoyilgan kuch intensivligi bo'lib, quyidagi munosabatdan topiladi:

$$\frac{q(z_1)}{q} = \frac{z_1}{3l} \text{ yoki } q(z_1) = \frac{q \cdot z_1}{3l}.$$

Shunday qilib, I oraliqda ichki zo'riqishlar quyidagi tenglamalar yordamida ifodalanadi (chiziqli bo'lmagan bog'lanish):

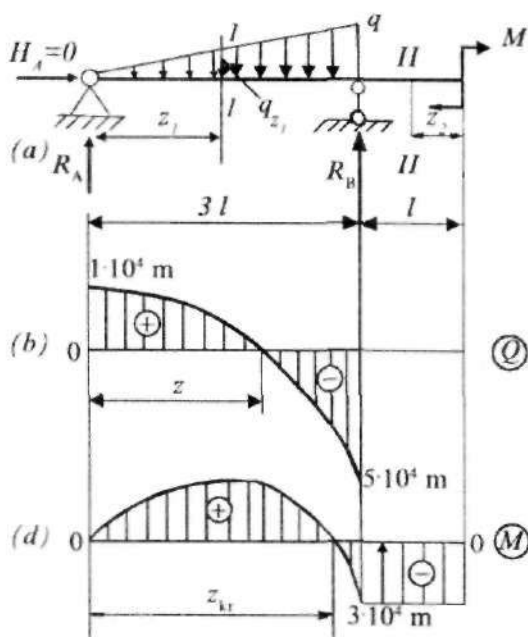
$$Q_y(z_1) = R_A - \frac{q \cdot z_1^2}{6l}; \quad M(z_1) = R_A \cdot z_1 - \frac{q \cdot z_1^3}{18l};$$

$$z_1 = 0 \text{ bo'lsa, } Q_y(0) = 1 \cdot 10^4 \text{ N, } M(0) = 0;$$

$$z_1 = 3 \text{ m bo'lsa, } Q_y(3) = -5 \cdot 10^4 \text{ N, } M(3) = -3 \cdot 10^4 \text{ N} \cdot \text{m}.$$

Bu oraliqda ichki zo'riqishlar to'sin o'qi bo'yicha chiziqli bo'lmagan qonuniyatga ko'ra o'zgaruvchanligi sababli, ularning epyurasini qurishda 1- jadvaldan foydalanamiz (oldingi masalaga qarang). Unda:

$$Q^y(z_1) = 0, \quad R_A - \frac{q \cdot z_1^2}{6l} = 0.$$



VI.12- shakl

Bundan kritik nuqtani topamiz:  $z = 0$ .

Demak, I oraliqning boshida  $Q$  ning epyurasiga urunma o'tkazish lozim.

|          |                      |
|----------|----------------------|
|          | $0 \leq z_1 \leq 3l$ |
| $Q^I(z)$ | —                    |
| $Q(z)$   | (kamayadi)           |

Ikkinchi tartibli hosila  $Q^{II}(z_1) = -\frac{q}{3l} < 0$  bo'lganligi uchun  $Q$  epyurasi  $[0, 3l]$  oraliqda qavariq bo'ladi; bu epyuraning absissa o'qi bilan kesishuv nuqtasi  $M^I(z_1) = 0$  tenglamadan topiladi:

$$z_{kr1} = \left[ \sqrt{\frac{6R_A \cdot l}{q}} \right] = \sqrt{\frac{3}{2}} \text{ m}$$

tenglik o'rinli bo'ladi.

$Q^I(z_1) = R_A - \frac{q \cdot z_1^2}{6l} = 0$  tenglamadan kritik nuqtani topamiz:

$$z_{kr} = \sqrt{\frac{6}{4}} \text{ m} = \sqrt{\frac{3}{2}} \text{ m}.$$

|          |                    |          |                     |
|----------|--------------------|----------|---------------------|
|          | $0 < z_1 < z_{kr}$ | $z_{kr}$ | $z_{kr} < z_1 < 3l$ |
| $M^I(z)$ | +                  | 0        | —                   |
| $M(z)$   | ↗                  | max      | ↘                   |

Tekshirilayotgan oraliqda ikkinchi tartibli hosila  $M^{II}(z) = -\frac{q \cdot z_1}{3l} < 0$  bo'lganligi uchun  $M$  epyurasi qavariq bo'ladi. Eguvchi moment epyurasi I oraliqda  $Z$  o'qini ikki joyda: koordinata boshida va  $M(z_1) = 0$  tenglamadan aniqlanadigan

$$z_{kr2} = \sqrt{\frac{18R_A \cdot l}{q}} = 2,12 \text{ m}$$

masofada kesib o'tadi.

II oraliq: (o'ng tomon uchun)  $0 \leq z_2 \leq l$

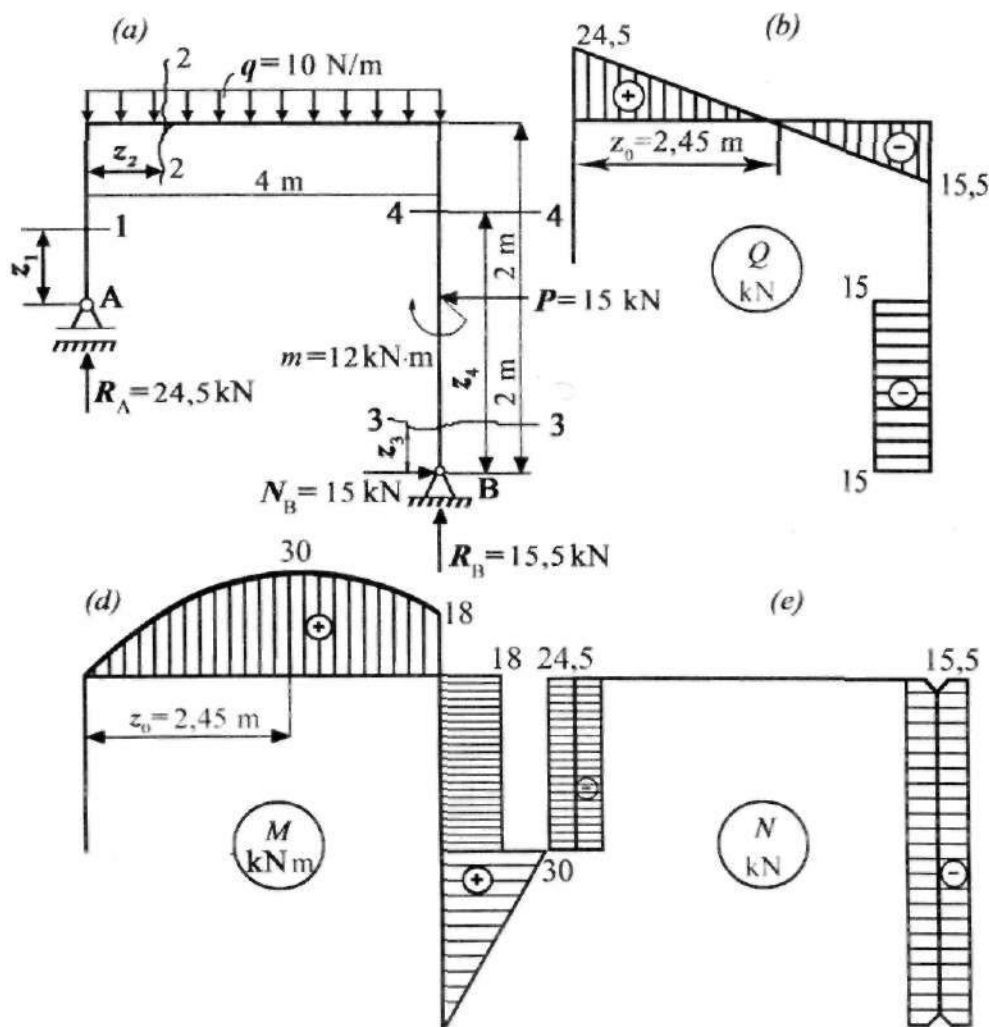
$$Q(z_2) = 0; \quad M(z_2) = -M = \text{const.}$$

VI.12- shakl (b, d) da  $Q$  va  $M$  epyuralari tasvirlangan.

### 6.4- §. Statik aniq rama, siniq va egri balkalar uchun ichki kuch faktorlari epyuralarini qurish

#### 63- masala

Quyida berilgan statik aniq rama uchun kesuvchi kuch ( $Q$ ), eguvchi moment ( $M$ ) va bo'ylama kuch ( $N$ ) epyuralari qurilsin. Qiymatlar VI.13- shaklda berilgan.



VI.13- shakl

**Yechish:**1. Tayanch reaksiya kuchlarini aniqlaymiz:

$$\Sigma X = 0; H_B - P = 0 \Rightarrow H_B = P = 15 \text{ kN};$$

$$\Sigma M_A = 10 \cdot 4 \cdot 2 - 15 \cdot 2 + 12 - 4R_B = 0 \Rightarrow R_B = 15,5 \text{ kN};$$

$$\Sigma M_B = 4R_A - 10 \cdot 4 \cdot 2 - 15 \cdot 2 + 12 = 0 \Rightarrow R_A = 24,5 \text{ kN}.$$

$$\text{Tekshirish: } \Sigma Y = 0; 24,5 + 15,5 - 10 \cdot 4 = 0.$$

Demak, tayanch reaksiya kuchlari to'g'ri topilgan.

Ramani to'rtta uchastkaga bo'lib, kesish usulini qo'llab, uchastkalardagi  $Q$ ,  $M$  va  $N$  qiymatlarini aniqlaymiz.

2. Kesuvchi kuch qiymatlarini aniqlaymiz:

I uchastka:  $0 \leq z_1 \leq 2 \text{ m}$   $Q = 0$ ;

II uchastka:  $0 \leq z_2 \leq 4 \text{ m}$   $Q = R_A - q \cdot z_2$ ;

$$z_2 = 0 \text{ bo'lsa, } Q = 24,5 \text{ kN};$$

$$z_2 = 4 \text{ m bo'lsa, } Q = 24,5 - 10 \cdot 4 = -15,5 \text{ kN};$$

III uchastka:  $0 \leq z_3 \leq 2 \text{ m}$   $Q = -H_B = -15 \text{ kN}$ ;

IV uchastka:  $2 \text{ m} \leq z_4 \leq 4 \text{ m}$   $Q = -H_B + P = -15 + 15 = 0$ .

Aniqlangan qiymatlar bo'yicha  $Q$  epyurasini quramiz (VI.13- shakl, b).

3. Eguvchi moment qiymatlarini aniqlaymiz:

I uchastka:  $0 \leq z_1 \leq 2 \text{ m}$   $M = 0$ ;

II uchastka:  $0 \leq z_2 \leq 4 \text{ m}$   $M = R_A \cdot z_2 - q \cdot z_2^2 / 2$ ;

$$z_2 = 0 \text{ bo'lsa, } M = 0;$$

$$z_2 = 4 \text{ m bo'lsa, } M = 24,5 \cdot 4 - 10 \cdot 4^2 / 2 = 18 \text{ kN} \cdot \text{m}.$$

$M$  ning ekstremal qiymatlarini aniqlaymiz:  $\frac{dM}{dz} = R_A - q \cdot z_2$ ;  $24,5 - 10 \cdot z_2 = 0$ ;

$$z_0 = z_2 = 2,45 \text{ m bo'lsa, } M_{\max} = 24,5 \cdot 2,45 - 10 \cdot 2,45^2 / 2 = 31,2 \text{ kN} \cdot \text{m}.$$

III uchastka:  $0 \leq z_3 \leq 2 \text{ m}$   $M = H_B \cdot z_3$ ;

$$z_3 = 0 \text{ bo'lsa, } M = 0;$$

$$z_3 = 2 \text{ m bo'lsa, } M = 15 \cdot 2 = 30 \text{ kN} \cdot \text{m}.$$

IV uchastka: (sof egilish, chunki  $Q_4 = 0$ )

$$M = \text{const} = H_B \cdot 2 - m = 30 - 12 = 18 \text{ kN} \cdot \text{m}.$$

Aniqlangan qiymatlar bo'yicha  $M$  epyurasini quramiz (VI.13- shakl, d).

4. Bo'ylama kuch qiymatlarini aniqlaymiz:

I uchastka:  $0 \leq z_1 \leq 2 \text{ m}$   $N = -R_A = -24,5 \text{ kN}$ ;

II uchastka:  $0 \leq z_2 \leq 4 \text{ m}$   $N = 0$ ;

III uchastka:  $0 \leq z_3 \leq 2 \text{ m}$   $N = -R_B = -15,5 \text{ kN}$ ;

IV uchastka:  $2 \text{ m} \leq z_4 \leq 4 \text{ m}$   $N = -R_B = -15,5 \text{ kN}$ .

Aniqlangan qiymatlar bo'yicha  $N$  epyurasini quramiz (VI.13- shakl, e).



## 64- masala

Berilgan siniq balka uchun  $M$ ,  $Q$  va  $N$  epyuralari aniqlansin. Qiymatlar VI.14- shaklda berilgan.

## Yechish:

## 1. Tayanch reaksiya kuchlarini aniqlaymiz:

$$\Sigma X = 0; H_A - 10 \cdot 2 = 0 \Rightarrow H_A = 20 \text{ kN};$$

$$\Sigma Y = 0; R_A - 15 = 0 \Rightarrow R_A = 15 \text{ kN};$$

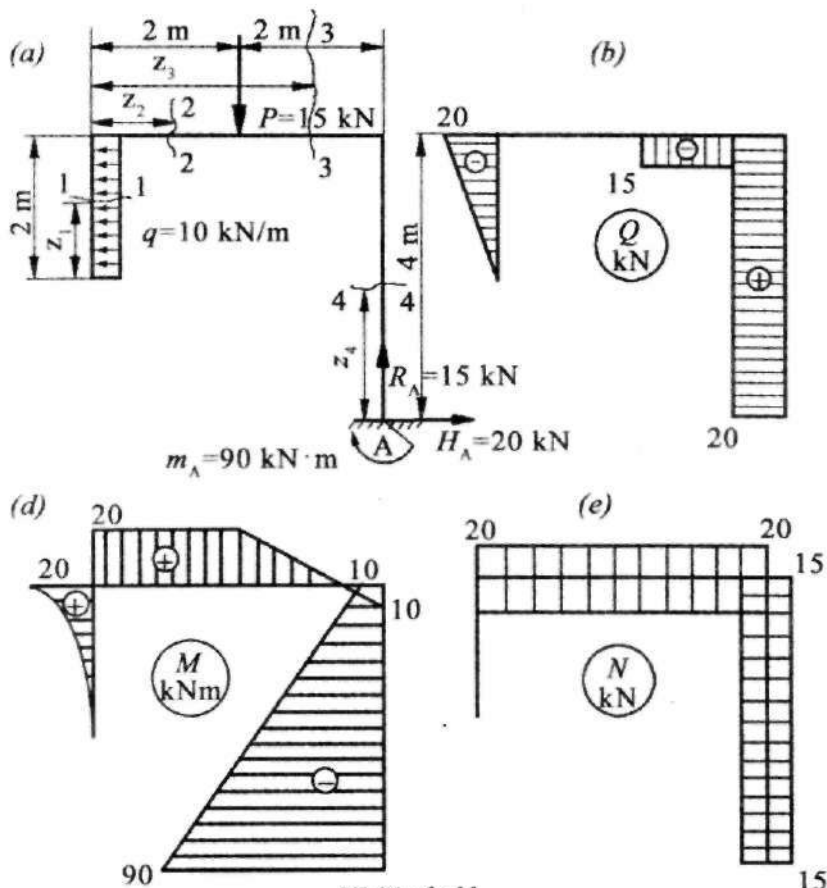
$$\Sigma M_A = 0; 10 \cdot 2 \cdot 3 + 15 \cdot 2 - m_A = 0 \Rightarrow m_A = 90 \text{ kN} \cdot \text{m}.$$

## 2. Kesuvchi kuch qiymatlarini aniqlaymiz:

I uchastka:  $0 \leq z_1 \leq 2 \text{ m}; Q = q \cdot z_1;$

$z_1 = 0$  bo'lsa,  $Q = 0;$

$z_1 = 2 \text{ m}$  bo'lsa,  $Q = 10 \cdot 2 = 20 \text{ kN}.$



VI.14- shakl

II uchastka:  $0 \leq z_2 \leq 2 \text{ m}; Q = 0;$

III uchastka:  $2 \text{ m} \leq z_3 \leq 4 \text{ m}; Q = -P = -15 \text{ kN};$

IV uchastka:  $0 \leq z_4 \leq 4 \text{ m}; Q = -H_A = -20 \text{ kN}.$

Aniqlangan qiymatlar bo'yicha  $Q$  epyurasini quramiz (VI.14- shakl, b).

3. Eguvchi moment qiymatlarini aniqlaymiz:

I uchastka:  $0 \leq z_1 \leq 2 \text{ m}; M = q \cdot z_1^2 / 2;$

$z_1 = 0$  bo'lsa,  $M = 0;$

$z_1 = 2 \text{ m}$  bo'lsa,  $M = 10 \cdot 2^2 / 2 = 20 \text{ kN} \cdot \text{m};$

II uchastka:  $0 \leq z_2 \leq 2 \text{ m}; M = \text{const} = 10 \cdot 2 = 20 \text{ kN} \cdot \text{m};$

III uchastka:  $2 \text{ m} \leq z_3 \leq 4 \text{ m}; M = q \cdot 2 \cdot 1 - P \cdot (z_3 - 2);$

$z_3 = 2 \text{ m}; M = 20 \text{ kN} \cdot \text{m};$

$z_3 = 4 \text{ m}; M = 20 - 15(4 - 2) = -10 \text{ kN} \cdot \text{m};$

IV uchastka:  $0 \leq z_4 \leq 4 \text{ m}; M = -m_A + H_A \cdot z_4;$

$z_4 = 0; M = -m_A = -90 \text{ kN} \cdot \text{m};$

$z_4 = 4 \text{ m}; M = -90 + 20 \cdot 4 = -10 \text{ kN} \cdot \text{m}.$

Aniqlangan qiymatlar bo'yicha  $M$  epyurasini quramiz (VI.14- shakl, d).

4. Bo'ylama kuch qiymatlarini aniqlaymiz:

I uchastka:  $0 \leq z_1 \leq 2 \text{ m}; N = 0;$

II uchastka:  $0 \leq z_2 \leq 2 \text{ m}; N = 20 \text{ kN};$

III uchastka:  $0 \leq z_3 \leq 4 \text{ m}; N = 20 \text{ kN};$

IV uchastka:  $2 \text{ m} \leq z_4 \leq 4 \text{ m}; N = -R_A = -15 \text{ kN}.$

Aniqlangan qiymatlar bo'yicha  $N$  epyurasini quramiz (VI.14- shakl, e).

### 65- masala

Berilgan siniq balka uchun  $M, Q$  va  $N$  epyuralari qurilsin. Qiymatlar VI.15- shaklda berilgan.

### Yechish:

1. Tayanch reaksiya kuchlarini aniqlaymiz:

$\Sigma X = 0; H_A = 0;$

$\Sigma Y = 0; R_A - 10 \cdot 2 - 15 = 0 \Rightarrow R_A = 35 \text{ kN};$

$\Sigma M_A = 0; M_A - 10 \cdot 2 \cdot 1 - 15 \cdot 2 - 12 = 0 \Rightarrow M_A = 62 \text{ kN} \cdot \text{m}.$

2. Kesuvchi kuch qiymatlarini aniqlaymiz:

I uchastka:  $0 \leq z_1 \leq 2 \text{ m};$

$z_1 = 0$  bo'lsa,  $Q = 35 \text{ kN};$

$z_1 = 2 \text{ m}$  bo'lsa,  $Q = 35 - 10 \cdot 2 = 15 \text{ kN};$

II uchastka:  $2 \text{ m} \leq z_2 \leq 4 \text{ m}; Q = 15 \text{ kN};$

III uchastka:  $0 \leq z_3 \leq 2 \text{ m}; Q = -P = -15 \text{ kN};$

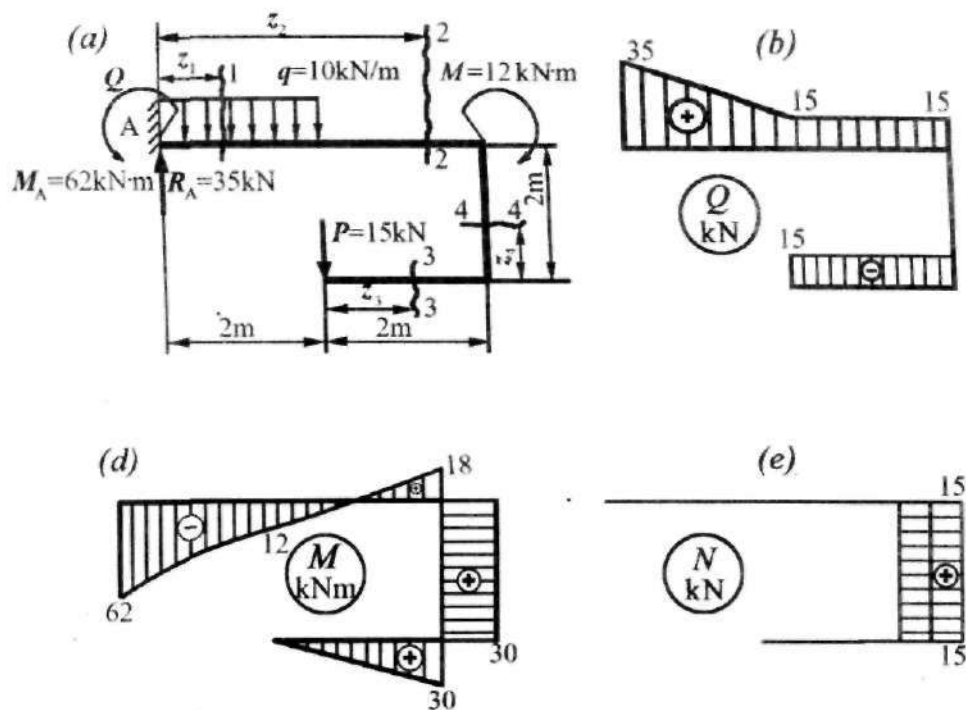
IV uchastka:  $0 \leq z_4 \leq 2 \text{ m}; Q = 0.$

Aniqlangan qiymatlar bo'yicha  $Q$  epyurasini quramiz (VI.15- shakl, b).

## 3. Eguvchi moment qiymatlarini aniqlaymiz:

I uchastka:  $0 \leq z_1 \leq 2$  m;  $M = -M_A + R_A \cdot z_1 - q \cdot z_1^2/2$ ; $z_1 = 0$  bo'lsa,  $M = -M_A = -62$  kN·m; $z_1 = 2$  m bo'lsa,  $M = -62 + 35 \cdot 2 - 10 \cdot 2^2/2 = -62 + 70 - 20 = -12$  kN·m.II uchastka:  $2 \leq z_2 \leq 4$  m;  $M = -M_A + R_A \cdot z_2 - q \cdot 2(z_2 - 1)$ ; $z_2 = 2$  m bo'lsa,  $M = -62 + 35 \cdot 2 - 10 \cdot 2 \cdot 1 = -12$  kN·m; $z_2 = 4$  m bo'lsa,  $M = -62 + 35 \cdot 2 - 10 \cdot 2 \cdot 3 = 18$  kN·m.III uchastka:  $0 \leq z_3 \leq 2$  m;  $M = P \cdot z_3$ ; $z_3 = 0$  bo'lsa,  $M = 0$ ; $z_3 = 2$  m bo'lsa,  $M = 15 \cdot 2 = 30$  kN·m.IV uchastka:  $0 \leq z_4 \leq 2$  m;  $M = P \cdot z_4$ ; $z_4 = 0$  bo'lsa,  $M = 0$ ; $z_4 = 2$  m bo'lsa,  $M = 15 \cdot 2 = 30$  kN·m;Aniqlangan qiymatlar bo'yicha  $M$  epyurasini quramiz (VI.15- shakl, d).

## 4. Bo'yлама kuch qiymatlarini aniqlaymiz:

I uchastka:  $0 \leq z_1 \leq 2$  m;  $N = 0$ ;II uchastka:  $2 \text{ m} \leq z_2 \leq 4$  m;  $N = 0$ ;

VI.15- shakl

III uchastka:  $0 \leq z_3 \leq 2 \text{ m}$ ;  $N = 0$ ;

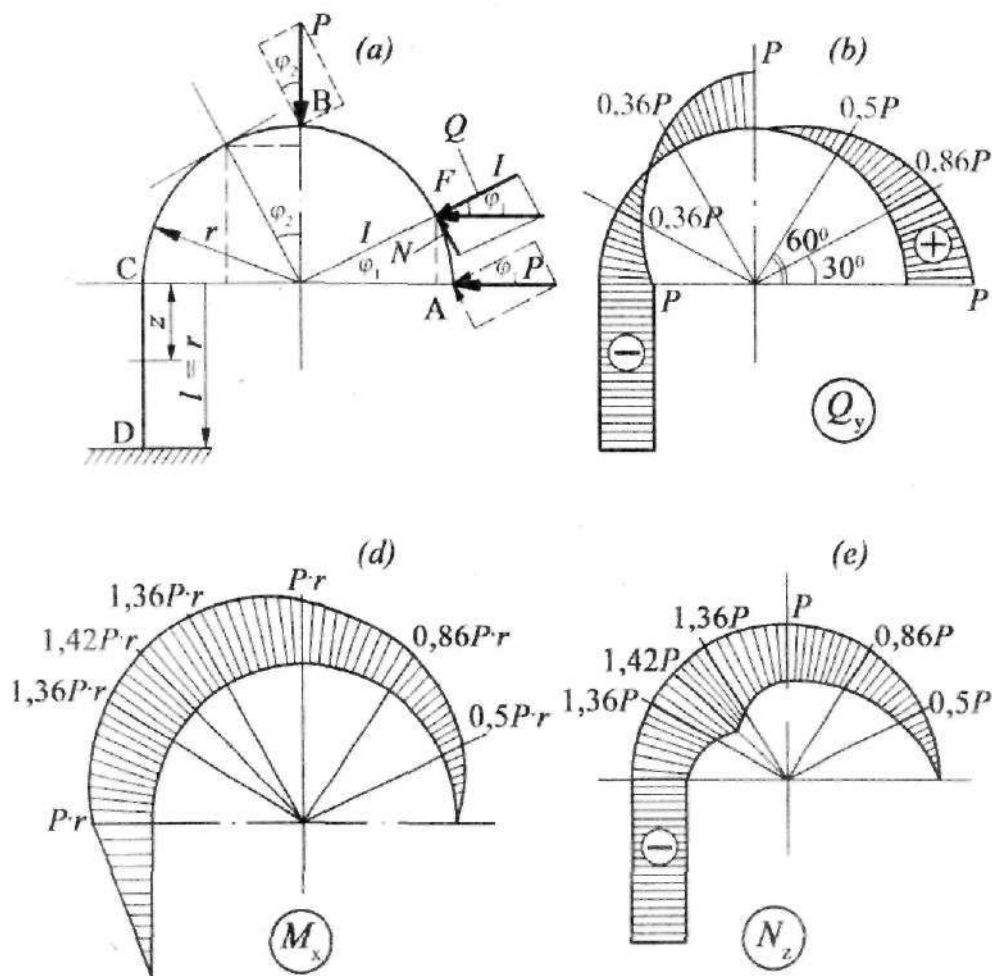
IV uchastka:  $0 \leq z_4 \leq 2 \text{ m}$ ;  $N = 15 \text{ kN}$ .

Aniqlangan qiymatlar bo'yicha  $N$  epyurasini quramiz (VI.15- shakl, e).

Yuqorida keltirilgan masalani siniq balkalardagi tayanch reaksiya kuchlarini aniqlamasdan yechish ham mumkin. Unda balka uchastkalari erkin uchidan boshlab fikran kesilib, har gal mahkamlangan tomon tashlab yuboriladi.

### 66- masala

Berilgan egri sterjen uchun  $M$ ,  $Q$  va  $N$  epyuralari qurilsin. Qiymatlar VI.16-shaklda berilgan.



VI.16- shakl

**Yechish:**

Bu masalani tayanch reaksiya kuchlarini aniqlamasdan, erkin uchidan boshlab yechamiz. Brus uchta uchastkadan iborat bo'lib, ular egri chiziqli AB va BC hamda to'g'ri chiziqli CD lardir.

Bu uchastkalarni alohida ko'rib o'tamiz:

1. AB uchastka:  $0 \leq \varphi_1 \leq \pi/2$ .

AB uchastkadan fikran F nuqta orqali I-I kesim o'tkazamiz. R kuchni F nuqtaga ko'chiramiz. Unda birinchi uchastkada hosil bo'lgan ichki kuch faktorlari teng bo'ladi:

$$Q^I(\varphi_1) = P \cdot \cos \varphi_1; \quad M_z^I(\varphi_1) = P \cdot r \cdot \sin \varphi_1; \quad N_z^I(\varphi_1) = -P \cdot \sin \varphi_1.$$

Yuqoridagi tenglamalarga  $\varphi_1$  ning qiymatlarini qo'yib, quyidagi jadvalni tuzamiz:

|   | $\varphi_1$                                         | 0   | $\pi/6$  | $\pi/3$   | $\pi/2$ |
|---|-----------------------------------------------------|-----|----------|-----------|---------|
| 1 | $Q^I(\varphi_1) = P \cdot \cos \varphi_1$           | $P$ | $0,86 P$ | $-0,5 P$  | 0       |
| 2 | $M_z^I(\varphi_1) = P \cdot r \cdot \sin \varphi_1$ | 0   | $0,5 Pr$ | $0,86 Pr$ | $Pr$    |
| 3 | $N_z^I(\varphi_1) = -P \cdot \sin \varphi_1$        | 0   | $-0,5 P$ | $0,86 P$  | $-P$    |

2. BC uchastka:  $\pi/2 \geq \varphi_2 \geq 0$ .

Ikkinchi uchastkada esa tenglamalar quyidagi ko'rinishda bo'ladi:

$$Q^II(\varphi_2) = -P \cdot \sin \varphi_2 + P \cdot \cos \varphi_2; \quad M_z^II(\varphi_2) = P \cdot r \cdot \cos \varphi_2 + P \cdot r \cdot \sin \varphi_2;$$

$$N_z^II(\varphi_2) = -P \cdot \cos \varphi_2 - P \cdot \sin \varphi_2.$$

Bu tenglamalarga ham  $\varphi_2$  ning qiymatlarini qo'yib, quyidagi jadvalni tuzamiz:

|   | $\varphi_2$                                                                           | 0    | $\pi/6$   | $\pi/3$   | $\pi/2$ |
|---|---------------------------------------------------------------------------------------|------|-----------|-----------|---------|
| 1 | $Q^II(\varphi_2) = -P \cdot \sin \varphi_2 + P \cdot \cos \varphi_2$                  | $P$  | $0,36 P$  | $-0,36 P$ | $-P$    |
| 2 | $M_z^II(\varphi_2) = P \cdot r \cdot \cos \varphi_2 + P \cdot r \cdot \sin \varphi_2$ | $Pr$ | $1,36 Pr$ | $1,36 Pr$ | $Pr$    |
| 3 | $N_z^II(\varphi_2) = -P \cdot \cos \varphi_2 - P \cdot \sin \varphi_2$                | $-P$ | $-1,36 P$ | $1,36 P$  | $-P$    |

2. CD uchastka:  $0 \leq z \leq l$ .

Uchinchi uchastkada hosil bo'lgan ichki kuch faktorlari quyidagiga teng bo'ladi:

$$Q^III(z) = -P; \quad N^III(z) = -P; \quad M_z^III(z) = -P \cdot z + P \cdot 2; \quad M_z^III(0) = P \cdot r; \quad M_z^III(l) = 0.$$

Topilgan qiymatlar bo'yicha  $Q$  (VI.16-shakl, b),  $M$  (VI.16-shakl, d) va  $N$  (VI.16-shakl, e) epyuralarini quramiz.

## 6.5- §.To'g'ri egilishda balka va ramalar uchun ichki kuch faktorlari epyuralarini qurish bo'yicha topshiriqlar

### 9- topshiriq

To'g'ri egilishda kesuvchi kuch va eguvchi moment epyuralarini qurish. To'sinlar ko'ndalang kesimlarini tanlash.

**Berilgan:** Keltirilgan shakllarda tashqi tomondan yuklangan to'sinlar berilgan.

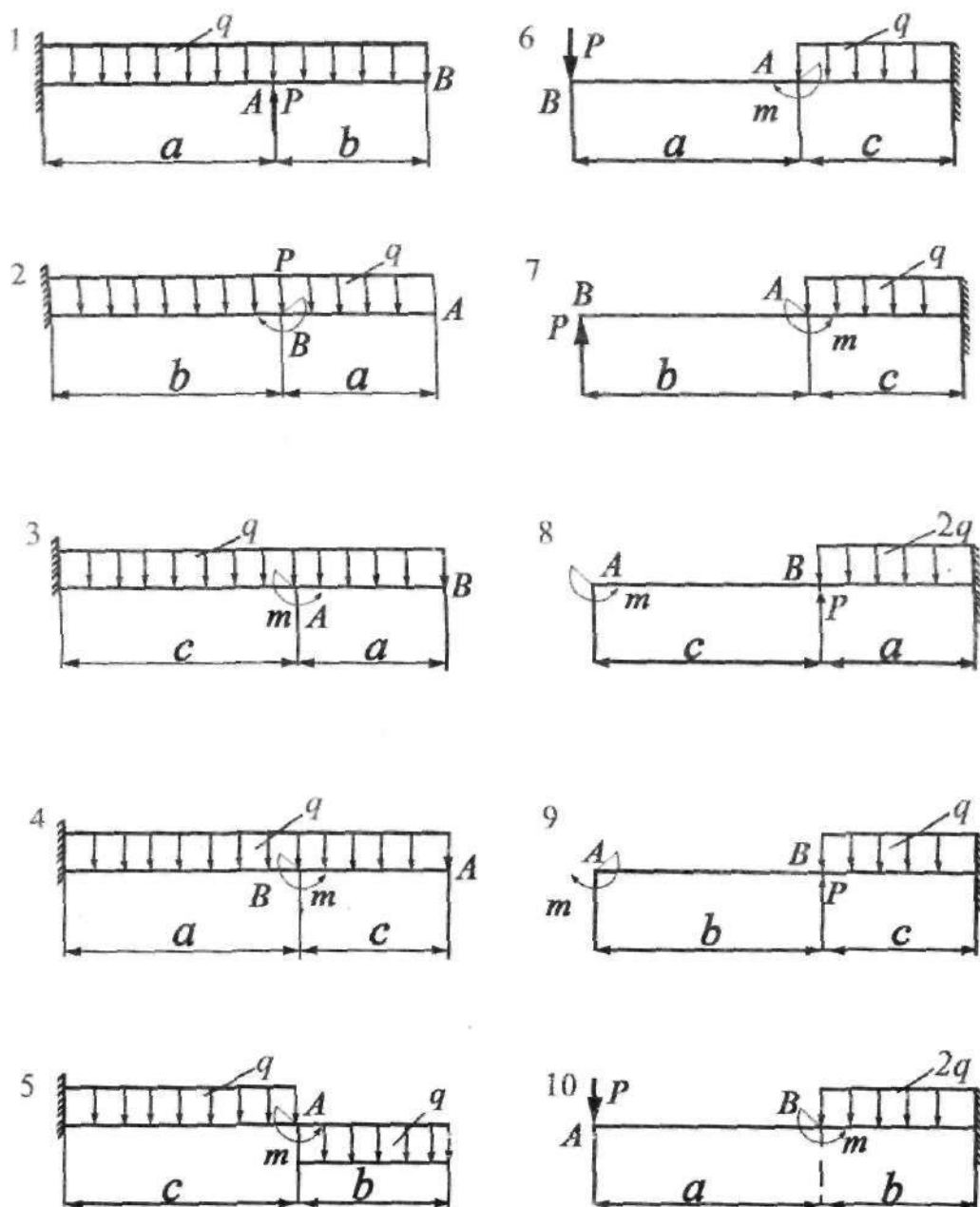
**Topish kerak:**

- 1) berilgan to'sinlar uchun kesuvchi kuch va eguvchi moment epyuralari qurilsin;
- 2) mustahkamlik shartiga binoan, to'sinning ko'ndalang kesimi tanlansin (kesim ko'rinishi – o'qituvchi ko'rsatmasi bo'yicha).

Kerakli ma'lumotlar VI.1-jadvalda, hisoblash sxemalari esa VI.17- shaklda berilgan.

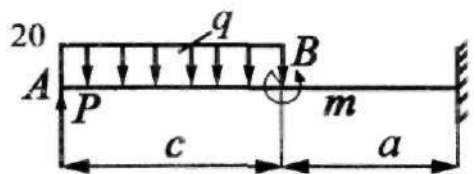
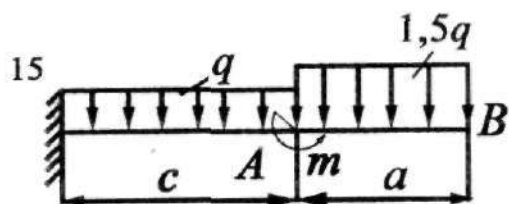
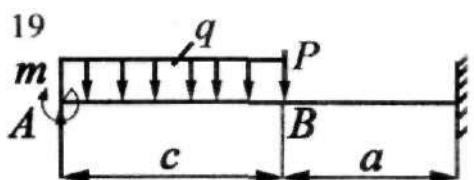
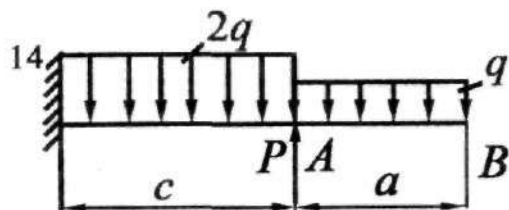
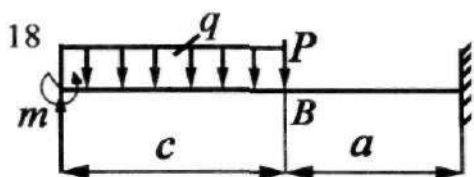
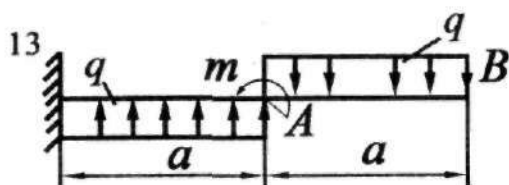
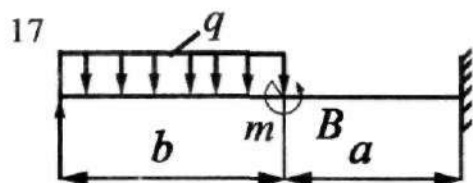
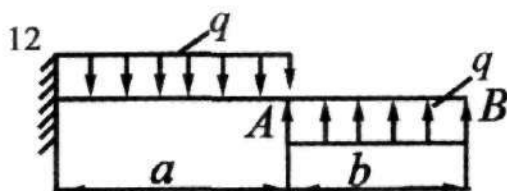
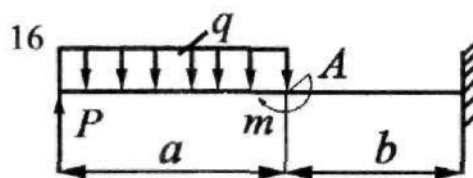
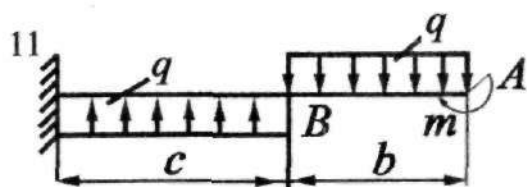
VI.1- jadval

| №  | $\alpha$ | $b$  | $C$  | $P$   | $M$     | $q, \text{kN/m}$ | $l, \text{m}$ |
|----|----------|------|------|-------|---------|------------------|---------------|
| 1  | $l$      | $2l$ | $3l$ | $ql$  | $2ql^2$ | 2                | 1             |
| 2  | $2l$     | $3l$ | $4l$ | $2ql$ | $3ql^2$ | 3                | 1             |
| 3  | $3l$     | $4l$ | $l$  | $3ql$ | $4ql^2$ | 4                | 1             |
| 4  | $4l$     | $l$  | $2l$ | $4ql$ | $5ql^2$ | 5                | 1             |
| 5  | $l$      | $2l$ | $3l$ | $5ql$ | $6ql^2$ | 6                | 1             |
| 6  | $2l$     | $3l$ | $4l$ | $6ql$ | $7ql^2$ | 2                | 1             |
| 7  | $3l$     | $4l$ | $l$  | $7ql$ | $8ql^2$ | 3                | 1             |
| 8  | $4l$     | $l$  | $2l$ | $8ql$ | $ql^2$  | 4                | 1             |
| 9  | $l$      | $2l$ | $3l$ | $9ql$ | $2ql^2$ | 5                | 1             |
| 10 | $2l$     | $3l$ | $4l$ | $ql$  | $3ql^2$ | 6                | 1             |



VI.17- shakl

VI.17- shakl (davomi)





## 10- topshiriq

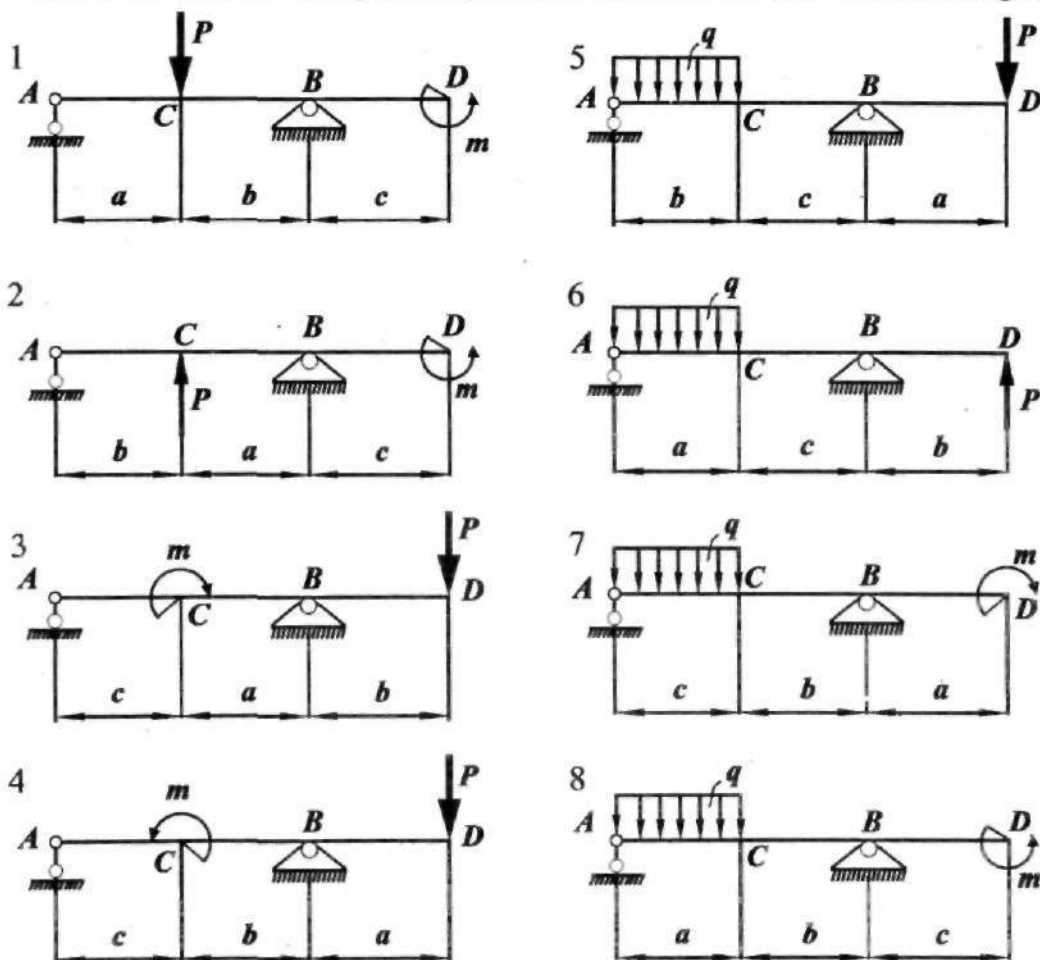
To'g'ri egilishda kesuvchi kuch va eguvchi moment epyuralarini qurish. To'sinlar ko'ndalang kesimlarini tanlash.

**Berilgan:** Keltirilgan shakllarda (VI.18- shakl) tashqi tomondan yuklangan to'sinlar berilgan.

**Topish kerak:**

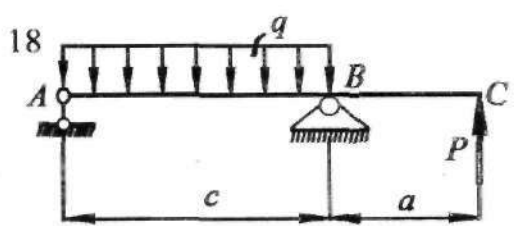
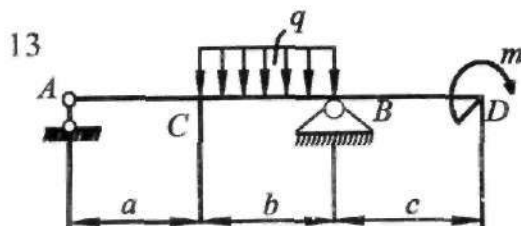
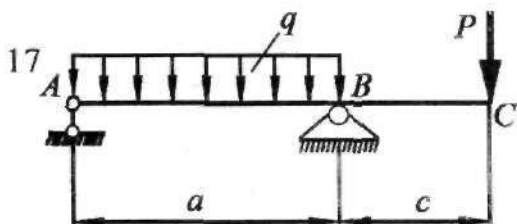
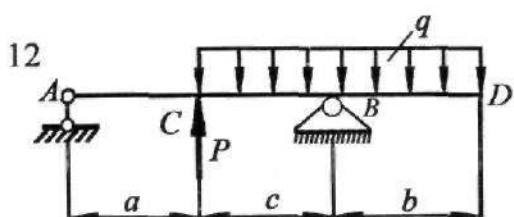
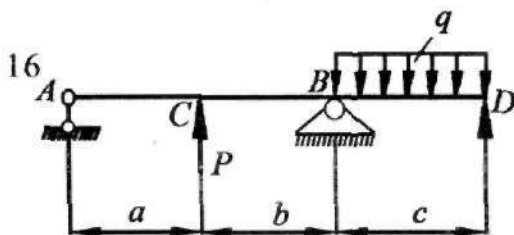
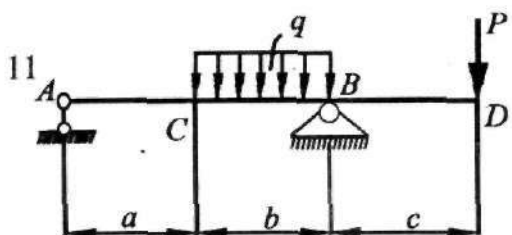
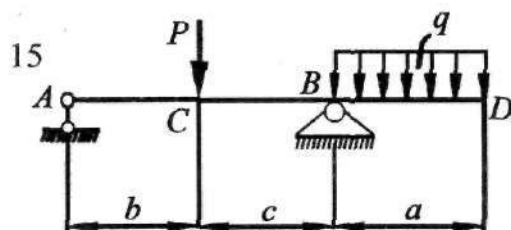
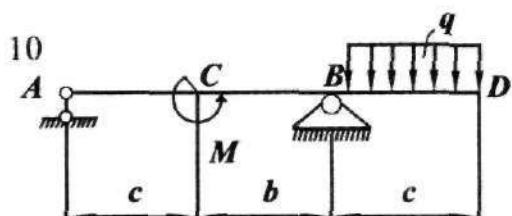
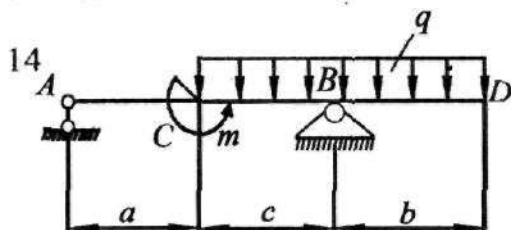
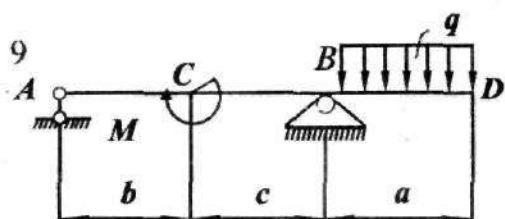
- 1) berilgan to'sinlar uchun kesuvchi kuch va eguvchi moment epyuralari qurilsin;
- 2) mustahkamlik shartiga binoan to'sinning ko'ndalang kesimi tanlansin (kesim ko'rinishi – o'qituvchi ko'rsatmasi bo'yicha).

Kerakli ma'lumotlar VI.1- jadvalda, hisoblash sxemalari esa VI.18- shaklda berilgan.

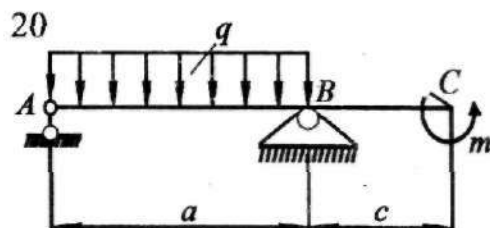
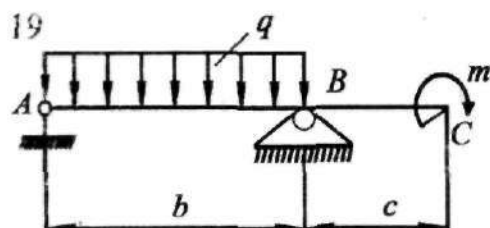


VI.18- shakl

VI.18- shakl (davomi)



VI.18 - shakl (davomi)



## 11- topshiriq

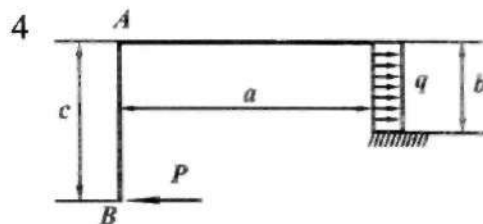
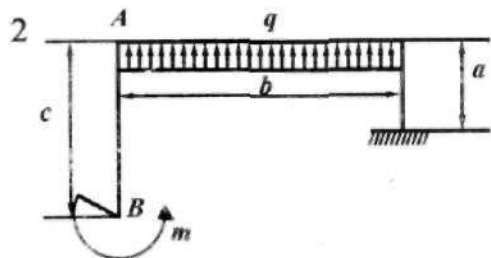
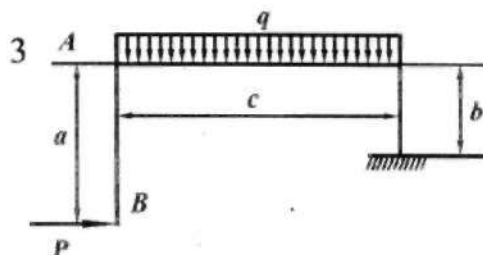
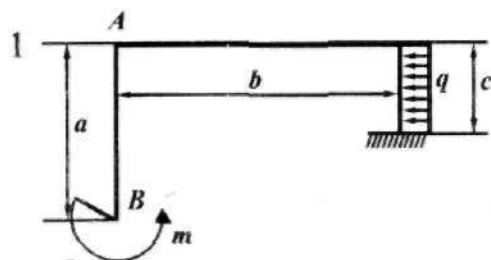
Siniq sterjenlar uchun ichki kuch faktorlari epyuralarini qurish.

**Topish kerak:**

1) berilgan siniq sterjen uchun (VI.19- shakl) bo'ylama kuch, kesuvchi kuch va eguvchi moment epyuralari qurilsin;

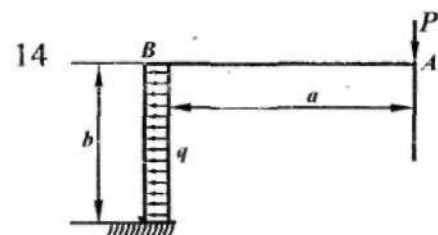
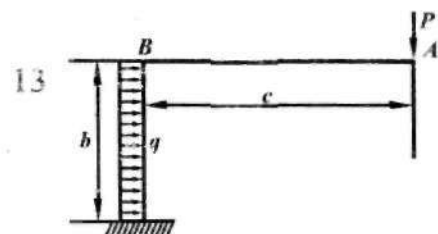
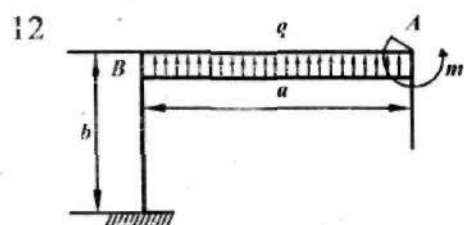
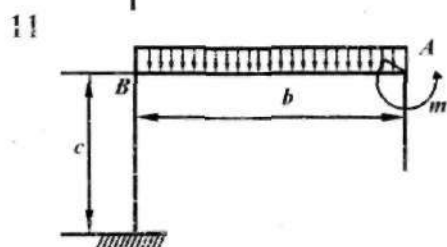
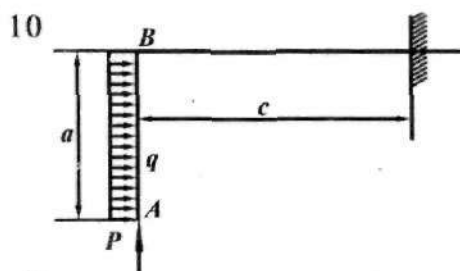
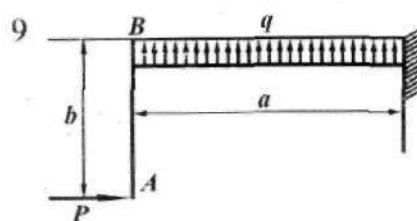
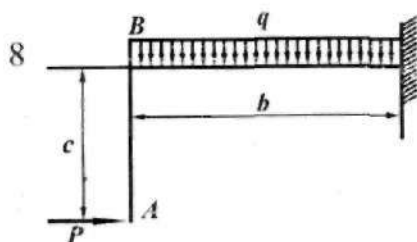
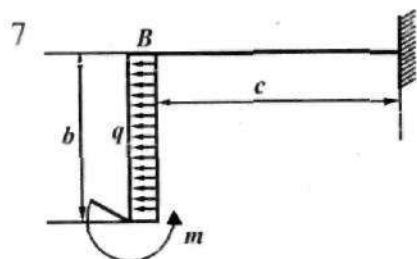
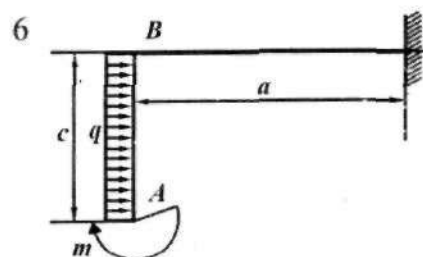
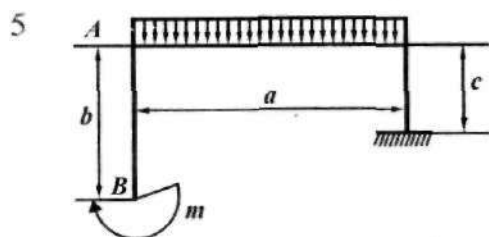
2) mustahkamlik shartiga binoan, sterjenning ko'ndalang kesimi tanlansin (kesim ko'rinishi – o'qituvchi ko'rsatmasi bo'yicha).

Kerakli ma'lumotlar VI.1- jadvalda, hisoblash sxemalari VI.19- shaklda keltirilgan.

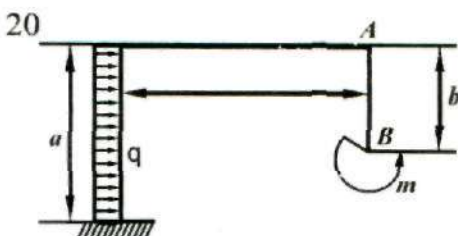
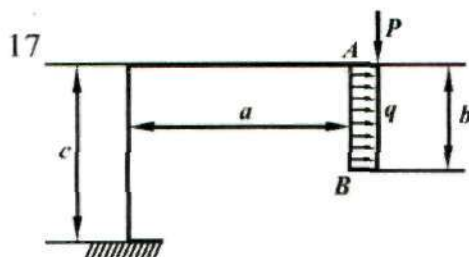
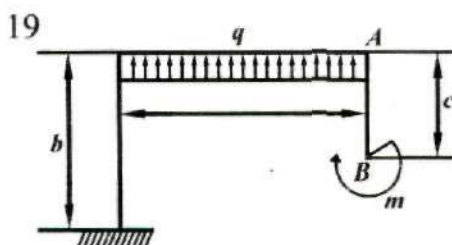
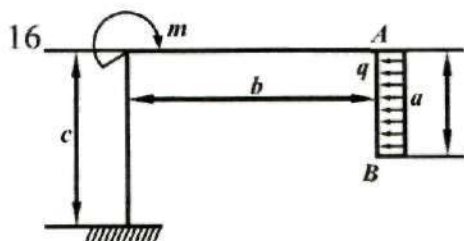
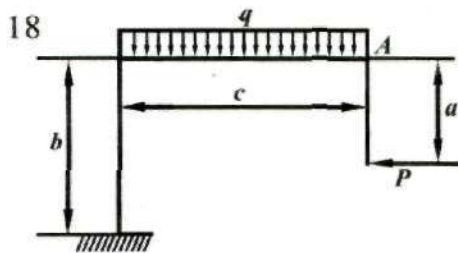
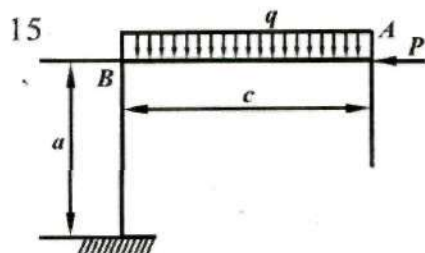


VI.19- shakl

VI.19- shakl (davomi)



VI.19- shakl (davomi)



### 12- topshiriq

Egri sterjenlar uchun ichki kuch faktorlari epyuralarini qurish.

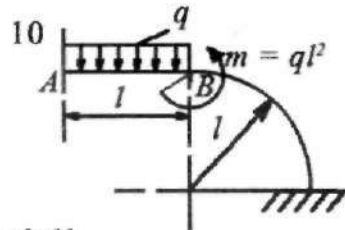
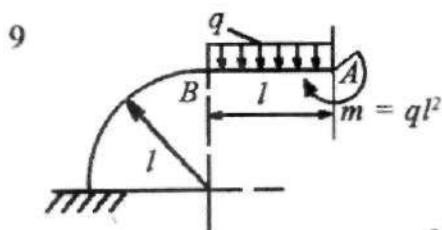
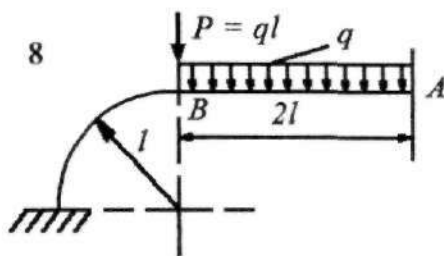
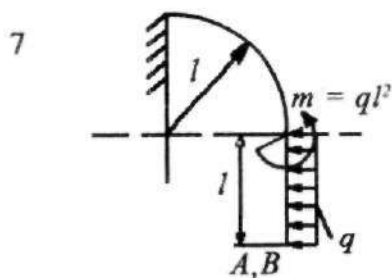
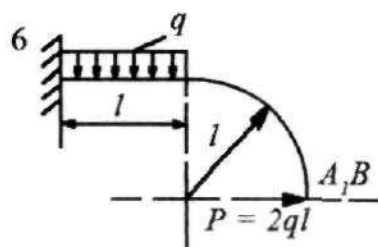
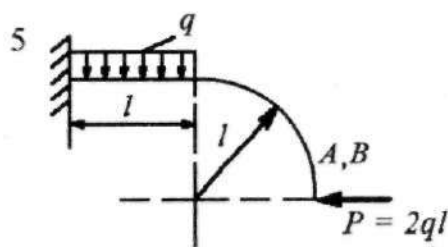
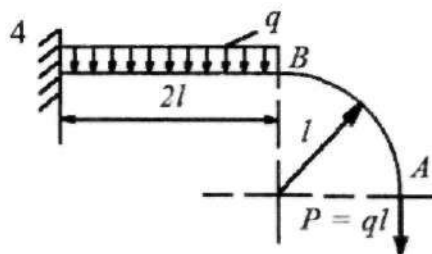
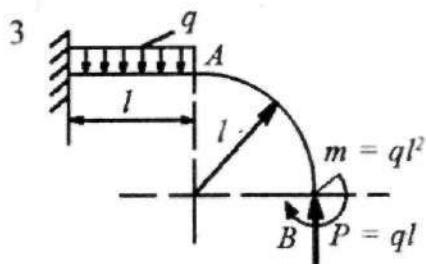
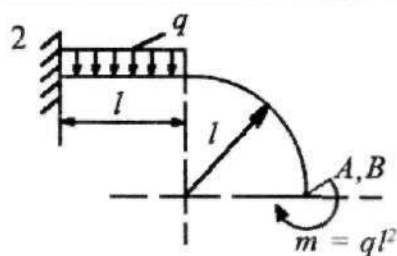
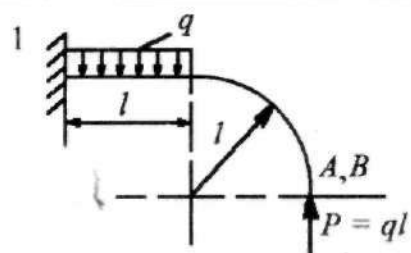
**Berilgan:** Keltirilgan shakllarda (VI.20- shakl) tashqi tomondan yuklangan to'sinlar berilgan.

**Topish kerak:**

1) berilgan egri sterjen uchun bo'ylama kuch, kesuvchi kuch va eguvchi moment epyuralari qurilsin;

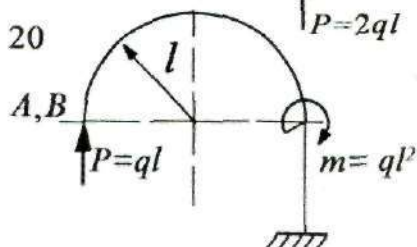
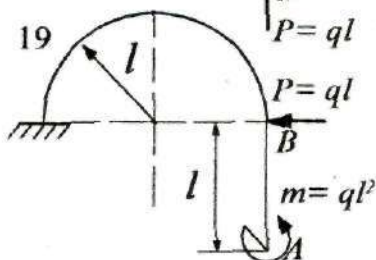
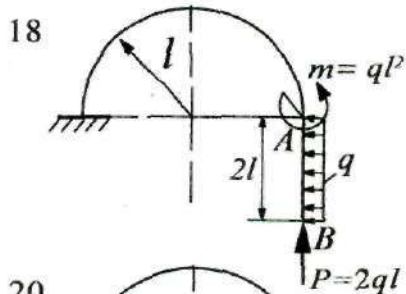
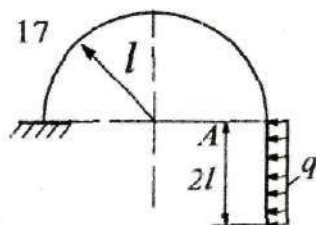
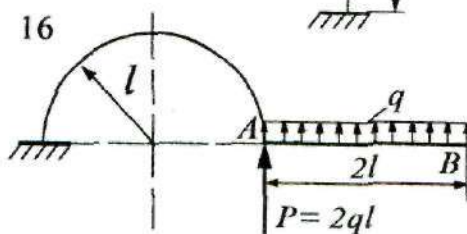
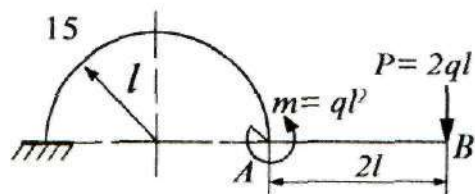
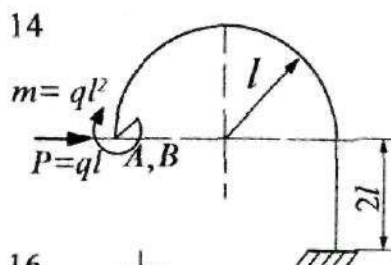
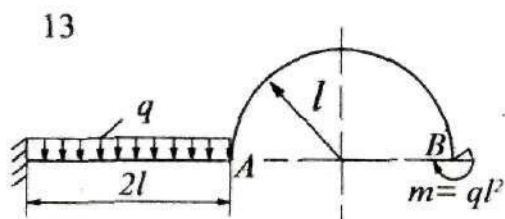
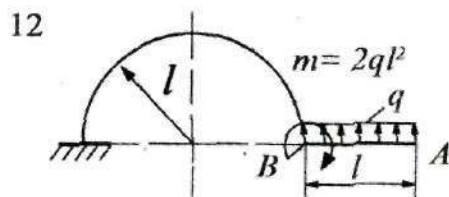
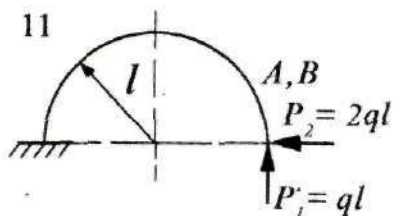
2) mustahkamlik shartiga binoan, egri sterjenning ko'ndalang kesimi tanlansin (kesim ko'rinishi - o'qituvchi ko'rsatmasi bo'yicha).

Kerakli ma'lumotlar VI.1- jadvalda, hisoblash sxemalari VI.20- shaklda keltirilgan.



VI.20- shakl

## VI.20- shakl (davomi)



## 13- topshiriq

Statik aniq ramalar uchun ichki kuch faktorlari epyuralarini qurish.

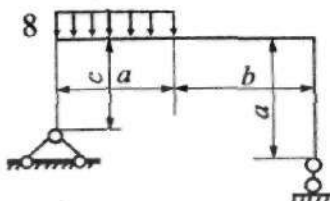
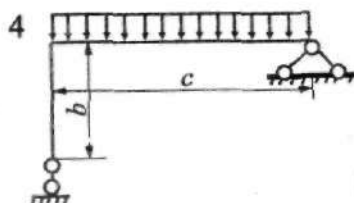
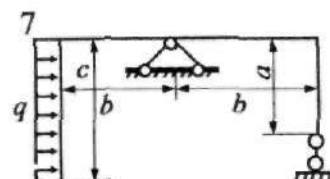
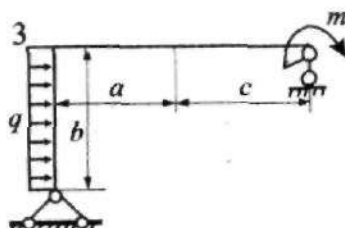
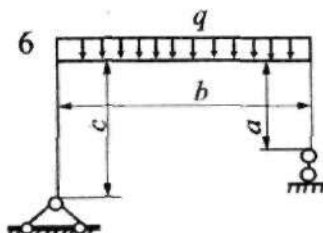
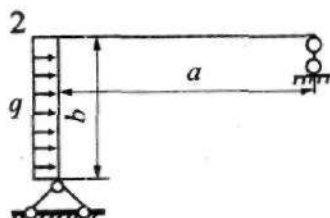
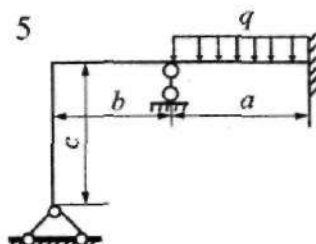
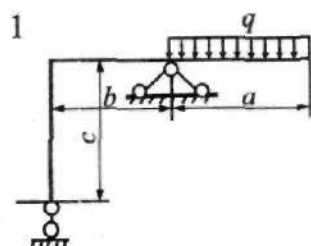
**Berilgan:** Keltirilgan shakllarda (VI.21- shakl) tashqi tomondan yuklangan statik aniq rama berilgan.

**Topish kerak:**

1) berilgan egri sterjen uchun bo'ylama kuch, kesuvchi kuch va eguvchi moment epyuralari qurilsin;

2) mustahkamlik shartiga binoan, egri sterjenning ko'ndalang kesimi tanlansin (kesim ko'rinishi – o'qituvchi ko'rsatmasi bo'yicha).

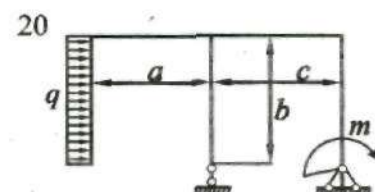
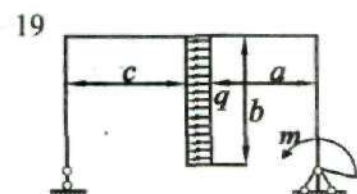
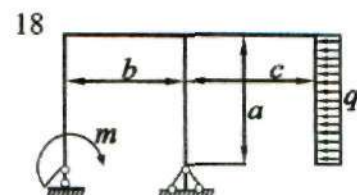
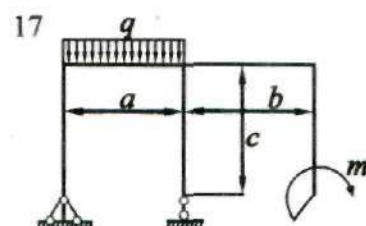
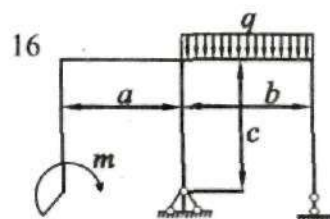
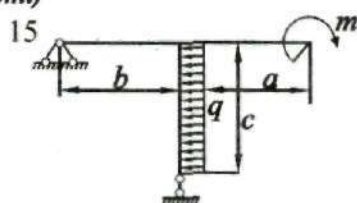
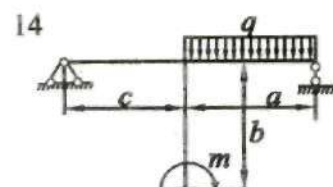
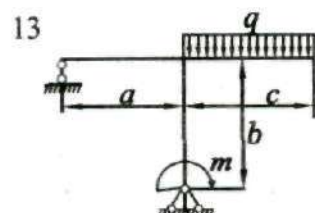
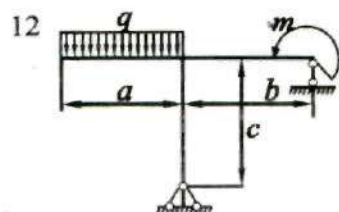
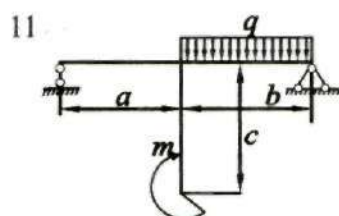
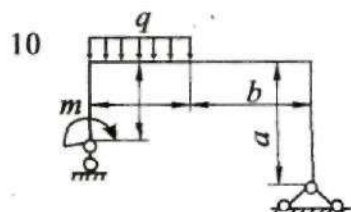
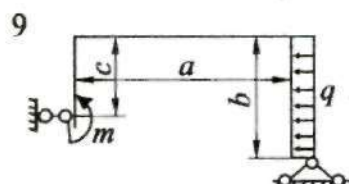
Kerakli ma'lumotlar VI.1- jadvalda, hisoblash sxemalari VI.21- shaklda keltirilgan.



VI.21- shakl



VI.21- shakl (davomi)



## VII BOB

EGILISHDA TO'SINLARNI MUSTAHKAMLIK SHARTI BO'YICHA  
HISOBLASH

## 7.1- §. Asosiy mulohazalar

- Ko'ndalang egilishga qarshilik ko'rsatuvchi to'sinlarning ixtiyoriy kesimlarida normal va urinma kuchlanishlar hosil bo'ladi.
- Normal kuchlanishlari eng katta qiymatga erishgan nuqtalar xavfli nuqtalar hisoblanib, ular yuzaning eng chekka to'larida joylashgan bo'ladi. Normal kuchlanish bo'yicha mustahkamlik sharti quyidagiga teng:

$$\sigma_{\max} = \frac{M_{\max}}{W_x} \leq \sigma_{\text{adm}}; \quad (\text{VII.1})$$

bu yerda,  $W_x$  – kesim qarshilik momenti;

$\sigma_{\text{adm}}$  – ruxsat etilgan normal kuchlanish.

- Urinma kuchlanishlari eng katta qiymatga erishgan nuqtalar ham xavfli nuqtalar hisoblanib, ular neytral qatlamda joylashadi. Urinma kuchlanish bo'yicha mustahkamlik sharti quyidagiga teng:

$$\tau_{\max} = \frac{Q_{\max} \cdot S_{\max}}{b \cdot J_x} \leq \tau_{\text{adm}}; \quad (\text{VII.2})$$

bu yerda,  $Q_{\max}$  – eng katta kesuvchi kuch;

$S_{\max}$  – kesimning eng katta statik momenti;

$b$  – kesim eni;

$J_x$  – inersiya momenti;

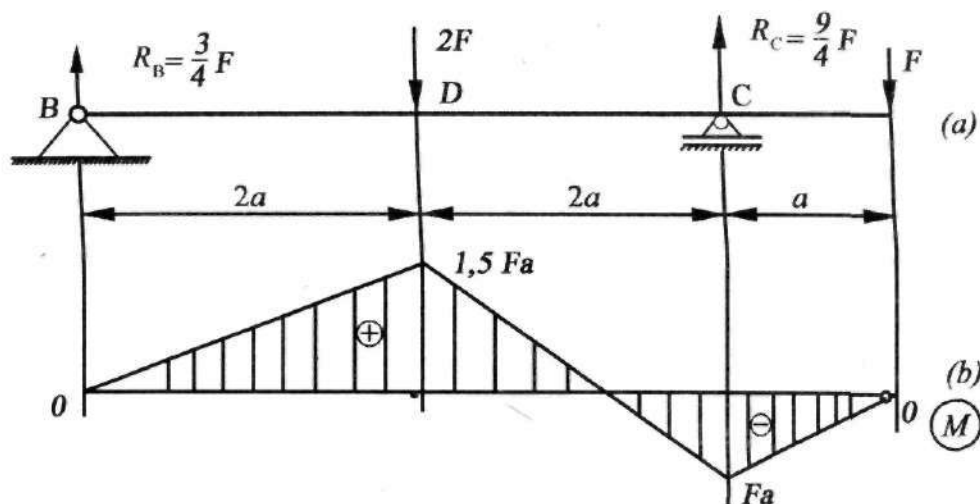
$\tau_{\text{adm}}$  – ruxsat etilgan urinma kuchlanish.

- Normal va urinma kuchlanishlari birgalikda yetarli darajada katta qiymatga ega bo'lgan nuqtalar ham xavfli nuqtalar deb hisoblanadi. Bunday holatda bosh kuchlanishlar aniqlanib, mustahkamlik sharti yoziladi.
- Quyidagi vaziyatlarda  $\sigma$  va  $\tau$  lar birgalikda yetarli darajada katta qiymatga ega bo'ladi:
  - eguvchi moment va ko'ndalang kuchlar birgalikda o'zlarining eng katta yoki unga yaqinroq qiymatlariga erishgan kesimlarida;
  - ko'ndalang kesim o'zgargan joylarda.

## 7.2- §. Egilishda to'sinlarni mustahkamlik sharti bo'yicha hisoblashga doir masalalar

### 67- masala

Uzunligi  $l=5a$  bo'lgan qo'shtavrli to'sinning sortament jadvalidagi nomeri 24 (GOST 8239-72) bo'lib, to'plangan kuchlar bilan yuklangan (88- shakl, a) normal kuchlanish  $\sigma=120$  MPa dan oshmasligi uchun  $F$  kuchning eng katta qiymati qancha bo'ladi? Hisoblashda  $a=0,9$  m deb qabul qilinsin.



VII.1- shakl

### Yechish:

N24 profil uchun  $W_z=289$  sm<sup>3</sup> to'sinning mustahkamlik shartidan.

$$M_{\max} = \sigma_{\max} \cdot W_z = 120 \cdot 10^6 \cdot 289 = 34\,680 \text{ N} \cdot \text{m} = 34,68 \text{ kN} \cdot \text{m} \quad (\text{a})$$

bo'ladi.

Eguvchi moment epyurasidan ko'rinib turibdiki (VII.1- shakl, b), to'sinning  $D$  kesimi xavfli kesim bo'lib, unga eng katta eguvchi moment

$$M_{\max} = 1,5Fa \quad (\text{b})$$

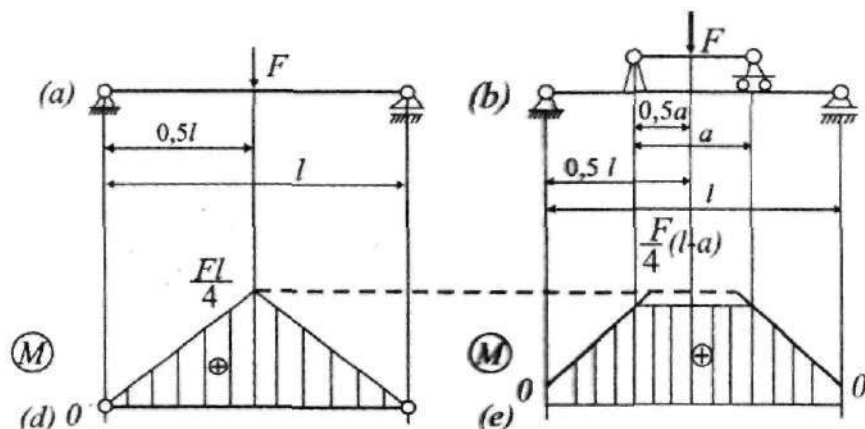
mos keladi.

(a) va (b) larni solishtirib, kuchning eng katta qiymatini aniqlaymiz:

$$1,5Fa = 34,68; \quad F = 25,69 \text{ kN}.$$

## 68- masala

Asosiy to'sinning o'rtasiga shunday  $F$  kuch qo'yilganki, uning ta'sirida xavfli kesimda vujudga keladigan eng katta normal kuchlanish to'sin materiali uchun ruxsat etilgan normal kuchlanish  $\sigma_{adm}$  dan 20 % oshib ketadi (VII.2- shakl, a). Ortiqcha kuchlanishni yo'qotish maqsadida yordamchi to'sindan foydalanilgan (VII.2- shakl, b). Yordamchi to'sinning uzunligi aniqlansin.



VII.2- shakl

## Yechish:

Ikkala hol uchun ham eguvchi moment epyuralarini qurib, xavfli kesimlardagi eng katta eguvchi momentlarni aniqlaymiz:

1-hol. Yordamchi to'sin bo'lmaganda (VII.2- shakl, d):

$$M_{\max} = \frac{Fl}{4};$$

2-hol. Yordamchi to'sin bo'lganda (VII.2- shakl, e):

$$M_{\max} = \frac{Fl}{4} - \frac{Fa}{4}$$

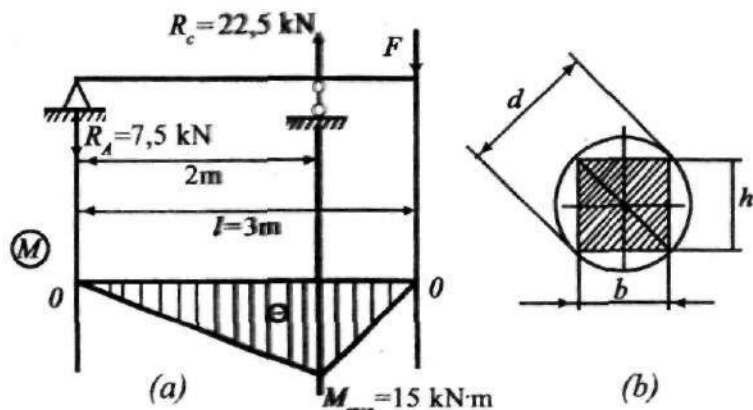
ortiqcha kuchlanishni yo'qotish uchun  $\frac{Fl}{4}$  ni 20 % kamaytirish kifoya.

$$0,2 \cdot \frac{Fl}{4} - \frac{Fa}{4} = 0;$$

bundan,  $a = 0,2l$  bo'ladi.

## 69- masala

VII.3- shaklda tasvirlangan to'sinning ko'ndalang kesimi  $b \times h$  o'lchamli to'g'ri to'rt-burchakli bo'lib, qarag'ay yog'ochidan yasalgan.



VII.3- shakl

To'sinning uzunligi  $l = 3$  m, unga qo'yilgan kuch esa  $F = 15$  kN, ruxsat etilgan kuchlanish  $\sigma_{adm} = 10$  MPa. Ko'ndalang kesimi doiraviy brusdan, ya'ni xuddi shunday o'lchamdagi to'sin arralash uchun brusning minimal diametri qancha bo'lishi kerak?  $b:h$  ning qanday qiymatida to'sinning qarshilik momenti eng katta bo'ladi?

**Yechish:**

Ta'sir reaksiyalarini aniqlab, eguvchi moment epyurasini quramiz (VII.3- shakl, b). Xavfli kesimda  $M_{max} = 15$  kN·m ta'sir etayotganligi uchun qarshilik momenti

$$W_x = \frac{M_{max}}{\sigma_{adm}} = \frac{15 \cdot 10^3}{10 \cdot 10^6} = 15 \cdot 10^{-4} \text{ m}^3$$

bo'ladi.

Ikkinchi tomondan, ko'ndalang kesimning qarshilik momentini kesim yuza o'lchamlari orqali quyidagicha yozish mumkin:

$$W_x = \frac{bh^2}{6} = \frac{b(d^2 - b^2)}{6}.$$

Qarshilik momenti eng katta qiymatga erishishi uchun

$$\frac{dW_x}{db} = \frac{1}{6}(d^2 - 3b^2) = 0$$

bo'lishi kerak.

$$\text{Bundan, } b = \frac{d}{\sqrt{3}}; \quad h = \sqrt{\frac{2}{3}} \cdot d; \quad \frac{b}{h} = \frac{\sqrt{2}}{2} \text{ kelib chiqadi. Demak, } W_{max} = \frac{d^3}{9\sqrt{3}}.$$

Oxirgi ifodani  $15 \cdot 10^{-4} \text{ m}^3$  ga tenglab,  $d$  ni topamiz:  $d = 28,6 \cdot 10^{-2} \text{ m}$ .

## 70- masala

Uzunligi  $l = 5a$  bo'lgan konsol uchun quyidagi ikki xil ko'rinishdagi kesim yuza tanlansin (VII.4- shakl, a):

- 1) qo'shtavrli kesim yuza;
- 2) yonma-yon qo'yilgan ikkita shvellardan iborat kesim yuza.

Hisoblashlarda  $a = 0,8$  m,  $F = 25$  kN va  $\sigma_{adm} = 160$  MPa ga teng deb olinsin.

## Yechish:

Kesish usulidan foydalanib, eguvchi moment epyurasini quramiz (VII.4- shakl, b).

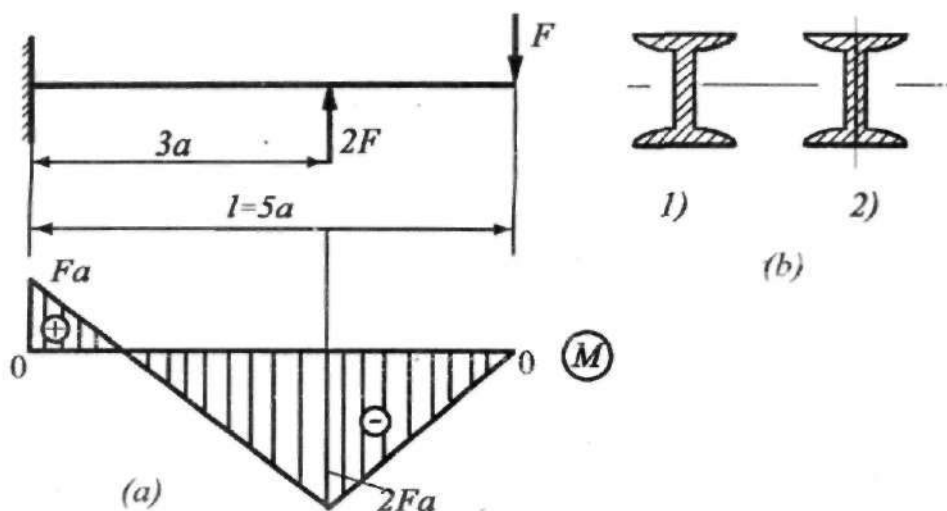
Hisob tenglamasidan qarshilik momentini aniqlaymiz:

$$W_x \geq \frac{M_{\max}}{\sigma_{adm}} = \frac{2Fa}{\sigma_{adm}} = \frac{2 \cdot 25 \cdot 10^3 \cdot 0,8}{160 \cdot 10^6} = 0,25 \cdot 10^{-3} \text{ m}^3 = 250 \text{ sm}^3$$

1) Qarshilik momentning bu qiymati bo'yicha GOST 8239-72 dan profil numeri 22<sup>a</sup> bo'lgan qo'shtavrni tanlaymiz; bu qo'shtavr qarshilik momenti  $W_{x1} = 254 \text{ sm}^3$ ; massasi  $q_1 = 25,8 \text{ kg/m}$  ga tengdir.

2) Bitta shveller uchun  $W_{x1} = 0,5 W_x = 125 \text{ sm}^3$  bo'lgani uchun GOST 8240-72 dan profil numeri 18 bo'lgan shveller tanlanadi; bu shveller uchun:  $W_x = 121 \text{ sm}^3$ ;  $q_2 = 16,3 \text{ kg/m}$ .

Shunday qilib, qo'shtavrli to'sin kesimi yonma-yon qo'yilgan ikkita shvellardan iborat to'sindan 20,8 % yengil ekan.



VII.4- shakl

## 71- masala

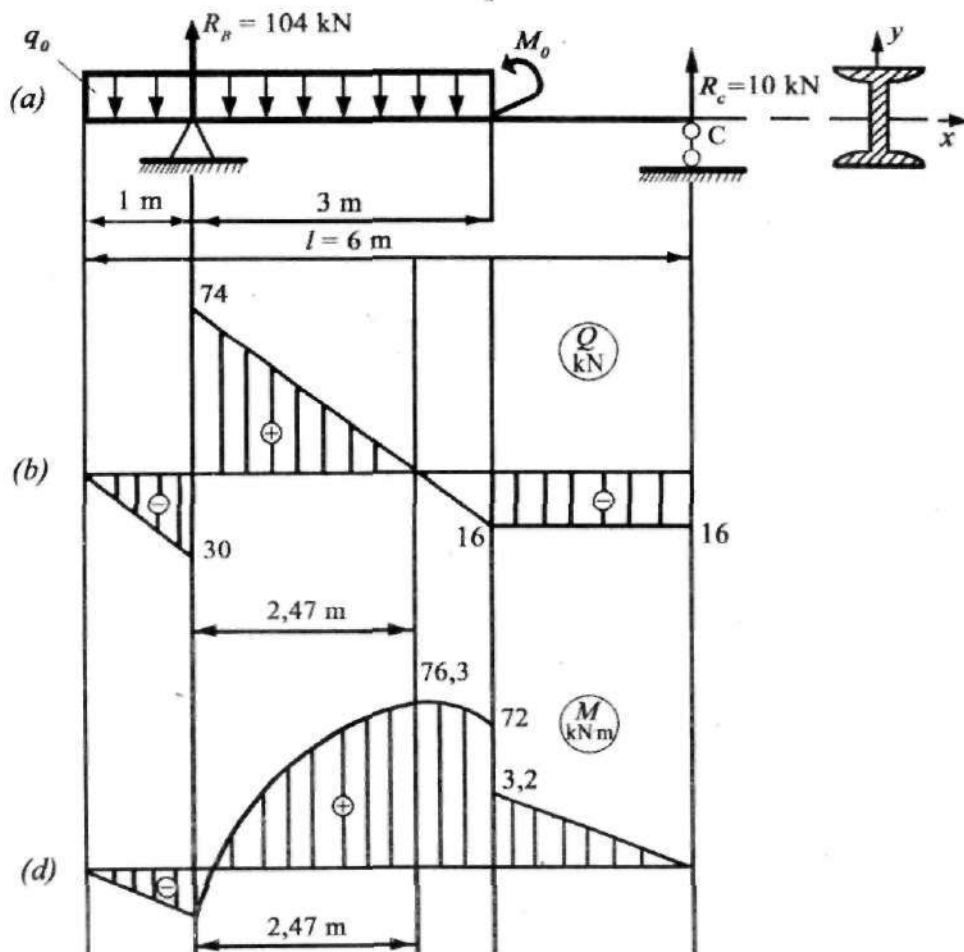
Uzunligi  $l = 6$  m bo'lgan qo'shtavrli to'sin juft kuch va tekis taralgan kuchlar bilan yuklangan (VII.5-shakl, a). To'sinning mustahkamligi normal va urinma kuchlanishlar bo'yicha tekshirilsin.

Hisoblashlarda  $q_0 = 30$  kN/m,  $M_0 = 40$  kNm,  $\sigma_{adm} = 160$  MPa,  $\tau_{adm} = 100$  MPa ga teng deb olinsin.

## Yechish:

Tayanch reaksiyalarini aniqlab, ko'ndalang kuch va eguvchi moment epyuralarini quramiz (VII.5-shakl, b). Qo'zg'almas tayanchdan 2,47 m o'ngda joylashgan xavfli kesim uchun mustahkamlik shartini yozamiz:

$$\sigma_{max} = \frac{M_{max}}{W_x} \leq \sigma_{adm}.$$



VII.5- shakl

Bundan, zaruriy qarshilik momenti:

$$W_x \geq \frac{M_{\max}}{\sigma_{\text{adm}}} = \frac{76,3 \cdot 10^3}{160 \cdot 10^6} = 0,477 \cdot 10^{-3} \text{ m}^3 = 477 \text{ sm}^3.$$

Qarshilik momentining bu qiymati bo'yicha sortament jadvalidan profil nomeri 30 bo'lgan qo'shtavr tanlaymiz; bu qo'shtavr uchun:  $W_{xI} = 472 \text{ sm}^3$ ;  $I_{xI} = 7080 \text{ sm}^4$ ;  $b = 0,65 \text{ sm}$  (qo'shtavr devorining qalinligi);  $S_{\max} = 268 \text{ sm}^3$ .

Normal kuchlanish bo'yicha mustahkamlikka tekshiramiz:

$$\sigma_{\max} = \frac{M_{\max}}{W_{xI}} = \frac{76,3 \cdot 10^3}{472 \cdot 10^{-6}} = 161,65 \cdot 10^6 \frac{\text{N}}{\text{m}^2} = 161,65 \text{ MPa};$$

bu kuchlanish xavfli emas, chunki u  $\sigma_{\text{adm}}$  dan atigi 1,03 % gina katta. Urinma kuchlanish bo'yicha mustahkamlikka tekshiramiz:

$$\tau_{\max} = \frac{Q_{\max} S_{\max}}{b \cdot I_{xI}} \leq \tau_{\text{adm}};$$

bu yerda,  $Q_{\max} = 74 \text{ kN}$  bo'lib, ko'ndalang kuch epyurasidan olinadi. Shu tufayli

$$\tau_{\max} = \frac{74 \cdot 10^3 \cdot 268 \cdot 10^{-6}}{0,65 \cdot 10^{-2} \cdot 7080 \cdot 10^{-8}} = 43,094 \cdot 10^6 \frac{\text{N}}{\text{m}^2} = 43,09 \text{ MPa};$$

bu kuchlanish  $\tau_{\text{adm}}$  dan 56,91 % kichik.

Shunday qilib, to'sinning kesim yuza o'lchamlari normal va urinma kuchlanishlar bo'yicha mustahkamlik shartini qanoatlantiradi.

## 72- masala

Uzunligi  $l = 4 \text{ m}$  bo'lgan to'sin tekis taralgan kuchlar bilan yuklangan (VII.6- shakl, a).

Chizmada tasvirlangan yetti xil ko'rinishdagi kesim yuzalardan qaysi biri ratsional kesim yuza bo'la oladi?

Hisoblashlarda  $q_0 = 50 \text{ kN/m}$ ;  $l = 4 \text{ m}$ ;  $\sigma_{\text{adm}} = 160 \text{ MPa}$  ga teng deb olinsin.

## Yechish:

Tayanch reaksiyalarini topib, eguvchi moment epyurasini quramiz (VII.6- shakl, b). Xavfli kesim tayanchlar o'rtasida bo'lib, unga  $M_{\max} = q_0 l^2 / 16 = 50,0 \text{ kN} \cdot \text{m}$  moment ta'sir etadi.

Hisob tenglamasidan qarshilik momentining zaruriy qiymatini aniqlaymiz:

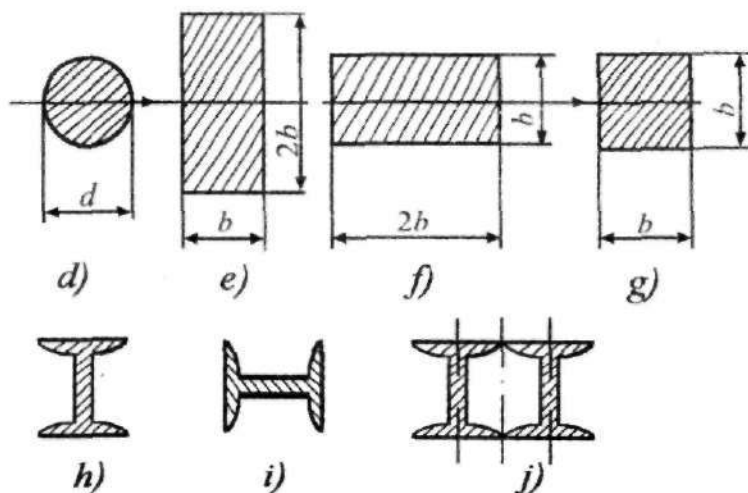
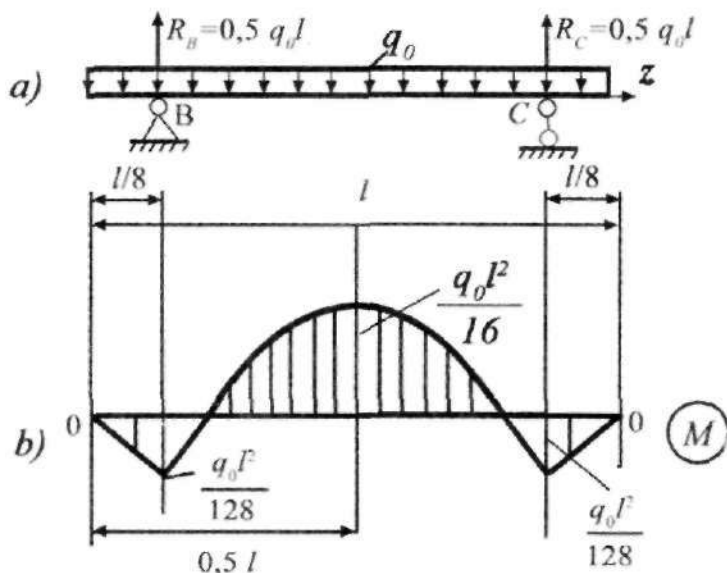
$$W_x \geq \frac{M_{\max}}{\sigma_{\text{adm}}} = \frac{50 \cdot 10^3}{160 \cdot 10^6} = 0,3125 \cdot 10^{-3} \text{ m}^3 = 312,5 \text{ sm}^3.$$

Endi har bir kesim yuza uchun navbat bilan tegishli hisoblashlarni bajaramiz.

1. Doiraviy kesim yuza (VII.6- shakl, d):

$$W = \frac{\pi d^3}{32} \geq 312,5 \text{ sm}^3; \quad d \geq \sqrt[3]{\frac{32 \cdot 312,5}{3,14}} = 14,71 \text{ sm}$$





VII.6- shakl

qabul qilamiz:  $d_0 = 15$  sm, u holda:  $W_0 = \pi d_0^3 / 32 = 331,17 \text{ sm}^3$ ;  $A = \pi d_0 / 4 = 176,625 \text{ sm}^2$ ;

$$\delta_\sigma = \frac{W_x - W_0}{W_0} \cdot 100\% = -5,46\%; \quad \eta = \sqrt[3]{\frac{A^3}{W^3}} = \sqrt[3]{\frac{(176,625)^3}{(331,17)^3}} = 3,6898.$$

2. To'g'ri to'rtburchakli kesim yuza (VII.6- shakl, e):

$$W = \frac{b \cdot (2b)^2}{6} = \frac{2}{3} b^3 \geq 312,5 \text{ sm}^3; \quad b \geq \sqrt[3]{468,75} = 7,7679 \text{ sm}$$

qabul qilamiz:  $b_0 = 8$  sm, u holda:  $W_0 = \frac{2b_0^3}{3} = 341,33 \text{ sm}^3$ ;  $A = 2b_0^2 = 128 \text{ sm}^2$ ;

$$\delta_\sigma = \frac{W_x - W_0}{W_0} \cdot 100\% = \frac{312,5 - 341,33}{341,33} \cdot 100\% = -8,45\%; \eta = \sqrt[3]{\frac{(128)^3}{(341,33)^2}} = 2,62.$$

3. To'g'ri to'rtburchakli kesim yuza (VII.6- shakl, f):

$$W = \frac{2b \cdot b^2}{6} = \frac{b^3}{3} \geq 312,5 \text{ sm}^3; b = 9,787 \text{ sm}$$

qabul qilamiz:  $b_0 = 10$  sm, u holda:  $W_0 = b_0^3/3 = 333,333 \text{ sm}^3$ ;  $A = 2b_0^2 = 200 \text{ sm}^2$ ;

$$\delta_\sigma = \frac{W_x - W_0}{W_0} \cdot 100\% = \frac{312,5 - 333,33}{333,33} \cdot 100\% = -6,25\%; \eta = \sqrt[3]{\frac{A^3}{W_0^2}} = \sqrt[3]{\frac{200^3}{333,33^2}} \approx 4,116.$$

4. Kvadrat kesim yuza (VII.6- shakl, g):

$$W = \frac{b \cdot 2b^2}{6} = \frac{b^3}{3} \geq 312,5 \text{ sm}^3; b = 12,33 \text{ sm}$$

qabul qilamiz:  $b_0 = 13$  sm, u holda:  $W_0 = b_0^3/3 = 366,166 \text{ sm}^3$ ;  $A = 2b_0^2 = 169 \text{ sm}^2$ ;

$$\delta_\sigma = \frac{W_x - W_0}{W_0} \cdot 100\% = \frac{312,5 - 366,166}{366,166} \cdot 100\% = -14,66\%; \eta = \sqrt[3]{\frac{A^3}{W_0^2}} = \sqrt[3]{\frac{169^3}{366,166^2}} = 3,3.$$

5. Qo'shtavrli kesim yuza (VII.6- shakl, h):

GOST 8239-72 dan tanlaymiz: №24<sup>a</sup>;  $W_1 = 317 \text{ sm}^3$ ;  $A_1 = 37,5 \text{ sm}^2$ ;

$$\delta_\sigma = \frac{W_x - W_1}{W_1} \cdot 100\% = -1,42\%; \eta = \sqrt[3]{\frac{A_1^3}{W_1^2}} = \sqrt[3]{\frac{37,5^3}{317^2}} = 0,8066.$$

6. Qo'shtavrli kesim yuza (VII.6- shakl, i):

GOST 8239-56 dan tanlaymiz: №70<sup>a</sup>;  $W_H = 309 \text{ sm}^3$ ;  $A_H = 202 \text{ sm}^2$ ;

$$\delta_\sigma = \frac{W_x - W_H}{W_H} \cdot 100\% = \frac{325,5 - 309}{309} \cdot 100\% = 1,32\%; \eta_H = \sqrt[3]{\frac{A_H^3}{W_H^2}} = \sqrt[3]{\frac{202^3}{309^2}} = \sqrt[3]{86,325} = 4,42.$$

7. Yonma-yon joylashgan ikkita qo'shtavrli kesim yuza (VII.6- shakl, j):

GOST 8239-72 dan tanlaymiz №18<sup>a</sup>;  $W_1^0 = 159 \text{ sm}^3$ ;  $A_1^0 = 25,4 \text{ sm}^2$ ;  $W_1 = 2 \cdot 159 = 318 \text{ sm}^3$ ;  $A_1 = 50,8 \text{ sm}^2$ ;

$$\delta_\sigma = \frac{W_x - W_1}{W_1} \cdot 100\% = \frac{312,5 - 2 \cdot 159}{2 \cdot 159} \cdot 100\% = -1,73\%; \eta = \sqrt[3]{\frac{(2 \cdot 25,4)^3}{(2 \cdot 159)^2}} = 1,09.$$

Hisoblangan qiymatlardan quyidagi xulosaga kelamiz: kesim shaklining ratsional koef-fitsienti eng kichik, ya'ni  $\eta = 0,8066$  bo'lgan qo'shtavrli to'sin boshqalariga nisbatan ancha tejimli ekan.

## 73- masala

Uzunligi  $l = 3a$  kesimi bo'lgan halqasimon to'sin juft kuch va tekis taralgan kuchlar bilan yuklangan (VII.7- shakl, a). To'singa qo'yilgan tashqi kuchning ruxsat etilgan qiymatini aniqlang.

Hisoblashda  $\sigma_{adm} = 160 \text{ MPa}$ ,  $\alpha = d:D = 0,7$ ,  $a = 1,1 \text{ m}$ ,  $D = 25 \cdot 10^{-2} \text{ m}$  ga teng deb olinsin.

## Yechish:

Tayanch reaksiyalarini topib, eguvchi moment epyurasini quramiz (VII.7- shakl, b). Xavfli kesim uchun mustahkamlik shartini yozamiz:

$$\sigma_{max} = \frac{M_{max}}{W_x} \leq \sigma_{adm};$$

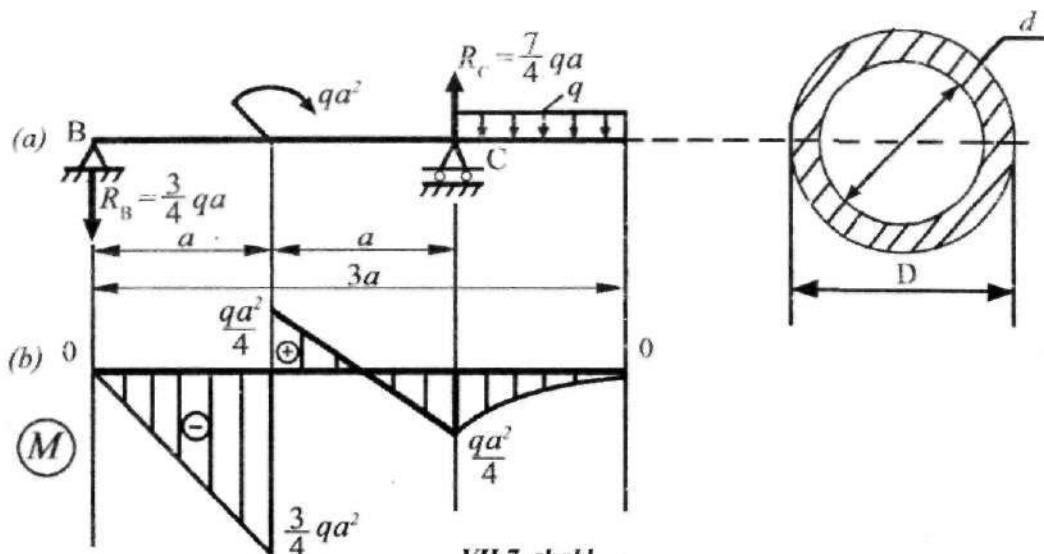
bu yerda,  $M_{max} = \frac{3qa^2}{4}$  bo'lib, eguvchi moment epyurasidan olinadi;

$$W_x = \frac{\pi D^3 \cdot (1 - d^4)}{32} - \text{qarshilik momenti.}$$

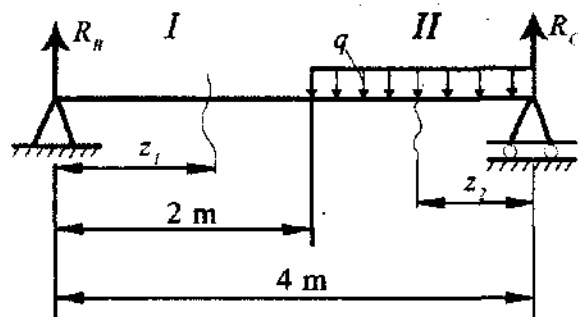
Demak, tashqi kuchning ruxsat etilgan qiymati:

$$q_{adm} = q \leq \frac{4 \cdot \pi D^3 (1 - d^4) \sigma_{adm}}{3 \cdot 32 \cdot a^2}$$

$$\text{yoki } q_{adm} = \frac{4 \cdot 3,14 \cdot (25 \cdot 10^{-2})^3 (1 - 0,2401) \cdot 160 \cdot 10^6}{96 \cdot 1,21} = 205,4 \text{ kN/m ga teng ekan.}$$



VII.7- shakl



VII.8- shakl

## 74- masala

Profil nomeri 60 bo'lgan qo'shtavrli po'lat to'sin  $q=400$  kN/m tekis taralgan kuchlar bilan yuklangan (VII.8- shakl). Mazkur to'sin uchun deformatsiyaning potensial energiyasini aniqlash talab etiladi. Qo'shtavr uchun ko'ndalang kesim yuzining shakliga bog'liq bo'lgan koeffitsient  $K=1,9$  deb olinsin.

## Yechish:

Dastlab, tayanch reaksiyalarini topamiz:  $R_B=200$  kN,  $R_C=600$  kN. Keyin esa to'sinning har bir oralig'i uchun ichki zo'riqlashlarning ifodalarini tuzamiz:

$$\begin{aligned} 0 \leq z_1 \leq 2; \quad Q(z_1) &= R_B; \quad M(z_1) = R_B z_1; \\ 0 \leq z_2 \leq 2; \quad Q(z_2) &= qz_2 - R_C; \quad M(z_2) = R_C z_2 - 0,5q \cdot z_2. \end{aligned}$$

Egilishdagi potensial energiyani aniqlaymiz:

$$U_M = \sum \int_{(e)} \frac{M^2(z) dz}{2EI_x} = \frac{1}{2EI_x} \left[ \int_0^2 (200z_1)^2 dz_1 + \int_0^2 (600z_2 - 200z_2^2)^2 dz_2 \right] = 1180 \text{ J.}$$

Siljishdagi potensial energiyani aniqlaymiz:

$$U_Q = \sum \int_{(i)} \frac{KQ^2(z) dz}{2GF} = \frac{1,9}{2GF} \left[ \int_0^2 (200)^2 dz_1 + \int_0^2 (400z_2 - 600)^2 dz_2 \right] = 229 \text{ J.}$$

Hisoblashlardan ko'rinib turibdiki, siljishdagi potensial energiya egilishdagi potensial energiyaning 19,4 % ni tashkil qilar ekan. Shunday qilib, potensial energiya:

$$U_M + U_Q = 1409 \text{ J.}$$

## 75- masala

To'plangan kuch va tekis taralgan kuchlar bilan yuklangan oddiy to'sin "IT" shaklli ko'ndalang kesimga ega (VII.9- shakl, a). To'sin cho'yandan yasalgan bo'lib, tayanchlar orasidagi masofa  $l = 4a$  ga teng.

To'sin mustahkamlikka tekshirilsin. Hisoblashlarda  $\sigma_{adm}^+ = 35$  MPa;  $\sigma_{adm}^- = 110$  MPa;  $a = 0,5$  m;  $q = 5$  kN/m ga teng deb olinsin. Kesimning o'lchamlari shaklda mm hisobida berilgan (VII.9- shakl, b).

## Yechish:

Tayanch reaksiyalari aniqlangach, eguvchi moment epyurasini quramiz (VII.9- shakl, d). Epyuradan xavfli kesimlardagi eguvchi momentlarni aniqlaymiz:

I-I kesimda (bu yerda neytral o'qdan yuqoridagi to'lalar siqiladi):

$$M_{\max} = \frac{25 qa^2}{32} = 0,9765 \text{ kNm.}$$

II-II kesimda (bu yerda neytral o'qdan yuqoridagi to'lalar cho'ziladi):

$$M_{\max} = \frac{qa^2}{4} = 0,3125 \text{ kNm.}$$

Kesim yuza vertikal o'qqa nisbatan simmetrik bo'lgani uchun,  $Y_c$  neytral o'qning holatini aniqlaydi:  $Y_c = \frac{10 \cdot 16 \cdot 5 - 8 \cdot 14 \cdot 4}{10 \cdot 16 - 8 \cdot 14} = 7,33 \text{ sm} = 73,3 \text{ mm}.$

Inersiya momentini hisoblaymiz:

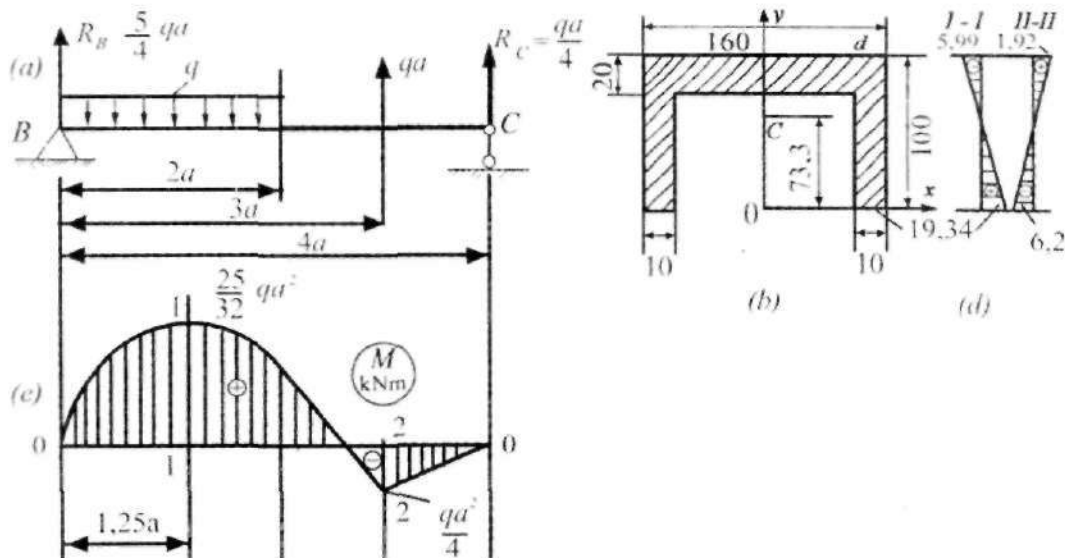
$$I_{x_c} = \frac{16 \cdot 10^3}{12} + 2,33^2 \cdot 16 \cdot 10 - \frac{14 \cdot 8^3}{12} - 3,33^2 \cdot 14,8 = 370 \text{ sm}^4$$

Kesimlardagi cho'zuvchi va siquvchi kuchlanishlarni aniqlaymiz.

I-I kesim uchun eng katta cho'zuvchi kuchlanishni aniqlaymiz:

$$\sigma_A = \frac{M_{\max}}{I_{x_c}} \cdot y_A = \frac{25 qa^2}{32 \cdot 370 \cdot 10^{-8}} \cdot 7,33 \cdot 10^{-2} = 19,34 \cdot 10^6 \text{ N/m}^2 = 19,34 \text{ MPa}$$

bo'lib,  $\sigma_{\text{adm}}$  dan 44,7 % kichikdir.



VII.9- shakl

Eng katta siquvchi kuchlanishni aniqlaymiz:

$$\sigma_B = -\frac{M_{\max}}{I_{x_c}} \cdot y_B = \frac{-25qa^2 \cdot 2,27 \cdot 10^{-2}}{32 \cdot 370 \cdot 10^{-8}} = -5,99 \cdot 10^6 \text{ N/m}^2 = -5,99 \text{ MPa}.$$

II-II kesim uchun eng katta cho'zuvchi kuchlanish quyidagiga teng:

$$\sigma_B = \frac{M_{\max}}{I_{x_c}} \cdot y_B = \frac{0,3125 \cdot 10^3 \cdot 2,27 \cdot 10^{-2}}{370 \cdot 10^{-8}} = 1,92 \cdot 10^6 \text{ N/m}^2 = 1,92 \text{ MPa}.$$

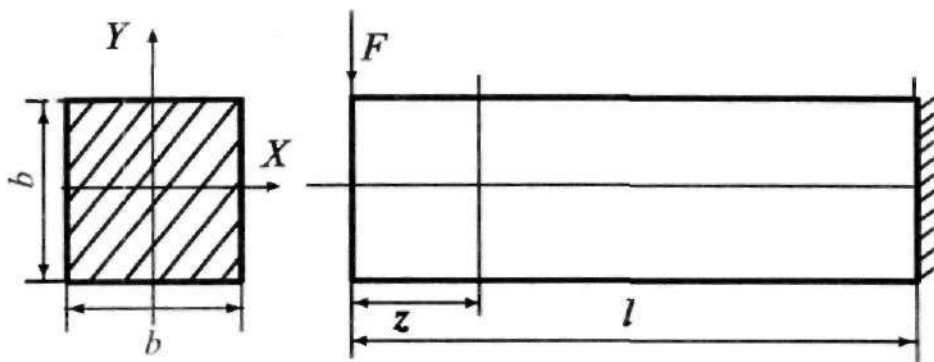
Eng katta siquvchi kuchlanish esa quyidagiga teng bo'ladi:

$$\sigma_A = -\frac{M_{\max}}{I_{x_c}} \cdot y_A = -\frac{0,3125 \cdot 7,33 \cdot 10^3 \cdot 10^{-2}}{370 \cdot 10^{-8}} = -6,2 \cdot 10^6 \text{ N/m}^2 = -6,2 \text{ MPa}.$$

VII.9- shakl (e) da keltirilgan kuchlanish epyuralaridan ko'rinib turibdiki, to'sinning mustahkamligi ta'minlangan.

#### 76- masala

Kesimi kvadrat shaklidagi ( $b = 5 \cdot 10^{-2} \text{ m}$ ) konsolning uchiga  $F$  kuch qo'yilgan (VII.10- shakl). Konsolning shunday ko'ndalang kesimi topilsinki, unda eng katta normal kuchlanish eng katta urinma kuchlanishdan 3 marta katta bo'lsin.



VII.10- shakl

#### Yechish:

Ma'lumki, eng katta normal kuchlanish kesimning chetki nuqtasida bo'lib,

$$\sigma_{\max} = \frac{M_{z_{\max}}}{W_x} = \frac{F \cdot z}{\frac{b^3}{6}} = \frac{6F \cdot z}{b^3}$$

formuladan topiladi; urinma kuchlanishning eng katta qiymati esa xolis qatlamda yotuvchi nuqtalarda bo'ladi:

$$\tau_{\max} = \frac{3}{2} \cdot \frac{F}{b^2}.$$

Masalaning shartiga ko'ra:

$$\frac{6FZ}{b^3} = 3 \cdot \frac{3}{2} \cdot \frac{F}{b^2}$$

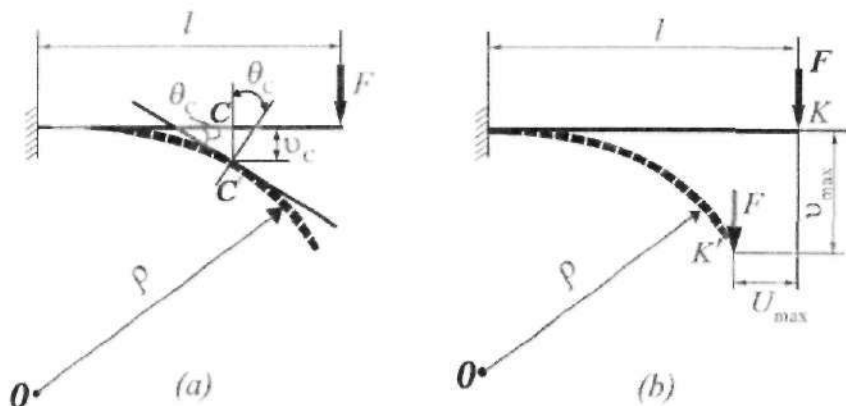
bo'lishi kerak; bundan,  $z = \frac{3}{4}b$  ekanligi kelib chiqadi.

## VIII BOB

## EGILISHDA KO'CHISHLARNI ANIQLASH

## 8.1- §. Asosiy mulohazalar

Egilishda to'sinning mustahkamligini ta'minlash bilan birga uning bikrligini ham ta'minlash zarurdir. To'sinlarni bikrlikka hisoblash jarayonlarida ularning tashqi kuchlar natijasida olgan deformatsiyalarini bilish muhimdir.



VIII.1- shakl

## Yechish:

To'sinning deformatsiyalarini istalgan ko'ndalang kesimlarning vaziyatlarini tavsiflay oladigan quyidagi ikkita ko'chishlardan iborat, deb qarash mumkin (VIII.1- shakl):

- istalgan nuqtalarning solqiligi – chiziqli ko'chish;
- istalgan ko'ndalang kesimlarning aylanish burchaklari – burchakli ko'chish.

To'sinning ko'ndalang kesimi og'irlik markazining to'sin o'qiga tik (perpendikular) yo'nalishdagi ko'chishi uning mazkur kesimdagi solqiligi deyiladi va  $v_z$  yoki  $F_{max}$  bilan belgilanadi.

To'sin uzunligi bo'yicha olingan ixtiyoriy ko'ndalang kesimning dastlabki (deformatsiyalanmagan) vaziyatiga nisbatan tekis holda neytral o'q atrofida ma'lum burchakka og'ishiga mazkur kesimning aylanish burchagi deyiladi va  $u$   $\theta$  bilan belgilanadi.



Deformatsiyalangan to'sinning barcha ko'ndalang kesim og'irlik markazlarining geometrik o'rniga egilgan o'q yoki elastik chiziq deyiladi; elastik chiziq tekis egri chiziq bo'lib, u kuch tekisligida yotadi.

Chiziqli ko'chishning gorizontall tashkil etuvchisi ( $U_{\max}$ ) nisbatan kichik qiymatga ega bo'lgani uchun hisoblash jarayonlarida uni e'tiborga olmasa ham bo'ladi.

Egilishdagi deformatsiyalarni aniqlashning bir qancha usullari mavjud; biz bu bobda faqat ayrim usullar bilan tanishib chiqamiz:

- Egilgan o'qning taqribiy differensial tenglamasini bevosita integrallash usuli:

$$\pm \frac{d^2 v}{dz^2} = -\frac{M(z)}{EJ_x}; \quad (\text{VIII.1})$$

- Boshlang'ich parametrlar usuli yoki universal formula;
- Mor usuli;
- Vereshagin usuli.

## 8.2- §. Egilgan o'qning taqribiy differensial tenglamasini bevosita integrallash usuli

### 77- masala

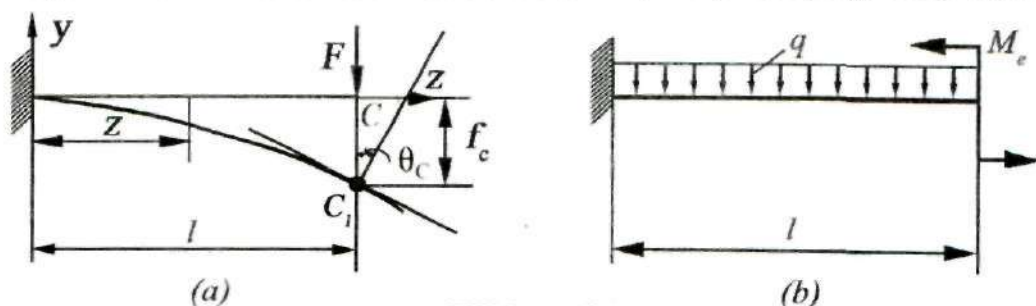
Uzunligi  $l$ , bikrligi o'zgarmas ( $EI_x = \text{const}$ ) bo'lgan konsol erkin uchining aylanish burchagi va solqiligi quyidagi uch hol uchun aniqlansin: a) o'ng uchiga  $F$  yuk qo'yilgan; b) o'ng uchiga  $M_e$  juft kuch qo'yilgan; d) tekis taralgan  $q$  yuk qo'yilgan (VIII.2- shakl a, b).

Masala egilgan o'qning taqribiy defferensial tenglamasini bevosita integrallash usuli yordamida yechilsin.

### Yechish:

Masalani birinchi hol uchun yechamiz (VIII.2- shakl, a).

Tayanch kesimni koordinatalar boshi deb hisoblab,  $Y$  o'qini yuqoriga va abssissalar



VIII.2- shakl

o'qini esa o'ng tomonga yo'naltiramiz. Tanlangan koordinatalarga ko'ra, elastik chiziqning taqribiy differensial tenglamasi  $EI_x v_z = M_z$  ko'rinishga ega bo'ladi.

Koordinata boshidan ixtiyoriy  $Z$  masofadagi kesim uchun eguvchi momentning ifodasini yozamiz:  $M_z = -F(l - z)$ ; u holda yuqoridagi tenglama:

$$EI_x v_z'' = -F(l - z) \text{ ko'rinishida bo'ladi.}$$

Bu tenglamani ketma-ket ikki marta integrallaymiz:

$$EI_x v_z' = EI_x \theta_z = -F \left( lz - \frac{z^2}{2} \right) + C; \quad (1)$$

$$EI_x v_z = -F \left( l \frac{z^2}{2} - \frac{z^3}{6} \right) + Cz + D. \quad (2)$$

Integral o'zgarmlarni aniqlash uchun chegaraviy shartlardan foydalanamiz:

$$Z=0 \text{ bo'lsa, } \theta(l)=0; v(l)=0.$$

Bu shartni (1) va (2) tenglamalarga qo'yib,  $C=0$  va  $D=0$  ekanligiga ishonch hosil qilamiz. Shunday qilib, aylanish burchagi va solqilik tenglamasi quyidagicha bo'lar ekan:

$$\theta_z = -\frac{Flz}{2EI_x} \left( 2 - \frac{z}{l} \right);$$

$$v_z = -\frac{Flz}{6EI_x} \left( 3 - \frac{z}{l} \right).$$

Oxirgi tenglamalarga  $z=l$  ni qo'yib, so'ralgan kesimning aylanish burchagi va solqiligini topamiz:

$$\theta_C = -\frac{Fl^2}{2EI_x}; \quad v_b = f_b = -\frac{Fl^3}{6EI_x}.$$

Bu ifodalarning birinchisidagi manfiy ishora  $C$  kesimning soat strekasi yo'nalishida aylanishini, ikkinchisidagi manfiy ishora esa solqilikning pastga qarab yo'nalganligini ko'rsatadi.

Ikkinchi holni qaraymiz (VIII.2- shakl, b).

Yuqoridagi ishlarni yana takrorlab, quyidagi ko'rinishdagi aylanish burchagi va solqilik tenglamalariga ega bo'lamiz:

$$\theta_z = \frac{1}{EI_x} \left( M_e Z - q \frac{Z^3}{6} \right);$$

$$v_z = \frac{1}{EI_x} \left( M_e \frac{z^2}{2} - q \frac{Z^4}{24} \right).$$

Bu tenglamalardan konsol erkin uchidagi kesimning aylanish burchagi va solqilgini osongina aniqlash mumkin.

Quyidagi xususiy hollarni qaraymiz:

a) konsolga faqat juft kuch qo'yilgan bo'lsin, ya'ni  $q=0$ ;  $M_e \neq 0$  ga teng, u holda:

$$\theta_C = \frac{M_e l}{EI_x}; \quad v_C = f_C = \frac{M_e l^2}{2 EI_x};$$

b) konsolga faqat tekis taralgan kuchlar ta'sir etayotgan bo'lsin, ya'ni,  $M_e = 0$ ;  $q \neq 0$ , u holda:

$$\theta_C = -\frac{ql^3}{6 EI_x}; \quad v_C = f_C = -\frac{ql^4}{24 EI_x}.$$

### 78- masala

Oddiy to'sinning o'ng tayanchiga juft kuch qo'yilgan (VIII.3- shakl). To'sin o'zgarmas bikrlikka ega bo'lib, uzunligi  $l$  ga teng.

To'sinning eng katta solqiligi topilsin va u tayanchlar o'rtasidagi kesimning solqiligi bilan solishtirilsin.

Masala elastik chiziqning taqribiy differensial tenglamasini bevosita integrallash usuli bilan yechilsin.

### Yechish:

Tayanch reaksiyalarini topamiz:  $R_A = R_B = \frac{M_e}{l}$ .

O'ng tayanchdan ixtiyoriy  $Z$  masofada joylashgan kesimdagi eguvchi moment:

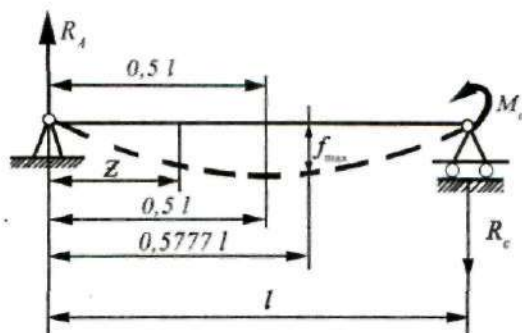
$M(z) = \frac{M_e}{l} Z$  ga teng. U holda :

$$EI_x v_z'' = \frac{M_e}{l} Z. \quad (a)$$

Oxirgi tenglamaning integralini yozamiz:

$$EI_x \theta_z = \frac{M_e}{l} \cdot \frac{z^2}{2} + C; \quad (b)$$

$$EI_x v_z = \frac{M_e}{l} \cdot \frac{z^3}{6} + Cz + D. \quad (d)$$



VIII.3- shakl

To'sinning tayanchlariga tiralgan kesimlarida solqilikning 0 ga tengligi quyidagi chegaraviy shartlarni beradi:

$$Z=0 \text{ da } \theta_{Z=0}=0 \text{ bo'ladi;}$$

$$Z=l \text{ da } \theta_{Z=l}=0 \text{ bo'ladi.}$$

Bulardan,  $D=0$  va  $C=M_e l/6$  ekanligi kelib chiqadi.

Nihoyat, aylanish burchagi va solqilik uchun quyidagi tenglamalarga ega bo'lamiz:

$$\theta_Z = \frac{M_e Z^2}{2l \cdot EI_x} - \frac{M_e l}{6 EI_x}; \quad (e)$$

$$v_Z = \frac{1}{EI} \cdot \frac{M_e Z^3}{6l} - \frac{M_e l}{6 EI_x} Z. \quad (f)$$

(d) tenglamaga  $Z=0,5l$  ni qo'yib, tayanchlar orasidagi kesimning solqiligini topamiz:

$$v_D = v_{Z=0,5l} = -\frac{M_e l}{16 EI_x}.$$

(e) tenglamani nolga tenglab, solqiligi eng katta bo'lgan kesimning absissasi  $Z_0$  ni aniqlaymiz:

$$\frac{M_e Z^2}{2l \cdot EI_x} - \frac{M_e l}{6 EI_x} = 0;$$

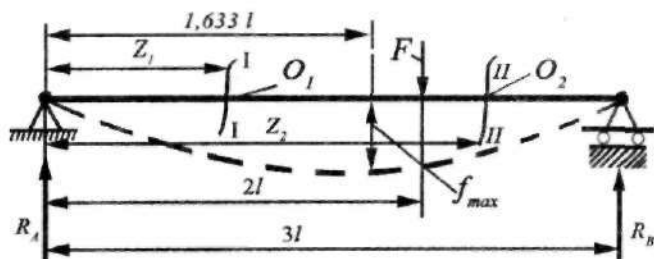
bundan,  $Z_0=0,577l$ . Maksimal solqilikni hisoblaymiz:

$$f_{\max} = \frac{1}{EI_x} \cdot \frac{M_e (0,577l)^3}{6l} - \frac{M_e l}{6 EI_x} \cdot 0,577l = -\frac{M_e l^2}{15,57 EI_x}.$$

Demak,  $v_D$  maksimal solqilikdan 2,76 % ga farq qilar ekan.

### 79- masala

Uzunligi  $3l$ , bikrligi o'zgarmas bo'lgan oddiy to'singa to'plangan kuch qo'yilgan. Ana shu to'sin uchun aylanish burchagi va solqilik tenglamalarini, maksimal solqilik hamda tayanch kesimlarining aylanish burchaklarini toping (VIII.4- shakl).



VIII.4- shakl

Masalani yechish uchun egilgan o'qning taqribiy differensial tenglamasini bevosita integrallash usuli tavsiya etiladi.

### Yechish:

Avval to'sinning tayanch reaksiyalarini topamiz:

$$R_A = \frac{F}{3}; \quad R_B = \frac{2F}{3}.$$

$F$  yuk to'sinni ikkita oraliqqa (uchastkaga) ajratganligi sababli, har bir oraliq uchun quyidagi ifodalarni tuzish zarur:

I oraliq ( $0 \leq Z_1 \leq 2l$ ):

II oraliq ( $2l \leq Z_2 \leq 3l$ ):

$$M(Z_1) = \frac{F}{3} Z_1; \quad (a) \quad M(Z_2) = \frac{F}{3} Z_2 - F(Z_2 - 2l); \quad (a')$$

$$EI_x v''_{Z_1} = \frac{F}{3} Z_1; \quad (b) \quad EI_x v''_{Z_2} = \frac{F}{3} Z_2 - F(Z_2 - 2l); \quad (b')$$

$$EI_x \theta_{Z_1} = \frac{F Z_1^2}{3 \cdot 2} + C_1; \quad (d) \quad EI_x \theta_{Z_2} = \frac{F Z_2^2}{3 \cdot 2} - F \frac{(Z_2 - 2l)^2}{2} + C_2; \quad (d')$$

$$EI_x v_{Z_1} = \frac{F Z_1^3}{3 \cdot 6} + C_1 Z_1 + D_1; \quad (e) \quad EI_x v_{Z_2} = \frac{F Z_2^3}{3 \cdot 6} - F \frac{(Z_2 - 2l)^3}{6} + C_2 Z_2 + D_2. \quad (e')$$

Yuqoridagi tenglamalar tarkibidagi  $C_1, D_1, C_2, D_2$  ixtiyoriy o'zgarmaslarni aniqlash uchun quyidagi to'rtta chegaraviy shartlardan foydalanamiz:

$Z_1 = 0$  da  $v_{Z_1} = 0$ ; bundan,  $D = 0$  kelib chiqadi.

$Z_2 = 3l$  da  $v_{Z_2} = 0$  yoki  $\frac{F(3l)^3}{3 \cdot 6} - F \frac{l^3}{6} + C_2 3l + D_2 = 0$  bo'ladi.

$Z_1 = Z_2 = 2l$  da  $\theta_{Z_1} = \theta_{Z_2}$  yoki  $\frac{F(2l)^2}{3 \cdot 2} + C_1 = \frac{F(2l)^2}{3 \cdot 2} + C_2$ ; bundan,  $C_1 = C_2$  kelib chiqadi.

$Z_1 = Z_2 = 2l$  da  $v_{Z_1} = v_{Z_2}$  yoki  $\frac{F(2l)^3}{3 \cdot 6} + C_1 2l + D_1 = \frac{F(2l)^3}{3 \cdot 6} + C_2 2l + D_2 = 0$  bo'ladi.

Bundan,  $D_1 = D_2$  kelib chiqadi.

Shunday qilib,  $D_1 = D_2 = 0$ ;  $C_1 = C_2 = -\frac{4Fl^2}{9}$ .

I va II uchastkalar uchun aylanish burchagi hamda solqilik qiymatlarini aniqlaymiz.

I oraliq:

$$\theta_{z_1} = \frac{1}{EI_x} \left( \frac{FZ_1^2}{6} - \frac{4Fl^2}{9} \right) = \frac{F}{6EI_x} \left( Z_1^2 - \frac{8l^2}{3} \right); \quad (f) \quad \theta_{z_2} = \frac{F}{6EI_x} \left[ Z_2^2 - 3(Z_2 - 2l)^2 - \frac{8l^2}{3} \right]; \quad (f')$$

$$\nu_{z_1} = \frac{F}{18EI_x} (Z_1^3 - 8l^2 Z_1); \quad (g) \quad \nu_{z_2} = \frac{F}{18EI_x} [Z_2^3 - 3(Z_2 - 2l)^3 - 8l^2 Z_2]; \quad (g')$$

Endi solqilikning eng katta qiymati  $f_{\max}$  ni aniqlashga o'tamiz. Odatda, solqiligi  $f_{\max}$  bo'lgan kesimda aylanish burchagi nolga teng bo'ladi; tekshirilayotgan to'sinda bunday kesim  $0 \leq Z_1 \leq 2l$  oraliqda yotishi tabiiy. Shuning uchun:

$$\frac{d\nu_{z_1}}{dZ_1} = \frac{F}{6EI_x} \left( Z_1^2 - \frac{8l^2}{3} \right) = 0.$$

$$\text{Bundan, } Z_1 = 1,633l, \text{ demak, } f_{\max} = \frac{F}{18EI_x} [(1,633l)^3 - 8l^2 \cdot 1,633l] = -0,4838 \frac{Fl^3}{EI_x}.$$

(f) tenglamaga  $Z=0$  ni, (f') tenglamaga esa  $Z_2=3l$  ni qo'yib, tayanch kesimlaridagi aylanish burchagini topamiz:

$$\theta_B = -\frac{4Fl^2}{9EI_x}; \quad \theta_C = \frac{5Fl^2}{9EI_x}.$$

### 8.3- §. Universal tenglama yordamida deformatsiyalarni aniqlash (boshlang'ich parametrlar usuli)

Egillishdagi deformatsiyalarni aniqlash universal tenglamasi quyidagi ko'rinishga ega bo'ladi:

$$\nu_z = \nu_0 + \theta_0 \cdot Z + \frac{1}{EJ_x} \left[ \sum \frac{M(z-a)^2}{2} + \sum \frac{F(z-b)^3}{6} + \sum \frac{q(z-c)^4}{24} - \sum \frac{q(z-d)^4}{24} \right]; \quad (\text{VIII.2})$$

Bundan bir marta xosila olinsa, kesimning aylanish burchagi tenglamasi chiqadi:

$$\theta = \theta_0 + \frac{1}{EJ_x} \left[ \sum M(z-a) + \sum \frac{F(z-b)^2}{2} + \sum \frac{q(z-c)^3}{6} - \sum \frac{q(z-d)^3}{6} \right]; \quad (\text{VIII.3})$$

bu yerda,  $\nu_0, \theta_0$  – koordinata boshidagi solqilik va aylanish burchaklari;

$a, b, c, d$  – koordinata boshidan mos ravishda juft kuch, to'plangan kuch va yoyilgan kuchlarga bo'lgan masofa.

Bu usul quyidagi asosiy qoidalarga tayanadi:

1) koordinata boshi to'sinning chap uchidan tanlanadi va u hamma oraliqlar uchun umumiy hisoblanadi;

2) qirqimdan chap tomonda joylashgan tashqi kuchlardan eguvchi moment ifodasi tuziladi;

3)  $(z-a)^n$  ko'rinishdagi ko'phadlarni integrallashda qavslarni ochmaslik lozim:

$$\int (z-a)^n dz = \frac{(z-a)^{n+1}}{n+1} + C;$$

4) to'singa qo'yilgan juft kuchlardan eguvchi moment ifodasini tuzayotganda, uni  $(z-a_1)^0 = 1$  binomga ko'paytirish tavsiya qilinadi; bunda,  $a_1$  - koordinata boshidan juft kuchlar qo'yilgan kesimgacha bo'lgan masofa;

5) agar tekis yoyilgan yuk  $q = \text{const}$  to'sinning oxirgi uchiga yetmagan bo'lsa, u "sun'iy" ravishda davom ettiriladi.

### 80- masala

Uzunligi  $3l$  va bikrligi o'zgarmas bo'lgan konsol  $F = 2ql$  to'plangan kuch va tekis taralgan yoyilgan kuchlar bilan yuklangan (VIII.5- shakl, a). Universal formula yordamida konsol erkin uchining salqiligi va aylanish burchagi aniqlansin.

### Yechish:

1. Tayanch reaksiyalarini aniqlaymiz:

$$\Sigma M_{B_1} = 0; \quad -M_B + ql(l + 0,5l) + F \cdot 3l = 0; \quad \text{bundan, } M_B = 7,5 \, ql^2;$$

$$\Sigma Y_1 = 0; \quad R_B - ql - F = 0; \quad \text{bundan, } R_B = 3 \, ql.$$

2. Konsolni uchta oraliqqa ajratamiz, keyin esa 8.3- § da aytib o'tilgan 1- va 5- qoidalarga tayanib (VIII.5- shakl, b):

a) koordinatalar boshini chap tayanch ustiga qo'yamiz;

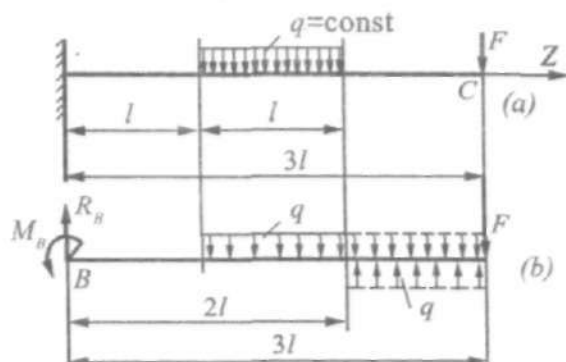
b) III oraliqni sun'iy ravishda tekis taralgan kuchlar bilan yuklaymiz va ularni muvozanatlaydigan kuchlarni ham kiritamiz.

3. Har bir oraliqning boshlanishi uchun quyidagi ifodalarni tuzib chiqamiz:

$$\text{I oraliq: } v_0 = 0; \theta_0 = 0; m_1 = -7,5 \, ql^2; \\ F_1 = 3 \, ql; a_1 = 0; b_1 = 0; \\ c_1 = 0; q_1 = 0.$$

$$\text{II oraliq: } m_2 = 0; q_2 = -q; F_2 = 0; \\ c_2 = l.$$

$$\text{III oraliq: } m_3 = 0; q_3 = q; F_3 = 0; \\ c_3 = 2l.$$



VIII.5- shakl



Bu ifodalarni (VIII.3), (VIII.2) universal formulaga qo'yib, tegishli aylanish burchagi va solqilikning tenglamalarini umumiy holda yozib olamiz:

$$\theta_z = \frac{1}{EI_x} \left( -7,5ql^2 \cdot Z + 3ql \frac{Z^2}{2} \right) \Big|_{z=0}^I + \frac{1}{EI_x} \left[ -q \frac{(Z-l)^3}{6} \right] \Big|_{z=R}^{II} + \frac{1}{EI_x} \left[ q \frac{(Z-2l)^3}{6} \right] \Big|_{z=2l}^{III}; \quad (a)$$

$$v_z = \frac{1}{EI_x} \left( -7,5ql^2 \frac{Z^2}{2} + 3ql \frac{Z^3}{6} \right) \Big|_{z=0}^I + \frac{1}{EI_x} \left[ -q \frac{(Z-l)^4}{24} \right] \Big|_{z=l}^{II} + \frac{1}{EI_x} \left[ q \frac{(Z-2l)^4}{24} \right] \Big|_{z=2l}^{III} \quad (b)$$

So'ralgan kesimning aylanish burchagi va solqiligini topish uchun oxirgi ifodalarni  $Z=3l$  da hisoblaymiz:

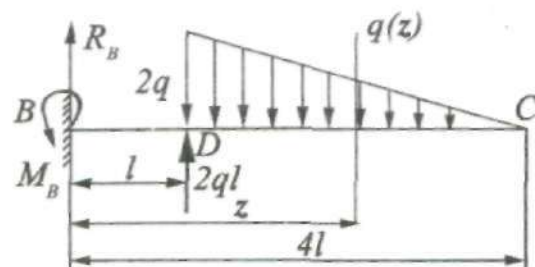
$$\theta_c = \theta_{z=3l} = \frac{1}{EI_x} \left[ -7,5ql^2 \cdot 3l + 3ql \frac{(3l)^2}{2} \right] + \frac{1}{EI_x} \left[ -q \frac{(2l)^3}{6} \right] + \frac{1}{EI_x} \left[ q \frac{l^3}{6} \right] = -10,17 \frac{ql^3}{EI_x};$$

$$v_c = v_{z=3l} = \frac{1}{EI_x} \left[ -7,5ql^2 \frac{(3l)^2}{2} + 3ql \frac{(3l)^3}{6} \right] + \frac{1}{EI_x} \left[ -q \frac{(2l)^4}{24} \right] + \frac{1}{EI_x} \left[ q \frac{l^4}{24} \right] = 20,875 \frac{ql^4}{EI_x}.$$

Izoh: bordi-yu, so'ralgan kesim II oraliqda yotsa, (a) va (b) ifodalardagi oxirgi had e'tiborga olinmaydi.

### 81- masala

Bikrligi o'zgarmas konsol VIII.6- shaklda ko'rsatilganidek, to'plangan kuch va yoyilgan kuchlar bilan yuklangan. Konsol erkin uchidagi aylanish burchagi va to'plangan kuch qo'yilgan kesimining solqiligi topsin.



VIII.6- shakl

#### Yechish:

1) Tayanch reaksiyalarini topamiz:

$$R_B = ql; M_B = 2ql^2.$$

2) Konsolni ikkita oraliqqa ajratib, yoyilgan kuchning ta'sir etish qonuniyatini aniqlaymiz:

$$\frac{q(Z)}{2q} = \frac{4l-Z}{3l} \quad \text{yoki} \quad q(Z) = \frac{(4l-Z)}{3l} \cdot 2q;$$

$$\text{bundan, } q'(Z) = -\frac{2q}{3l} = \text{const.}$$

3) Har bir oraliqning boshlanishi uchun quyidagi ifodalarni tuzib olamiz:

I oraliq:  $v_0 = 0; \theta_0 = 0; m_1 = -2ql^2; F_1 = ql; q_1 = 0; a_1 = 0; b_1 = 0; c_1 = 0.$

II oraliq:  $m_2 = 0; F_2 = 2ql; q_2 = -2q; q_2' = -(-2q/3l) = 2q/3l; b_2 = l; c_2 = l; d_2 = l.$



Bundan chiqdi, aylanish burchagi va solqilik tenglamalari quyidagi ko'rinishda bo'ladi:

$$\theta_z = \frac{1}{EI_x} \left( -2ql^2 \cdot z + ql \frac{z^2}{2} \right) \Big|_{z=0}^I + \frac{1}{EI_x} \left[ 2ql \frac{(z-l)^2}{2} - 2q \frac{(z-l)^3}{6} + \frac{2q}{3l} \frac{(z-l)^4}{24} \right] \Big|_{z=l}^l;$$

$$v_z = \frac{1}{EI_x} \left( -2ql^2 \cdot \frac{z^2}{2} + ql \frac{z^3}{6} \right) \Big|_{z=0}^I + \frac{1}{EI_x} \left[ 2ql \frac{(z-l)^3}{6} - 2q \frac{(z-l)^4}{24} + \frac{2q}{3l} \frac{(z-l)^5}{120} \right] \Big|_{z=l}^l;$$

C kesimning aylanish burchagini topamiz:

$$\theta_c = \theta_{z=l} = \frac{1}{EI_x} \left( -2ql^2 \cdot 4l + ql \frac{16l^2}{2} \right) + \frac{1}{EI_x} \left[ 2ql \cdot \frac{(3l)^2}{2} - 2q \frac{(3l)^3}{6} + \frac{2q}{3l} \frac{(3l)^4}{24} \right] = -\frac{87}{96} \cdot \frac{ql^3}{EI_x}.$$

D kesimning solqiligini hisoblaymiz:

$$v_D = v_{z=l} = \frac{1}{EI_x} \left( -2ql^2 \cdot \frac{l^2}{2} + ql \cdot \frac{l^3}{6} \right) = -\frac{5}{6} \cdot \frac{ql^4}{EI_x}.$$

## 82- masala

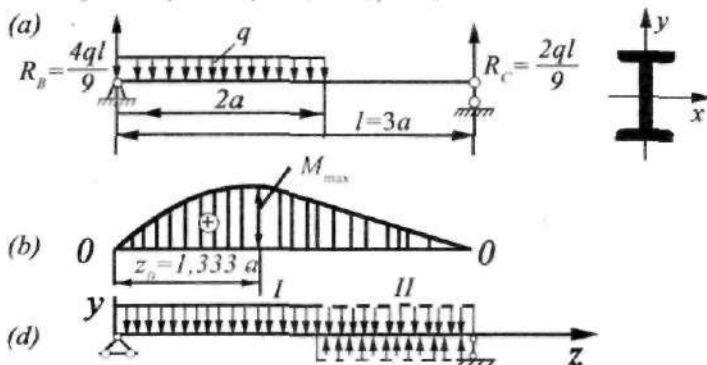
Uzunligi  $l=3a$  bo'lgan oddiy to'sin tekis taralgan kuchlar bilan yuklangan (VIII.7- shakl). Mustahkamlik va bikrlilik shartlaridan foydalanib, qo'shtavrlı kesim tanlansin. Hisoblashlarda  $\sigma_{adm} = 160 \text{ MPa}$ ,  $E = 2 \cdot 10^5 \text{ MPa}$ ,  $f_{adm} = \frac{1}{600}$ ,  $a = 1,2 \text{ m}$ ,  $q = 20 \text{ kN/m}$  deb qabul qilinsin.

### Yechish:

1) Tayanch reaksiyalarini aniqlab, eguvchi moment epyurasini quramiz (VIII.7- shakl, b). Epyuradan  $M_{max} = 9,87 \cdot 10^{-2} ql^2$  ekanligi ma'lum.

2) VIII.7- shakl (b) ni chizib, to'sinning har bir oraliq'i uchun tegishli ifodalarni yozib olamiz.

I oraliq:  $v_0 = 0$ ;  $\theta_0 \neq 0$ ;  $m_1 = 0$ ;  $F_1 = 4ql/9$ ;  $q_1 = -q$ .



VIII.7- shakl

II oraliq:  $m_2 = 0$ ;  $F_2 = 0$ ;  $q_2 = q$ ;  $c_2 = 2a$ .

Bu ifodalardan foydalanib, aylanish burchagi va solqilikning tenglamalarini umumiy holda yozamiz:

$$\theta_z = \theta_0 + \frac{1}{EI_x} \left( \frac{4}{9} ql \cdot \frac{Z^2}{2} - q \frac{Z^3}{6} \right) \Big|_I + \frac{1}{EI_x} \left[ q \frac{(Z-2a)^3}{6} \right] \Big|_{II};$$

$$v_z = \theta_0 Z + \frac{1}{EI_x} \left( \frac{4}{9} ql \frac{Z^3}{6} - q \frac{Z^4}{24} \right) \Big|_I + \frac{1}{EI_x} \left[ q \frac{(Z-2a)^4}{24} \right] \Big|_{II}.$$

C tayanchda solqilikning nolga tenglik shartidan  $\theta_0$  ni aniqlaymiz:

$$\theta_0 l + \frac{1}{EI_x} \left( \frac{4}{9} ql \cdot \frac{l^3}{6} - q \frac{l^4}{24} \right) + \frac{1}{EI_x} q \frac{l^4}{24 \cdot 81} = 0; \text{ bundan, } \theta_0 = -\frac{8}{243} \frac{ql^3}{EI_x}.$$

Nihoyat quyidagilarga ega bo'lamiz:

$$\theta_z = -\frac{8}{243} \frac{ql^3}{EI_x} + \frac{1}{EI_x} \left( \frac{4}{18} ql \cdot Z^2 - \frac{q}{6} Z^3 \right) \Big|_I + \frac{q \left( Z - \frac{2}{3} l \right)^3}{6 EI_x} \Big|_{II};$$

$$v_z = -\frac{8}{243} \frac{ql^3}{EI_x} Z + \frac{1}{EI_x} \left( \frac{2}{27} ql Z^3 - \frac{q}{24} Z^4 \right) \Big|_I + \frac{q \left( Z - \frac{2}{3} l \right)^4}{24 EI_x}.$$

Eng katta solqiligni aniqlaymiz – tekshirilayotgan to'sinda  $f_{\max}$  I oraliqda yotadi. Shuning uchun:

$$-\frac{8}{243} \frac{ql^2}{EI_x} + \frac{1}{EI_x} \left( \frac{4}{18} ql \cdot Z^2 - \frac{q}{6} Z^3 \right) = 0.$$

Tenglamani yechib,  $Z = 0,482l$  ni hosil qilamiz.

Demak,

$$f_{\max} = -\frac{8}{243} \frac{ql^3}{EI_x} \cdot 0,482l + \frac{1}{EI_x} \left[ \frac{2}{27} ql \cdot (0,482l)^3 - \frac{q}{24} (0,482l)^4 \right] = -9,876 \cdot 10^{-3} \frac{ql^4}{EI_x}.$$

3) To'sin uchun birlilik shartini yozamiz:  $9,876 \cdot 10^{-3} \frac{ql^4}{EI_x} \leq f_{\text{adm}};$

bundan, inersiya momentining qiymati  $I_x \geq \frac{9,876 \cdot 10^{-3} ql^4}{E f_{\text{adm}}}$  yoki

$$I_x = \frac{9,876 \cdot 10^{-3} \cdot 20 \cdot 10^3 (3,1,2)^4 \cdot 600}{2 \cdot 10^8 \cdot 3,1,2} = 2764,6510^{-8} \text{ m}^4 = 2764,65 \text{ sm}^4.$$

Inersiya momentining bu qiymatiga qarab, GOST 8239-72 dan profil nomeri 22<sup>a</sup> bo'lgan qo'shtavni tanlaymiz. Bu qo'shtavr uchun quyidagilarni jadvaldan olish mumkin:  $I_x = 2790 \text{ sm}^4$ ;  $W_x = 254 \text{ sm}^3$ ; endi tanlab olingan qo'shtavni mustahkamlikka tekshiramiz:

$$\sigma_{\text{adm}} = \frac{M_{\text{max}}}{W_x} = \frac{9,87 \cdot 10^{-2} \cdot 20 \cdot 10^3 (3 \cdot 1,2)^2}{254 \cdot 10^{-6}} = 100,72 \cdot 10^6 \frac{\text{N}}{\text{m}^2} = 100,72 \text{ MPa} < \sigma_{\text{adm}} = 160 \text{ MPa}.$$

To'sinning mustahkamligi ta'minlangan.

## 8.4- §. Egilishda deformatsiyalarni aniqlash Mor usuli

Egilishda deformatsiyalarni aniqlash Mor integrali quyidagi ko'rinishga ega:

$$\Delta = \sum_{i=1}^n \int_0^l \frac{M_i \cdot \bar{M}_i}{EJ} dz; \quad (\text{VIII.4})$$

bu yerda,  $M_i$  – tashqi kuchlardan olingan eguvchi moment tenglamasi;

$\bar{M}_i$  – birlik kuchdan olingan eguvchi moment tenglamasi.

Mor usulida ko'chishlar quyidagi tartibda aniqlanadi:

1. Elastik deformatsiyalanuvchi brus (to'sin, sterjen, rama, arka) oraliqlarga ajratilib, tayanch reaksiyalari topiladi.

2. Brusning yordamchi holati qurilib, u ko'chishi aniqlanadigan kesimga qarab birlik kuch bilan yuklanadi:

- chiziqli ko'chishni aniqlashda kesimga birlik to'plangan kuch qo'yiladi;
- burchakli ko'chishni aniqlashda kesimga birlik juft kuch (moment) qo'yiladi.

3. Brusning har bir oraliq'i uchun kesish usulini qo'llab,  $M_i$  hamda  $\bar{M}_i$  larning analitik ifodasi tuziladi.

### 83- masala

Bikrligi o'zgarmas bo'lgan oddiy to'sinning o'rtasiga  $2F$  kuch qo'yilgan (VIII.8- shakl, a). Kuch qo'yilgan nuqtaning solqiligi va  $B$  kesimining aylanish burchagi Mor va Vereshagin usullarida aniqlansin.

### Yechish:

Masalani Mor usuli yordamida yechish uchun to'sinning asosiy (VIII.8- shakl, a) va yordamchi (VIII.8- shakl, b, d) holatlari oraliqlarga ajratilib, tayanch reaksiyalari topiladi (tayanch reaksiyalarining qiymati va yo'nalishlari chizmalarda ko'rsatilgan).

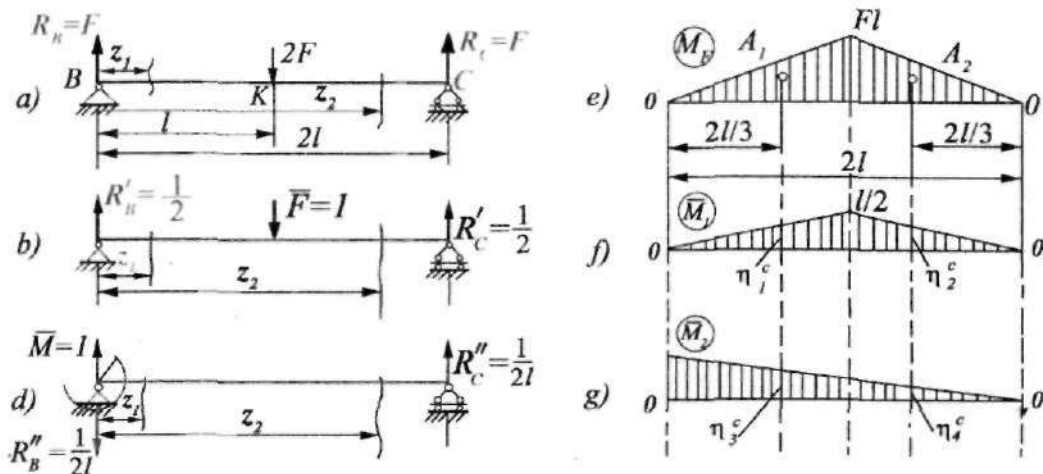
Kesish usulini qo'llab, har bir oraliq uchun asosiy va yordamchi holatlar bo'yicha eguvchi momentlarning ifodalarini tuzamiz:

$$I \text{ oraliq: } (0 \leq Z_1 \leq l): M_1^I = FZ_1; M_1^I = 0,5Z_1; M_2^I = 1 - \frac{1}{2l} Z_1.$$

II oraliq: ( $l \leq Z_2 \leq 2l$ )  $M_F^{\text{II}} = FZ_2 - 2F(Z_2 - l)$ ;  $M_1^{\text{II}} = 0,5Z_2 - (Z_2 - l)$ ;  $M_2^{\text{II}} = 1 - \frac{1}{2l}Z_2$ .

K kesimning solqiliginı topamiz:

$$\begin{aligned} v_k &= \frac{1}{EI} \int_0^l M_1^{\text{I}} \cdot M_1^{\text{I}} dZ_1 + \frac{1}{EI} \int_l^{2l} M_1^{\text{II}} \cdot M_1^{\text{II}} dZ_2 = \\ &= \frac{1}{EI} \int_0^l FZ_1 \frac{Z_1}{2} dZ_1 + \frac{1}{EI} \int_l^{2l} [FZ_2 - 2F(Z_2 - l)] \cdot \left[ \frac{Z_2}{2} - 1(Z_2 - l) \right] dZ_2 = \frac{Fl^3}{3EI}. \end{aligned}$$



VIII.8-shakl

Kuch to'sinning o'rtasiga qo'yilgani uchun eng katta solqilik  $V_k$  ga teng bo'ladi:

$$f_{\max} = \frac{Fl^3}{3EI_x}.$$

Xuddi shu tarzda B kesimning aylanish burchagi topiladi:

$$\begin{aligned} \theta_k &= \frac{1}{EI_x} \int_0^l M_1^{\text{I}} \cdot M_2^{\text{I}} dZ_1 + \frac{1}{EI_x} \int_l^{2l} M_1^{\text{II}} \cdot M_2^{\text{II}} dZ_2 = \\ &= \frac{1}{EI_x} \int_0^l FZ_1 \left( 1 - \frac{Z_1}{2l} \right) dZ_1 + \frac{1}{EI_x} \int_l^{2l} [FZ_2 - 2F(Z_2 - l)] \cdot \left( 1 - \frac{Z_2}{2l} \right) dZ_2 = \frac{Fl^2}{2EI_x}. \end{aligned}$$

Vereshagin usulida ko'chishlarni topish uchun tashqi kuch va birlik kuchdan eguvchi moment epyuralarini quramiz (VIII.8- shakl, e, f, g).

Chiziqli ko'chishni aniqlash uchun VIII.8- shakl (e), (f) va (g) larda ko'rsatilgan epyuralar ko'paytiriladi (odatda, Vereshagin usuli «epyuralarni ko'paytirish usuli» deb ham yuritiladi):

$$\nu_k = \nu_k (M_F, \bar{M}_1) = \frac{1}{EI_x} (A_1 \cdot \eta_1^C + A_2 \cdot \eta_2^C);$$

bu yerda,  $A_1 = \frac{1}{2} \cdot Fl \cdot l = \frac{Fl^2}{2}$ ;  $\eta_1^C = \frac{l}{3}$ ;  $A_2 = \frac{1}{2} \cdot Fl \cdot l = \frac{Fl^2}{2}$ ;  $\eta_2^C = \frac{l}{3}$ .

Bularni e'tiborga olsak,  $\nu_k = \frac{l}{EI_x} \left( \frac{Fl^2}{2} \cdot \frac{l}{3} + \frac{Fl^2}{2} \cdot \frac{l}{3} \right) = \frac{Fl^3}{3EI_x}$ .

B kesimning aylanish burchagi quyidagicha topiladi:

$$\theta_k = \theta_k (M_F, M_1) = \frac{1}{EI_x} (A_1 \eta_1^C + A_2 \eta_2^C);$$

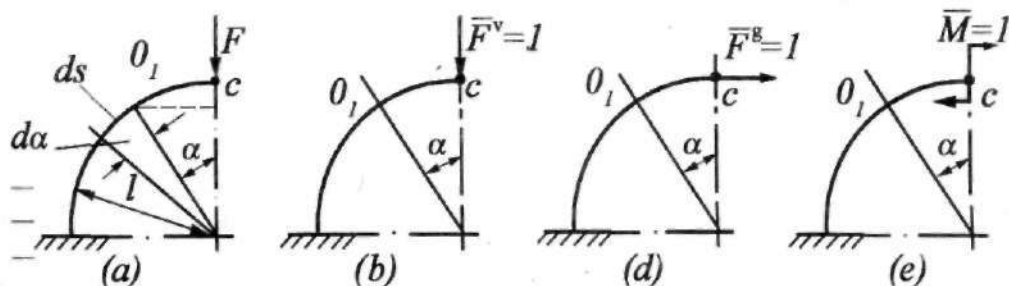
bu yerda,  $\eta_3^C = 2/3$ ,  $\eta_4^C = 1/3$ .

Demak,  $\theta_k = \frac{1}{EI_x} \left( \frac{Fl^2}{2} \cdot \frac{2}{3} + \frac{Fl^2}{2} \cdot \frac{1}{3} \right) = \frac{Fl^3}{2EI_x}$ .

Ikkala usulda ham bir xil natijaga erishdik. Ammo yuqorida ko'rdikki, Vereshagin usulida ko'chishlarni aniqlash bir muncha osonroq ekan.

#### 84- masala

Egriligi kichik brus  $F$  kuch bilan yuklangan (VIII.9- shakl, a). Kuch qo'yilgan kesimning vertikal, gorizontal va burchakli ko'chishlari aniqlansin. Brusning bikrligi o'zgarmas deb hisoblansin.



VIII.9- shakl

**Yechish:**

Bu masala Mor usuli yordamida yechiladi.

Brusning asosiy va uchala yordamchi holatlari uchun eguvchi moment ifodasini tuzamiz:

$\overline{M}^F = -Fl \sin \alpha$  (VIII.9- shakl,  $a$  – asosiy holat);

$\overline{M}_1^v = -l \sin \alpha$  (VIII.9- shakl,  $b$  – yordamchi holat);

$\overline{M}_1^s = -(l - l \sin \alpha) = -l(1 - \sin \alpha)$  (VIII.9- shakl,  $d$  – yordamchi holat);

$M_2 = -1$  (VIII.9- shakl,  $e$  – yordamchi holat).

Yoy differensialini  $ld\alpha$  bilan almashtirib, quyidagilarni aniqlaymiz:

a) vertikal ko'chish:

$$v_C^v = \frac{1}{EI_x} \int_0^{\pi/2} (-Fl \sin \alpha)(-l \sin \alpha) \cdot ld\alpha = \frac{\pi Fl^3}{4 EI_x};$$

b) gorizontal ko'chish:

$$v_C^g = \frac{1}{EI_x} \int_0^{\pi/2} (-Fl \sin \alpha)[-l(1 - \cos \alpha)] \cdot ld\alpha = \frac{Fl^3}{2 EI_x};$$

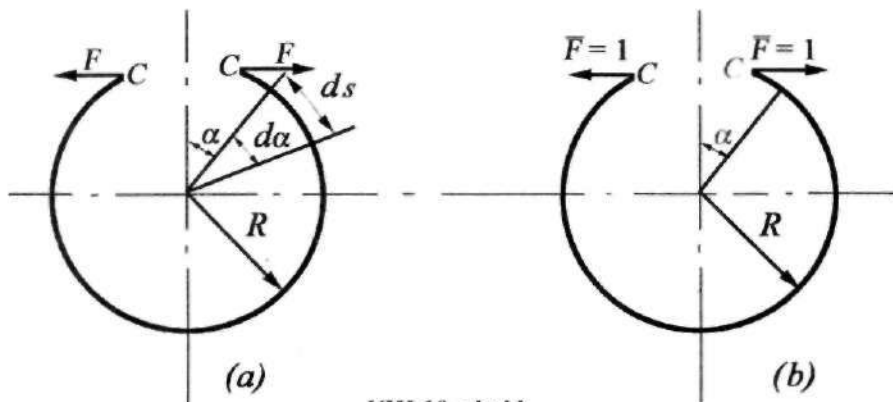
C kesimning to'liq ko'chishi  $v_C = \sqrt{(v_C^v)^2 + (v_C^g)^2} \approx 0,93 \frac{Fl^3}{EI_x};$

d) C kesimning aylanish burchagi – burchakli ko'chish:

$$\theta_C = \frac{1}{EI_x} \int_0^{\pi/2} (-Fl \sin \alpha)(-1) ld\alpha = \frac{Fl^2}{EI_x}.$$

**85- masala**

$F$  kuch ta'sirida kesik halqadagi tirqish qanchaga ochiladi (VIII.10- shakl,  $a$ )? Halqaning bikrligi  $EI = \text{const}$ .



VIII.10- shakl

**Yechish:**

Masala Mor integrali yordamida yechiladi.

Asosiy va yordamchi holatlar uchun mos ravishda, tashqi kuch va birlik kuchdan paydo bo'luvchi eguvchi momentlarni aniqlaymiz:

$$0 \leq \alpha \leq 2\pi: M_F = FR(1 - \cos \alpha); M_1 = R(1 - \cos \alpha).$$

Kuch qo'yilgan kesimlarning o'zaro uzoqlashishini hisoblaymiz:

$$\delta_c = \frac{1}{EI} \int_{(i)} M_F \cdot \bar{M}_1 ds = \frac{1}{EI} \int_0^{2\pi} FR(1 - \cos \alpha) \cdot R(1 - \cos \alpha) R d\alpha = \frac{FR^3}{EI} \int_0^{2\pi} (1 - \cos \alpha)^2 d\alpha = 3\pi \frac{FR^3}{EI}.$$

**8.5- §. Egilishda deformatsiyalarni aniqlash Vereshagin usuli**

Egilishda deformatsiyalarni aniqlashning Vereshagin formulasi quyidagi ko'rinishga ega:

$$\Delta = \sum_{i=1}^n \frac{A_i \cdot \eta_i^c}{E J_i}, \quad (\text{VIII.5})$$

bu yerda,  $A_i$  – tashqi kuchlardan olingan eguvchi moment epyura yuzasi;

$\eta_i^c$  –  $A_i$  og'irlik markaziga to'g'ri kelgan birlik kuch (yoki birlik moment)dan olingan eguvchi moment epyura ordinatasi.

Shuni ta'kidlab o'tish lozimki, o'zgaruvchan kesimli bruslarning ko'chishlarini Vereshagin usulida aniqlab bo'lmaydi, bunday hollarda Mor integralidan foydalanish ma'qul. Bundan tashqari,  $\eta_i^c$  ordinalarni faqat to'g'ri chiziqli bilan chegaralangan eguvchi moment epyuralaridan olishni unutmaslik kerak.

Agar tashqi va birlik kuchlardan qurilgan eguvchi moment epyuralari brusning bo'ylama o'qidan bir tomonda yotsa, ko'paytma musbat, aksincha, turli tomonlarda yotsa, manfiy ishorali hisoblanadi.

**86- masala**

Oddiy to'sinning chap tayanchidan qoq o'rtasigacha intensivligi  $q$  bo'lgan tekis taralgan yuk qo'yilgan (VIII.11- shakl, a).  $K$  kesimning solqiligi aniqlansin.

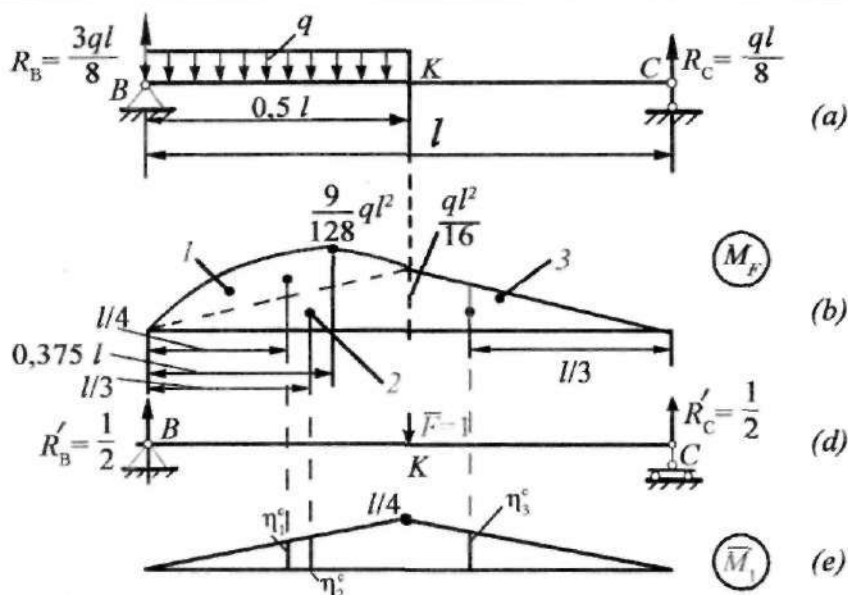
To'sin o'zgarmas bikrlikka ega.

**Yechish:**

Masalani Vereshagin usulida yechamiz.

Asosiy holat bo'yicha yuklangan to'sinning tayanchlardagi reaksiyalari aniqlangach, tashqi yukdan eguvchi moment epyurasini quramiz (VIII.11- shakl, b).

$K$  kesimga  $F=1$  birlik kuch qo'yib, to'sinning yordamchi holati quriladi (VIII.11- shakl, d), keyin esa tayanch reaksiyalarini aniqlab, yordamchi holatga tegishli bo'lgan  $M_1$  epyurani quramiz (VIII.11- shakl, e).



VIII.11- shakl

$M_f$  epyurani uchta bo'lakka ajratamiz va ularning yuzalarini hisoblaymiz:

$$A_1 = \frac{2}{3} \cdot \frac{l}{2} \cdot \frac{q \left( \frac{l}{2} \right)^2}{8} = \frac{ql^3}{96} \sim \text{parabolik segmentning yuzasi};$$

$$A_2 = A_3 = \frac{1}{2} \cdot \frac{l}{2} \cdot \frac{ql^2}{16} = \frac{ql^3}{64} \sim \text{uchburchakning yuzasi}.$$

Bu yuzalarning og'irlik markazlariga to'g'ri keluvchi ordinatalar quyidagicha:

$$\eta_1^c = l/2; \quad \eta_2^c = \eta_3^c = l/6.$$

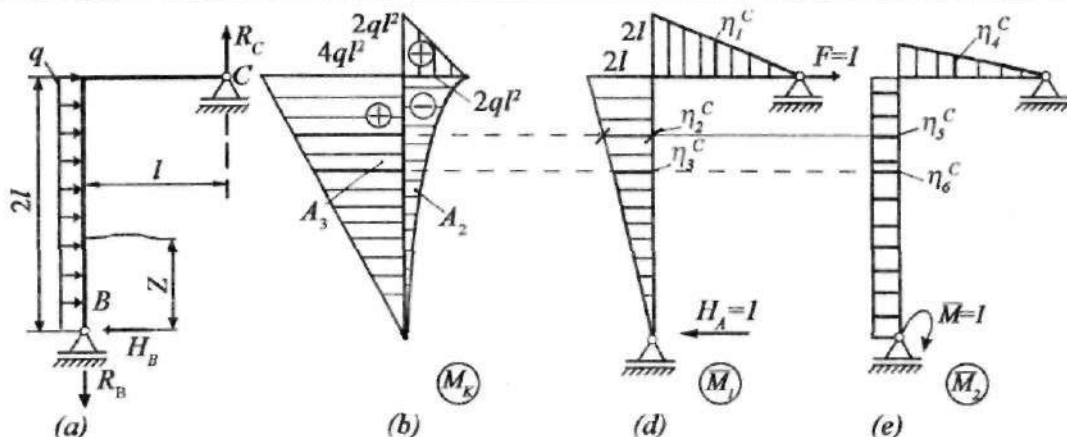
Vereshagin formulasidan  $v_K$  ni aniqlaymiz:

$$v_K = \frac{1}{EI_x} (A_1 \cdot \eta_1^c + A_2 \cdot \eta_2^c + A_3 \cdot \eta_3^c) = \frac{1}{EI_x} \left( \frac{ql^3}{96} \cdot \frac{l}{8} + 2 \cdot \frac{ql^3}{64} \cdot \frac{l}{6} \right) = \frac{5}{768} \cdot \frac{ql^4}{EI_x}.$$

### 87- masala

VIII.12- shakl (a) da tasvirlangan tekis rama C kesimining gorizontall ko'chishi va B tayanch kesimining aylanish burchagini aniqlang. Rama o'zgarmas bikrlikka ega:  $EY = \text{const}$ .





VIII.12- shakl

**Yechish:**

Masalani Vereshagin usulida yechamiz.

Berilgan ramaning muvozanatini tekshirib, tayanchlarda paydo bo'luvchi reaksiyalarning o'zaro tengligiga ishonch hosil qilamiz:

$$H_B = R_B = R_C = 2ql.$$

Tashqi kuchlardan hosil bo'lgan eguvchi moment epyurasi (yuk epyurasi)ni «qatlamlarga ajratilgan» ko'rinishda quramiz (VIII.12- shakl, b).

Izoh: epyuralarni qiymatlarga ajratib chizish Vereshagin usulini ishlatishda ancha qulaylik tug'diradi. Chunki eguvchi moment tenglamasi ko'phadlardan iborat bo'lishiga qaramasdan (masalan, ramaning vertikal qismi uchun yozilgan tenglama ikkita haddan iborat:  $M_F = H_B \cdot Z - 0,5 qZ^2$ ), epyura ko'phad uchun qurilmaydi, balki har bir had (qo'shiluvchi) uchun alohida quriladi.

Yuk epyurasining yuzalarini hisoblaymiz:

$$A_1 = \frac{1}{2} 2ql^2 \cdot l = ql^3; \quad A_2 = \frac{1}{3} 2ql^2 \cdot 2l = \frac{4}{3} ql^3; \quad A_3 = \frac{1}{2} 4ql^2 \cdot 2l = 4ql^3.$$

C tayanchga  $F=1$  birlik gorizonttal kuch qo'yib, tayanchlardagi reaksiyalarni aniqlaymiz hamda  $M_1$  birlik epyurani quramiz (VIII.12- shakl, d).

B tayanchga  $M_1$  birlik moment qo'yib, ramaning VIII.12- shakl (e) da tasvirlangan yordamchi holati quriladi. Bu holat uchun tayanch reaksiyalarini topib, ikkinchi birlik epyura  $M_2$  ni quramiz.

Birlik epyuralardan  $\eta_i^c$  ordinalarni hisoblaymiz:

$$\eta_1^c = \frac{4l}{3}; \quad \eta_2^c = \frac{3l}{2}; \quad \eta_3^c = \frac{4l}{3}; \quad \eta_4^c = \frac{2}{3}; \quad \eta_5^c = \eta_6^c = 1.$$

$C$  kesimning gorizontal ko'chishi quyidagiga teng:

$$v_C^g = \frac{1}{EI_x} (A_1 \eta_1^C + A_2 \eta_2^C + A_3 \eta_3^C) = \frac{1}{EI_x} \left( ql^3 \frac{4}{3} l - \frac{4}{3} ql^3 \frac{3}{2} l + 4 ql^3 \frac{4}{3} l \right) = 4,667 \frac{ql^4}{EI_x}.$$

$B$  kesimning aylanish burchagi quyidagiga teng:

$$\theta_B = \frac{1}{EI_x} (A_1 \eta_4^C + A_2 \eta_5^C + A_3 \eta_6^C) = \frac{1}{EI_x} \left( ql^3 \frac{2}{3} - \frac{4}{3} ql^3 \cdot 1 + 4 ql^3 \cdot 1 \right) = 3,333 \frac{ql^4}{EI_x}.$$

## 8.6- §. Egilishda berilgan balkalar uchun deformatsiyalarni aniqlash bo'yicha topshiriqlar

### 14- topshiriq

**Berilgan:** keltirilgan shakllarda tashqi tomondan yuklangan balkalar va siniq sterjenlar berilgan.

**Topish kerak:**

1) VI.19- va VI.20- shakllardagi  $A$  nuqtaning solqiligi va  $B$  kesimning burilish burchagi Vereshagin usulida aniqlansin;

2) VI.18- shakldagi  $C$  nuqtaning solqiligi va  $A$  kesimning burilish burchagi Mor usulida aniqlansin.

Kerakli ma'lumotlar VI.1- jadvalda, hisoblash sxemalari esa VI.18- va VI.19- shakllarda berilgan.

## IX BOB

### MURAKKAB DEFORMATSIYA

#### 9.1- §. Asosiy mulohazalar

Inshoot, mashina va mexanizm qismlarining barcha ko'ndalang kesim yuzalariga ta'sir ko'rsatuvchi ikki yoki undan ortiq ichki zo'riqishlar natijasida vujudga keladigan deformatsiyalar murakkab deformatsiya yoki murakkab qarshilik deyiladi.

Eng ko'p uchraydigan murakkab deformatsiya turlari quyidagilardir:

- qiyshiq egilish;
- markaziy bo'lmagan cho'zilish yoki siqilish;
- egilish va buralishning birgalikdagi ta'siri.

Murakkab deformatsiyaga ishlayotgan bruslar quyidagi tartibda hisoblanadi:

- 1) brus ko'ndalang kesimlaridagi ichki zo'riqish kuchlari aniqlanib, ularning epyuralari quriladi;
- 2) eng katta yuklangan kesim vaziyati aniqlanadi;
- 3) har bir zo'riqish kuchidan hosil bo'lgan kuchlanishni aniqlab, ular algebratik ravishda qo'shiladi va eng katta kuchlanish hosil bo'lgan xavfli nuqta aniqlanadi;
- 4) brus materiali uchun uning mustahkamlik sharti tekshiriladi.

#### 9.2- §. Qiyshiq egilish

Qiyshiq egilishda natijaviy eguvchi moment tekisligi bilan egilish tekisligi ustma-ust tushmaydi.

- Qiyshiq egilishda normal kuchlanish quyidagiga teng:

$$\sigma_z = \pm \frac{M_y}{J_y} \cdot x \pm \frac{M_x}{J_x} \cdot y. \quad (\text{IX.1})$$

Nuqta cho'zilayotgan yuzachada bo'lsa,  $M_x$  va  $M_y$  larning ishorasi musbat, siqilayotgan yuzachada bo'lsa, manfiy olinadi.

- Neytral o'qning holati quyidagi formula asosida aniqlanadi:

$$\operatorname{tg} \varphi = \frac{J_x}{J_y} \cdot \operatorname{tg} \alpha; \quad (\text{IX.2})$$

bu yerda,  $\alpha$  – kuch ta'sir chizig'i bilan bosh markaziy o'q o'rtasidagi burchak.

## 88- masala

Uzunligi  $l=1$ , profil nomeri 24 (GOST 8239-72) bo'lgan qo'shtavrli konsolning erkin uchiga  $\alpha$  burchak ostida  $F$  kuch qo'yilgan (IX.1- shakl, a).

Quyidagilarni aniqlash talab etiladi:

- 1) konsolni mustahkamlikka tekshirish va uning erkin uchi solqilgini hisoblash;
- 2)  $\alpha = 0$  hol uchun (to'g'ri ko'ndalang egilish) kesimdagi eng katta normal kuchlanish hamda eng katta solqilgini aniqlash.

Quyidagilar ma'lum:  $\alpha = 12^\circ$ ;  $F=15$  kN;  $\sigma_{adm} = 160$  MPa;  $E=2 \cdot 10^5$  MPa;  $W_x=289 \cdot 10^{-6}$  m<sup>3</sup>;  $W_y=34,5 \cdot 10^{-6}$  m<sup>3</sup>;  $I_x=3460 \cdot 10^{-8}$  m<sup>4</sup>;  $I_y=198 \cdot 10^{-8}$  m<sup>4</sup>.

## Yechish:

1)  $\alpha \neq 0$  bo'lganligi sababli, brus qiyshiq egilishga qarshilik ko'rsatadi.  $F$  kuchni tashkil etuvchilarga ajratib, xavfli kesimdagi eguvchi momentlarni aniqlaymiz (IX.1-shakl, b):

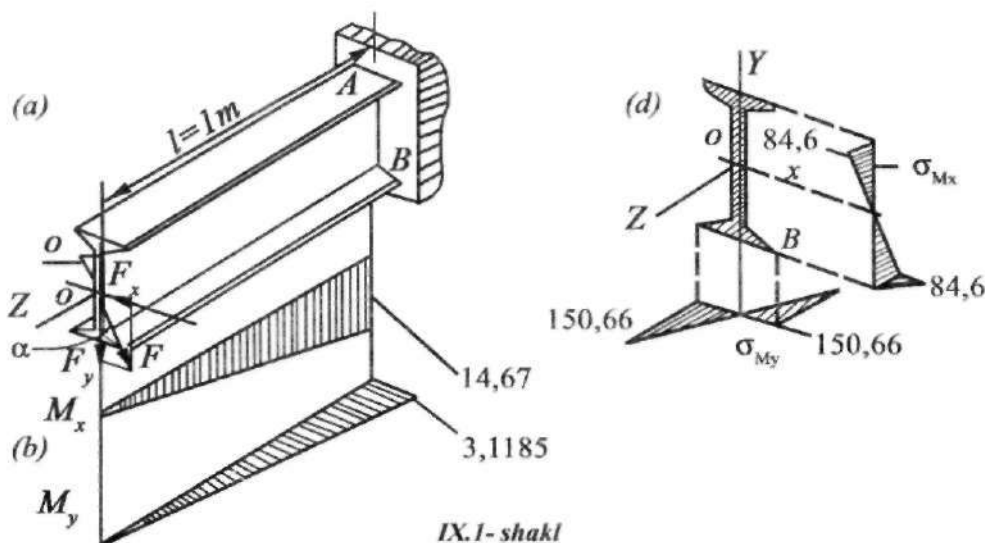
$$M_{x(max)} = F_y \cdot l = F \cdot l \cos \alpha = 15 \cdot 10^3 \cdot 1 \cdot 0,9781 = 14,67 \cdot 10^3 \text{ N} \cdot \text{m} = 14,67 \text{ kN} \cdot \text{m};$$

$$M_{y(max)} = F_x \cdot l = F \cdot l \sin \alpha = 15 \cdot 10^3 \cdot 1 \cdot 0,2079 = 3,1185 \cdot 10^3 \text{ N} \cdot \text{m} = 3,1185 \text{ kN} \cdot \text{m}.$$

U holda, normal kuchlanishlar:

$$\sigma_{M_x}^c = \frac{M_{x(max)}}{w_x} = \frac{14,67 \cdot 10^3}{289 \cdot 10^{-6}} = 50,77 \cdot 10^6 \frac{\text{N}}{\text{m}^2} = 50,77 \text{ MPa};$$

$$\sigma_{M_y}^B = \frac{M_{y(max)}}{w_y} = \frac{3,1185 \cdot 10^3}{34,5 \cdot 10^{-6}} = 90,39 \cdot 10^6 \frac{\text{N}}{\text{m}^2} = 90,39 \text{ MPa}.$$



IX.1- shakl

Bu qiymatlar yordamida qurilgan kuchlanish epyurasidan (IX.1- shakl, b) ko'rinib turibdiki, material cho'zilish va siqilishga bir xil qarshilik ko'rsatar ekan.

U holda,  $C$  nuqtada natijaviy kuchlanish quyidagiga teng bo'ladi:

$$\sigma_{\max} = \sigma_{M_x}^c + \sigma_{M_y}^c = 50,77 + 90,39 = 141,16 \text{ MPa.}$$

Brusning yuklanganlik darajasini ko'rib o'tamiz:

$$(160 - 141,16)/160 \cdot 100\% = 11,77\%.$$

Demak, brus 11,77% ga yuklanmagan. Endi konsol erkin uchi solqilgining bosh o'qlardagi proyeksiyalarini aniqlaymiz:

$$f_y = \frac{F_y \cdot l^3}{3EI_x} = \frac{F \cdot \cos \alpha \cdot l^3}{3EI_x} = \frac{15 \cdot 10^3 \cdot 0,9781 \cdot l^3}{3 \cdot 2 \cdot 10^5 \cdot 10^6 \cdot 3460 \cdot 10^{-8}} = 0,7067 \cdot 10^{-3} \text{ m} = 0,7067 \text{ mm};$$

$$f_x = \frac{F_x \cdot l^3}{3EI_y} = \frac{F \cdot \sin \alpha \cdot l^3}{3EI_y} = \frac{15 \cdot 10^3 \cdot 0,2079 \cdot l^3}{3 \cdot 2 \cdot 10^5 \cdot 10^6 \cdot 198 \cdot 10^{-8}} = 2,625 \cdot 10^{-3} \text{ m} = 2,625 \text{ mm}.$$

To'liq solqilik esa quyidagiga teng bo'ladi:

$$f = \sqrt{f_x^2 + f_y^2} = 2,7185 \cdot 10^{-3} \text{ m} = 2,7185 \text{ mm}.$$

$\alpha = 0$  bo'lganda, to'g'ri ko'ndalang egilish sodir bo'ladi. Shuning uchun:

$$\sigma_{\max} = \frac{F \cdot l}{w_x} = \frac{15 \cdot 10^3 \cdot l}{289 \cdot 10^{-6}} = 51,9 \cdot 10^6 \frac{\text{N}}{\text{m}^2} = 51,9 \text{ MPa};$$

$$f = \frac{F \cdot l^3}{3EI_x} = \frac{15 \cdot 10^3 \cdot l^3}{3 \cdot 2 \cdot 10^{11} \cdot 3460 \cdot 10^{-8}} = 0,72254 \cdot 10^{-3} \text{ m} \approx 0,723 \text{ mm}.$$

Yuqoridagi hisoblashlardan shunday xulosa chiqadi: kuch tekisligiga nisbatan bikrligi eng katta bo'lgan bosh inersiya tekisligiga atigi  $120^\circ$  ga og'dirilganda normal kuchlanish  $(141 - 51,9)/51,9 \cdot 100\% = 171,98\%$  ga, solqiligi esa  $(2,7185 - 0,723)/0,723 \cdot 100\% = 276,3\%$  (deyarli 3,76 marta) ga oshar ekan.

### 89- masala

Qiyshiq egilishga qarshilik ko'rsatayotgan yog'och konsol uchun (IX.2- shakl):

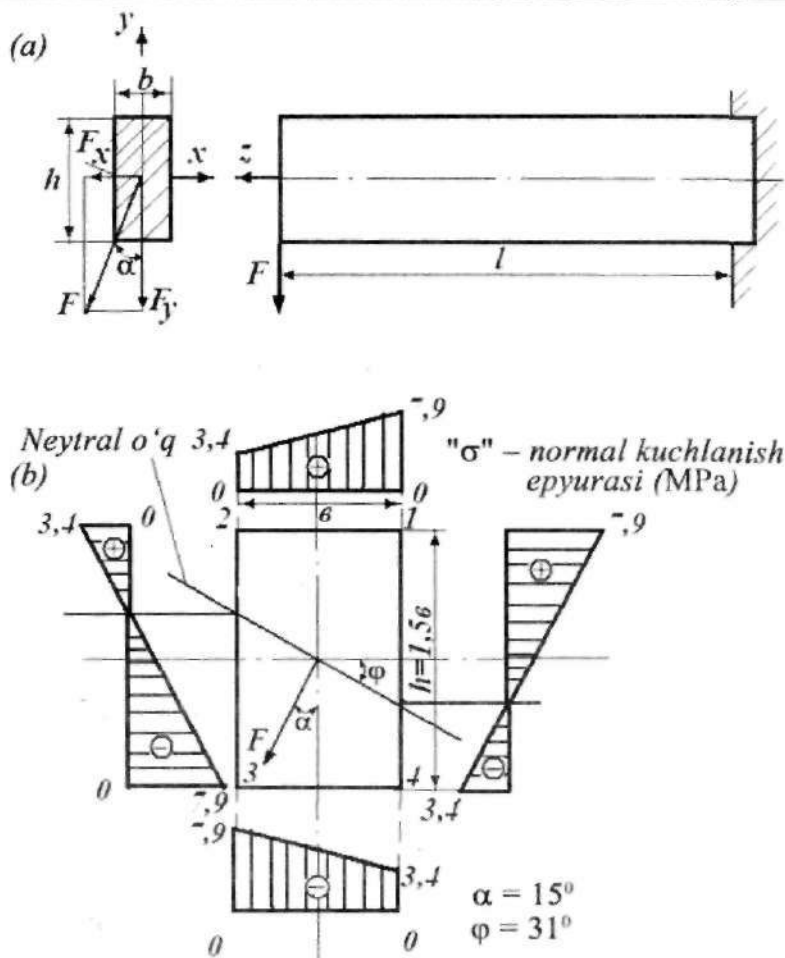
- ko'ndalang kesim o'lchamlari -  $b$  va  $h$  lar topilsin;
- kesimning tomonlari bo'yicha normal kuchlanish epyuralari qurilsin;
- neytral o'qning holati aniqlansin;
- konsol erkin uchining to'liq solqiligi aniqlansin.

Quyidagilar ma'lum:  $F = 12 \text{ kN}$ ;  $\alpha = 15^\circ$ ;  $l = 0,85 \text{ m}$ ;  $h/b = 1,5$ ;  $\sigma_{\text{adm}} = 8 \text{ MPa}$ ;  $E = 1 \cdot 10^4 \text{ MPa}$ .

### Yechish:

- $F$  kuchni tashkil etuvchilarga ajratib, xavfli kesimdagi eguvchi momentlarni aniqlaymiz:

$$M_{x(\max)} = F \cdot l \cos \alpha = 12 \cdot 0,85 \cdot 0,9659 = 9,8524 \text{ kN} \cdot \text{m};$$



IX.2- shakl

$$M_{y(\max)} = F \cdot l \sin \alpha = 12 \cdot 0,85 \cdot 0,2588 = 2,6399 \text{ kN} \cdot \text{m};$$

$$K_0 = W_x / W_y = h / b = 1,5$$

ekanligini nazarda tutib, qarshilik momentini hisoblaymiz:

$$W_x = \frac{(9,8524 + 1,5 \cdot 2,6399) \cdot 10^{-3}}{8 \cdot 10^{-6}} = 1726,54 \cdot 10^{-6} \text{ m}^3$$

Bundan tashqari, qarshilik momentini yana quyidagicha yozish ham mumkin:

$$W_x = \frac{bh^2}{6} = \frac{3b^3}{8}$$

Bularni tenglasak,  $b = \sqrt[3]{\frac{8 \cdot 1726,54 \cdot 10^{-6}}{3}} = 0,1664 \text{ m}$ ;  $h = 1,5b = 0,2496 \text{ m}$  ekanligi kelib chiqadi.

b) Xavfli kesimning istalgan nuqtasidagi normal kuchlanishni aniqlaymiz:

$$\sigma_z = \frac{M_x(\max)}{I_y} \cdot x + \frac{M_x(\max)}{I_x} \cdot y.$$

Bunda,

$$I_x = \frac{bh^3}{12} = \frac{0,1664 \cdot (0,249)^3}{12} = 21,563 \cdot 10^{-5} \text{ m}^4;$$

$$I_y = \frac{bh^3}{12} = \frac{0,2496 \cdot (0,1664)^3}{12} = 9,5835 \cdot 10^{-5} \text{ m}^4;$$

$$\sigma_z = \frac{2,6399 \cdot 10^3}{9,5835 \cdot 10^{-5}} \cdot x + \frac{9,8524 \cdot 10^3}{21,563 \cdot 10^{-5}} \cdot y = 0,27546 \cdot 10^8 x + 0,4569 \cdot 10^8 y \text{ N/m}^2.$$

Endi kesim yuzada joylashgan xarakterli nuqtalardagi kuchlanishlarni hisoblaymiz (IX.2- shakl, b):

$$\sigma_{1,3} = \pm 0,27546 \cdot 10^8 \cdot \frac{0,1664}{2} \pm 0,4569 \cdot \frac{0,2496}{2} \cdot 10^8 = \pm (2,2918 + 5,7022) \cdot 10^6 \frac{\text{N}}{\text{m}^2} = \pm 7,994 \text{ MPa};$$

$$\sigma_{2,4} = \mp 0,27546 \cdot 10^8 \cdot \frac{0,1664}{2} \pm 0,4569 \cdot \frac{0,2496}{2} \cdot 10^8 = (\mp 2,2918 \pm 5,7022) \cdot 10^6 \frac{\text{N}}{\text{m}^2} = \pm 3,4104 \text{ MPa}.$$

d) (IX.2) formuladan foydalanib, neytral o'qning holatini aniqlaymiz:

$$\operatorname{tg} \varphi = \frac{21,563 \cdot 10^{-5}}{9,5835 \cdot 10^{-5}} \cdot \operatorname{tg} 15^\circ \approx 0,6029 = \operatorname{tg} 31^\circ 08' \text{ yoki } \operatorname{tg} \varphi = \left| \frac{y}{x} \right| = \frac{0,2754}{0,4569} = 0,603.$$

e) Kuch qo'yilgan kesimning gorizontaal va vertikal solqiliklarini hisoblaymiz:

$$f_x = \frac{F_x l^3}{3 E I_y} = \frac{F \sin \alpha l^3}{3 E I_y} = \frac{12 \cdot 0,2588 \cdot (0,85)^3 \cdot 10^3}{3 \cdot 10^{10} \cdot 9,5835 \cdot 10^{-5}} = 6,634 \cdot 10^{-4} \text{ m} = 0,0663 \text{ sm};$$

$$f_y = \frac{F_y l^3}{3 E I_x} = \frac{F \cos \alpha l^3}{3 E I_x} = \frac{12 \cdot 0,9659 \cdot (0,85)^3 \cdot 10^3}{3 \cdot 10^{10} \cdot 21,563 \cdot 10^{-5}} = 11,004 \cdot 10^{-4} \text{ m} = 0,11 \text{ sm}.$$

To'liq solqilik:

$$f = \sqrt{f_x^2 + f_y^2} = 1,2849 \cdot 10^{-3} \text{ m} = 0,1285 \text{ sm}.$$

To'liq solqilikning yo'nalishi neytral o'qqa tik bo'lib, vertikal  $OY$  o'qi bilan  $\varphi = 31^\circ 08'$  burchak hosil qiladi.

### 9.3- §. Markaziy bo'lmagan cho'zilish yoki siqilish

➤ Markaziy bo'lmagan cho'zilish yoki siqilishda normal kuchlanish quyidagicha aniqlanadi:

$$\sigma_z = \frac{N}{A} + \frac{M_y}{J_y} \cdot x + \frac{M_x}{J_x} \cdot y. \quad (\text{IX.3})$$

➤ Neytral o'qning bosh o'qlaridan ajratgan kesmalari quyidagicha aniqlanadi:

$$a_x = -\frac{i_y^2}{X_F}; \quad (\text{IX.4})$$

$$a_y = -\frac{i_x^2}{Y_F}; \quad (\text{IX.5})$$

bu yerda,  $X_F$  va  $Y_F$  lar – kuch qo'yilgan nuqtadan bosh markaziy o'qlargacha olingan masofa.

➤ Markaziy bo'lmagan cho'zilish yoki siqilishda qarshilik markazi atrofida shunday yopiq soha mavjudki, agar kuch shu sohaning ichkarisiga yoki uning konturiga qo'yilsa, kesimda faqat bir xil ishorali kuchlanish paydo bo'ladi. Bu yopiq sohaga kesim yadrosi deyiladi.

#### 90- masala

Detallarni teshishda dastgoh (stanok) shpindeli  $D$  ga shu shpindel uchi bo'ylab  $F$  kuch ta'sir qiladi. Doiraviy kesimli cho'yan ustun  $C$  ning diametri aniqlansin (IX.3- shakl). Cho'yan uchun cho'zilishda ruxsat etilgan kuchlanish  $\sigma'_{adm} = 40 \text{ MPa}$  ga teng. Hisoblashlarda  $F = 10 \text{ kN}$  va  $a = 0,4 \text{ m}$  deb olinsin.

#### Yechish:

Ustun markaziy bo'lmagan cho'zilishga qarshilik ko'rsatadi. (IX.3) formulaga ko'ra, mustahkamlik sharti:

$$\sigma = \frac{N}{A} + \frac{M_{\max}}{W_x} \leq \sigma'_{adm};$$

bu ifodada:  $N = F = 10 \text{ kN}$ ;  $A = \pi d^2/4$ ;  $W_x = \pi d^3/32$ ;  $M_{\max} = Fa = 4 \text{ kNm}$ .

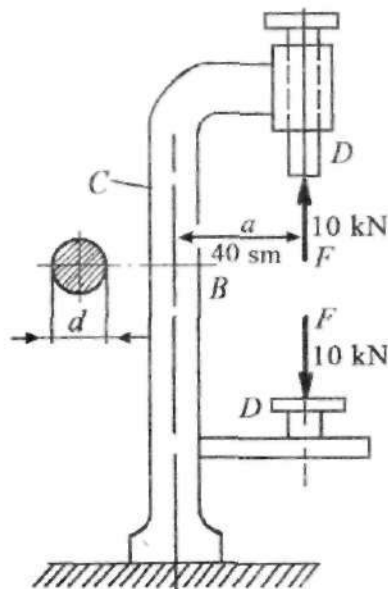
Bularni e'tiborga olib:

$$4 \cdot 10 \cdot 10^3 / \pi d^2 + 32 \cdot 10 \cdot 10^3 / \pi d^3 \leq 4 \cdot 10^6 \text{ (N/m}^2\text{)}$$

munosabatni hosil qilamiz.

Tanlash yo'li bilan ustunning diametri topiladi:

$$d = 10,1 \cdot 10^{-2} \text{ m} = 10,1 \text{ sm.}$$



IX.3- shakl



## 91- masala

Kesimi to'g'ri to'rtburchakli kalta (qisqa) yog'och ustunning  $K (X_F; Y_F)$  nuqtasiga siquvchi bo'ylama kuch  $F$  qo'yilgan (IX.4- shakl). Bu masala uchun:

- kesim yadrosi qurilsin;
- xolis o'qning holati aniqlansin;
- kesimning eng chetki nuqtalaridagi kuchlanishlar topilsin;
- kesimning tomonlari bo'yicha normal kuchlanish epyuralari qurilsin.

Hisoblashlar uchun ushbu ma'lumotlar ma'lum:  $F = 120$  kN;  $X_F = 0,04$  m;  $Y_F = 0,06$  m;  $b = 0,2$  m;  $h = 0,25$  m.

## Yechish:

Ustun nomarkaziy siqilishga qarshilik ko'rsatmoqda. Uning ko'ndalang kesimida quyidagi ichki kuchlar paydo bo'ladi:

$N_z = -120$  kN – bo'ylama kuch;

$M_x = -120 \cdot Y_F = -7,2$  kN·m – eguvchi moment;

$M_y = 120 \cdot X_F = 4,8$  kN·m – eguvchi moment.

(Eslatma: qisqa ustunlar uchun bu ichki zo'riqishlar uning uzunligi bo'yicha o'zgarmasdan qoladi.)

Ko'ndalang kesimning geometrik xarakteristikalarini hisoblaymiz:

$$I_x = \frac{bh^3}{12} = 2,6 \cdot 10^{-4} \text{ m}^4; \quad I_y = \frac{hb^3}{12} = 1,667 \cdot 10^{-4} \text{ m}^4.$$

Kesim yuza  $A = bh = 0,05$  m<sup>2</sup> bo'lganligi uchun inersiya radiuslarining kvadratlari:

$$i_x^2 = \frac{I_x}{A} = 5,2 \cdot 10^{-3} \text{ m}^2; \quad i_y^2 = \frac{I_y}{A} = 3,334 \cdot 10^{-3} \text{ m}^2$$

ga teng bo'ladi.

a) (IX.4), (IX.5) formulalardan foydalanib, neytral o'qning bosh o'qlardan ajratgan kesmalarini aniqlaymiz:

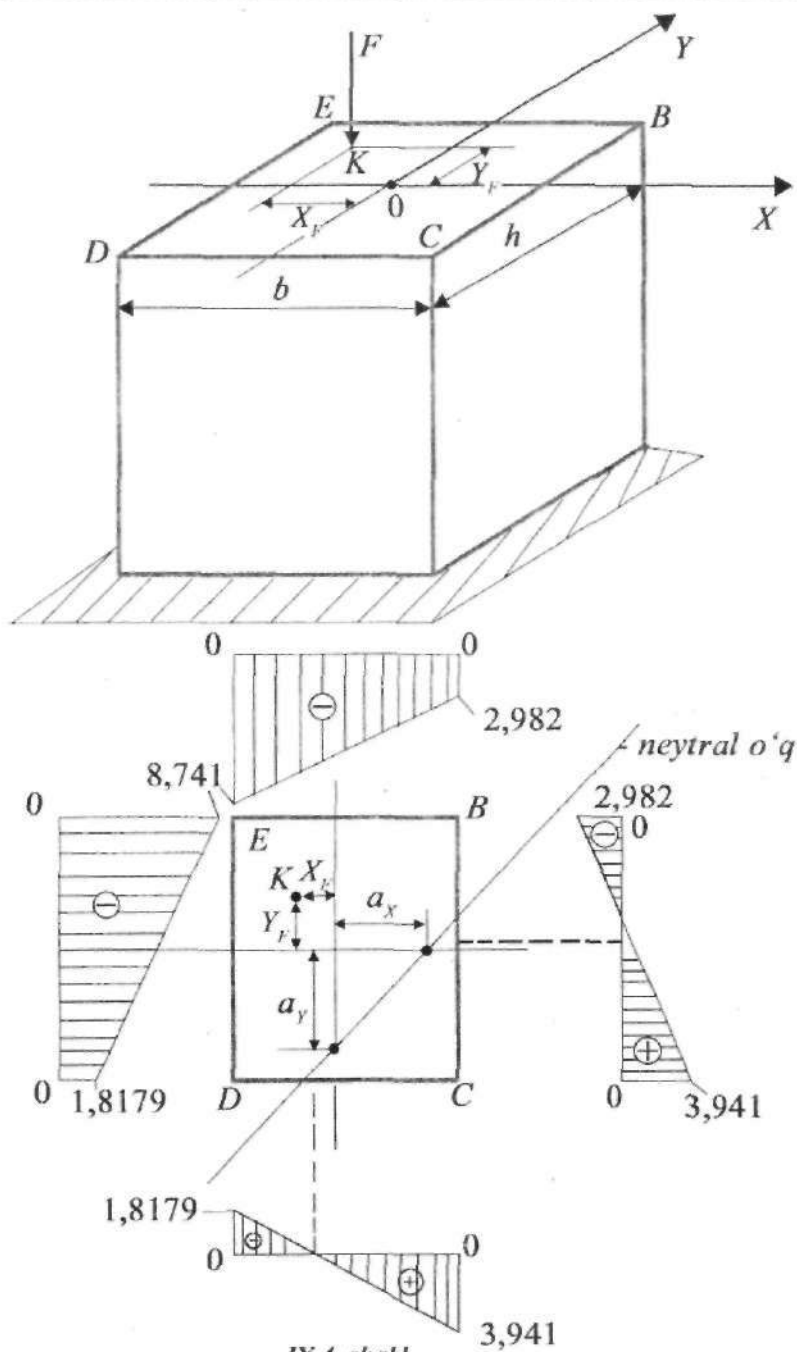
$$a_x = -\frac{i_y^2}{(-X_F)} = \frac{3,334 \cdot 10^{-3}}{0,04} = 8,335 \cdot 10^{-2} \text{ m}; \quad a_y = -\frac{i_x^2}{Y_F} = -\frac{5,2 \cdot 10^{-3}}{0,06} = -8,667 \cdot 10^{-2} \text{ m}.$$

Bu kesmalarni bosh inersiya o'qlari ustiga masshtab bilan qo'yib, hosil bo'lgan nuqtalar tutashtirilsa, neytral o'qning holati aniqlanadi (IX.4- shakl, b):

b) (IX.3) formulaga binoan, kesimning istalgan nuqtasidagi kuchlanishni aniqlash mumkin:

$$\sigma_z = -\frac{F}{A} \left( 1 - \frac{X_F}{i_y^2} \cdot X + \frac{Y_F}{i_x^2} \cdot Y \right) \text{ yoki } \sigma_z = -\frac{120 \cdot 10^3}{0,05} \left( 1 - \frac{0,04}{3,334 \cdot 10^{-3}} \cdot X + \frac{0,06}{5,2 \cdot 10^{-3}} \cdot Y \right) =$$

$$= -2,4 \cdot 10^6 (1 - 11,9976 \cdot X + 11,5385 \cdot Y) = -2,4(1 - 11,9976 \cdot X + 11,5385 \cdot Y) \text{ (MPa)}.$$



IX.4-shakl

So'ralayotgan nuqtalardagi kuchlanishlarni hisoblaymiz:

$$\sigma_B = -2,4 \left( 1 - 11,9976 \cdot \frac{0,2}{2} + 11,5385 \cdot \frac{0,25}{2} \right) = -2,982 \text{ MPa};$$

$$\sigma_C = -2,4 \left( 1 - 11,9976 \cdot \frac{0,2}{2} - 11,5385 \cdot \frac{0,25}{2} \right) = 3,941 \text{ MPa};$$

$$\sigma_D = -2,4 \left( 1 + 11,9976 \cdot \frac{0,2}{2} - 11,5385 \cdot \frac{0,25}{2} \right) = -1,8179 \text{ MPa};$$

$$\sigma_E = -2,4 \left( 1 + 11,9976 \cdot \frac{0,2}{2} + 11,5385 \cdot \frac{0,25}{2} \right) = -8,741 \text{ MPa}.$$

d) Topilgan qiymatlar yordamida aniq masshtab bilan normal kuchlanishlarning epyuralari quriladi (IX.4- shakl, b).

### 92- masala

IX.5- shakl, (a) va (b) da ko'rsatilgan sterjenlarning qaysi biri katta yukka bardosh bera oladi? Hisoblashlarda  $F$  va  $a$  lar ma'lum deb hisoblansin.

#### Yechish:

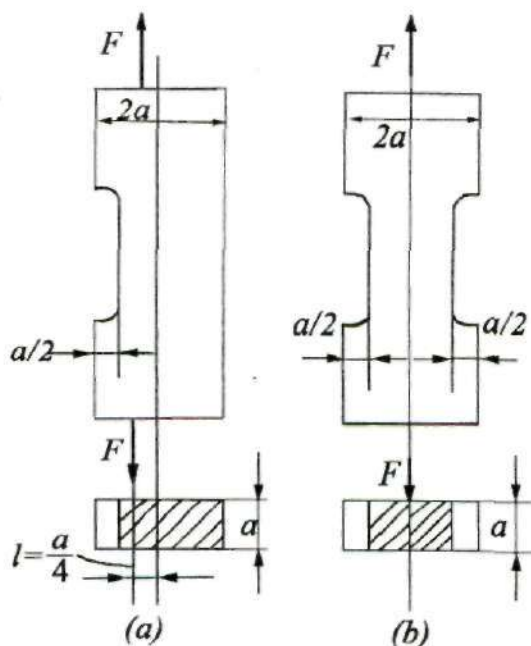
a) bu holatda sterjen nomarkaziy cho'zilishga qarshilik ko'rsatmoqda; kuch qo'yilgan nuqtaning kesim og'irlik markazidan uzoqligi  $l = \frac{a}{4}$  (ekssentrisitet) ga teng. Shu sababli eng katta cho'zuvchi kuchlanish quyidagicha bo'ladi:

$$\sigma_{\max} = \frac{F}{a \cdot 1,5a} + \frac{F \cdot \frac{a}{4}}{a \frac{(1,5a)^2}{6}} = \frac{4}{3} \cdot \frac{F}{a^2}.$$

b) ikkinchi holatda sterjenga markaziy kuch qo'yilgan; kesimdagi eng katta kuchlanish

$$\sigma_{\max} = \frac{F}{a^2};$$

bundan chiqdi, simmetrik sterjen ko'proq yukni ko'tara olar ekan.



IX.5- shakl

## 9.4- §. Buralish va egilishning birgalikdagi ta'siri

- Ko'ndalang kesimi aylanadan iborat bo'lgan sterjen buralish va egilishning birgalikdagi ta'sirida bo'lsa, uning ko'ndalang kesimida (xavfli nuqtasida) tekis kuchlanish holati ro'y beradi.
- Bunda valning mustahkamligi mustahkamlik nazariyalarining birortasi bo'yicha quyidagicha tekshiriladi:

$$\sigma_{ekv} = \frac{M_{ekv}}{W_X} \leq \sigma_{adm}; \quad (IX.6)$$

bu yerda,  $M_{ekv}$  – hisobiy ekvivalent moment.

- III mustahkamlik nazariyasi bo'yicha

$$M_{ekv}^{III} = \sqrt{M_{um}^2 + M_b^2}; \quad (IX.7)$$

bu yerda,  $M_{um}$  – umumiy eguvchi moment;  $M_b$  – burovchi moment.

- Valning xavfli kesimi  $M_x$ ,  $M_y$  va  $M_b$  larning qiymatlarini solishtirish yo'li bilan amalga oshiriladi.  $M_{um}$  va  $M_b$  larning birgalikdagi eng katta qiymatiga ega bo'lgan kesimlar xavfli kesimlar hisoblanadi.

### 93-masala

IX.6- shaklda bir uchi bilan devorga mahkamlangan, ikkinchi uchiga esa  $BC$  krivoship o'rnatilgan yaxlit val tasvirlangan. Krivoshipning uchiga kuch qo'yilgan. Mustahkamlikning uchinchi nazariyasi bo'yicha valning mustahkamlikdagi ehtiyoj koeffitsiyentini aniqlang.

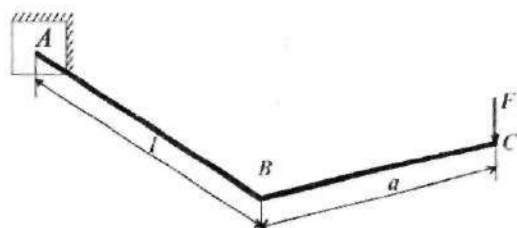
Quyidagi ma'lumotlar ma'lum:  $F = 5 \text{ kN}$ ;  
 $l = 50 \cdot 10^{-2} \text{ m}$ ;  $a = 30 \cdot 10^{-2} \text{ m}$ ;  $d = 6 \cdot 10^{-2} \text{ m}$ ;  
 $\sigma_T = 240 \text{ MPa}$ .

### Yechish:

Ko'rinib turibdiki, valning tayanch kesimi xavfli kesim hisoblanadi, unga eng katta  $M_e = Fl$  eguvchi va  $M_b = Fa$  burovchi momentlar ta'sir ko'rsatadi.

Xavfli kesimdagi birorta  $A$  nuqtaning normal va urinma kuchlanishlarini aniqlaymiz:

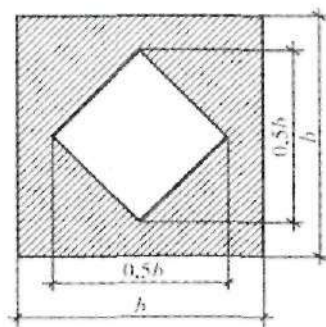
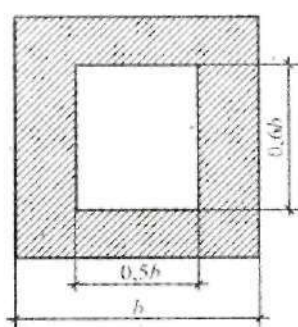
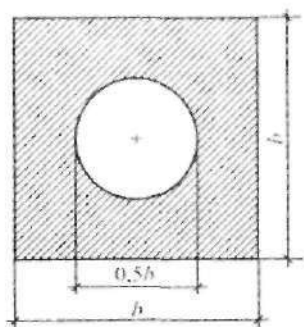
$$\sigma_A = \frac{M_e}{W_X} = \frac{Fl}{\frac{\pi d^3}{32}} = \frac{32 \cdot 5 \cdot 10^3 \cdot 50 \cdot 10^{-2}}{3,14 \cdot (0,06)^3} = 117,95 \cdot 10^6 \text{ N/m}^2 = 117,95 \text{ MPa};$$



IX.6- shakl

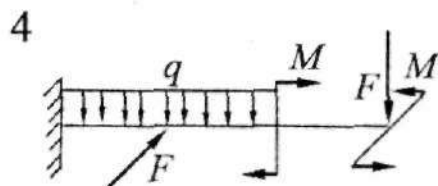
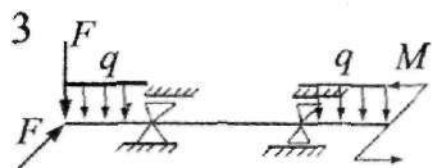
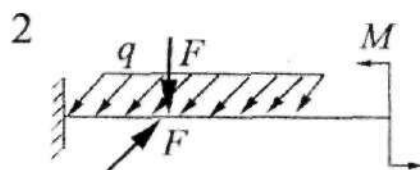
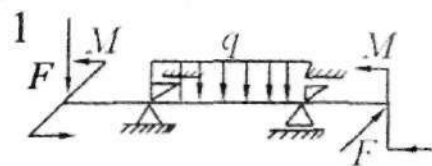
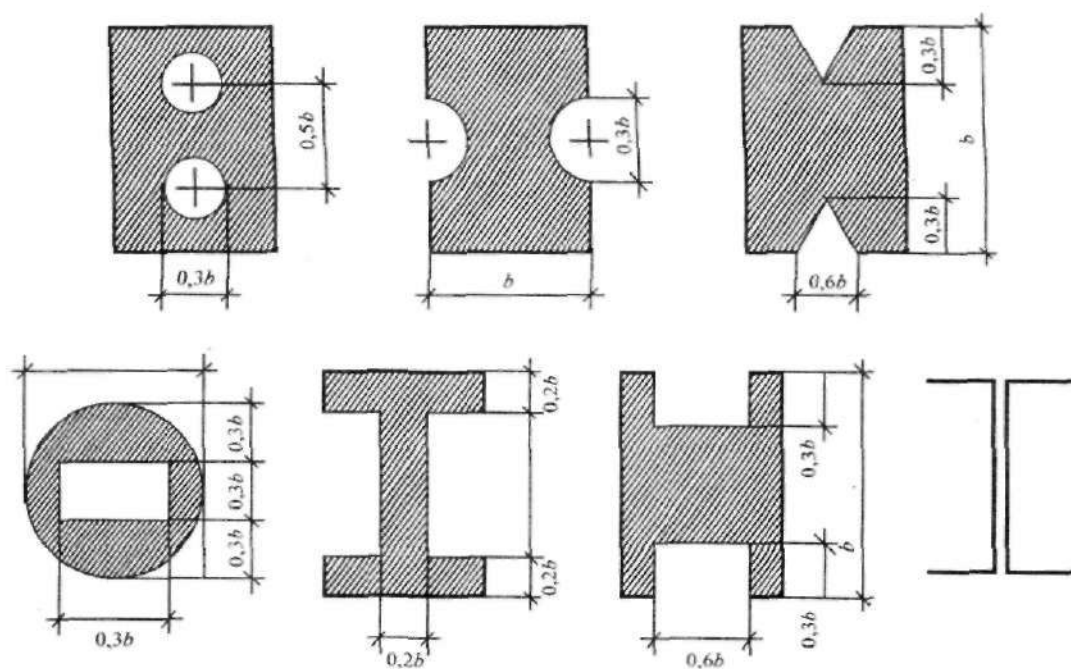
IX.1- jadval (davomi)

| №  | $a, m$ | $c, m$ | $d, m$ | $F, kN$ | $q, kN/m$ | $M, kN \cdot m$ | $h, sm$ | $b, sm$ | Profillar nomeri |          |
|----|--------|--------|--------|---------|-----------|-----------------|---------|---------|------------------|----------|
|    |        |        |        |         |           |                 |         |         | qo'shtavr        | shveller |
| 8  | 2      | 2      | 2      | 20      | 10        | 20              | 20      | 12      | 30               | 2014 a   |
| 9  | 1      | 3      | 2      | 20      | 10        | 20              | 27      | 16      | 27               | 22       |
| 10 | 2      | 2      | 2      | 10      | 30        | 10              | 21      | 12      | 27 a             | 2214 a   |
| 11 | 1      | 3      | 2      | 10      | 30        | 20              | 20      | 12      | 24               | 24       |
| 12 | 2      | 2      | 2      | 10      | 30        | 20              | 18      | 12      | 24 a             | 2414 a   |
| 13 | 1      | 3      | 2      | 20      | 10        | 10              | 24      | 16      | 27               | 14       |
| 14 | 2      | 2      | 2      | 20      | 10        | 30              | 24      | 16      | 24               | 16       |
| 15 | 1      | 3      | 2      | 10      | 20        | 30              | 30      | 18      | 24 a             | 1614a    |
| 16 | 2      | 2      | 2      | 20      | 20        | 10              | 30      | 18      | 30               | 27       |
| 17 | 1      | 3      | 2      | 10      | 30        | 10              | 30      | 18      | 30 a             | 18       |
| 18 | 2      | 2      | 2      | 20      | 20        | 20              | 28      | 12      | 20               | 16       |
| 19 | 1      | 3      | 2      | 20      | 20        | 20              | 28      | 15      | 20 a             | 20       |
| 20 | 2      | 2      | 2      | 10      | 30        | 10              | 24      | 18      | 18               | 22       |



IX.7- shakl

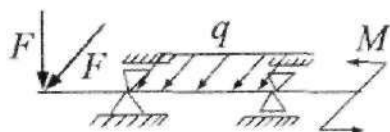
IX.7- shakl (davomi)



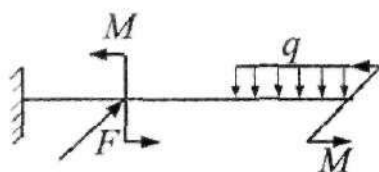
IX.8- shakl

## IX.8- shakl (davomi)

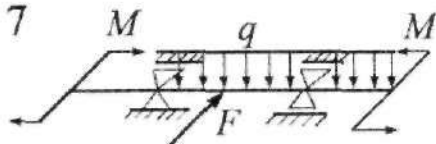
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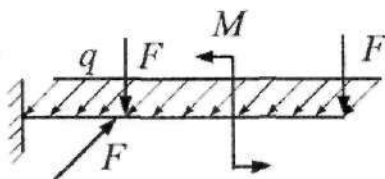
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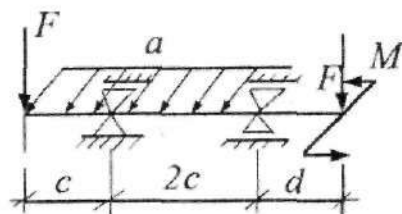
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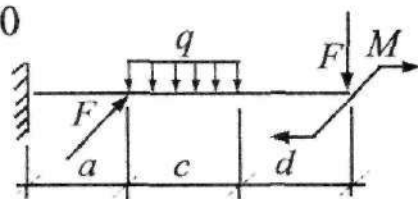
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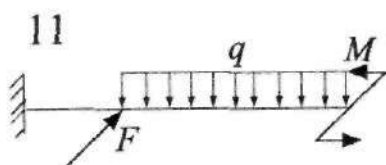
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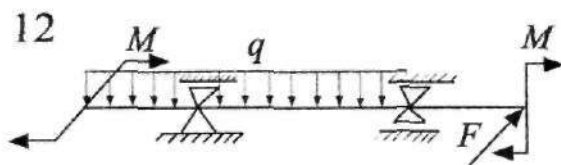
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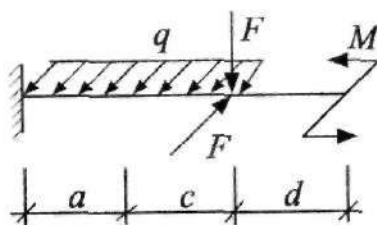
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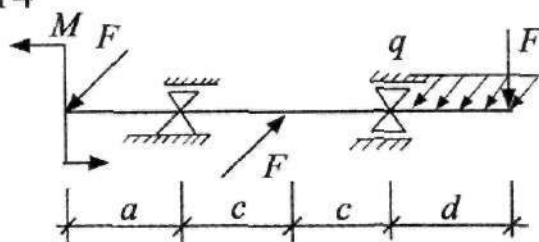
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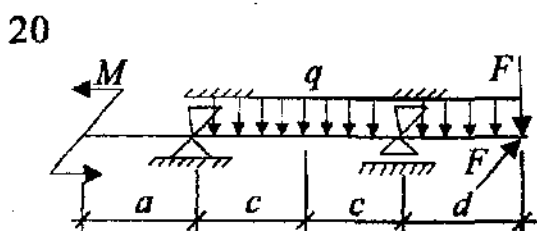
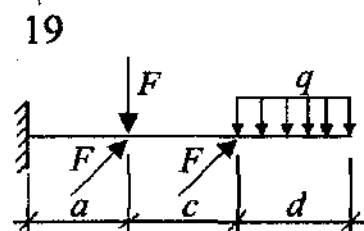
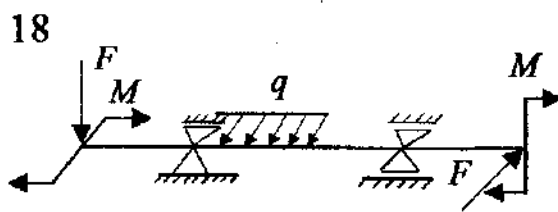
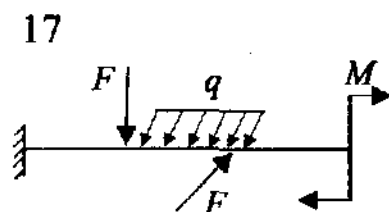
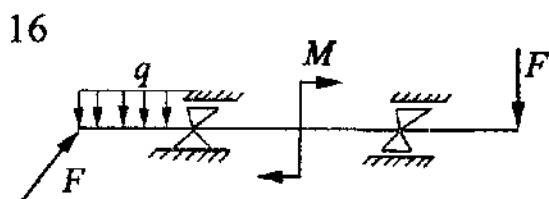
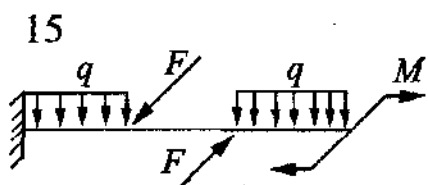
13



14



## IX.8- shakl (davomi)



## 16- topshiriq

**Markaziy bo'lmagan siqilish.**

**Berilgan:** Birkir kolonna o'qiga parallel yo'nalgan bo'lib, kesimning sxemada (IX.8- shakl) ko'rsatilgan nuqtasiga qo'yilgan. Material uchun ruxsat etilgan normal kuchlanish cho'zilishda  $[\sigma] = 3 \text{ MPa}$ ; siqilishda esa  $30 \text{ MPa}$  ga teng.

**Topish kerak:**

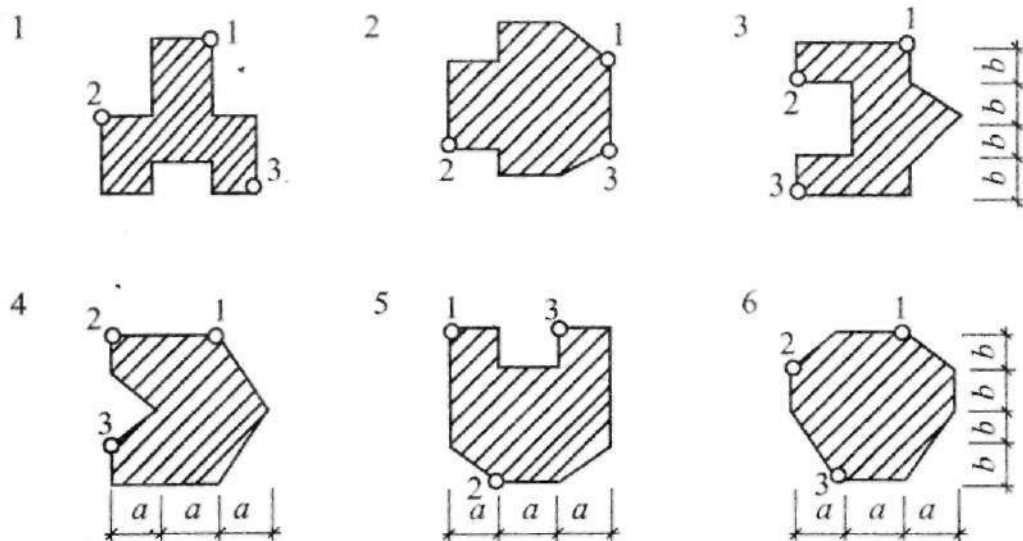
- 1) nol chiziqning vaziyati aniqlansin;
- 2) eng katta siquvchi va cho'zuvchi kuchlanishlarning epyurasi qurilsin; kolonnaning mustahkamligi haqida xulosa berilsin;
- 3) berilgan kesim uchun ruxsat etilgan  $F_{adm}$  kuch aniqlansin;
- 4) kesim yadrosi aniqlansin.

Kerakli ma'lumotlar IX.2- jadvalda, hisoblash sxemalari esa IX.9- shaklda berilgan.



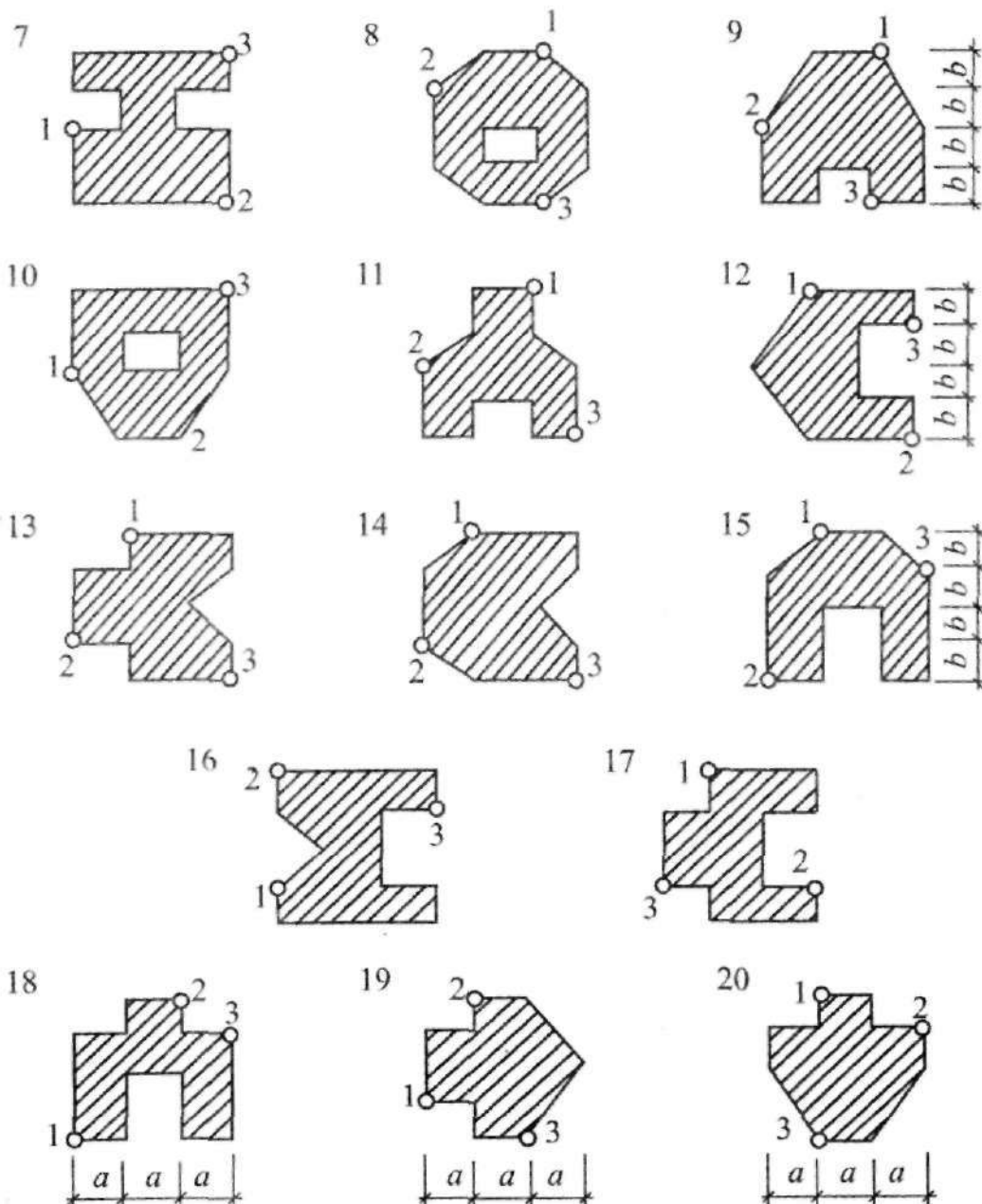
IX.2- jadval

| №  | F, kN | Kesim o'lchamlari |    | Kuchning<br>qo'yilish nuqtasi |
|----|-------|-------------------|----|-------------------------------|
|    |       | a                 | b  |                               |
| 1  | 12    | 30                | 12 | 1                             |
| 2  | 100   | 24                | 10 | 2                             |
| 3  | 160   | 30                | 12 | 3                             |
| 4  | 100   | 24                | 14 | 1                             |
| 5  | 180   | 36                | 15 | 2                             |
| 6  | 200   | 40                | 18 | 3                             |
| 7  | 320   | 50                | 20 | 1                             |
| 8  | 220   | 28                | 16 | 2                             |
| 9  | 240   | 36                | 18 | 3                             |
| 10 | 260   | 40                | 16 | 1                             |



IX.9 - shakl

## IX.9 - shakl (davomi)



## 17- topshiriq

Fazoviy sterjenlarni hisoblash.

**Berilgan:** Bir xil uzunlikdagi o'zaro perpendikular ko'ndalang kesimi aylanadan iborat uchta sterjen o'zaro bika qilib mahkamlangan. Sterjenlarga gorizontaal va vertikal tekisliklar bo'yicha kuchlar ta'sir etmoqda. Sterjenli po'latdan yasalgan bo'lib, ruxsat etilgan normal kuchlanishlar cho'zilishga  $[\sigma_z]=210 \text{ MPa}$ ; siqilishga  $[\sigma]=130 \text{ MPa}$ .

**Topish kerak:**

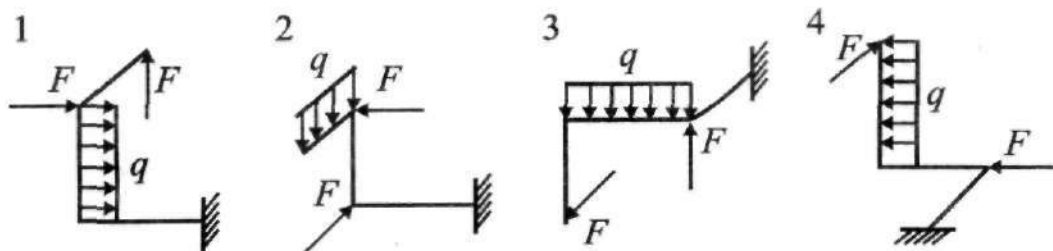
1) angonometriyada bo'ylama kuch, kesuvchi kuch va eguvchi moment epyuralari qurilsin;

2) xavfli kesim aniqlansin va uning mustahkamligi haqida xulosa berilsin.

Kerakli ma'lumotlar IX.3-jadvalda, hisoblash sxemalari IX.10- shaklda berilgan.

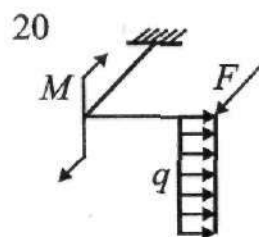
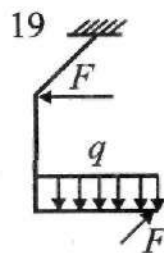
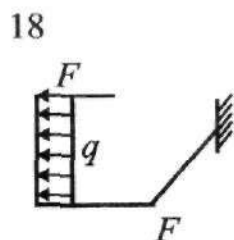
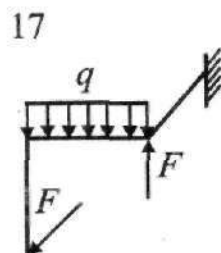
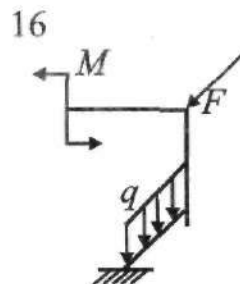
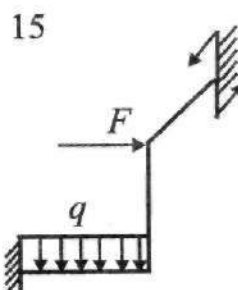
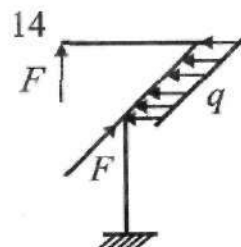
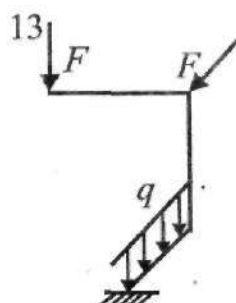
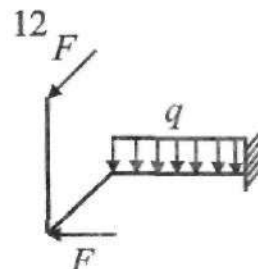
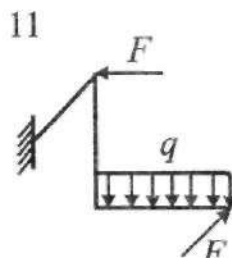
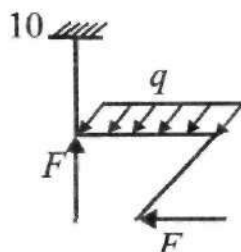
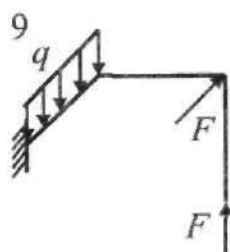
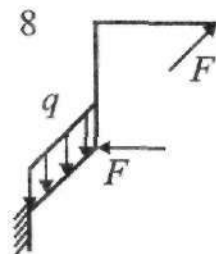
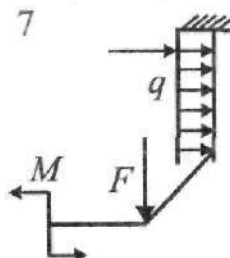
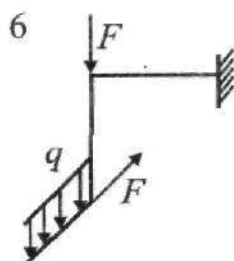
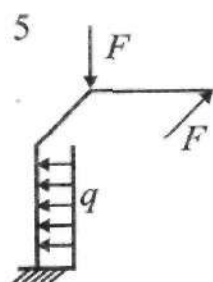
IX.3- jadval

| No | $F, \text{ kN}$ | $q, \text{ kN/m}$ | $M, \text{ kN/m}$ | $t, \text{ m}$ | $d, \text{ sm}$ |
|----|-----------------|-------------------|-------------------|----------------|-----------------|
| 1  | 8               | 6                 | 4                 | 0,6            | 5               |
| 2  | 10              | 4                 | 1                 | 0,4            | 6               |
| 3  | 6               | 10                | 2                 | 0,5            | 8               |
| 4  | 4               | 10                | 6                 | 0,6            | 6               |
| 5  | 4               | 6                 | 8                 | 0,4            | 8               |
| 6  | 8               | 10                | 8                 | 0,6            | 5               |
| 7  | 4               | 4                 | 4                 | 0,5            | 8               |
| 8  | 6               | 4                 | 6                 | 0,4            | 7               |
| 9  | 6               | 8                 | 4                 | 0,6            | 8               |
| 10 | 5               | 6                 | 4                 | 0,4            | 10              |



IX.10- shakl

## IX.10- shakl (davomi)



## X BOB

## STATIK NOANIQ RAMALARNI KUCH USULIDA HISOBLASH

## 10.1- §. Asosiy mulohazalar

Statik noaniq ramalar deb, tayanchlarda paydo bo'luvchi reaksiya kuchlari hamda barcha kesimlardagi ichki zo'riqish kuchlarini statikaning muvozanat tenglamalari yordamida aniqlash mumkin bo'lmagan ramalarga aytiladi.

Statik noaniq ramalar «ortiqcha» bog'lanishlar soniga teng bo'lgan statik noaniqlik darajasi bilan xarakterlanadi. Odatda, tekis ramalarning statik noaniqlik darajasi quyidagi formuladan topiladi:

$$S = n - 3; \quad (X.1)$$

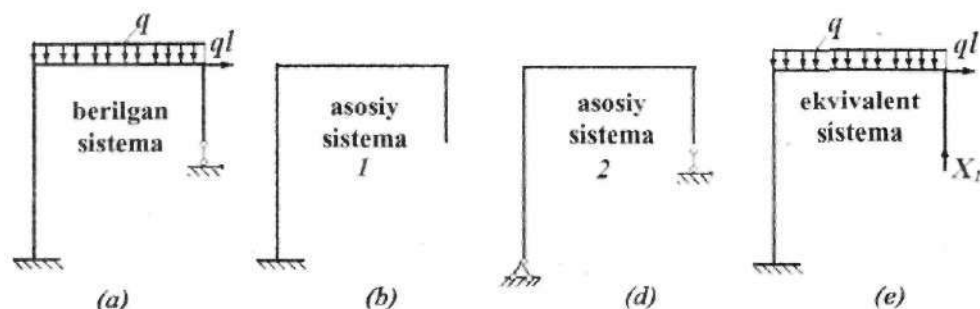
bu yerda,  $n$  – ramaning tayanchlardagi noma'lum reaksiya kuchlari soni.

Masalan, X.1- shakl (a) da tasvirlangan rama bir marta, X.2- shakl (a) dagi rama esa uch marta statik noaniqdir.

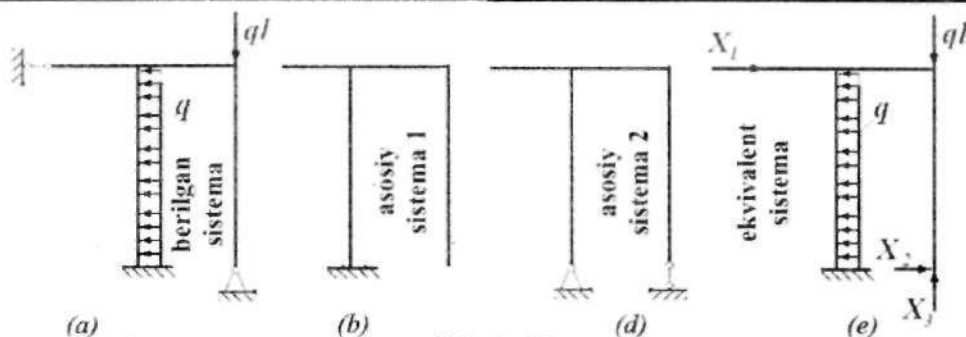
Ramadagi ortiqcha bog'lanishlarni olib tashlash yo'li bilan hosil qilingan statik aniq va geometrik o'zgarmas sistemaga asosiy sistema deyiladi.

X.1- shakl (b), (d) va X.2- shakl (b), (d) larda berilgan statik noaniq rama uchun turli xil variantlarda asosiy sistemalar tanlanishi tasvirlangan.

Ramaga qo'yilgan tashqi kuchlar hamda noma'lum reaksiya kuchlari bilan yuklatilgan asosiy sistema teng kuchli (ekvivalent) sistema deb ataladi (X.1- shakl, e, X.2- shakl, e).



X.1- shakl



X.2- shakl

$n$  marta statik noaniq rama uchun kuch usulining kanonik tenglamalar sistemasi quyidagi ko'rinishga ega:

$$\left. \begin{aligned} \delta_{11} \cdot X_1 + \delta_{12} \cdot X_2 + \dots + \delta_{1n} \cdot X_n + \Delta_{1P} &= 0 \\ \delta_{21} \cdot X_1 + \delta_{22} \cdot X_2 + \dots + \delta_{2n} \cdot X_n + \Delta_{2P} &= 0 \\ \dots &\dots \\ \delta_{n1} \cdot X_1 + \delta_{n2} \cdot X_2 + \dots + \delta_{nn} \cdot X_n + \Delta_{nP} &= 0 \end{aligned} \right\} \quad (X.2)$$

bu yerda:  $\delta_{ij}$  – birlik kuchlardan hosil bo'lgan bosh ko'chishlar;

$\delta_{ik} = \delta_{ki}$  – birlik kuchlardan hosil bo'lgan yordamchi ko'chishlar;

$\Delta_{iP}$  – tashqi kuchlardan hosil bo'lgan ko'chishlar.

(X.2) kanonik tenglamalar sistemasi tarkibidagi ko'chishlar Mor integrali va Vereshagin formulasi yordamida aniqlanadi.

Statik noaniq ramalarni kuch usulida hisoblash tartibi quyidagicha:

- ramalarning statik noaniqlik darajasini topish;
- asosiy va teng kuchli (ekvivalent) sistemalarni tanlash;
- kanonik tenglama yoki tenglamalar sistemasini tuzish;
- birlik kuchlardan va tashqi kuchlardan hosil bo'lgan ko'chishlarni aniqlash;
- kanonik sistema yoki tenglamalar sistemasini yechish;
- eguvchi moment, kesuvchi kuch va bo'ylama kuchlarning tugallangan epyuralarini qurish;
- tugallangan epyuralarning qanchalik to'g'ri chizilganligini deformatsion tekshirish.

Agar eguvchi momentning tugallangan  $M$  epyurasi to'g'ri chizilgan bo'lsa, u holda har bir  $X_1, X_2, \dots, X_n$  noma'lum kuchlarning yo'nalishi bo'yicha umumiy ko'chish nolga teng bo'lishi mumkin.

Bu ko'chishlarni Mor integrali va Vereshagin usulida eguvchi momentning tugallangan  $M$  epyurasini  $M_1$  va  $M_2$  birlik kuch epyuralariga ko'paytirish orqali topish mumkin:

$$\delta_{um} = \sum \int \frac{M \cdot \bar{M}_i}{E_i \cdot I_i} dz = 0 \quad \text{yoki} \quad \delta_{um} = \sum \frac{\omega_i \cdot \eta_i}{E_i \cdot I_i} = 0.$$

## 10.2- §. Statik noaniq ramalarga doir masalalar

### 94- masala

X.3- shaklda tasvirlangan rama uchun tugallangan eguvchi moment, kesuvchi kuch va bo'yлама kuch epyuralari qurilsin.

Berilgan:  $a = 2l$ ,  $b = 3l$ ,  $EI = \text{const}$ .

### Yechish:

Masalani kuch usulida yechamiz.

1. Berilgan ramaning statik noaniqlik darajasini topamiz:

$$S = n - 3 = 5 - 3 = 2.$$

Demak, berilgan rama ikki marta statik noaniq bo'lib, ikkita «ortiqcha» bog'lanishga ega ekan.

2. Ramadagi ortiqcha bog'lanishlarni yo'qotib, asosiy sistema tanlaymiz (X.4- shakl, a), keyin uni tashqi kuchlar hamda noma'lum reaksiya kuchlari  $X_1$  va  $X_2$  lar bilan yuklab, ekvivalent (teng kuchli) sistemani tuzamiz (X.4- shakl, b).

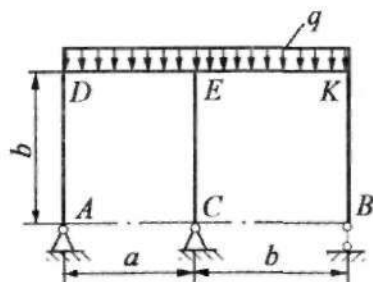
3. Ekvivalent sistema uchun kanonik tenglamalar sistemasi quyidagicha yoziladi:

$$\left. \begin{aligned} \delta_{11} \cdot X_1 + \delta_{12} \cdot X_2 + \Delta_{1P} &= 0 \\ \delta_{21} \cdot X_1 + \delta_{22} \cdot X_2 + \Delta_{2P} &= 0 \end{aligned} \right\}$$

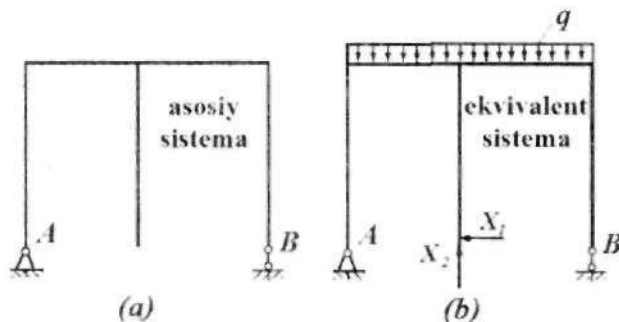
Asosiy sistemani alohida-alohida tashqi kuch (taqsimlangan kuch  $q$ , X.5- shakl, a) hamda noma'lum  $X_1$  va  $X_2$  reaksiya kuchlari o'rniga qo'yilgan  $\bar{X}_1 = 1$  va  $\bar{X}_2 = 1$  birlik kuchlar bilan yuklab (X.5- shakl, b va d), tayanchlarda hosil bo'luvchi reaksiya kuchlarini topamiz.

X.5- shakl (a) uchun:

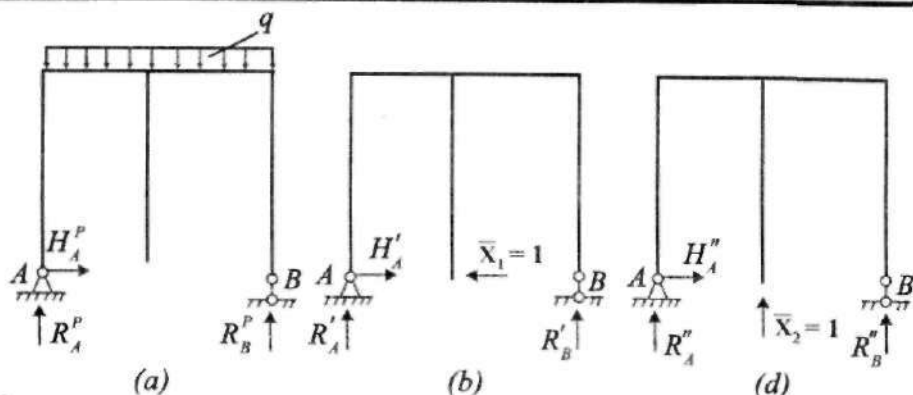
$$\sum M_A = 0; \quad q \frac{(a+b)^2}{2} - R_B^p (a+b) = 0; \quad R_B^p = \frac{q(a+b)^2}{2(a+b)} = \frac{5}{2}ql;$$



X.3- shakl



X.4- shakl



X.5-shakl

$$\sum M_{B_i} = 0; \quad R_A^p(a+b) - q \frac{(a+b)^2}{2} = 0; \quad R_A^p = \frac{q(a+b)^2}{2(a+b)} = \frac{5}{2}ql;$$

$$\sum X_i = 0; \quad H_A^p = 0.$$

X.5-shakl (b) uchun:

$$\sum M_{A_i} = 0; \quad R_B'(a+b) = 0; \quad R_B' = 0;$$

$$\sum M_{B_i} = 0; \quad R_A'(a+b) = 0; \quad R_A' = 0;$$

$$\sum X_i = 0; \quad H_A' - \bar{X}_1 = 0; \quad H_A' = 1.$$

X.5-shakl (d) uchun:

$$\sum M_{A_i} = 0; \quad \bar{X}_2 \cdot a - R_B''(a+b) = 0; \quad R_B'' = \frac{\bar{X}_2 \cdot a}{a+b} = -\frac{2}{5};$$

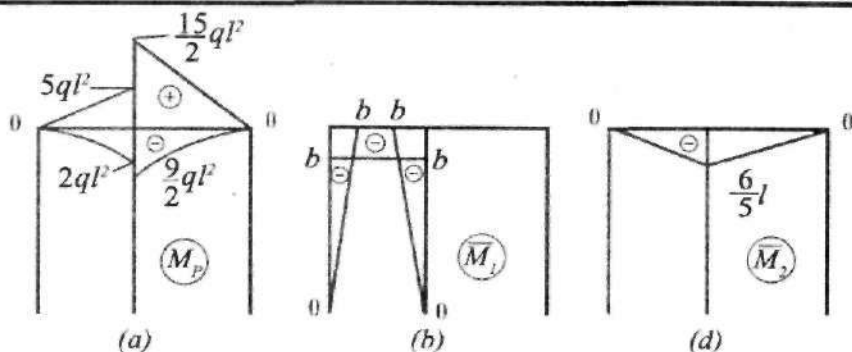
$$\sum M_{B_i} = 0; \quad -R_A''(a+b) - \bar{X}_2 \cdot b = 0; \quad R_A'' = \frac{\bar{X}_2 \cdot b}{a+b} = -\frac{3}{5};$$

$$\sum X_i = 0; \quad H_A'' = 0.$$

Kesish usulidan foydalanib, tashqi kuchdan  $M_p$ , birlik  $\bar{X}_1$  va  $\bar{X}_2$  kuchlardan esa  $\bar{M}_1$  va  $\bar{M}_2$  eguvchi moment epyuralarini quramiz (X.6-shakl). Bu epyuralardan foydalanib, Vereshagin usulida kanonik tenglamalar sistemasi tarkibidagi  $\delta_{ii}$ ,  $\delta_{ij}$  va  $\Delta_{ip}$  ko'chishlarni aniqlaymiz:

$$\delta_{11} = \delta(\bar{M}_1, \bar{M}_1) = \frac{1}{EI} \left( 2 \cdot \frac{b \cdot b}{2} \cdot \frac{2}{3} \cdot b + b \cdot a \cdot b \right) = \frac{36l^3}{EI};$$





X.6-shakl

$$\delta_{22} = \delta(\bar{M}_2 \cdot \bar{M}_2) = \frac{1}{EI} \left( \frac{1}{2} \cdot \frac{6l}{5} \cdot a \cdot \frac{2}{3} \cdot \frac{6l}{5} + \frac{1}{2} \cdot \frac{6l}{5} \cdot b \cdot \frac{2}{3} \cdot \frac{6l}{5} \right) = \frac{12l^3}{5EI};$$

$$\delta_{12} = \delta_{21} = \delta(\bar{M}_1 \cdot \bar{M}_2) = \frac{1}{EI} \left[ \frac{1}{2} \left( -\frac{6l}{5} \right) \cdot a \cdot (-b) \right] = \frac{18l^3}{5EI};$$

$$\Delta_{1p} = \Delta(\bar{M}_1 \cdot \bar{M}_p) = \frac{1}{EI} \left[ \frac{1}{2} \cdot 5ql^2 \cdot a \cdot (-b) + \frac{1}{3} \cdot (-2ql^2) \cdot a \cdot (-b) \right] = -\frac{11ql^4}{EI};$$

$$\Delta_{2p} = \Delta(\bar{M}_2 \cdot \bar{M}_p) = \frac{1}{EI} \left[ \frac{1}{2} \cdot 5ql^2 \cdot a \cdot \frac{2}{3} \cdot \left( -\frac{6l}{5} \right) + \frac{1}{3} \cdot (-2ql^2) \cdot a \cdot \frac{3}{4} \cdot \left( -\frac{6l}{5} \right) + \right. \\ \left. + \frac{1}{2} \cdot \frac{15}{2} ql^2 \cdot b \cdot \frac{2}{3} \cdot \left( -\frac{6l}{5} \right) + \frac{1}{3} \cdot \left( -\frac{9}{2} ql^2 \right) \cdot b \cdot \frac{3}{4} \cdot \left( -\frac{6l}{5} \right) \right] = -\frac{31ql^4}{4EI}.$$

$$\begin{cases} \frac{36l^3}{EI} \cdot X_1 + \frac{18l^3}{5EI} \cdot X_2 - \frac{11ql^4}{EI} = 0 \\ \frac{18l^3}{5EI} \cdot X_1 + \frac{12l^3}{5EI} \cdot X_2 - \frac{31ql^4}{4EI} = 0 \end{cases} \begin{cases} \times \frac{5EI}{l^3} \\ \times \frac{20EI}{l^3} \end{cases}$$

$$\begin{cases} 180X_1 + 18X_2 = 55ql \\ 72X_1 + 48X_2 = 155ql \end{cases}, \text{ bundan, } X_1 = -\frac{150}{7344} ql = -0,02ql; X_2 = \frac{23940}{7344} ql = 3,25ql.$$

4.  $M$ ,  $Q$  va  $N$  larning tugallangan epyuralarini chizish. Tashqi yuk hamda topilgan  $X_1$  va  $X_2$  kuchlarni ramaga qo'yib, ularda hosil bo'lgan tayanch reaksiyalarini topamiz (X.7-shakl):

$$\sum M_{A_i} = 0; -q \frac{(a+b)^2}{2} - R_B (a+b) + X_2 \cdot a = 0; R_B = \frac{q(a+b)^2}{2(a+b)} - X_2 \cdot a = 1,196ql;$$

$$\sum M_{B_i} = 0; \quad q \frac{(a+b)^2}{2} - R_A(a+b) - X_2 \cdot b = 0;$$

$$R_A = \frac{q(a+b)^2 - X_2 \cdot b}{(a+b)} = 0,544 ql;$$

$$\sum X_i = 0; \quad H_A - X_1 = 0; \quad H_A = X_1 = -0,02 ql.$$

Endi ramani uchastkalarga ajratib, har bir oraliq uchun  $N$ ,  $Q$  va  $M$  larning analitik ifodasini tuzamiz:

$AD$  oraliq:  $0 \leq z_1 \leq b$

$$N_{z_1} = -R_A = -0,544 ql; \quad Q_{z_1} = -H_A = 0,02 ql;$$

$$M_{z_1} = -H_A \cdot z_1; \quad M_{z_1=0} = 0; \quad M_{z_1=b} = -H_A \cdot b = 0,06 ql^2.$$

$DE$  oraliq:  $0 \leq z_2 \leq a$

$$N_{z_2} = -H_A = 0,02 ql; \quad Q_{z_2} = R_A - qz_2;$$

$$Q_{z_2=0} = R_A = 0,544 ql; \quad Q_{z_2=a} = R_A - q \cdot 2l = -1,456 ql;$$

(agar  $Q_{z_2} = 0$  bo'lsa, u holda,  $z_2 = R_A/q = 0,544 l$ )

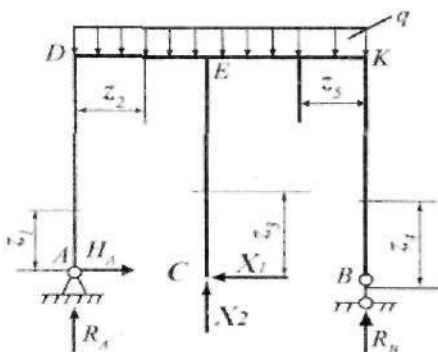
$$M_{z_2} = R_A \cdot z_2 - q \frac{z_2^2}{2} - H_A \cdot b; \quad M_{z_2=0} = -H_A \cdot b = 0,06 ql^2;$$

$$M_{z_2=0,544l} = R_A \cdot 0,544l - q \frac{(0,544l)^2}{2} - H_A \cdot b = 1,42 ql^2; \quad M_{z_2=a} = -0,852 ql^2.$$

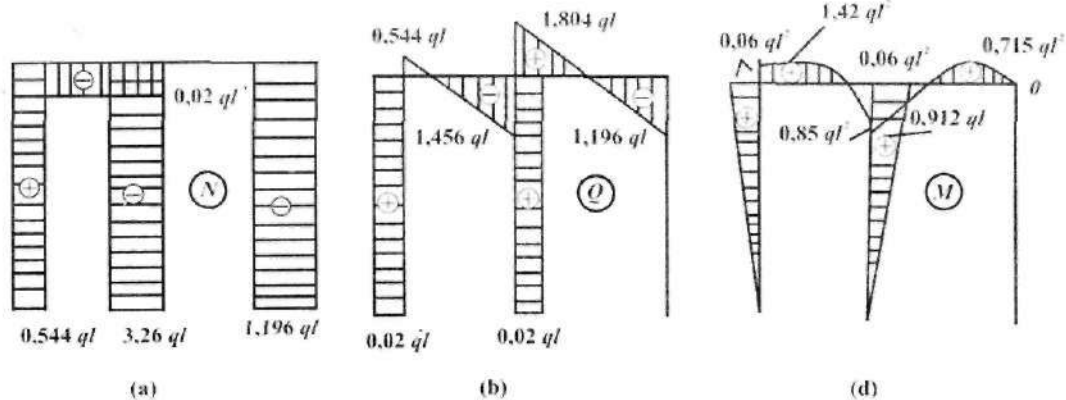
$CE$  oraliq:  $0 \leq z_3 \leq b$

$$N_{z_3} = -X_2 = -3,26 ql; \quad Q_{z_3} = X_1 = -0,02 ql;$$

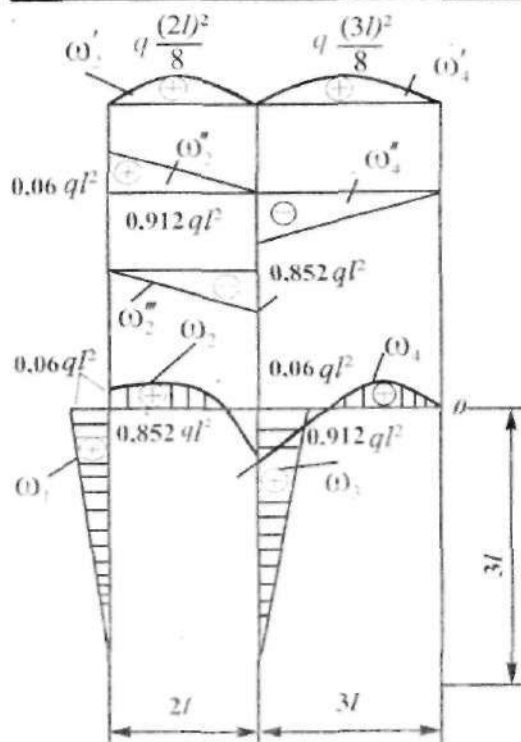
$$M_{z_3} = X_1 \cdot z_3; \quad M_{z_3=0} = 0; \quad M_{z_3=b} = X_1 \cdot b = 0,06 ql^2.$$



X.7-shakl



X.8-shakl



X.9-shakl

BK oraliq:  $0 \leq z_4 \leq b$ 

$$N_{z_4} = -R_B = -1,196 ql; \quad Q_{z_4} = 0; \quad M_{z_4} = 0.$$

KE oraliq:  $0 \leq z_5 \leq b$ 

$$N_{z_5} = 0; \quad Q_{z_5} = -R_B + qz_5; \quad Q_{z_5=0} = -R_B;$$

$$Q_{z_5=b} = -R_B + qb = 1,804 ql;$$

(agar  $Q_{z_5} = 0$  bo'lsa,  $z_5 = R_B/q = 1,196l$ )

$$M_{z_5} = R_B \cdot z_5 - q \frac{z_5^2}{2};$$

$$M_{z_5=0} = 0; \quad M_{z_5=b} = -0,912ql^2;$$

$$M_{z_5=1,196l} = R_B \cdot 1,196l - q \frac{(1,196l)^2}{2} = 0,715ql^2.$$

Hosil qilingan qiymatlar asosida  $M$ ,  $Q$  va  $N$  larning tugallangan epyuralarini chizamiz (X.8-shakl).

5. Epyuralarni deformatsion tekshirish. Buning uchun tugallangan  $M$  epyurasini (X.8-shakl, d)  $\bar{M}_1$  va  $\bar{M}_2$  epyuralarga (X.6-shakl) ko'paytiramiz. Bunda tugallangan  $M$  epyurasini oddiy shakllarga ajratish ko'chishlarni aniqlashda qulaylik tug'diradi:

$$\begin{aligned} \sum \int \frac{M_i \bar{M}_i}{EI} = 0 \quad \text{yoki} \quad \delta(M \cdot \bar{M}_1) &= \frac{1}{EI} (\omega_1 \eta'_1 + \omega'_2 \eta'_2 + \omega''_2 \eta'_2 + \omega'''_2 \eta'_2 + \omega_3 \eta'_3) = \\ &= \frac{1}{EI} \left[ \frac{0,06ql^2 \cdot 3l}{2} \cdot \frac{2}{3} (-3l) + \frac{2 \cdot \frac{1}{2} \cdot ql^2 \cdot 2l}{3} \cdot (-3l) + \frac{0,06ql^2 \cdot 2l}{2} \cdot (-3l) - \frac{0,852ql^2 \cdot 2l}{2} \cdot (-3l) + \right. \\ &\quad \left. + \frac{0,06ql^2 \cdot 3l}{2} \cdot \frac{2}{3} \cdot (-3l) \right] = \frac{ql^4}{EI} (-0,18 - 2 - 0,18 + 2,556 - 0,18) = \frac{0,016ql^4}{EI} \approx 0. \end{aligned}$$

Bu qiymat  $\Delta_{1p} = \frac{11ql^4}{EI}$  ga nisbatan 3,7% ni tashkil etganligi uchun uni nolga teng deb qabul qilish mumkin:

$$\begin{aligned} \delta(M, \bar{M}_2) &= \frac{1}{EI} (\omega_2' \eta_2^2 + \omega_2'' \eta_2^2 + \omega_2''' \eta_2^2 + \omega_4' \eta_4^2 + \omega_4'' \eta_4^2) = \\ &= \frac{1}{EI} \left[ \frac{2}{3} \cdot \frac{ql^2}{2} \cdot 2l \cdot \frac{1}{2} \cdot \left(-\frac{6}{5}l\right) + \frac{0,06ql^2}{2} \cdot 2l \cdot \frac{1}{3} \cdot \left(-\frac{6}{5}l\right) - \frac{0,852ql^2}{2} \cdot 2l \cdot \frac{2}{3} \cdot \left(-\frac{6}{5}l\right) + \right. \\ &\quad \left. + \frac{2}{3} \cdot \frac{9ql^2}{8} \cdot 3l \cdot \frac{1}{2} \cdot \left(-\frac{6}{5}l\right) - \frac{0,912ql^2}{2} \cdot 3l \cdot \frac{2}{3} \cdot \left(-\frac{6}{5}l\right) \right] = \frac{0,098ql^4}{EI} \approx 0. \end{aligned}$$

## 95-masala

X.10- shaklda tasvirlangan rama uchun tugallangan eguvchi moment, kesuvchi va bo'yama kuch epyuralari qurilsin.

Berilgan:  $a = l$ ;  $b = 2l$ ;  $EI = \text{const}$ ;  $P = ql$ .

## Yechish:

Masalani kuch usulida yechamiz.

1. Berilgan ramaning statik noaniqlik darajasini aniqlaymiz:

$$S = n - 3 = 5 - 3 = 2.$$

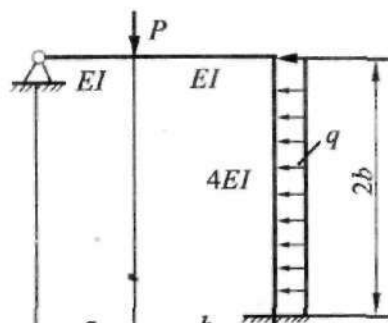
Demak, ramani hisoblash uchun statikaning muvozanat tenglamalaridan tashqari, yana ikkita qo'shimcha deformatsiya tenglamasini tuzish zarur ekan.

2. Ramani qo'zg'almas sharnirli tayanchdan ozod qilib, asosiy sistemani tanlaymiz (X.11- shakl, a), keyin uni tashqi kuchlar hamda noma'lum reaksiya kuchlari  $X_1$  va  $X_2$  lar bilan yuklab, ekvivalent sistemani tuzamiz (X.11- shakl, b).

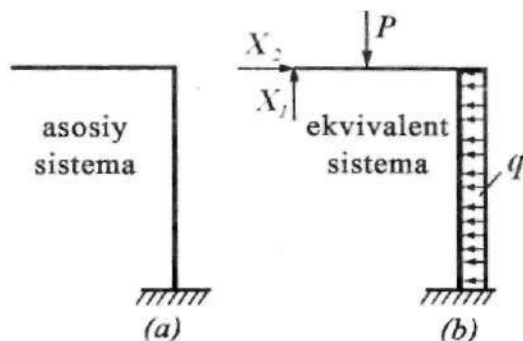
3. Ekvivalent sistema uchun kanonik tenglamalar sistemasi quyidagicha yoziladi:

$$\left. \begin{aligned} \delta_{11} \cdot X_1 + \delta_{12} \cdot X_2 + \Delta_{1P} &= 0 \\ \delta_{21} \cdot X_1 + \delta_{22} \cdot X_2 + \Delta_{2P} &= 0 \end{aligned} \right\}$$

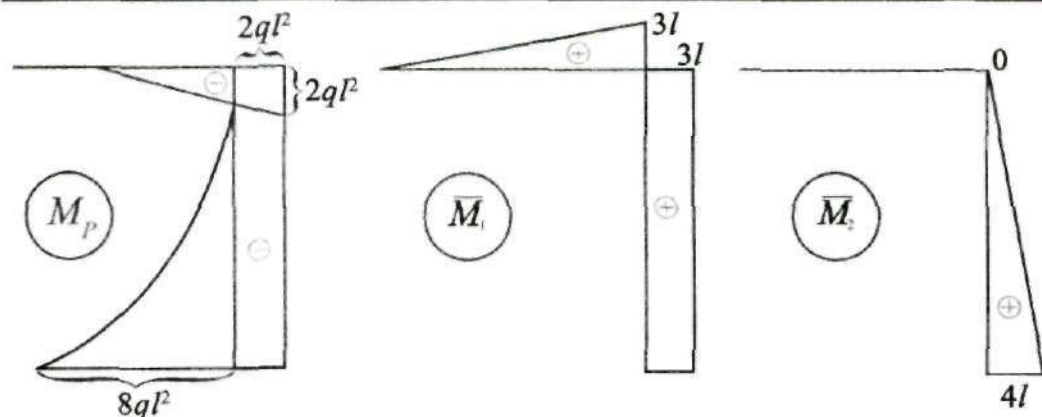
Asosiy sistemani alohida-alohida tashqi kuch hamda noma'lum  $X_1$  va  $X_2$  reaksiya kuchlari o'rniga qo'yilgan  $\bar{X}_1 = 1$  va  $\bar{X}_2 = 1$  birlik kuchlar bilan yuklaymiz va ular uchun  $M_p$ ,  $\bar{M}_1$  va



X.10- shakl



X.11- shakl



X.12-shakl

$\bar{M}_2$  eguvchi moment epyuralarini quramiz (X.12-shakl). Bunda asosiy sistema bitta tayanchga ega bo'lgani uchun uning reaksiya kuchlari aniqlanmaydi.

$$\delta_{11} = (\bar{M}_1, \bar{M}_1) = \frac{1}{EI} \cdot \frac{3l \cdot 3l}{2} \cdot \frac{2}{3} \cdot 3l + \frac{1}{4EI} \cdot 3l \cdot 2b \cdot 3l = \frac{18l^3}{EI};$$

$$\delta_{22} = (\bar{M}_2, \bar{M}_2) = \frac{1}{4EI} \cdot \frac{1}{2} \cdot 4l \cdot 2b \cdot \frac{2}{3} \cdot 4l = \frac{16l^3}{3EI};$$

$$\delta_{12} = \delta_{21} = (\bar{M}_1, \bar{M}_2) = \frac{1}{EI} \cdot \frac{1}{2} \cdot 4l \cdot 2b \cdot 3l = \frac{6l^3}{EI};$$

$$\Delta_{1P} = (\bar{M}_1, M_P) =$$

$$= \frac{1}{EI} \cdot \frac{1}{2} \cdot (-2ql^2) \cdot \frac{7l}{3} + \frac{1}{4EI} \left[ (-2ql^2) \cdot 2b \cdot 3l + \frac{1}{3} (-8ql^2) \cdot 2b \cdot 3l \right] = \frac{56ql^4}{3EI}$$

$$\Delta_{2P} = (\bar{M}_2, M_P) = \frac{1}{4EI} \left[ (-2ql^2) \cdot 2b \cdot \frac{1}{2} \cdot 4l + (-8ql^2) \cdot 2b \cdot \frac{1}{3} \cdot \frac{3}{4} \cdot 4l \right] = -\frac{12ql^4}{EI};$$

$$\begin{cases} \frac{18l^3}{EI} \cdot X_1 + \frac{6l^3}{EI} \cdot X_2 - \frac{56ql^4}{3EI} = 0 \\ \frac{6l^3}{EI} \cdot X_1 + \frac{16l^3}{3EI} \cdot X_2 - \frac{12ql^4}{EI} = 0 \end{cases} \quad \begin{cases} \times \frac{3EI}{l^3} \\ \times \frac{3EI}{l^3} \end{cases}$$

$$\begin{cases} 54X_1 + 18X_2 = 56ql \\ 18X_1 + 16X_2 = 36ql \end{cases}, \text{ bundan, } X_1 = 0,46ql; X_2 = 1,73ql.$$

4. Eguvchi moment, kesuvchi kuch va bo'ylama kuchlarning tugallangan epyuralarini chizish. Kesish usulidan foydalanib (X.13- shakl), quyidagi ifodalarni yozamiz:

1-uchastka:  $0 \leq z_1 \leq a$

$$N_{z_1} = -X_2 = -1,73 \, ql; \quad Q_{z_1} = -X_1 = 0,46 \, ql;$$

$$M_{z_1} = X_1 \cdot z_1; \quad M_{z_1=0} = 0; \quad M_{z_1=a} = X_1 a = 0,46 \, ql^2.$$

2-uchastka:  $0 \leq z_2 \leq b$

$$N_{z_2} = -X_2 = -1,73 \, ql; \quad Q_{z_2} = X_1 - P = -0,54 \, ql;$$

$$M_{z_2} = X_1(a + z_2) - Pz_2;$$

$$M_{z_2=0} = 0,46 \, ql^2; \quad M_{z_2=b} = X_1 a = 0,62 \, ql^2.$$

3-uchastka:  $0 \leq z_3 \leq 2b$

$$N_{z_3} = X_1 - P = -0,54 \, ql; \quad Q_{z_3} = X_2 - qz_3;$$

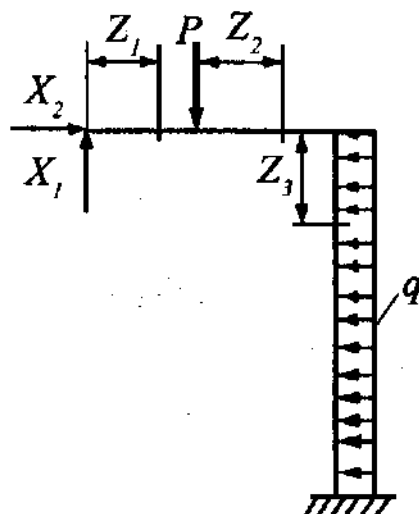
$$Q_{z_3=0} = 1,73 \, ql; \quad Q_{z_3=2b} = -2,27 \, ql;$$

$$M_{z_3} = X_1(a + b) - Pb + X_2 z_3 - qz_3^2/2;$$

$$M_{z_3=0} = -0,62 \, ql^2; \quad M_{z_3=1,73a} = 0,88 \, ql^2;$$

$$M_{z_3=2b} = -1,69 \, ql^2$$

(agar  $Q_{z_3} = 0$  bo'lsa, u holda,  $z_3 = X_2/q = 1,73a$ ).



X.13- shakl

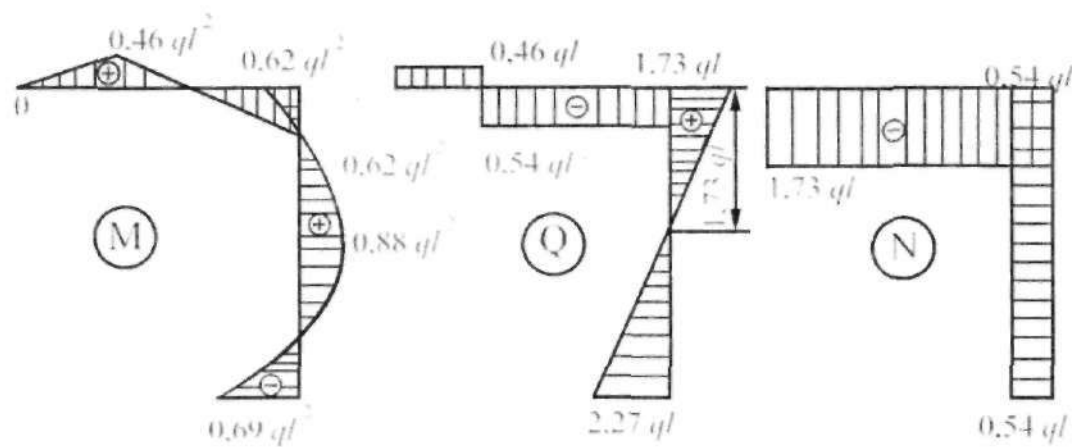
Hosil qilingan qiymatlar asosida  $M$ ,  $Q$  va  $N$ larning tugallangan epyuralarini chizamiz (X.14- shakl).

5. Epyuralarni deformatsion tekshirish. Buning uchun tugallangan  $M$  epyurasini (X.14- shakl, a)  $\bar{M}_1$  va  $\bar{M}_2$  epyuralarga (X.12- shakl) ko'paytiramiz. Tugallangan  $M$  epyurasini oddiy shakllarga ajratish X.15- shaklda ko'rsatilgan.

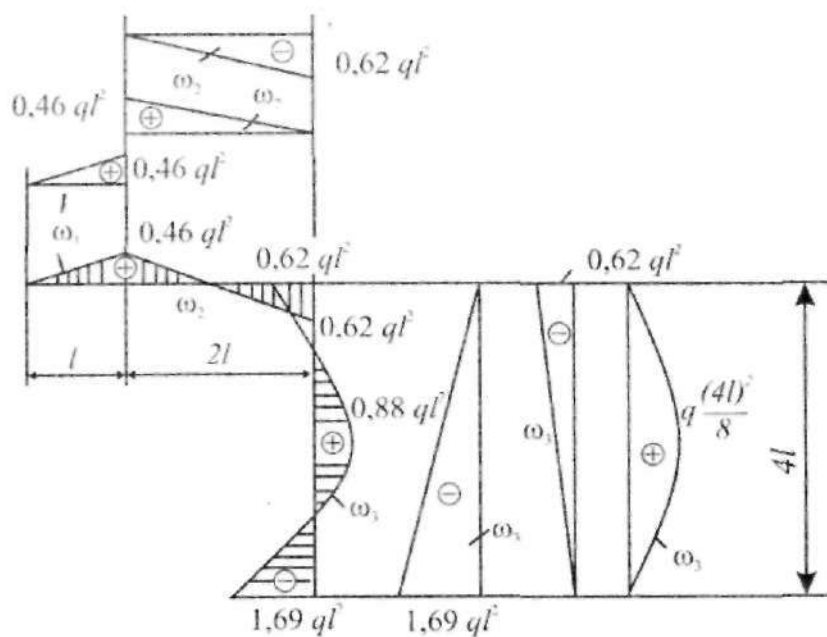
$$\begin{aligned} \int_c \frac{M \bar{M}_1}{EI} dz &= 0 \quad \text{yoki} \quad \delta(M, \bar{M}_1) = \frac{1}{EI} (\omega'_1 \eta'_1 + \omega'_2 \eta'_2 + \omega'_3 \eta'_3) + \frac{1}{4EI} (\omega'_3 \eta'_3 + \omega''_3 \eta''_3 + \omega'''_3 \eta'''_3) = \\ &= \frac{1}{EI} \left[ \frac{0,46ql^2 \cdot l}{2} \cdot \frac{2}{3}l - \frac{0,62ql^2 \cdot 2l}{2} \cdot \left(1 + \frac{2}{3}\right)l + \frac{0,46ql^2 \cdot 2l}{2} \cdot \left(1 + \frac{1}{3}\right)l \right] + \\ &+ \frac{1}{4EI} \left[ -\frac{1,69ql^2 \cdot 4l}{2} \cdot 3l - \frac{0,62ql^2 \cdot 4l}{2} \cdot 3l + \frac{2}{3} \cdot 2ql^2 \cdot 4l \cdot 3l \right] = \frac{0,26ql^4}{EI}. \end{aligned}$$

Bu qiymat  $\Delta_{1P} = -\frac{56}{3} \cdot \frac{ql^4}{EI}$  ga nisbatan 1,4% ni tashkil etganligi uchun uni nolga teng deb qabul qilish mumkin:

$$\begin{aligned} \delta(M, \bar{M}_2) &= \frac{1}{4EI} (\omega'_3 \eta'_3 + \omega''_3 \eta''_3 + \omega'''_3 \eta'''_3) = \\ &= \frac{1}{4EI} \left[ -\frac{1,69ql^2 \cdot 4l}{2} \cdot \frac{2}{3} \cdot 4l - \frac{0,62ql^2 \cdot 4l}{2} \cdot \frac{1}{3} \cdot 4l + \frac{2}{3} \cdot 2ql^2 \cdot 4l \cdot \frac{1}{2} \cdot 4l \right] = 0. \end{aligned}$$



X.14- shakl



X.15- shakl

### 10.3- §. Statik noaniq ramalarni kuch usulida hisoblash bo'yicha topshiriqlar

#### 18- topshiriq

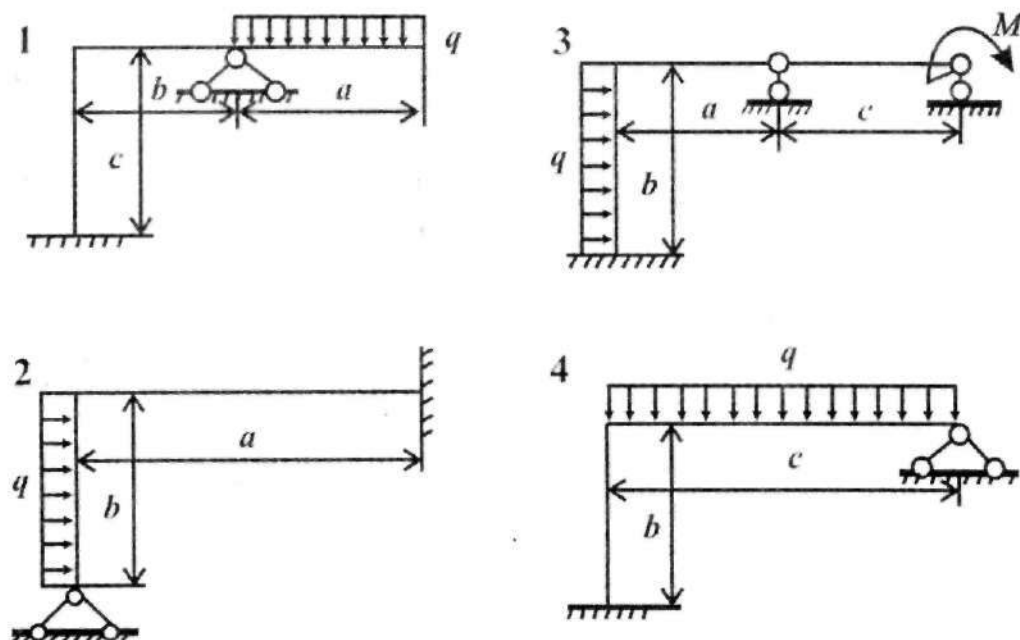
Statik noaniq ramalar uchun ichki kuch faktorlari epyuralarini qurish.

**Berilgan:** keltirilgan shakllarda (X.16- shakl) tashqi tomondan yuklangan statik noaniq rama berilgan.

**Topish kerak:**

- 1) ramaning statik noaniqlik darajasi aniqlansin;
- 2) asosiy va ekvivalent sistemalar tuzilsin;
- 3) noaniq tenglamalar tuzilib ortiqcha reaksiya kuchlari topilsin;
- 4) rama uchun kesuvchi kuch, bo'ylama kuch va eguvchi moment epyuralari qurilsin;
- 5) topilgan reaksiya kuchlari to'g'riligi tekshirilsin;
- 6) mustahkamlik shartiga binoan, ramaning ko'ndalang kesimi tanlansin (kesim ko'rinishi – o'qituvchi ko'rsatmasi bo'yicha).

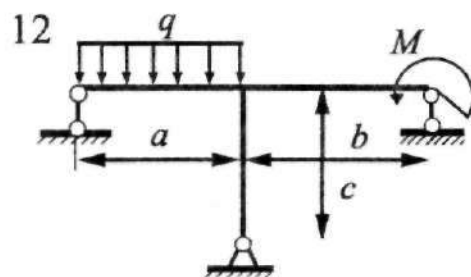
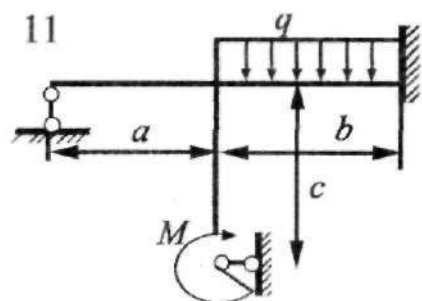
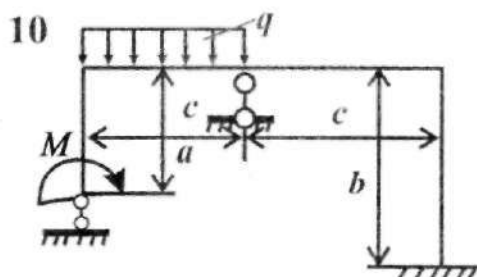
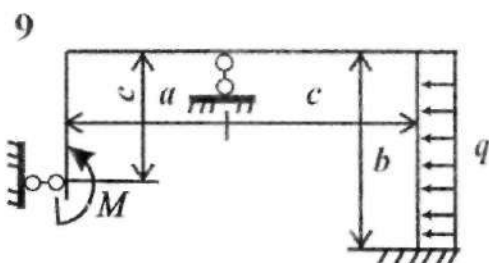
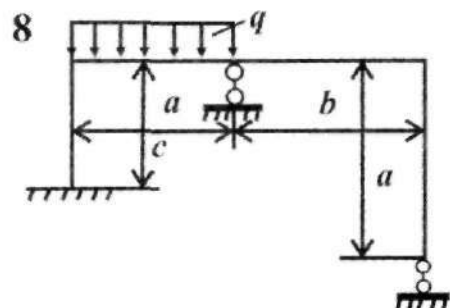
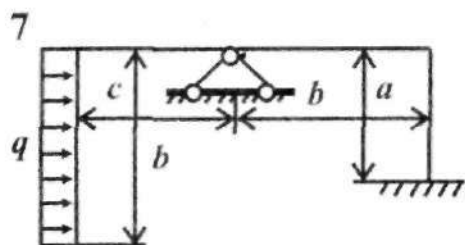
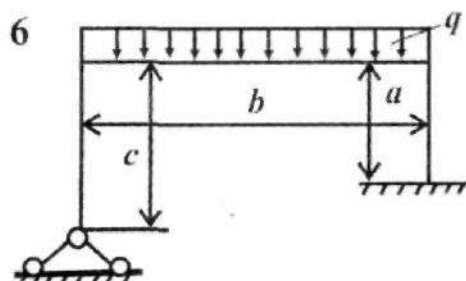
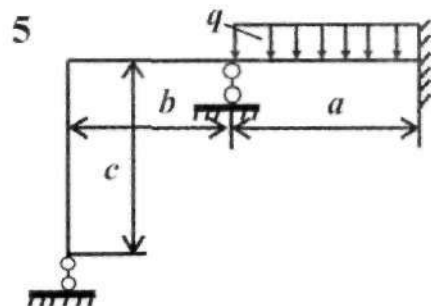
Kerakli ma'lumotlar VI.1- jadvalda, hisoblash sxemalari esa X.16- shaklda berilgan.



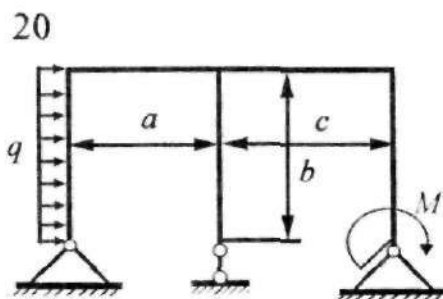
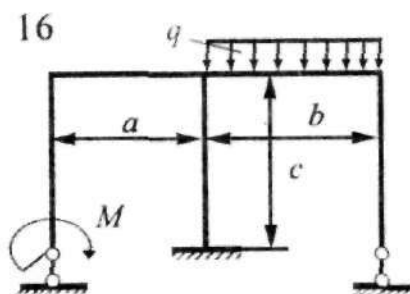
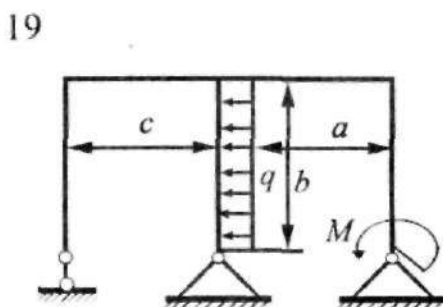
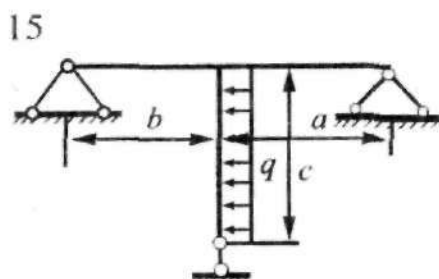
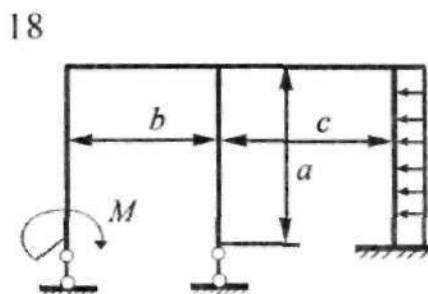
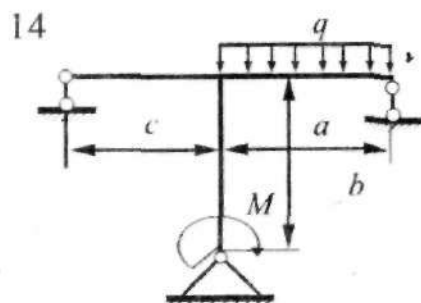
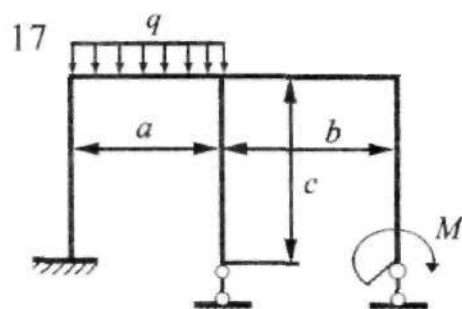
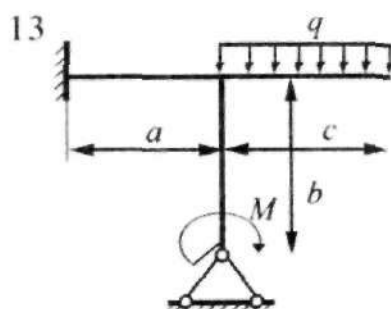
X.16- shakl



X.16- shakl (davomi)



X.16- shakl (davomi)



## XI BOB

## STATIK NOANIQ TO'SINLARNI HISOBLASH

## 11.1- §. Asosiy mulohazalar

Statik noaniq to'sinlarni kuch usulida hisoblash tartibi statik noaniq ramalarni hisoblashdagi kabi amalga oshiriladi:

- masalaning statik noaniqlik darajasi aniqlanadi;
- masalaning statik noaniqlik darajasiga teng deformatsiya tenglamalari tuziladi;
- deformatsiya tenglamalaridagi birlik kuch, hamda tashqi kuchlardan hosil bo'lgan ko'chishlar Vereshagin usulida topiladi;
- deformatsiya tenglamalarini birgalikda yechib, undagi ortiqcha reaksiya kuchlari aniqlanadi va masala statik aniq masalaga aylantiriladi.

## 11.2- §. Statik noaniq to'sinlarni kuch usulida hisoblash

## 96- masala

Berilgan birligi o'zgarmas bo'lgan statik noaniq balkaning ko'ndalang kesim yuzalari to'g'ri to'rtburchak shaklida aniqlansin.

$K$  nuqtaning ko'chishi topilsin:  $[\sigma] = 10 \text{ MPa}$ .

## Yechish:

Berilgan balka bir marta statik noaniqdir, chunki  $B$  nuqtada uchta va  $A$  nuqtada esa bitta reaksiya kuchlari mavjud. Bunda,  $S=1$ .

$A$  nuqtadagi bog'lanishni tashlab yuborib, uni  $X_1$  noma'lum reaksiya kuchi bilan almash-tiramiz (XI.1-shakl).  $A$  nuqtaning ko'chishi nolga teng bo'lgani uchun quyidagi deformatsiya tenglamasini yozamiz:

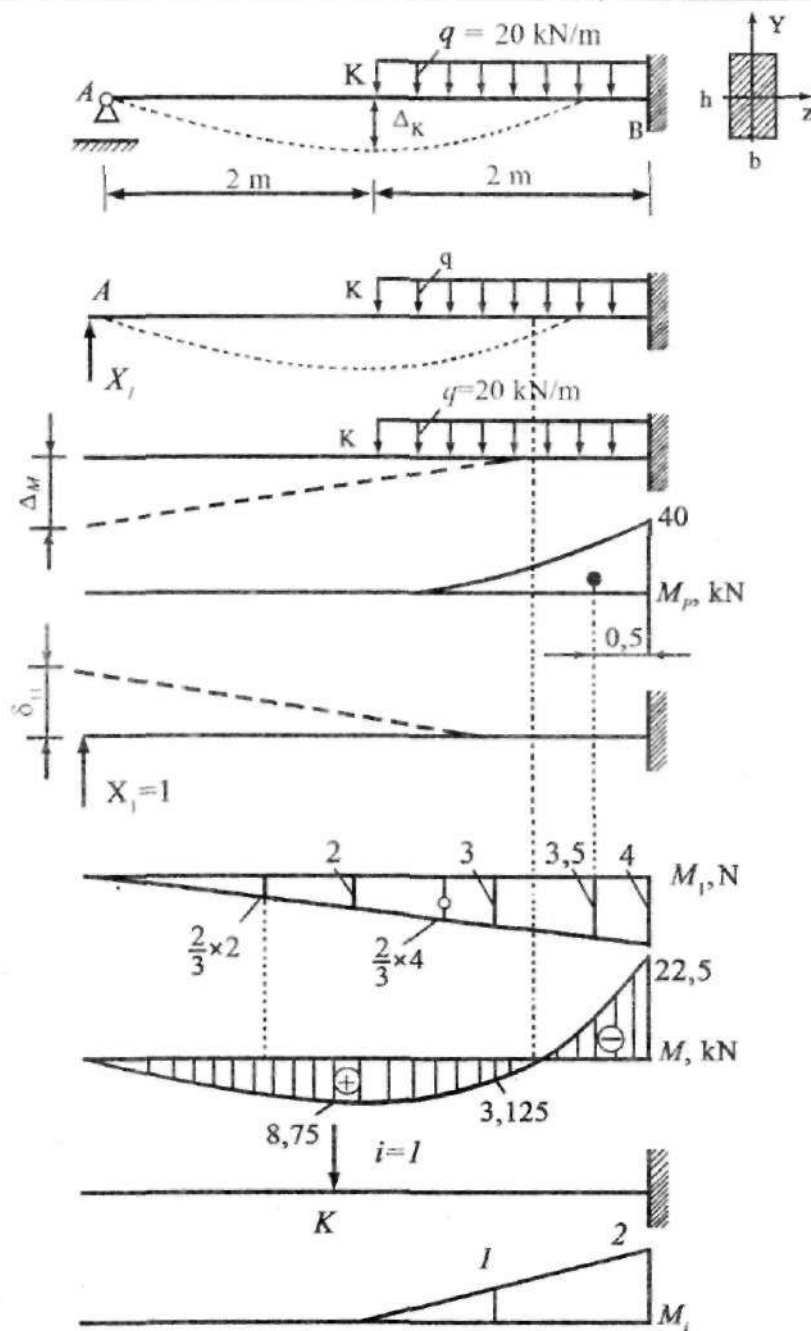
$$\Delta_A = \Delta_{AX_1} + \Delta_{AP} = \delta_{11} \cdot X_1 + \Delta_{1P} = 0; \quad (a)$$

bu yerda,  $\delta_{11}$  –  $A$  nuqtaning birlik  $X_1 = 1$  ga teng bo'lgan kuchdan hosil bo'lgan ko'chishi;

$\Delta_{1P}$  –  $A$  nuqtaning tashqi kuchlardan hosil bo'lgan ko'chishidir.

$\delta_{11}, \Delta_{1P}$  larni Vereshagin usulidan foydalangan holda aniqlaymiz:

$$\delta_{11} = \frac{\omega_1^0 \cdot \eta_1^0}{EI} = \frac{1}{EI} \cdot \frac{4}{2} \cdot \frac{2}{3} \cdot 4 = \frac{64}{3EI};$$



XI.1- shakl

$$\Delta_{1P} = \frac{\omega_1 \cdot \eta_1}{EI} = -\frac{1}{EI} \cdot \frac{1}{3} \cdot 40 \cdot 2 \cdot 3,5 = -\frac{280}{3EI}.$$

Topilgan qiymatlarni deformatsiya tenglamasiga (a) qo'yib,  $X_1$  reaksiya kuchini aniqlaymiz:

$$\frac{64}{3EI} \cdot X_1 - \frac{280}{3EI} = 0;$$

bu yerdan,  $X_1 = 4,375$  kN.

Masala statik aniq masalaga aylagandan so'ng, kesuvchi kuch va eguvchi moment epyuralari oddiy balkalarning yechimi singari amalga oshiriladi.

Topilgan  $X_1$  ning qiymati to'g'riligini tekshirish uchun  $\Delta_A = 0$  dan foydalanamiz ( $M$  epyura yuzasini  $M_1$  epyura ordinatalariga ko'paytiramiz):

$$\Delta_A = \sum \frac{\omega \cdot \eta_1}{EI} = \frac{1}{EI} \cdot \left[ \frac{1}{2} \cdot 8,75 \cdot 2 \cdot \frac{2}{3} \cdot 2 + \frac{2}{6} (8,75 \cdot 2 + 4 \cdot 3,125 \cdot 3 - 22,5 \cdot 4) \right] = 0.$$

$A$  nuqta ko'chishining nolga tengligi masalani to'g'ri yechilganligini ko'rsatadi.

Egillishdagi mustahkamlik sharti bo'yicha balka kesim yuzasi o'lchamlarini aniqlaymiz:

$$\sigma_{\max} = M_{\max} / W_x \leq [\sigma];$$

bu yerda,  $W_x = bh^2/6$ ;  $M_{\max} = 22,5$  kN·m. U  $h = 3b$  ekanligini e'tiborga olib, quyidagini hosil qilamiz:

$$\frac{M_{\max}}{\frac{3}{2}b^3} \leq [\sigma]. \text{ U holda, } b \geq \sqrt[3]{\frac{2 M_{\max}}{3 R}} = \sqrt[3]{\frac{2 \cdot 2250}{3 \cdot 10 \cdot 10^6}} = 11,5 \cdot 10^{-2} \text{ m} = 11,5 \text{ sm};$$

$$\text{bunda, } h = 3b = 34,5 \text{ sm}; I_z = \frac{bh^3}{12} = \frac{11,5 \cdot 34,5^3}{12} = 39350 \text{ sm}^4.$$

$K$  nuqta ko'chishini aniqlash uchun bu nuqtaga  $i=1$  ga teng kuch qo'yamiz va undan birlik eguvchi moment epyurasi quramiz ( $M_1$ ).  $M$  va  $M_1$  epyuralarini o'zaro ko'paytirib (Vereshagin usuli),  $K$  nuqta ko'chishini aniqlaymiz:

$$V_k = \sum \frac{\omega \cdot \eta_1}{EI} = \frac{2}{6} (0 - 4 \cdot 3,125 \cdot 1 + 22,5 \cdot 2) = \frac{65}{6EI} = \frac{65000}{6 \cdot 1 \cdot 10^{10} \cdot 39350 \cdot 10^{-8}} = 2,75 \cdot 10^{-3} \text{ m} = 2,75 \text{ mm}.$$

### 11.3- §. Statik noaniq to'sinlarni uch moment tenglamasi yordamida yechish

➤ Uch moment tenglamasi quyidagi ko'rinishga ega:

$$M_{n-1} \cdot l_n + 2M_n (l_n + l_{n+1}) + M_{n+1} \cdot l_{n+1} = -6 \cdot \left( \frac{\omega_n \cdot a_n}{l_n} + \frac{\omega_{n+1} \cdot b_{n+1}}{l_{n+1}} \right); \quad (\text{XI.1})$$

- bu yerda,  $M_n, M_{n+1}, \dots$  – tayanchlardagi eguvchi momentlar;  
 $l_n, l_{n+1}, \dots$  – tayanchlar orasidagi masofalar;  
 $a_n, b_{n+1}$  – tashqi kuchlardan hosil bo'lgan eguvchi moment epyuralari ( $\omega_n, \omega_{n+1}$ ) yuzalarining og'irlik markazidan chap va o'ng tayanchlargacha bo'lgan masofa;  
 $\omega_n, \omega_{n+1}$  – berilgan tashqi kuchlardan  $n$  va  $n+1$  prolyotlarda hosil bo'lgan eguvchi moment epyurasining yuzasi.

### 97-masala

Bir nechta tayanchlardan iborat bo'lgan statik noaniq balka uchun (X1.2- shakl) eguvchi moment va kesuvchi kuch epyuralari qurilsin ( $q = 2P/e$ ).

### Yechish:

Balkaning qistirib mahkamlangan chap qismini fikran davom ettirib, qo'shimcha tayanch (0) hosil qilamiz (X1.2- shakl, b). Bu shakldan  $S = m - 2 = 5 - 2 = 3$ , demak, masala uch marta statik noaniqdir. 0, 1; 1, 2; 2, 3 va 3, 4 tayanchlarda yotgan balkalarni alohida olib, tashqi kuchlardan hosil bo'lgan eguvchi moment epyuralarini quramiz (X1.2- shakl, d). Ulardan hosil bo'lgan epyura yuzalari va masofalar teng bo'ladi.

$$\omega_1 = 0; \omega_2 = \frac{Pl^2}{8}; a_2 = b_2 = \frac{l}{2}; \omega_3 = 0; \omega_4 = \frac{ql^2}{12} = \frac{Pl^2}{6}; a_4 = b_4 = \frac{l}{2}.$$

Balkaning uch oraliq tayanchi uchun uch moment tenglamasini tuzamiz ( $n = 1, 2, 3$ ):

$$\left. \begin{aligned} 2M_1 + M_2 &= -\frac{3}{8}Pl & (n=1) \\ M_1 + 4M_2 + M_3 &= -\frac{3}{8}Pl & (n=2) \\ M_2 + 4M_3 + M_4 &= -\frac{3}{8}Pl & (n=3) \end{aligned} \right\} \quad (a)$$

Shakldan ko'rinib turibdiki, oxirgi tayanchdan  $M_4$  moment quyidagiga teng bo'ladi:

$$M_4 = -\frac{Pl}{4}. \quad (b)$$

(a) tenglamalarni (b)ni e'tiborga olgan holda yechib, quyidagilarni olamiz:

$$M_1 = -0,168 Pl; \quad M_2 = -0,038 Pl; \quad M_3 = -0,053 Pl.$$

Tayanchlarda hosil bo'lgan eguvchi momentlar qiymati grafik ravishda X1.2- shakl (b)da ko'rsatilgan. Bu momentlarning manfiy ishoralari ularning haqiqiy yo'nalishi shakldagidan teskari tomonga ekanligini ko'rsatadi.

Balkaning tayanch reaksiya kuchlarini aniqlash uchun har bir oraliq masofani alohida olib (oddiy balka ko'rinishida), unga tashqi hamda topilgan moment qiymatlari

qo'yiladi. Shundan so'ng statika tenglamalari yordamida oddiy balka reaksiya kuchlari topiladi:

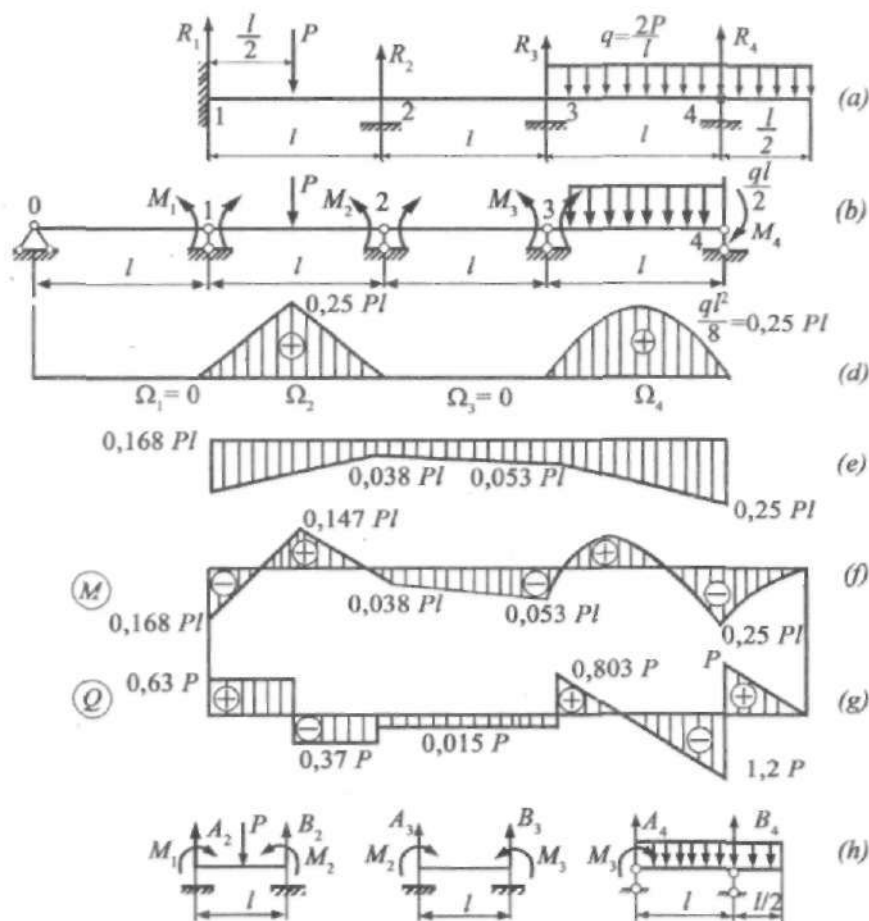
$$A_2 = 0,63 P; \quad B_2 = 0,37 P; \quad A_3 = \frac{M_3 - M_2}{l} = 0,015 P; \quad B_3 = -\frac{M_3 - M_2}{l} = -0,015 P;$$

$$A_4 = \frac{3}{8}ql - \frac{M_3}{l} = 0,803 P; \quad B_4 = \frac{9}{8}ql + \frac{M_3}{l} = 2,20 P.$$

Unda tayanchlardagi haqiqiy reaksiya kuchlari quyidagilarga teng bo'ladi:

$$R_1 = A_2 = 0,63 P; \quad R_2 = B_2 + A_3 = 0,36 P; \quad R_3 = B_3 + A_4 = 0,82 P; \quad R_4 = B_4 = 2,20 P.$$

Reaksiya kuchlari topilgandan so'ng, har bir oddiy balka uchun  $Q$  va  $M$  epyuralari quriladi va ular umumlashtiriladi (XI.2-shakl, f, g).



XI.2-shakl

## 11.4- §. Statik noaniq to'sinlarni hisoblash bo'yicha topshiriqlar

### 19- topshiriq

Statik noaniq to'sinlarni hisoblash.

**Berilgan:** bir necha tayanchlardan iborat bo'lgan uzluksiz to'singa tashqi kuchlar ta'sir etayapti. To'sin po'latdan yasalgan bo'lib, ruxsat etilgan normal kuchlanish  $[a]=160$  MPa ga teng.

**Topish kerak:**

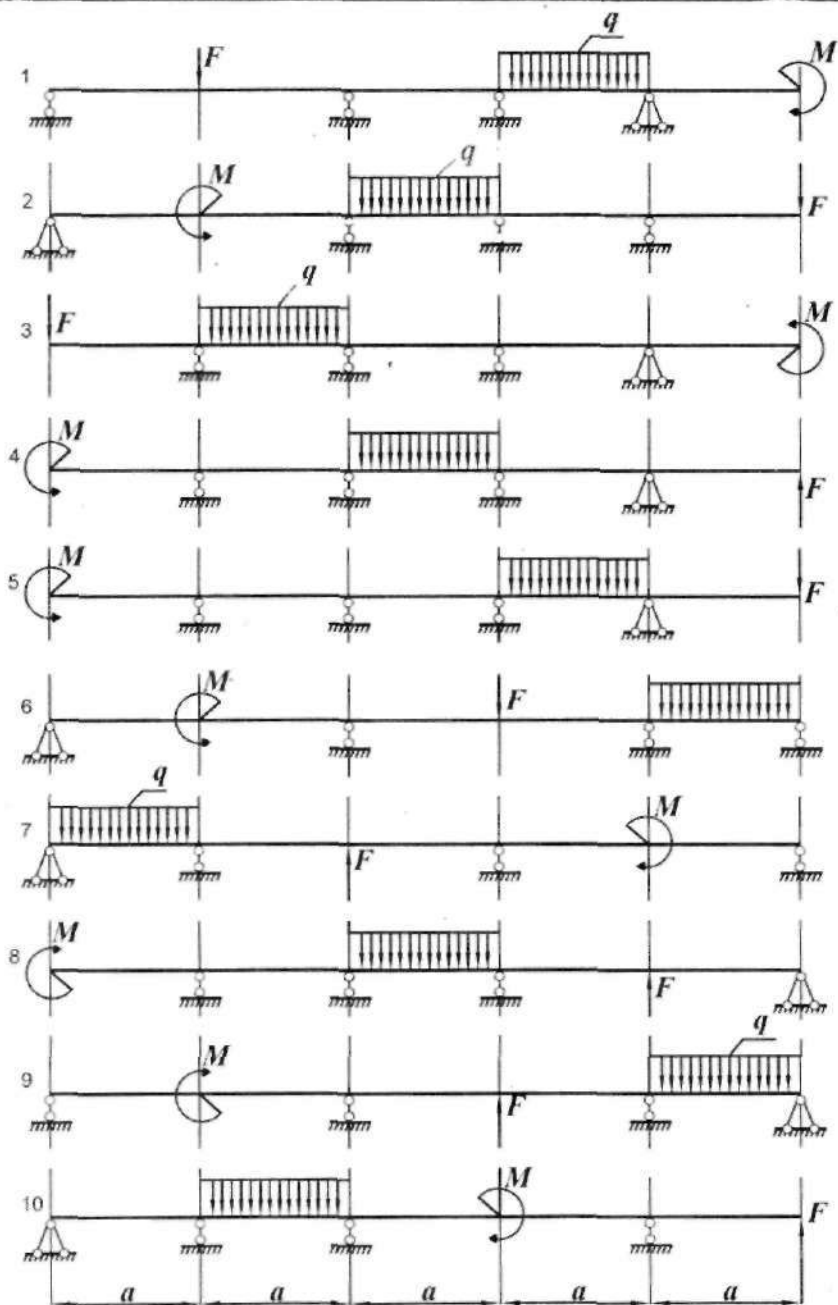
- 1) noma'lum tayanch reaksiya kuchlari uch moment tenglamasi yordamida topilsin;
- 2) eguvchi moment va kesuvchi kuch epyuralari qurilsin;
- 3) mustahkamlik shartiga asosan, to'sinning qo'shtavr ko'rinishdagi ko'ndalang kesim yuzasi tanlansin.

Kerakli ma'lumotlar XI.1- jadvalda, hisoblash sxemalari esa XI.3- shaklda berilgan.

*XI.1- jadval*

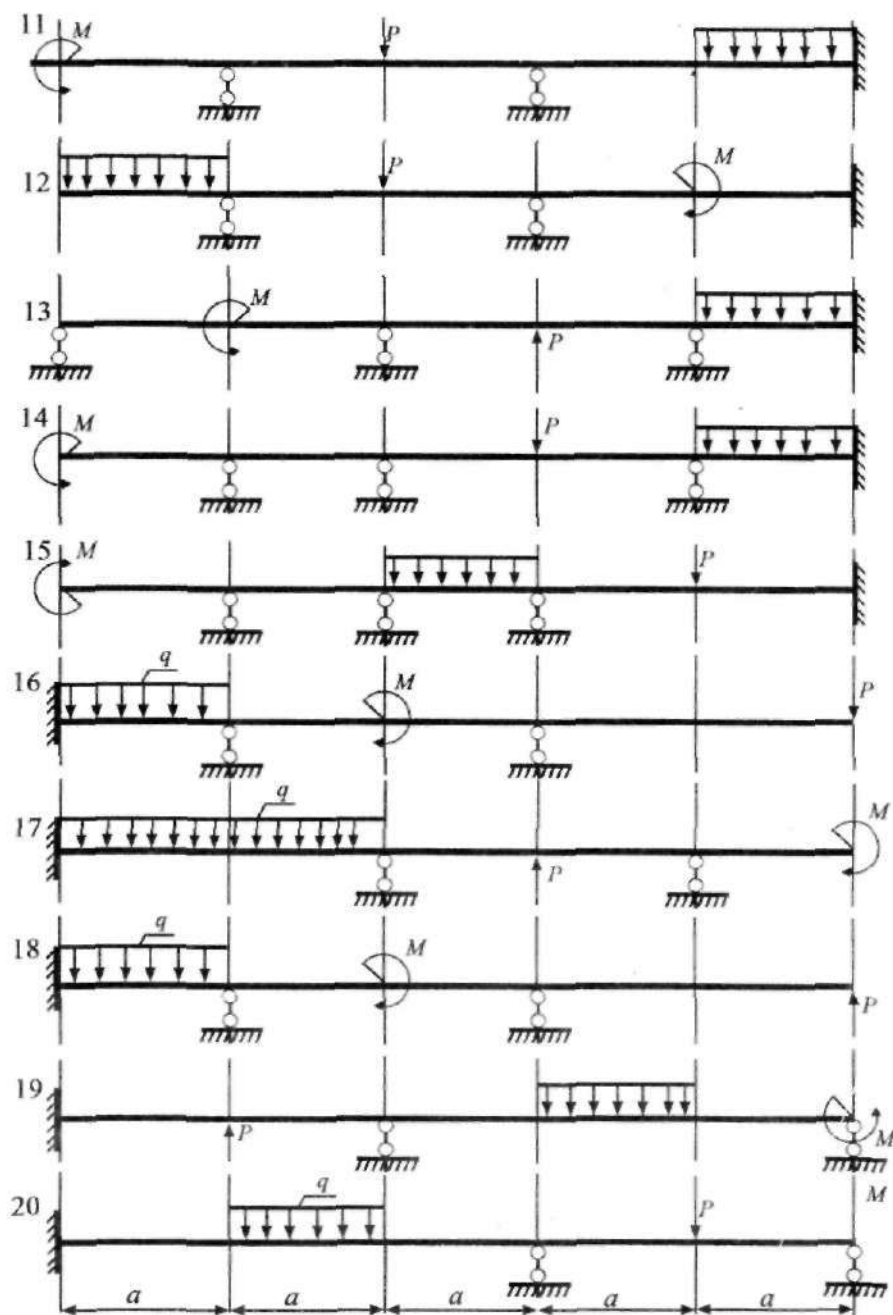
| №  | O'lchamlar | Yuklanish |         |                 |
|----|------------|-----------|---------|-----------------|
|    | $a, m$     | $q, kN/m$ | $F, kN$ | $M, kN \cdot m$ |
| 1  | 2          | 20        | 30      | 18              |
| 2  | 1,2        | 28        | 28      | 20              |
| 3  | 1,4        | 26        | 32      | 24              |
| 4  | 1,6        | 24        | 40      | 30              |
| 5  | 1,8        | 30        | 42      | 32              |
| 6  | 1          | 32        | 36      | 24              |
| 7  | 12         | 34        | 48      | 20              |
| 8  | 1,4        | 28        | 42      | 26              |
| 9  | 1,6        | 20        | 36      | 32              |
| 10 | 1,8        | 30        | 28      | 34              |





XI.3- shakl

XI.3- shakl (davomi)



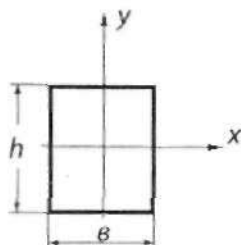
## XII BOB

BO'YLAMA EGILISH  
(SIQILGAN STERJENLARNING USTUVORLIGI)

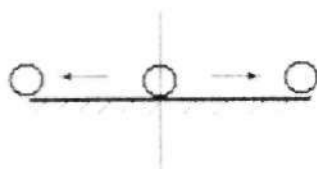
## 12.1- §. Asosiy mulohazalar

- Uzun ingichka sterjen deb, ko'ndalang o'lchamlari uzunligidan bir necha (8–10) marta kichik bo'lgan sterjenga aytiladi. Bunday sterjenni markaziy kuch bilan siqqanimizda u ham siqilishga, ham egilishga ishlaydi.
- Uzun ingichka sterjen siqilganida, ko'ndalang kesim yuzasining inersiya momenti qaysi o'qqa nisbatan kichik bo'lsa, o'sha o'qqa nisbatan egiladi. Shuning uchun hisob formulalariga ko'ndalang kesim yuzasining minimal inersiya momenti  $J_{min}$  kiritiladi:

$$J_x > J_y; J_x = \frac{bh^3}{12}; J_y = \frac{hb^3}{12}; h > b.$$



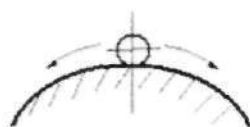
- Ustuvor muvozanat haqida tushuncha:



befarq holat



ustuvor holat



noustuvor holat

- Kritik kuch deb, sterjenning ham to'g'ri chiziqli, ham egri chiziqli muvozanat holatlari ustuvor bo'lgan vaqtga to'g'ri kelgan siquvchi kuchga aytiladi. Bunda sterjenning egri chiziqli holati ustuvor bo'ladi.
- Siquvchi kuch kritik qiymatga yetib bormaganda sterjen faqat sof siqilishga ishlaydi. Kritik qiymatdan ortganidan keyin esa ham siqilish, ham egilishga ishlaydi.

- Kritik kuchni topish Eyler formulasi quyidagiga teng:

$$F_{kr} = \frac{\pi^2 E J_{min}}{(\mu l)^2}; \quad (XII.1)$$

bu yerda,  $E$  – elastiklik moduli;

$J_{min}$  – kesimning minimal inersiya momenti;

$l$  – sterjen uzunligi;

$\mu$  – sterjenning mahkamlanish turini hisobga olish koeffitsienti.

- Kritik kuchlanish quyidagi qiymatga teng:

$$\sigma_{kr} = \frac{\pi^2 E}{\lambda^2}; \quad (XII.2)$$

bu yerda,  $\lambda$  – sterjen egiluvchanligi.

- Eyler formulasidan hamma vaqt ham foydalanib bo'lmaydi. Undan foydalanish uchun quyidagi shart bajarilishi zarur:

$$\sigma_{kr} = \frac{\pi^2 E}{\lambda^2} \leq \sigma_n \quad (XII.3)$$

yoki

$$\lambda \geq \sqrt{\frac{E}{\sigma_n}}; \quad (XII.4)$$

bu yerda,  $\sigma_n$  – sterjen materialining proporsionallik chegarasi.

Shunga ko'ra, Eyler formulasini St.3 navli po'latdan yasalgan sterjenlar uchun egiluvchanlik 100 dan katta bo'lgandagina tatbiq etish mumkin.

$\lambda \leq 100$  bo'lganda, kritik kuch Yasinskiy formulasi yordamida aniqlanadi:

po'lat uchun:  $\sigma_{kr} = a - b \cdot \lambda$ ;

cho'yan uchun:  $\sigma_{kr} = a - b \cdot \lambda + c \lambda^2$ ;

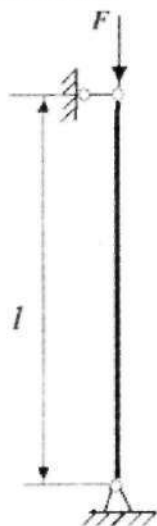
bu yerda,  $a, b, c$  – materiallarning xossasiga bog'liq bo'lgan o'zgarmaslar bo'lib, ular tajribalardan aniqlanadi.

## 12.2- §. Bo'ylama egilishga doir masalalar

### 98- masala

Uzunligi  $l = 1,85$  m bo'lgan sterjenga ta'sir etuvchi siquvchi kuchning ruxsat etilgan qiymati aniqlansin (XII.1- shakl). Sterjen St.3 po'latdan yasalgan bo'lib, ko'ndalang

kesim profili 12- nomerli qo'shtavrdan iborat. Hisoblashda  $E = 2,1 \cdot 10^5$  MPa;  $n_{adm}^s = 3$  deb olinsin.



XII.1- shakl

**Yechish:**

Dastlab, Eyler formulasini qo'llash haqidagi masalani hal qilish zarur. Buning uchun sterjenning egiluvchanligini hisoblaymiz:

$$\lambda = \frac{\mu l}{i_{\min}} = \frac{1 \cdot 1,85}{1,38 \cdot 10^{-2}} = 134,06;$$

bu yerda inersiya radiusi  $i_{\min}$  ning qiymati GOST 8239-72 bo'yicha sortament jadvalidan olindi.

Demak,  $\lambda > \lambda_{\text{cheg}} = 100$  bo'lgani uchun kritik kuch Eyler formulasi bo'yicha aniqlanadi:

$$F_{kp} = \frac{\pi^2 EI_{\min}}{(\mu l)^2} = \frac{(3,14)^2 \cdot 2,1 \cdot 10^5 \cdot 10^6 \cdot 27,9 \cdot 10^{-8}}{(1,85)^2} = 168,958 \text{ kN};$$

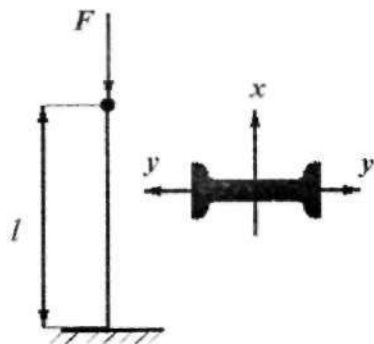
bu yerda,  $I_{\min} = 27,9 \text{ cm}^4$  bo'lib, sortament jadvalidan olindi.

U holda siquvchi kuchning ruxsat etilgan qiymati quyidagicha hisoblanadi:

$$F_{adm}^s = \frac{F_{kr}}{n_{adm}^s} = \frac{168,958}{3} = 56,319 \text{ kN}.$$

**99- masala**

Uzunligi  $l = 2,5$  m bo'lgan, St.3 navli po'latdan yasalgan qo'shtavr kesimli ustun  $F = 110$  kN siquvchi kuch bilan yuklangan (XII.2- shakl). Ustunning talab etilgan profil nomeri aniqlansin. Hisoblashlarda  $E = 2 \cdot 10^5$  MPa;  $n_{adm}^s = 2,8$  deb olinsin.



XII.2- shakl

**Yechish:**

Hisoblashni Eyler formulasi bo'yicha olib boramiz. Ustunning ustuvorlik shartini

$$F \leq \frac{F_{sch}}{n_{adm}^s} \quad (a)$$

ko'rinishda yozib olamiz.

(a) formulani nazarda tutib, yuqoridagi shartdan ko'ndalang kesimning talab etilgan minimal inersiya momentini aniqlaymiz:

$$J_{\min} \geq \frac{F \cdot n_{\text{adm}}^s (\mu l)^2}{\pi^2 \cdot E} = \frac{110 \cdot 10^3 \cdot 2,8 \cdot (2 \cdot 2,5)^2}{3,14^2 \cdot 2 \cdot 10^{11}} = 390,48 \cdot 10^{-8} \text{ m}^4 = 390,48 \text{ sm}^4.$$

Bu qiymatga qarab, sortament jadvalidan 30<sup>a</sup> nomerli qo'shtavr tanlanadi, bu qo'shtavr uchun  $I_y = I_{\min} = 436 \text{ sm}^4$ ,  $i_{\min} = 2,95 \text{ sm}$ .

Endi ustunning qabul qilingan profili uchun Eyler formulasini tatbiq qilish mumkin yoki mumkin emasligini tekshirib ko'ramiz. Buning uchun ustunning egiluvchanligini aniqlab, uni  $\lambda_{\text{cheg}} = 100$  bilan solishtirish kifoya:

$$\lambda = \frac{\mu l}{i_{\min}} = \frac{2 \cdot 2,5}{2,95 \cdot 10^{-2}} = 169,49 > 100.$$

Demak, Eyler formulasini qo'llash mumkin ekan.

### 100- masala

Pastki uchi qistirib tiralgan, yuqori uchi esa qo'zg'aluvchan sharnirli tayanchga mahkamlangan ustunga  $F = 120 \text{ kN}$  yuk qo'yilgan (XII.3- shakl, a). Ustunning uzunligi  $l = 5,5 \text{ m}$  bo'lib, ko'ndalang kesimi yonma-yon o'rnatilgan ikkita shvellardan iborat (XII.3- shakl, b).

Quyidagilarni aniqlash talab etiladi:

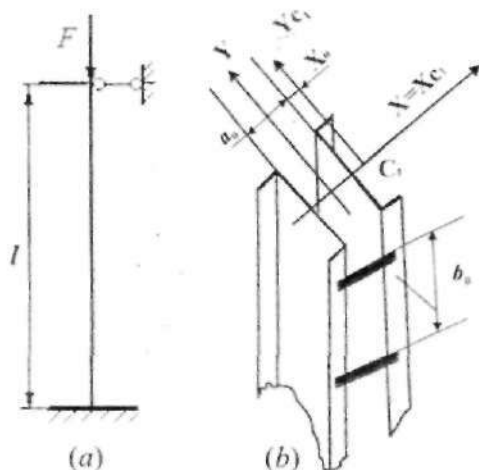
- ustunning zaruriy profil nomeri tanlansin;
- shvellarlardan ratsional foydalanish uchun ularning orasidagi  $\alpha_0$  masofa qanchaga teng bo'lishi kerak?

- belbog' polosalarning oraliqlari aniqlansin.

Hisoblashda ustuvorlikning zaruriy ehtiyot koeffitsienti  $n_{\text{adm}}^s = 4$  qilib olinsin.

### Yechish:

Butun ko'ndalang kesimning zaruriy minimal inersiya momentini quyidagi shartdan aniqlaymiz (oldingi masalaga qarang):



XII.3- shakl

$$I_{\min} \geq \frac{F n_{\text{adm}}^s (\mu l)^2}{\pi^2 E} = \frac{120 \cdot 10^3 \cdot 4 \cdot (0,7 \cdot 5,5)^2}{\pi^2 \cdot 2 \cdot 10^{11}} = 360,81 \cdot 10^{-8} \text{ m}^4 = 360,81 \text{ sm}^4.$$

Bitta shveller uchun esa

$$I_{\min}^c = \frac{I_{\min}}{2} = 180,405 \text{ sm}^4 \quad \text{bo'lgani uchun GOST 8239-72 bo'yicha profili 22<sup>a</sup> no-}$$

merli shveller tanlanadi. Bu shveller uchun:

$$I_{\min}^c = 187 \text{ sm}^4; \quad A^c = 28,8 \text{ sm}^2.$$

$$\text{Ikkita shveller uchun esa: } I_{\min} = 374 \text{ sm}^4; \quad A = 57,6 \text{ sm}^2.$$

Tanlab olingan profil uchun Eyler formulasini qo'llash mumkinligini tekshiramiz:

$$\lambda = \frac{\mu l}{\sqrt{\frac{I_{\min}}{A}}} = \frac{0,7 \cdot 5,5 \cdot 100}{\sqrt{\frac{374}{57,6}}} = 151,1 > \lambda_{\text{cheg}} = 100.$$

Bundan chiqdi, Eyler formulasini ishlatish mumkin ekan.

Endi shvellerlar oralig'ini aniqlaymiz.

Agar  $I_y \geq I_x$  shart bajarilsa, shvellerlardan ratsional foydalanish mumkin. Bu shartdan quyidagi tenglama kelib chiqadi:

$$I_y = 2 \left[ I_y^0 + A^0 \left( \frac{a_0}{2} + X_0 \right)^2 \right] \geq 2 I_x^0.$$

Bunda,  $I_x^0 = 2330 \text{ sm}^4$ ;  $I_y^0 = 187 \text{ sm}^4$ ;  $A^c = 28,8 \text{ sm}^2$ ;  $X_0 = 2,46 \text{ sm}$  bo'lib, sortament jadvalidan olinadi. Bu qiymatlarni e'tiborga olib, tegishli soddalashtirishlardan keyin  $a_0$  ga nisbatan kvadrat tenglamaga ega bo'lamiz:

$$a_0^2 + 9,84a_0 - 273,4 = 0; \quad \text{bundan } a_0 = 12,33 \text{ ekanligi kelib chiqadi.}$$

Ustun balandligi bo'yicha oraliqni ta'minlash uchun shvellerlar albatta XII.3- shakl (b) da tasvirlangandek, polosalar bilan bog'lab qo'yilishi lozim.

**1-usul.** Quyidagi mulohazaga tayanib, belbog' polosalar orasidagi  $b_0$  masofani aniqlaymiz. Har bir shveller mustaqil holda  $0,5F$  kuchni qabul qilib, ustuvorlik shartini bajarishi kerak:

$$\frac{F}{2} = \frac{\pi^2 EI_{\min}^c}{n_{\text{adm}}^s b_0^2}; \quad \text{bundan, } b_0 = \pi \sqrt{\frac{2 EI_{\min}^c}{n_{\text{adm}}^s F}} = 3,14 \sqrt{\frac{2 \cdot 2 \cdot 10^{11} \cdot 187 \cdot 10^{-8}}{4 \cdot 120 \cdot 10^3}} = 3,92 \text{ m.}$$

**2-usul.** Quyidagi mulohazalarga tayanib, belbog' polosalar orasidagi  $b_0$  masofani aniqlaymiz. Har bir shvellarning  $b_0$  uzunlikdagi egiluvchanligi butun ustunning egiluvchanligidan kichik bo'lish shart:

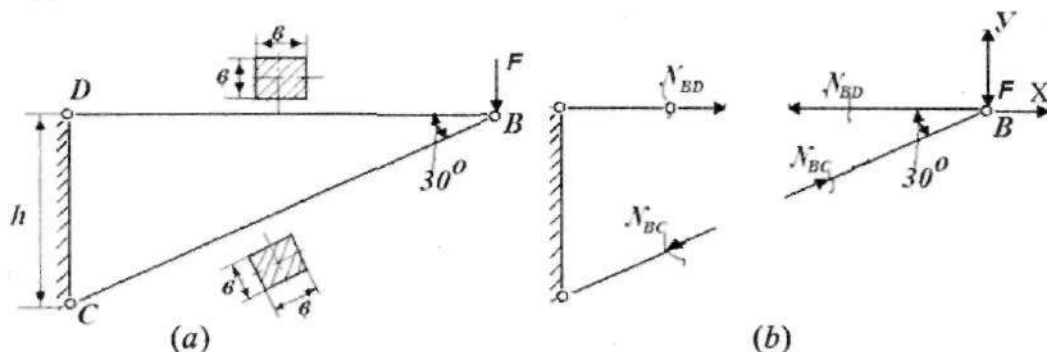
$$\lambda_c = \frac{b_0}{i_{\min}^c} \leq \lambda_{\text{ustun}}; \text{ bundan, } b_0 = \lambda_{\text{ustun}} \cdot i_{\min}^c = \frac{\mu l}{\sqrt{\frac{2 I_{\min}^c}{2 A^c}}} \cdot \sqrt{\frac{I_{\min}^c}{A^c}} = 0,7 \cdot 5,5 = 3,85 \text{ m.}$$

### 101- masala

Xrom-molibden po'latidan yasalgan kronshteyn  $B$  tuguniga qo'yilgan kuchning ruxsat etilgan qiymati aniqlansin (XII.4- shakl, a). Hisoblashlar uchun quyidagilar ma'lum:

$$\sigma_{pr} = 540 \text{ MPa}; \sigma_{0,r} = 600 \text{ MPa}; E = 2,1 \cdot 10^5 \text{ MPa}; n_{adm} = 2,5 \text{ (mustahkamlikda)};$$

$$n_{adm}^s = 4 \text{ (ustuvorlikda)}; h = 30 \cdot 10^{-2} \text{ m}; b = 2 \cdot 10^{-2} \text{ m}.$$



XII.4- shakl

### Yechish:

$B$  tugunni qirqib, uning muvozanatini tekshiramiz (XII.4- shakl, b):

$$\sum X_i = N_{BC} \cos 30^\circ - N_{BD} = 0; \quad \sum Y_i = N_{BC} \sin 30^\circ - F = 0.$$

Bulardan sterjendagi zo'riqlishlarni topamiz:

$$N_{BC} = 2F \text{ (BC sterjen siqiladi);}$$

$$N_{BD} = 1,73 \text{ (BD sterjen cho'ziladi).}$$

Oddiy cho'zilishdagi mustahkamlik shartini yozamiz:

$$\sigma_{BD} = \frac{1,73 F}{b^2} \leq \sigma_{adm}$$



Bunda ruxsat etilgan kuchlanish:  $\sigma_{adm} = \frac{\sigma_{0,r}}{n_{adm}} = 240 \text{ MPa}$  ga teng.

Demak, cho'zuvchi kuchning ruxsat etilgan qiymati:

$$F_{adm} = \frac{240 \cdot (2 \cdot 10^{-2})^2 \cdot 10^3}{1,73} = 55,49 \text{ kN.}$$

BC sterjenni ustuvorlikka tekshiramiz. Eyler formulasini qo'llash mumkinligi haqidagi masalani hal qilamiz. XII.4- shakldan egiluvchanlikning chegaraviy qiymatini aniqlaymiz:

$$\lambda_{cheg} = \pi \sqrt{\frac{E}{\sigma_{pr}}} = 3,14 \cdot \sqrt{\frac{2,1 \cdot 10^5}{540}} = 62.$$

Sterjenning egiluvchanligi:

$$\lambda = \frac{\mu l_{BC}}{i_{min}} = \frac{1 \cdot 2 \cdot h}{\sqrt{\frac{b^4}{12 \cdot b^2}}} = 103,92 > \lambda_{cheg}. \text{ Shunday qilib, Eyler formulasi bo'yicha:}$$

$$(N_{BC})_{cr} = \frac{\pi^2 EI_{min}}{(\mu l_{BC})^2} = \frac{(3,14)^2 \cdot 2,1 \cdot 10^5 \cdot 10^6 \cdot (2 \cdot 10^{-2})^4}{(1 \cdot 2 \cdot 30 \cdot 10^{-2})^2 \cdot 12} = 76,76 \cdot 10^3 \text{ N} = 76,76 \text{ kN.}$$

Ustuvorlik shartidan sterjen uchun ruxsat etilgan kuchni aniqlaymiz:

$$(N_{BC})_{adm} = \frac{(N_{BC})_{cr}}{n_s} = 19,19; \quad F_{adm} = 0,5 (N_{BC})_{adm} = 9,595 \text{ kN.}$$

Demak,  $F$  kuchning ruxsat etilgan qiymati 9,595 kN ga teng ekan.

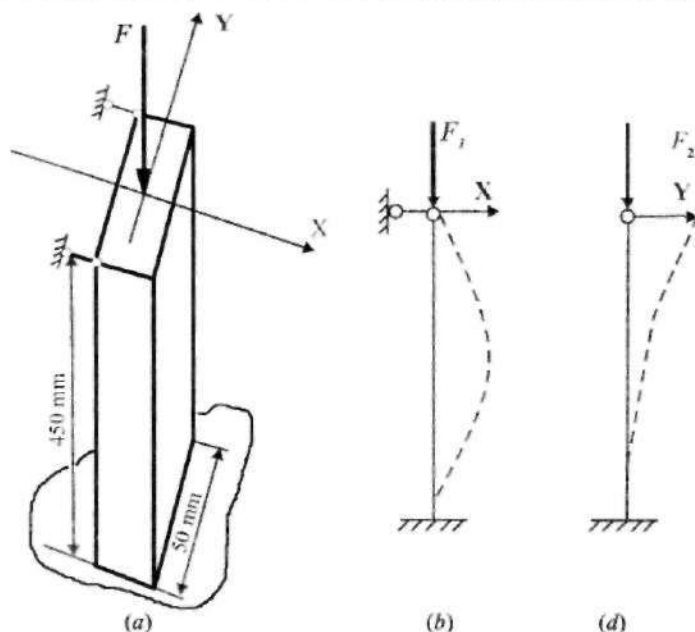
### 102- masala

XII.5- shakl (a) da tasvirlangan sterjen uchun ustuvorlikning haqiqiy ehtiyot koeffitsienti aniqlansin.

Sterjenning o'lchamlari mm larda berilgan bo'lib, u St.3 navli po'latdan yasalgan.  $l = 450 \text{ mm}$ ;  $F = 44 \cdot 10^3 \text{ N}$ .

### Yechish:

Sterjenning ustuvorligi yo'qoladigan tekislikni aniqlash uchun egiluvchanliklarni o'zaro taqqoslash zarur.



XII.5- shakl

a) XOZ tekisligida (XII.5- shakl, b)  $\lambda_x = \frac{\mu_1 l}{i_y} = \frac{0,7 \cdot 450}{\sqrt{\frac{I_y}{A}}} = \frac{0,7 \cdot 450}{\sqrt{\frac{50 \cdot 15^3}{12 \cdot 15 \cdot 50}}} = 72,75.$

b) YOZ tekisligida (XII.5- shakl, d)  $\lambda_y = \frac{\mu_2 l}{i_x} = \frac{2 \cdot 450}{\sqrt{\frac{I_x}{A}}} = \frac{2 \cdot 450}{\sqrt{\frac{15 \cdot 50^3}{12 \cdot 15 \cdot 50}}} = 62,35.$

Bundan chiqdi, ustuvorlikning yo'qolishi XOZ tekisligida sodir bo'lar ekan.

Sterjenning egiluvchanligi  $40 < \lambda_x < 100$  oraliqda bo'lganligi sababli, kritik kuchlanish F. S. Yasinskiy formulasidan topiladi:

$$\sigma_{cr} = 310 - 1,14 \cdot 72,75 = 227,065 \text{ MPa.}$$

Siquvchi kuchlanishning haqiqiy qiymati:

$$\sigma = \frac{F}{A} = \frac{44 \cdot 10^3 \text{ N}}{15 \cdot 50 \cdot 10^{-6} \text{ m}^2} = 58,67 \cdot 10^6 \text{ N/m}^2 = 58,67 \text{ MPa ni tashkil etadi. Bunga}$$

ruxsat beriladi.

Ustuvorlikning haqiqiy (hisoblab topiladigan) ehtiyoat koeffitsienti quyidagiga teng:

$$n^s = \frac{\sigma_{cr}}{\sigma} = \frac{227,065}{58,67} = 3,87.$$

### 103- masala

XII.6- shaklda tasvirlangan sterjen ustuvorlikka tekshirilsin. Sterjen cho'yan materialdan yasalgan bo'lib, uning barcha o'lchamlari mm larda berilgan.

Hisoblashlar uchun quyidagi ma'lumotlar berilgan:  $F = 80 \text{ kN}$ ;  $\sigma_{adm}^- = 135 \text{ MPa}$ .

### Yechish:

Quyidagi miqdorlarni aniqlaymiz.

Ko'ndalang kesim yuzasi:

$$A = \frac{\pi D^2}{4} \left( 1 - \frac{d^2}{D^2} \right) = \frac{3,14 \cdot 80^2}{4} \left( 1 - \frac{50^2}{80^2} \right) = 3061,5 \text{ mm}^2 = 3061,5 \cdot 10^{-6} \text{ m}^2.$$

Inersiya momenti:

$$I_x = I_y = \frac{\pi D^4}{64} \left( 1 - \frac{d^4}{D^4} \right) = \frac{3,14 \cdot 80^4}{64} \left( 1 - \frac{50^4}{80^4} \right) = 1702959,3 \text{ mm}^4 = 170,296 \cdot 10^{-8} \text{ m}^4.$$

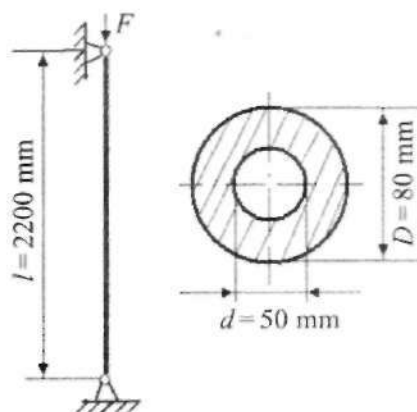
Minimal inersiya radiusi:  $i_{\min} = \sqrt{\frac{I_x}{A}} = 23,585 \text{ mm} = 23,585 \cdot 10^{-3} \text{ m}.$

Sterjenning egiluvchanligi:

$$\lambda = \frac{\mu l}{i_{\min}} = \frac{1 \cdot 2,2}{23,585 \cdot 10^{-3}} = 93,28.$$

Bo'ylama egilish koeffitsienti  $\varphi$  ni jadvaldan topish uchun  $\lambda = 90$  va  $\lambda = 100$  orasidagi qiymatlarini interpolyatsiya qilamiz:

$$\begin{aligned} \varphi_{\lambda=93,28} &= \varphi_{\lambda=90} - \frac{\varphi_{\lambda=90} - \varphi_{\lambda=100}}{10} \cdot (93,28 - 90) = \\ &= 0,2 - \frac{0,2 - 0,16}{10} \cdot 3,28 = 0,1869. \end{aligned}$$



XII.6- shakl

Ruxsat etilgan kritik kuchlanish:

$$\sigma_{adm}^s = \varphi \cdot \sigma_{adm}^- = 0,1869 \cdot 135 \text{ MPa} = 25,23 \text{ MPa}.$$

Siquvchi kuchlanishning haqiqiy qiymati esa:

$$\sigma = \frac{F}{A} = \frac{80 \cdot 10^3}{3061,5 \cdot 10^{-6}} = 26,13 \cdot 10^6 \text{ N/m}^2 = 26,13 \text{ MPa}.$$

Shunday qilib,  $\sigma < \sigma_{adm}^s$  sharti saqlanmagan, ya'ni sterjen noustuvor muvozanat holatida.

Ammo sterjenning o'ta yuklanganligi:

$$\frac{26,13 - 25,23}{25,23} \cdot 100\% = 3,57\% \text{ ni tashkil etadi. Bunga ruxsat etiladi.}$$

### 104- masala

XII.7- shaklda ko'rsatilgan ustun uchun sortament jadvalidan qo'shtavrli kesim nomeri tanlansin.

Ustunning uzunligi  $l = 2,6 \text{ m}$ ; unga qo'yilgan siquvchi kuch  $F = 210 \text{ kN}$ ; materiali St.4 navli po'lat; siqilishdagi ruxsat etilgan kuchlanish  $\sigma_{adm}^- = 160 \text{ MPa}$ .

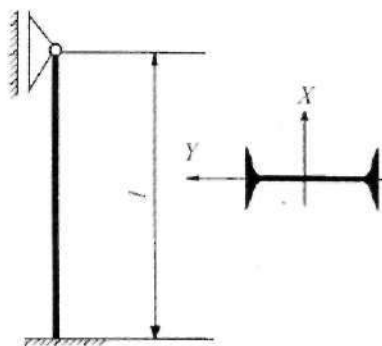
#### Yechish:

Ustuvorlikni ta'minlay oladigan kesim yuza tanlash uchun ketma-ket yaqinlashish usulidan foydalanamiz.

Birinchida  $\varphi_1 = 0,5$  deb qabul qilamiz va hisob tenglamasidan zaruriy ko'ndalang kesim yuzani aniqlaymiz:

$$A_1 = \frac{F}{\varphi_1 \cdot \sigma_{adm}^-} = \frac{210 \cdot 10^3}{0,5 \cdot 160 \cdot 10^6} = 26,25 \cdot 10^{-4} \text{ m}^2.$$

Sortament jadvali (GOST 8239-72) dan 20-raqamli qo'shtavrni tanlaymiz; bu qo'shtavrning yuzasi  $A_1 = 26,8 \cdot 10^{-4} \text{ m}^2$ , minimal inersiya radiusi  $i_{min} = 2,07 \cdot 10^{-2} \text{ m}$  ga teng.



XII.7- shakl

$$\text{Ustunning egiluvchanligini hisoblaymiz: } \lambda_1 = \frac{\mu l}{i_{min}} = \frac{0,7 \cdot 2,6}{2,07 \cdot 10^{-2}} = 87,92.$$

Egiluvchanlikning bu qiymatiga mos keluvchi  $\varphi$  ni aniqlash uchun jadvalga murojaat qilamiz.  $\lambda = 80$  va  $\lambda = 90$  orasidagi qiymatlarni chiziqli interpolyatsiyalaymiz:

$$\varphi_1 = \varphi_{\lambda=87,92} = \varphi_{\lambda=80} - \frac{\varphi_{\lambda=80} - \varphi_{\lambda=90}}{10} (87,92 - 80) = 0,75 - \frac{(0,75 - 0,69)}{10} \cdot 7,92 = 0,7025.$$

$\varphi_1$  va  $\varphi_1^I$  lar orasidagi farq ancha katta, shu sababli hisoblashni yana takrorlaymiz:

$$\varphi_2 = \frac{\varphi_1 + \varphi_1^I}{2} = 0,6013.$$

Yangi kesim yuzasini topamiz:

$$A_2 = \frac{F}{\varphi_2 \sigma_{adm}} = \frac{210 \cdot 10^3}{0,6013 \cdot 160 \cdot 10^6} = 21,83 \cdot 10^{-4} \text{ m}^2.$$

Bu kesim yuzasiga profil nomeri 18 bo'lgan qo'shtavr to'g'ri keladi. Ustunning egiluvchanligini aniqlaymiz:

$$\lambda_2 = \frac{\mu l}{i_{min}} = \frac{0,7 \cdot 2,6}{1,88 \cdot 10^{-2}} = 96,81.$$

Chiziqli interpolatsiyalab,  $\varphi_2^I = 0,6287$  ni hosil qilamiz. Shu koeffitsient bilan kesimda paydo bo'ladigan haqiqiy kuchlanishni aniqlaymiz va uni  $\sigma_{adm}$  bilan taqqoslaymiz:

$$\sigma_x = \frac{F}{\varphi_2^I A_{21}} = \frac{210 \cdot 10^3}{0,6287 \cdot 23,4 \cdot 10^{-4}} = 142,74 \cdot 10^6 \text{ N/m}^2 = 142,74 \text{ MPa} < 160 \text{ MPa}.$$

$$\text{Ustun } \delta_\sigma = \frac{|142,74 - 160|}{160} \cdot 100\% = -10,78\% \text{ ga yuklanmagan.}$$

Bu farq 5% dan sezilarli darajada katta bo'lganligi uchun hisoblashni yana davom ettiramiz:

$$\varphi_3 = \frac{0,6013 + 0,6287}{2} = 0,615.$$

Bu koeffitsient bo'yicha ustunning kesim yuzasini hisoblaymiz:

$$A_3 = \frac{F}{\varphi_3 \sigma_{adm}} = \frac{210 \cdot 10^3}{0,615 \cdot 160 \cdot 10^6} = 21,34 \cdot 10^{-4} \text{ m}^2.$$

Sortament jadvalidan yana 18- nomerli qo'shtavrni olishga to'g'ri keladi. Boshqacha aytganda, ustun 10,78 % ga yuklanmagan bo'lishiga qaramasdan, hisoblashni to'xtatishga majburmiz.

Nihoyat, ustunning kesimi uchun profil nomeri 18 bo'lgan qo'shtavrni tanlaymiz.

### 12.3- §. Bo'ylama egilish (siqilgan sterjenlarning ustuvorligi) bo'yicha topshiriq

#### 20- topshiriq

Siqilgan sterjenlarni ustuvorlikka hisoblash.

Berilgan:

$l$  uzunligiga teng bo'lgan po'lat sterjen  $F$  kuch ta'sirida simmetrik o'qi bo'ylab siqilyapti.

Ruxsat etilgan normal kuchlanish  $\sigma_{adm} = 210$  MPa ga teng.

Topish kerak:

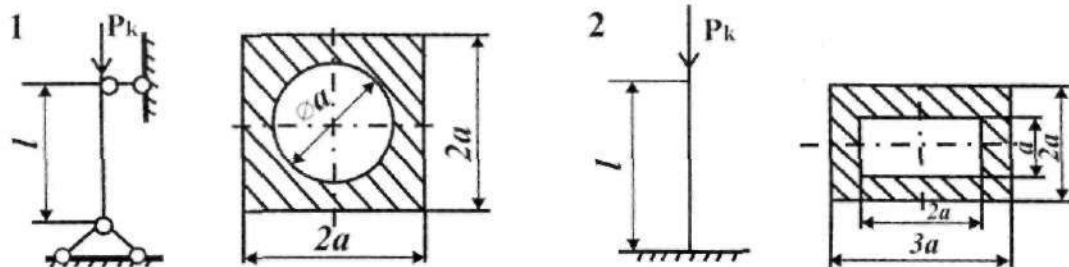
1) ustuvorlik shartiga binoan, sterjenning ko'ndalang kesim yuzasi tanlansin;

2) berilgan sterjen uchun kritik kuch miqdori aniqlansin.

Kerakli ma'lumotlar XII.1- jadvalda, hisoblash sxemalari esa XII.8- shaklda keltirilgan.

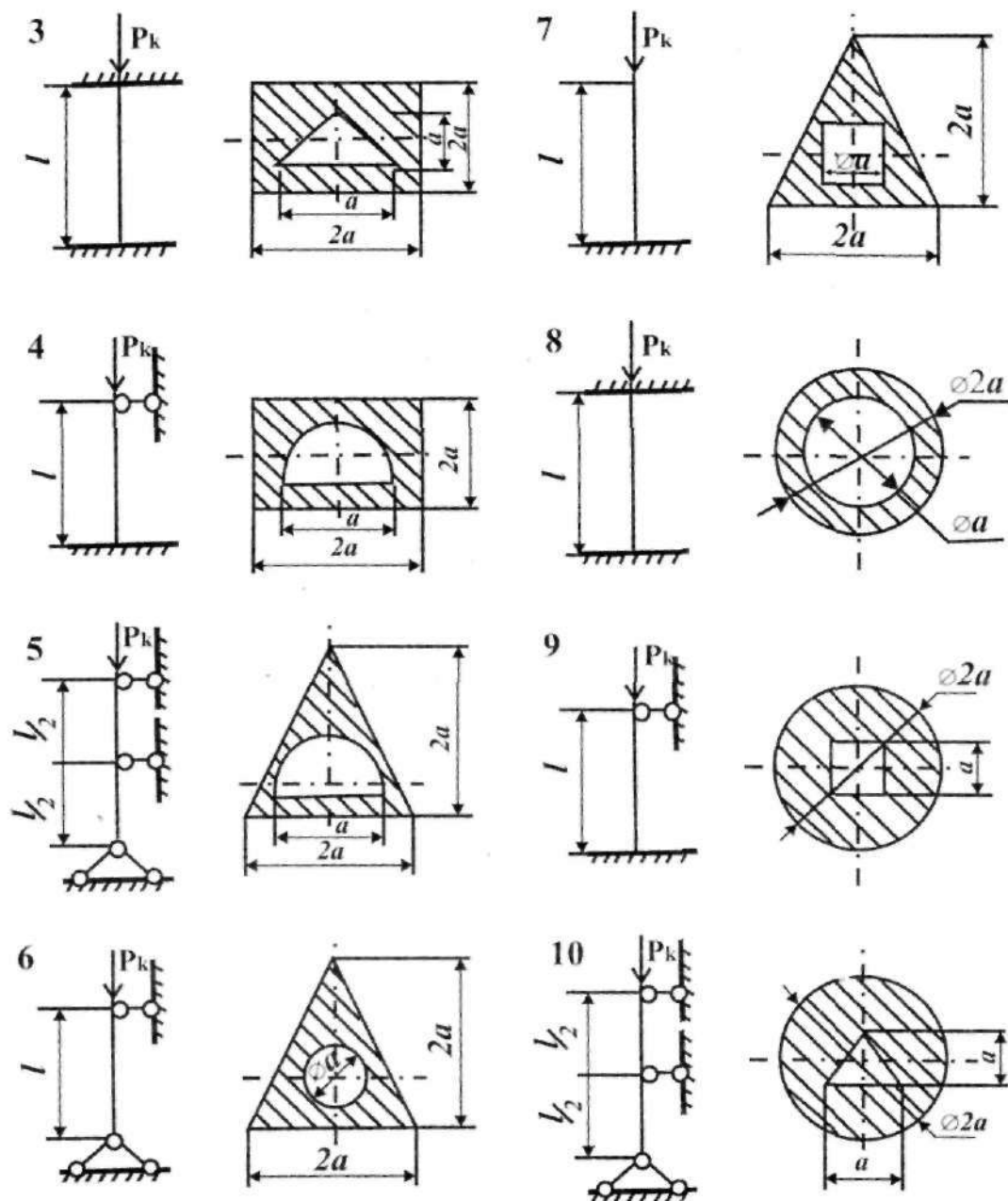
XII.1- jadval

| $N_2$ | $P$ , kN | $l$ , m |
|-------|----------|---------|
| 1     | 160      | 3,5     |
| 2     | 210      | 3,0     |
| 3     | 176      | 3,4     |
| 4     | 124      | 3,6     |
| 5     | 110      | 4,0     |
| 6     | 210      | 3,2     |
| 7     | 172      | 2,8     |
| 8     | 140      | 3,6     |
| 9     | 100      | 4,0     |
| 10    | 200      | 3,5     |

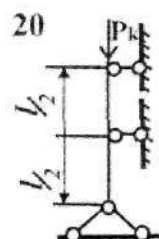
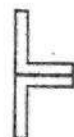
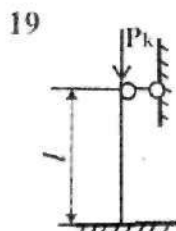
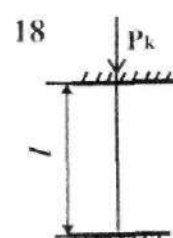
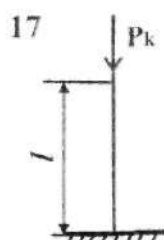
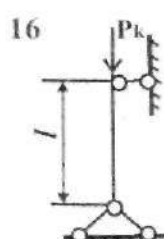
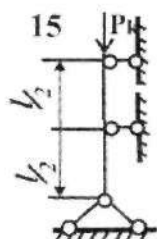
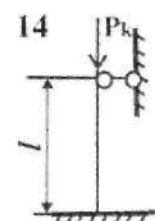
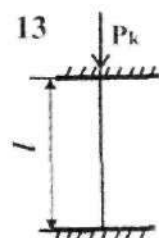
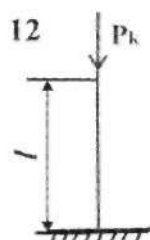
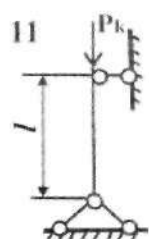


XII.8- shakl

## XII.8- shakl (davomi)



XII.8- shakl (davomi)





## XIII BOB

## ZARBA

## 13.1- §. Asosiy mulohazalar

Ma'lumki statik yuklar inshoot va mashina qismlariga sekin-asta qo'yiladi, natijada ularda hosil bo'ladigan harakat tezlanishi juda kichik bo'lib, loyihalash paytida ular e'tiborga olinmaydi. Agarda kuchlar ta'sirida konstruksiya elementlari katta tezlanishga ega bo'lsa, unda inersiya kuchlari hosil bo'ladi va bunday yuklanishga zarbiy (dinamik) yuklanish deyiladi.

- Juda ham qisqa vaqt ichida qo'yilgan va tezligi bir lahzada nolga tenglashuvchi yuk zarbali yuk deyiladi.

Odatda, zarbali yuklarning ta'siri amalda dinamik koeffitsient yordamida baholanadi:

$$k_d = \frac{\lambda_d}{\lambda_{st}}; \quad (\text{XIII.1})$$

bu yerda,  $\lambda_{st}$  – yuk statik ravishda qo'yilganda hosil bo'ladigan ko'chish;

$\lambda_d$  – dinamik (zarbali) yuk ta'siridan paydo bo'lgan ko'chish.

Xuddi shu tarzda, zarbali kuchlardan hosil bo'ladigan deformatsiya (kuchlanish)larni tegishli statik deformatsiya (kuchlanish)lar orqali ifodalash mumkin:

$$\Delta l_d = k_d \Delta l_{st}; \quad (\text{XIII.2})$$

$$\sigma_d = k_d \sigma_{st}. \quad (\text{XIII.3})$$

Yuqoridagi formulalardan ko'rinib turibdiki, zarba hodisasini o'rganishda  $k_d$  ni aniqlash muhim ahamiyatga ega ekan.

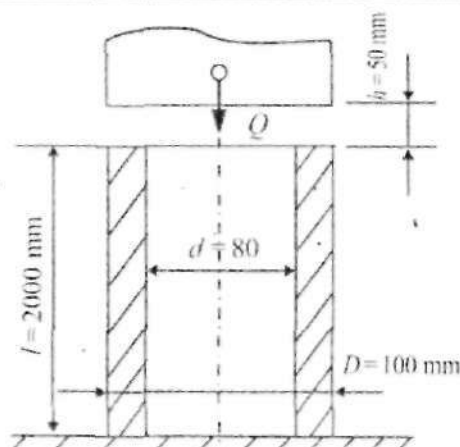
## 13.2- §. Zarbiy yuklanishga doir masalalar

## 105- masala

Pastki uchi bilan yerga biki qilib mahkamlangan  $l = 2,0$  m uzunlikdagi halqasimon kesimli po'lat sterjenga  $h = 5$  sm balandlikdan og'irligi  $Q = 1000$  kg bo'lgan yuk zarb bilan tushmoqda (XIII.1- shakl).

Quyidagi hollar uchun sterjen ko'ndalang kesimida hosil bo'luvchi eng katta siquvchi normal kuchlanish aniqlansin:

- sterjenning xususiy og'irligi hisobga olinmaganda;
- sterjenning xususiy og'irligi ( $\gamma = 7,85 \cdot 10^4 \text{ N/m}^3$ ) hisobga olinganda.



XIII.1- shakl

**Yechish:**

Statik ko'chishni aniqlaymiz:

$$\Delta l_{st} = \frac{Ql}{EA} = \frac{1000 \cdot 200}{2 \cdot 10^6 \cdot \frac{3,14}{4} (10^2 - 8^2)} = 3,54 \cdot 10^{-3} \text{ sm.}$$

Bu yerda,  $h > \Delta l_{st}$  bo'lgani uchun:

$$k_d = \sqrt{\frac{2h}{\Delta l_{st}}} = \sqrt{\frac{2 \cdot 5}{3,54 \cdot 10^{-3}}} = 53.$$

$$\text{U holda, } \sigma_d = k_d \cdot \sigma_{st} = k_d \cdot \frac{Q}{A} = 53 \cdot \frac{1000}{28,2} = 1880 \text{ kg/sm}^2.$$

Sterjenning xususiy og'irligini hisobga olgandagi dinamik koeffitsientni hisoblaymiz:

$$k_d = \sqrt{\frac{2h}{\Delta l_{st} (1 + \alpha \frac{G}{Q})}} = \sqrt{\frac{2 \cdot 5}{3,54 \cdot 10^{-3} (1 + \frac{1}{3} \frac{44}{1000})}} = 52,6.$$

$$\text{bu yerda, } G = \gamma \cdot A \cdot l = 7,85 \cdot 10^{-3} \cdot 28,2 \cdot 200 = 44 \text{ kg.}$$

$$\text{U holda, } \sigma_d = 52,6 \cdot \frac{1000}{28,2} \approx 1865 \text{ kg/sm}^2.$$

Hisoblash natijalarini taqqoslab, zarblanuvchi jism xususiy og'irligining dinamik koeffitsientga ta'siri sezilarsiz ekanligini ko'rish mumkin.

## 106- masala

Uzunligi  $l=2$  m bo'lgan po'lat sterjenning pastki uchiga «deformatsiyalanmaydigan» disk o'rnatilgan (XIII.2- shakl).  $Q=8$  kg yuk qancha balandlikdan unga zarb bilan tushganda, sterjenning ko'ndalang kesimida qiymati  $\sigma=1000$  kg/sm<sup>2</sup> dinamik kuchlanish paydo bo'ladi?

Ishqalanish kuchi, sterjen va disklarning massalari e'tiborga olinmasin. Masala sterjen massasi e'tiborga olingan va olinmagan hollar uchun yechilsin.

**Berilgan:**  $\gamma=8$  g/sm<sup>3</sup>;  $A=4$  sm<sup>2</sup>;  $E=2 \cdot 10^6$  kg/sm<sup>2</sup>.

**Yechish:**

$Q$  kuchning statik ta'siridan hosil bo'ladigan kuchlanishni aniqlaymiz:

$$\sigma_{st} = \frac{Q}{A} = \frac{8}{4} = 2 \text{ kg/sm}^2,$$

Unda dinamik koeffitsient quyidagiga teng bo'ladi:

$$k_d = \frac{\sigma_d}{\sigma_{st}} = \frac{1000}{2} = 500.$$

Agarda  $Q$  yukning boshlang'ich tezligini  $v_0 = \sqrt{2gh}$ , sterjenning cho'zilishdagi bikrligini  $c = \frac{EA}{l}$ , sterjen og'irligini  $Q_0 = \gamma \cdot A \cdot l$  va  $k_m = \frac{1}{3}$  deb olsak, unda dinamik koeffitsient quyidagiga teng bo'ladi:

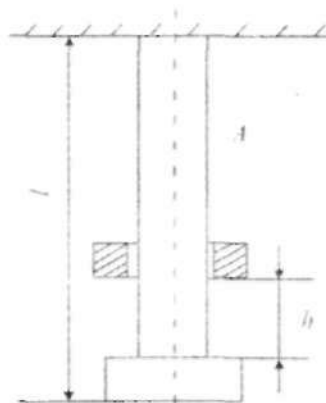
$$k_d = 1 + \sqrt{1 + \frac{2h \cdot EA}{Q \cdot l} \cdot \frac{1}{1 + \frac{1}{3} \cdot \frac{Q_0}{Q}}} = 1 + \sqrt{1 + \frac{2h \cdot 2 \cdot 10^6 \cdot 4}{8 \cdot 2 \cdot 10^2} \cdot \frac{1}{1 + \frac{1}{3} \cdot \frac{64}{8}}} = 1 + \sqrt{1 + \frac{3 \cdot 10^4}{3,8} \cdot h}.$$

$$\text{Unda, } 500 = 1 + \sqrt{1 + \frac{3 \cdot 10^4}{3,8} h}; \text{ bu yerdan, } h = \frac{(499^2 - 1) \cdot 3,8}{3 \cdot 10^4} \approx 31,5 \text{ sm.}$$

Sterjen massasini e'tiborga olmaganda:

$$k_d = 500 = \sqrt{\frac{v_0^2 \cdot c}{Q \cdot g}} = \sqrt{\frac{2h \cdot EF}{Q \cdot l}} = \sqrt{\frac{2h \cdot 2 \cdot 10^6 \cdot 4}{8 \cdot 2 \cdot 10^2}} = 10^2 \sqrt{h};$$

bu yerdan,  $h=25$  sm.



XIII.2- shakl

Demak, sterjen xususiy og'irligi e'tiborga olinmaganda; yukning xavfsiz tushish balandligi kamaytirilgan holda bo'lar ekan, ya'ni  $\frac{31,5-25}{31,5} \cdot 100 = 21\%$ .

### 107- masala

$Q = 500 \text{ kg} = 5 \text{ kN}$  og'irlikdagi yuk  $v = 1.5 \text{ m/s}$  sek gorizontal tezlik bilan harakatlanib, o'z yo'lida uzunligi  $l = 3 \text{ m}$ , ko'ndalang kesimining yuzasi  $d = 15 \text{ sm}$  bo'lgan va pastki uchi bilan yerga biki mahkamlab qo'yilgan po'lat ustunning yuqori uchiga to'qnashadi (XIII.3- shakl). Ustunning xususiy og'irligi e'tiborga olinmagan holda unda hosil bo'luvchi eng katta kuchlanish aniqlansin.

#### Yechish:

Zarba ta'sirida ustun egiladi. Boshqacha aytganda, yuk sterjenga urilishi bilanoq, uning to'la energiyasi sterjenning egilishdagi potensial energiyasiga aylanadi:

$$T = U_g \text{ yoki } \frac{Qv^2}{2g} = \int_0^l \frac{M_g^2 dz}{2EI_x};$$

bu yerda,  $T = \frac{Qv^2}{2g}$  – harakatdagi jismning kinetik energiyasi.

Kesish usuliga asosan:  $M_g = P_g z$ .

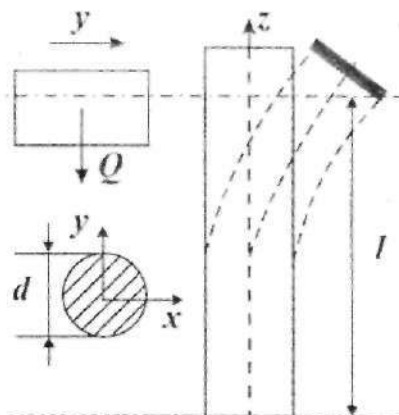
$$U \text{ holda, } U_g = \int_0^l \frac{P_g^2 z^2 dz}{2EI_x} = \frac{P_g^2 l^3}{6EI_x}.$$

Energiyalarni solishtirib, sterjenga ta'sir etuvchi dinamik kuchni, keyin esa dinamik kuchlanishni hisoblaymiz:

$$P_g = \frac{v}{l} \sqrt{\frac{3QE I_x}{ql}} = \frac{vd^2}{8l} \sqrt{\frac{3\pi QE}{ql}} = 7892,5 \text{ kg} = 78925 \text{ N};$$

$$\sigma_g = \frac{P_g l}{W_x} = \frac{32 P_g l}{\pi d^3} = \frac{32 vd^2 l}{\pi d^3 8l} \sqrt{\frac{3\pi QE}{ql}} = \frac{4v}{\pi d} \sqrt{\frac{3\pi QE}{ql}} = 714 \cdot 10^5 \frac{\text{kg}}{\text{m}^2};$$

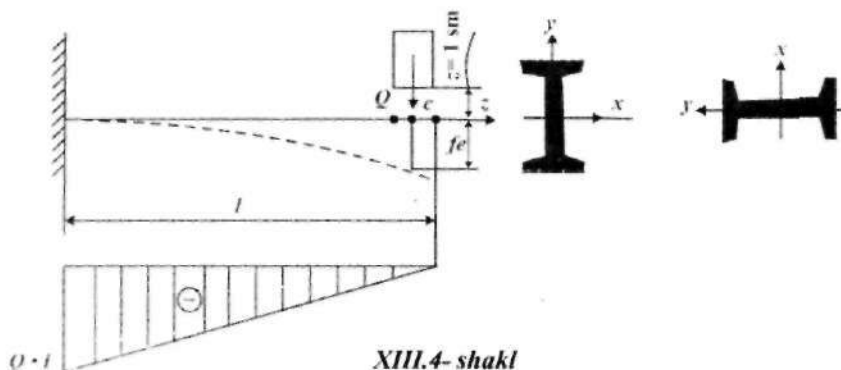
$$\text{bu yerda, } I_x = \frac{\pi d^4}{64}; W_x = \frac{\pi d^3}{32}.$$



XIII.3- shakl

## 108- masala

Qo'shtavr kesimli (№ 20, GOST 8239-72),  $l = 1,0$  m uzunlikdagi konsol  $Q = 75$  kg og'irlikdagi yukka ikki xil ko'rinishda, ya'ni bikrligi eng katta va eng kichik tekisliklar bo'yicha qarshilik ko'rsata oladigan qilib mahkamlangan (XIII.4- shakl). Ikkala holat uchun ham eng katta statik va dinamik kuchlanish (solqilik)larni topib, natijalarni taqqoslang. Konsolning o'z og'irligi hisobga olinmasin.



XIII.4- shakl

## Yechish:

1- hol. Dastlab, konsolning eng katta tekislikda egilishini ko'rib chiqamiz.

Sortament jadvalidan quyidagi ma'lumotlarni olamiz:  $I_x = 1810 \text{ sm}^4$ ;  $I_y = 112 \text{ sm}^4$ ;  $W_x = 181 \text{ sm}^3$ ;  $W_y = 22,4 \text{ sm}^3$ .

Kuch statik ravishda qo'yilganda, kesimdagi eng katta normal kuchlanish quyidagicha topiladi:

$$\sigma_{st} = \frac{M_{\max}}{W_x} = \frac{75 \cdot 100}{181} = 41,5 \text{ kg/sm}^2.$$

Dinamik koefitsient:

$$k_d = 1 + \sqrt{1 + \frac{2h}{\Delta l_{st}}}; \text{ bu yerda, } \Delta l_{st} = \frac{Q \cdot l^3}{3EI_x} = f_{st} \text{ ga teng bo'ladi.}$$

Balka  $Q$  yuk ta'sirida statik yuklanganda:

$$\Delta l_{st} = \frac{75 \cdot 100^3}{3 \cdot 2 \cdot 10^5 \cdot 1810} = 6,91 \cdot 10^{-3} \text{ sm};$$

$$k_d = 1 + \sqrt{1 + \frac{2 \cdot 1,0}{6,91 \cdot 10^{-3}}} = 18,1.$$

Dinamik solqilik va eng katta dinamik kuchlanish quyidagiga teng bo'ladi:

$$\Delta l_d = f_d = k_d \cdot f_{st} = 18,1 \cdot 6,91 \cdot 10^{-3} = 0,125 \text{ sm};$$

$$\sigma_d = k_d \cdot \sigma_{st} = 18,1 \cdot 41,5 = 750 \text{ kg/sm}^2.$$

**2- hol.** Xuddi shu tartibda hisoblashni davom ettirib, konsolning bikrligi eng kichik tekislikda egilishini tekshiramiz:

$$\sigma_{st} = \frac{Ql}{W_y} = \frac{75 \cdot 100}{22,4} = 335 \text{ kg/sm}^2;$$

$$\Delta l_{st} = f_{st} = \frac{Ql^3}{3EI_y} = \frac{75 \cdot 100^3}{3 \cdot 2 \cdot 10^6 \cdot 112} = 112 \cdot 10^{-3} \text{ sm};$$

$$k_d = 1 + \sqrt{1 + \frac{2 \cdot 10}{112 \cdot 10^{-3}}} = 5,35;$$

$$\Delta l_d = f_d = k_d \cdot f_{st} = 5,35 \cdot 112 \cdot 10^{-3} = 0,6;$$

$$\sigma_d = f_d \cdot \sigma_{st} = 5,35 \cdot 335 = 1790 \text{ kg/sm}^2.$$

Demak, ikkinchi holatdagi kuchlanish yukning statik ta'sirida birinchi holatdagidan 8,08 marta, zarbiy ta'sirida esa 2,39 marta ko'p. Buning sababi – ikkinchi holatda balka bikrligi birinchi holatga nisbatan ancha kam. Bu dinamik koeffitsientning kamayishiga olib keladi.

### 109- masala

Qo'shtavr kesimli (№ 20) ikki tayanchdagi konsol balkaning (XIII.5- shakl, a) C kesimiga  $H=6$  sm balandlikdan  $F=1,2$  kN og'irlikdagi yuk ta'sir etadi.

Quyidagilar berilgan:  $l=2$  m;  $a=1$  m;  $\sigma_{adm}=210$  MPa;  $E=2 \cdot 10^5$  MPa.

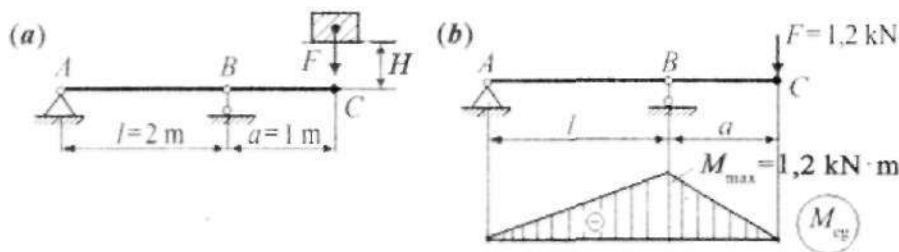
Quyidagilar aniqlansin:

1. Balkaning mustahkamligi;
2. Dinamik kuch ta'siridagi C kesimning solqiligi.

### Yechish:

Sortament jadvalidan 20- nomerli qo'shtavr uchun quyidagilarni olamiz:  $J_x = 1840 \text{ sm}^4$ ;  $W_x = 184 \text{ sm}^3$ . Konsol balkaning C kesimiga ta'sir qiladigan  $F$  kuchning statik holda ta'sir etishidagi solqilikni Mor yoki Vereshagin usulida aniqlaymiz. Uning qiymati quyidagiga teng bo'ladi (bu qiymatni topish talabaga havola):

$$\Delta_{st} = \frac{F \cdot a^2}{3 E J_x} (l+a) = \frac{1,2 \cdot 10^3 \cdot 1}{3 \cdot 2 \cdot 10^{11} \cdot 1840 \cdot 10^{-8}} (2+1) = 3,26 \cdot 10^{-4} \text{ m} = 0,0326 \text{ sm}.$$



XIII.5- shakl

Dinamik koeffitsientni aniqlaymiz:

$$k_D = 1 + \sqrt{1 + \frac{2H}{\Delta_{st}}} = 1 + \sqrt{1 + \frac{2 \cdot 6 \cdot 10^{-2}}{0,0326 \cdot 10^{-2}}} = 20,21.$$

Statik kuch ta'sirida konsol balking B tayanchida hosil bo'ladigan kuchlanishni aniqlaymiz (XIII.5- shakl, b):

$$\sigma_{st} = \frac{M_{max}}{W_x} = \frac{1,2 \cdot 10^{-3}}{184 \cdot 10^{-6}} = 6,52 \cdot 10^6 \text{ Pa} = 6,52 \text{ MPa}.$$

Konsol balking B tayanchida hosil bo'ladigan dinamik kuchlanishni aniqlaymiz:

$$\sigma_D = \sigma_{st} \cdot k_D = 6,52 \cdot 20,21 = 131,8 \text{ MPa} < [\sigma] = 210 \text{ MPa}.$$

Demak, konsol balking mustahkamligi ta'minlangan.

Dinamik kuch ta'sirida konsol balking C kesimidagi solqilikni aniqlaymiz:

$$\Delta_D = \Delta_{st} \cdot k_D = 0,0326 \cdot 20,21 = 0,659 \text{ sm}.$$

Demak, dinamik kuch ta'sirida konsol balking C kesimidagi solqiligi 20,21 marta katta bo'lar ekan.

### 13.3- §. Zarbiy yuklanish bo'yicha topshiriqlar

#### 21- topshiriq

**Zarba nazariyasi.**

**Berilgan:** elastik sistemaga  $F$  yuk  $H$  balandlikdan tushib uriladi. Sterjen po'latdan yasalgan. Statik yuklanish uchun ruxsat etilgan normal kuchlanish  $[\sigma] = 210 \text{ MPa}$ .

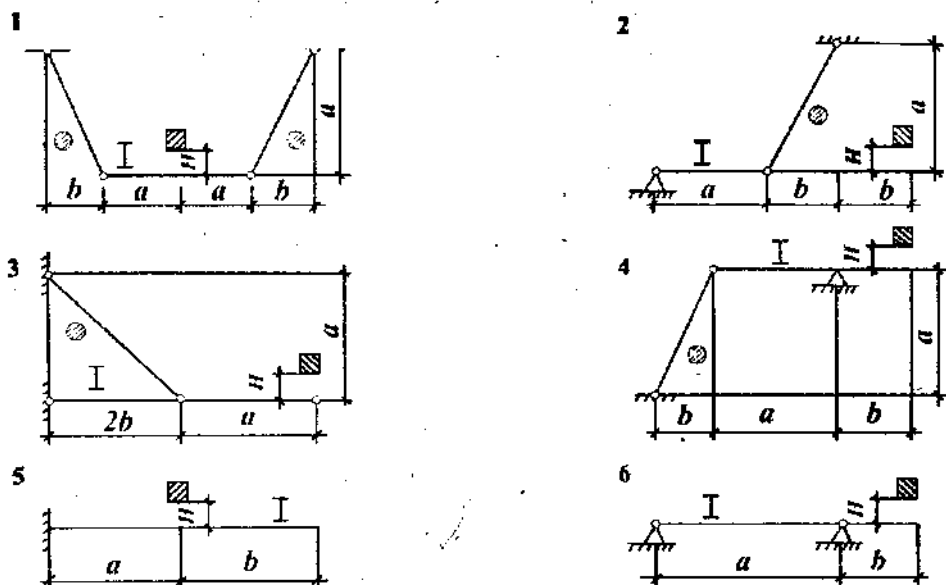
**Topish kerak:**

- 1) sistemaning ko'ndalang kesimlaridagi eng katta normal kuchlanishlar aniqlansin;
- 2) yuk ta'sir etayotgan nuqtaning dinamik ko'chishi topilsin.

Kerakli ma'lumotlar XIII.1- jadvalda, hisoblash sxemalari esa XIII.6- shaklda keltirilgan.

XIII.1- jadval

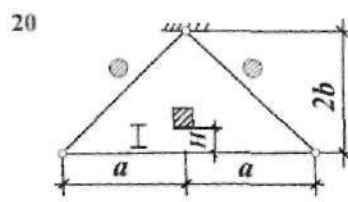
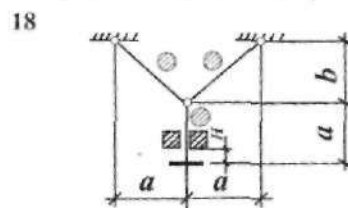
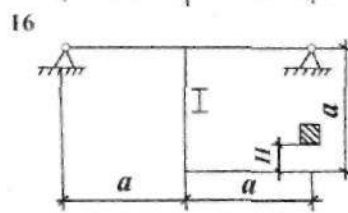
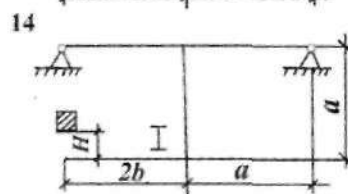
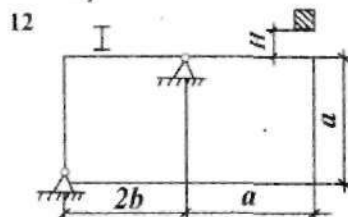
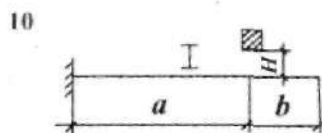
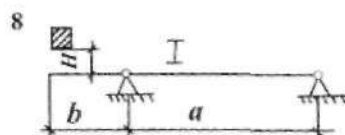
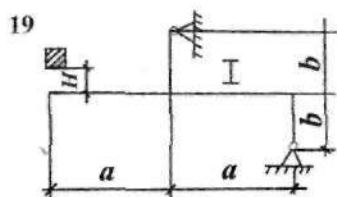
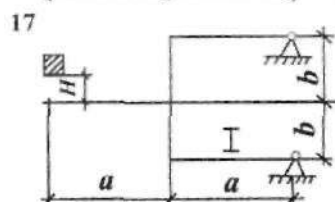
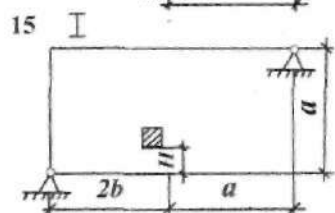
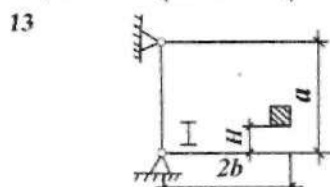
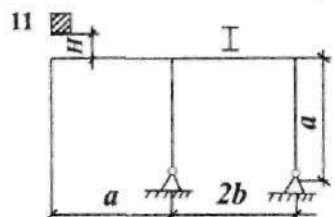
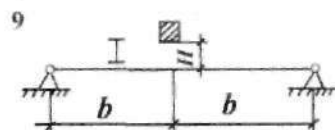
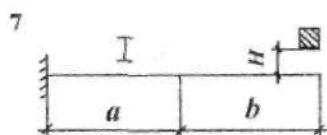
| No | $F, N$ | $H, sm$ | $a, m$ | $F, m$ | Qo'shtavr<br>nomeri | $d, sm$ |
|----|--------|---------|--------|--------|---------------------|---------|
| 1  | 500    | 6       | 4,0    | 1,2    | 27                  | 1,4     |
| 2  | 450    | 4       | 3,8    | 1,0    | 24a                 | 1,6     |
| 3  | 600    | 7       | 3,4    | 1,4    | 24                  | 1,8     |
| 4  | 650    | 6,2     | 3,2    | 1,6    | 22a                 | 2,0     |
| 5  | 700    | 5       | 3,4    | 1,8    | 22                  | 2,2     |
| 6  | 740    | 6       | 2,6    | 1,2    | 20a                 | 2,4     |
| 7  | 600    | 4       | 3,4    | 3,0    | 20                  | 2,6     |
| 8  | 400    | 4,6     | 3,2    | 2,6    | 18a                 | 2,8     |
| 9  | 460    | 4,2     | 3,0    | 2,2    | 18                  | 3,0     |
| 10 | 700    | 5,2     | 2,6    | 2,4    | 16                  | 3,2     |



XIII.6- shakl



## XIII.6- shakl (davomi)



## XIV BOB

### OLIMPIADA MASALALARI

#### 14.1-§. Cho'zilish va siqilishga doir masalalar

##### 110- masala

Mutlaq bikr  $AB$  balka orqali to'rtta ustunga  $P$  kuch uzatiladi (XIV.1- shakl). Ustunlar-ning loyihaviy uzunligi  $l$  ga teng, ko'ndalang kesimlari, materiali bir xil. Ikkinchi ustunning uzunligi loyihadagidan  $\Delta_2$  ga, to'rtinchi ustunning uzunligi  $\Delta_4$  ga kalta, uchinchi ustunning uzunligi  $\Delta_3$  ga uzun.  $P$  kuch ta'sir etganda,  $AB$  balka gorizontol holatda qolishi uchun  $\Delta_3$  nimaga teng bo'lishi kerak?

**Berilgan:**  $\Delta_2 = 0,2$  mm;  $\Delta_4 = 0,1$  mm;  $l = 50$  sm;  $E = 0,1 \cdot 10^6$  kg/sm<sup>2</sup>;  $F = 12 \times 12$  sm<sup>2</sup>;  $a = 0,5$  m;  $P = 40$  t.

##### Yechish:

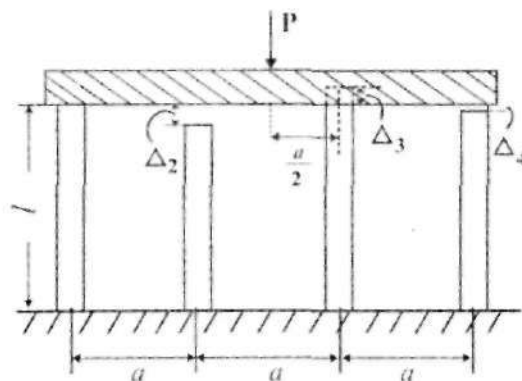
Statika tenglamalarini tuzamiz (XIV.2- shakl):

$$\sum y = 0; N_1 + N_2 + N_3 + N_4 - P = 0; \quad (1)$$

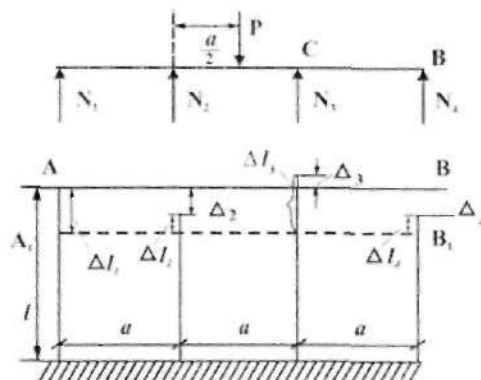
$$\sum mom_c = 0; 2N_1 + N_2 - N_4 = \frac{P}{2}. \quad (2)$$

Deformatsiya tenglamalarini tuzamiz:

$$\Delta l_2 = \Delta l_1 - \Delta_2 \Rightarrow N_2 = N_1 - \Delta_2 \frac{EF}{l}; \quad (3)$$



XIV.1- shakl



XIV.2- shakl

$$\Delta l_4 = \Delta l_1 - \Delta_4 \Rightarrow N_4 = N_1 - \Delta_4 \frac{EF}{l}. \quad (4)$$

$\frac{EF}{l} = B$  belgilash kiritamiz va (3), (4) ni (2) ga qo'yamiz:

$$N_1 = (\Delta_2 - \Delta_4) \frac{B}{2} + \frac{P}{4}. \quad (5)$$

(5) ni (3), (4) ga qo'yamiz:

$$\left. \begin{aligned} N_2 &= -(\Delta_2 + \Delta_4) \frac{B}{2} + \frac{P}{4} \\ N_4 &= (\Delta_2 - 3\Delta_4) \frac{B}{2} + \frac{P}{4} \end{aligned} \right\} \quad (6)$$

$$N_3 = (5\Delta_4 - \Delta_2) \frac{B}{2} + \frac{P}{4}.$$

(5), (6) ni (1) ga qo'yib, quyidagilarni aniqlaymiz:

$$\Delta_3 = \Delta l_3 - \Delta l_1.$$

Shunga ko'ra:

$$B = \frac{EF}{l} = \frac{0,1 \cdot 10^6 \cdot 144}{50} = 28,8 \cdot 10^4 \text{ kg/sm}, \quad P = 4 \cdot 10^4 \text{ kg};$$

$$N_1 = 0,01 \frac{28,8 \cdot 10^4}{2} + 10^4 = 11440 \text{ kg};$$

$$N_2 = -0,03 \frac{28,8 \cdot 10^4}{2} + 10^4 = 5680 \text{ kg};$$

$$N_3 = 0,03 \frac{28,8 \cdot 10^4}{2} + 10^4 = 14320 \text{ kg};$$

$$N_4 = -0,01 \frac{28,8 \cdot 10^4}{2} + 10^4 = 8560 \text{ kg};$$

$$\Delta l_1 = \frac{N_1 l}{EF} = \frac{11440 \cdot 50}{0,1 \cdot 10^6 \cdot 144} = 0,039;$$

$$\Delta l_3 = \frac{N_3 l}{EF} = \frac{14320 \cdot 50}{0,1 \cdot 10^6 \cdot 144} = 0,049;$$

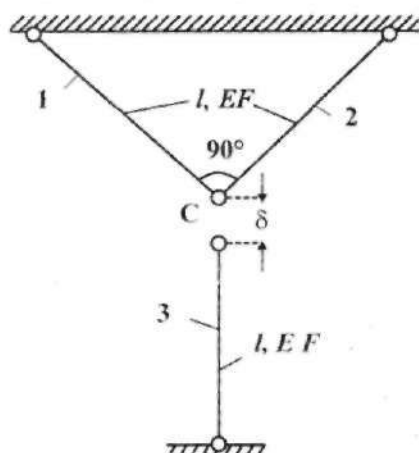
$$\Delta l_3 = 0,049 - 0,039 = 0,01 \text{ sm}; \quad \Delta = 0,1 \text{ mm}.$$

## 111- masala

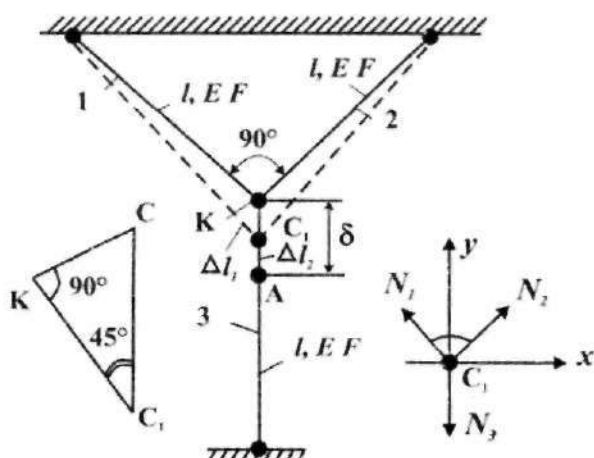
1-, 2-, 3- sterjenlardan uchinchisi  $\delta$  miqdor ( $\delta$  – kichik miqdor)ga qisqa tayyorlangan (XIV.3- shakl). Ularning uchlarini  $C$  sharnirda tutashtirish uchun 3- sterjen  $\Delta r^0$  ga qizdirildi.

**Topish kerak:**

- 1) 3- sterjen qanchaga ( $\Delta r^0$ –?) qizdirilgan?
- 2) Bu sterjenning harorati avvalgi holiga qaytganda ( $\Delta r^0 = 0$  bo'lganda), barcha sterjenlardagi zo'riqish kuchlari nimaga teng bo'ladi?



XIV.3- shakl



XIV.4- shakl

**Yechish:**

3- sterjen qizdirilganda,  $\Delta l_1^{(3)} = \alpha \cdot l \cdot \Delta t_c^0 = \delta$

$$\text{Bundan, } \Delta t_c^0 = \frac{\delta}{\alpha l}.$$

3- sterjen harorati avvalgi holiga qaytganda ( $\Delta t_c^0 = 0$ ),  $C$  tugun  $C_1$  ga ko'chadi (XIV.4- shakl).

Unda,  $C_1$  tugunning muvozanat sharti quyidagiga teng:

$$\sum X = 0; N_1 = N_2;$$

$$\sum Y = 0, N_3 = \sqrt{2} \cdot N_1. \quad (1)$$

Demak, masala statik noaniq. U holda deformatsiya tenglamasi quyidagiga teng bo'ladi:

$$CC_1 = AC - C_1A \text{ yoki } \sqrt{2} \cdot \Delta l_1 = \delta - \Delta l_3;$$

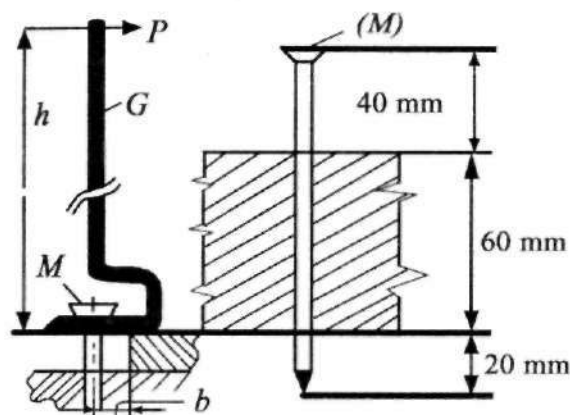
$$\text{bu yerda, } CC_1 = \frac{\Delta l_1}{\cos 45^\circ} = \sqrt{2} \Delta l_1.$$

$$\sqrt{2} \cdot \frac{N_1 l}{EF} = \delta - \frac{N_3 l}{EF}, \text{ bu tenglamaga (1) ni olib kelib qo'yamiz:}$$

$$\frac{\sqrt{2} N_1 l}{EF} = \delta - \frac{\sqrt{2} N_1 l}{EF}; \text{ bu yerdan, } N_1 = \frac{EF\delta}{2\sqrt{2}l}; N_3 = \frac{EF\delta}{2l}.$$

### 112- masala

Qalinligi 60 mm yog'ochdan (*G*) mix sug'urgich yordamida (*M*) mix sug'uriladi (XIV.5- shakl). Mixda hosil bo'lgan *N* bo'ylama kuchning ruxsat etilgan qiymati, mix sug'urgich dastasiga qo'yiladigan *P* kuch aniqlansin. Mix uchun:  $[\sigma] = 1800 \text{ kg/sm}^2$ ;  $l = 120 \text{ mm}$ ;  $d = 5 \text{ mm}$ ;  $h = 35 \text{ sm}$ ;  $b = 2,8 \text{ sm}$ .



XIV.5- shakl

### Yechish:

Mixning o'qi bo'ylab qo'yiladigan kuch quyidagiga teng (XIV.6- shakl):

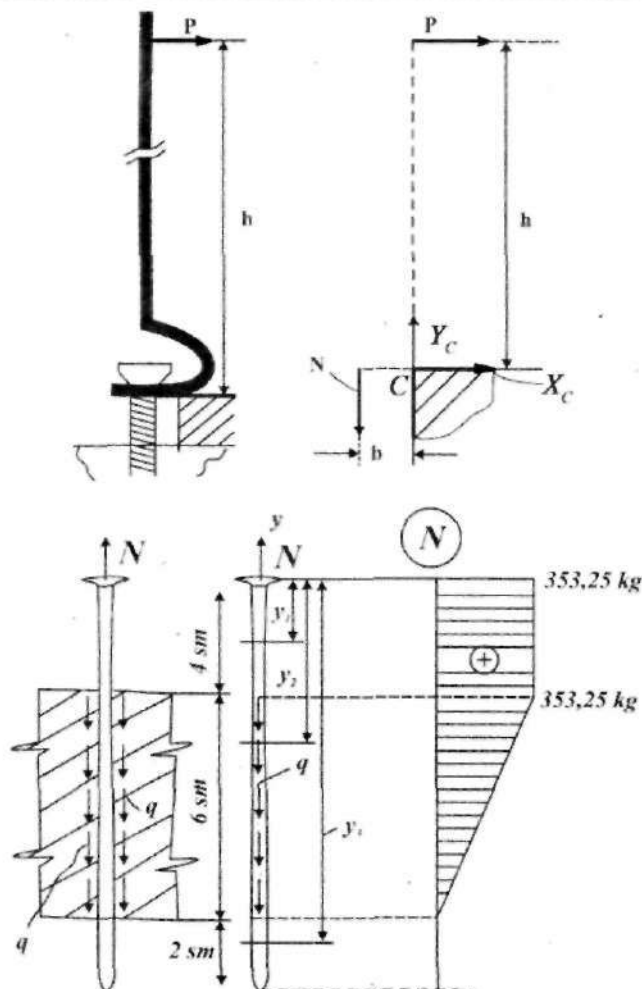
$$N \leq [\sigma] \cdot F = 1800 \text{ kg/cm}^2 \cdot \frac{3,14 \cdot (0,5)^2}{4} \text{ cm}^2 = 353,25 \text{ kg}.$$

Mix sug'uradigan moslamaning dastasiga qo'yiladigan kuchni aniqlaymiz:

$$\sum \text{mom}_c = P \cdot h - N \cdot b = 0; \quad P = \frac{N \cdot b}{h} = \frac{353,25 \cdot 2,5}{35} = 25,2.$$

Mixni sug'urish vaqtida mixning yog'och ichidagi qismida urinma kuchlar hosil bo'ladi. Bu kuchlar mixni yog'och bilan ishqalanishidan hosil bo'ladi, ularni yog'och qalinligi bo'ylab tekis taqsimlangan deb qabul qilamiz ( $q = \text{const}$ ).

$$\text{U holda, } \sum Y = N - q \cdot 6 = 0; \quad q = \frac{N}{6} = 58,87 \text{ kg/sm}.$$



XIV.6-shakl

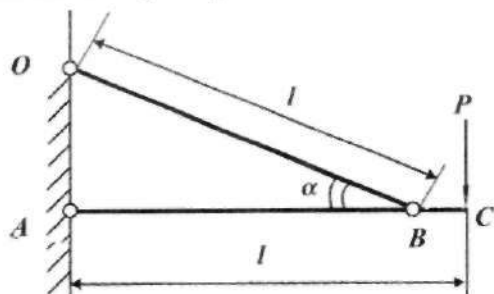
Bo'ylama kuch epyurasini quramiz:

- I.  $0 \leq Y_1 \leq 4$ ;  $\sum Y = N - N_1 = 0$ ;  $N_1 = N = 353,25 \text{ kg}$ .
- II.  $0 \leq Y_2 \leq 10$  da,  $N_2 = N - q(Y_2 - 4)$ ;  $Y_2 = 4$  da,  $N_2 = 353,25$ ;  $Y_2 = 10$  da,  $N_2 = 0$ .
- III.  $0 \leq Y_3 \leq 12$ ;  $N_3 = 0$ .

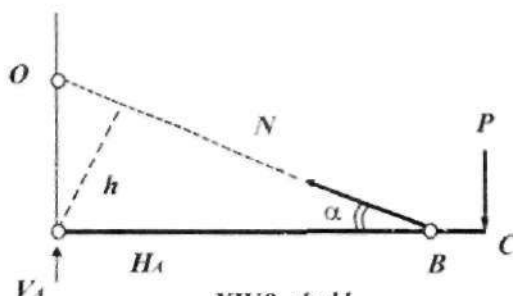
### 113- masala

OB tortqichning uzunligini o'zgartirmagan holda uning shunday holatini ( $\alpha = ?$ ) aniqlash kerakki, natijada tortqichning massasi minimum qiymatga ega bo'lsin (XIV.7-shakl).

$l, P, \rho$  – tortqich materialining solishtirma og'irligi va  $[\sigma]$  – ruxsat etilgan kuchlanish ma'lum deb qabul qilinsin.



XIV.7-shakl



XIV.8-shakl

**Yechish:**

XIV.8- shakldan:  $OB=l$ ;  $AC=l$ ;  $h=\frac{l}{2}\sin 2\alpha$ .

U holda,  $\sum m_A=0$ ;  $p \cdot l - N \cdot h = 0$ ; bu yerdan,  $N = \frac{2P}{\sin 2\alpha}$ .

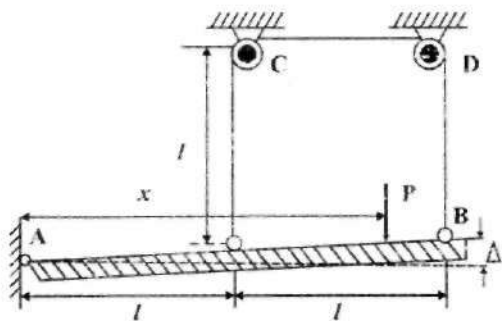
Bizga ma'lumki,  $\sigma = \frac{N}{F} \leq [\sigma]$ ; u holda,  $F \geq \frac{N}{[\sigma]} = \frac{2P}{\sin 2\alpha \cdot [\sigma]}$ .

$OB$  sterjen massasi  $m = \frac{F \cdot l \cdot \rho}{g}$  ga teng; bu yerda,  $m$   $F$  ga proporsionaldir.

Demak,  $OB$  sterjen massasi  $\sin 2\alpha = 1$  yoki  $\alpha = 45^\circ$  da minimum qiymatga ega bo'ladi.

#### 114- masala

Mutlaq qattiq  $AB$  brus  $C, D$  rolklar hamda tros vositasida og'ma holda o'rnatilgan (XIV.9(1)- shakl). Brusning og'maligi kichik son  $\Delta$  bilan berilgan.  $P$  kuchning qanday holatida ( $x=?$ ) brus gorizontol holatni qabul qiladi?  $P, l, E, F, \Delta$  – berilgan deb hisoblansin ( $P = 5 \text{ t}$ ;  $l = 2 \text{ m}$ ;  $\Delta = 1 \text{ sm}$ ;  $F = 0,5 \text{ sm}^2$ ;  $E = 2 \cdot 10^6 \text{ kg/sm}^2$ ).



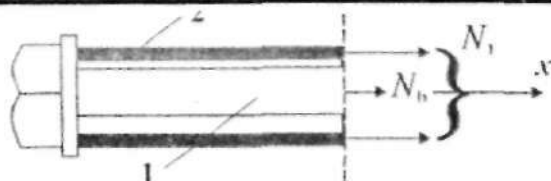
XIV.9(1)-shakl

**Yechish:**

Trosda hosil bo'ladigan taranglik kuchini  $N$  bilan belgilaymiz (XIV.9(2)- shakl).

U holda,  $\sum m_A=0$ ;  $3 \cdot N \cdot l = P \cdot x$ ;

$$N = \frac{P x}{3 l} \quad (1)$$



XIV.9(2)-shakl

$AB$  brus gorizontol holatga ( $AB_1$ ) kelishi uchun tros  $\Delta + \frac{\Delta}{2} = 1,5 \Delta$  ga uzayishi kerak.

Unda,  $\Delta l = \frac{Nl}{EF}$  formuladan:  $l = 3l$ ;  $\Delta l = 1,5\Delta$  ekanligi aniqlanadi. Shunga ko'ra:

$$N = \frac{1,5 \Delta EF}{3l} \quad (2)$$

$$(1) \text{ va } (2) \text{ dan } x = \frac{1,5 \Delta EF}{P}$$

yoki

$$x = \frac{1,5 \cdot 1 \cdot 2 \cdot 10^{-6} \cdot 0,5}{0,5 \cdot 10^{-4}} = 300 \text{ sm} = 3 \text{ m.}$$

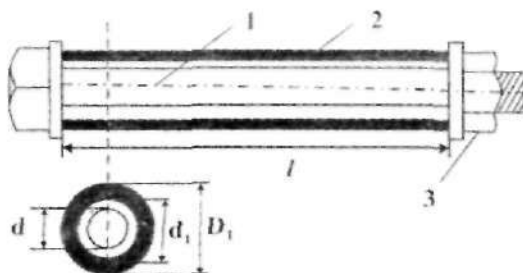
### 115- masala

Duraluminiy trubka (2) po'lat bolt (1) ga kiygizilgan va gayka (3)  $60^\circ$  ga aylantirilib, bolt tortib qo'yilgan (XIV.10(1)- shakl). Boltning vint qadami  $\Delta = 2,4 \text{ mm}$ .

Trubka va bolt kesimlarida hosil bo'ladigan zo'riqishlar aniqlansin. Trubka harorati  $30^\circ$  ga kamaytirilganda zo'riqishlar qanchaga o'zgaradi?

**Berilgan:**  $D_1 = 32 \text{ mm}$ ;  $d_1 = 26 \text{ mm}$ ;  $d_2 = 21 \text{ mm}$ ;  $l = 400 \text{ mm}$ ;  $E_1 = 2 \cdot 10^6 \text{ kg/sm}^2$ ;

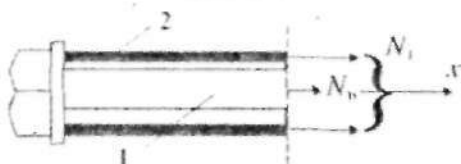
$$E_2 = 0,7 \cdot 10^6 \text{ kg/sm}^2; \alpha = 12,5 \cdot 10^{-6} \left( \frac{1}{\text{grad}} \right); \alpha_2 = 25 \cdot 10^{-6} \left( \frac{1}{\text{grad}} \right)$$



XIV.10(1)-shakl



## Yechish:



XIV.10(2)-shakl

Quyidagi belgilashlarni kiritamiz (XIV.10(2)- shakl):  $N_b = N_1$ ;  $N_T = N_2$ .

Muvozanat tenglamasini tuzamiz:

$$\sum X = 0; \quad N_1 + N_2 = 0 \quad (1); \quad N_2 = -N_1.$$

Deformatsiya tenglamasini tuzamiz:

$$\Delta l_1 + |\Delta l_2| = \lambda_0; \quad (2)$$

bu yerda,  $\lambda_0 = \frac{\Delta}{6} = 4 \text{ mm}$ .

$$\text{Unda, } \Delta l_1 = \frac{N_1 l}{E_1 F_1}; \quad \Delta l_2 = -\frac{N_2 l}{E_2 F_2} - \alpha_2 l \Delta t.$$

(1) va (2) dan

$$\frac{N_1 l}{E_1 F_1} + \frac{N_1 l}{E_2 F_2} - \alpha_2 l \Delta t = \lambda_0. \quad (3)$$

U holda,

$$N_1 = \frac{\frac{\lambda_0}{l} - \alpha_2 \Delta t}{\frac{1}{E_1 F_1} + \frac{1}{E_2 F_2}}. \quad (4)$$

Bolt va trubkaning ko'ndalang kesim yuzalarini aniqlaymiz:  $F_1 = 3,46 \text{ sm}^2$ ;  $F_2 = 2,73 \text{ sm}^2$ .  
Shunga ko'ra,

$$E_1 F_1 = 2 \cdot 10^6 \cdot 3,46 = 6,92 \cdot 10^6;$$

$$E_2 F_2 = 0,7 \cdot 10^6 \cdot 2,79 = 1,95 \cdot 10^6.$$

$\Delta t = 30^\circ$  deb topilgan qiymatlarni (4) ga qo'ysak,  $N_1 = 374 \text{ kg}$  bo'ladi.

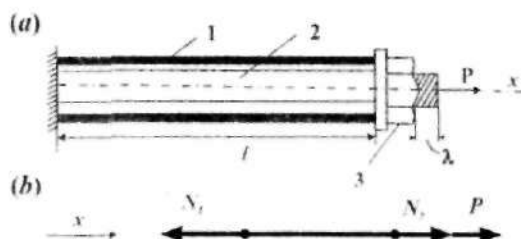
$\Delta t = 0$  da esa  $N_1 = 1496 \text{ kg}$ .

## 116- masala

Trubka (1) ni gayka bilan qisilganda boltning (2) uchi gaykadan  $\lambda_0$  ga chiqib qolgan (XIV.11- shakl). Shundan keyin bolt uchiga  $P$  kuch ta'sir etdi.

Trubka va bolt kesimlarida hosil bo'ladigan zo'riqishlar aniqlansin.  $P$  ning qanday qiymatida trubkadagi zo'riqish nolga teng bo'ladi?

$P, l, \lambda_0, E_1, F_1, E_2, F_2$  lar berilgan deb hisoblansin.



XIV.11- shakl

### Yechish

XIV.11- shakl (b)da  $N_1$  – boltidagi,  $N_2$  – trubkadagi zo'riqish.

X o'qiga nisbatan kuchlardan proyeksiya olamiz:

$$\sum X = 0; \quad P + N_2 - N_1 = 0. \quad (1)$$

Bu tenglamadan:

$$N_1 + N_2 = P. \quad (2)$$

Trubka va boltlarning deformatsiyasi esa quyidagiga teng bo'ladi:

$$\Delta l_1 = \frac{N_1 l}{E_1 F_1}; \quad \Delta l_2 = \frac{N_2 l}{E_2 F_2}.$$

Endi quyidagi belgilashlarni kiritamiz:

$$E_1 F_1 = B_1;$$

$$E_2 F_2 = B_2.$$

Unda,

$$\Delta l_1 - \Delta l_2 = \lambda_0 \quad (3)$$

yoki

$$\frac{N_1}{B_1} - \frac{N_2}{B_2} = \frac{\lambda_0}{l}. \quad (4)$$

(2) dan,

$$N_1 = P - N_2. \quad (5)$$

(5) ni (4) ga olib borib qo'yamiz:

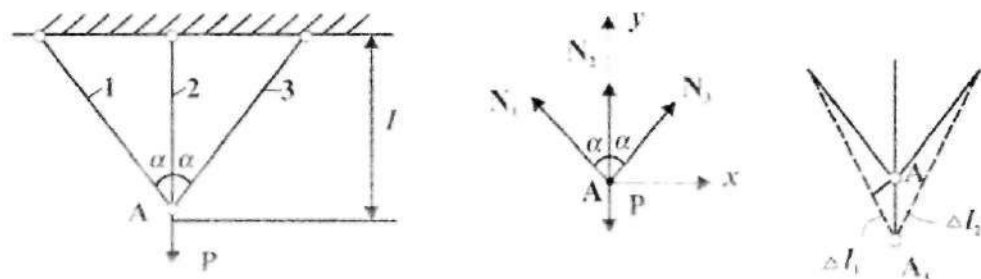
$$N_2 = \frac{\frac{P}{B_1} - \frac{\lambda_0}{l}}{\frac{1}{B_1} + \frac{1}{B_2}}; \quad N_1 = \frac{\frac{P}{B_1} + \frac{\lambda_0}{l}}{\frac{1}{B_1} + \frac{1}{B_2}}.$$

$$P = \frac{\lambda_0 B_1}{l} = \frac{\lambda_0 E_1 F_1}{l} \text{ da } N_2 = 0 \text{ bo'ladi.}$$

## 117- masala

A tugunda tutashtirilgan sterjenli sistemaga  $P$  kuch ta'sir etadi (XIV.12- shakl). 1- va 3-sterjenlarning kesim yuzalari  $F_1 = F_3 = 4 \text{ sm}^2$ , ikkinchisidagi  $F_2 = 3 \text{ sm}^2$ . Sterjenlarning materiali po'lat-3.  $E = 2 \cdot 10^6 \text{ kg/sm}^2$  ( $2 \cdot 10^5 \text{ MPa}$ );  $l = 2 \text{ m}$ ;  $P = 40 \text{ t}$ .

Burchak  $\alpha$  ning qanday qiymatida barcha sterjenlardagi zo'riqishlar bir xil qiymatga ega bo'ladi?



XIV.12- shakl

## Yechish:

Muvozanat tenglamalarini tuzamiz (XIV.12- shakl):

$$\sum x = 0; -N_1 \cdot \sin \alpha + N_3 \cdot \sin \alpha = 0; \text{ unda, } N_1 = N_3;$$

$$\sum y = 0; 2N_1 \cdot \cos \alpha + N_2 - P = 0.$$

(1)

Deformatsiya tenglamasini tuzamiz:

$$\Delta l_1 = \Delta l_2 \cdot \cos \alpha.$$

(2)

Unda,

$$l_2 = l; \quad l_1 = \frac{l}{\cos \alpha};$$

$$N_1 = \frac{F_1}{F_2} \cos^2 \alpha N_2.$$

(3)

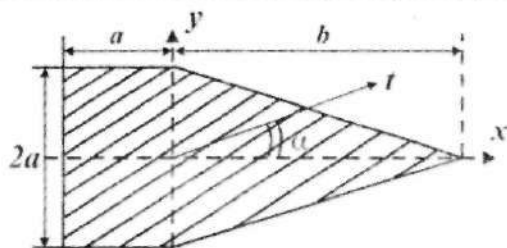
Agarda (1) da  $\alpha = 30^\circ$  bo'lsa,  $N_1 = N_2$  bo'ladi.

Unda,  $\frac{F_1}{F_2} \cos^2 \alpha = 1$ ; bu yerda,  $\cos \alpha = \sqrt{\frac{3}{4}} = \frac{\sqrt{3}}{2}$ . Demak,  $\alpha = 30^\circ$  da  $N_1 = N_2 = N_3 = 14,65 \text{ t}$ .

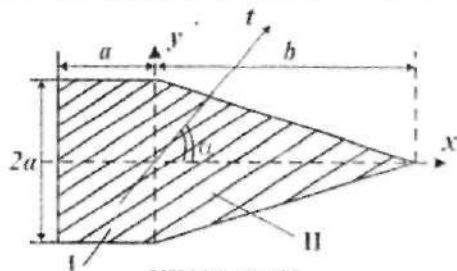
## 14.2- §. Tekis kesimlarning geometrik xarakteristikalar

## 118- masala

$\frac{b}{a}$  nisbatning qanday qiymatida 0 nuqtadan o'tuvchi istalgan  $l$  o'qqa nisbatan kesimning inersiya momenti  $\alpha$  burchakka bog'liq bo'lmaydi?  $\alpha$  berilgan deb hisoblansin (XIV.13- shakl).



XIV.13- shakl



XIV.14- shakl

Yechish:

Quyidagi belgilashni kiritamiz (XIV.14- shakl):  $\frac{b}{a} = k$ , bu yerda  $b = ak$ .

$$J_x = J_x^I + J_x^{II} = \frac{a(2a)^3}{12} + 2 \frac{ba^3}{12};$$

bu demak,

$$J_x = \frac{2}{3}a^4 + \frac{k^3 a^4}{6}.$$

$$J_y = J_y^I + J_y^{II} = \frac{(2a)a^3}{3} + \frac{2a(ka)^3}{12};$$

bu demak,

$$J_y = \frac{2}{3}a^4 + \frac{k^3 a^4}{6}.$$

U holda,

$$J_x = J_y \Rightarrow \frac{2}{3}a^4 + \frac{k^3 a^4}{6} = \frac{2}{3}a^4 + \frac{k^3 a^4}{6}. \quad (1)$$

(1) dan  $k(k^2 - 1) = 0$ ;  $k_1 = 0$ ;  $k_{2,3} = \pm 1$ ;  $k_1 = 0$ ;  $k_3 = -1$  masala ma'nosiga zid.  $k_2 = 1$  yechimni olamiz. Demak,  $b = a$  ekan. U holda:

$$J_x = J_y = \frac{5}{6}a^4; \quad J_{xy} = 0 \quad (X\text{-simmetriya o'qi}).$$

Unda,

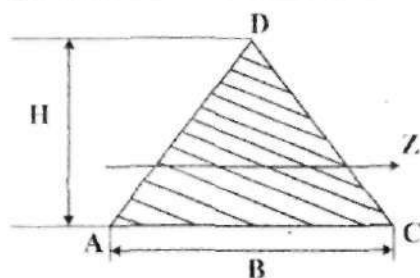
$$J_t = J_x \cos^2 \alpha + J_y \sin^2 \alpha = \frac{5a^4}{6}(\cos^2 \alpha + \sin^2 \alpha) = \frac{5}{6}a^4.$$

Ushbu qiymat  $\alpha$  ga bog'liq emas.

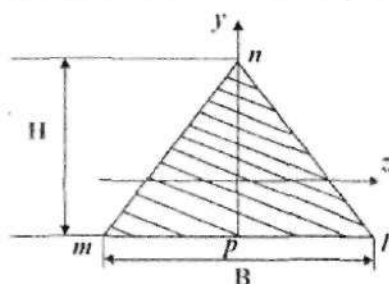
### 119- masala

$AD = DC = a$ ,  $k = \frac{B}{H}$  nisbatning qanday qiymatida kesimning markaziy  $z$  o'qiga

nisbatan inersiya momenti ( $k = ?$ ) eng katta qiymatga ega bo'ladi (XIV.15- shakl)?



XIV.15- shakl



XIV.16- shakl

**Yechish:**

Quyidagicha belgilashlar kiritamiz (XIV.16- shakl):

$$mn = nl = a; \quad k = \frac{B}{H}; \quad B = kH.$$

Unda,

$$J_z = \frac{BH^3}{36} = \frac{kH^4}{36};$$

Uchburchak  $pnl$  dan (XIV.16- shakl):

$$a^2 = H^2 + \left(\frac{B}{2}\right)^2 = H^2 + \frac{k^2 H^2}{4} = H^2 \left(1 + \frac{k^2}{4}\right);$$

$$H = \frac{a}{\sqrt{1 + \frac{k^2}{4}}}; \quad J_z = \frac{a^4}{36} \cdot \frac{k}{\left(1 + \frac{k^2}{4}\right)^2};$$

bu yerda,  $J_z = J_z(k)$ .

$$\text{U holda, } (J_z)'_k = \frac{a^4}{36} \cdot \frac{1 \cdot \left(1 + \frac{k^2}{4}\right)^2 - 2k \left(1 + \frac{k^2}{4}\right) \cdot \frac{2k}{4}}{\left(1 + \frac{k^2}{4}\right)^4} = 0.$$

$$\text{Bu yerda, } \frac{a^4}{36} \neq 0; \text{ u holda, } \left(1 + \frac{k^2}{4}\right) \cdot \left(1 + \frac{k^2}{4} - k^2\right) = 0.$$

$$\text{Shunga ko'ra, } 1 + \frac{k^2}{4} - k^2 = 0 \Rightarrow k = \frac{2\sqrt{3}}{3} \approx 1,15.$$

## 120- masala

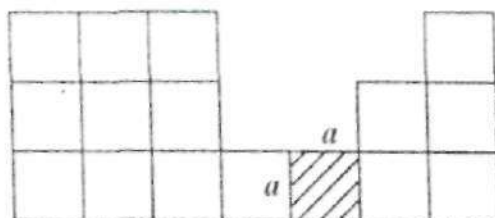
Bizning ixtiyorimizda kartondan tayyorlangan, tomonlari  $a$  ga teng bo'lgan 16 ta kvadratchalar bor (XIV.17- shakl). Balka eng katta mustahkamlikka ega bo'lishi uchun mazkur kvadratchalardan terib hosil qilingan kesimning eng maqbul shakli qanday bo'lishi kerak?

## Yechish:

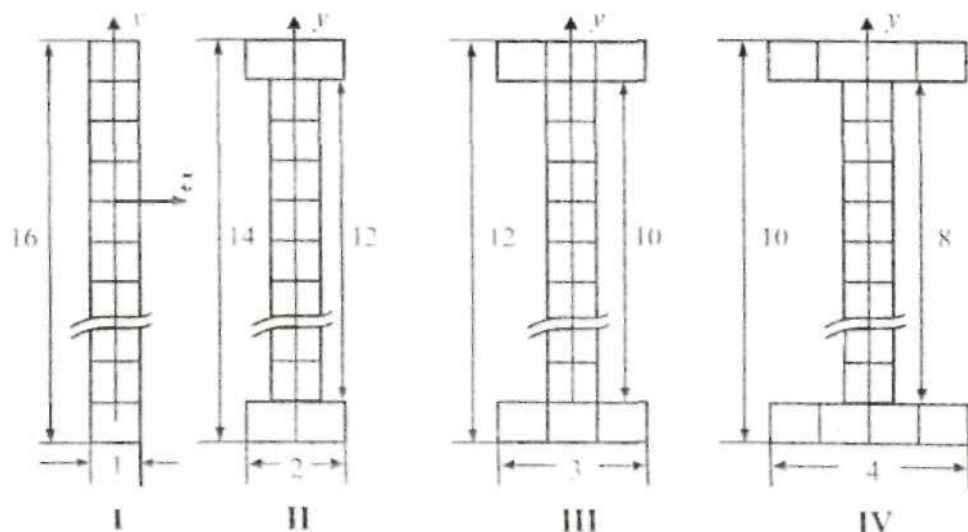
Masalani yechish uchun 2 ta tushuncha asos qilib olinadi:

1. Kesim vertikal o'qqa ( $y$ ) simmetrik bo'lishi kerak;

2. Balkaning mustahkamligi kesimning qarshilik momenti  $W_z$  ga to'g'ri proporsional.



XIV.17- shakl



XIV.18- shakl

Yuqorida 4 xil kesim ( $a=1$ ) hosil qilindi (XIV.18- shakl).  $z$  o'qi bo'yicha ularning inersiya momentlarini aniqlaymiz:

$$\text{I. } J_z = \frac{bh^3}{12} = \frac{1 \cdot 16^3}{12}; \quad Y_{\max} = 8; \quad W_z = \frac{J_z}{Y_{\max}} = \frac{16^3}{12 \cdot 8} = 42,6.$$

$$\text{II. } J_z = \frac{2 \cdot 14^3}{12} - \frac{1 \cdot 12^3}{12} = 313; \quad Y_{\max} = 7; \quad W_z = \frac{313}{7} = 44,76.$$

$$\text{III. } J_z = \frac{3 \cdot 12^3}{12} - \frac{2 \cdot 10^3}{12} = 265; \quad Y_{\max} = 6; \quad W_z = 44,22.$$

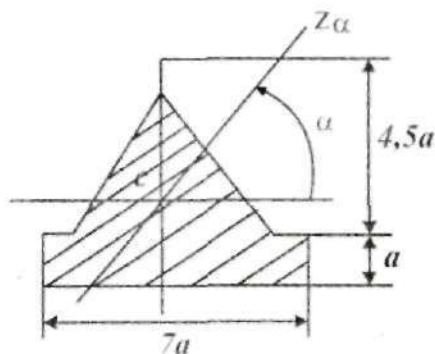
$$\text{IV. } J_z = \frac{4 \cdot 10^3}{12} - \frac{3 \cdot 8^3}{12} = 205,33; \quad Y_{\max} = 5; \quad W_z = 41,06.$$

V. Kvadrat (4x4) uchun  $W_z = 10,6$ .

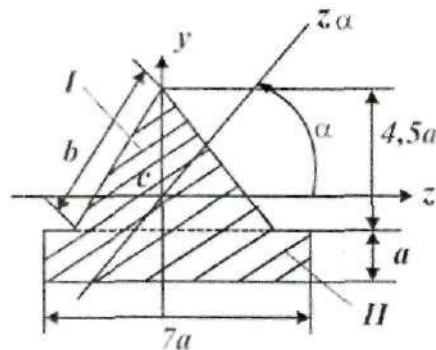
II kesim eng maqbul ekan, chunki  $W_z = W_z^{\max} = 44,76$ .

### 121- masala

Kesim teng tomonli uchburchak va to'g'ri to'rtburchakdan tashkil topgan (XIV.19- shakl). Uchburchakning og'irlik markazidan o'tgan istalgan o'qqa nisbatan kesimning inersiya momenti o'zgarmas qiymatga ega ekanligi isbot etilsin.



XIV.19- shakl



XIV.20- shakl

### Yechish:

Bizga ma'lumki,

$$b^2 - \left(\frac{b}{2}\right)^2 = \left(\frac{9}{2}a\right)^2; \quad \text{bu yerdan, } b = 3a\sqrt{3}; \quad h = 4,5a.$$

Kesimlarning  $z$  va  $y$  o'qlariga nisbatan inersiya momentlarini aniqlaymiz (XIV.20- shakl). Teng tomonli uchburchak uchun:

$$J_z^I = \frac{bh^3}{36} = 7,59 \sqrt{3} a^4;$$

$$J_y^I = \frac{bh^3}{36} = 7,59 \sqrt{3} a^4.$$

To'g'ri burchakli to'rtburchak uchun:

$$J_z^{\text{II}} = \frac{7aa^3}{12} + 7a^2 \cdot 4a^2 = \frac{343a^4}{12} = 28,58a^4;$$

$$J_y^{\text{II}} = \frac{a(7a)^3}{12} = \frac{343a^4}{12} = 28,58a^4.$$

Unda,

$$J_z = J_z^{\text{I}} + J_z^{\text{II}} = 7,59\sqrt{3}a^4 + 28,58a^4 = 41,71a^4;$$

$$J_y = J_y^{\text{I}} + J_y^{\text{II}} = 7,59\sqrt{3}a^4 + 28,58a^4 = 41,71a^4; J_{xy} = 0.$$

Demak, shakl simmetrikdir.

$$\text{Ya'ni, } \operatorname{tg} 2\alpha_0 = \frac{J_{zy}}{J_z - J_y} = \frac{0}{0}.$$

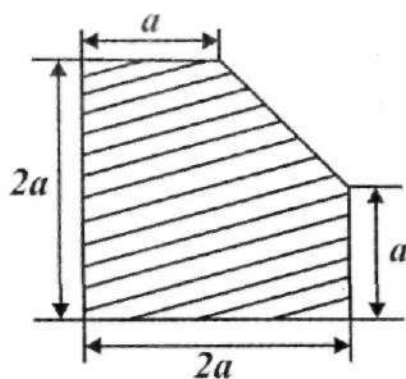
Demak,  $O$  nuqtadan o'tuvchi har qanday o'q bosh o'qdan iborat.

Shuning uchun,  $J_{z_a} = 41,71a^4$ ;  $J_{z_a} = J_z \cos^2 \alpha + J_y \sin^2 \alpha = J_z$ .

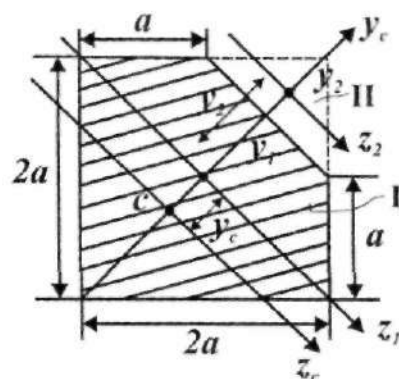
### 122- masala

Berilgan kesimning markaziy bosh o'qlariga nisbatan inersiya momentlari aniqlansin (XIV.21- shakl).

$a$  – berilgan deb hisoblansin.



XIV.21- shakl



XIV.22- shakl

### Yechish:

Kesim simmetriya o'qiga ega. Uning og'irlik markazi  $C$  nuqta simmetriya o'qida yotadi. Boshlang'ich o'qlarni kesimning diagonallari bo'yicha yo'naltiramiz (XIV.22- shakl).



U holda,

$$Z_c = 0; Y_c = \frac{F_1 Y_1 - F_2 \cdot Y_2}{F_1 - F_2};$$

bu yerda,

$$F_1 = 4a^2; F_2 = \frac{a^2}{2}; Y_1 = 0; Y_2 = \frac{2a\sqrt{2}}{3};$$

$$Y_c = -0,134a.$$

Bosh o'qlarning bittasi ( $Y_c$ ) simmetriya o'qi bo'ylab yo'naladi.

$Z_c$  va  $Y_c$  o'qlari bo'yicha kesimning inersiya momentlarini aniqlaymiz:

$$J_{Zc}^I = \frac{(2a)^4}{12} + (0,134a)^2 \cdot 4a^2 = 1,404a^4;$$

$$J_{Zc}^{II} = \frac{a\sqrt{2} \left( \frac{a\sqrt{2}}{2} \right)^3}{36} + \frac{a^2}{2} \left( a\sqrt{2} + 0,134 - \frac{a\sqrt{2}}{3} \right)^2 = 0,69a^4;$$

$$J_{Zc} = J_{Zc}^I - J_{Zc}^{II} = 1,404a^4 - 0,69a^4 = 0,714a^4.$$

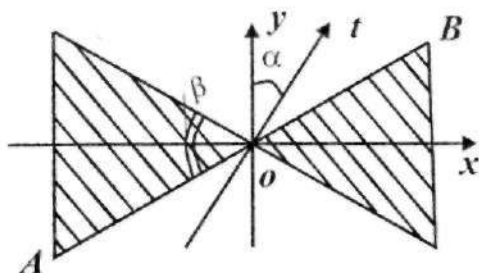
Unda,

$$J_{Yc} = J_{Yc}^I - J_{Yc}^{II} = \frac{(2a)^4}{12} - \frac{a^4}{12} \cdot \frac{1}{2} = \left( \frac{16}{12} - \frac{1}{24} \right) a^4 = \frac{31}{24} a^4 = 1,291a^4.$$

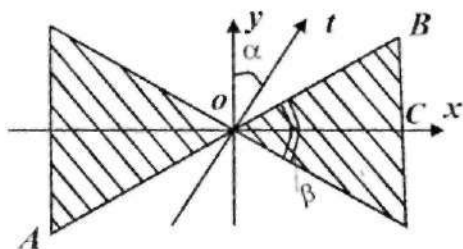
### 123- masala

Burchak  $\beta$  ning qanday qiymatida kesimning og'irlik markazi  $O$  dan o'tuvchi istalgan  $t$  o'qqa nisbatan inersiya momenti  $\alpha$  ga bog'liq bo'lmaydi?

$AO = OB = l$  berilgan deb hisoblansin (XIV.23- shakl).



XIV.23- shakl



XIV.24- shakl

**Yechish:**

$OBC$  uchburchakdan (XIV.24- shakl):

$$OC = OB \cos \frac{\beta}{2} = l \cos \frac{\beta}{2}; \quad BC = OB \sin \frac{\beta}{2} = l \sin \frac{\beta}{2}.$$

Unda,

$$J_x = \frac{4 OC (BC)^3}{12} = \frac{1}{3} l^4 \cos \frac{\beta}{2} \sin^3 \frac{\beta}{2};$$

$$J_y = \frac{4 BC (OC)^3}{4} = l^4 \sin \frac{\beta}{2} \cos^3 \frac{\beta}{2};$$

$$J_x = J_y \Rightarrow 4 \cos^2 \frac{\beta}{2} = 1; \quad \cos \frac{\beta}{2} = \pm 1.$$

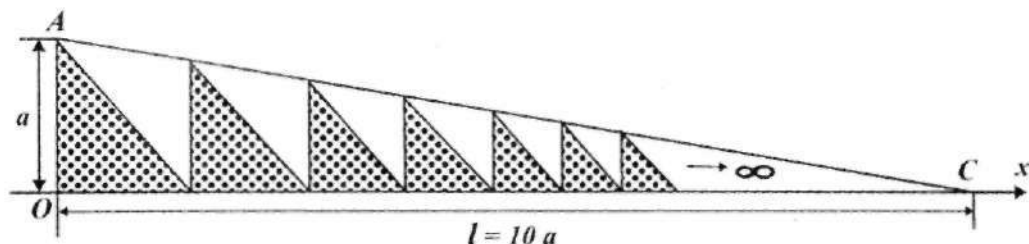
Bu yerda,  $\frac{\beta}{2} = 60^\circ$ ;  $\beta = 120^\circ$ , unda,

$$J_x = J_y = \frac{l^4 \sqrt{3}}{16}; \quad J_{xy} = 0;$$

$$J_1 = J_x \cos^2 \alpha + J_y \sin^2 \alpha - J_{xy} \sin 2\alpha = J_x = \frac{l^4 \sqrt{3}}{16}.$$

**124- masala**

Rasmdagi bo'yalgan yuzaning  $OX$  o'qqa nisbatan inersiya momenti  $AOC$  uchburchak to'liq yuzining mazkur o'qqa nisbatan inersiya momentining necha foizini tashkil etadi (XIV.25- shakl)?



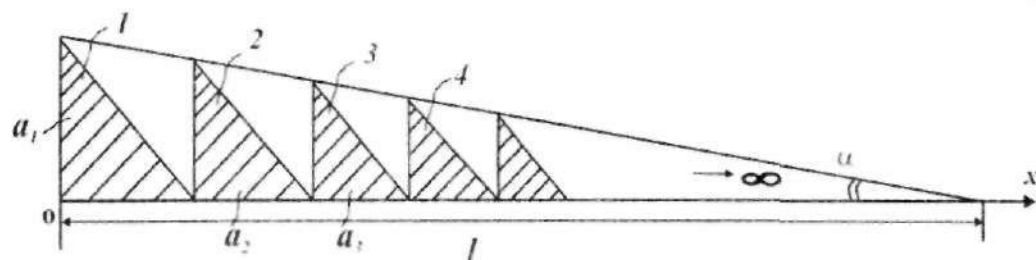
XIV.25- shakl

**Yechish:**

Quyidagi belgilashlarni kiritamiz:

$$a_1 = l \lg \alpha = l \cdot k; \quad k = \lg \alpha; \quad a_2 = (l - l \cdot k) k = l \cdot k (k - 1);$$

$$a_3 = a_2 - a_2 k = l \cdot k (1 - k)^2; \quad a_4 = a_3 - a_3 k = l \cdot k (1 - k)^3.$$



XIV.26- shakl

XIV.26- shaklda shtrixlangan uchburchaklarning  $x$  o'qiga nisbatan inersiya momentlari yig'indisi quyidagiga teng bo'ladi:

$$J_x = J_x^{(1)} + J_x^{(2)} + J_x^{(3)} + J_x^{(4)} \dots + J_x^{(n)} \quad (1)$$

Bu yerda,

$$J_x^{(1)} = \frac{(l \cdot k)^4}{12}; \quad J_x^{(2)} = \frac{(l \cdot k)^4 (1-k)}{12};$$

$$J_x^{(3)} = \frac{(l \cdot k)^4 (1-k)^2}{12}; \quad J_x^{(4)} = \frac{(l \cdot k)^4 (1-k)^3}{12};$$

unda,

$$\frac{J_x^{(2)}}{J_x^{(1)}} = (1-k); \quad \frac{J_x^{(3)}}{J_x^{(2)}} = (1-k); \quad \frac{J_x^{(4)}}{J_x^{(3)}} = (1-k), \dots$$

(1) tenglama cheksiz kamayuvchi geometrik progressiya bo'lib, uning maxraji  $q = (1-k)^4$  bo'lsa, yig'indi  $S = \frac{a_1}{1-q}$  ga tengdir. Shunga ko'ra,

$$J_x = \frac{J_x^{(1)}}{1-q} = \frac{(lk)^4}{12(1-q)} = \frac{(lk)^4}{12[1-(1-k)^4]}.$$

U holda to'liq uchburchak yuzining inersiya momenti quyidagiga teng bo'ladi:

$$J_x^T = \frac{l \cdot (lk)^3}{12} = \frac{l^4 k^3}{12}; \quad k = \frac{1}{10}.$$

$$\text{Unda, } \rho = \frac{J_x}{J_x^T} \cdot 100\% = \frac{k}{1-(1-k)} \cdot 100\% = \frac{10^5}{3439} = 29,07\%.$$

Demak, rasmda bo'yalgan yuzaning  $OX$  o'qqa nisbatan inersiya momenti  $AOC$  uchburchak to'liq yuzining mazkur o'qqa nisbatan inersiya momentining 29,07% ini tashkil qilar ekan.



$$\sigma_{cz} = \frac{P}{F_{cz}} = \frac{P}{0,55 \cdot 7,5} \leq [\sigma]_e = 2100 \text{ kg/sm}^2;$$

bu yerdan,

$$[P] \leq 8662 \text{ kg.}$$

$$P = [P] \leq 1,8 \cdot 7,5 \cdot 600 = 8100 \text{ kg ni qabul qilamiz.}$$

Z o'qiga nisbatan valga ta'sir etayotgan kuchlardan moment olamiz:

$$\sum \text{mom}_z = 0; \quad M - P \cdot \frac{d}{2} = 0;$$

$$[M] = [P] \cdot \frac{d}{2} = 8100 \text{ kg} \cdot 3 \text{ sm} = 24300 \text{ kg} \cdot \text{sm.}$$

$$\text{Valning mustahkamlik shartidan: } \tau_{\max} = \frac{M^b}{W_\rho} \leq [\tau];$$

$$[M] = \frac{\pi d^3}{16} \cdot 800 = \frac{3,14 \cdot 6^3 \cdot 800}{16};$$

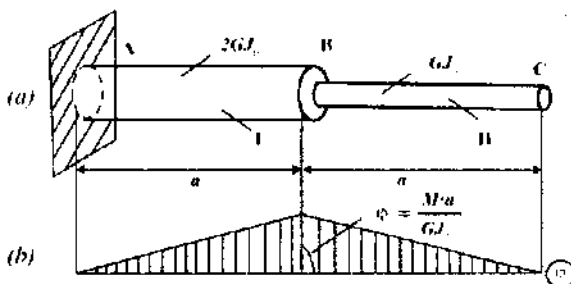
$$[M] = 33912 \text{ kg} \cdot \text{sm.}$$

$[M]$  ning ikkita qiymatidan kichigi olinadi, ya'ni:  $[M] = 24,3 \text{ kg} \cdot \text{m.}$

### 126- masala

Berilgan valning I- qismi bikrligi 2- qismi bikrligidan 2 marta katta. XIV.29- shakl (b) da valning buralish burchaklar  $\varphi$  epyurasi keltirilgan.

Valga qo'yilgan tashqi kuchlar aniqlansin. Burovchi moment  $M_b$  epyurasi qurilsin. Valning bikrligi  $G \cdot J_\rho$  va  $a$  aniq deb hisoblansin.

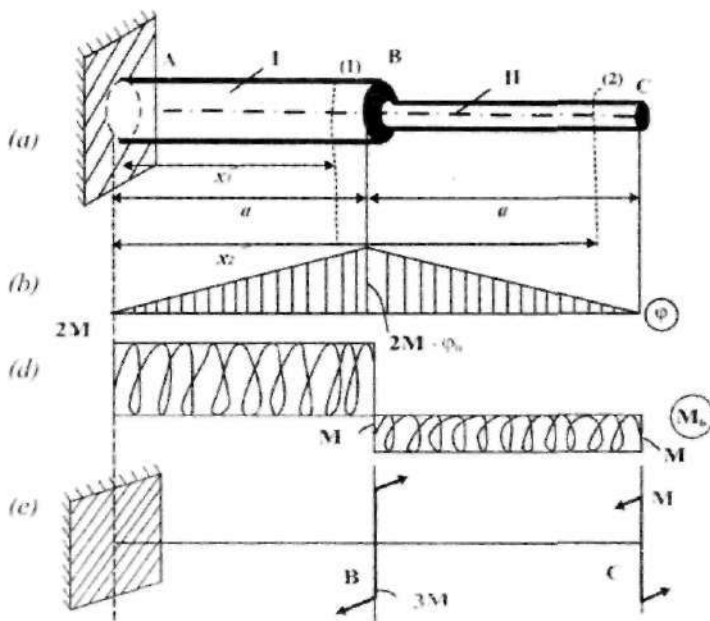


XIV.29- shakl

### Yechish:

Valning II qismidagi bikrligi  $GJ_\rho$  bo'lsa, I qismining bikrligi  $2GJ_\rho$  bo'ladi. Valning buralish burchagini aniqlash formulasi quyidagiga teng:

$$\varphi = \frac{M \cdot l}{GJ_\rho}.$$



XIV.30- shakl

Valning birinchi uchastkasida:  $0 \leq x_1 \leq a$  (XIV.30- shakl).

Unda,

$$\varphi_1 = \frac{M_b^{(1)} \cdot x_1}{2 GJ_\rho};$$

bu yerda,  $x_1 = 0$ ;  $\varphi_1 = \varphi_A = 0$ .

$$x_1 = a \text{ da } \varphi_1 = \varphi_B = \frac{M_b^{(1)} \cdot a}{2 GJ_\rho} = \frac{M \cdot a}{GJ_\rho};$$

bu yerda,  $M_b^{(1)} = 2M$ .

Valning ikkinchi uchastkasida  $a \leq x_2 \leq 2a$ ;

$$\varphi_2 = \varphi_B + \frac{M_b^{(2)} \cdot (x_2 - a)}{GJ_\rho};$$

$$x_2 = a \text{ da } \varphi_2 = \varphi_B = \frac{M \cdot a}{GJ_\rho};$$

$$x_2 = a \text{ da } \varphi_2 = 0; \text{ unda, } \frac{M \cdot a}{GJ_\rho} + \frac{M_b^{(2)} \cdot a}{GJ_\rho} = 0.$$

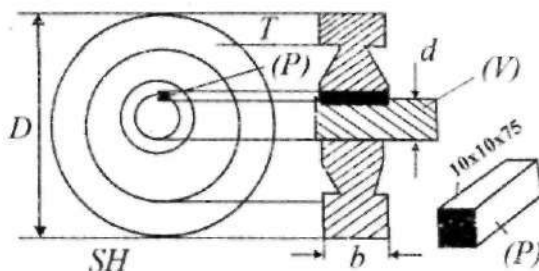
Bu yerda,  $M_b^{(2)} = -M$ .

Demak (1) uchastkada burovchi moment  $2M$  ga, (2) uchastkada esa  $M$  ga teng ekan, topilgan qiymatlar bo'yicha  $M_b$  epyurasini quramiz.

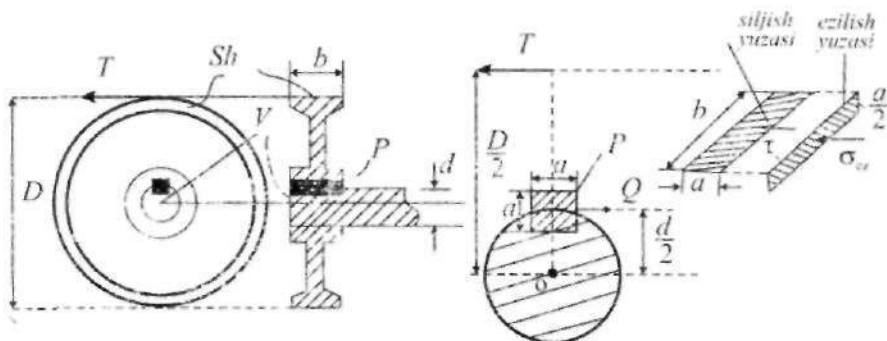
Epyuradan ko'rinib turibdiki, valdagi  $C$  nuqtaga  $M$  va  $B$  nuqtaga esa  $3M$  ga teng bo'lgan burovchi momentlar ta'sir etayotgan ekan (XIV.30- shakl, e).

### 127- masala

(V) Val (Sh) shkiv bilan (P) pona vositasida birlashtirilgan (XIV.31- shakl). Ponaning yarmi valga, yarmi shkivga kirib turadi. Ponaning siljish va ezilish bo'yicha mustahkamligi tekshirilsin.  $[\tau] = 900 \text{ kg/sm}^2$ ;  $[\sigma_{ez}] = 2200 \text{ kg/sm}^2$ ;  $T = 400 \text{ kg}$  ( $D = 900 \text{ mm}$ ;  $d = 60 \text{ mm}$ ;  $b = 75 \text{ mm}$ ;  $a = 10 \text{ mm}$ ).



XIV.31- shakl



XIV.32- shakl

**Yechish:**

XIV.32- shakldan val ( $V$ ) va shkiv ( $Sh$ ) ni birlashtiruvchi ( $P$ ) ponaga tushadigan kuchni aniqlaymiz:

$$\Sigma m_0 = 0; T \cdot \frac{D}{2} - Q \cdot \frac{d}{2} = 0; Q = T \cdot \frac{D}{d} = 400 \cdot \frac{90}{6} = 6000 \text{ kg.}$$

Ponada hosil bo'ladigan kesuvchi urinma kuchlanish quyidagiga teng bo'ladi:

$$\tau_c = \frac{Q}{a \cdot b} = \frac{6000 \text{ kg}}{1 \cdot 7,5 \text{ sm}^2} = 800 \text{ kg/sm}^2 < 900 \text{ kg/sm}^2$$

Eguvchi normal kuchlanish:

$$\sigma_{cz} = \frac{Q}{\frac{a \cdot b}{2}} = \frac{6000 \text{ kg}}{0,5 \cdot 7,5 \text{ sm}^2} = 1600 \text{ kg/sm}^2 < 2200 \text{ kg/sm}^2.$$

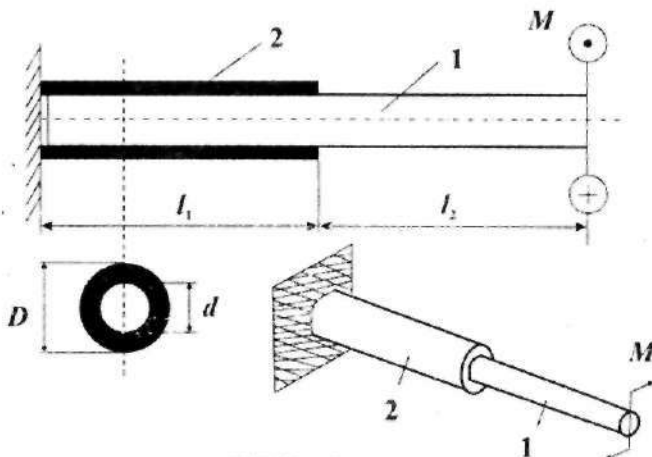
Demak, birikma mustahkam.

**128- masala**

Uzunligi  $2l$  bo'lgan (1) val  $l$  qismining chap kesimi biki mahkamlangan (2) trubka ichida qisilgan holda joylashgan (XIV.33- shakl). Trubkaning val sirtiga ko'rsatadigan bosimi  $p$  val sirti bo'yicha tekis tarqalgan. Trubka va val orasidagi ishqalanish koeffitsienti  $f$  ga teng. Valning uchiga ta'sir etuvchi moment  $M$  qanday qiymatga erishganda val (1) trubka (2) ga nisbatan aylanish boshlaydi?

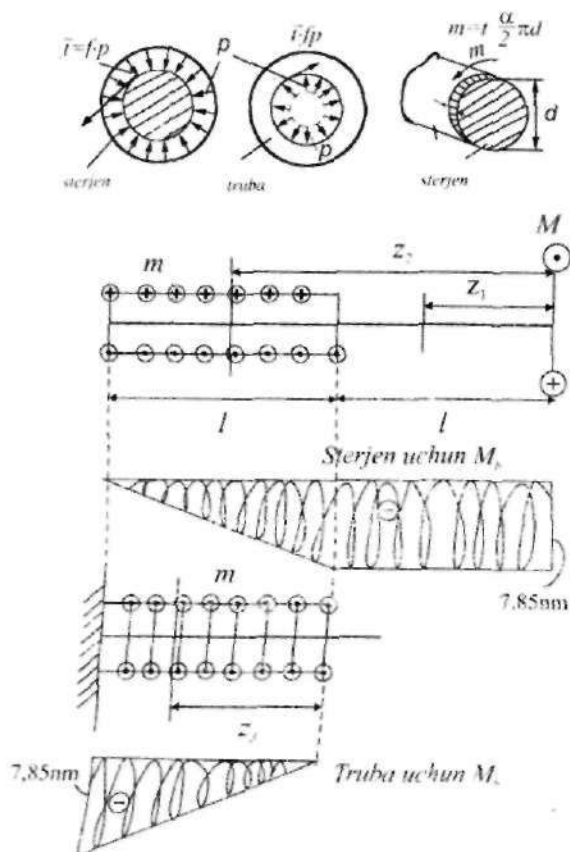
Mazkur holatda (1) val va (2) trubka uchun burovchi moment epyuralari qurilsin.

**Berilgan:**  $D = 12,5 \text{ mm}$ ;  $d = 10 \text{ mm}$ ;  $p = 2,5 \text{ MPa}$ ;  $l = 100 \text{ mm}$ ;  $f = 0,2$ .



XIV.33- shakl





XIV.34- shakl

**Yechish:**

Kesish usulidan foydalanib, 2- uchastka uchun burovchi moment tenglamasini tuzamiz (XIV.34- shakl):

$$\sum \text{mom}_z = 0; \quad M - ml = 0; \quad \text{unda,} \quad M = \frac{1}{2} p f d^2 \pi l = -7,85 \text{ nm}$$

$M \geq 7,85 \text{ nm}$  da sterjen trubaga nisbatan aylana boshlaydi.

Burovchi moment epyurasini quramiz:

1. Val uchun

I uchastkada:  $0 \leq z_1 \leq l; M_1 = -M = -7,85 \text{ nm}$ .

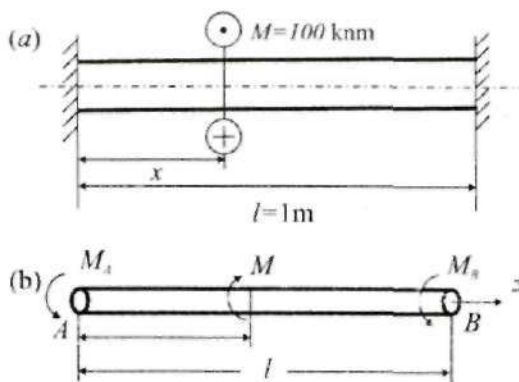
II uchastkada:  $l \leq z_2 \leq 2l; M_2 = -M + m(z_2 - l)$ .

2. Truba uchun  $M_3 = -mz_3; 0 < z_3 < l$ .

## 129- masala

Valni (XIV.35- shakl) mustahkamlik va bikrlilik shartlaridan aniqlangan diametri bir xil qiymatga ega bo'lishi uchun valga ta'sir etuvchi juft kuch  $M$  val tayanchidan ( $x=?$ ) qanday masofaga qo'yilishi kerak?

**Berilgan:**  $[\tau] = 100 \text{ MPa}$ ;  $[\theta] = 0,5^\circ (\text{grad/m})$ ;  $G = 8 \cdot 10^4 \text{ MPa}$ .



XIV.35- shakl

## Yechish:

Statika tenglamasini tuzamiz:

$$\sum m_z = 0; \quad M_A + M_B = M. \quad (1)$$

$\varphi_B = 0$  shartidan deformatsiya tenglamalarini tuzamiz:

$$\left. \begin{aligned} M_B &= \frac{M \cdot x}{l} \\ M_A &= M \left( 1 - \frac{x}{l} \right) \end{aligned} \right\} \quad (2)$$

Mustahkamlik sharti bo'yicha:

$$\tau_{\max} = \frac{M}{W_p} \leq [\tau]; \quad D_1 = \sqrt[3]{\frac{10^5 \cdot 16 \left( 1 - \frac{x}{l} \right)}{\pi \cdot 10^8}} = 0,72 \sqrt[3]{\left( 1 - \frac{x}{l} \right)}.$$

Bikrlilik sharti bo'yicha:

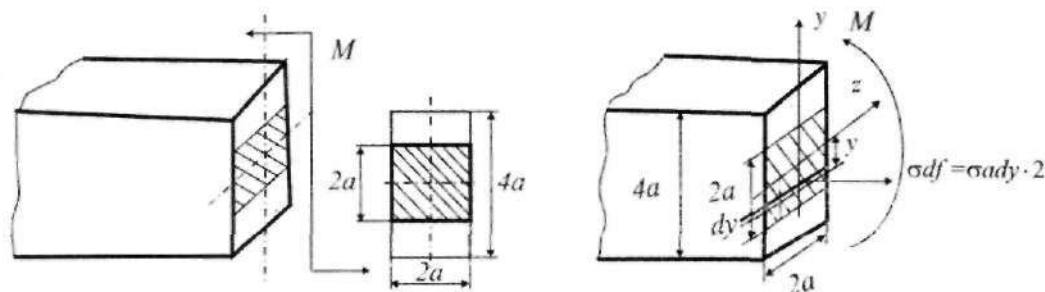
$$\varphi = \frac{M \cdot (l-x) x \cdot 32}{\pi D^4 G l^2} \leq \frac{0,5}{57,3}; \quad D_2 = 0,195 \sqrt[4]{\frac{(l-x) x}{l}}.$$

$D_1 = D_2$  shartiga ko'ra,  $x = 0,482l = 0,482 \text{ m}$ .

## 14.4- §. Egilishga doir masalalar

## 130- masala

Balka kesimidagi eguvchi moment  $M$  ga teng. Mazkur momentning necha foizini kesimning shtrixlangan qismi va necha foizini shtrixlanmagan qismi qabul qiladi?  $M, a$  lar berilgan deb hisoblansin (XIV.36- shakl).



XIV.36- shakl

## Yechish:

Balka kesimidagi normal kuchlanish quyidagi formula yordamida aniqlanadi:

$$\sigma = \frac{M \cdot y}{J_z} \quad (1)$$

Shtrixlangan yuza uchun esa eguvchi moment quyidagiga teng:

$$\bar{M} = \int \int (\bar{F}) \sigma \cdot y dF = \frac{M \cdot 2a}{J_z} \int_{-a}^a y^2 dy = \frac{M \cdot 2a}{J_z} \cdot \frac{y^3}{3} \Big|_{-a}^a = \frac{M}{J_z} \cdot \frac{4a^3}{3} = \frac{M}{J_z} \cdot \bar{J}_z ;$$

bu yerda,  $\bar{J}_z$  – kesim shtrixlangan qismining inersiya momenti.

$$\bar{M} = \frac{M}{J_z} \bar{J}_z \text{ tenglikdan:}$$

$$\frac{\bar{M}}{M} = \frac{\bar{J}_z}{J_z}; \quad J_z = \frac{32a^4}{3}; \quad \bar{J}_z = \frac{4a^4}{3}.$$

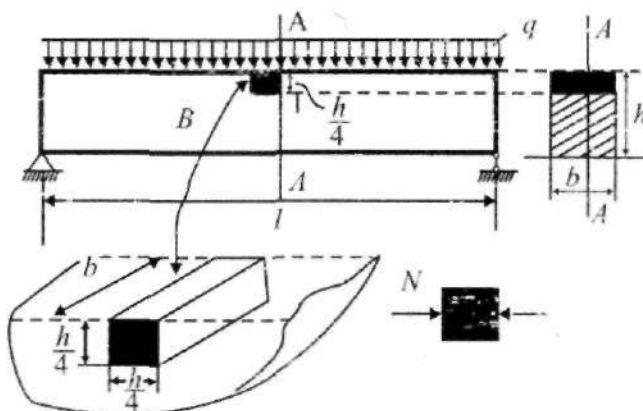
Unda,

$$\frac{\bar{M}}{M} = \frac{1}{8}; \quad \bar{M} = \frac{1}{8} M.$$

Demak, kesimning shtrixlangan qismi  $M$  ning  $\frac{1}{8}$  yoki 12,5 %, shtrixlanmagan qismi esa  $\frac{7}{8}$  yoki 87,3% ni qabul qiladi.

### 131- masala

Yog'och balka o'rta kesimining yuqorisida kvadrat kesimli  $\frac{h}{4} \times \frac{h}{4}$  o'yma hosil qilinib, bu o'ymaga shu o'lchamga ega bo'lgan yog'och brus zich qilib joylashtirilgan (XIV.37- shakl). Mazkur (B) brusga ta'sir etuvchi (N) kuchning qiymati aniqlansin (brus siqiladi).  $q=0,4$  t/m;  $l=4$  m;  $b=15$  sm;  $h=30$  sm.



XIV.37- shakl

### Yechish:

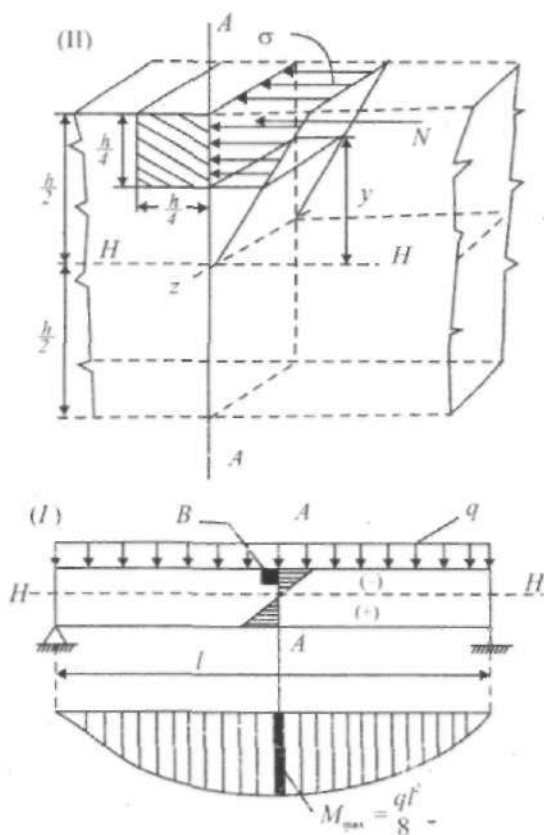
Balka  $\frac{h}{4} \times \frac{h}{4}$  oralig'ining o'rtasida eguvchi moment  $M$  eng katta qiymatga erishadi:

$M_{\max} = \frac{ql^2}{8}$  (XIV.38- shakl, b). Balkaning neytral o'qidan (H-H) yuqori qismi siqiladi.

Demak, (B) brus tomonlariga siquvchi kuch ta'sir etadi.

A-A kesimdagi kuchlanganlik holati XIV.38- shakl (a) da keltirilgan. Brus (B) tomonlariga ta'sir etuvchi siquvchi kuch  $N$  shu tomonga qo'yilgan kuchlanishlarning yig'indisiga tengdir:

$$N = \int_{h/4}^h \sigma dF = \int_{h/4}^h \frac{h/2 M_{\max} \cdot y}{J_z} dF.$$



XIV.38- shakl

Bu yerda,

$$dF = b \cdot dy; \quad J_z = \frac{bh^3}{12}.$$

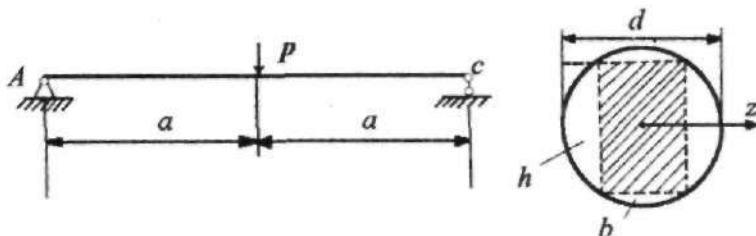
Unda,

$$N = \frac{\frac{ql^2}{8} \cdot b}{\frac{bh^3}{12}} \int_{h/4}^{h/2} y dy = \frac{3ql^2}{2h^3} \int_{h/4}^{h/2} y dy = B \frac{y^2}{2} \Big|_{h/4}^{h/2};$$

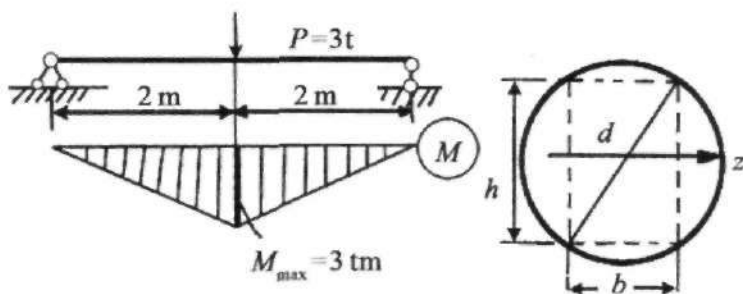
$$N = \frac{B}{2} \left( \frac{h^2}{4} - \frac{h^2}{16} \right) = \frac{B}{2} \cdot \frac{3h^2}{16} = \frac{9}{64} \frac{ql^2}{h} = \frac{9 \cdot 0,5 \cdot 4^2}{64 \cdot 0,3} = 2,94 \text{ t}.$$

## 132- masala

Doira kesimli yog'och balkadan to'g'ri to'rtburchak kesimli balka tayyorlangan (XIV.39- shakl). Bu balkaning mustahkamligi eng katta bo'lishi uchun to'sin diametri ( $d$ ) va to'rtburchak tomonlari nimaga teng bo'ladi? Yog'och uchun  $[\sigma] = 100 \text{ kg/sm}^2$ ;  $P = 3 \text{ t}$ ;  $a = 2 \text{ m}$ .



XIV.39- shakl



XIV.40- shakl

## Yechish:

Ma'lumki,  $W_z = W_{\max}$  bo'lsa, balkaning mustahkamligi eng katta bo'ladi. Unda:

$$W_z = \frac{bh^2}{6} = \frac{b(d^2 - b^2)}{6}; \quad \frac{dW_z}{db} = d^2 - 3b^2 = 0.$$

Bu yerdan,

$$b = \frac{d}{\sqrt{3}}; \quad h^2 = d^2 - \frac{d^2}{3} = \frac{2}{3}d^2; \quad h = \frac{\sqrt{2}}{\sqrt{3}}d.$$

Unda,

$$\frac{b}{h} = \frac{\sqrt{2}}{2}; \quad W_z = \frac{d^3}{9\sqrt{3}}; \quad (1); \quad W_z = \frac{W_{\max}}{[\sigma]} = 3000 \text{ sm}^3.$$

Bu tenglamadagi  $W_z$  ning o'rniga (1) ni qo'yib, quyidagini hosil qilamiz:

$$\frac{d^3}{9\sqrt{3}} = 3000 \text{ sm}^3.$$

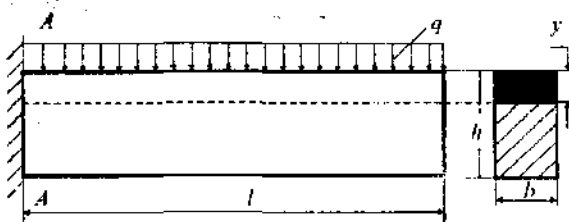
Bu yerdan,  $d \approx 30$  sm. Unda,

$$b \approx 0,58 d = 17,4 \text{ sm};$$

$$h \approx 0,82 d = 24,49 \text{ sm}.$$

### 133- masala

Yog'och balka tayanch kesimi (A—A)ning yuqori qismidan arralangan (XIV.41- shakl). Qancha arralanganda ( $y = ?$ ) balkaning mustahkamligi 50 % ga kamayadi.  $q$ ;  $l$ ;  $h = 2b$  berilgan deb qabul qilinsin.



XIV.41- shakl

### Yechish:

Balka xavfli kesimidan arralangan.

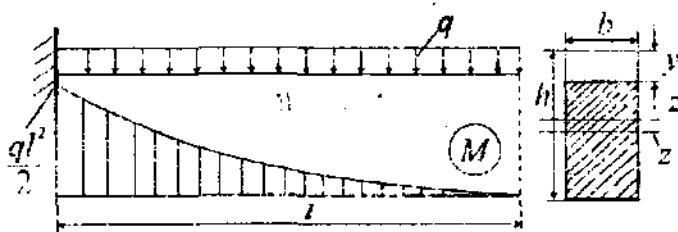
Balkaning mustahkamlik shartidan:  $M_{\max} \leq [\sigma] \cdot W_z$ . Qarshilik momenti  $W_z$  qanchaga kamaysa, mustahkamlik ham shunchaga kamayadi. Demak, arralangan balkaning mustahkamligi 0,5 marta kamayishi uchun:

$$\bar{W}_z = 0,5 W_z : \frac{b(h-y)^2}{b} = 0,5 \frac{bh^2}{b}.$$

Bu tenglamadan,

$$y^2 - 2yh + 0,5h^2 = 0.$$

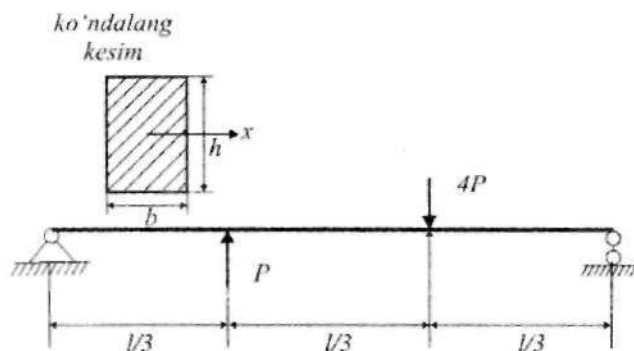
U holda,  $y_1 = 1,7h$ ;  $y_2 = 0,3h$ . Bu yerda,  $y_1 = 1,7h$  ma'noga zid yechim bo'lganligi sababli,  $y = 0,3h$  qabul qilinadi.



XIV.42- shakl

## 134- masala

$\frac{l}{h}$  nisbatning qanday qiymatlarida balka uchun normal va urinma kuchlanishlar bo'yicha mustahkamlik shartlari bajariladi? Balka materiali uchun ruxsat etilgan normal kuchlanish  $[\sigma]$ , urinma kuchlanish  $[\tau]=0,1[\sigma]$ ;  $P, l, b$  lar berilgan deb hisoblansin (XIV.43- shakl).



XIV.43- shakl

## Yechish:

1. Balkaning  $A$  va  $B$  nuqtalaridagi reaksiya kuchlari quyidagilarga teng:

$$V_A = \frac{2}{3}P; \quad V_B = \frac{7}{3}P.$$

2. Topilgan qiymatlar bo'yicha  $Q$  va  $M$  epyuralarini quramiz. Bu epyuralardan (XIV.44- shakl):

$$M_{\max} = \frac{7}{9}Pl; \quad Q_{\max} = \left| -\frac{7}{3}P \right|.$$

3. Balka uchun mustahkamlik shartlari quyidagiga teng:

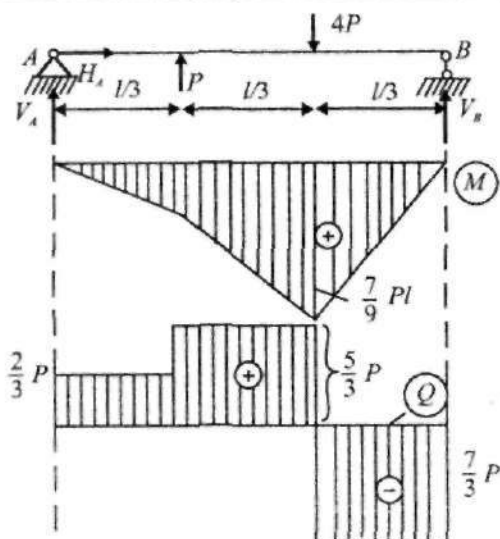
$$\sigma_{\max} = \frac{M_{\max}}{W_z} \leq [\sigma]; \quad (1)$$

bu yerda,  $W_z = \frac{bh^2}{6} = \frac{h^3}{9}$ .

$$\tau_{\max} = \frac{Q_{\max} \cdot S_z}{J_z \cdot b} \leq [\tau]; \quad (2)$$

$$F = \frac{h^2}{1,5}; \quad \frac{h}{b} = 1,5.$$





XIV.44- shakl

(1) dan:

$$\frac{7 Pl}{h^3} \leq [\sigma]; \quad (3)$$

$$[\tau] = 0,1 [\sigma]. \quad (4)$$

U holda,

$$\tau_{\max} = \frac{3 Q}{2 F} = \frac{21 P}{4 h^2}. \quad (5)$$

(2), (3), (5) dan:

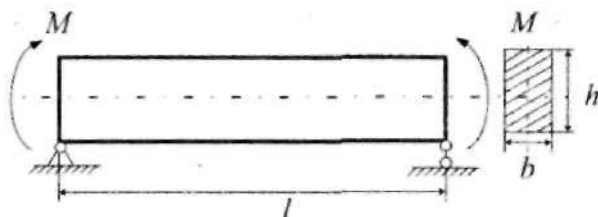
$$\frac{21 P}{4 h^2} \leq 0,1 \frac{7 Pl}{h^3}.$$

Bu yerdan,  $\frac{l}{h} \geq \frac{30}{4} = 7,5.$

**135- masala**

XIV.45- shaklda berilgan yog'och balking tag tomoniga mustahkamligi yuqori bo'lgan yupqa metall tasma yopishtirib qo'yilgan. Yog'och balka uchun  $[\sigma] = 100 \text{ kg/sm}^2$ ;  $l = 5 \text{ m}$ ;  $b = 10 \text{ sm}$ ;  $h = 20 \text{ sm}$ . Balkaga ta'sir etuvchi  $M$  ning ruxsat etilgan qiymati

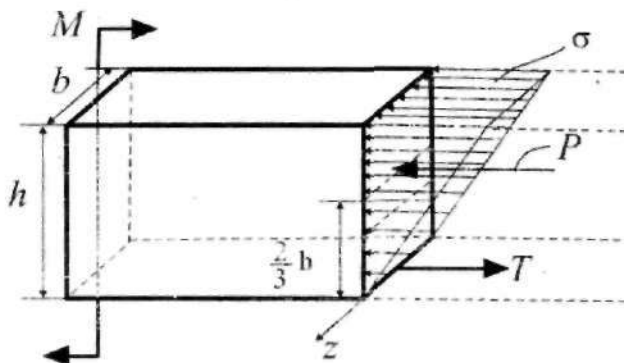
aniqlansin. *Izoh:* metall tasma uzilmaydi, yog'ochdan ko'chib ketmaydi hamda uzunligi o'zgarmaydi.



XIV.45- shakl

**Yechish:**

Balka kesimining neytral o'qi Z balka tagidagi tasmadan o'tadi.  $T$  – tasmadagi zo'riqish.  $P$  – balka kesimidagi normal kuchlanishning teng ta'sir etuvchisi (XIV.46- shakl).



XIV.46- shakl

Statika tenglamasini tuzamiz:

$$\sum \text{mom}_z = 0; \quad -M + \frac{\sigma \cdot h}{2} \cdot b \cdot \frac{2}{3} h = 0;$$

bu yerdan,

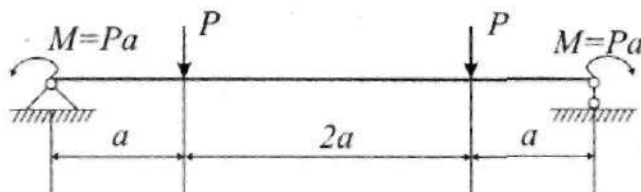
$$M = \frac{\sigma h^2 b}{3}.$$

$$\sigma = [\sigma] \text{ da } [M] = [\sigma] \frac{h^2 b}{3} = \frac{4}{3} \cdot 10^5 \text{ kg.sm} = \frac{4}{3} 10^3 \text{ kg.m.}$$

## 14.5- §. Egilishda deformatsiyalarni aniqlash

## 136-masala

Balka egilgan o'qining shakli qurilsin.  $P$ ,  $a$  berilgan deb hisoblansin (XIV.47- shakl).



XIV.47- shakl

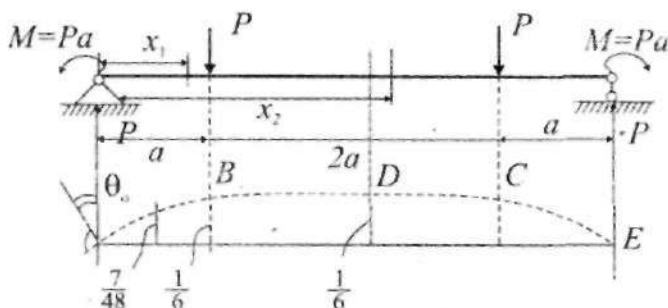
## Yechish:

Balka uchastkalari bo'yicha universal tenglamalar tuzamiz (XIV.48- shakl):

$$Y_1 = Y_0 + \theta_0 x_1 + \frac{1}{EJ} \left( \frac{-Pax_1^2}{2} + \frac{Px_1^3}{6} \right); \quad 0 \leq x_1 \leq a;$$

$$Y_2 = Y_0 + \theta_0 x_2 + \frac{1}{EJ} \left( \frac{-Pax_2^2}{2} + \frac{Px_2^3}{6} - \frac{P(x_2 - a)^3}{6} \right); \quad a \leq x_2 \leq 2a;$$

$$\theta_2 = \frac{dY_2}{dx_2} = \theta_0 + \frac{1}{EJ} \left( -Pax_2 + \frac{Px_2^2}{2} - \frac{P(x_2 - a)^2}{2} \right).$$



XIV.48- shakl



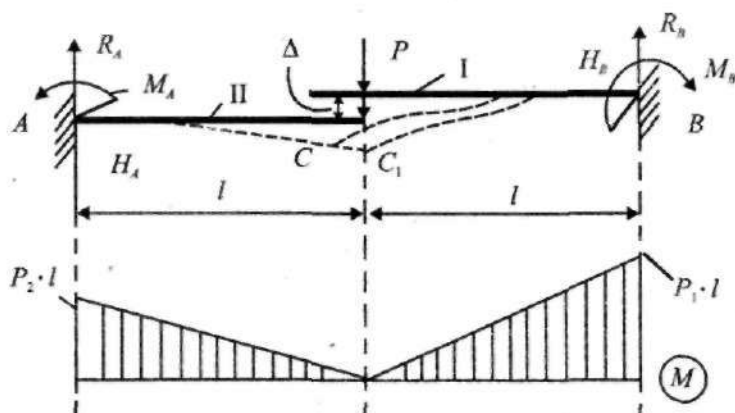
**Yechish:**

Konsol balkaning uchidagi solqiligi  $Y = \frac{Pl^3}{3EJ}$  formula bilan aniqlanadi.

Agarda  $\frac{Pl^3}{3EJ} = \Delta$  bo'lsa, I balka II balkaning uchiga C nuqtada urinadi (XIV.50- shakl).

Bunda I balka II balkaga uringan vaqtdagi  $P$  kuch quyidagiga teng bo'ladi:

$$P = \frac{3EJ\Delta}{l^3}.$$



XIV.50- shakl

Uringandan so'ng,  $P > P$  da ikkala balka birgalikda egila boshlaydi.

Masala statik noaniq bo'lib qoladi, chunki statika tenglamalari soni beshta, noma'lumlar soni esa 6 ta.

$$\left. \begin{aligned} \sum m_A &= 0; \quad \sum x = 0 \\ \sum m_B &= 0; \quad \sum y = 0 \\ \sum m_C &= 0. \end{aligned} \right\} \quad (1)$$

Qo'shimcha tenglamani sistemaning deformatsiyalanish shaklidan hosil qilamiz.

$$Y_c^I = Y_c^{II} + \Delta \quad (2)$$

yoki

$$\frac{P_1 l^3}{3EJ} = \frac{P_2 l^3}{3EJ} + \Delta. \quad (3)$$

C nuqtaga ta'sir etayotgan kuchlardan  $Y$  o'qiga proyeksiya olsak:

$$\begin{aligned}\sum Y &= 0; & P_1 + P_2 &= P; \\ P_1 &= P - P_2;\end{aligned}\quad (4)$$

(4) ni (3) ga olib borib qo'yamiz:

$$\frac{(P-P)l^3}{3EJ} = \frac{P_2 l^3}{3EJ} + \Delta \Rightarrow P_2 = \frac{1}{2} \left( P - \frac{3EJ\Delta}{l^3} \right);$$

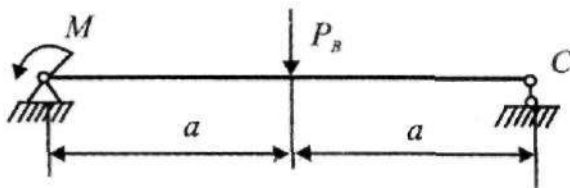
yoki

$$P_1 = P - P_2 = \frac{1}{2} \left( P + \frac{3EJ\Delta}{l^3} \right).$$

$P_1$  va  $P_2$  ma'lum bo'lgandan so'ng, I va II balkalar uchun  $M$  epyurasi quriladi.

### 138- masala

Balkaga ta'sir etayotgan kuch –  $P$ , masofa –  $a$ , balkaning bikrligi –  $EJ$  berilgan (XIV.51- shakl).  $M$  ning qanday qiymatida balka egilgan o'qining  $BC$  oralig'i to'g'ri chiziqdan iborat bo'ladi?



XIV.51- shakl

### Yechish:

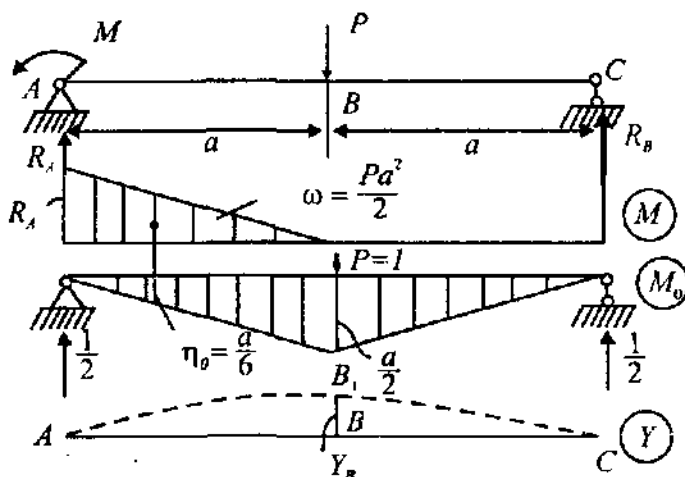
Balka egilgan o'qining  $BC$  oralig'i ushbu oraliqda  $M(x)$  bo'lsa, to'g'ri chiziq bo'ladi. Haqiqatan ham,  $EJy'' = 0$  dan  $EJy = Cx + D$  – to'g'ri chiziq.  $M(x) = 0$  bo'lganligidan  $R_B = 0$  ekanligi kelib chiqadi.

Statika tenglamalarini tuzib,  $M$  va  $R_A$  larni aniqlaymiz:

$$\sum \text{mom}_A = 0; \quad M - Pa = 0; \quad M = Pa;$$

$$\sum Y = 0; \quad R_A - P = 0; \quad R_A = P.$$

$$Y_B = \frac{\omega \cdot \eta_0}{EJ} = \frac{\frac{Pa^2}{2} \cdot \left( -\frac{a}{6} \right)}{EJ} = -\frac{Pa^3}{12EJ}.$$



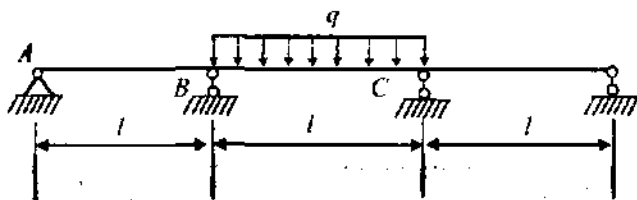
XIV.52- shakl

Ishora « $\rightarrow$ » bo'lganligi uchun  $B$  kesimdagi solqilik  $P=1$  kuch yo'nalishiga teskari.

### 139- masala

Balka  $B$  va  $C$  tayanchlarining vertikal ko'chishlari qanday qiymatga teng bo'lganda, mazkur kesimlarda eguvchi momentlar nolga teng bo'ladi?  $q, l, EJ$  lar berilgan deb qabul qilinsin (XIV.53- shakl).

Izoh:  $B$  va  $C$  tayanchlar faqat vertikal yo'nalishda ko'chish imkoniyatiga ega.



XIV.53- shakl

### Yechish:

Masala sharti bo'yicha:

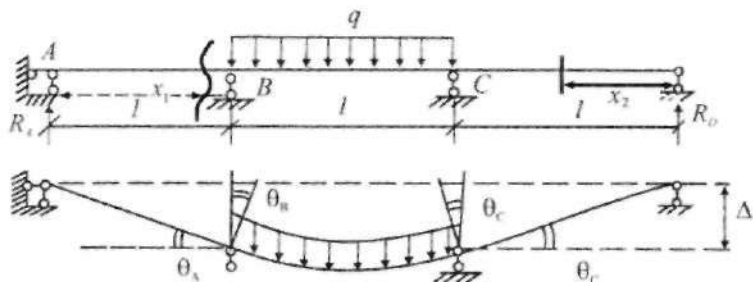
$$M_B = R_A \cdot l = 0; \quad M_C = R_D \cdot l = 0.$$

Bundan,  $R_A = R_D = 0$ ;

$$M_1 = R_A \cdot x_1 = 0; \quad M_2 = R_D \cdot x_2 = 0.$$

Ya'ni,  $AB, CD$  uchastkalarda eguvchi moment nolga teng.

Shu uchastkalar uchun  $EJy'' = 0$ ;  $EJy = C_1 \cdot x + C_2$ . Bu esa to'g'ri chiziqli tenglamasi. Demak, deformatsiya vaqtida  $AB$  va  $CD$  uchastkalar to'g'ri chiziqli holda qoladi.



XIV.54- shakl

Agar  $A$  va  $D$  tayanchlar bo'lmaganda, balkaning  $A$  va  $D$  kesimlari  $\Delta$  ga yuqoriga ko'tarilgan bo'lar edi. Lekin  $A$  va  $D$  kesimlarda qo'zg'almas tayanch bor. Shuning uchun  $C$  va  $B$  kesimlarni  $\Delta$  ga pastga tushiramiz (XIV.54- shakl).

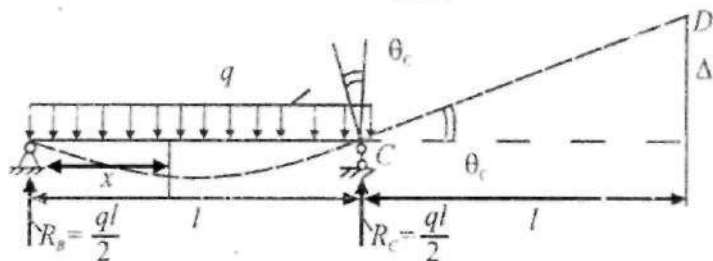
$$y = y_0 + \theta_B x + \frac{1}{EJ} \left( \frac{ql}{2} x^3 - \frac{qx^4}{24} \right)$$

Bu yerda,  $x = l$  da  $y(l) = 0$ ; u holda,

$$\theta_B l + \frac{1}{EJ} \left( \frac{ql^4}{12} - \frac{ql^4}{24} \right) = 0 \Rightarrow \theta_B = -\frac{ql^3}{24 EJ}; \quad \theta_C = |\theta_B| = \frac{ql^3}{24 EJ};$$

$$\Delta = \lg \theta_C \approx l \theta_C = \frac{ql^4}{24 EJ}.$$

Demak,  $B$  va  $C$  tayanchlarni vertikal holda  $\Delta = \frac{ql^4}{24 EJ}$  masofaga pastga ko'chirish kerak.

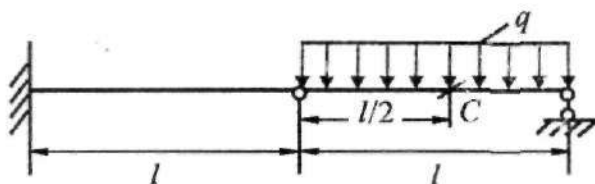


XIV.55- shakl

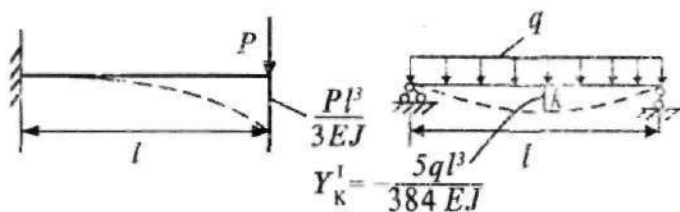
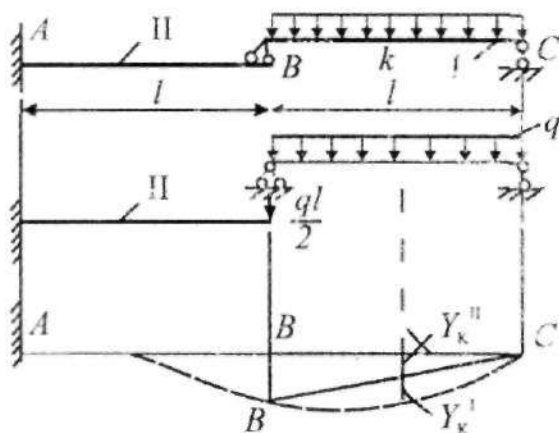


## 140- masala

Balkaning  $C$  kesimidagi solqiligi, nazariy usullardan foydalanilmasdan, oldin ma'lum bo'lgan yechimlardan aniqlansin.  $q$ ,  $l$ ,  $EJ$  lar ma'lum deb qabul qilinsin (XIV.56- shakl).



XIV.56- shakl



XIV.57- shakl

**Yechish:**

II konsol balkaning egilishi hisobiga I balka absolut qattiq jism kabi ko'chadi (XIV.57- shakl), ya'ni:

$$y_k^{II} = \frac{5ql^3}{384EJ}; \quad y_k^{II} = \frac{BB_1}{2} = -\frac{ql^4}{12EJ};$$

bu yerda,

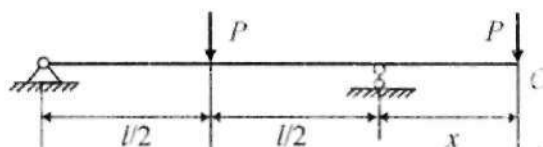
$$BB_1 = Y_B^{II} = -\frac{\frac{ql}{2} \cdot l^3}{3EJ} = -\frac{ql^4}{6EJ};$$

unda,

$$y_k = y_k^I + y_k^{II} = -\frac{5ql^4}{384EJ} - \frac{ql^4}{12EJ} = -\frac{37ql^4}{384EJ}.$$

**141- masala**

Balka konsolining uzunligi  $x$  nimaga teng bo'lganda,  $C$  kesimdagi solqilik nolga teng bo'ladi?  $P, l, EJ$  berilgan deb hisoblansin (XIV.58- shakl).



XIV.58- shakl

**Yechish:**

Balkani ikkita (I va II) balkalar yig'indisi deb qaraymiz (XIV.59- shakl).

U holda,

$$Y_C = Y_C^I + Y_C^{II}. \quad (1)$$

I balka uchun:

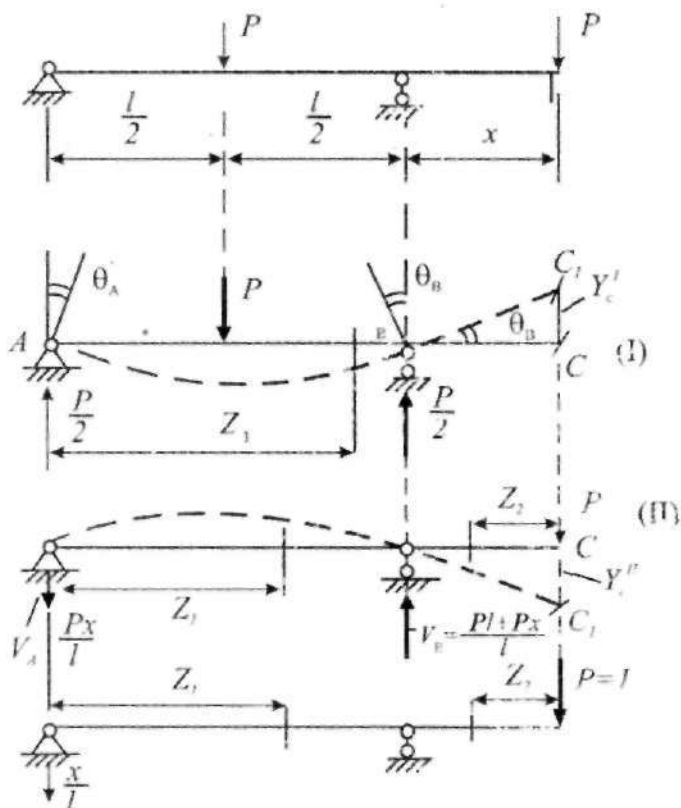
$$Y = Y_0 + \theta_0 z + \frac{1}{EJ} \frac{Px^3}{12};$$

$$Y_0 = 0; \quad \theta = \frac{dy}{dx} = \theta_0 + \frac{Px^2}{4EJ};$$

bu yerda,

$$x = \frac{l}{2} \text{ da } \theta = 0; \quad \theta_0 = -\frac{Pl^2}{16EJ}; \quad \theta_A = -\theta_B;$$

$$\theta_B = \frac{Pl^2}{16EJ}; \quad Y_C^I = \frac{Pl^2}{16EJ} \cdot x. \quad (2)$$



XIV.59- shakl

II balka uchun Mor integralidan foydalanamiz.

$$Y_c = \int_0^l \frac{M_1 \bar{M}_1}{EJ} \cdot dz_1 + \int_0^x \frac{M_2 \bar{M}_2}{EJ} \cdot dz_2 = \frac{1}{EJ} \left( \frac{Px^2 l}{3} + \frac{Px^3}{3} \right); \quad (3)$$

bu yerda,

$$M_1 = -\frac{Px}{l} \cdot z_1; \quad M_2 = -Px z_2;$$

$$\bar{M}_1 = -\frac{x}{l} \cdot z_1; \quad \bar{M}_2 = -z_2.$$

(2) va (3) ni (1) ga qo'yamiz:

$$\frac{Pl^3}{16 EJ} - \frac{1}{EJ} \left( \frac{Plx^2}{3} + \frac{Px^3}{3} \right) = 0.$$

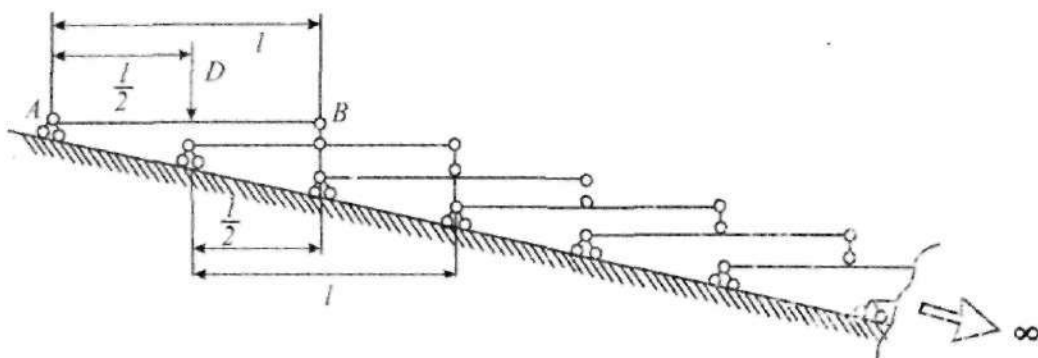
Bu yerdan,

$$16x^2 + 16xl - 3l^2 = 0.$$

$$x_{1,2} = \frac{-16 \pm 21,2}{32} \cdot l; \quad x_1 \approx 0,16l.$$

#### 142- masala

*AB* balkaning o'rtasidagi solqiligi aniqlansin.  $P, l$ , barcha balkalarning egilishidagi bikrligi  $EJ$  doimiy va berilgan deb qabul qilinsin (XIV.60- shakl).



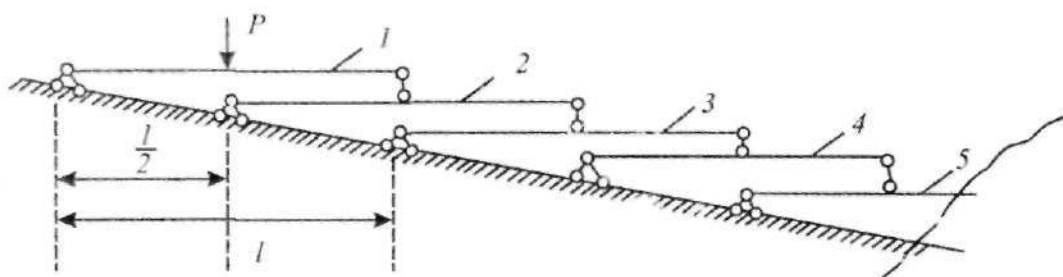
XIV.60- shakl

#### Yechish:

Balkalarning maksimal solqiliklari quyidagilarga teng (XIV.61- shakl):

$$\left. \begin{aligned} 1\text{- balkaning maksimal solqiligi:} \quad Y_1 &= \frac{Pl^3}{48 EJ}; \\ 2\text{- balkaning solqiligi:} \quad Y_2 &= \frac{Pl^3}{2 \cdot 48 EJ}; \\ 3\text{- balkaga } \frac{P}{4} \text{ kuch uzatiladi, shuning uchun: } Y_3 &= \frac{Pl^3}{4 \cdot 48 EJ}; \\ \text{va h.k.} \quad Y_4 &= \frac{Pl^3}{8 \cdot 48 EJ} \end{aligned} \right\} \quad (1)$$

1- balkada 2- balkaning solqiligi hisobiga  $Y_{1,2} = \frac{Y_2}{2}$  (2) solqilik hosil bo'ladi.



XIV.61- shakl

3- balkaning solqiligi hisobiga esa

$$Y_{1,3} = \frac{Y_3}{4}. \quad (3)$$

U holda,

$$Y_{1,4} = \frac{Y_4}{8}; \quad Y_{1,5} = \frac{Y_5}{16}.$$

Demak, 1- balkaning C kesimidagi solqiligi:

$$Y_c = Y_{11} + Y_{12} + Y_{13} + Y_{14} + Y_{15} + \dots \quad (4)$$

(4) formulaga (1), (2) va (3) larni olib kelib qo'yamiz:

$$Y_c = \frac{Pl^3}{48 EJ} + \frac{Pl^3}{4 \cdot 48 EJ} + \frac{Pl^3}{16 \cdot 48 EJ} + \frac{Pl^3}{64 \cdot 48 EJ} + \dots = \sigma_1 + \sigma_1 q + \sigma_1 q^2 + \sigma_1 q^3 + \dots$$

bu yerda,  $\sigma_1 = \frac{Pl^3}{48 EJ}$ .

Shunga ko'ra,  $q = \frac{1}{4}$  cheksiz kamayuvchi geometrik progressiya maxrajidir.

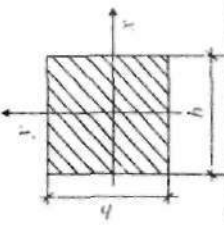
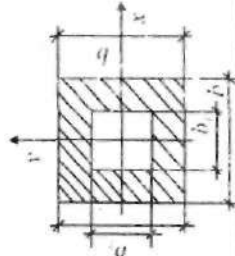
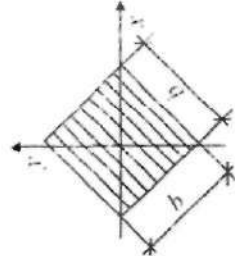
Yig'indi formulasi  $S = \frac{\sigma_1}{1-q}$ .

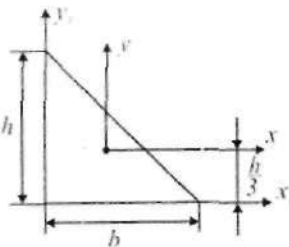
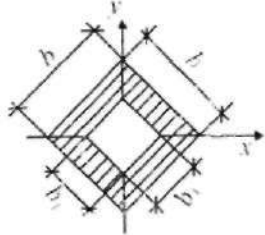
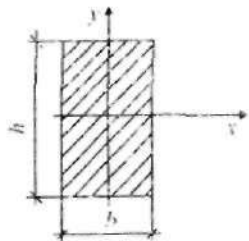
Unda,

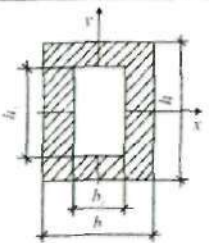
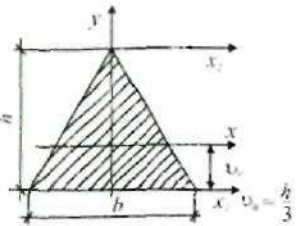
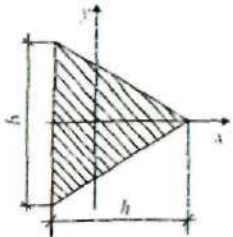
$$Y_c = \frac{\sigma_1}{1-q} = \frac{Pl^3}{48 EJ \left(1 - \frac{1}{4}\right)} = \frac{Pl^3}{36 EJ}.$$

1- ilova

Ba'zi tekis kesimlarning yuzalari, og'irlik markazi va geometrik tavsifnomalari

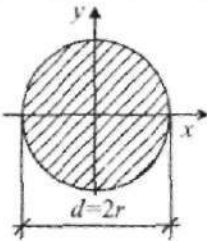
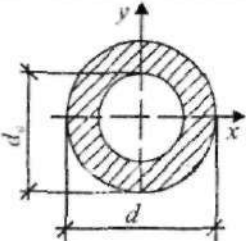
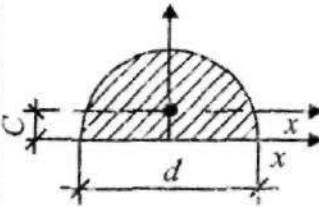
| Kesim                                                                                | Kesim yuzasi  | O'qlarga nisbatan inersiya momenti   | Qarshilik momenti                    | Inersiya radiusi                       |
|--------------------------------------------------------------------------------------|---------------|--------------------------------------|--------------------------------------|----------------------------------------|
| 1                                                                                    | 2             | 3                                    | 4                                    | 5                                      |
|   | $b^2$         | $I_x = I_y = \frac{b^4}{12}$         | $W_x = W_y = \frac{b^3}{6}$          | $i_x = i_y = \sqrt{\frac{b}{12}}$      |
|   | $b^2 - b_1^2$ | $I_x = I_y = \frac{b^4 - b_1^4}{12}$ | $W_x = W_y = \frac{b^4 - b_1^4}{6b}$ | $i_x = i_y = 0,289 \sqrt{b^2 + b_1^2}$ |
|  | $b^2$         | $I_x = I_y = \frac{b^4}{12}$         | $W_x = W_y = 0,118 b^3$              | $i_x = i_y = 0,289 b$                  |

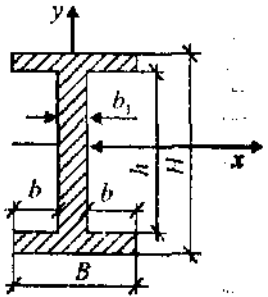
| 1                                                                                  | 2              | 3                                                                                                                | 4                                                                                                                    | 5                                                                                                                  |
|------------------------------------------------------------------------------------|----------------|------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|
|   | $\frac{hb}{2}$ | $J_x = \frac{bh^3}{36}$<br>$J_{x_1} = \frac{bh^3}{12}$<br>$J_y = \frac{bh^3}{36}$<br>$J_{y_1} = \frac{hb^3}{12}$ | <p>Yuqoridagi tolalar uchun:</p> $W_x = \frac{bh^2}{24}$<br><br><p>Pastki tolalar uchun:</p> $W_x = \frac{bh^2}{12}$ | <p>Markazdan qochirma inersiya momentlari:</p> $J_{xy} = \frac{h^2 b^2}{72}$<br>$J_{x_1 y_1} = \frac{b^2 h^2}{24}$ |
|   | $b^2 - b_1^2$  | $I_x = I_y = \frac{b^4 - b_1^4}{12}$                                                                             | $W_x = W_y = \frac{b^4 - b_1^4}{6\sqrt{2} \cdot b}$                                                                  | $i_x = i_y = 0,289 \sqrt{b^2 + b_1^2}$                                                                             |
|  | $bh$           | $I_x = \frac{bh^3}{12}$<br>$I_y = \frac{b^3 h}{12}$                                                              | $W_x = \frac{bh^2}{6}$<br>$W_y = \frac{b^2 h}{6}$                                                                    | $i_x = \frac{h}{\sqrt{12}}$<br>$i_y = \frac{b}{\sqrt{12}}$                                                         |

| 1                                                                                  | 2               | 3                                                                              | 4                                                                                                                                                                      | 5                                                                                                             |
|------------------------------------------------------------------------------------|-----------------|--------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------|
|   | $bh - b_1h_1$   | $I_x = \frac{bh^3 - b_1h_1^3}{12}$ $I_y = \frac{b^3h - b_1^3h_1}{12}$          | $W_x = \frac{bh^3 - b_1h_1^3}{6h}$ $W_y = \frac{b^3h - b_1^3h_1}{6b}$                                                                                                  | $i_x = \sqrt{\frac{bh^3 - b_1h_1^3}{12(bh - b_1h_1)}}$ $i_y = \sqrt{\frac{b^3h - b_1^3h_1}{12(bh - b_1h_1)}}$ |
|    | $\frac{1}{2}bh$ | $I_x = \frac{bh^3}{36}; I_{x_1} = \frac{bh^3}{12}$ $I_{x_1} = \frac{bh^3}{48}$ | <p>Uchburchak uchidagi kuchlanishni aniqlashda:</p> $W_x = \frac{bh^2}{24}$ <p>Uchburchak asosidagi nuqtalarning kuchlanishini aniqlashda:</p> $W_x = \frac{bh^2}{12}$ | $i_x = 0,236 h$                                                                                               |
|  | $\frac{1}{2}bh$ | $I_x = \frac{bh^3}{48}$                                                        | $W_x = \frac{bh^2}{24}$                                                                                                                                                | $i_x = 0,204 b$                                                                                               |

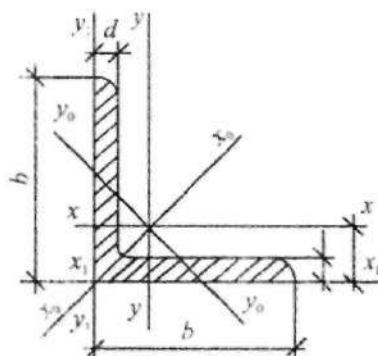


| 1                                                            | 2                   | 3                                                    | 4                                                                                                                                                                                                                                       | 5                                                               |
|--------------------------------------------------------------|---------------------|------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|
| <p> <math>u_x = \frac{h}{3} \frac{b+2b_1}{b+b_1}</math> </p> | $\frac{b+b_1}{2} h$ | $I_x = \frac{h^3 (b^2 + 4bb_1 + b_1^2)}{36 (b+b_1)}$ | <p>Yuqori asosdagi nuqtalarning kuchlanishini aniqlashda:</p> $W_x = \frac{h^2 (b^2 + 4bb_1 + b_1^2)}{12 (2b+b_1)}$ <p>Pastki asosdagi nuqtalarning kuchlanishini aniqlashda:</p> $W_y = \frac{h^2 (b^2 + 4bb_1 + b_1^2)}{12 (b+2b_1)}$ | $i_x = \frac{h}{6(b+b_1)} \times \sqrt{2(b^2 + 4bb_1 + b_1^2)}$ |
|                                                              | $\frac{b+b_1}{2} h$ | $I_x = \frac{h}{48} \frac{b^4 - b_1^4}{b - b_1}$     | $W_x = \frac{h}{24} \frac{b^4 - b_1^4}{b^2 - bb_1}$                                                                                                                                                                                     | $i_x = \sqrt{\frac{b^2 + b_1^2}{24}}$                           |
|                                                              | $2,598 a^2$         | $I_x = I_y = 0,541 a^4$                              | $W_x = 0,625 a^3$ $W_y = 0,541 a^3$                                                                                                                                                                                                     | $i_x = i_y = 0,4565 a$                                          |

| 1                                                                                                              | 2                        | 3                                                              | 4                                                                                                                                    | 5                                           |
|----------------------------------------------------------------------------------------------------------------|--------------------------|----------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------|
|  <p><math>d=2r</math></p>     | $\frac{\pi d^2}{4}$      | $I_x = I_y = \frac{\pi d^4}{64} = \frac{\pi r^4}{4}$           | $W_x = W_y = \frac{\pi d^3}{32} = \frac{\pi r^3}{4}$                                                                                 | $i_x = i_y = \frac{d}{4} = \frac{r}{2}$     |
|  <p><math>c = d_0/2</math></p> | $\frac{\pi(d-d_0^3)}{4}$ | $I_x = I_y = \frac{\pi d^4}{64}(1-c^4)$<br>$C = \frac{d_0}{d}$ | $W_x = W_y = \frac{\pi d^3}{32}(1-c^4)$                                                                                              | $i_x = i_y = \frac{1}{4}\sqrt{d^2 + d_0^2}$ |
|  <p><math>c=0,424r</math></p> | $\frac{\pi d^2}{8}$      | $I_x = 0,00686 d^4$<br>$I_y = \frac{\pi d^4}{128}$             | <p>Pastki tolalar uchun:</p> $W_x \approx 0,0324 d^3$ <p>Yuqoridagi tolalar uchun:</p> $W_x = 0,0239 d^3$ $W_y = \frac{\pi d^3}{64}$ | $i_x = 0,13 d$<br>$i_y = \frac{d}{4}$       |

| 1                                                                                 | 2              | 3                                                                   | 4                                                                   | 5                                                         |
|-----------------------------------------------------------------------------------|----------------|---------------------------------------------------------------------|---------------------------------------------------------------------|-----------------------------------------------------------|
|  | $2Bh_1 + b_1h$ | $I_x = \frac{Bh^3 - 2bh^3}{12}$ $I_y = \frac{hb_1^3 - 2h_1B^3}{12}$ | $W_x = \frac{BH^3 - 2bh^3}{6H}$ $W_y = \frac{hb_1^3 + 2h_1B^3}{6H}$ | $i_x = \sqrt{\frac{I_x}{A}}$ $i_y = \sqrt{\frac{I_y}{A}}$ |

# GOST 8509-72 ga muvofiq prokat po'latning sortamenti



## Yonlari teng burchakliklar

1- jadval

| Profilar<br>nomeri | O'lchamlari,<br>mm |   | Kesim<br>yuzasi<br>$A$ , $\text{sm}^2$ | $I_x$ , $\text{sm}^4$ | $I_y$ , $\text{sm}^4$ | $I_{x_0 \text{ max}}$ ,<br>$\text{sm}^4$ | $i_{x_0 \text{ max}}$ ,<br>$\text{sm}^4$ | $I_{y_0 \text{ min}}$ ,<br>$\text{sm}^4$ | $i_{y_0 \text{ min}}$ ,<br>$\text{sm}^4$ | $I_{x_1}$ ,<br>$\text{sm}^4$ | $z_0$ , $\text{sm}$ | Massa<br>1 m, kg |
|--------------------|--------------------|---|----------------------------------------|-----------------------|-----------------------|------------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|------------------------------|---------------------|------------------|
|                    | b                  | d |                                        |                       |                       |                                          |                                          |                                          |                                          |                              |                     |                  |
| 1                  | 2                  | 3 | 4                                      | 5                     | 6                     | 7                                        | 8                                        | 9                                        | 10                                       | 11                           | 12                  | 13               |
| 5                  | 50                 | 3 | 2,96                                   | 7,11                  | 1,55                  | 11,3                                     | 1,95                                     | 2,95                                     | 1                                        | 12,4                         | 1,33                | 2,38             |
|                    |                    | 4 | 3,89                                   | 9,21                  | 1,54                  | 14,6                                     | 1,94                                     | 3,8                                      | 0,99                                     | 16,6                         | 1,38                | 3,05             |
|                    |                    | 5 | 4,8                                    | 11,2                  | 1,53                  | 17,8                                     | 1,92                                     | 4,63                                     | 0,98                                     | 20,9                         | 1,42                | 3,77             |
| 5,6                | 56                 | 4 | 4,38                                   | 13,1                  | 1,73                  | 20,8                                     | 2,18                                     | 5,41                                     | 1,11                                     | 23,3                         | 1,52                | 3,44             |
|                    |                    | 5 | 5,41                                   | 16                    | 1,72                  | 25,4                                     | 2,16                                     | 6,54                                     | 1,1                                      | 29,2                         | 1,57                | 4,25             |

| 1   | 2  | 3   | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12   | 13   |
|-----|----|-----|------|------|------|------|------|------|------|------|------|------|
| 6,3 | 63 | 4   | 4,96 | 18,9 | 1,95 | 29,9 | 2,45 | 7,81 | 1,25 | 33,1 | 1,69 | 3,9  |
|     |    | 5   | 6,13 | 23,1 | 1,94 | 36,6 | 2,44 | 9,52 | 1,25 | 41,5 | 1,74 | 4,81 |
|     |    | 6   | 7,28 | 27,1 | 1,93 | 42,9 | 2,43 | 11,2 | 1,24 | 50   | 1,78 | 5,72 |
|     |    | 4,5 | 6,2  | 29   | 2,16 | 46   | 2,72 | 12   | 1,39 | 51   | 1,88 | 4,87 |
|     |    | 5   | 6,86 | 31,9 | 2,16 | 50,7 | 2,72 | 13,2 | 1,39 | 56,7 | 1,9  | 5,38 |
| 7   | 70 | 6   | 8,15 | 37,6 | 2,15 | 59,6 | 2,71 | 15,5 | 1,38 | 68,4 | 1,94 | 6,39 |
|     |    | 7   | 9,42 | 43   | 2,14 | 68,2 | 2,69 | 17,8 | 1,37 | 80,1 | 1,99 | 7,39 |
|     |    | 8   | 10,7 | 48,2 | 2,13 | 76,4 | 2,68 | 20   | 1,37 | 91,9 | 2,02 | 8,37 |
| 7,5 | 75 | 5   | 7,39 | 39,5 | 2,31 | 62,6 | 2,91 | 16,4 | 1,49 | 69,6 | 2,02 | 5,8  |
|     |    | 6   | 8,78 | 46,6 | 2,3  | 73,9 | 2,9  | 19,3 | 1,48 | 83,9 | 2,06 | 6,89 |
|     |    | 7   | 10,1 | 53,3 | 2,29 | 84,6 | 2,89 | 22,1 | 1,48 | 98,3 | 2,1  | 7,96 |
|     |    | 8   | 11,5 | 59,8 | 2,28 | 94,6 | 2,87 | 24,8 | 1,47 | 113  | 2,15 | 9,2  |
|     |    | 9   | 12,8 | 66,1 | 2,27 | 105  | 2,86 | 27,5 | 1,46 | 127  | 2,18 | 10,1 |
| 8   | 80 | 5,5 | 8,63 | 52,7 | 2,47 | 83,6 | 3,11 | 21,8 | 1,59 | 93,2 | 2,17 | 6,78 |
|     |    | 6   | 9,38 | 57   | 2,47 | 90,4 | 3,11 | 23,5 | 1,58 | 102  | 2,19 | 7,36 |
|     |    | 7   | 10,8 | 65,3 | 2,45 | 104  | 3,09 | 27   | 1,58 | 119  | 2,23 | 8,51 |
|     |    | 8   | 12,3 | 73,4 | 2,44 | 116  | 3,08 | 30,3 | 1,57 | 137  | 2,27 | 9,65 |

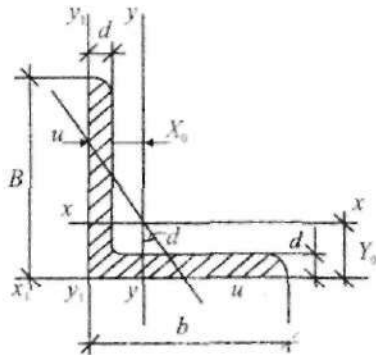
| 1    | 2   | 3   | 4    | 5    | 6    | 7   | 8    | 9    | 10    | 11   | 12   | 13   |
|------|-----|-----|------|------|------|-----|------|------|-------|------|------|------|
| 9    | 90  | 6   | 10,6 | 82,1 | 2,78 | 130 | 3,5  | 34   | 1,79  | 145  | 2,43 | 8,33 |
|      |     | 7   | 12,3 | 94,3 | 2,77 | 150 | 3,49 | 38,9 | 1,78  | 169  | 2,47 | 9,65 |
|      |     | 8   | 13,9 | 106  | 2,76 | 168 | 3,48 | 43,8 | 1,77  | 194  | 2,51 | 10,9 |
|      |     | 9   | 15,6 | 118  | 2,75 | 186 | 3,46 | 48,6 | 1,77  | 129  | 2,55 | 12,2 |
| 10   | 100 | 6,5 | 12,8 | 122  | 3,09 | 193 | 3,88 | 50,7 | 1,99  | 214  | 2,68 | 10,1 |
|      |     | 7   | 13,8 | 131  | 3,09 | 207 | 3,88 | 54,2 | 1,98  | 231  | 2,71 | 10,8 |
|      |     | 8   | 15,6 | 147  | 3,07 | 233 | 3,87 | 60,9 | 1,98  | 265  | 2,75 | 12,2 |
|      |     | 10  | 19,2 | 179  | 3,05 | 284 | 3,84 | 74,1 | 10,96 | 333  | 2,83 | 15,1 |
|      |     | 12  | 22,8 | 209  | 3,03 | 331 | 3,81 | 86,9 | 1,95  | 402  | 2,91 | 17,9 |
|      |     | 14  | 26,3 | 237  | 3    | 371 | 3,78 | 99,3 | 1,94  | 472  | 2,99 | 20,6 |
|      |     | 16  | 29,7 | 264  | 2,98 | 416 | 3,74 | 112  | 1,94  | 542  | 3,06 | 23,3 |
| 11   | 110 | 7   | 15,2 | 176  | 3,4  | 279 | 4,29 | 72,7 | 2,19  | 308  | 2,96 | 11,9 |
|      |     | 8   | 17,2 | 198  | 3,39 | 315 | 4,28 | 81,8 | 2,18  | 353  | 3    | 13,5 |
| 12.5 | 125 | 8   | 19,7 | 294  | 3,87 | 467 | 4,87 | 122  | 2,49  | 516  | 3,36 | 15,5 |
|      |     | 9   | 22   | 327  | 3,86 | 520 | 4,86 | 135  | 2,48  | 582  | 3,4  | 17,3 |
|      |     | 10  | 24,3 | 360  | 3,85 | 571 | 4,84 | 149  | 2,47  | 649  | 3,45 | 19,1 |
|      |     | 12  | 28,9 | 422  | 3,82 | 570 | 4,82 | 174  | 2,46  | 782  | 3,53 | 22,7 |
|      |     | 14  | 33,4 | 482  | 3,8  | 764 | 4,78 | 200  | 2,45  | 916  | 3,61 | 26,2 |
|      |     | 16  | 37,8 | 539  | 3,78 | 853 | 4,75 | 224  | 2,44  | 1051 | 3,68 | 29,6 |

| 1  | 2   | 3  | 4     | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12   | 13   |
|----|-----|----|-------|------|------|------|------|------|------|------|------|------|
| 14 | 140 | 9  | 24,7  | 466  | 4,34 | 739  | 5,47 | 192  | 2,79 | 888  | 3,78 | 19,4 |
|    |     | 10 | 27,3  | 512  | 4,33 | 814  | 5,46 | 211  | 2,78 | 911  | 3,82 | 21,5 |
|    |     | 12 | 32,5  | 602  | 4,31 | 957  | 5,43 | 248  | 2,76 | 1097 | 3,9  | 25,5 |
| 16 | 160 | 10 | 31,4  | 774  | 4,96 | 1229 | 6,25 | 319  | 3,19 | 1356 | 4,3  | 24,7 |
|    |     | 11 | 34,4  | 844  | 4,95 | 1341 | 6,24 | 348  | 3,18 | 1494 | 4,39 | 27   |
|    |     | 12 | 37,4  | 913  | 4,94 | 1450 | 6,23 | 376  | 3,17 | 1633 | 4,47 | 29,4 |
|    |     | 14 | 43,3  | 1046 | 4,92 | 1662 | 6,2  | 431  | 3,16 | 1911 | 4,55 | 34   |
|    |     | 16 | 49,1  | 1175 | 4,89 | 1866 | 6,17 | 485  | 4,14 | 2191 | 4,63 | 38,5 |
|    |     | 18 | 54,8  | 1299 | 4,87 | 2061 | 6,13 | 537  | 3,13 | 2472 | 4,7  | 43   |
|    |     | 20 | 60,4  | 1419 | 4,85 | 2248 | 6,10 | 589  | 3,12 | 2756 | 4,85 | 47,7 |
| 18 | 180 | 11 | 38,8  | 1216 | 5,6  | 1933 | 7,06 | 500  | 3,59 | 2128 | 4,89 | 30,5 |
|    |     | 12 | 42,2  | 1317 | 5,59 | 2093 | 7,04 | 540  | 3,58 | 2324 | 5,37 | 33,1 |
| 20 | 200 | 12 | 47,1  | 1823 | 6,22 | 2896 | 7,84 | 749  | 3,99 | 3182 | 5,42 | 37   |
|    |     | 13 | 5,9   | 1961 | 6,21 | 3116 | 7,83 | 805  | 3,98 | 3452 | 5,46 | 39,9 |
|    |     | 14 | 54,6  | 2094 | 6,2  | 3333 | 7,81 | 861  | 3,97 | 3722 | 5,54 | 42,8 |
|    |     | 16 | 62    | 2363 | 6,17 | 3755 | 7,78 | 970  | 3,96 | 4265 | 5,7  | 48,7 |
|    |     | 20 | 76,5  | 2871 | 6,12 | 4560 | 7,72 | 1182 | 3,93 | 5355 | 5,89 | 60,1 |
|    |     | 25 | 94,3  | 3466 | 6,06 | 5494 | 7,63 | 1438 | 3,91 | 6733 | 6,07 | 74   |
|    |     | 30 | 111,5 | 4020 | 6    | 6351 | 7,55 | 1688 | 3,89 | 8130 | 6,07 | 87,6 |

| 1  | 2   | 3  | 4     | 5    | 6    | 7     | 8    | 9    | 10   | 11    | 12   | 13    |
|----|-----|----|-------|------|------|-------|------|------|------|-------|------|-------|
| 22 | 220 | 14 | 60,4  | 2814 | 6,83 | 4470  | 8,6  | 1159 | 4,38 | 4941  | 5,93 | 47,4  |
|    |     | 16 | 68,6  | 3175 | 6,81 | 5045  | 8,58 | 1306 | 4,36 | 5661  | 6,02 | 53,8  |
| 25 | 250 | 16 | 78,4  | 4717 | 7,76 | 7492  | 9,78 | 1942 | 4,98 | 8286  | 6,75 | 61,5  |
|    |     | 18 | 87,7  | 5247 | 7,73 | 8337  | 9,75 | 2158 | 4,96 | 9342  | 6,83 | 68,9  |
|    |     | 20 | 97    | 5765 | 7,71 | 9160  | 9,72 | 2370 | 4,94 | 10401 | 6,91 | 76,1  |
|    |     | 22 | 106,1 | 5270 | 7,69 | 9961  | 9,69 | 2579 | 4,93 | 11464 | 7    | 83,3  |
|    |     | 25 | 119,7 | 7006 | 7,65 | 11125 | 9,64 | 2887 | 4,91 | 13064 | 7,11 | 94    |
|    |     | 28 | 133,1 | 7717 | 7,61 | 12244 | 9,59 | 3190 | 4,89 | 14674 | 7,23 | 104,5 |
|    |     | 30 | 142   | 8177 | 7,59 | 12965 | 9,56 | 3389 | 4,89 | 15753 | 7,31 | 111,4 |



# GOST 8510-72 ga muvofiq prokat po'latning sortamenti



## Yonlari teng bo'lmagan burchakliklar

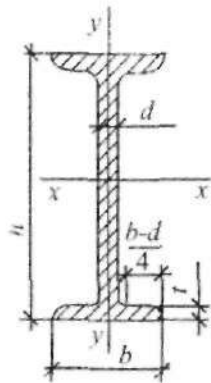
2- jadval

| Pro-<br>fillar<br>nomeri | O'lchamlari,<br>mm |    |   | Kesim<br>yuzasi<br>A, sm <sup>2</sup> | $I_{x1}$ ,<br>sm <sup>4</sup> | $i_{x1}$ ,<br>sm | $I_{y1}$ ,<br>sm <sup>4</sup> | $i_{y1}$ ,<br>sm | $I_{x0}$ ,<br>sm <sup>4</sup> | $i_{x0}$ ,<br>sm | tg $\alpha$ | $I_{y0}$ ,<br>sm <sup>4</sup> | $i_{y0}$ ,<br>sm | $x_{01}$ ,<br>sm | $y_{01}$ ,<br>sm | Mas-<br>sa 1 m,<br>kg |
|--------------------------|--------------------|----|---|---------------------------------------|-------------------------------|------------------|-------------------------------|------------------|-------------------------------|------------------|-------------|-------------------------------|------------------|------------------|------------------|-----------------------|
|                          | B                  | b  | d |                                       |                               |                  |                               |                  |                               |                  |             |                               |                  |                  |                  |                       |
| 1                        | 2                  | 3  | 4 | 5                                     | 6                             | 7                | 8                             | 9                | 10                            | 11               | 12          | 13                            | 14               | 15               | 16               | 17                    |
| 5,6/3,6                  | 56                 | 36 | 4 | 3,58                                  | 11,4                          | 1,78             | 3,7                           | 1,02             | 2,19                          | 0,78             | 0,406       | 23,2                          | 6,25             | 0,84             | 1,82             | 2,81                  |
|                          |                    |    | 5 | 4,41                                  | 13,8                          | 1,77             | 4,48                          | 1,01             | 2,66                          | 0,78             | 0,404       | 29,2                          | 7,91             | 0,88             | 1,86             | 3,46                  |
| 6,3/4                    | 63                 | 40 | 4 | 4,04                                  | 16,3                          | 2,01             | 5,16                          | 1,13             | 3,07                          | 0,87             | 0,397       | 33                            | 8,51             | 0,91             | 2,03             | 3,17                  |
|                          |                    |    | 5 | 4,98                                  | 19,9                          | 2                | 6,26                          | 1,12             | 3,72                          | 0,86             | 0,396       | 41,4                          | 10,8             | 0,95             | 2,08             | 3,91                  |
|                          |                    |    | 6 | 5,9                                   | 23,3                          | 1,99             | 7,28                          | 1,11             | 4,36                          | 0,86             | 0,393       | 49,9                          | 13,1             | 0,99             | 2,12             | 4,91                  |
|                          |                    |    | 8 | 7,68                                  | 29,6                          | 2,23             | 9,15                          | 1,09             | 5,58                          | 0,85             | 0,386       | 66,9                          | 17,9             | 1,07             | 2,20             | 4,63                  |

| 1      | 2   | 3  | 4   | 5     | 6    | 7     | 8    | 9    | 10   | 11   | 12    | 13   | 14   | 15   | 16   | 17   |
|--------|-----|----|-----|-------|------|-------|------|------|------|------|-------|------|------|------|------|------|
| 7/4,5  | 70  | 45 | 5   | 5,95  | 27,8 | 2,39  | 9,05 | 1,27 | 5,34 | 0,98 | 0,406 | 56,7 | 15,2 | 1,05 | 2,28 | 6,03 |
|        |     |    | 5   | 6,11  | 34,8 | 2,38  | 12,5 | 1,43 | 7,24 | 1,09 | 0,436 | 69,7 | 20,8 | 1,17 | 2,39 | 4,39 |
| 7,5/5  | 75  | 50 | 6   | 7,25  | 40,9 | 2,35  | 14,6 | 1,42 | 8,48 | 1,08 | 0,435 | 83,9 | 25,2 | 1,21 | 2,44 | 4,79 |
|        |     |    | 8   | 9,47  | 52,4 | 2,56  | 18,5 | 1,4  | 10,9 | 1,07 | 0,43  | 112  | 34,2 | 1,29 | 2,52 | 5,69 |
| 8/5    | 80  | 50 | 5   | 6,36  | 41,6 | 2,55  | 12,7 | 1,41 | 7,58 | 1,09 | 0,387 | 84,6 | 20,8 | 1,13 | 2,6  | 7,43 |
|        |     |    | 6   | 7,55  | 49   | 2,88  | 14,8 | 1,4  | 8,88 | 1,08 | 0,386 | 102  | 25,2 | 1,17 | 2,65 | 4,99 |
| 9/5,6  | 90  | 56 | 5,5 | 7,86  | 65,3 | 2,88  | 19,7 | 1,58 | 11,8 | 1,22 | 0,384 | 132  | 32,2 | 1,26 | 2,92 | 5,92 |
|        |     |    | 6   | 8,54  | 79,6 | 2,858 | 21,2 | 1,58 | 12,7 | 1,22 | 0,384 | 145  | 35,2 | 1,28 | 2,95 | 6,17 |
|        |     |    | 8   | 11,18 | 90,9 | 3,2   | 27,1 | 1,56 | 16,3 | 1,21 | 0,38  | 194  | 47,8 | 1,36 | 3,04 | 6,7  |
| 10/6,3 | 100 | 63 | 6   | 9,59  | 98,3 | 3,19  | 30,6 | 1,79 | 18,2 | 1,38 | 0,393 | 198  | 49,9 | 1,42 | 3,23 | 7,53 |
|        |     |    | 7   | 11,1  | 113  | 3,15  | 35   | 1,78 | 20,8 | 1,37 | 0,392 | 232  | 58,7 | 1,46 | 3,28 | 8,7  |
|        |     |    | 8   | 12,6  | 127  | 3,53  | 39,2 | 1,77 | 23,4 | 1,36 | 0,391 | 266  | 67,6 | 1,5  | 3,32 | 9,87 |
|        |     |    | 10  | 15,5  | 154  | 3,50  | 47,1 | 1,75 | 28,3 | 1,35 | 0,387 | 333  | 85,8 | 1,58 | 3,4  | 12,1 |
| 11/7   | 110 | 70 | 6,5 | 11,4  | 142  | 4,01  | 45,6 | 2    | 26,9 | 1,53 | 0,402 | 286  | 74,3 | 1,58 | 3,55 | 8,98 |
|        |     |    | 8   | 13,9  | 172  | 4     | 54,6 | 1,98 | 32,3 | 1,52 | 0,4   | 353  | 92,3 | 1,64 | 3,61 | 10,9 |
| 12,5/8 | 125 | 80 | 7   | 14,1  | 227  | 3,98  | 73,7 | 2,29 | 43,4 | 1,76 | 0,407 | 452  | 119  | 1,8  | 4,01 | 11   |
|        |     |    | 8   | 16    | 256  | 3,95  | 83   | 2,28 | 48,8 | 1,75 | 0,406 | 518  | 137  | 1,84 | 4,05 | 12,5 |
|        |     |    | 10  | 19,7  | 312  | 4,49  | 100  | 2,26 | 59,3 | 1,74 | 0,404 | 649  | 173  | 1,92 | 4,14 | 15,5 |
|        |     |    | 12  | 23,4  | 365  | 4,47  | 117  | 2,24 | 69,5 | 1,72 | 0,4   | 781  | 210  | 2    | 5,22 | 18,3 |

| 1       | 2   | 3   | 4  | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12    | 13    | 14   | 15   | 16   | 17   |
|---------|-----|-----|----|------|------|------|------|------|------|------|-------|-------|------|------|------|------|
| 14/9    | 140 | 90  | 8  | 18   | 364  | 5,15 | 120  | 2,58 | 70,3 | 1,98 | 0,411 | 727   | 194  | 2,03 | 4,49 | 14,1 |
|         |     |     | 10 | 22,2 | 444  | 5,13 | 146  | 2,56 | 85,5 | 1,96 | 0,409 | 911   | 245  | 2,12 | 4,58 | 17,5 |
| 16/10   | 160 | 100 | 9  | 22,9 | 606  | 5,11 | 186  | 2,85 | 110  | 2,2  | 0,391 | 1212  | 300  | 2,23 | 5,19 | 18   |
|         |     |     | 10 | 25,3 | 667  | 5,08 | 204  | 2,84 | 121  | 2,19 | 0,39  | 1359  | 335  | 2,28 | 5,23 | 19,8 |
|         |     |     | 12 | 30   | 784  | 5,8  | 239  | 2,82 | 142  | 2,18 | 0,388 | 1634  | 405  | 2,36 | 5,32 | 23,6 |
|         |     |     | 14 | 34,7 | 897  | 8,17 | 272  | 2,8  | 162  | 2,16 | 0,385 | 1910  | 477  | 2,43 | 5,4  | 27,3 |
| 18/11   | 180 | 110 | 10 | 28,3 | 952  | 5,7  | 276  | 3,12 | 165  | 2,42 | 0,375 | 1933  | 444  | 2,44 | 5,88 | 22,2 |
|         |     |     | 12 | 33,7 | 1123 | 5,77 | 324  | 3,1  | 194  | 2,4  | 0,374 | 2324  | 537  | 2,52 | 5,97 | 26,4 |
|         |     |     | 11 | 34,9 | 1449 | 6,45 | 446  | 3,58 | 264  | 2,75 | 0,392 | 2920  | 718  | 2,79 | 6,5  | 27,4 |
| 20/12,5 | 200 | 125 | 12 | 37,9 | 1568 | 6,43 | 482  | 3,57 | 285  | 2,74 | 0,392 | 3189  | 786  | 2,83 | 6,54 | 29,7 |
|         |     |     | 14 | 43,9 | 1801 | 6,41 | 551  | 3,54 | 327  | 2,73 | 0,39  | 3726  | 922  | 2,91 | 6,62 | 34,4 |
|         |     |     | 16 | 49,8 | 2026 | 6,38 | 617  | 3,52 | 367  | 2,72 | 0,388 | 4264  | 1061 | 2,99 | 6,71 | 39,1 |
| 25/16   | 250 | 160 | 12 | 48,3 | 3147 | 8,07 | 1032 | 4,62 | 604  | 3,54 | 0,41  | 6212  | 1634 | 3,53 | 7,97 | 37,9 |
|         |     |     | 16 | 62,6 | 4091 | 8,02 | 1333 | 4,58 | 781  | 3,5  | 0,408 | 8308  | 2200 | 3,69 | 8,14 | 49,9 |
|         |     |     | 18 | 71,7 | 4545 | 7,99 | 1475 | 4,56 | 866  | 3,49 | 0,407 | 9358  | 2487 | 3,77 | 8,23 | 55,8 |
|         |     |     | 20 | 78,5 | 4987 | 7,97 | 1613 | 4,53 | 949  | 3,48 | 0,405 | 10410 | 2776 | 3,85 | 8,31 | 61,7 |

## Qo'shtavrlar (GOST 8239-72)

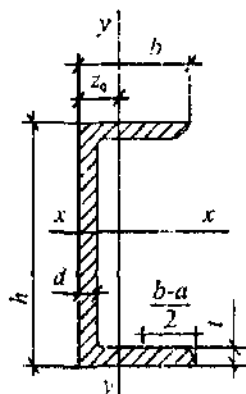


3- jadval

| Profilar<br>raqami | O'lchamlari, mm |     |     |     | Kesim<br>yuzasi<br>A, sm <sup>2</sup> | $I_x$ ,<br>sm <sup>4</sup> | $W_x$ ,<br>sm <sup>3</sup> | $i_x$ ,<br>sm | $S_x$ ,<br>sm <sup>3</sup> | $I_y$ ,<br>sm <sup>4</sup> | $W_y$ ,<br>sm <sup>3</sup> | $i_y$ ,<br>sm | massa 1 m,<br>kg |
|--------------------|-----------------|-----|-----|-----|---------------------------------------|----------------------------|----------------------------|---------------|----------------------------|----------------------------|----------------------------|---------------|------------------|
|                    | h               | b   | d   | t   |                                       |                            |                            |               |                            |                            |                            |               |                  |
| 1                  | 2               | 3   | 4   | 5   | 6                                     | 7                          | 8                          | 9             | 10                         | 11                         | 12                         | 13            | 14               |
| 10                 | 100             | 55  | 4,5 | 7,2 | 12                                    | 198                        | 39,7                       | 4,06          | 23                         | 17,9                       | 6,49                       | 1,22          | 9,46             |
| 12                 | 120             | 64  | 4,8 | 7,3 | 14,7                                  | 350                        | 58,4                       | 4,88          | 33,7                       | 27,9                       | 8,72                       | 1,38          | 11,5             |
| 14                 | 140             | 73  | 4,9 | 7,5 | 17,4                                  | 352                        | 81,7                       | 5,73          | 46,8                       | 41,9                       | 11,5                       | 1,55          | 13,7             |
| 16                 | 160             | 81  | 5   | 7,8 | 20,2                                  | 873                        | 109                        | 6,57          | 62,3                       | 58,6                       | 14,5                       | 1,70          | 15,9             |
| 18                 | 180             | 90  | 5,1 | 8,1 | 23,4                                  | 1290                       | 143                        | 7,42          | 81,4                       | 82,6                       | 18,4                       | 1,88          | 18,4             |
| 18a                | 180             | 100 | 5,1 | 8,3 | 25,4                                  | 1430                       | 159                        | 7,51          | 89,8                       | 114                        | 22,8                       | 2,12          | 19,9             |
| 20                 | 200             | 100 | 5,2 | 8,4 | 26,8                                  | 1840                       | 184                        | 8,28          | 104                        | 115                        | 23,1                       | 2,07          | 21               |
| 20a                | 200             | 110 | 5,2 | 8,6 | 28,9                                  | 2030                       | 203                        | 8,37          | 114                        | 155                        | 28,2                       | 2,32          | 22,7             |
| 22                 | 220             | 110 | 5,4 | 8,7 | 30,6                                  | 2550                       | 232                        | 9,13          | 131                        | 157                        | 28,6                       | 2,27          | 24               |
| 22a                | 220             | 120 | 5,4 | 8,9 | 32,8                                  | 2790                       | 254                        | 9,22          | 143                        | 206                        | 34,3                       | 2,5           | 25,8             |

| 1   | 2   | 3   | 4   | 5    | 6    | 7     | 8    | 9    | 10   | 11   | 12   | 13   | 14   |
|-----|-----|-----|-----|------|------|-------|------|------|------|------|------|------|------|
| 24  | 240 | 115 | 5.6 | 9.5  | 34.8 | 3460  | 289  | 9.97 | 163  | 198  | 34.5 | 2.37 | 27.3 |
| 24a | 240 | 125 | 5.6 | 9.8  | 37.5 | 3800  | 317  | 10.1 | 178  | 260  | 41.6 | 2.63 | 29.4 |
| 27  | 270 | 125 | 6   | 9.8  | 40.2 | 5010  | 371  | 11.2 | 210  | 260  | 41.5 | 2.54 | 31.5 |
| 27a | 270 | 135 | 6   | 10.2 | 43.2 | 5500  | 407  | 11.3 | 229  | 337  | 50   | 2.8  | 33.9 |
| 30  | 300 | 135 | 6.5 | 10.2 | 46.5 | 7080  | 472  | 12.3 | 268  | 337  | 49.9 | 2.69 | 36.5 |
| 30a | 300 | 145 | 6.5 | 10.7 | 49.9 | 7780  | 518  | 12.5 | 292  | 436  | 60.1 | 2.95 | 39.2 |
| 33  | 330 | 140 | 7   | 11.2 | 53.8 | 9840  | 597  | 13.5 | 339  | 419  | 59.9 | 2.79 | 42.2 |
| 36  | 360 | 145 | 7.5 | 12.3 | 61.9 | 13380 | 743  | 14.7 | 423  | 516  | 71.1 | 2.89 | 48.6 |
| 40  | 400 | 155 | 8.3 | 13   | 71.6 | 19062 | 953  | 16.2 | 545  | 667  | 86.1 | 3.03 | 57   |
| 45  | 450 | 160 | 9   | 14.2 | 84.7 | 27696 | 1231 | 18.1 | 708  | 808  | 101  | 3.09 | 66.5 |
| 50  | 500 | 170 | 10  | 15.2 | 100  | 39727 | 1589 | 19.9 | 919  | 1043 | 123  | 3.23 | 78.5 |
| 55  | 550 | 180 | 11  | 16.5 | 118  | 55962 | 2035 | 21.8 | 1181 | 1356 | 151  | 3.39 | 92.6 |
| 60  | 600 | 190 | 12  | 17.8 | 138  | 76806 | 2560 | 23.6 | 1491 | 1725 | 182  | 3.54 | 108  |

## Shvellerlar (GOST 8240-72)

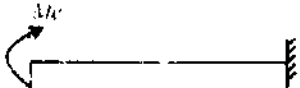
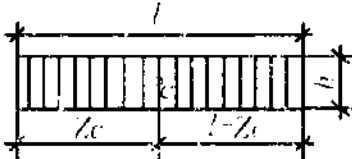
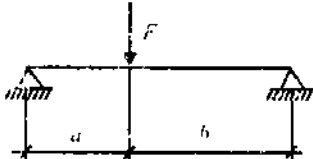
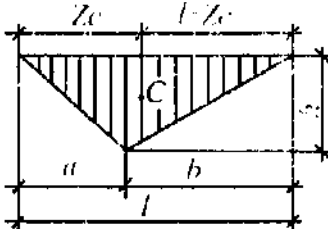
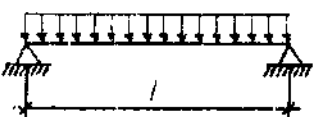
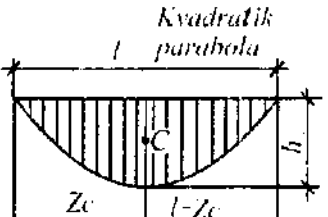


4- jadval

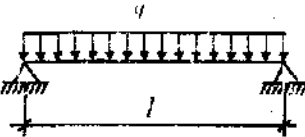
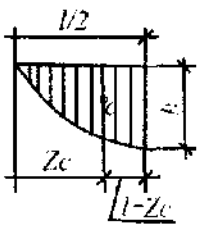
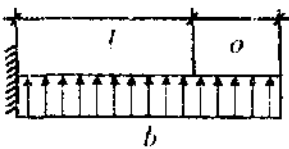
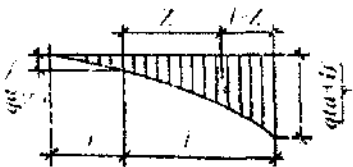
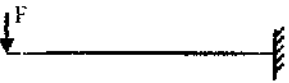
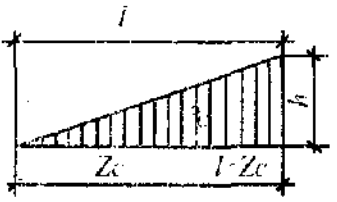
| Profilar<br>nomeri | O'lchamlari, mm |    |     |     | Kesim<br>yuzasi A,<br>sm <sup>2</sup> | $I_x$ ,<br>sm <sup>4</sup> | $W_x$ ,<br>sm <sup>3</sup> | $i_x$ ,<br>sm | $S_x$ ,<br>sm <sup>3</sup> | $I_y$ ,<br>sm <sup>4</sup> | $W_y$ ,<br>sm <sup>3</sup> | $i_y$ ,<br>sm | $z_0$ ,<br>sm | massa<br>l m,<br>kg |
|--------------------|-----------------|----|-----|-----|---------------------------------------|----------------------------|----------------------------|---------------|----------------------------|----------------------------|----------------------------|---------------|---------------|---------------------|
|                    | h               | b  | d   | t   |                                       |                            |                            |               |                            |                            |                            |               |               |                     |
| 1                  | 2               | 3  | 4   | 5   | 6                                     | 7                          | 8                          | 9             | 10                         | 11                         | 12                         | 13            | 14            | 15                  |
| 5                  | 50              | 32 | 4,4 | 7   | 6,16                                  | 22,8                       | 9,1                        | 1,92          | 5,59                       | 5,61                       | 2,75                       | 0,954         | 1,16          | 4,84                |
| 6,5                | 65              | 36 | 4,4 | 7,2 | 7,51                                  | 48,6                       | 15                         | 2,54          | 9                          | 8,7                        | 3,68                       | 1,08          | 1,24          | 5,9                 |
| 8                  | 80              | 40 | 4,5 | 7,4 | 8,98                                  | 89,4                       | 22,4                       | 3,16          | 13,3                       | 12,8                       | 4,75                       | 1,19          | 1,31          | 7,05                |
| 10                 | 100             | 46 | 4,5 | 7,6 | 10,9                                  | 174                        | 34,8                       | 3,99          | 20,4                       | 20,4                       | 6,46                       | 1,37          | 1,44          | 8,59                |
| 12                 | 120             | 52 | 4,8 | 7,8 | 13,3                                  | 304                        | 50,6                       | 4,78          | 29,6                       | 31,2                       | 8,52                       | 1,53          | 1,54          | 10,4                |
| 14                 | 140             | 58 | 4,9 | 8,1 | 15,6                                  | 491                        | 70,2                       | 5,6           | 40,8                       | 45,4                       | 11                         | 1,7           | 1,67          | 12,3                |
| 14a                | 140             | 62 | 4,9 | 8,7 | 17                                    | 545                        | 77,8                       | 5,66          | 45,1                       | 57,5                       | 13,3                       | 1,84          | 1,87          | 13,3                |

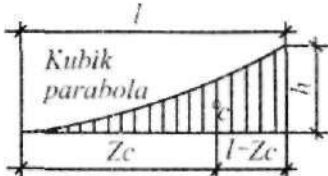
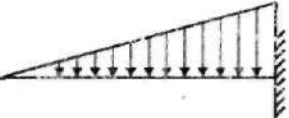
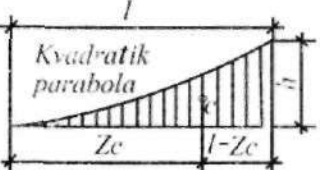
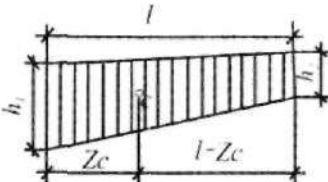
| 1   | 2   | 3   | 4   | 5    | 6    | 7     | 8    | 9    | 10   | 11   | 12   | 13   | 14   | 15   |
|-----|-----|-----|-----|------|------|-------|------|------|------|------|------|------|------|------|
| 16  | 160 | 64  | 5   | 8,4  | 18,1 | 747   | 93,4 | 6,42 | 54,1 | 63,6 | 13,8 | 1,87 | 1,8  | 14,2 |
| 16a | 160 | 68  | 5   | 9    | 19,5 | 823   | 103  | 6,49 | 59,4 | 78,8 | 16,4 | 2,01 | 2    | 15,3 |
| 18  | 180 | 70  | 5,1 | 8,7  | 20,7 | 1090  | 121  | 7,24 | 69,8 | 86   | 17   | 2,04 | 1,94 | 16,3 |
| 18a | 180 | 74  | 5,1 | 9,3  | 22,2 | 1190  | 132  | 7,32 | 76,1 | 105  | 20   | 2,18 | 2,13 | 17,4 |
| 20  | 200 | 78  | 5,2 | 9    | 23,4 | 1520  | 152  | 8,07 | 87,8 | 113  | 20,5 | 2,2  | 2,07 | 18,4 |
| 20a | 200 | 80  | 5,2 | 9,7  | 25,2 | 1670  | 167  | 8,1  | 95,9 | 139  | 24,2 | 2,35 | 2,28 | 19,8 |
| 22  | 220 | 82  | 5,4 | 9,5  | 26,7 | 2110  | 192  | 8,89 | 110  | 151  | 25,1 | 2,37 | 2,21 | 21   |
| 22a | 220 | 87  | 5,4 | 10,2 | 28,8 | 2330  | 212  | 8,99 | 121  | 187  | 30   | 2,55 | 2,46 | 22,6 |
| 24  | 240 | 90  | 5,6 | 10   | 30,6 | 2900  | 242  | 9,73 | 139  | 208  | 31,6 | 2,6  | 2,42 | 24   |
| 24a | 240 | 95  | 5,6 | 10,7 | 32,9 | 3180  | 265  | 9,84 | 151  | 254  | 37,2 | 2,78 | 2,67 | 25,8 |
| 27  | 270 | 95  | 6   | 10,5 | 35,2 | 4160  | 308  | 10,9 | 178  | 262  | 37,3 | 2,73 | 2,47 | 27,7 |
| 30  | 300 | 100 | 6,5 | 11   | 40,5 | 5810  | 387  | 12   | 224  | 327  | 43,6 | 2,84 | 2,52 | 31,8 |
| 33  | 330 | 105 | 7   | 11,7 | 46,5 | 7980  | 484  | 13,1 | 281  | 410  | 51,8 | 2,97 | 2,59 | 36,5 |
| 36  | 360 | 110 | 7,6 | 12,6 | 53,4 | 10820 | 601  | 14,2 | 350  | 513  | 61,7 | 3,1  | 2,68 | 41,9 |
| 40  | 400 | 115 | 8   | 13,5 | 61,5 | 15220 | 761  | 15,7 | 444  | 642  | 73,4 | 3,23 | 2,75 | 48,3 |

## Oddiy kesmalar yuzalari va og'irlik markazlarining joylashishi

| Yuklama                                                                           | Epyura $M$                                                                         | Yuza            | Og'irlik markazi |                 |
|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------|-----------------|------------------|-----------------|
|                                                                                   |                                                                                    |                 | $z_c$            | $l - z_c$       |
| 1                                                                                 | 2                                                                                  | 3               | 4                | 5               |
|   |   | $lh$            | $\frac{l}{2}$    | $\frac{l}{2}$   |
|   |   | $\frac{lh}{2}$  | $\frac{a+l}{3}$  | $\frac{b+l}{3}$ |
|  |  | $\frac{2}{3}lh$ | $\frac{l}{2}$    | $\frac{l}{2}$   |



| 1                                                                                | 2                                                                                                                            | 3                                           | 4                                                              | 5                                                             |
|----------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------|----------------------------------------------------------------|---------------------------------------------------------------|
|  | <p><i>Kvadratik parabolaning yarmi</i></p>  | $\frac{lh}{3}$                              | $\frac{5}{16}l$                                                | $\frac{3}{16}l$                                               |
|  | <p><i>Kvadratik parabola</i></p>            | $\frac{ql}{6} \left[ l^2 + 3a(a+l) \right]$ | $\frac{1}{4} \frac{6d^2l + 8al^2 + 3l^3}{3a^2l + 3al^2 + l^3}$ | $\frac{1}{4} \frac{6a^2l + 4al^2 + l^3}{3a^2l + 3al^2 + l^3}$ |
|  |                                            | $\frac{lh}{2}$                              | $\frac{2}{3}l$                                                 | $\frac{1}{3}l$                                                |

| 1                                                                                | 2                                                                                 | 3                        | 4                                    | 5                                    |
|----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|--------------------------|--------------------------------------|--------------------------------------|
|  |  | $\frac{lh}{3}$           | $\frac{3}{4}l$                       | $\frac{1}{4}l$                       |
|  |  | $\frac{lh}{4}$           | $\frac{4}{5}l$                       | $\frac{1}{5}l$                       |
|  |  | $\frac{(h_1 + h_2)l}{2}$ | $\frac{(h_1 + 2h_2)l}{3(h_1 + h_2)}$ | $\frac{(h_1 + 2h_2)l}{3(h_1 + h_2)}$ |

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