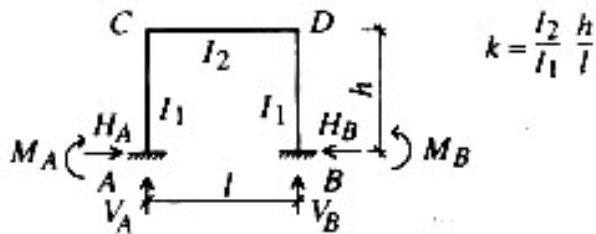
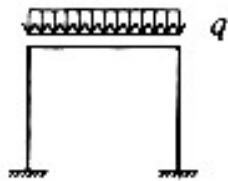


## Proračun uklještenih ramova – vertikalno opterećenje

1



$$k = \frac{I_2}{I_1} \frac{h}{l}$$



$$H = H_A = H_B = \frac{ql^2}{4h(k+2)}$$

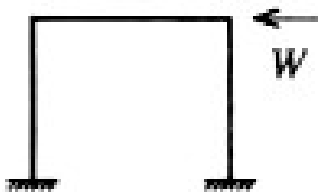
$$V_A = V_B = \frac{ql}{2}$$

$$M_A = M_B = \frac{ql^2}{12(k+2)} = H \frac{h}{3}$$

$$M_C = M_D = \frac{ql^2}{6(k+2)} = -2H \frac{h}{3}$$

## Uklješteni ramovi – horizontalno opterećenje

2



$$H_A = -H_B = \frac{W}{2}$$

$$V_A = -V_B = \frac{3Whk}{l(6k+1)}$$

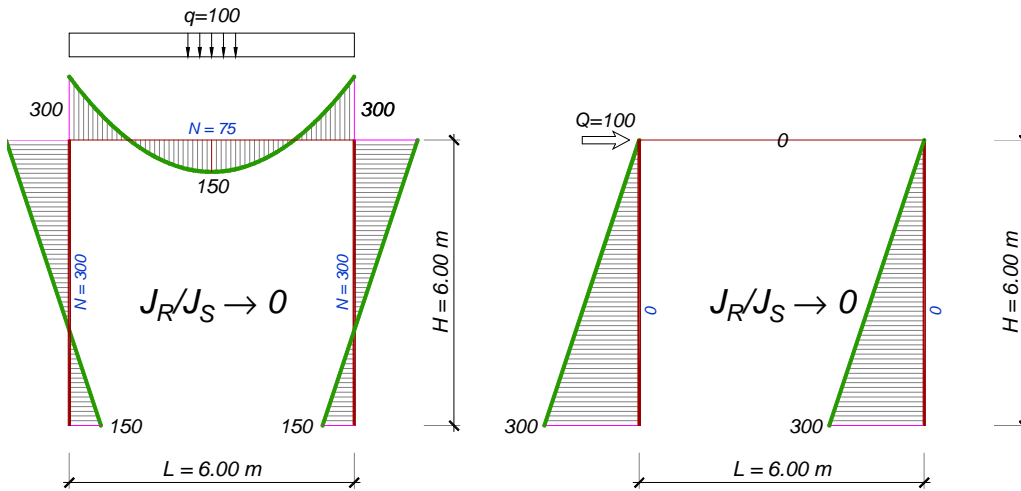
$$M_A = -M_B = \frac{Wh}{2} \frac{3k+1}{6k+1}$$

$$M_C = -M_D = \frac{Wh}{2} \frac{3k}{6k+1}$$

$$k = \frac{J_2}{J_1} \times \frac{H}{L}$$

**“beskonačno” kruta ploča**

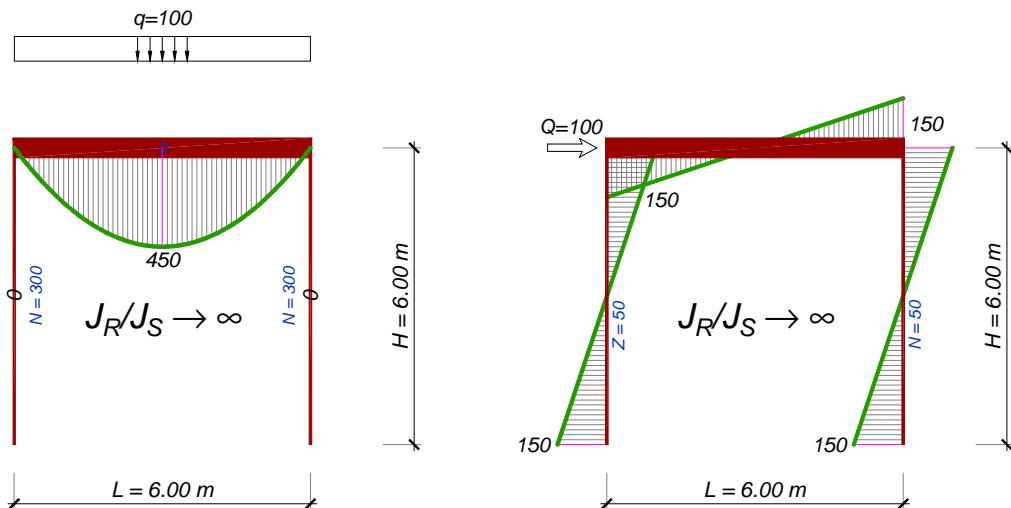
3



$$dx = \frac{Q_1 H^3}{3EJ_1} ; L_i = 2H$$

**“beskonačno” kruta greda**

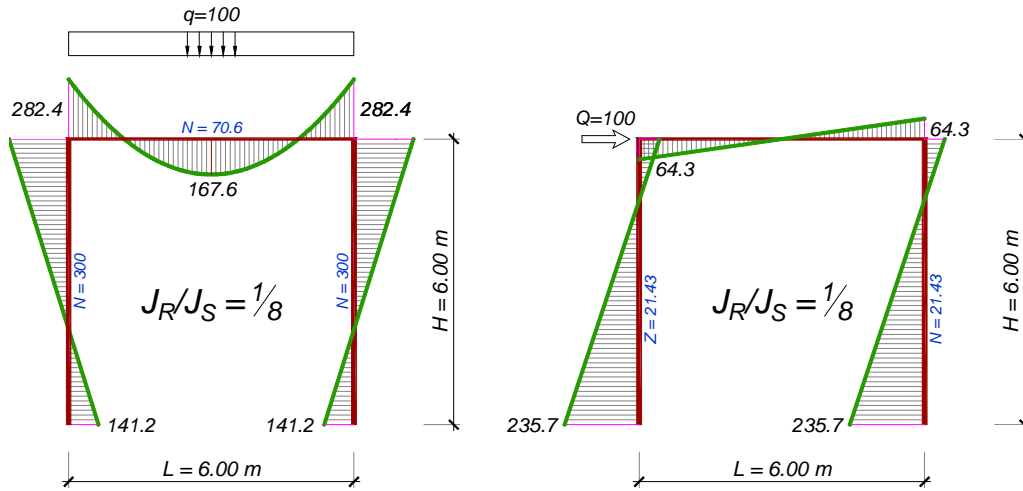
4



$$dx = \frac{Q_1 H^3}{12EJ_1} ; L_i = H$$

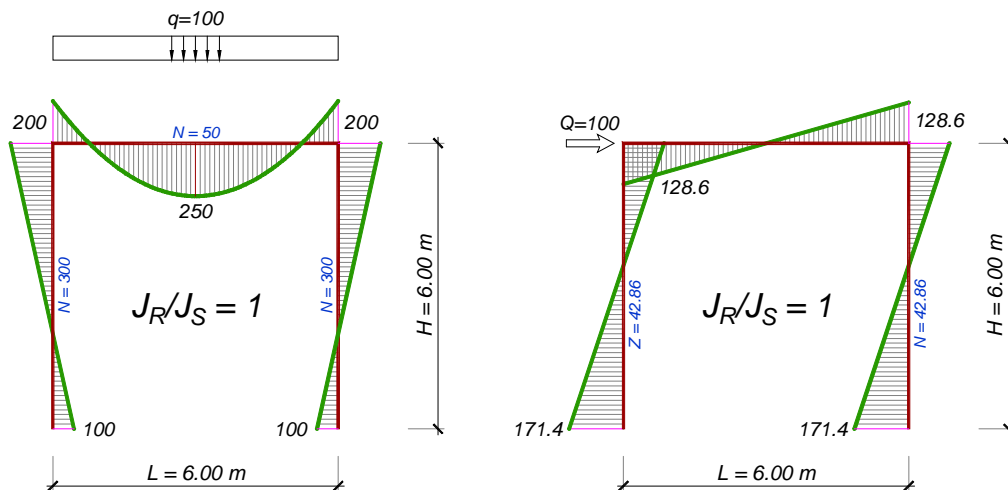
**Greda 30/30 cm, stubovi 30/60 cm**

5



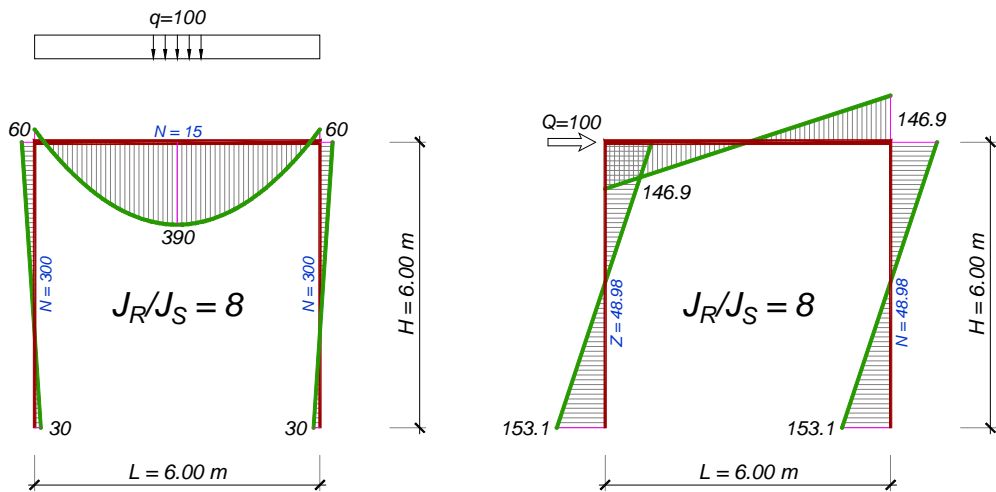
**Greda 30/60 cm, stubovi 30/60 cm**

6



### Greda 30/60 cm, stubovi 30/30 cm

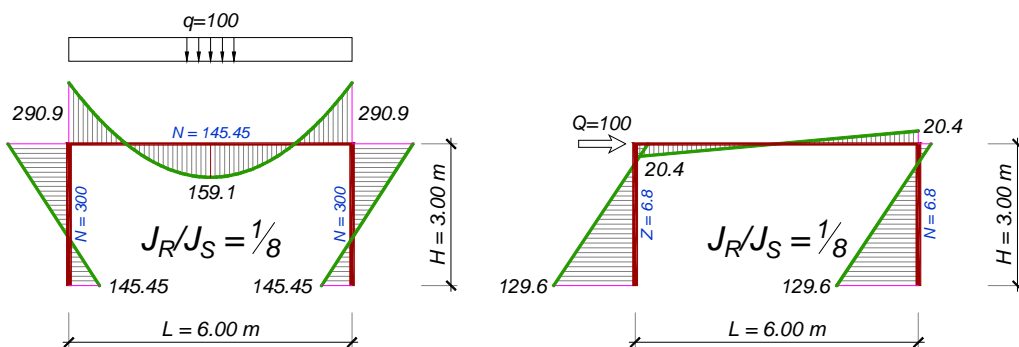
7



$$dx \approx \frac{Q_1 H^3}{12 E J_1} ; L_i \approx H$$

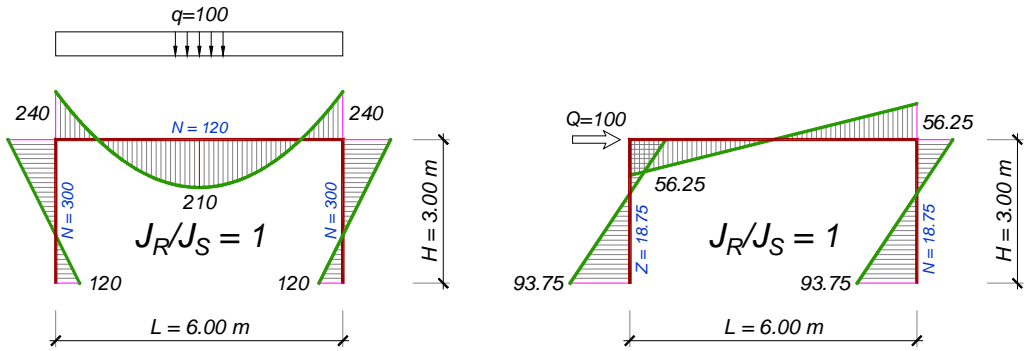
### Greda 30/30 cm, kratki stubovi 30/60 cm

8



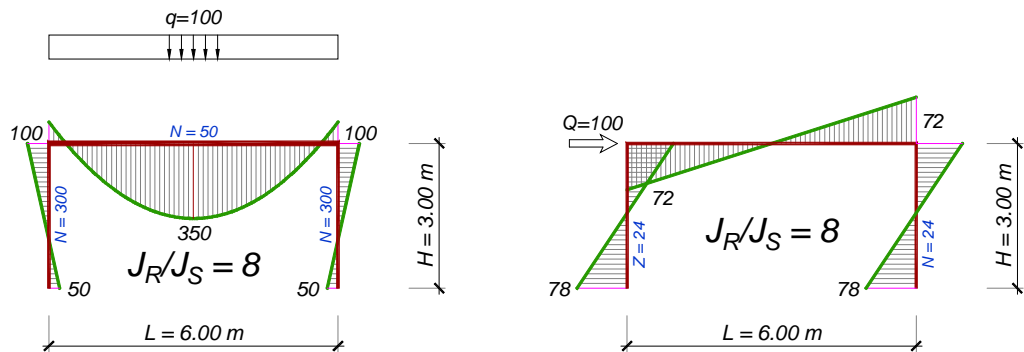
**Greda 30/60 cm, kratki stubovi 30/60 cm**

9



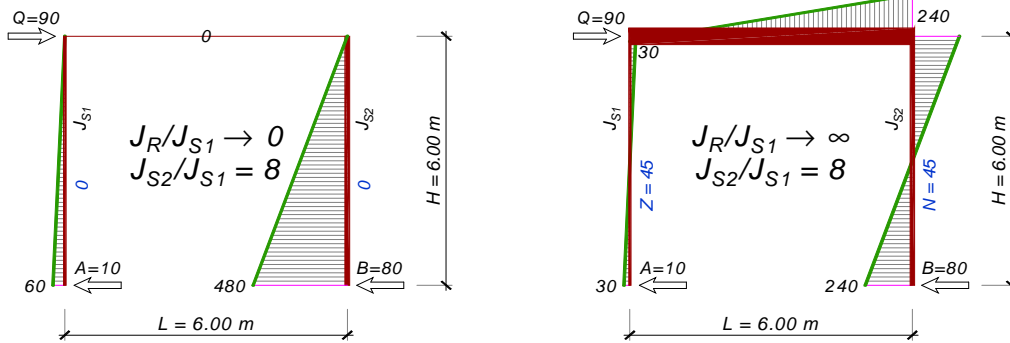
**Greda 30/60 cm, kratki stubovi 30/30 cm**

10



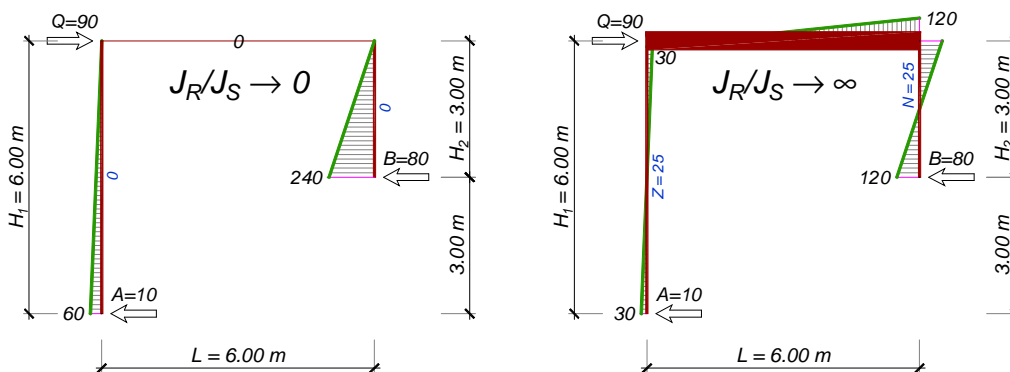
## Stubovi različite krutosti

11



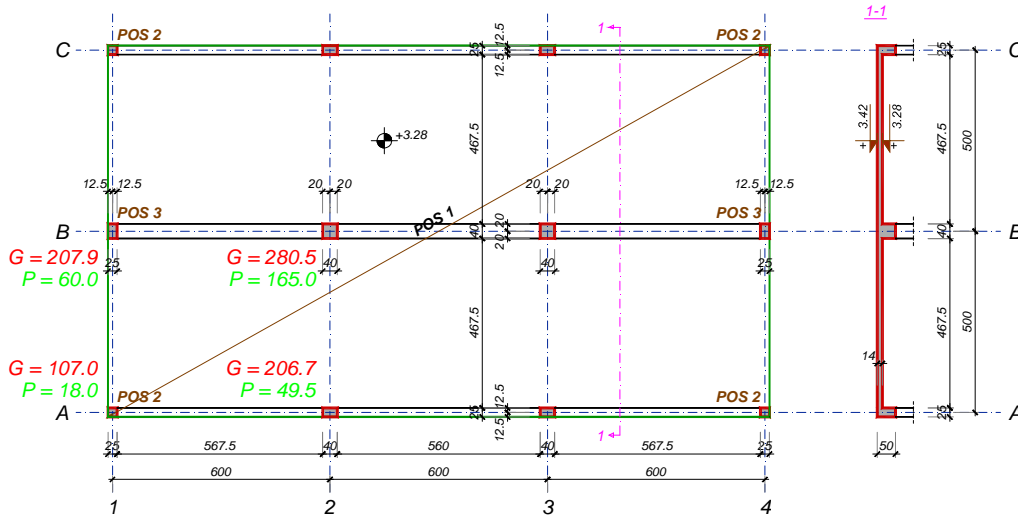
## Stubovi različite krutosti i visine

12



## Sile u stubovima (vertikalno opterećenje)

13



## Ukupno vertikalno opterećenje od POS 1+

14

### Rezultanta jednako raspodijeljenog opterećenja POS 1

$$\Sigma G = (3.5+2.5) \times 18.0 \times 10.0 = 1080 \text{ kN}$$

$$\Sigma P = 4.0 \times 18.0 \times 10.0 = 720 \text{ kN}$$

### težina greda POS 2, POS 3:

$$\Sigma G_g = 2 \times 0.25 \times 0.5 \times 25 \times 18.0 + 0.4 \times 0.5 \times 25 \times 18.0 = 202.5 \text{ kN}$$

### težina fasade:

$$g_f = (3.5 - 0.5) \times 4.60 + 3.5 \times 0.9 = 16.95 \text{ kN/m}$$

$$\Sigma G_f = 2 \times (18.0 + 10.0) \times 16.95 = 949.2 \text{ kN}$$

### težina stubova:

$$\Sigma G_s = [4 \times 0.25 \times 0.25 + (4+2) \times 0.25 \times 0.4 + 2 \times 0.4 \times 0.4] \times 3.5 \times 25$$

$$\Sigma G_s = 102.4 \text{ kN}$$

## Proračun horizontalnih sila - seizmika

15

ukupno, vertikalno opterećenje:

Usvojeno najverovatnije povremeno opterećenje u iznosu od  
POLOVINE ukupnog povremenog opterećenja

$$Q = \Sigma G + \Sigma P/2 + \Sigma G_g + \Sigma G_f + \Sigma G_s/2$$

$$Q = 1080 + 720/2 + 202.5 + 949.2 + 102.4/2 = 2643 \text{ kN}$$

ukupno, seizmička sila u nivou ploče POS 1:

$k_o = 1.0$  (objekat II kategorije, član 4 Pravilnika)

$k_s = 0.1$  (IX zona MCS skale, član 24 Pravilnika)

$k_d = 1.0$  (članovi 25, 26 - bez proračuna perioda oscilovanja)

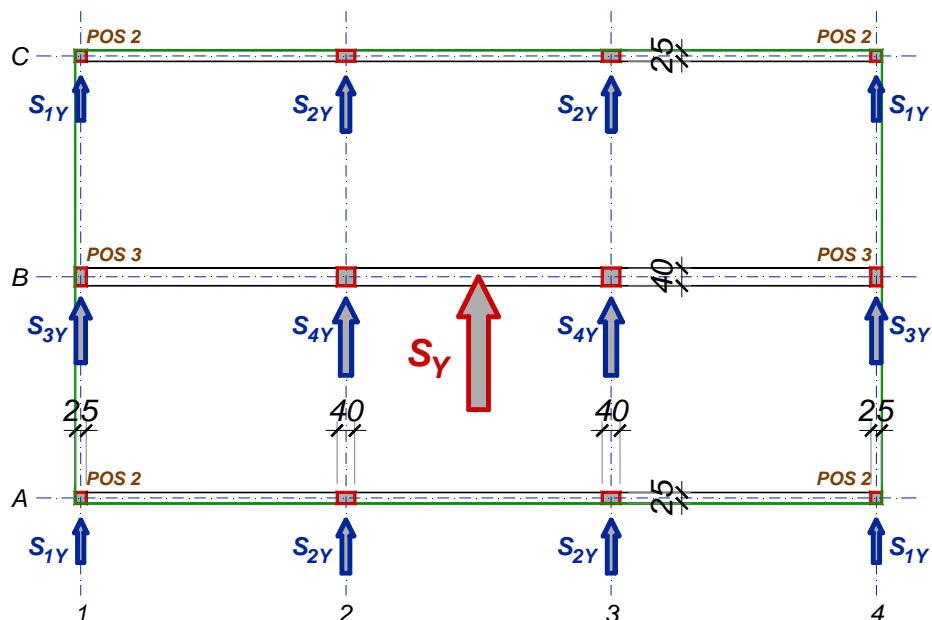
$k_p = 1.0$  (član 27 Pravilnika)

$$K = k_o \times k_s \times k_d \times k_p = 1 \times 0.1 \times 1 \times 1 = 0.10$$

$$S = K \times Q = 0.10 \times 2643 = 264.3 \text{ kN}$$

## Seizmička sila - poprečni pravac

16





## Seizmička sila - poprečni pravac

17

$$S_Y = 4S_{1Y} + 4S_{2Y} + 2S_{3Y} + 2S_{4Y} = 264.3 \text{ kN}$$

$$J_{Y,S1} = \frac{25 \times 25^3}{12} = 32,552 \text{ cm}^4 ; J_{Y,S2} = \frac{40 \times 25^3}{12} = 52,083 \text{ cm}^4$$

$$J_{Y,S3} = \frac{25 \times 40^3}{12} = 133,333 \text{ cm}^4 ; J_{Y,S4} = \frac{40 \times 40^3}{12} = 213,333 \text{ cm}^4$$

$$J_Y = 4 \times (32,552 + 52,083) + 2 \times (133,333 + 213,333) = 1,031,875 \text{ cm}^4$$

$$S_{1Y} = \frac{32,552}{1,031,875} \times 264.3 = 8.34 \text{ kN} \Rightarrow M_{S1,Y} = 8.34 \times 3.5 = 29.2 \text{ kNm}$$

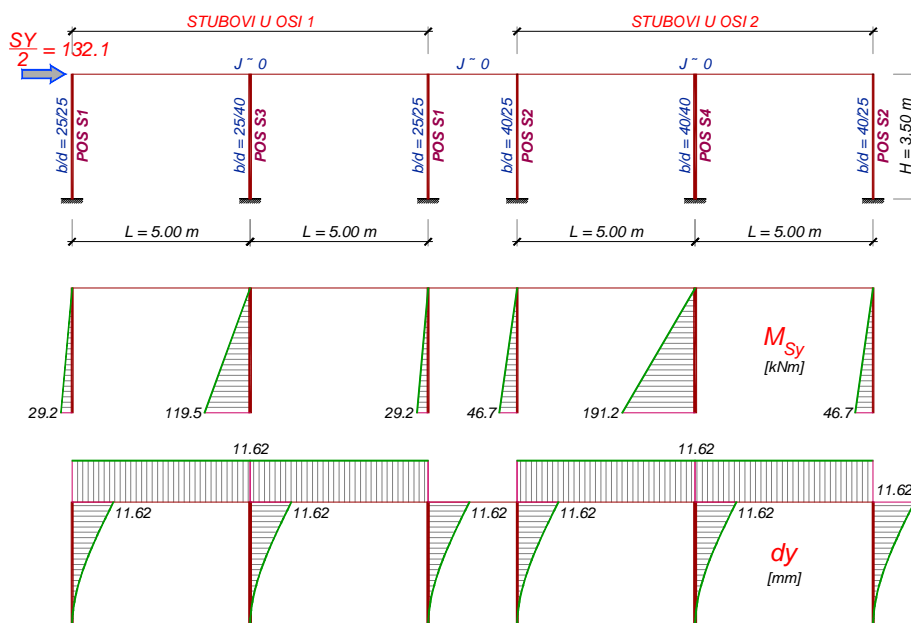
$$S_{2Y} = \frac{52,083}{1,031,875} \times 264.3 = 13.34 \text{ kN} \Rightarrow M_{S2,Y} = 13.34 \times 3.5 = 46.7 \text{ kNm}$$

$$S_{3Y} = \frac{133,333}{1,031,875} \times 264.3 = 34.15 \text{ kN} \Rightarrow M_{S3,Y} = 34.15 \times 3.5 = 119.5 \text{ kNm}$$

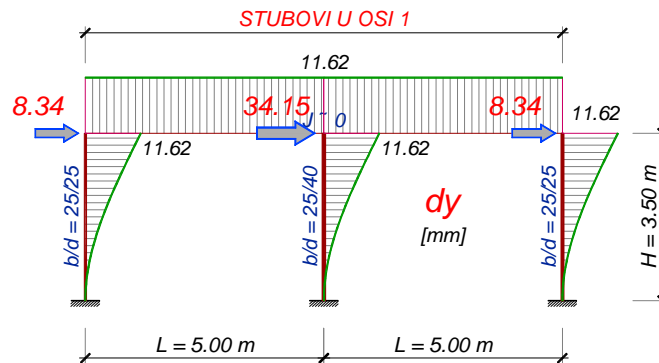
$$S_{4Y} = \frac{213,333}{1,031,875} \times 264.3 = 54.64 \text{ kN} \Rightarrow M_{S4,Y} = 54.64 \times 3.5 = 191.2 \text{ kNm}$$

## Seizmički uticaji - poprečni pravac

18



$$dy = \frac{S_Y \times H^3}{3EJ_Y} = \frac{264.3 \times 3.5^3}{3 \times 31.5 \times 10^6 \times 1,031,875 \times 10^{-8}} = 11.62 \times 10^{-3} \text{ m} = 11.62 \text{ mm}$$



$$dy = \frac{S_{1Y} \times H^3}{3EJ_{Y,S1}} = \frac{8.34 \times 3.5^3}{3 \times 31.5 \times 10^6 \times 32,552 \times 10^{-8}} = 11.62 \times 10^{-3} \text{ m} = 11.62 \text{ mm}$$

$$dy_{\text{dop.}} = \frac{H}{600} = \frac{3.5}{600} = 5.83 \times 10^{-3} \text{ m} = 5.83 \text{ mm}$$

## Određivanje perioda oscilacija

Seizmičku silu je **MOGUĆE** smanjiti sračunavanjem vrednosti koeficijenta dinamičnosti  $k_d$  (u preliminarnom proračunu usvojena je njena maksimalna vrednost  $k_d = 1.0$ ). Prema članu 26 Pravilnika, za objekte do 5 spratova, **MOGUĆE** je uzeti njegovu maksimalnu vrednost.

Period oscilovanja konstrukcije u prvom tonu se približno sračunava pomoću pojednostavljene Rejljeve relacije:

$$T_1 = 2\sqrt{d}$$

gde je  $d$  – pomeranje vrha konstrukcije u **metrima** usled opterećenja horizontalnim silama jednakim težinama spratova ( $Q = 2643 \text{ kN}$ ):

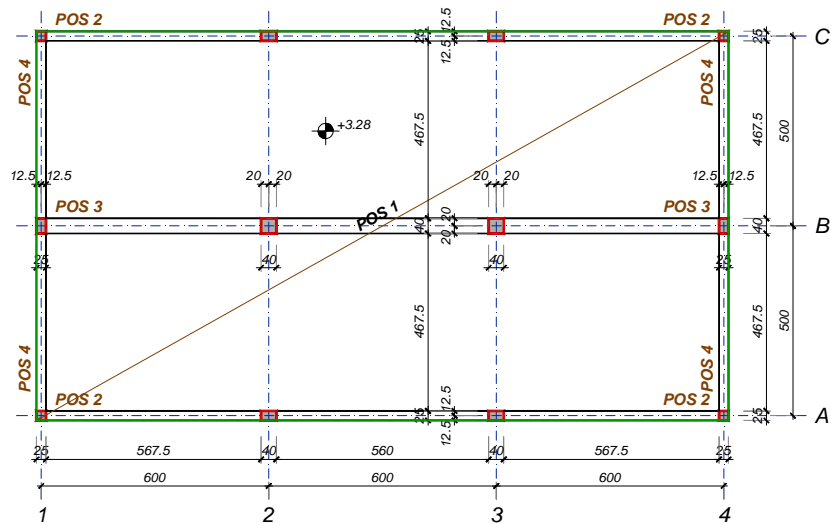
$$d = \frac{Q}{S_Y} \times dy = \frac{2643}{264.3} \times 11.62 \text{ mm} = 116.2 \text{ mm} = 0.116 \text{ m}$$

$$T_1 = 2\sqrt{0.116} = 0.682 \text{ sec} \Rightarrow k_d = \frac{0.7}{0.682} \Rightarrow k_d = 1$$

## Ojačavanje konstrukcije u poprečnom pravcu

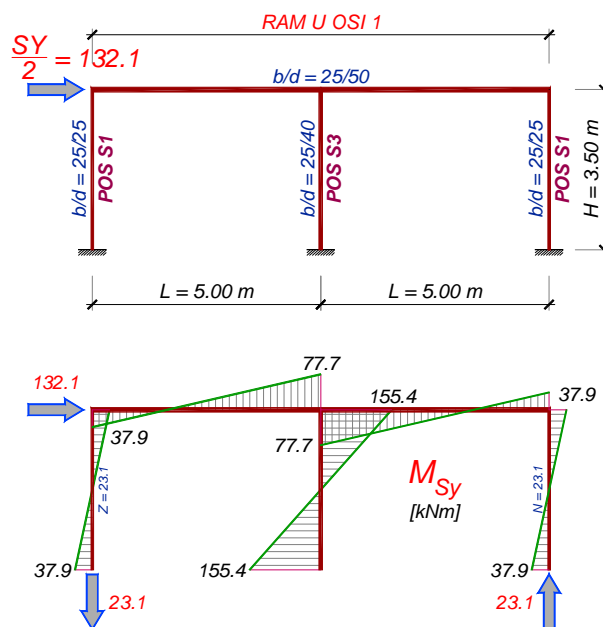
21

Formiranje ramova u osama 1 i 4 (postojeći stubovi povezani gredama POS 4, istih dimenzija kao POS 2 u osama A i C)



## Seizmički uticaji - poprečni pravac

22



$$S_y/2 = 2S_{1Y} + S_{3Y} = 264.3/2 = 132.1 \text{ kN}$$

$$J_{Y,S1} = \frac{25 \times 25^3}{12} = 32,552 \text{ cm}^4 ; J_{Y,S3} = \frac{25 \times 40^3}{12} = 133,333 \text{ cm}^4$$

$$J_Y = 2 \times 32,552 + 133,333 = 198,439 \text{ cm}^4$$

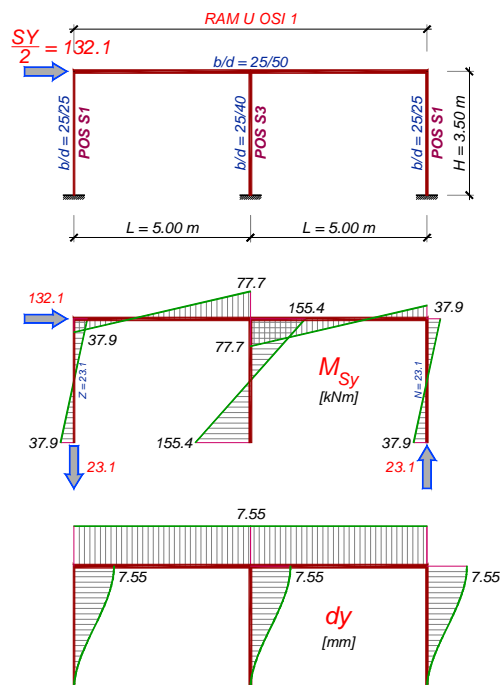
$$S_{1Y} = \frac{32,552}{198,439} \times 132.1 = 21.68 \text{ kN} \Rightarrow M_{S1,Y} \approx \frac{21.68 \times 3.5}{2} = 37.9 \text{ kNm}$$

$$S_{3Y} = \frac{133,333}{198,439} \times 132.1 = 88.79 \text{ kN} \Rightarrow M_{S3,Y} \approx \frac{88.79 \times 3.5}{2} = 155.4 \text{ kNm}$$

$$-A_{sY} = C_{sY} = \frac{37.9 + \frac{155.4}{2}}{5.0} = 23.1 \text{ kN}$$

$$dy \approx \frac{S_{1Y} \times H^3}{12EJ_{Y,S1}} = \frac{21.68 \times 3.5^3}{12 \times 31.5 \times 10^6 \times 32,552 \times 10^{-8}} = 7.55 \times 10^{-3} \text{ m}$$

$$dy \approx 7.55 \text{ mm} > dy_{dop.} = 5.83 \text{ mm} = \frac{H}{600}$$



## Ojačavanje konstrukcije u poprečnom pravcu

25

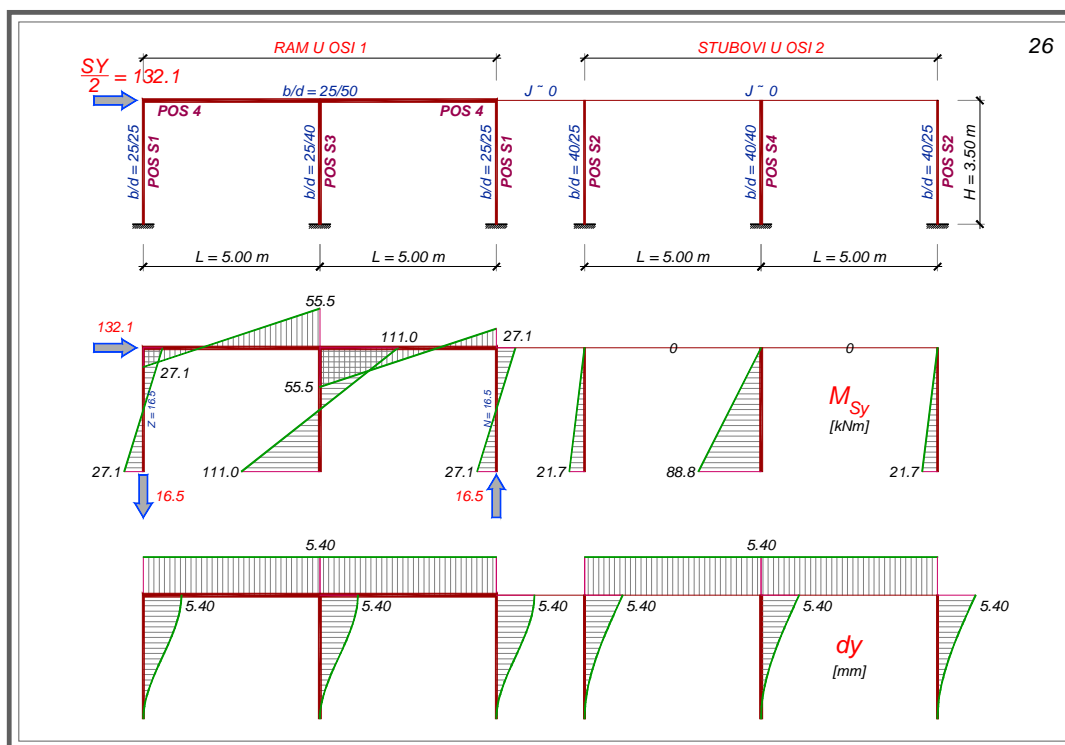
Kako je pomeranje i dalje prekoračeno, postoji opcija da se stubovi povećaju dovoljno da se pomeranje smanji do dopuštene vrednosti, ili da se u proračun uključe i elementi koji realno postoje u konstrukciji, ali je njihova krutost manja od krutosti ramova pa su u prethodnom koraku zanemareni (konzolni stubovi u osama 2 i 3).

Seizmička sila će ponovo biti raspodeljena na pojedine stubove izjednačavanjem pomeranja njihovih vrhova, pri čemu će za pomeranja u ramovima (ose 1 i 4) biti usvojena približna vrednost

$$dy \approx \frac{S_i \times H^3}{12EJ_i}$$

a za pomeranja konzolnih stubova (ose 2 i 3):

$$dy = \frac{S_i \times H^3}{3EJ_i}$$



$$S_{Y/2} = 2S_{1Y} + S_{3Y} + 2S_{2Y} + S_{4Y} = 264.3/2 = 132.1 \text{ kN}$$

$$J_{Y,S1} = \frac{25 \times 25^3}{12} = 32,552 \text{ cm}^4 ; J_{Y,S2} = \frac{40 \times 25^3}{12} = 52,083 \text{ cm}^4$$

$$J_{Y,S3} = \frac{25 \times 40^3}{12} = 133,333 \text{ cm}^4 ; J_{Y,S4} = \frac{40 \times 40^3}{12} = 213,333 \text{ cm}^4$$

$$\frac{J_Y}{2} = 2 \times (4 \times 32,552 + 52,083) + (4 \times 133,333 + 213,333) = 1,111,250 \text{ cm}^4$$

$$S_{1Y} = \frac{4 \times 32,552}{1,111,250} \times 132.1 = 15.48 \text{ kN} \Rightarrow M_{S1,Y} \approx \frac{15.48 \times 3.5}{2} = 27.1 \text{ kNm}$$

$$S_{3Y} = \frac{4 \times 133,333}{1,111,250} \times 132.1 = 63.42 \text{ kN} \Rightarrow M_{S3,Y} \approx \frac{63.42 \times 3.5}{2} = 111.0 \text{ kNm}$$

$$S_{2Y} = \frac{52,083}{1,111,250} \times 132.1 = 6.19 \text{ kN} \Rightarrow M_{S2,Y} = 6.19 \times 3.5 = 21.7 \text{ kNm}$$

$$S_{4Y} = \frac{213,333}{1,111,250} \times 132.1 = 25.37 \text{ kN} \Rightarrow M_{S4,Y} = 25.37 \times 3.5 = 88.8 \text{ kNm}$$

Aksijalne sile u stubovima u osi 1 (i osi 4) usled seizmike:

$$-A_{sY} = C_{sY} = \frac{27.1 + \frac{111.0}{2}}{5.0} = 16.5 \text{ kN}$$

Pomeranje u poprečnom pravcu:

$$dy \approx \frac{S_{1Y} \times H^3}{12EJ_{Y,S1}} = \frac{15.48 \times 3.5^3}{12 \times 31.5 \times 10^6 \times 32,552 \times 10^{-8}} = 5.40 \times 10^{-3} \text{ m}$$

odnosno:

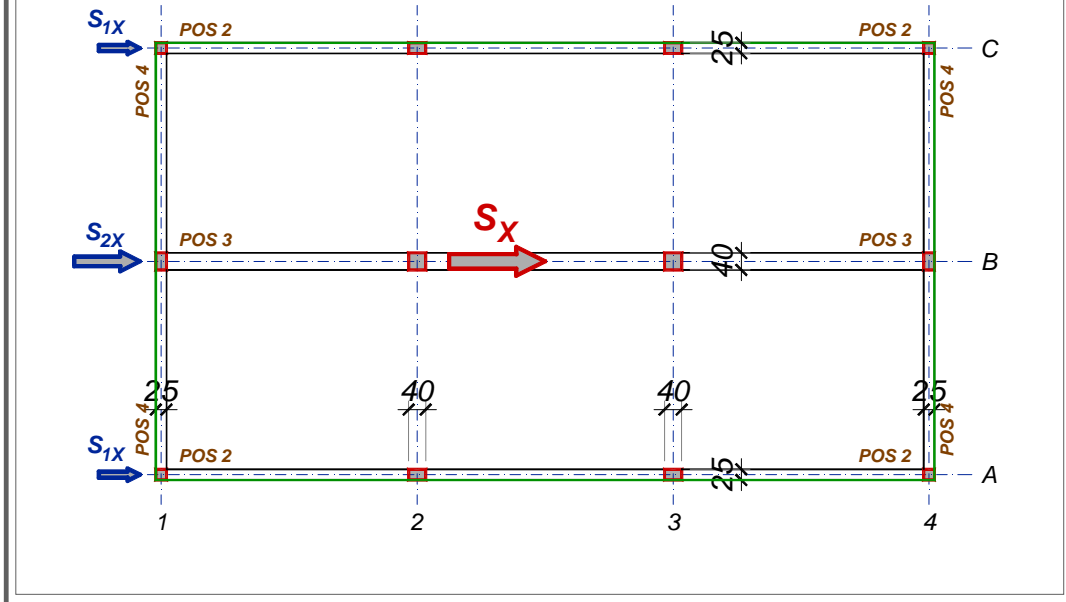
$$dy = \frac{S_{2Y} \times H^3}{3EJ_{Y,S2}} = \frac{6.19 \times 3.5^3}{3 \times 31.5 \times 10^6 \times 52,083 \times 10^{-8}} = 5.40 \times 10^{-3} \text{ m}$$

$$dy \approx 5.40 \text{ mm} < dy_{dop.} = 5.83 \text{ mm} = \frac{H}{600}$$

Kako je pomeranje u poprečnom pravcu manje od dopuštenog, rešenje se usvaja i pristupa se proveru podužnog pravca.

## Seizmička sila – podužni pravac

29



## Seizmička sila – podužni pravac

30

$$S_x = 2S_{1X} + S_{2X} = 264.3 \text{ kN}$$

$$\frac{J_{x,S2}}{J_{x,S1}} = \frac{b_2}{b_1} = \frac{40}{25} = 1.6 \Rightarrow S_{1,X} = S_x \times \frac{J_{x,S1}}{J_x} = S_x \times \frac{J_{x,S1}}{J_{x,S1} \times (1 + 1.6 + 1)} = \frac{S_x}{3.6}$$

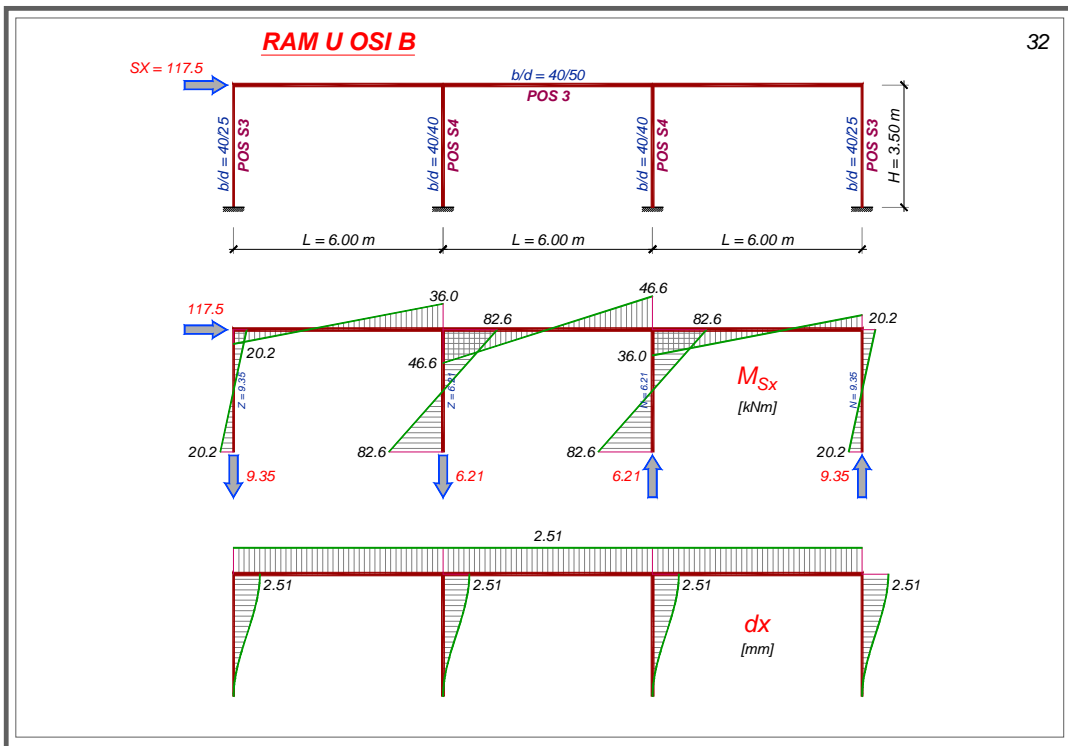
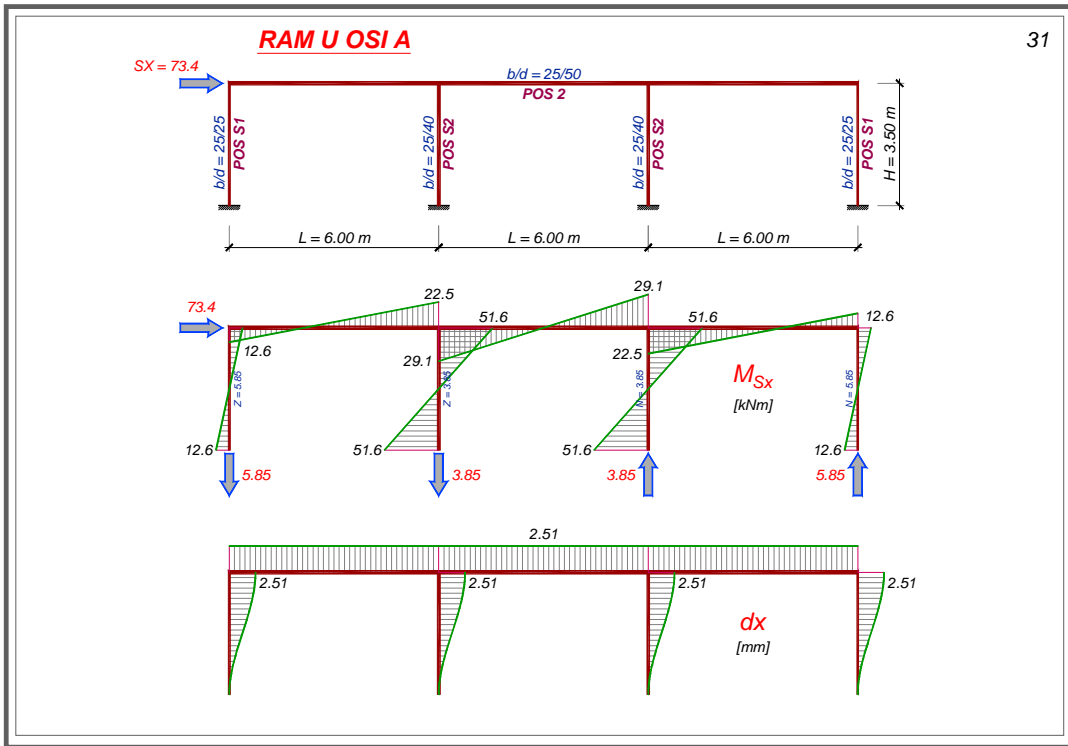
Sila koju prihvataju ramovi u osama A i C:

$$S_{1X} = \frac{264.3}{3.6} = 73.41 \text{ kN}$$

Sila koju prihvata ram u osi B:

$$S_{2X} = \frac{1.6 \times 264.3}{3.6} = 117.5 \text{ kN}$$

Raspodela na pojedine stubove u okviru ramova se sprovodi na isti način kao kod poprečnog pravca, pa su u nastavku prikazani samo dijagrami uticaja za ramove u osama A i B.





## Kontrola duktilnosti stubova

33

Sprovodi se prema članu 61. Pravilnika o tehničkim normativima za izgradnju objekata visokogradnje u seizmičkim područjima:

$$\frac{\sigma_0}{f_B} = \frac{\sigma_0}{0.7 \times f_{bk}} \leq 0.35$$

$$\sigma_0 = \frac{N}{A_b} = \frac{G+P}{b \times d} \leq 0.35 \times 0.7 \times f_{bk}$$

### Srednji stubovi (B2,B3)

Stubovi su dimenzija 40/40 cm. Izvedeni su od betona MB 30.

$$G+P = 280.5 + 165.0 = 445.5 \text{ kN}$$

$$\sigma_0 = \frac{G+P}{A_b} = \frac{445.5}{40 \times 40} = 0.278 \frac{\text{kN}}{\text{cm}^2} < 0.35 \times 0.7 \times 3.0 = 0.735 \frac{\text{kN}}{\text{cm}^2}$$

## Kontrola duktilnosti stubova

34

### Ivični stubovi (A2,A3, C2,C3, B1,B4)

Stubovi su dimenzija 40/25 cm. Izvedeni su od betona MB 30.

$$(G+P)_{\max.} = 207.9 + 60.0 = 267.9 \text{ kN}$$

$$\sigma_0 = \frac{G+P}{A_b} = \frac{267.9}{40 \times 25} = 0.268 \frac{\text{kN}}{\text{cm}^2} < 0.735 \frac{\text{kN}}{\text{cm}^2}$$

### Ugaoni stubovi (A1,A4, C1,C4)

Stubovi su dimenzija 25/25 cm. Izvedeni su od betona MB 30.

$$G+P = 107.0 + 18.0 = 125.0 \text{ kN}$$

$$\sigma_0 = \frac{G+P}{A_b} = \frac{125.0}{25 \times 25} = 0.20 \frac{\text{kN}}{\text{cm}^2} < 0.735 \frac{\text{kN}}{\text{cm}^2}$$

Duktilnost sve tri grupe stubova je zadovoljena i proračun se nastavlja sa pretpostavljenim dimenzijama.

## Dimenzionisanje stubova B1,B4

35

U poprečnom pravcu, ovi stubovi su dimenzija  $b/d = 25/40$  cm (srednji stubovi u ivičnim ramovima, osa 1, slajd 26).

$$M_u = 1.3 \times 111.0 = 144.3 \text{ kNm (seizmika, poprečni pravac)}$$

$$N_u = 1.3 \times (207.9 + 60/2) = 309.3 \text{ kN (slajd 13, slajd 26)}$$

$$m_u = \frac{144.3 \times 10^2}{25 \times 40^2 \times 2.05} = 0.176$$

$$n_u = \frac{309.3}{25 \times 40 \times 2.05} = 0.151$$

$$\frac{a}{d} = \frac{5}{40} = 0.125 \Rightarrow \bar{\mu}_1 = \bar{\mu}_2 = 0.15$$

$$A_{a1} = A_{a2} = 0.15 \times \frac{25 \times 40 \times 2.05}{40} = 7.76 \text{ cm}^2$$

$$A_{a1,\text{min.}} = 0.2 \times 10^{-2} \times 25 \times 40 = 2.0 \text{ cm}^2 \Rightarrow \text{usv. } 4R\emptyset 16$$

## Dimenzionisanje stubova B1,B4

36

Kao delovi podužnih ramova, ovi stubovi su dimenzija  $b/d = 40/25$  cm (krajnji stubovi u srednjem ramu, osa B, slajd 32).

$$M_u = 1.3 \times 20.2 = 26.2 \text{ kNm (seizmika, podužni pravac)}$$

$$N_u = 1.3 \times (207.9 + 60/2 - 9.35) = 297.2 \text{ kN (slajd 13, slajd 32)}$$

$$m_u = \frac{26.2 \times 10^2}{40 \times 25^2 \times 2.05} = 0.051$$

$$n_u = \frac{297.2}{40 \times 25 \times 2.05} = 0.145$$

$$\frac{a}{d} = \frac{5}{25} = 0.2 \Rightarrow \bar{\mu}_1 = \bar{\mu}_2 = 0$$

$$A_{a1,\text{min.}} = 0.2 \times 10^{-2} \times 25 \times 40 = 2.0 \text{ cm}^2$$

